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THREE APPROACHES TO SPACE SYSTEMS ACQUISITIONS AND THEIR APPLICATION TO THE DEFENSE DEPARTMENT'S WEATHER SATELLITE PROGRAM

by

Wellington V.G. Phillips

March 2012

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For more than a half century, the United States government has been acquiring and launching satellites. However, throughout these years, there has been a shift in the space systems acquisitions model, from acquiring greater quantities but less complex satellites, to fewer quantities but drastically more complex individualized satellites. Within the past two decades, when a new satellite was to be built, whether as part of an existing generation of satellites or the first of its kind, it appeared that the acquisition process starts over from the beginning as if it was the first time building a satellite. This shift in the model has resulted in these individualized systems being extremely costly and taking a long time to be produced. The acquisition of the Defense Department's Weather Satellites is one such example.

This author asserts that effective systems acquisition requires a system engineering-inspired approach. The result of systems engineering guidance is to synthesize general principles from case studies. Therefore, this thesis researched the history of some Air Force Space acquisitions programs, current factors affecting the way systems are acquired, and new approaches (Fast, Inexpensive, Simple, Tiny [FIST], and Evolutionary Acquisition for Space Efficiency [EASE]) that are intended to remedy the aforementioned problems. In addition, Toyota's process for producing new vehicles models was also reviewed. These three approaches were then applied to the Defense Department's Weather Satellite program to develop recommendations for its follow-on program's acquisition strategy.

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THREE APPROACHES TO SPACE SYSTEMS ACQUISITIONS AND THEIR APPLICATION TO THE DEFENSE DEPARTMENT'S WEATHER SATELLITE PROGRAM

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ABSTRACT

For more than a half century, the United States government has been acquiring and launching satellites. However, throughout these years, there has been a shift in the space systems acquisitions model, from acquiring greater quantities but less complex satellites, to fewer quantities but drastically more complex individualized satellites. Within the past two decades, when a new satellite was to be built, whether as part of an existing generation of satellites or the first of its kind, it appeared that the acquisition process starts over from the beginning as if it was the first time building a satellite. This shift in the model has resulted in these individualized systems being extremely costly and taking a long time to be produced. The acquisition of the Defense Department's Weather Satellites is one such example.

This author asserts that effective systems acquisition requires a system engineering-inspired approach. The result of systems engineering guidance is to synthesize general principles from case studies. Therefore, this thesis researched the history of some Air Force Space acquisitions programs, current factors affecting the way systems are acquired, and new approaches (Fast, Inexpensive, Simple, Tiny [FIST], and Evolutionary Acquisition for Space Efficiency [EASE]) that are intended to remedy the aforementioned problems. In addition, Toyota's process for producing new vehicles models was also reviewed. These three approaches were then applied to the Defense Department's Weather Satellite program to develop recommendations for its follow-on program's acquisition strategy.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADM	Acquisition Decision Memorandum
AEHF	Advanced Extremely High Frequency
AT&L	Acquisition Technology and Logistics
CAIP	Capability and Affordability Insertion Program
CSP	Cost, Schedule, and Performance
DAE	Defense Acquisition Executive
DMSP	Defense Metrological Satellite Program
DoC	Department of Commerce
DoD	Department of Defense
DSCS	Defense Satellite Communications System
DWSS	Defense Weather Satellite System
EASE	Evolutionary Acquisition for Space Efficiency
EELVs	Evolved Expendable Launch Vehicles
EOL	End of Life
FAR	Federal Acquisition Regulations
FIST	Fast, Inexpensive, Simple, Tiny
FOUO	For Official Use Only
FPIF	Fixed Price Incentive Firm
Ft-lbs	Foot-Pounds
GAO	Government Accountability Office
GEO	Geosynchronous Earth Orbit
GPS	Global Positioning System
HAF	Headquarters Air Force
HP	Horse Power
ILC	Initial Launch Capability
IMU	Inertial Measurement Unit
JPASS	Joint Polar Satellite System
LMSSC	Lockheed Martin Space Systems Company
LTAN	Local Time at Ascending Node
MILSATCOM	Military Satellite Communications
MIMU	Miniature Inertial Measurement Unit

MIS	Microwave Imager/Sounder
MPG	Miles per Gallon
MUOS	Mobile User Objective System
NASA	National Aeronautics and Space Administration
NET	No Earlier Than
NGAS	Northrop Grumman Aerospace Systems
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRO	National Reconnaissance Office
NRP	National Reconnaissance Program
NSOF	NOAA Satellite Operations Facility (NSOF)
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
POES	Polar-orbiting Operational Environmental Satellite
RCA	Radio Corporation of America
RPM	Revolutions per Minute
SATCOM	Satellite Communications
SBIRS High	Space Based Infrared System
SECOR	Sequential Correlation of Range System
SEM	Space Environmental Monitor
SE&TD	Systems Engineering and Technical Direction
SLEP	Service Life Extension Program
SMC	Space and Missile Systems Center
SV	Space Vehicles
SWaP	Size Weight and Power
TSAT	Transformational Satellite Communication System
UNK	Unknown
USD	Under Secretary of Defense
VIIRS	Visible/Infrared Imager Radiometer Suite
WGS	Wideband Global SATCOM

EXECUTIVE SUMMARY

For more than a half century the United States government has been acquiring and launching satellites. However, throughout these years there has been a shift in the space systems acquisitions model, from acquiring greater quantities but less complex and smaller satellites, to fewer quantities but drastically more complex and larger individualized satellites. In addition, within the past two decades, when a new satellite was to be built, whether as part of an existing generation of satellites or the first of its kind, it appears that the acquisition process starts over from the beginning as if it was the first time building a satellite. This shift in the model and apparent lack of reuse of technology has resulted in these individualized systems being extremely costly and taking a long time to be produced. The acquisition of the Defense Department's Weather Satellites is one such example that has seen this pendulum swing, and the DoD is taking steps to get it under control.

This author asserts that effective systems acquisition requires a system engineering inspired approach. Result of systems engineering guidance is to synthesize general principles from case studies. Therefore, this thesis researched the history of the DMSP, MILSATCOM, and GPS Space acquisitions programs, current factors affecting the way systems are acquired, and new approaches, Fast, Inexpensive, Simple, Tiny (FIST), and Evolutionary Acquisition for Space Efficiency (EASE), that are intended to remedy the aforementioned problems. In addition, Toyota's process for producing new vehicles models was also reviewed, specifically the 14 principles of the Toyota Way because of similarities between the automotive industry and space systems acquisitions.

These three approaches were then applied to the Defense Department's Weather Satellite program to develop recommendations for its follow-on program's acquisition strategy to meet the program's need as it is currently understood. Essentially, the main aspects of the recommendation were to follow a block acquisition approach with the procurement of two satellites at a time, similar to what is being done for AEHF 5 and 6 and utilize Fixed Price Incentive Firm contracts for the majority of the acquisition.

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I. INTRODUCTION

A. BACKGROUND

For more than half a century, the U.S. government has been acquiring, launching, and learning important lessons about Satellite acquisitions, yet it appears that lessons learned earlier do not necessarily propagate throughout later years, leading one to ask if we constantly have to relive and relearn lessons of the past versus capitalizing on them and moving forward. In particular, "over the past two decades, DoD has had difficulties with nearly every space acquisition program, with years of cost and schedule growth, technical and design problems, and oversight and management weaknesses" (GAO, 2011, May).

The current model of Space Systems acquisition has the taxpayer paying for fewer, drastically more complex space systems that are extremely costly and takes a significantly long time to become operational (GAO, 2011, May), as shown in Figure 6. These systems are often very individualized and do not share many similarities with other systems. In addition, systems acquisition normally relies on significant research and development, a stage that does not have adequate technology maturation, which has led to programs costing significantly more and taking a long time to be fielded. On the other hand, compare that approach to an acquisition model where simpler, less capable systems, greater quantities, are acquired and as time evolve and technology matures, capabilities are gradually increased and delivered to the Warfighter. This latter approach would almost certainly allow systems to be fielded faster and with a greater probability of meeting the program's Cost, Schedule, and Performance (CSP) objectives. If there are failures, having more systems available would better enable sustainment of greater losses versus systems that contain fewer, more complex individualized units, based on the principles of the division of risk.

As some of DoD's space systems approach their end of life, their follow-on programs have experienced significant problems with meeting performance requirements, schedule, cost, and are in jeopardy of being cancelled. In fact, the Transformational

Satellite Communication System (TSAT) program was cancelled in 2009, likewise the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program in 2010 and its initial successor, the Defense Weather Satellite System (DWSS) in 2012. While Warfighters are depending on these capabilities being available, they are becoming increasingly unaffordable and taking longer to be fielded. It is plausible that if strong systems engineering, forward-looking practices were used during their initial designs, and during transition to systems with greater capabilities, there would be fewer obstacles to overcome as transition is made from one generation of satellites to the next. For example, the Defense Metrological Satellite Program (DMSP), DoD's sole weather satellite program has successfully served the nation for over 50 years and was preparing to end after the last two satellites in the current acquisition block are launched. DMSP yet again has been extended because its initial successor, NPOESS, a merger between DoD weather and Civilian Weather, had experienced significant CSP difficulties to the extent that the government decided to separate NPOESS back into two programs (GAO, 2010, May). DoD's piece, initially called DWSS, was similarly cancelled within less than one year of being in existence. Congress expressed concerns that DWSS was "not on a sound acquisition footing, despite the restructure of the program….The Committee does not want to repeat the costly mistakes of the NPOESS program with DWSS. Therefore, the Committee recommends the termination of the DWSS program" (Senate, 2011). These cancellations have resulted in DMSP's last two satellites further being heavily relied on to perform beyond their original design life so as to bridge any potential weather coverage gap until DMSP's follow-on program, become operational. It is important to note that these satellites were built during the late 1990s and will be approximately 20 years old by the time they are launched. In fact, the last satellite (Flight 20) was once thought not to be needed and to be placed in a museum, is now the key to preventing a potential weather coverage gap between the current block of DMSP satellites and the follow-on program's satellites.

The current DMSP satellites were procured in "batches," also known as a block acquisition approach, with minor upgrades made throughout the program's duration to address parts degradation and some obsolescence issues. This combined approach created program stability and is directly attributed to the current program's success because there was not frequent starting and stopping of production lines (Tobias, 2011). However, simultaneously this approach has contributed to NPOESS' dilemma because sufficient early resources were not allocated to solving new technological challenges that follow-on programs experience. Three approaches discussed in Chapter III contain provisions to solve this dilemma.

"Current Air Force procurement practices have led to increased cost due to production line breaks, parts obsolescence and inefficient use of labor" (Tobias, 2011). The aforementioned challenges such as parts obsolescence, slow technological maturation, starting and stopping of production lines are not only unique to Space Acquisitions but experienced in other industries such as the automotive industry. While automobiles are produced in mass quantities unlike satellites, automobiles do follow a similar block acquisition approach and may have best practices that can be adopted and applied to the acquisitions of space systems. For this reason, Toyota's approach to updating and acquiring new models will be investigated; particularly the 14 Toyota Way Principles according to Jeffrey Liker, co-founder of the Japan Technology Management Program at the University of Michigan, Ann Arbor.

B. PURPOSE

The purpose of this thesis is to recognize there may be a better way for the Air Force to procure satellites than the current model. That way could be smaller, less capable systems that are faster to build and then gradually increase the capabilities once technology matures. This thesis will evaluate the model that is used to acquire Space systems, new approaches to improve acquisitions such as, Fast, Inexpensive, Simple, Tiny (FIST), Evolutionary Acquisition for Space Efficiency (EASE) to be implemented in fiscal year 2012 (GAO, 2011, May), and the 14 Principles of the Toyota Way, and apply these three approaches to the Defense Department' Weather Satellite program. Thereby, outlining a program that theoretically should cost less, take less time to field, and provide the warfighter with the desired scope of functionality and performance (Tobias, 2011).

While the purpose of this thesis is geared toward recommendations for what the Defense Department' should do for its follow-on Weather Satellite program acquisition strategy, information learned should also be transferable to other space acquisition programs because they all operate in the same domain and experience similar challenges. Implementing these recommendations should minimize the inadvertent challenges, such as technological immaturity that delays new programs and thereby should reduce the cost and time it takes to bring new programs to realization, while ensuring that the warfighter is able to take advantage of newer needed technologies once they become available, are proven, and have desired characteristics.

C. RESEARCH QUESTIONS

This thesis aims to answer the following questions:

1. What are some of the acquisition challenges facing current Space systems?
2. What acquisition approach is best suited for Space systems? Single Step, Incremental/Block, Spiral, or a combination?
3. What is a possible solution for the DMSP follow-on program if FIST, EASE, and Toyota's approaches were used to help define it?
4. What lessons, if any, can Space System acquisition leverage from other acquisition approaches such as those used in the automotive industry?

D. BENEFITS OF STUDY

This thesis will provide a basis of knowledge that can be leveraged by space systems acquisition professionals, in particular, program managers and system engineers; which will in turn improve the space systems acquisition cycle, cost and time it takes to get new capabilities to the Warfighter. It should be insightful to the program office with the responsibility for the DMSP follow-on program's acquisition, as they seek to design and implement an executable program solution.

E. SCOPE

This thesis will focus on the systems acquisition approaches used on the various current and follow-on DMSP, Military Satellite Communication (MILSATCOM), and Global Positioning System (GPS) programs and compare them to the Toyota Way of producing new and upgraded vehicle models. Specific attention will also be given to the DMSP satellites which should form the basis for the follow-on program. Much of the analysis will be dependent on research and content analysis.

F. METHODOLOGY

1. Conduct a literature review of DMSP, MILSATCOM, and GPS program documents.
2. Research and describe various proposed methods to improve acquisitions as applied to Space Systems such as, Fast Inexpensive, Simple, Tiny (FIST), and Evolutionary Acquisition for Space Efficiency (EASE).
3. Review and summarize the goals and objectives for the DMSP follow-on program.
4. Review applicable cases from the automotive industry, paying particular attention to Toyota's way of improving its automobiles.
5. Use the principles of FIST, EASE, and the Toyota Way to develop recommendations for improving space systems acquisitions, specifically for the DMSP follow-on program.

G. THESIS ORGANIZATION

The remaining chapters of this thesis are organized as follows. Chapter II contains a literature review of the acquisitions framework being used to acquire space systems. This acquisition framework review is required so that informed recommendations can be made in Chapter V, for what the DoD should do for its follow-on Weather Satellite program. To effectively generate recommendations, reviews of the history of space acquisitions and key factors that influences today's space systems acquisitions are required so the reader gains the understanding of the current era under which decisions are made for the new system to be acquired. Equally, it is important to understand the history of the current program, what satellites have been acquired throughout the years and what are the issues facing the current and proposed follow-on programs. This type of in-depth literature review of the DMSP program will also be conducted in Chapter II. In addition, the literature review would not be complete if other similar systems were not reviewed so as to gain an understanding of what has been done, currently being done, and proposed to be done for future similar programs. So, the MILSATCOM and GPS systems will also be reviewed. Together, information learned in the literature review will become a basis for the recommendations in Chapter V. When problems are posed that defy thinking "linearly," systems engineering suggests and the author believes it is also important to "think outside the box." Reviewing what is being done in other industries, such as the automotive industry which faces similar challenges, may offer insight into solutions not yet considered. So, Chapter II ends with a review of Toyota's approach, paying particular attention to the 14 Toyota Way Principles. Chapter III will introduce two recent DoD initiatives, FIST and EASE, to improve acquisitions and will focus on their application to space systems acquisitions. It also includes discussions about how the Toyota Way principles are applicable to space acquisitions. Chapter IV merges the information in Chapters II and III and analyzes them. It begins with a mapping of the relevant aspects of the three approaches, showing a comparison and connections among them. Next, a summary of where things currently stand with the DMSP follow-on program was made, and then applicable aspects of FIST, EASE, and Toyota's principles were applied to generate a possible strategy for the DMSP follow-on program. Chapter V brings the thesis to a close, restating the research questions, summarizing their answers, then wraps up with a conclusion, recommendations and identifies areas to conduct further research.

H. CHAPTER SUMMARY

In summary, Chapter I introduced the problem by identifying the most important issues currently affecting space acquisitions and then posing key questions whose answers help suggest solutions. The DoD Weather program was used as an example to illustrate the points that were discussed. Specifically, how DoD's space systems are extremely costly, to the point of some being unaffordable and cancelled, and take a long time to become operational. Next, the purpose of this thesis was stated and why it is important. It is recognized that there may be a better way for the Air Force to procure satellites than the current model, such going back to smaller, less capable systems that are faster to build and then gradually increase the capabilities once technology matures. Two Air Force acquisition improvement initiatives, FIST and EASE, were first introduced along with the Toyota Way 14 principles. Research questions then followed, which guided the research work; obtaining answers to these questions resulted in answering the main thesis problem. After which, the benefits of this study were outlined and its linkage to the DMSP follow-on program office. Particularly, how this thesis will provide a basis of knowledge that space systems acquisition professionals can leverage so as to improve their acquisitions of space systems. The scope was then explained, looking at satellite programs such as DMSP, MILSATCOM, and GPS, and non-satellite systems such as the automotive industry, specifically, the Toyota Way. The methodology followed, outlining seven steps that were used to accomplish this thesis. And finally, this chapter ended with a chapter by chapter outline of how the thesis is organized.

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II. LITERATURE REVIEW

A. INTRODUCTION

To appreciate the issues being addressed in this thesis, it is important to first review the framework being used to acquire DoD space systems. Having a basic understanding of the history of space acquisitions, together with current significant influences, provide clarity to some of the aforementioned issues that affect space acquisitions today. These two items are covered in Section B of this chapter. Since this thesis will research the current model that is used to acquire space systems and recommend a proposed solution for the DMSP follow-on program, it is important to do a detailed examination of the existing DMSP program and a summary level review of other similar programs such as MILSATCOM and GPS so as to understand what historically has been done in the space community and planned for the future. These reviews are covered in sections C, D, and E of this chapter, which will form a baseline for the recommendations in Chapter V. The purpose of the chronological history is to show how the programs have evolved to where they are today and to see if lessons from the past can be used to help make better decisions for the future.

However, because some issues affecting space acquisitions, such as technology refresh, are not only unique to space but can also be found in other industries, it is equally important to conduct research in these non-space acquisition areas to find best practices or lessons learned that may be applicable to space systems acquisitions. For example, the automotive industry is uniquely comparable to space acquisitions because they both deal with emerging technologies. This author posits that an equivalent review provides a basic understanding of what that industry does to deal with similar problems. This is premised on the following similarities of like-kind situations in different industries going through similar processes of system design, development, build, and test. The particular interest to this research is how well these similarities can extend to the production lines. Both experience parts manufacturer issues and function in cost constrained environments. The dissimilarities such as quantities produced and one being government versus the other is in the private sector are not significant because it is the similarities in the processes that are used to generate the quantities that are important. At the end of the day, both answer to someone, the taxpayer and the shareholder, respectively. Even though the feedback loops with the taxpayers and shareholders are wildly different (years versus months), the ever present fiduciary duty persists in all decisions. Therefore, this chapter ends with a review of Toyota's approach to creating new models and updating existing models.

B. SPACE SYSTEMS ACQUISITIONS FRAMEWORK

> The current Air Force space management structure was directed by the Secretary of Defense in 2002 and 2003 in response to findings from the Commission to Assess United States National Security Space Management and Organization (commonly referred to as the Space Commission). In that reorganization, the Secretary of the Air Force was designated as the Department of Defense (DoD) Executive Agent for Space with centralized responsibilities for Air Force and DoD space management. (Department of The Air Force, 2010, p. 4)

The Air Force has been designated as the Executive Agent for Space for DoD with the responsibility for acquiring the vast majority of space assets. As a means to improve cost, schedule, and performance, the literature review focused on the acquisition process for space systems the Air Force had and is responsible for acquiring.

Several factors affect the Space Systems Acquisition framework but currently the most significant one is cost, as conveyed in a 2010 "Memorandum for Acquisition Professionals" from Dr. Ashton Carter, the Under Secretary of Defense, titled: "Better Buying Power: Mandate for Restoring Affordability and Productivity in Defense Spending." In this memo, he "give[s] direction…[for] delivering better value to the taxpayer and improving the way the Department does business."

Dr. Carter laid out "an initial framework for restoring affordability to defense" (Under Secretary of Defense [AT&L], 2010), as seen in Figures 1 through 3. Figure 1 highlight "Objectives" of the new acquisition framework that Dr. Carter wants acquisition professionals to follow. He believes that if implemented appropriately, his framework should result in the DoD being more efficient. The goals of this thesis in conjunction with the FIST and EASE initiatives, which are outlined in Chapters III and IV, support Dr. Carter's objectives.

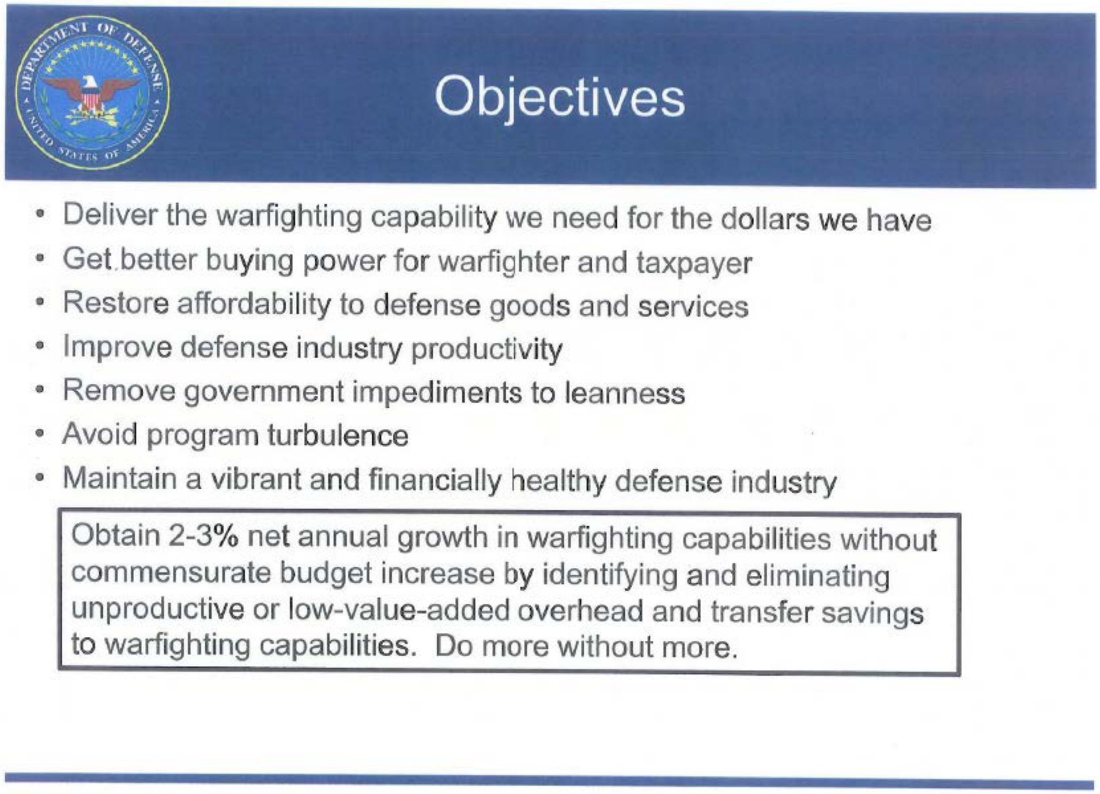


Figure 1. Initial Framework for Restoring Affordability to Defense (From Under Secretary of Defense [AT&L], 2010, p. 4)

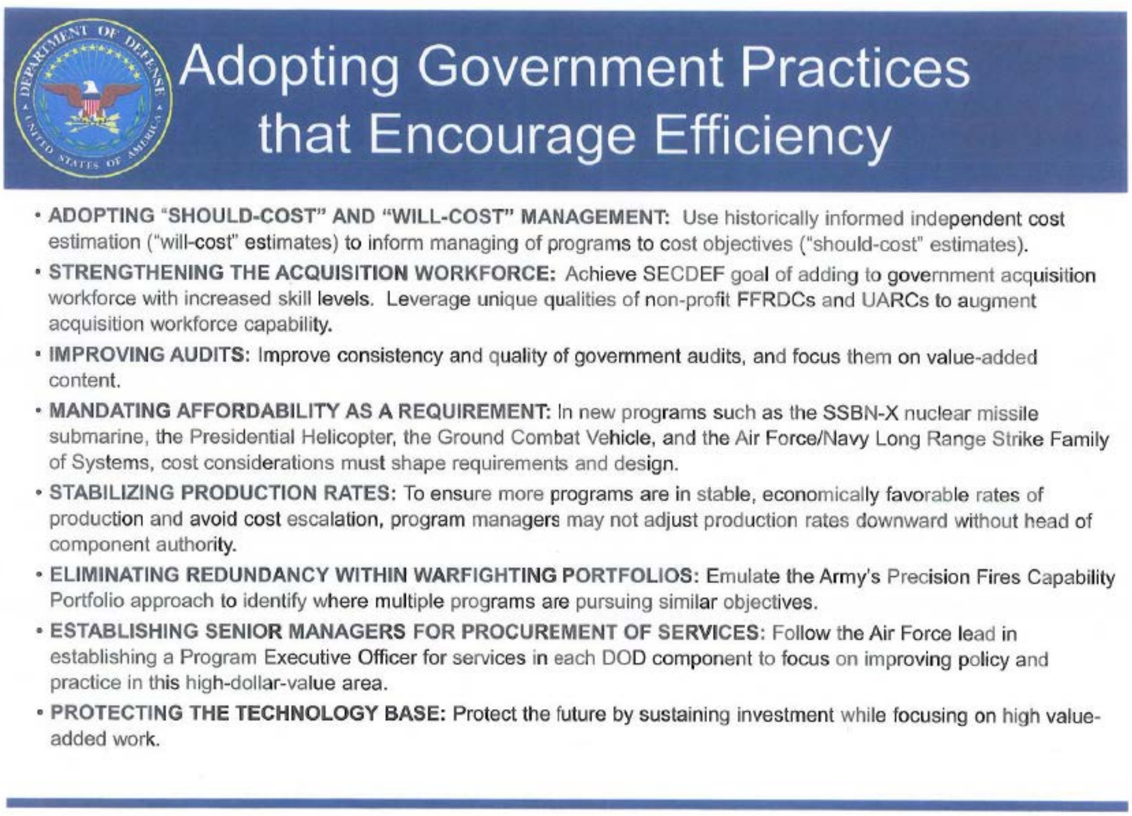
Figure 2 shows a list of incentives that, according to Dr, Carter, if implemented appropriately, should drive industry to greater efficiency thereby lowering acquisition costs. The second item "Using Proper Contract Type For Development and Procurement," is the third tenet of the EASE process that will be discussed in Chapter III.

Providing Incentives for Greater Efficiency in Industry

- **LEVERAGING REAL COMPETITION:** Avoid directed buys and other substitutes for real competition. Use technical data packages and open systems architectures to support a continuous competitive environment.
- **USING PROPER CONTRACT TYPE FOR DEVELOPMENT AND PROCUREMENT:** Phase out award-fee contracts and favor fixed-price or cost-type incentive contracts in which government and industry share equally in overruns and underruns, and overruns have analytically-based caps. Use cost-reimbursement contracts only when either government requirements or industry processes cannot be adequately specified to support pricing. Adjust sole-source fixed-price contracts over time to reflect realized costs. Work down undefinitized contract actions. Seek authority for multi-year contracts where significant savings are possible.
- **USING PROPER CONTRACT TYPE FOR SERVICES:** Phase out Time and Material and sole-source ID/IQ contracts wherever possible. Utilize fixed-price performance-based contracts when requirements are firm and can be measured, with payments tied to performance. Utilize fixed-price level of effort or cost-plus-fixed-fee contracts (with profit/fee tied to weighted guidelines) when requirements are still being defined. Award fees should be used only by exception. Maximize the use of multiple-source, continuously competitive contracts.
- **ALIGNING POLICY ON PROFIT AND FEE TO CIRCUMSTANCE:** Align opportunity to earn profits/fees to both value to the taxpayer and risk to the contractor. Apply weighted guidelines to profit/fee levels. Reward higher productivity with higher profits. Incentivize investment in innovation.
- **SHARING THE BENEFITS OF CASH FLOW:** Ensure that taxpayers receive adequate consideration (price reductions) for improved cash flows. Progress payments must reflect performance but can be increased above customary levels in return for consideration by the contractor. Reduce over time the gap between proposed and actual rates in forward price rate agreements.
- **TARGETING NON-VALUE-ADDED COSTS:** Identify and eliminate non-value-added overhead and G&A charged to contracts. Limit fees for subcontractor management to reflect actual value provided (risk assumed by prime and continuous subcontractor risk reduction). Limit B&P allowable costs in sole source contracts and encourage effective use of IRAD.
- **INVOLVING DYNAMIC SMALL BUSINESS IN DEFENSE:** When establishing multiple award contracts for services, make every effort to provide for small business participation. If at least two small businesses are deemed capable of performing on such a contract, consider setting aside that work for competition among them.
- **REWARDING EXCELLENT SUPPLIERS:** Emulate the Navy's pilot program to provide special benefits to consistently excellent industrial performers.

Figure 2. Initial Framework for Restoring Affordability to Defense (From Under Secretary of Defense [AT&L], 2010, p. 5)

Figure 3 shows Dr. Carter's eight steps for "Adopting Government Practices that Encourage Efficiency." While all of them deal with some aspect of efficiency, it is particularly important to highlight one of them: "MANDATING AFFORDABILITY AS A REQUIREMENT: In new programs…cost considerations must shape requirements and design" (Under Secretary of Defense (AT&L), 2010). By making this mandate, it reinforces the notion that cost is currently the key influence to Acquisitions today, which dovetails nicely with the purpose of this thesis.



- **ADOPTING "SHOULD-COST" AND "WILL-COST" MANAGEMENT:** Use historically informed independent cost estimation ("will-cost" estimates) to inform managing of programs to cost objectives ("should-cost" estimates).
- **STRENGTHENING THE ACQUISITION WORKFORCE:** Achieve SECDEF goal of adding to government acquisition workforce with increased skill levels. Leverage unique qualities of non-profit FFRDCs and UARCs to augment acquisition workforce capability.
- **IMPROVING AUDITS:** Improve consistency and quality of government audits, and focus them on value-added content.
- **MANDATING AFFORDABILITY AS A REQUIREMENT:** In new programs such as the SSBN-X nuclear missile submarine, the Presidential Helicopter, the Ground Combat Vehicle, and the Air Force/Navy Long Range Strike Family of Systems, cost considerations must shape requirements and design.
- **STABILIZING PRODUCTION RATES:** To ensure more programs are in stable, economically favorable rates of production and avoid cost escalation, program managers may not adjust production rates downward without head of component authority.
- **ELIMINATING REDUNDANCY WITHIN WARFIGHTING PORTFOLIOS:** Emulate the Army's Precision Fires Capability Portfolio approach to identify where multiple programs are pursuing similar objectives.
- **ESTABLISHING SENIOR MANAGERS FOR PROCUREMENT OF SERVICES:** Follow the Air Force lead in establishing a Program Executive Officer for services in each DOD component to focus on improving policy and practice in this high-dollar-value area.
- **PROTECTING THE TECHNOLOGY BASE:** Protect the future by sustaining investment while focusing on high value-added work.

Figure 3. Initial Framework for Restoring Affordability to Defense (From Under Secretary of Defense [AT&L], 2010, p. 6)

1. Space Acquisition History

The launch of Sputnik in October 1957, combined with continued test failures in the Viking Launch Vehicle, drove the DoD to focus on developing more reliable and technologically sophisticated space launch systems. In November 1957, the DoD authorized the Army Ballistic Missile Agency (ABMA) to launch a satellite using its ABMA Jupiter rocket. This marked the first successful U.S. satellite launch, earning the

> U.S. Army the right to claim that it was 'the first in space' among the agencies of the U.S. government. Although the U.S. Army continued to conduct research on space-related technologies between 1958–1975, other conflicting initiatives, policy developments and the impact of the Vietnam War constrained its space programs. (Boehm, n.d.)

While the Army can claim to be the "first in space," according to the Space and Missile Systems Center (SMC) fact sheet, 2010, the Air Force's space acquisition, as it is known today, began in July 1954 at the Western Development Division (WDD) of the Air Research and Development Command (ARDC), the precursor to the Space and Missile Systems Center. Their initial priority was to develop Inter Continental Ballistic Missiles. In 1955, ARDC added military satellite system development to WDD's original mission.

> Starting with the first military satellite program, a reconnaissance concept known as Weapon System 117L, WDD and its successors developed progressively more capable satellite systems in four primary mission areas: surveillance, communications, meteorology, and navigation. (SMC, 2010)

Currently, "some of the more recent operational systems performing these missions are the Defense Support Program infrared missile surveillance system, the Defense Satellite Communications System and Milstar communications systems, the Defense Meteorological Satellite Programs (DMSP)…and the Global Positioning System (GPS) navigation system" (SMC, 2010). The latter three are discussed later in this chapter and throughout this thesis.

Acquisitions today have become a very requirements-driven process as evident from the previous discussions on "affordability"—i.e., cost—now mandated as a requirement. Essentially it is no longer a trade-off factor with schedule and performance, so basically it is a constant and only schedule and performance are allowed to change. However, in 1957, at the beginning of the space race, schedule was paramount, performance needed to be acceptable, and the cost had to be reasonable. But, it was a race. As the space effort matured around simple physical structures, technology advancements afforded us the opportunity to increase technical performances, but cost and schedule were its victims. Now we have sacrificed cost and schedule for performance. This is evident from Dr. Pedro Rustan's 2005 testimony to a House Armed Services Committee Hearing:

> During the first 30 years of the space program, we built capability-driven systems that provided the best that our advanced technologies could offer. That strategy worked well in offering innovative solutions, but it did not always represent the customer's needs. During the last 15 years, however, we have swung the pendulum to the other extreme by collecting overly broad requirements sets that our space systems should meet. This strict requirements-driven process often includes mutually exclusive capabilities that cannot be easily integrated on the same spacecraft. When we attempt to do so, it can drive significant increases in cost and schedule. Our requirements driven stakeholders often do not understand the cost implications of the various elements of their respective wish lists, and when we proceed to blindly integrate these capabilities, considerable problems develop. This problem is exacerbated when we are asked to hold fixed performance, cost and schedule at the beginning of any space acquisitions, thereby inexorably increasing program risk. (Space Acquisitions, 2005)

Figure 4 shows an illustration of the program management pendulum swing that Dr. Rustan talked about. While it shows the years from 1957 to 2005, the date of Dr. Rustan's testimony, between 2005 and today, essentially all of the issues still remain but the priority has changed with cost being the most important.

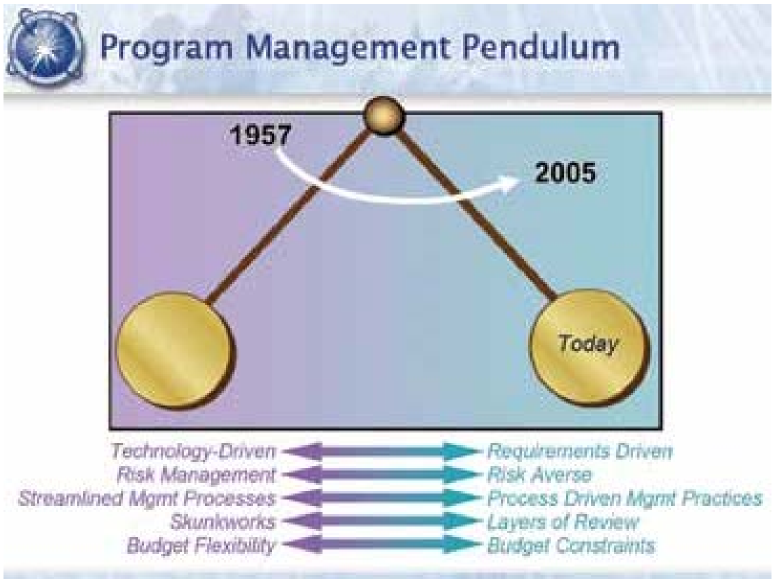


Figure 4. Program Management Pendulum Swing (From Space Acquisitions, 2005)

As shown in Figure 4, the general culture of acquiring Space systems has changed over the years. For example, risk tolerance has drastically been reduced; it has changed from being actively managed to one of risk aversion. While not ideal, during the initial years of space acquisition, it was tolerable when some systems failed because that normally resulted in more knowledge being gained, cheaper and hence affordable systems, faster acquisition of systems, and data reaching the Warfigher. However, since decision makers have become very risk adverse, significant amount of money is spent to prevent failures, commonly referred to as "mission assurance." To accomplish this, several redundancies for various system components are built into the systems. To compound the affordability problem, spacecrafts have grown in size to accommodate more instruments because of increased requirements. This change has resulted in significant complexities, such as integration, which further exaggerates the costs and schedule it takes for satellites to be built, launched, and become operational.

So, in the end, the tax-payer now pays for large, individualized, more complex systems that take a very long time to be acquired and at a significantly greater cost than what is affordable. While one may justify this previous approach because of the high costs to launch satellites into orbit, there needs to be a balance between the two. This balance is what DoD has struggled with throughout the years. These issues are summarized in the following excerpt from Secretary Gates' speech.

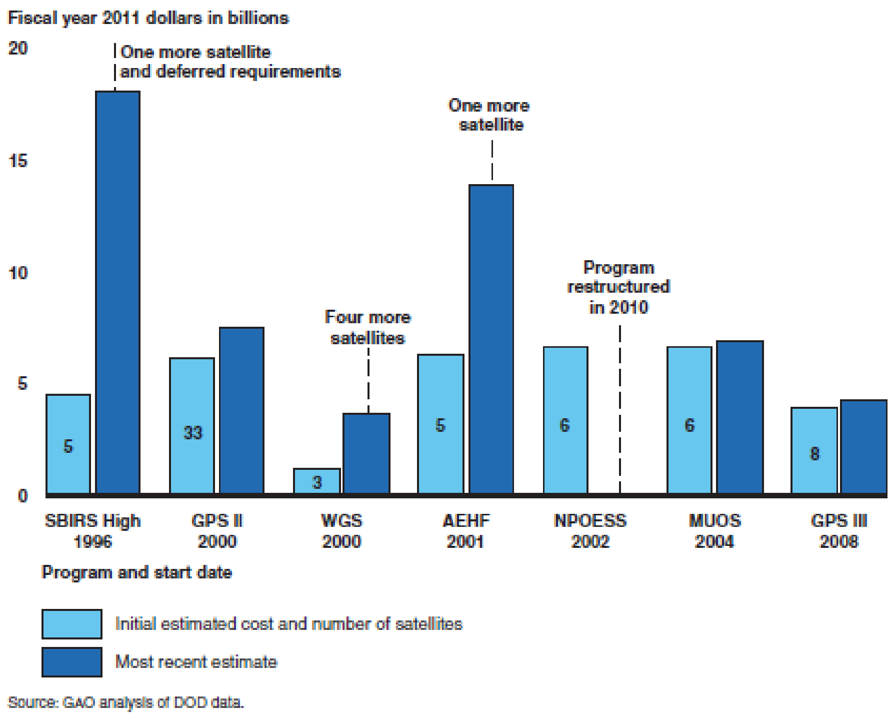
> The perennial procurement and contracting cycle—going back many decades—of adding layer upon layer of cost and complexity onto fewer and fewer platforms that take longer and longer to build must come to an end. There is broad agreement on the need for acquisition and contracting reform in the Department of Defense. There have been enough studies. Enough hand-wringing. Enough rhetoric. Now is the time for action. (Office of the Assistant Secretary of Defense, 2009)

In her May 2011 testimony before the subcommittee on Strategic Forces, Committee on Armed Services, and the U.S. Senate, Christina T. Chaplain, Director of Acquisition and Sourcing Management of the Government Accountability Office (GAO), summarized the events of the last 20 years of space acquisitions as follows:

> Each year DoD spends billions of dollars to acquire space-based capabilities to support current military and other government operations,

> as well as to enable DoD to transform the way it collects and disseminates information. Despite the significant investment in space, the majority of large-scale acquisition programs in DoD's space portfolio have experienced problems during the past two decades that have driven up costs by hundreds of millions and even billions of dollars, stretched schedules by years, and increased technical risks. To address the cost increases, DoD altered its acquisitions by reducing the number of satellites it intended to buy, reducing the capabilities of the satellites, or terminating major space system acquisitions. Moreover, along with the cost increases, many space acquisitions have experienced significant schedule delays—of as much as 9 years—resulting in potential capability gaps in areas such as missile warning, military communications, and weather monitoring. These problems persist; however, the Air Force and the Office of the Secretary of Defense have taken a wide range of actions to prevent them from occurring in new programs. (GAO, 2011, May, p.1)

Systems inherently cost significantly more than their initial estimates and thus making other systems unaffordable due to the limited budget available. The issues GAO identified above and their study of seven current satellite programs revealed that "the cumulative costs for the major space acquisition programs have increased by about $13.9 billion from initial estimates for fiscal years 2010 through 2015, almost a 286 percent increase" (GAO, 2011, May). Figure 5 shows the seven space programs that the GAO studied for this report. It is important to highlight that in three cases, additional satellites were procured than what were originally intended. The reason for the additional AEHF satellite was because of the cancellation of the TSAT program. It is also important to highlight that Figure 5 does not include the "most recent estimate" for the restructured NPOESS program because at the time of that GAO study, it was not an official program of record. The DWSS program, to be discussed in this thesis, was one aspect of the restructured program which has recently been cancelled.



Legend: SBIRS = Space Based Infrared System High; GPS = Global Positioning System; WGS = Wideband Global SATCOM; AEHF = Advanced Extremely High Frequency; NPOESS = National Polar-orbiting Operational Environmental Satellite System; MUOS = Mobile User Objective System.

Figure 5. Differences in Total Costs from Program Start to Most Recent Estimates (From GAO, 2011, May, p. 6)

The Warfighter needs these capabilities faster due to legacy systems failing, the enemy being more agile, adapting faster, and thus a changing threat. However, space systems are taking longer to become operational. All seven major systems acquisition programs GAO studied are years behind schedule and the estimated additional time needed for many of them to launch their first satellites are significant, as seen in Figure 6.

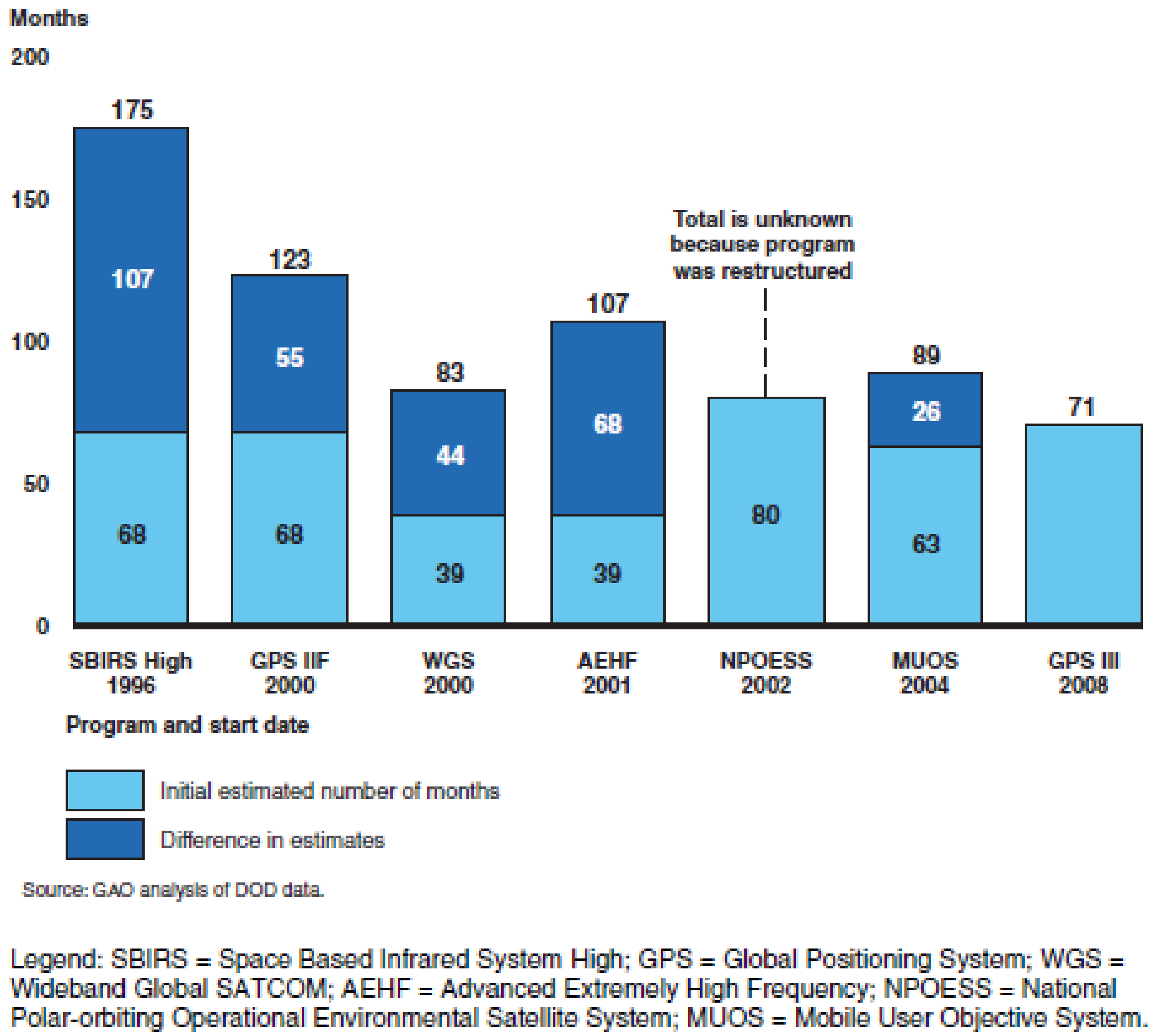


Figure 6. Total Number of Estimated or Actual Months from Program Start to Initial Launch (From GAO, 2011, May, p. 7)

2. Key Influences of Today's Space Systems Acquisitions

Foil (2009) researched and listed 16 initiatives that were geared toward improving acquisitions of major weapon systems, each of which has influenced Acquisitions as it is known today. Table 1 shows the summary of these initiatives and their respective dates; now a 17th, "Better Buying Power," can be added for year 2010 as previously mentioned and conveyed in Dr. Carter's memo. So, while there are several factors that influence Space Systems Acquisition, currently the most significant one is cost.

Table 1. Acquisition Improvement Initiatives (From Foil, 2009, p. 20)

Year	Improvement Initiatives
1949	First Hoover Commission
1953	Rockefeller Committee
1955	Second Hoover Commission
1961	McNamara Initiative
1970	Fitzhugh Commission / Blue Ribbon Defense Panel
1971	DoDD 5000.1 was issued
1972	Commission on Government Procurement
1978	Defense Science Board Acquisition Cycle Study
1979	Defense Resources Management Study
1981	Carlucci Initiatives
1983	Grace Commission / President's Private Sector Survey on Cost Controls
1986	Packard Commission / Presdident's Blue Ribbon Defense Commission
1986	Goldwater-Nichols Act
1989	Defense Management Review
1994	Process Action Team on Oversight and Review
2009	Weapon Systems Acquisition Reform Act

As shown in Figure 3, "MANDATING AFFORDABILITY AS A REQUIREMENT: In new programs…cost considerations must shape requirements and design" is one of the eight mandates under the title "Adopting Government Practices that Encourage Efficiency." By mandating this requirement, it reinforces DoD's focus on cost as currently having the single most influence on Acquisitions. Also shown in Figure 3, Initial Framework for Restoring Affordability to Defense, is the requirement for "STABILIZING PRODUCTION RATES: To ensure more programs are in stable, economically favorable rates of production and avoid cost escalation, program managers may not adjust production rates downward without head of component authority" (Under Secretary of Defense (AT&L) 2010). Together, these two mandates will significantly influence the way how systems are acquired now and into the future.

GAO (2011) highlighted the following influences to Space Acquisitions that resulted in cost growth and related problems:

> First, on a broad scale, DoD has tended to start more weapon programs than it can afford, creating a competition for funding that encourages low cost estimating, optimistic scheduling, overpromising, suppressing bad news, and for space programs, forsaking the opportunity to identify and assess potentially more executable alternatives. Programs focus on advocacy at the expense of realism and sound management. Invariably, with too much programs in its portfolio, DoD is forced to continually shift funds to and from programs-particularly as programs experience problems that require additional time and money to address. Such shifts, in turn, have had costly reverberating effects. Second, DoD has tended to start its space programs too early…before it has the assurance that the capabilities it is pursuing can be achieved within available resources and time constraints….Third, programs have historically attempted to satisfy all requirements in a single step, regardless of the design challenges or the maturity of the technologies necessary to achieve the full capability. DoD has preferred to make fewer but heavier, large, and more complex satellites that perform a multitude of missions rather than larger constellations of smaller, less complex satellites that gradually increase in sophistication. (GAO, 2011, May, pp. 17–18)

Another issue that the GAO found is that there is no set process for transferring Science and Technology from research laboratories to program offices. This has created a problem for program managers to know when technologies are ready to be transferred into acquisition programs (GAO, 2011, Jul). Figure 7 shows various factors that can break acquisitions and thus are key influences to today's Space Systems acquisitions.

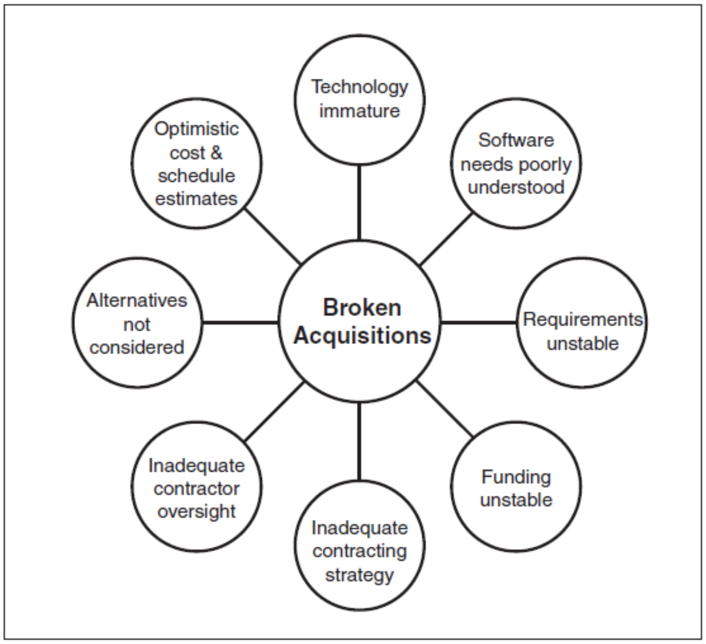


Figure 7. Key Underlying Problems that Can Break Acquisitions (From GAO, 2011, p.18)

In 2010, after Secretary of the Air Force, Michael Donley, directed a review of Air Force Headquarter Management of Space responsibilities, he issued an Air Force directive that would implement several findings based on that review. This directive contained nine actions that will influence the way Space systems are acquired via a more streamlined and effective way. The nine crucial actions are listed below:

> 1) The Under Secretary of the Air Force will serve as the focal point for space within the Air Force Headquarters and be responsible for coordinating the functions and activities across the Air Force space enterprise….2) The position of Deputy Under Secretary of the Air Force for Space will be retained and re-designated as SAF/SP. SAF/SP will report to the Under Secretary and will direct the headquarters staff responsible for space policy, issue integration, and strategy….3) The Deputy Under Secretary of the Air Force for International Affairs (SAF/IA) will continue in their role as the office of primary responsibility for AF international space matters….4) The Assistant Secretary of the Air Force for Acquisition (SAF/AQ) will serve as the single Service Acquisition Executive (SAE) for the Air Force with responsibilities covering all Air Force acquisitions (space and non-space). The Air Force Program Executive Officer (AFPEO) for Space will report to SAF/AQ for space acquisition matters, in accordance with statutory and DoD direction.

> The supporting HAF acquisition staff for space (now SAF/USA), will be realigned under SAF/AQ and redesignated as SAF/AQS. These actions consolidate all Air Force acquisition functions in one office, streamlining the structure….5) Air Force Space Command (AFSPC) will continue to execute duties as the Air Force's Lead Command for space related capabilities, to include such major functions as: developing and coordinating space system requirements, overseeing daily space operations; and planning/programming for AF space programs….6) The Deputy Chief of staff for Operations, Plans and Requirements (AF/A3/5) maintains its role as the principal Air Staff organization for space operations and requirements….7) Create an Air Force Space Board as the governance mechanism to coordinate Air Force positions regarding multi-organization, service, and inter-agency issues….8) Realign those manpower billet in the NSSO that were within the Air Force to SAF/SP….9) Discuss with Air Force leaders, OSD space leaders, and the Congress the optimal reporting structure for the Operationally Responsive Space (ORS) office going forward. (Secretary of the Air Force, 2010, pp. 2–3)

In addition to the aforementioned management and oversight changes made by the Secretary of the Air Force, in 2011 the GAO highlighted eight categories of actions that the DoD has implemented or is in the process of implementing, that will affect Space Systems Acquisitions. The third in the list of eight categories is a summary of the aforementioned "Management and Oversight," contained in the Air Force directive from Secretary Donley. Tables 2 and 3 summarize the eight categories of actions the GAO highlighted.

Table 2. Actions Taken or Being Taken That Could Benefit Space Acquisition Outcomes (From GAO, 2011, May, pp. 20–21)

Category	Actions
National policy	• In June 2010, the President of the United States issued the new *National Space Policy* which establishes overarching national policy for the conduct of U.S. space activities. The policy states that the Secretary of Defense and the Director of National Intelligence are responsible for developing, acquiring, and operating space systems and supporting information systems and networks to support U.S. national security and enable defense and intelligence operations. The policy helps to clarify the Secretary of Defense's roles and responsibilities for coordinating space system acquisitions that span DOD and federal agencies, such as those for space situational awareness. • In January 2011, the Secretary of Defense and the Director of National Intelligence issued the *National Security Space Strategy* to build on the *National Space Policy* and help inform planning, programming, acquisition, operations, and analysis.
Acquisition policy	• We expressed concern over DOD's tailored national security space acquisition policy—initially issued in 2003—primarily because it did not alter DOD's practice of committing to major investments before knowing what resources will be required to deliver promised capability. Instead, the policy encouraged development of leading-edge technology within product development, that is, at the same time the program manager is designing the system and undertaking other product development activities. In 2009, DOD eliminated the space acquisition policy and moved the acquisition of space systems under DOD's updated acquisition guidance for defense acquisition programs (DOD Instruction 5000.02). In October 2010, the Under Secretary of Defense for Acquisition, Technology and Logistics issued a new space acquisition policy to be incorporated into DOD Instruction 5000.02 that introduces specific management and oversight processes for acquiring major space systems, including retaining the requirement for independent program assessments to be conducted prior to major acquisition milestones.
Management and oversight	• In August 2010, the Secretary of Defense announced the elimination of the Office of the Assistant Secretary of Defense for Networks and Information Integration (ASD/NII) as part of a broader effort to eliminate organizations that perform duplicative functions or that have outlived their purpose.[a] The elimination of this organization may help to reduce the problems associated with the wide range of stakeholders within DOD responsible for overseeing the development of space-based capabilities. • In May 2009, Air Force leadership signed the *Acquisition Improvement Plan* which lists five initiatives for improving how the Air Force obtains new capabilities.[b] One of these initiatives relates to establishing clear lines of authority and accountability within acquisition organizations. In August 2010, the Secretary of the Air Force transferred space system acquisition responsibility from the Under Secretary of the Air Force to the Assistant Secretary of the Air Force for Acquisition, thereby aligning all Air Force acquisition responsibility to one office. As part of this realignment, the Program Executive Officer for Space now reports to the Assistant Secretary of the Air Force for Acquisition (previously, the Program Executive Officer for Space reported to the Under Secretary of the Air Force).

Table 3. Actions Taken or Being Taken That Could Benefit Space Acquisition Outcomes–Continuation of Table 2 (From GAO, 2011, May, pp. 20–21)

Category	Actions
	• In November 2010, the Deputy Secretary of Defense authorized the disestablishment of the National Security Space Office (NSSO).[c] The elimination of this office may also help to streamline national security space system acquisition management and oversight. Furthermore, the Deputy Secretary of Defense revalidated the Secretary of the Air Force as DOD Executive Agent for Space and directed the creation of a Defense Space Council (DSC)—chaired by the DOD Executive Agent for Space and with representatives from across DOD—to inform, coordinate, and resolve space issues for DOD. The DSC held its first meeting in December 2010. According to DOD, first on the council's agenda was streamlining the many defense and national security space committees, boards, and councils by reviewing more than 15 space-related organizations and making recommendations on their cancellation, consolidation, dissolution, or realignment under the DSC.
Requirements	• Another of the Air Force's *Acquisition Improvement Plan* initiatives covers requirements generation and includes the direction for the Air Force to certify that the acquisition community can successfully fulfill required capabilities in conjunction with the Air Force Requirements for Operational Capabilities Council. Certification means the required capabilities can be translated in a clear and unambiguous way for evaluation in a source selection, are prioritized if appropriate, and are organized into feasible increments of capability.
Program management assistance	• The Space and Missile Systems Center—the Air Force's primary organization responsible for acquiring space systems—resurrected a program management assistance group in 2007 to help mitigate program management, system integration, and program control deficiencies within specific ongoing programs. This group assists and supplements wing commanders and program offices in fixing common problems, raising core competencies, and providing a consistent culture that sweeps across programs. As we reported last year, the GPS Wing Commander stated this group was an integral part of the overall process providing application-oriented training, templates, analyses, and assessments vital to the GPS IIIA baseline review. According to a senior program management assistance group official, the group has provided assistance to other major programs, including GPS OCX, SBIRS High, and SBSS.
Workforce	• Another initiative in the Air Force's *Acquisition Improvement Plan* is to revitalize the acquisition workforce by, among other things, increasing the number of authorized positions and providing for additional hiring, examining the proper mix of military and civilian personnel, and establishing training and experience objectives as part of the career paths for each acquisition specialty and increasing the availability of specialized training. Also, as we reported last year, the Air Force was continuing efforts to bring space operators and space system acquirers together through the Advanced Space Operations School and the National Security Space Institute. The Air Force anticipated that this higher-level education would be integral to preparing space leaders with the best acquisition know-how.
Cost estimating	• The Air Force took actions to strengthen cost estimating. For example, we recommended that the Secretary of the Air Force ensure that cost estimates are updated as major events occur within a program that could have a material impact on cost, and that the roles and responsibilities of the various Air Force cost-estimating organizations be clearly articulated.[d] An Air Force policy directive now requires that cost estimates for major programs be updated annually, and lays out roles and responsibilities for Air Force cost-estimating organizations. Additionally, the Joint Space Cost Council—formed in 2007 with membership across industry and military and civil government agencies—is actively working to improve cost credibility and realism in estimates, budgets, schedules, data, proposals, and program execution. For example, one initiative has developed a standard work breakdown structure that is being vetted through industry and government.
Military standards	• Over the last several years, the Air Force Space and Missile Systems Center has taken action aimed at preventing parts quality problems by issuing policy relating to specifications and standards. It is requiring the GPS IIIA program development contractor to meet these specifications and standards.

C. THE DMSP PROGRAM

The DMSP program is the DoD's sole weather satellite program whose "mission is to generate terrestrial and space weather data for operational forces worldwide….The data from this program is also furnished to the civilian community through the Department of Commerce" (DMSP fact sheet, 2009). This program began as a temporary top secret classified program in the early 1960s to enable "[s]uccessful operation of overhead photoreconnaissance satellites…[which] depended on accurate and timely meteorological forecasts of the Sino-Soviet landmass" (Hall, 2001). Because of the purpose of this program and sensitivity at the time, "[t]his program, needless to say, had a succession of numeric and alphabetic names, including Program II, P-35, 698BH, 417, and Defense Systems Applications Program (DSAP)" (Hall, 2001). Today it remains vital to providing various types of global weather information to the Warfigher.

The initial spacecrafts identified as "the P35 series were grouped in generations known as "Blocks." Blocks 1 and 2 must be considered as experimental satellites. RCA manufactured the spacecraft of Blocks 1, 2, 3, 4A and 4B" (NOAA, 2008). Each successive block built on information from the previous block. Block 1 acquisitions began as a temporary program "for four 'earth-referenced' weather satellites" on June 21, 1961 with "a plan for a 22-month program, one that specified a small fixed budget and a first launch in ten months" (Hall, 2001). They were regarded as "a single purpose, minimum cost, 'high-risk program'. Smaller and lighter than the original TIROS, the 100-pound TIROS-derived RCA satellite was shaped like a 10-sided polyhedron, 23-inches across and 21-inches high" (Hall, 2001). Its first launch on 23 May 1962 ended in launch failure after the Scout booster second stage exploded. There were a total of eleven spacecrafts launched in this Block. Because of booster issues, four failed to reach orbit, one was placed in an elliptical orbit. Two launches contained two satellites each. Details are shown in Table 4. Note: there are inconsistencies in information from the various literature reviews, such as launch dates, binning satellites into the appropriate blocks, etc. When such situations arose, the information used in this thesis was found in multiple sources.

Table 4. DMSP Block 1 Satellites and Boosters (After Hall, 2001; Shaltanis, 2000, Heyman 2007, Bohlson 2007)

Initial Program – Block 1

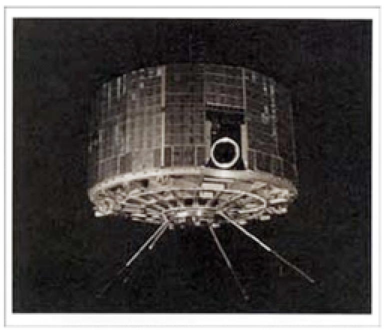


Illustration 07 - Tiros Operational System (TOS), which copied DMSP Block I satellite. Note the Vidicon pointing radially to take pictures on each revolution of the vehicle.

Vehicle(s)	Sensor(s)	Booster	Launch Date	End of Primary Mission	Decom.	Mission life (days)	Notes
Blk1–1 F-1	Vidicon	Scout	23 May 62	-	N/A	0	Booster failure
Blk1–2 F-2	Vidicon	Scout	23 Aug 62	11 Jun 63	UNK	290	Operated nominally until senor failure
Blk1–3 F-3	Vidicon & Infrared radiometer	Scout	19 Feb 63	Late Apr 63	7 Feb 64	55?	Elliptical Orbit due to poor 3rd stage performance, tape recorder & vidicon failure; satellite decom since spin was too low to maintain altitude
Blk1–4 F-4	Vidicon & Infrared radiometer	Scout	26 Apr 63	-	N/A	0	Booster failure
Blk1–5 F-5	Vidicon & Infrared radiometer	Scout	27 Sep 63	-	N/A	0	Booster failure
Blk1–6 & Blk1–7 F-6 & F-7	Vidicon & Infrared radiometer	Thor-Agena	19 Jan 64	10 Jul 64 & 17 Mar 65	28 Jul 64 & 17 Mar 65	173 & 423	Both launched together, Blk 1–7 out lasted Blk1–6; decommissioned b/c spin rate too low to operate
Blk1–8 & Blk1–9 F-8 & F-9	Vidicon & Infrared radiometer	Thor-Agena	17 Jun 64	16 Feb 66 & 15 Oct 65	UNK	609 & 516	Both launched together, Blk1–8 outlasted Blk1–9
Blk1–10 F-10	Vidicon & Infrared radiometer	Thor/ Burner I	18 Jan 65	-	N/A	0	Failed to orbit, nose fairing failed to separate
Blk1–11 F-11	Vidicon & Infrared radiometer	Thor/ Burner I	18 Mar 65	15 Jun 65	UNK	85	Launched noontime modified for direct readout to support operations in Southeast Asia

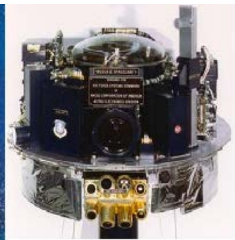
In 1964, three Block 2 satellites were produced from NRO's approval for modification of three Block 1 satellites. They were "160-pound vehicles, identical in size and shape to their 100-to-120 pound Block 1 predecessors, also mounted improved infrared radiometers" (Hall, 2001). In fact, launched before the Block 2 satellites, a "fourth satellite, the one equipped and launched expressly for tactical uses on 20 May 1965, came to be called Block 3. The reason for this curiosity, a 'one-vehicle block,' involved efforts to distinguish it from its Block 2 cousins that also supported the primary strategic mission for the NRP" (Hall, 2001).

Even before the first Block 2 satellite was launched in 1965, and just prior to stepping down as the DMSP first director, "Colonel Haig secured permission to begin the design of a more powerful military meteorological satellite that met more completely the demands of its customers. The Block 4 satellite[s], slightly larger than those in Blocks 1 and 2, was 30 inches in diameter, 29 inches high, and weighed 175 pounds" (Hall, 2001). These satellites were a significant improvement over Blocks 1, 2, & 3 which had a

> single 1/2-inch focal length RCA vidicon television camera … furnished a nadir resolution of 3-to-4 nautical miles (nm) over an 800-nm swath, with significant gaps in coverage of the Earth at the equator. Block 4 vehicles carried two one-inch focal length vidicons canted at 26 degrees from the vertical that provided global coverage of the Earth (contiguous coverage at the equator), along a 1,500-nm swath. The resolution varied from 0.8 nm at the nadir to 3 nm at the picture's edge. Besides a multi-sensor infrared subsystem, Block 4 also incorporated a high-resolution radiometer [HHR] that furnished cloud-height profiles. A tape recorder of increased capacity stored pictures of the entire northern hemisphere each day, while the satellite furnished realtime, direct local tactical weather coverage to small mobile ground or shipboard terminals. (Hall, 2001)

A total of eight Block 4 satellites were built and seven were launched. Table 5 shows a summary of the progression from Block 2 through Block 4. As with Table 4, literature review had conflicting information for some "Launch" and "End of Primary Mission" dates. In the case of launch dates, they were off by one day. The earlier dates were used in the table to represent the date at the launch site. These launches were at night from the pacific coast and could account for the one day discrepancy in launch dates. In addition, decommission dates were not readily available for these earlier Satellites.

Table 5. DMSP Blocks 2 thru 4 Satellites and Boosters (After Hall, 2001; Shaltanis, 2000; Heyman, 2007; Bohlson, 2007)

				Block 2				
	Vehicle(s)	**Sensor(s)**	**Booster**	**Launch Date**	**End of Primary Mission**	**Decom.**	**Mission life (days)**	**Notes**
 	Blk2–1 F-13	Video camera, C system, High Resolution radiometer	Thor/ Burner I	9 Sep 65	17 Aug 66	22 Sep 66	341	C System & Transmitter Failure
	Blk2–2 F-14		Thor/ Burner I	6 Jan 66	-	N/A	0	Launch failure
	Blk2–3 F-15		Thor/ Burner I	30 Mar 66	30 Mar 68	UNK	730	Recorder failure, C System degraded, Camera failed Feb 68
				Block 3				
	Blk3–1 F-12	Video, C, HRR	Thor/ Burner I	20 May 65	16 Feb 67	UNK	637	Launched expressly for tactical uses & before Block 2 satellites
				Blocks 4: A & B				
 Illustration 09 - DMSP Block 4 satellite	Blk4A-1 F-16	Video, C	Thor/ Burner II	15 Sep 66	3 Nov 68	UNK	780	Eventual Sensor Degradation
	Blk4A-2 F-17	Video, C	Thor/ Burner II	8 Feb 67	18 May 67	UNK	99	In Noon Orbit, Video System Failures
	Blk4A-3 F-18	Video, C, H	Thor/ Burner II	22 Aug 67	13 Mar 68	UNK	204	Eventual Sensor Degradation
	Blk4A-4 F-19	Video, C	Thor/ Burner II	11 Oct 67	26 Mar 68	23 Jun 68	167	In Noon Orbit, Cameras & Recorder Failure
	Blk4B-1 F-20	Video, C, H	Thor/ Burner II	23 May 68	11 Sep 68	26 May 69	112	Recorder, C System Failures
	Blk4B-2 F-21	Video, C, H	Thor/ Burner II	22 Oct 68	19 Sep 70	UNK	697	Recorder Failed
	Blk4B-3 F-22	Video, C, H	Thor/ Burner II	22 Jul 69	19 Mar 71	UNK	604	Recorder Failed
	Blk4B-4 F-23	Video, C	Never Launched, donated to the Chicago Museum of Science and Industry					

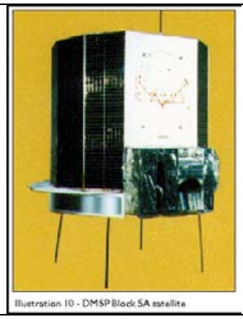
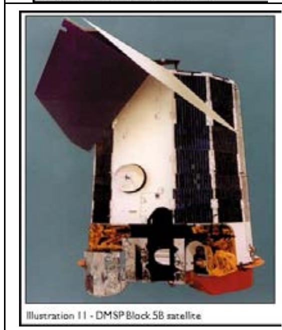
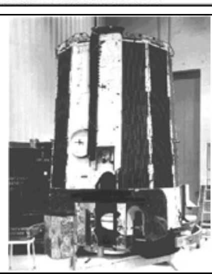
Concurrently, as Block 4 satellites were being delivered and launched under the guidance of the new program director, Major John Kulpa, he began work on the next series of satellites, Block 5, and used a different acquisition approach as explained below.

> [T]he revolutionary Block 5 spacecraft that resulted from the efforts of Geer and Blankenship took the form of an integrated system; it departed entirely from the TIROS-derived technology of its predecessors. The two men visited meteorologists at work, and then examined what the industry could produce. Instead of starting with a sensor in space and determining what it might tell the user about the weather, these two based the Block 5 design on the users' wish to receive a product in a form that approached as closely as possible the weather charts and maps that…the meteorologists employed.…A survey of the industry and new technologies revealed line scanning sensors and advances in highly sensitive visible light and infrared point (as opposed to array) detectors….[T]hey reasoned, one now could let the motion of the satellite provide the scanning along the line-of flight. That would require a spacecraft that always 'looked down,' rather than one that wheeled along its orbit. But a satellite stabilized on three axes would make possible acquiring a strip of imagery of indefinite length, imagery that could be rectified at will. (Hall, 2001)

These factors shaped the design of the Block 5 series of satellites which ultimately enabled "nadir visual-imaging resolution at the Earth's surface [to be] improved to 0.3 nm during daytime and 2 nm at night through quarter-moonlight illumination levels" (Hall, 2001). The system met both the field commander's tactical and the NRO's strategic needs. The "slab-sided, tube-shaped Block 5 satellite remained 30 inches in diameter, but its height increased to 40 inches and its weight rose to 230 pounds" (Hall, 2001). Three Block 5 satellites were built before requirements changed, requiring greater tactical meteorological support and thus the reason for three Block 5A spacecrafts, five Block 5B, and three Block 5C as found in Table 6. The latter two Blocks of satellites were larger:

> 84 inches in height, and heavier, at 425 pounds, these spacecraft exclusively required use of the updated booster called Thor/Burner IIA. Block 5B spacecraft added a large sunshade on the 'morning birds,' a more powerful 20-watt traveling-wave-tube amplifier (TWTA) transmitter that radiated ample power for receipt aboard ships, a second primary data recorder, and a gamma-radiation detector. Block 5C added a vertical temperature/moisture profile sensor and an improved IR sensor that now achieved a resolution of 0.3 nm at the Earth's surface. (Hall, 2001)

Table 6. DMSP Blocks 5A thru 5C Satellites and Boosters (After Hall, 2001; Shaltanis, 2000; Heyman 2007; Bohlson, 2007)

Blocks 5: A, B, & C								
	Vehicle(s)	**Sensor(s)**	**Booster**	**Launch Date**	**End of Primary Mission**	**Decom.**	**Mission Life days)**	**Notes**
	Blk5A-1 F-24	Operational Line Scan (OLS), WS	Thor/ Burner II	11 Feb 70	30 Apr 70	19 Mar 71	78	Spacecraft failed due to excessive brush wear in pitch control motor
	Blk5A-2 F-25		Thor/ Burner II	3 Sep 70	15 Feb 71	UNK	164	Sensor failed due to excessive brush wear
	Blk5A-3 F-26		Thor/ Burner II	17 Feb 71	3 Mar 73	UNK	746	V recorder failed, sensor failed due to excessive brush wear
	Blk5B-1 F-27	OLS, GRD	Thor/ Burner IIA	14 Oct 71	27 Apr 72	27 Apr 72	196	Rapid satellite degradation due to damage from backflow of heat from Burner IIA plume
	Blk5B-2 F-28		Thor/ Burner IIA	24 Mar 72	23 Feb 74	UNK	701	Sensor electrical failure
	Blk5B-3 F-29		Thor/ Burner IIA	8 Nov 72	21 Jun 73	UNK	225	Sensor electrical failure
	Blk5B-4 F-30		Thor/ Burner IIA	16 Aug 73	24 Jan 77	UNK	1257	Primary sensor degraded prior to spacecraft failure
	Blk5B-5 F-31		Thor/ Burner IIA	16 Mar 74	27 May 76		802	Flight Transmitter failure
	Blk5C-1 F-32	Vertical Temperature Moisture Recorder, IR, OLS	Thor/ Burner IIA	8 Aug 74	22 Nov 74	1 Dec 77	114	Sensor mechanical failure
	Blk5C-2 F-33		Thor/ Burner IIA	23 May 75	30 Nov 77	30 Nov 77	922	Primary sensor degraded due to temperature problems prior to spacecraft failure
	Blk5C-3 F-34		Thor/ Burner IIA	18 Feb 76	-	N/A	0	Launch failure: Booster ran out of fuel before achieving orbit

By the early 1970s, the initial size and shape of the Block 5 spacecrafts was no longer appropriate for the sensors it had to carry. "Moreover, this design, which took advantage of spin stabilization for internal thermal control, was ill suited to Block 5 operations in a 'de-spun' three axis stabilized attitude" (Hall, 2001). Another requirement was for the satellites to last longer on orbit. One way to achieve this requirement was to procure a larger spacecraft that would have enough space and power to allow for redundant components. Studies for Block 6 satellites began in the early 1970s but changing the name of the Block signified "a new start" and the political climate at the time was not favorable to the DoD starting a new military weather program during a period when the Office of Management and Budget (OMB) was more in favor of combining the military and civil meteorological programs. So, the Air Force decided to call the new spacecraft a modification of Block 5C and appropriated funds for five Block 5D spacecrafts in 1972. Greater pointing accuracy and the need to carry more instruments were added as new requirements which caused an increase in cost and delayed the initial launch to 1976. However, this delay coupled with the unanticipated launch failure of the last Block 5C-3 spacecraft (F-34), resulted in poor DMSP weather coverage between 1975 and 1977 (Hall, 2001).

In 1972 the OMB requested that the DoD and Department of Commerce (DoC) study the feasibility of consolidating both the military and civil programs and using one spacecraft for both. The study "concluded that the greatest savings would be realized in a single national meteorological satellite system managed by the Air Force, using a standard DMSP Block-5D satellite. This uncivil solution was quickly rejected by Congressmen who argued that it would violate the National Aeronautics and Space Act" (Hall, 2001). So to gain major cost savings, going forward, both agreed to use a larger version of the Block 5D spacecraft, so as to accommodate DoC's requirement for a larger spacecraft to carry additional sensors for NOAA. This change resulted in the first five spacecrafts being designated Block 5D-1 and later ones as Block 5D-2.

> The Block 5D-1 design…resembled in appearance conventional Earth-oriented satellites of this period. Sized to fit the space taken by the Burner IIA solid-propellant upper stage on the Thor…was five feet in diameter and 20 feet long….built by RCA consisted of three sections….A

> deployable, 6-by-16 foot sun-tracking solar array was also mounted aft....With its complement of additional sensors, the spacecraft weighed 1,150 pounds, making it more than twice as massive as its Block 5C predecessors. To heft the additional weight into orbit, the program office contracted with Boeing for a new, larger, solid propellant second stage. The original Burner-IIA second stage, now adapted as a third stage and fixed to the satellite, was used during ascent to inject the vehicle into its circular, sun-synchronous 450 nautical mile Earth orbit. (Hall, 2001)

Due to greater complexity of the Block 5D-2 satellites driven by NOAA's needs, the initial launch was delayed from 1980 to 1982. This delay coupled with the launch failure of the last Block 5D-1 satellite (F-5) in July 1980, created the first ever gap in military weather coverage from August 1980 to December 1982, since the program began in early 1960s (Hall, 2001).

The Block 5D-2 spacecrafts grew in length from 20 to 22.5 feet although the electronic components remained relatively the same. The solar array increased in size to eight by sixteen feet to give increased power. Two additional sensors were also added. This combined change caused the Block 5D-2 spacecrafts to now weigh 1,792 pounds; heavier than what the Thor/Burner IIA could launch and thus the change to the Atlas E launch vehicle. After the first five satellites were built in this block, an additional four were built in a Block 5D-2 follow-on program (Hall, 2001).

The Block 5D-3 spacecrafts, the current block being launched, were designed from the 1970s and to be compatible with launching from the space shuttle. Their length increased by 2 feet, to 24 feet long, hosted an improved Operational Line Scan sensor, more secondary sensors, a larger solar array, larger capacity batteries, a redesigned sunshade, and weighs 2,278 pounds. These changes resulted in an anticipated mean mission lifetime of five years on orbit. (Hall, 2001) Tables 7 and 8 show a summary of the satellites and boosters for Blocks 5D-1, 2, and 3, while Table 9 shows their sensor complements. The program's last two satellites remain to be launched from this block.

Table 7. DMSP Block 5D-1 and 5D-2 Satellites and Boosters (After: Hall, 2001; Shaltanis, 2000; Heyman, 2007; Bohlson, 2007)

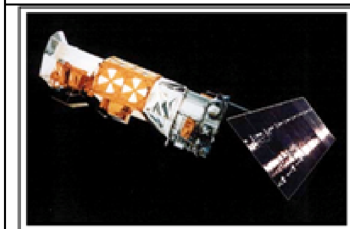
Blocks 5D: 1 & 2								
	Vehicle(s)	Sensor(s)	Booster	Launch Date	End of Primary Mission	Decom.	Mission & Active life (days)	Notes
 Illustration 12 - DMSP Block 5D1 satellite	Blk5D-1 F-1	Each satellite contained an OLS plus several secondary sensors that varied from satellite to satellite. See Table 9 for their respective sensors and the Appendix for the details of each sensor.	Thor/ Burner IIA	11 Sep 76	17 Sep 79	17 Sep 79	880	Battery failure; 6 months spin time subtracted from mission life
	Blk5D-1 F-2		Thor/ Burner IIA	5 Jun 77	19 Mar 80	19 Mar 80	910	S/C computer failure; 3 month spin time subtracted from mission life
	Blk5D-1 F-3		Thor/ Burner IIA	30 Apr 78	1 Dec 79	22 Feb 84	580	OLS failure; S/C operated in degraded mode due to IR failure
	Blk5D-1 F-4		Thor/ Burner IIA	6 Jun 79	14 Jul 80	29 Aug 80	430	Spacecraft (S/C) battery failure
	Blk5D-1 F-5		Thor/ Burner IIA	14 Jul 80	-	N/A	0	Launch failure (4th stage)
 Illustration 13 - DMSP Block 5D2 satellite	Blk5D-2 F-6		Atlas E	21 Dec 82	24 Aug 87	4 Oct 97	1708 5402	OLS bearing failed 8/87, First S/C with encryption; S/C failed 5/15/88
	Blk5D-2 F-7		Atlas E	18 Nov 83	17 Oct 87	15 May 88	1399 1641	OLS bearing failed
	Blk5D-2 F-8		Atlas E	18 Jun 87	13 Aug 91	16 Oct 06	1513 7059	OLS bearing failed
	Blk5D-2 F-9		Atlas E	3 Feb 88	23 Feb 92	3 Aug 94	1470 2374	OLS scanner shut off; S/C failed 11/97
	Blk5D-2 F-10		Atlas E	1 Dec 90	15 Aug 92	22 Nov 97	623 2548	Orbit drift; First RDS capable S/C
	Blk5D-2 F-11		Atlas E	28 Nov 91	15 Oct 93	31 Aug 00	690 3199	Recorder failure; **Block 5D-2 follow-on started with F 11**
	Blk5D-2 F-12		Atlas E	29 Aug 94	15 Jun 96	13 Oct 08	660	Recorder failure; OLS New bearing & Lubricant Test Vehicle
	Blk5D-2 F-13		Atlas E	24 Mar 95	18 Nov 09	Still Active	5353 -	Tactical satellite as of 18 Nov 11
	Blk5D-2 F-14		Titan II	4 Apr 97	12 Oct 98	Still Active	540 -	Recorder failure, Tactical satellite

Table 8. DMSP Block 5D-3 Satellites and Boosters (After Hall, 2001; Shaltanis, 2000; Heyman, 2007; Bohlson, 2007)

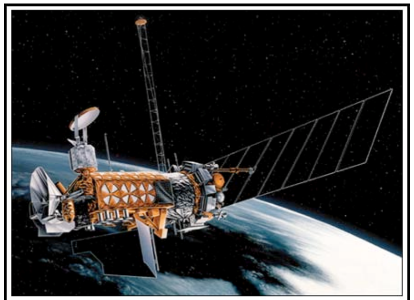
Blocks 5D: 1 & 2								
	Vehicle(s)	**Sensor(s)**	**Booster**	**Launch Date**	**End of Primary Mission**	**Decom.**	**Mission & Active life (days)**	**Notes**
	Blk5D-3 F-15	See Table 9 for a list of sensors on each Satellite	Titan II	12 Dec 99	5 Nov 03	Still Active	1410 -	**5D-3 satellite with 5D-2 sensors** **2 legacy tape & 2 digital recorders** Secondary satellite in early morning orbit
 Illustration 16 - DMSP Block 5D3 satellite	Blk5D-3 F-16		Titan II	18 Oct 03	5 Oct 06	Still Active	1080 -	4 digital solid state recorders on this S/C and later satellites Secondary Satellite in mid morning orbit
	Blk5D-3 F-17		Delta IV	4 Nov 06	Currently primary S/C in Early Morning orbit			Upgraded navigation package to 1 IMU & 1 MIMU & 4 digital recorders
	Blk5D-3 F-18		Atlas V	18 Oct 09	Currently primary S/C in Mid morning orbit			Upgraded navigation package to 1 IMU & 1 MIMU
	Blk5D-3 F-19		Atlas V (scheduled)	Currently scheduled for 2013				Further upgraded to Dual MIMUs & 1 Star tracker
	Blk5D-3 F-20		Delta IV (scheduled)	Currently scheduled for 2014				Dual MIMUs & 1 Star tracker; last satellite in this block & built for the DMSP program

Table 9. Blocks 5D-1, 5D-2, and 5D-3 Sensor Complements (After Bohlson, 2007)

	Satellite	Date Launched	Sensor Complement
Block 5D-1:			
	F-1	11 Sep 76	OLS, SSH, SSJ13, SSB, Contamination Monitor
	F-2	4 Jun 77	OLS, SSH, SSJ/3, SSB, SSB/O, IFM, SSI/E, SSI/P
	F-3	30 Apr 78	OLS, SSH, SSJ/3, SSB, CFE-3R
	F-4	6 Jun 79	OLS, SSH, SSJ/3, SSI/E, SSMIT, SSC, SSD
	F-5	14 Jul 80	OLS, SSH-2, SSJ13, SSI/E, SSBIO, SSR
Block 5D-2:			
	F-6	20 Dec 82	OLS, SSH-2, SSI/E, SSJ/4, SSBA
	F-7	17 Nov 83	OLS, SSM/T, SSI/E, SSJ/4, SSB, SSJ*M, SSM
	F-8	18 Jun 87	OLS, SSMII, SSM/T, SSI/ES, SSJ14, SSB/X-M
	F-9	2 Feb 88	OLS, SSM/T, SSI/ES, SSJ/4, SSB/X
	F-10	1 Dec 90	OLS, SSM/I, SSM/T, SSI/ES, SSJ/4, SSB/X-2
	F-11	28 Nov 91	OLS, SSM/I SSM/T, SSJ14, SSIIES-2, SSBIX-2, SSM
	F-12	29 Aug 94	OLS, SSMII, SSMIT, SSM/T-2, SSJ/4, SSI/ES-2, SSB/X-2
	F-13	24 Mar 95	OLS, SSM/I, SSM/T, SSM/T-2, SSJ/4, SSI/ES-2, SB/X-2, SSM, SSZ
	F-14	4 Apr 97	OLS, SSM/I , SSM/T, SSM/T-2, SSJ/4, SSI/ES-2, SSB/X-2, SSM
Block 5D-3			
	F-15	12 Dec 99	OLS, SSM/I , SSM/T, SSM/T-2, SSJ/4, SSI/ES-2, SSM, SSZ
	F-16	18 Oct 03	OLS,SSMIS,SSI/ES-3, SSJ/5, SSULI, SSUSI, SSM, SSF
	F-17	4 Nov 06	OLS,SSMIS,SSI/ES-3, SSJ/5, SSULI, SSUSI, SSM, SSF
	F-18	18 Oct 09	OLS,SSMIS,SSI/ES-3, SSJ/5, SSULI, SSUSI, SSM, SSF
	F-19	Currently scheduled for 2013	OLS,SSMIS,SSI/ES-3, SSJ/5, SSULI, SSUSI, SSM, SSF
	F-20	Currently scheduled for 2014	OLS,SSMIS,SSI/ES-3, SSJ/5, SSULI, SSUSI, SSM, SSF

1. Current Program

The current DMSP Block 5D-3 consists of six satellites, four of which have been launched and are currently operational. DMSP satellites fly in two orbits designated as early-morning and mid-morning based on the time that they cross the equator. Two satellites from the previous block, F-13 and F-14, are still on orbit and performing with degraded capabilities; they are termed as Tactical satellites. So, currently there are a total of six satellites on orbit. The primary operational satellites are F-17 and F-18, while two secondary and two tactical satellites remain with degraded capabilities: F-16, F-15, F-14, and F-13, respectively. The final two satellites, F-19 and F-20, are currently being prepared for launches in 2013 and 2014, initially based on anticipated end of life (EOL) for F-17 and F-18, but now subject to change and based on decisions from the follow-on program. Figure 8 shows the current DMSP constellation with the satellites Local Times at Ascending Nodes (LTAN).

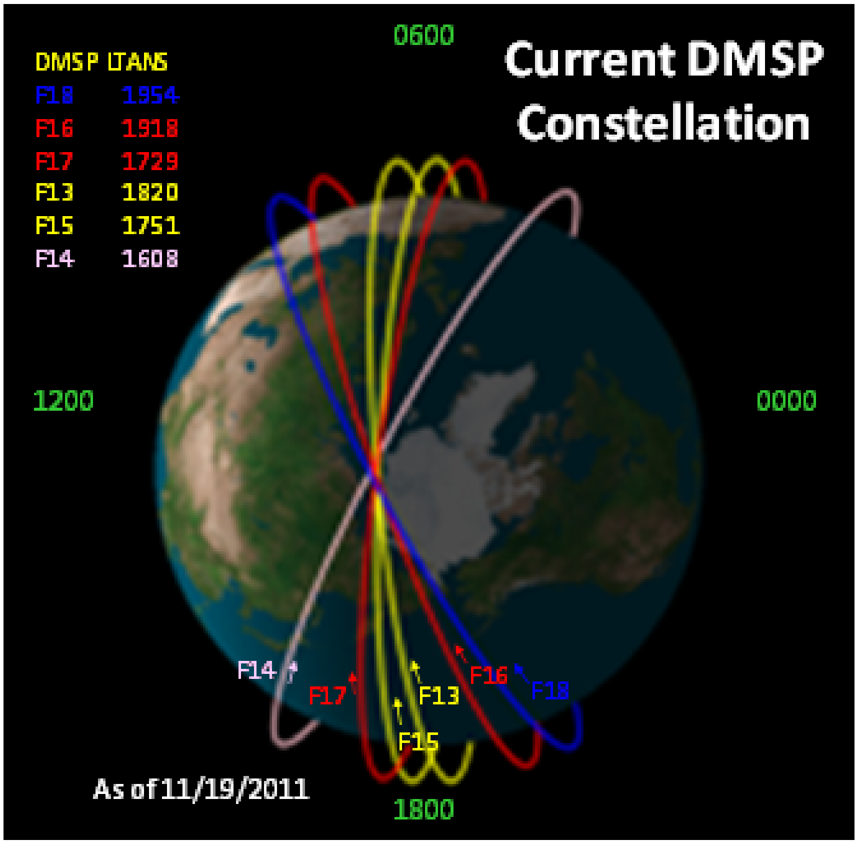


Figure 8. Configuration of DMSP Constellation (From DMSG Program Office, 2009)

Similar to previous DMSP satellite blocks, Block 5D-3 has its share of updates to some of the satellites within its block after they were built and delivered. In the case of Block 5D-3 satellites, it is mainly due to parts obsolescence issues because the satellites were built and kept in storage from the late 1990s. In fact, the last satellite was built in 1998 and certain parts have started to degrade. So, in 2006 a Service Life Extension Program (SLEP) began so as to address this parts degradation issue thereby extend the mission life and increase reliability for the last two satellites (Bohlson, 2007). Of the 22 items identified to improve the overall performance, one of the main ones for the spacecraft was to replace the old Inertial Measurement Units (IMUs) that contained mechanical gyros with newer technology ring laser gyros in the Miniature Inertial Measurement Units (MIMUs) (Bohlson, 2007). The IMUs were causing premature failure on orbit. Adding one each to F-17 and F-18 restored their reliability back to nominal. For improved reliability and extend life of the spacecraft, the program office decided to add an additional MIMU and a Star Tracker to each of the last two spacecrafts, F-19 and F-20. This change allows DoD to reasonably expect these satellites to last a minimum of 60 months on orbit. This life extension is especially important to the Warfighter and the nation especially because of NPOESS' significant delay and subsequent cancellation and DWSS' cancellation, DoD will require more time to acquire and field new satellites.

2. Proposed Follow-On

With the 1993 prompting by OMB and Congressional committees to justify separate military and civil polar orbiting metrological satellites, DoD, DoC, and National Aeronautics and Space Administration (NASA) met to study the issue. The joint recommendation was to combine the two programs, a similar conclusion which was reached 32 years before (in 1961) but did not materialize because then Under Secretary of the Air Force and head of the NRO, Joseph V. Charyk, remained unconvinced that it would work (Hall, 2001). However, because by 1993 space-based weather observations had been developed and proven, it was harder to justify the existence of two separate programs. This led to President William Clinton's issuing a Presidential Decision Directive on May 5, 1994, to merge the two programs. This directive produced a "tri-agency" program that would "create an Integrated Program Office that would develop, acquire, and operate the converged National Polar-orbiting Operational Environmental Satellite system (NPOESS)" (Hall, 2001). NOAA was designated to have the overall responsibility for the converged system, DoD to contract, acquire, and launch the satellites, and NASA was responsible for "facilitating the development and incorporation of new cost-effective technologies into the converged system" (Hall, 2001). Figure 9 shows the NPOESS program's roles and responsibilities based on GAO's analysis of NPOESS program office data.

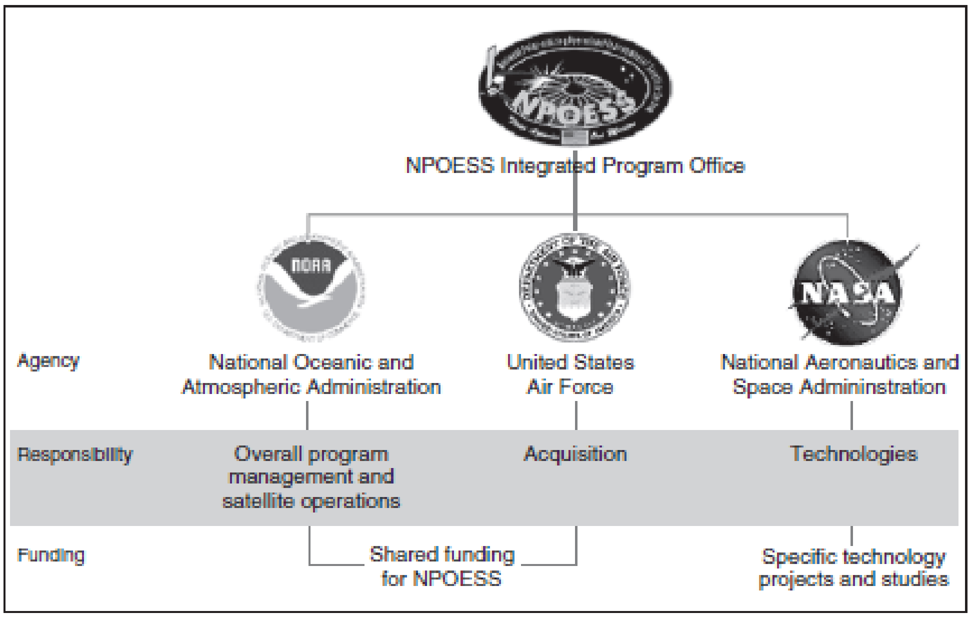


Figure 9. NPOESS Program Roles and Responsibilities (From GAO, 2010, p.7)

The original NPOESS program estimate was $6.5 billion, for 24 years, starting in 1995 through 2018 and procurement of six satellites containing 13 instruments. However, by the time the development contract was to be awarded in 2002, the new estimate was $7 billion. Additionally, a demonstration satellite, NPOESS Preparatory Project (NPP), a joint mission between NPOESS and NASA was to be built and launched several years before the first NPOESS satellite. Its purpose was to test four of NPOESS' sensors on orbit and provide the program office with early performance information (GAO, 2010, May).

> When the NPOESS development contract was awarded in 2002, the schedule for launching the satellites was driven by a requirement that the NPOESS satellites be available to backup the final POES and DMSP satellites should anything go wrong during the planned launches of these satellites. Early program milestones included (1) launching NPP by May 2006, (2) having the first NPOESS satellite available to back up the final POES satellite launch then planned for March 2008, and (3) having the second NPOESS satellite available to back up the final DMSP satellite launch then planned for October 2009. If the NPOESS satellites were not needed to back up the final predecessor satellites, their anticipated launch dates would have been April 2009 and June 2011, respectively. (GAO, 2010, May, p. 8)

After significant schedule delays and cost growth by November 2005, breaching the 25% threshold for Nunn-McCurdy, the program was recertified and re-baselined in 2006 with a new estimated cost of $12.5 billion through 2024, delay of NPP and the first two NPOESS satellites (called C1 and C2) by three to five years and reducing the number of satellites from six to four. In addition, the number of sensors was reduced from 13 to 9, four of whose functionality also were reduced. This reduction in satellites caused the U.S. Government to rely on a European satellite, called Meteorological Operational (MetOp), to cover the midmorning orbit while NPOESS would cover the early morning and afternoon orbits. (GAO, 2010, May) Table 10 shows these changes.

Table 10. Major Changes to the NPOESS Program by the Nunn-McCurdy Certification Decision (From GAO, 2010, p. 10)

Key area	Program before the Nunn-McCurdy decision	Program after the Nunn-McCurdy decision (as of June 2006)
Life-cycle range	1995 through 2020	1995 through 2026
Estimated life-cycle cost	$8.4 billion	$12.5 billion[a]
Launch schedule	NPP by October 2006 First NPOESS (C1) by November 2009 Second NPOESS (C2) by June 2011	NPP by January 2010 C1 by January 2013 C2 by January 2016
Management structure	System Program Director reports to a tri-agency steering committee and the tri-agency Executive Committee Independent program reviews noted insufficient system engineering and cost analysis staff	System Program Director is responsible for day-to-day program management and reports to the Program Executive Officer Program Executive Officer oversees program and reports to the tri-agency Executive Committee
Number of satellites	6 (in addition to NPP)	4 (in addition to NPP)
Number of orbits	3 (early morning, midmorning, and afternoon)	2 (early morning and afternoon; will rely on European satellites for midmorning orbit data)
Number and complement of instruments	13 instruments (10 sensors and 3 subsystems)	9 instruments (7 sensors and 2 subsystems); 4 of the sensors are to provide fewer capabilities
Number of environmental data records	55	39 (6 are to be degraded products)

Source: GAO analysis of NPOESS program office data.

[a]Although the program's life cycle was through 2026, the cost estimate was only through 2024.

The reduction in sensors and functionality "affected the number and quality of the resulting weather and environmental products." (GAO, 2010, May). For these reasons, in 2008, the NPOESS Executive Committee re-manifested some of the sensors. Table 11 shows these changes for NPP and the four NPOESS satellites, C1 through C4.

Table 11. Configuration of Sensors Planned for NPP and NPOESS Satellites, as of May 2008 (From GAO, 2010, May, p .12)

Sensor	NPP	NPOESS C1 (PM)	NPOESS C2 (AM)	NPOESS C3 (PM)	NPOESS C4 (AM)
Advanced Technology Microwave Sounder	X	X	O	X	O
Microwave Imager/Sounder	—	—	X	X	X
Cross-track Infrared Sounder (CrIS)	X	X	O	X	O
Clouds and the Earth's Radiant Energy System sensor	X	X	—	—	—
Ozone Mapping and Profiler Suite (OMPS) Nadir / Limb components[a]	X/X	X/O	—	X/O	—
Space Environment Monitor	—	X	—	X	—
Total and Spectral Solar Irradiance Sensor	—	X	O	—	O
Visible/Infrared Imager/Radiometer Suite (VIIRS)	X	X	X	X	X

Key:
X = Sensor is currently planned for this satellite
O = Canceled during the Nunn-McCurdy certification, but could be restored to this satellite
— = Not applicable—sensor was never planned for this satellite
Source: GAO analysis of NPOESS program office data.
[a]The OMPS sensor consists of two components, called the nadir and limb. During the 2006 restructuring, a decision was made to remove the limb component from both C1 and C3 satellites.

Between the restructuring of June 2006 through June 2009, various acquisition challenges continued to plague the NPOESS program, resulting in increased life-cycle cost estimates (GAO estimates based on their analysis of contractor data) and later launch dates as shown in Table 12.

Table 12. Changes in NPOESS Life-Cycle Cost Estimates and Estimated Satellite Launch (From GAO, 2010, May, p .12)

(Dollars in billions)

As of	Life-cycle cost estimate	NPP launch	C1 launch	C2 launch
August 2002	$7.0	May 2006	April 2009	June 2011
July 2003	7.0	October 2006	November 2009	June 2011
September 2004	8.1	October 2006	November 2009	June 2011
August 2005	8.1	April 2008	December 2010	December 2011
June 2006	12.5	January 2010	January 2013	January 2016
December 2008	13.95	January 2010	January 2013	January 2016
June 2009	14.95[a]	January 2011	March 2014	May 2016

Acting on the recommendation of an independent review team, in August 2009, a task force was formed by the Executive Office of the President, led by the Office of Science and Technology Policy (OSTP), to investigate the NPOESS issues. On February 1, 2010, after 16 years, over $5 billion spent, more than five years launch schedule delays, and still nothing launched:

> The director of OSTP announced that NOAA and DoD will no longer jointly procure the NPOESS satellite system; instead, each agency would plan and acquire its own satellite system. Specifically, NOAA is to be responsible for the afternoon orbit and the observations planned for the first and third NPOESS satellites. DoD is to be responsible for the morning orbit and the observations planned for the second and fourth NPOESS satellites. The partnership with the European satellite agencies for the midmorning orbit is to continue as planned. (GAO, 2010, May)

This means that DoD is now responsible to maintain one spacecraft in the early morning orbit, a reduction from the two orbits that it currently flies in and has done since March 18, 1965 (Hall, 2001). Figure 10 shows the current configuration of the operational polar satellites that U.S. Government relies on for space based weather capabilities. In addition to the two DMSP primary satellites and one MetOp satellite on orbit, there is also one Polar-orbiting Operational Environmental Satellite (POES) that was launched February 2009, the last of the POES series of satellites (GAO, 2010, May).

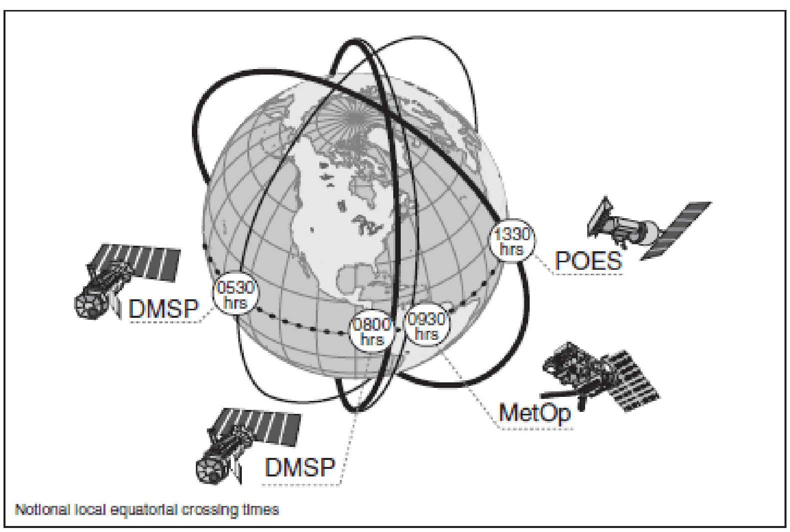


Figure 10. Configuration of Operational Polar Satellites
(From GAO, 2010, p. 4)

With the DoD now only responsible for the early morning orbit and having two satellites remaining to be launched (F-19, and F-20), it has more time than DoC before its first satellite is needed. DoD expected to officially begin the new DWSS program in 2013 (GAO, 2010, May). Table 13 shows a comparison of what NPOESS was supposed to be post Nunn-McCurdy in 2006, to what it became as of February 2010 when the decision was made to disband it, and now the initial thoughts on the new NOAA (Joint Polar Satellite System–JPASS) and DoD (DWSS) acquisitions.

Table 13. Comparison of NPOESS to the New NOAA and DoD Acquisitions (From GAO, 2010, May, p.19)

Key area	NPOESS program after the Nunn-McCurdy decision (as of June 2006)	NPOESS program (as of February 2010)	NOAA and DOD acquisition plans (as of February 2010)
Life-cycle range	1995-2026	1995-2026	*JPSS*: 1995-2024 *DOD program*: unknown
Estimated life-cycle cost[a]	$12.5 billion	$13.95+ billion[b]	*JPSS*: $11.9 billion (which includes about $2.9 billion in NOAA funds spent through fiscal year 2010 on NPOESS) *DOD program*: unknown; DOD's initial estimates include costs of about $5 billion through fiscal year 2015 (which includes about $2.9 billion in DOD funds spent through fiscal year 2010 on NPOESS)
Launch schedule	NPP by January 2010 C1 by January 2013 C2 by January 2016 C3 by January 2018 C4 by January 2020	NPP no earlier than September 2011 C1 by March 2014[c] C2 by May 2016 C3 by January 2018 C4 by January 2020	NPP no earlier than September 2011 JPSS-1 (C1 equivalent) available in 2015 JPSS-2 (C3 equivalent) available in 2018 *DOD program*: unknown
Number of sensors	NPP: 4 sensors C1: 6 sensors C2: 2 sensors C3: 6 sensors C4: 2 sensors	NPP: 5 sensors C1: 7 sensors[d] C2: 2 sensors C3: 6 sensors C4: 2 sensors	NPP: 5 sensors JPSS-1 and 2: Although NOAA has not determined the exact complement of sensors, it will have at least 5 of the original NPOESS sensors[e] *DOD program*: unknown

Source: GAO analysis of NOAA, DOD, and task force data.

[a]Although the life-cycle ranges for NPOESS are through 2026, the cost estimates for both NPOESS and JPSS are only through 2024.

[b]Although the program baseline is currently $13.95 billion, we estimated in June 2009 that this cost could grow by about $1 billion. In addition, officials from the Executive Office of the President stated that they reviewed life-cycle cost estimates from DOD and the NPOESS program office of $15.1 billion and $16.45 billion, respectively.

[c]Officials from the Executive Office of the President noted that the expected launch date of C1 had slipped to late 2014 by the time of their decision.

[d]In May 2008, the NPOESS Executive Committee approved an additional sensor—the Total and Spectral Solar Irradiance Sensor—for the C1 satellite.

[e]These five sensors are: VIIRS, CrIS, OMPS-nadir, the Advanced Technology Microwave Sounder, and the Clouds and the Earth's Radiant Energy System/Earth Radiation Budget Sensor.

In chapters IV and V, this thesis assesses and makes recommendations as to what the DoD acquisition program should be for the next generation of satellites. Figure 11 shows the current and planned satellites (as of May 2010) with potential weather data gaps. It shows DMSP F-20 being launched in Mid-morning orbit but that is subject to change based on a number of factors such as ongoing studies, on-orbit performance of DMSP F-17, and the fact that DoD is now only responsible for the early morning orbit.

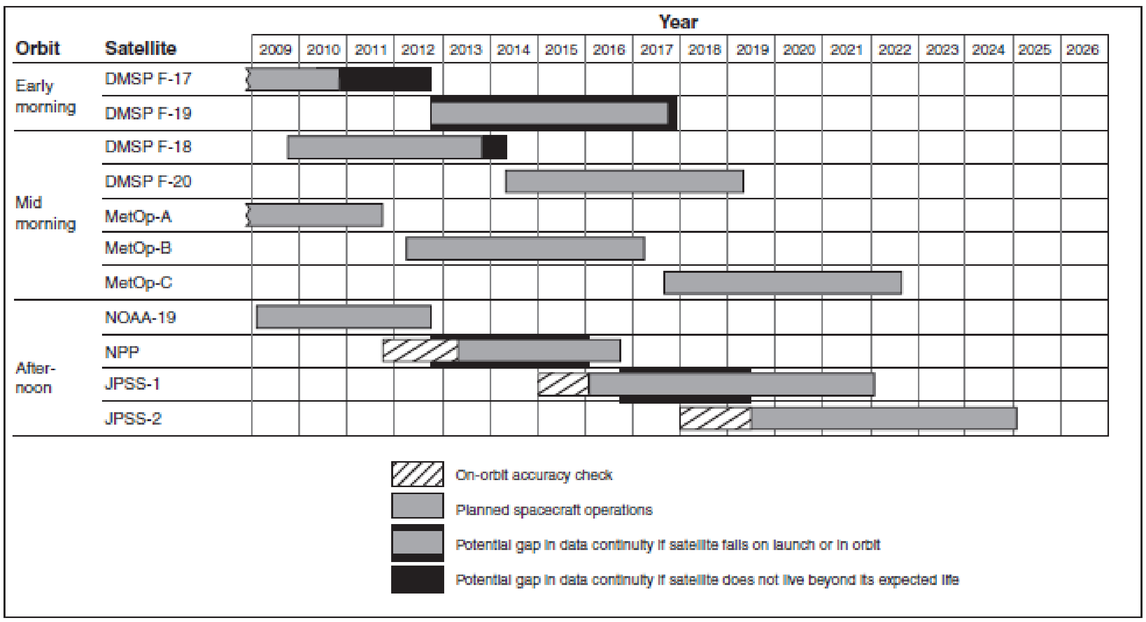


Figure 11. Planned Launch Dates and Potential Gaps in Satellite Data (From GAO, 2010, p. 24)

Based on the February 2010 announcement for DoD to take over the early morning, "[t]he DWSS program is expected to satisfy environmental monitoring requirements in the early morning orbit by developing and launching two satellites, with an initial capability no earlier than 2018" (GAO, 2011, May). This formed the initial acquisition strategy for the DWSS program that was subsequently cancelled in 2012.

Dr. Aston Carter's (USD/AT&L) August 13, 2010 Acquisition Decision Memorandum (ADM) approved the purchase of two spacecrafts from Northrop Grumman Aerospace Systems (NGAS). These are modified versions of the NPOESS C bus, approximately 40% smaller, 2600 kg lighter and have a seven-year design life. They were to host three sensors: Visible/Infrared Imager Radiometer Suite (VIIRS) sensor, Microwave Sensor based on legacy requirements, and a Space Environmental Monitor (SEM) sensor suite (Baldonado, 2011). On May 24, 2011, Northrop Grumman Space and Mission Systems:

> Received a $427.9 million contract modification, commissioning them to modify the NPOESS baseline to establish the Defense Weather Satellite System baseline. That means going back to design and development, including work to add…Pentagon mission assurance and compliance requirements. (Defense Industry Daily, 2011)

However, on September 15, 2011, the Senate Appropriations Committee released in the 2012 Department of Defense Appropriations Bill, the statement that:

> The current program [DWSS] remains challenged by a difficult and confusing set of management issues. Rights over intellectual property from the NPOESS program have been subject to protracted and contentious negotiations. For DWSS, redesign efforts are being conducted simultaneously with efforts to examine capability trades. Options for capability trades results in billions of dollars of uncertainty in cost estimates, and may lead to significant redesigns. Each of these areas of risk indicate that DWSS is not on a sound acquisition footing, despite the restructure of the program more than a year and a half ago. The Committee does not want to repeat the costly mistakes of the NPOESS program with DWSS. Therefore, the Committee recommends the termination of the DWSS program, and provides $250,000,000 for continued sensor development, as well as requirements definition and source selection activities for a full and open competition for a follow-on program. The Committee also provides $150,000,000 for the cost of termination of the current contract, and directs the Secretary of Defense to provide the congressional defense committees with a report within 30 days of enactment of this act to describe the Government's estimated liabilities under the current contract, the ability of the Government to leverage prior work within a new program, and a schedule for requirements, reviews, competition, and award of a new development contract. (Senate Bill, 2011)

On January 25, 2012, the Space and Missile Systems Center issued a news release that the "U.S. Air Force has stopped work on the Defense Weather Satellite System to implement the FY2012 National Defense Authorization Act and FY 12 Consolidated Appropriations Act" (SMC, 2012).

This section, Section C, served to give a detailed chronological history of the DMSP program: how the program started, its purpose, simplicity of initial satellite blocks, evolution of their size and complexity based on various decisions, capability changes that were made to the satellites and showing how the program evolved to where it is today. This history forms a reference for what the follow-on program, and hence this thesis' recommendation, should be (Chapters IV and V). Having a thorough understanding of the program's past, especially lessons learned, consequences of decisions made, and knowing factors that are currently affecting the program, will help define what the program of the future should be.

D. THE MILSATCOM PROGRAM

MILSATCOM refers to a system of systems working together to cover a broad range of users.

> Military Satellite Communications (or milsatcom) systems are typically categorized as wideband, protected, or narrowband. Wideband systems emphasize high capacity. Protected systems stress antijam features, covertness, and nuclear survivability. Narrowband systems emphasize support to users who need voice or low-data-rate communications and who also may be mobile or otherwise disadvantaged (because of limited terminal capability, antenna size, environment, etc.). (Elfers & Miller, 2002)

The MILSATCOM system consists of several satellites which began with the Defense Satellite Communications System (DSCS) constellation in the 1960s. This constellation of satellites covers the Wideband aspect of the communication spectrum. Throughout the years, these satellites were acquired using a block approach. The first block consisted of 26 satellites. The second block, DSCS II, consisted of 16 satellites and was launched from 1971 through 1978 (Boehm, n.d.).

Similar to the DSCS constellation, the MILSTAR constellation is a group of legacy satellites. It provides coverage to users requiring protected and secure communications. These satellites were also acquired in blocks; the first block consists of two satellites that were launched in the early 1990s, carrying low data rate payloads (MILSTAR fact sheet, 2011)

Figure 12 shows the names and timelines associated with the various satellite constellations that fall into each of the three categories that make up the communications framework. The slide was taken from a presentation given at a 2006 DoD Commercial SATCOM Workshop. At that time, the TSAT program was scheduled to be the follow-on program to link all three systems of systems; however, due to a number of reasons, to include not meeting cost, schedule, and performance requirements, the program was cancelled in 2009. This thesis only addressed satellites that were acquired to provide the Wideband and Protected aspects of the communications architecture.

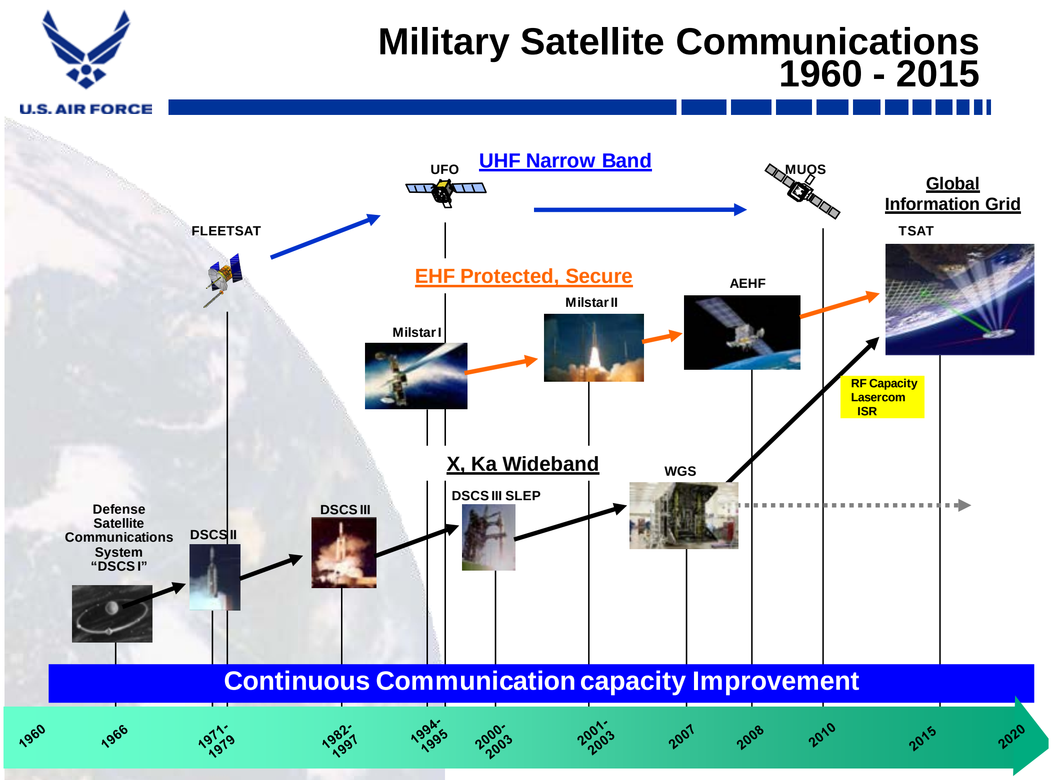


Figure 12. MILSATCOM Evolution (From Whitney, 2006)

1. Current Program

The third and current DSCS III satellite block built by Lockheed Martin Space Systems Company (LMSSC), consists of 14 satellites, eight of which are in a geosynchronous orbit and forms the on-orbit constellation while one is used for testing purposes is in a super synchronous orbit. Nine satellites are currently operational. The final four of the 14 satellites received SLEP modifications (DSCS fact sheet, 2011).

The second block of MILSTAR satellites, MILSTAR II, consisting of four satellites were built by LMSSC. The first satellite in this block, third Milstar satellite to be built, was launched in 1999 but was lost because it was launched into a lower orbit and could not be raised so it was determined to be non-operational. The final three satellites were successfully launched in the early 2000s. This block is an upgrade to the first block with these spacecrafts carrying both low and medium data rate payload (Jane's, 2010).

2. Proposed Follow-on

The follow-on system to DSCS is the Wideband Global SATCOM (WGS) system which is being built by Boeing Satellite Development Center, utilizes Boeing's commercial line of 702 spacecraft and acquired via "Commercial Like" Federal Acquisition Regulations (FAR) Part 12 Procurement. The capability of one WGS satellite is greater than the entire DSCS III constellation (Whitney, 2006). WGS is using a block approach to obtain a constellation of six satellites. Originally the plan was for five satellites but the Australian government partnered with the U.S. and funded a sixth. Block I, consisting of three satellites, were launched in October 2007, April 2009, and December 2009 and are DoD's highest capacity communication satellites. Similarly, Block II consists of three satellites. Space Vehicle (SV) 4 was launched in January 2012 and SVs 5 and 6 are scheduled for launches in 2013 and will have slight increase in capability over Block I satellites (WGS fact sheet, 2012). In addition, Boeing was awarded a contract in August 2010 to begin work on a Block II follow-on program, procuring long lead parts for SV-7. This contract has options for a total of six more clone WGS satellites (Space News, 2010). "Block II follow-on satellites 7, 8 and 9 are anticipated for launch in FYs 16, 17, and 18, respectively" (WGS fact sheet, 2012).

The Advanced Extremely High Frequency (AEHF) system is the follow-on system to 1990s-era MILSTAR, providing ten times more capacity of protected and secure communications (AEHF fact sheet, 2011). It is also being built by LMSSC and utilizes their heritage commercial A2100 Bus design with advanced technology from the commercial sector (Whitney, 2006). The original acquisition plan was for three satellites to be placed in the geosynchronous earth orbit (GEO) and then a fourth was added. The first AEHF satellite was launched in August 2010 after being delayed by almost six years. With the cancellation of the TSAT program, the DoD intends to procure two more satellites, using the new satellite acquisition strategy approach, EASE. The AEHF program decided to keep the design specifications for the first three satellites (AEHF 1, 2, and 3) the same as those for the last three satellites and only make adjustments for parts obsolescence (GAO, May 2011).

Section D gave a summary of the evolution of U.S. Military communication satellites, paying particular attention to the block acquisitions that occurred, and planned for the future for Wideband and Protected communication satellites. This information will be used in Chapter V to develop recommendations for the DMSP follow-on program.

E. THE GPS PROGRAM

GPS refers to a space based system of system that provides precise position, navigation, and timing (PNT) to users worldwide. It originally began in the late 1950s as four separate concepts. One was developed by scientists at Johns Hopkins University's Applied Physics Lab in September 1958, called Transit, and later turned over to the U.S. Navy (Milsatmagazine, 2008). Another concept called 621B was started by the U.S. Air Force in the late 1960s. At the same time, the Naval Research Laboratory started a parallel program called Timation (Time Navigation). In addition, the U.S. Army had a concept called SECOR (Sequential Correlation of Range System) with its first launch in January 1964 and other launches through 1969 (Boehn, n.d.). The system that became GPS as it is known today came from the Navy's and Air Force's concepts. This occurred after then "Deputy Secretary of the Defense William P, Clements authorized the start of a program to 'test and evaluate the concepts and costs of an advanced navigation system' on April 17, 1973, and he authorized the start of concept validation for the GPS system on December 22, 1973" (Milsatmagazine, 2008). The GPS system is a constellation of 24 satellites in a six orbital planes.

Similar to DMSP and MILSATCOM satellites, these satellites were acquired in blocks. Block I with a design life of five years consisted of 11 satellites (one of which failed to reach orbit) were launched in 1978 through 1985 with the final satellite deemed unusable in November 1995 (USNO, 2011). They were built by Rockwell International. The second block of satellites contains several incremental improvements within it and are designated as Blocks II, IIA (A - for advance), IIR (R - for replenishment), IIR-M (M – for modernization to IIR), and IIF (F – for follow-on) series. Block II and IIA series satellite design life was 7.3 years and contained four atomic clocks each (USNO, 2011). They were built by Rockwell International which later became Boeing in 1997. Together, Blocks II and IIA series satellites completed the 24 satellite operational constellation required for GPS. Block II series, consisting of nine satellites, was the first full scale operational satellites and was launched from 1989 through 1990. Its last satellite was decommissioned in March 2007 (USNO, 2011).

1. Current Program

The current GPS program consists of satellites remaining from the 19 Block IIA series satellites launched from 1990 through 1997. These are the second series of operational satellites. Block IIR satellites, the replenishment satellites, built by Lockheed Martin, were launched from July 1997 through November 2004 (USNO, 2011). Thirteen satellites were built but the first one failed to reach orbit; their design life was 7.8 years. In August 2000, Lockheed Martin was awarded a contract to modernize the eight remaining un-launched Block IIR satellites (GPS IIR/R-M fact sheet, 2011). These Block IIR-M satellites were launched from September 2005 through August 2009 and contained incremental improvements such as a second civil signal L2C (USNO, 2011). The 20th satellite in this Block IIR/R-M, IIR-20M (also known as space vehicle number (SVN) 49), carried the additional dedicated civil L5 signal for demonstration purposes (GPS IIR/R-M fact sheet, 2011). Beginning in 1996 Boeing was contracted to build the follow-on Block 2F series satellites (GPS IIF fact sheet, 2011). Twelve are currently on contract to be built; the first two of which were launched May 2010 and July 2011, respectively. The first satellite was delayed by 4.5 yrs and has cost 119% more than its initial estimate (GAO, 2011, May). These satellites include enhancements such as a dedicated civil signal (L-5), improved accuracy, greater security, anti-jam capabilities, and an increased design life of 12 years. Table 14 shows a list of information such as launch order, date, SVN, frequency standard for the current Block II, IIA, IIR, IIR-M, and IIF series satellites, while Figure 13 shows pictures of what they look like.

Table 14. GPS Block II/IIA/IIR/IIR-M/IIF Series Satellites (After: USNO, 2011, June)

LAUNCH ORDER	PRN	SVN	LAUNCH DATE	FREQ STD	PLANE	U.S. SPACE COMMAND **
*II-1		14	14 FEB 1989			19802
*II-2		13	10 JUN 1989			20061
*II-3		16	18 AUG 1989			20185
*II-4		19	21 OCT 1989			20302
*II-5		17	11 DEC 1989			20361
*II-6		18	24 JAN 1990			20452
*II-7		20	26 MAR 1990			20533
*II-8		21	02 AUG 1990			20724
*II-9		15	01 OCT 1990			20830
IIA-10	32	23	26 NOV 1990	Rb	E5	20959
IIA-11	24	24	04 JUL 1991	Cs	D5	21552
*IIA-12		25	23 FEB 1992	Rb	A5	21890
*IIA-13		28	10 APR 1992			21930
IIA-14	26	26	07 JUL 1992	Rb	F5	22014
IIA-15	27	27	09 SEP 1992	Cs	A4	22108
*IIA-16		32	22 NOV 1992		F6	22231
*IIA-17		29	18 DEC 1992			22275
*IIA-18		22	03 FEB 1993			22446
*IIA-19		31	30 MAR 1993			22581
*IIA-20		37	13 MAY 1993			22657
IIA-21	09	39	26 JUN 1993	Cs	A1	22700
*IIA-22		35	30 AUG 1993	Rb		22779
IIA-23	04	34	26 OCT 1993	Rb	D4	22877
IIA-24	06	36	10 MAR 1994	Rb	C5	23027
IIA-25	03	33	28 MAR 1996	Cs	C2	23833
IIA-26	10	40	16 JUL 1996	Cs	E3	23953
IIA-27	30	30	12 SEP 1996	Cs	B2	24320
IIA-28	08	38	06 NOV 1997	Cs	A3	25030
***IIR-1		42	17 JAN 1997			
IIR-2	13	43	23 JUL 1997	Rb	F3	24876
IIR-3	11	46	07 OCT 1999	Rb	D2	25933
IIR-4	20	51	11 MAY 2000	Rb	E1	26360
IIR-5	28	44	16 JUL 2000	Rb	B3	26407
IIR-6	14	41	10 NOV 2000	Rb	F1	26605
IIR-7	18	54	30 JAN 2001	Rb	E4	26690
IIR-8	16	56	29 JAN 2003	Rb	B1	27663
IIR-9	21	45	31 MAR 2003	Rb	D3	27704
IIR-10	22	47	21 DEC 2003	Rb	E2	28129
IIR-11	19	59	20 MAR 2004	Rb	C3	28190
IIR-12	23	60	23 JUN 2004	Rb	F4	28361
IIR-13	02	61	06 NOV 2004	Rb	D1	28474
IIR-14M	17	53	26 SEP 2005	Rb	C4	28874
IIR-15M	31	52	25 SEP 2006	Rb	A2	29486
IIR-16M	12	58	17 NOV 2006	Rb	B4	29601
IIR-17M	15	55	17 OCT 2007	Rb	F2	32260
IIR-18M	29	57	20 DEC 2007	Rb	C1	32384
IIR-19M	07	48	15 MAR 2008	Rb	A6	32711
IIR-20M	01	49	24 MAR 2009	Rb	B6	34661
IIR-21M	05	50	17 AUG 2009	Rb	E6	35752
IIF-1	25	62	28 MAY 2010	Rb	B2	36585
IIF-2			16 JUL 2011	Rb		

* Satellite is no longer in service.
** U.S. SPACE COMMAND, previously known as the NORAD object number; also referred to as the NASA Catalog number. Assigned at successful launch. Catalog numbers retrieved from SPACEWARN Bulletins: http://nssdc.gsfc.nasa.gov/spacewarn/
*** Unsuccessful launch.

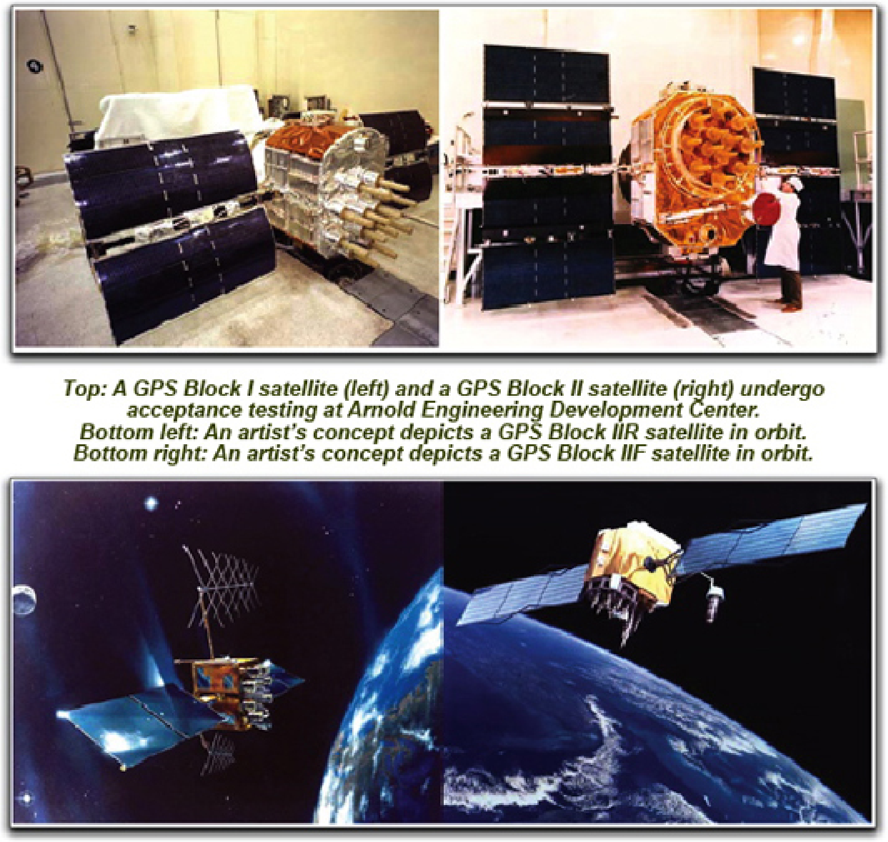


Figure 13. GPS Evolution (From Milsatmagazine, 2008)

2. Proposed Follow-On

The current contract for the third block of GPS satellites, GPS III, an increment contract awarded to Lockheed Martin in May 2008, is for "the development and production of two initial space vehicles (SV) with options for up to ten additional SVs" (GPS III fact sheet, 2011). This new block of satellites will provide new capabilities to meet greater demands of both the military and civilian communities. This block will also follow an incremental approach within the block (similar to Block II) to deliver increase in capability. For example, according to the GPS III fact sheet (2011), the first eight satellites (SV 1–8) will have increased accuracy, increased M-Code Earth coverage power, additional civil signal (L1C), and improved integrity. However, SV 9 and onwards will have digital waveform generator, real-time signal modulates L-Band carrier, distress alerting satellite system, enables global search and rescue, real time command and control cross links, allows satellite uploads via single contact, and improve constellation accuracy. In addition, the design life for these satellites has been increased to 15 years with mean mission duration of 13 years. The launch date of the first GPS IIIA is currently scheduled for May 2014 (GAO, 2011, May).

Section E gave a summary of the evolution of GPS satellites, paying particular attention to the various incremental improvements and block acquisitions that occurred and what is planned for the future. This information will be used in Chapters V to develop recommendations for the DMSP follow-on program.

F. TOYOTA'S APPROACH TO CREATING NEW MODELS OR UPDATE EXISTING MODELS

Toyota's approach to producing vehicles is summed up by the 14 principles that Jeffery Liker identified as "The Toyota Way" after studying the Toyota Company for 20 years (Liker, 2004). These principles, shown in Figures 14 through 17, have guided Toyota's manufacturing process to strive for constant quality, making the process a renowned excellence model. We can derive great information on their approach by reviewing these principles and the associated explanations that accompany each principle.

Executive Summary of the 14 Toyota Way Principles

Section I: Long-Term Philosophy

Principle 1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.

- Have a philosophical sense of purpose that supersedes any short-term decision making. Work, grow, and align the whole organization toward a common purpose that is bigger than making money. Understand your place in the history of the company and work to bring the company to the next level. Your philosophical mission is the foundation for all the other principles.
- Generate value for the customer, society, and the economy—it is your starting point. Evaluate every function in the company in terms of its ability to achieve this.
- Be responsible. Strive to decide your own fate. Act with self-reliance and trust in your own abilities. Accept responsibility for your conduct and maintain and improve the skills that enable you to produce added value.

Section II: The Right Process Will Produce the Right Results

Principle 2. Create continuous process flow to bring problems to the surface.

- Redesign work processes to achieve high value-added, continuous flow. Strive to cut back to zero the amount of time that any work project is sitting idle or waiting for someone to work on it.
- Create flow to move material and information fast as well as to link processes and people together so that problems surface right away.
- Make flow evident throughout your organizational culture. It is the key to a true continuous improvement process and to developing people.

Principle 3. Use "pull" systems to avoid overproduction.

- Provide your downline customers in the production process with what they want, when they want it, and in the amount they want. Material replenishment initiated by consumption is the basic principle of just-in-time.
- Minimize your work in process and warehousing of inventory by stocking small amounts of each product and frequently restocking based on what the customer actually takes away.
- Be responsive to the day-by-day shifts in customer demand rather than relying on computer schedules and systems to track wasteful inventory.

Principle 4. Level out the workload (*heijunka*). (Work like the tortoise, not the hare.)

Figure 14. Principles 1 through 4 of The Toyota Way (From Liker, 2004)

- Eliminating waste is just one-third of the equation for making lean successful. Eliminating overburden to people and equipment and eliminating unevenness in the production schedule are just as important—yet generally not understood at companies attempting to implement lean principles.
- Work to level out the workload of all manufacturing and service processes as an alternative to the stop/start approach of working on projects in batches that is typical at most companies.

Principle 5. Build a culture of stopping to fix problems, to get quality right the first time.

- Quality for the customer drives your value proposition.
- Use all the modern quality assurance methods available.
- Build into your equipment the capability of detecting problems and stopping itself. Develop a visual system to alert team or project leaders that a machine or process needs assistance. *Jidoka* (machines with human intelligence) is the foundation for "building in" quality.
- Build into your organization support systems to quickly solve problems and put in place countermeasures.
- Build into your culture the philosophy of stopping or slowing down to get quality right the first time to enhance productivity in the long run.

Principle 6. Standardized tasks are the foundation for continuous improvement and employee empowerment.

- Use stable, repeatable methods everywhere to maintain the predictability, regular timing, and regular output of your processes. It is the foundation for flow and pull.
- Capture the accumulated learning about a process up to a point in time by standardizing today's best practices. Allow creative and individual expression to improve upon the standard; then incorporate it into the new standard so that when a person moves on you can hand off the learning to the next person.

Principle 7. Use visual control so no problems are hidden.

- Use simple visual indicators to help people determine immediately whether they are in a standard condition or deviating from it.
- Avoid using a computer screen when it moves the worker's focus away from the workplace.
- Design simple visual systems at the place where the work is done, to support flow and pull.
- Reduce your reports to one piece of paper whenever possible, even for your most important financial decisions.

Figure 15. Principles 5 through 7 of The Toyota Way (From Liker, 2004)

Principle 8. Use only reliable, thoroughly tested technology that serves your people and processes.

- Use technology to support people, not to replace people. Often it is best to work out a process manually before adding technology to support the process.
- New technology is often unreliable and difficult to standardize and therefore endangers "flow." A proven process that works generally takes precedence over new and untested technology.
- Conduct actual tests before adopting new technology in business processes, manufacturing systems, or products.
- Reject or modify technologies that conflict with your culture or that might disrupt stability, reliability, and predictability.
- Nevertheless, encourage your people to consider new technologies when looking into new approaches to work. Quickly implement a thoroughly considered technology if it has been proven in trials and it can improve flow in your processes.

Section III: Add Value to the Organization by Developing Your People and Partners

Principle 9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.

- Grow leaders from within, rather than buying them from outside the organization.
- Do not view the leader's job as simply accomplishing tasks and having good people skills. Leaders must be role models of the company's philosophy and way of doing business.
- A good leader must understand the daily work in great detail so he or she can be the best teacher of your company's philosophy.

Principle 10. Develop exceptional people and teams who follow your company's philosophy.

- Create a strong, stable culture in which company values and beliefs are widely shared and lived out over a period of many years.
- Train exceptional individuals and teams to work within the corporate philosophy to achieve exceptional results. Work very hard to reinforce the culture continually.
- Use cross-functional teams to improve quality and productivity and enhance flow by solving difficult technical problems. Empowerment occurs when people use the company's tools to improve the company.
- Make an ongoing effort to teach individuals how to work together as teams toward common goals. Teamwork is something that has to be learned.

Figure 16. Principles 8 through 10 of The Toyota Way (From Liker, 2004)

Principle 11. Respect your extended network of partners and suppliers by challenging them and helping them improve.

- Have respect for your partners and suppliers and treat them as an extension of your business.
- Challenge your outside business partners to grow and develop. It shows that you value them. Set challenging targets and assist your partners in achieving them.

Section IV: Continuously Solving Root Problems Drives Organizational Learning

Principle 12. Go and see for yourself to thoroughly understand the situation (*genchi genbutsu*).

- Solve problems and improve processes by going to the source and personally observing and verifying data rather than theorizing on the basis of what other people or the computer screen tell you.
- Think and speak based on personally verified data.
- Even high-level managers and executives should go and see things for themselves, so they will have more than a superficial understanding of the situation.

Principle 13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.

- Do not pick a single direction and go down that one path until you have thoroughly considered alternatives. When you have picked, move quickly but cautiously down the path.
- *Nemawashi* is the process of discussing problems and potential solutions with all of those affected, to collect their ideas and get agreement on a path forward. This consensus process, though time-consuming, helps broaden the search for solutions, and once a decision is made, the stage is set for rapid implementation.

Principle 14. Become a learning organization through relentless reflection (*hansei*) and continuous improvement (*kaizen*).

- Once you have established a stable process, use continuous improvement tools to determine the root cause of inefficiencies and apply effective countermeasures.
- Design processes that require almost no inventory. This will make wasted time and resources visible for all to see. Once waste is exposed, have employees use a continuous improvement process (*kaizen*) to eliminate it.
- Protect the organizational knowledge base by developing stable personnel, slow promotion, and very careful succession systems.

Figure 17. Principles 11 through 14 of The Toyota Way (From Liker, 2004)

Based on these principles, Toyota has been able to engineer and manufacture "autos that led to unbelievable consistency in the process and product. Toyota designed autos faster, with more reliability, yet at a competitive cost, even when paying the relatively high wages of Japanese workers" (Liker, 2004). A review of these principles show that none of them are unique to the automotive industry and nothing precludes them from being applied to others industries such as Space Acquisitions. In fact, several of them (Principles 1, 2, 4, 6, 8, and 14) will resurface in Chapter III, where FIST and EASE processes are reviewed.

Toyota's acquisition process is truly unique. Liker summarizes it as follows:

> The incredible consistency of Toyota's performance is a direct result of operational excellence. Toyota has turned operational excellence into a strategic weapon. This operational excellence is based in part on tool and quality improvement methods made famous by Toyota in the manufacturing world, such as just-in-time, kaizen, one-piece flow, jidoka, and heijunka. These techniques helped spawn the "lean manufacturing" revolution. But tools and techniques are no secret weapon for manufacturing a business. Toyota's continued success at implementing these tools stems from a deeper business philosophy based on its understanding of people and human motivation. Its success is ultimately based on its ability to cultivate leadership, teams, and culture, to devise strategy, to build supplier relationships, and to maintain a learning organization. (2004)

Toyota's processes are demonstrated below by using the Toyota Highlander which is:

> Toyota's car-based midsize SUV that is updated for 2011 with new exterior styling. The Highlander was completely redesigned for 2008, the first redesign since it was introduced as a 2001 model. Built on a unibody platform with 4-wheel independent suspension, the Highlander offers a tight, quiet ride like a midsize sedan with the higher ride height, available 4-wheel drive and cargo capacity of a midsize SUV. (MSN Autos, 2011)

Once Toyota creates a product and once proven, they implement it fleet-wide and do not start over the process from one model to the next (Principle 8 above). Thus, there is a high percentage of reused technology across models and from year to year improvements within model (Principle 6 above). The example below also shows similarities between the automotive industry and Space Acquisitions, specifically, the block approach and incremental improvements within each block.

There are two generations of the Highlander, those built from 2001 through 2007, and 2008 through 2012 (equivalent to space acquisition's satellite blocks). Within these two generations there were incremental improvements. Specifically, Highlanders produced for model years 2001 through 2003 remained relatively the same and then Toyota made a few minor modifications which it implemented on the 2004 through 2007 model years. One such example was an engine upgrade. The original 3.0 liter V6 engine produced 220 horse power (hp) at 5800 revolutions per minute (RPMs) and 222 foot-pounds (ft-lbs) of torque at 4400 RPMs while delivering 23 miles per gallon (mpg) of gas at highway speeds was being fielded in the 2001–2003 models. However, they refined it and released an upgraded engine for the 2004 through 2007 model years (MSN Autos, 2011). While this engine upgrade had greater performance, it was more economical. Specifically, it was a 3.3 liter V6, 230 Hp at 5800 RPMs and 242 ft-lbs of torque at 4400 RPMs while delivering 25 highway mpg (MSN Autos, 2011). So essentially, Toyota made an incremental improvement within the first block of Highlanders. Once this engine was proven, Toyota deployed it to several other vehicles in its fleet such as the Camry, RAV 4, Lexus RX 330.

Toyota made significant changes such as body style, size, and engine for 2008–2010 models, as seen in Figure 14. Now they are offering an even more powerful engine that returns greater highway fuel economy than the original 3.0 V6 engine. This newest engine is a 3.5 liter V6 producing 270 hp at 6200 RPMs and 248 ft-lbs torque at 4700 RPMs while delivering 24 highway mpg at the stricter government rating standards than previous model years (MSN Autos, 2011). Since then, Toyota has deployed this 3.5 liter engine to several of its other models. Figure 14 shows some incremental upgrades made to the Highlander from model years 2003 to 2004 and again in 2010 to 2012. These incremental changes within the two "blocks" (model years 2001–2007, and 2008-present) are very similar to the incremental upgrades made in Space Systems as newer technologies become available, for example the incremental changes made between DMSP Block 5D-2 and 5D-3 satellites as discussed in Section C of Chapter II.

					
	2001 Toyota Highlander V6 2WD	**2003 Toyota Highlander** V6 2WD	**2004 Toyota Highlander** V6 2WD w / 3rd-Row Seat	**2008 Toyota Highlander** Sport 4X2	**2011 Toyota Highlander** SE 4X2 V6
Quick Facts	Highlander V6 2WD	Highlander V6 2WD	Highlander V6 2WD w/ 3rd-Row Seat	Highlander Sport 4X2	Highlander SE 4X2 V6
Standard Engine	3.0L 220 hp V6	3.0L 220 hp V6	3.3L 230 hp V6	3.5L 270 hp V6	3.5L 270 hp V6
Standard Transmission	4-Speed Automatic See details	4-Speed Automatic Overdrive See details	5-Speed Automatic Overdrive See details	5-Speed Automatic Overdrive See details	5-Speed Automatic Overdrive See details
Fuel Economy (MPG) (city/highway)	19 / 23	19 / 23	19 / 25	18 / 24	18 / 24
Horsepower	220 @ 5800 RPM	220 @ 5800 RPM	230 @ 5800 RPM	270 @ 6200 RPM	270 @ 6200 RPM
Standard Seating	5	5	7	7	7

Figure 18. Toyota Highlander Incremental Upgrades (After: MSN Autos, 2011)

G. CHAPTER SUMMARY

In conclusion, this chapter documented literature reviews of applicable information that will form the basis from which recommendations will be made in later chapters. It began with a review of the acquisition framework currently used for Space systems, to include the history of Space systems acquisitions and key influences affecting it today. The Air Force was identified as the responsible Service for DoD space acquisitions and the reason why this thesis focused on space systems acquired by the Air Force. Cost of space systems was identified as currently the most important factor and hence the main influence to how systems are acquired, not system performance characteristics or the time (schedule) it takes to produce systems. The history of the space systems that are discussed in this thesis (DMSP, MILSATCOM, and GPS) were reviewed, tracing their heritage back to the mid-1950s at the Western Development Division in Los Angeles. The culture shift that has occurred in acquisitions was discussed, for example, how during the first 30 years of these space programs, capability-driven systems were built but for the latter 20 years the pendulum has swung to the other extreme, to being very requirements driven. Similarly, the culture change from buying greater quantities of less complex systems to few quantities of more complex systems was discussed and the unintended consequences such as programs being unaffordable, delays and cancellations that have occurred.

Next, a detailed review of the entire DMSP program was conducted, to include the current and follow-on programs. The review began with identifying the purpose of the DMSP program, as an enabler of cloud free photoreconnaissance flights over the Soviet Union. The challenges, such as beginning as a temporary classified program and how it became a program of record, were discussed. The evolution of the various blocks of satellites was discussed and how each satellite block became more capable but larger and more complex at the same time. However, lessons were also learnt about how two periods in DMSP's history, 1975 to 1977, and 1980 to 1982, system complexities led to schedule delays, and coupled with launch failures, resulted in poor and no military weather coverage, respectively. The relationship between DoD's weather program and

DoC's was discussed and the fact that several earlier initiatives to merge the two programs failed and how the 1994 presidential decision to merge them also ended in failure as evident with the 2010 decision to separate them. The main reasons identified for the failure were complexity, both in management structure and system requirements, and technology maturity.

The MILSATCOM and GPS programs were similarly reviewed, particularly with an emphasis on their acquisition approaches. It was identified that the earlier MILSATCOM systems, such as DSCS followed a very similar block acquisition approach to DMSP with the procurement of several satellites in each block. However, as the progression was made from the first through the third DSCS block, the number of satellites in each block became fewer and fewer, from 26 to 16 and finally to 14 satellites. This trend has continued to the follow-on program, WGS, because the current plan is to procure only six satellites. While there may be valid reason for the reductions in the number of satellites from block to block, such as more capable and longer design satellite design lives, as evident with the cancellation of TSAT, there needs to be a balance with the expected capability jump from one block to the next. The GPS program showed more consistency with the number of satellites procured per block and showed more of an incremental increase in capability from block to block and within blocks, especially for block II satellites.

Based on these reviews, the instructive model for space procurement is for block acquisitions with incremental increases in capability be utilized for follow-on programs. This concept will be better supported when the principles of FIST and EASE are examined in the next chapter.

This chapter concluded with an examination of Toyota's approach to creating new models. The 14 principles, according to Liker, that make up "The Toyota Way" were identified, which revealed Toyota's unique acquisition approach. The Toyota Highlander was used to demonstrate some similarities between the automotive industry and space systems acquisitions, specifically, the block acquisition similarities with incremental improvements within. In the next chapter, each of the 14 principles will be related to space acquisitions so that the relations between Toyota's way and space systems development and manufacturing can be identified.

III. METHODOLOGY

A. INTRODUCTION

With the end of the cold war, reduction in military spending in the 1990s, the recent recession and further reductions in military spending, the DoD has significantly less money to spend on acquisitions. However, many of the systems that the United States relies on to maintain its dominance are nearing the end of their design lives and the need for their replacements remains valid requirements. Because of this need and less funding being available, the DoD has instituted several initiatives or "tools" to increase efficiency so as to maximize every dollar spent on Acquisition. This chapter will examine the principles of two such tools, FIST and EASE, and their application to space acquisitions. This chapter will also examine the Toyota Way Principles and their application to space acquisitions.

B. APPLICATION OF THE FIST PROCESS TO SPACE ACQUISITIONS

"Systems development projects should be done by: **small** teams of **talented** people using **short** schedules, **small** budgets and **mature** technologies. This approach is called FIST (Fast, Inexpensive, Simple, and Tiny)" (Ward, 2010b). FIST is a model developed by Daniel B. Ward after years of research into systems acquisitions with a focus on improving the operational effectiveness of defense acquisition projects versus focusing solely on programmatic outcomes. It is a model that depends on what are the organization's values as they relate each of the four elements: <u>Fast</u>, <u>Inexpensive</u>, <u>Simple</u>, and <u>Tiny</u>.

The "four elements…ha[ve] become the FIST model for system development" (Ward, 2009). These elements are in line with the 23 actions issued by Dr. Aston Carter, then director of USD (AT&L), in his September 14, 2010 memorandum to acquisition professionals to improve acquisitions. For example, "mandate affordability as a requirement" means treating the budget as a constraint to be maintained, not an estimate to be expanded later. FIST provides technical and programmatic decision-making guidelines that show how and why to do precisely that (Ward, 2010a).

The FIST approach is a continuous improvement approach that requires a culture change from the current norm of how acquisitions are accomplished. For this approach to be effective, enterprise commitment is required. "The FIST approach is most successful when done iteratively; it is most risky when done as a one-shot deal." (Ward, 2009) Case studies that he researched revealed that "short timelines help stabilize requirements, technology, budget and people. Short timelines also foster **accountability, ownership and learning**. To keep timelines short, projects must exercise restraint over **budgets, complexity and size**. Increases to the project's budget complexity or size inevitably reduce its speed." (Ward, 2010b) Table 15 shows the eight FIST Practices that are necessary to implement the FIST framework. These practices must be done on a continuous basis for the FIST approach to be effective, a process that is identified in Principles 2 and 14 of Liker's "The Toyota Way."

Table 15. FIST Practices (From Ward, 2010a)

- Minimize team size, maximize team talent.
- Use schedules and budgets to constrain the design.
- Insist on simplicity in organizations, processes and technologies.
- Incentivize and reward underruns.
- Requirements must be achievable within short time horizons.
- Designs must only include mature technologies.
- Documents and meetings must be short. Have as many as necessary, as few as possible.
- Delivering useful capabilities is the only measure of success.

Although Ward coined this FIST phraseology in the early 2000s, the FIST practices have been in existence and used in space acquisitions since the 1950s. For example, the initial DMSP Block I program would qualify as a FIST project because its literature search revealed strong “value clues” for all four FIST elements (i.e., Fast, Inexpensive, Simple, and Tiny), leading to an overall high FIST score. “Value clues” are statements of priorities and preferences that indicate the presence of the FIST values. Specifically, the program was FIST Fast, in fact, extremely fast by today’s standards. In 1961 Lt. Col Haig had 22 months to design, develop, build, test, and deliver four Weather satellites with the first satellite ready for launch in only 10 months from the onset of funding (FIST Fast). Based on the strong explicit affirmation of the importance of speed in this value clue and using the FIST Rubric in appendix A of Ward’s 2009 thesis, a high “F- score” of 10 is appropriate for this FIST element.

It was also FIST Inexpensive. The program of four satellites was developed on a “small fixed budget” (Hall, 2001). To ensure that it remained inexpensive, then Lt Col Haig dictated the

> use of fixed price, fixed delivery contracts under his direct control throughout the program. Evans [then Deputy Director of the Office of the Secretary of the Air Force for Special Projects and the person who appointed Lt Col Haig to be the first DMSP director] added a ‘kill switch’ of his own: if the first launch could not be met on schedule or if cost appeared certain to exceed the fixed budget, he instructed Haig to terminate the program and recover government funds immediately without further direction. (Hall, 2001)

These precautions proved invaluable for the program’s success.

> The RCA fixed-price, fixed delivery contract proved itself in December 1961 when a major structural member of the weather satellite, the base plate, failed during tests and company officials requested a three month delay for redesign. Croft [the officer responsible for overseeing contract management], after discussion with Haig, advised RCA that it had ten days to produce a fix or the contract would be terminated under procurement regulations ‘at no cost to the government.’ The RCA program manager appeared three days later with revised internal schedules that met the original launch date. (Hall, 2001)

These actions showed their commitment to ensuring that the program’s costs remained inexpensive. Based on the strong, explicit affirmation of the importance of low cost and selective contract type used to prevent overruns, the FIST Rubric would assign a high “I-score” of 10 for the Inexpensive FIST element.

The program was FIST Simple, in comparison to the requirements of the current DMSP constellation and the number of sensors currently being flown. The requirements were for “a ‘minimum’ proposal for four ‘Earth-referenced’ wheel-mode weather satellites to be launched on NASA Scout boosters” (Hall, 2001). The satellite mission was to enable “accurate and timely meteorological forecasts of the Sino-Soviet landmass. Such forecasts would make possible cloud-free photography over areas of interest” (Hall, 2001). To ensure that the system remained simple, then Lt Col Haig, “meteorologist and electrical engineer, accepted the assignment on condition that he would *not* have to use the resident ‘systems engineering and technical direction (SE&TD)’ contractor, [and] could select his own small staff….Haig divided the work among those he initially elected: three officers and…‘a very busy secretary’” (Hall, 2001). It was “Haig’s view, an SE&TD contractor could only justify its existence by introducing changes. Since changes involved time and cost money, SE&TD support was incompatible with fixed price, fixed delivery contracting” (Hall, 2001). Based on the strong, explicit affirmation of the importance of simplicity and deliberate steps taken to actually reduce complexity (no SE&TD), the FIST Rubric would assign a high “S-score” of 10 for the Simple FIST element.

Finally, these satellites were FIST Tiny. They were 100 pounds, 23 inches across, 21 inches high, and hosted one sensor (as shown in Table 4) as compared to current DMSP satellites that weigh 2,278 pounds, 24 feet long, and hosts eight sensors (Table 8). Apart from the size difference, the value clues found only had moderate, occasional affirmation of the importance of being small. This finding corresponds to a medium “T-score” of 5 for the Tiny FIST element.

Based on the fact that “Haig’s ‘blue suit’ program team met its ten-month schedule….[that the] program now possessed the first U.S. military satellite to be commanded and operated on orbit on a daily basis over an extended period of time” (Hall, 2001), the program would, according to the FIST Rubric (see Appendix B), obtain an “Outcome score” of A. The overall Rubric score of 35 (sum of the F, I, S, and T scores) is considered to be high because the scale ranges from -20 to 40 and hence the DMSP Block I program would be classified as a FIST project.

The FIST principles shown in Table 16 can be considered as FIST Heuristics because they are not rigid rules but rather general principles to be used as suggestions.

Table 16. FIST Principles (From Ward, 2010a)

- A project leader's influence is inversely proportional to the project's budget and schedule.
- Constraints foster creativity. Adding time and/or money does not improve outcomes.
- Fixed funding and floating requirements are better than fixed requirements and floating funding.
- Complexity is a cost.
- Complexity reduces reliability.
- Simplicity scales. Complexity doesn't.
- An optimal failure costs a little and teaches a lot. When FIST projects fail, they fail optimally.
- Iteration drives learning, discovery and efficiency. FIST is iterative.
- Talent trumps process.
- Teamwork trumps paperwork.
- Leadership trumps management.

Several of these principles and heuristics were shown in the previous DMSP Block I example and serves as a guide to Systems Engineers and Program Managers.

C. APPLICATION OF THE EASE PROCESS TO SPACE ACQUISITIONS

In June of last year, and as part of the Secretary of Defense's Efficiencies Initiative, the Under Secretary of Defense for Acquisition, Technology and Logistics began an effort to restore affordability and productivity in defense spending. Major thrusts of this effort include targeting affordability and controlling cost growth, incentivizing productivity and innovation in industry, promoting real competition, improving tradecraft in services acquisition, and reducing nonproductive processes and bureaucracy. As part of this effort, the Office of the Secretary of Defense and the Air Force are proposing a new acquisition strategy for procuring satellites, called the Evolutionary Acquisition for Space Efficiency (EASE), to be implemented starting in fiscal year 2012. (GAO, 2011, May)

Before delving into the application of the EASE process to space acquisitions, Figures 19 through 22 shows how the Air Force views its current challenges with space acquisitions and hence its reason for developing EASE to help alleviate these challenges.

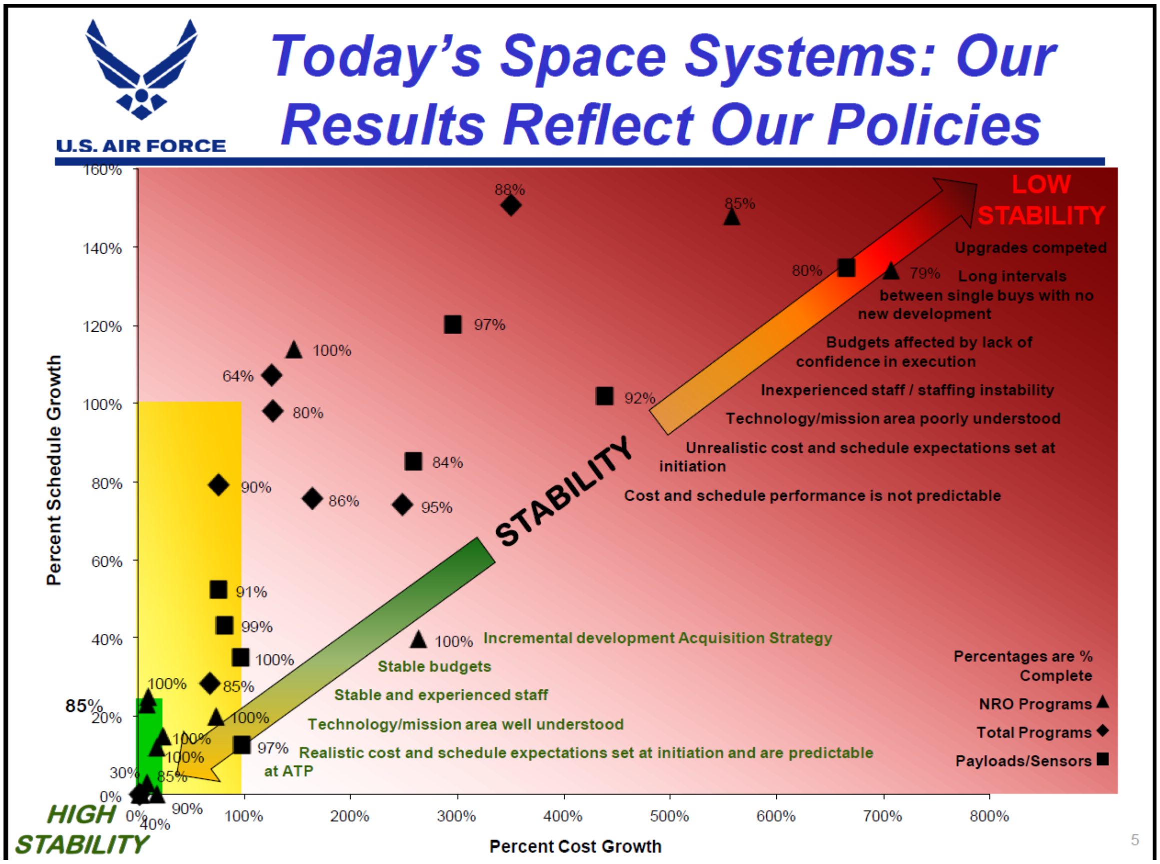


Figure 19. Plot of Percentage Schedule versus Cost Growth (From Hyten, 2011)

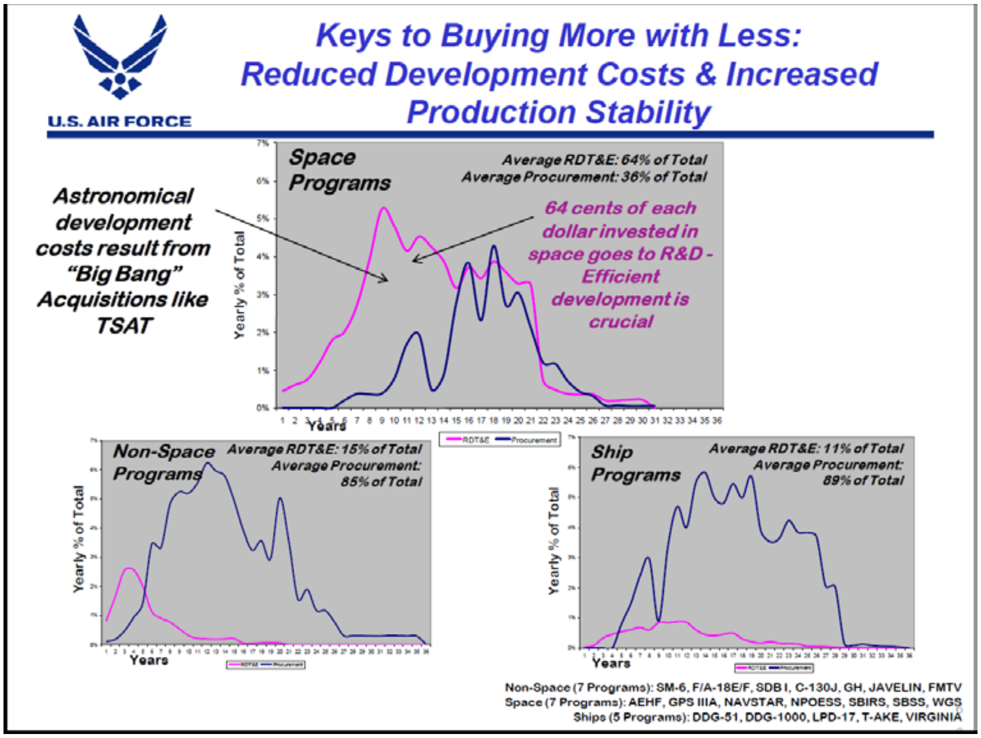


Figure 20. Cost Comparison of Space Programs against Non-Space Programs (From Hyten, 2011)

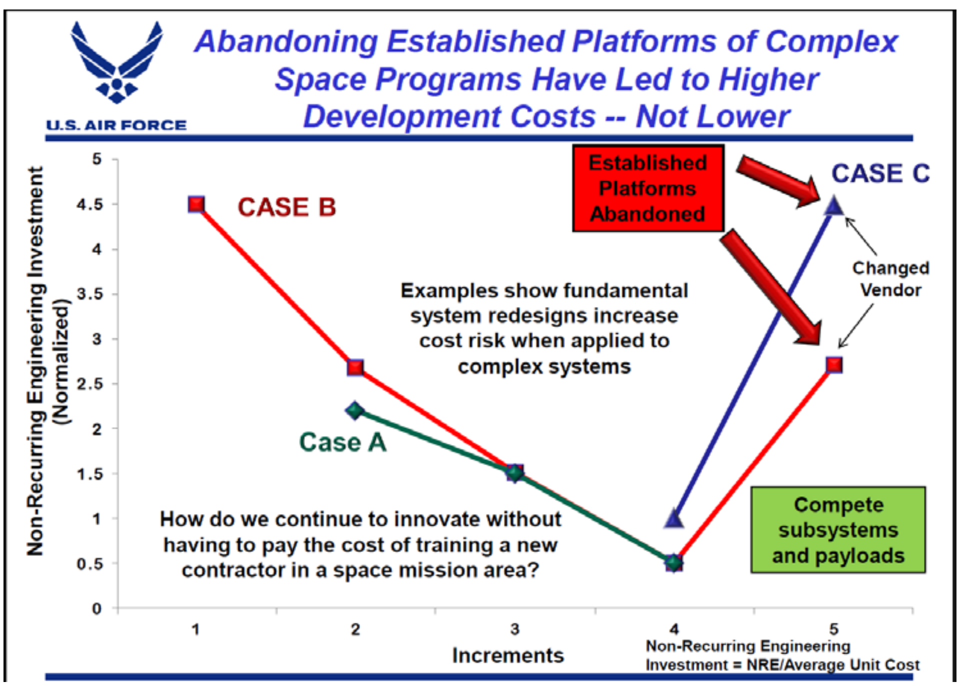


Figure 21. Consequences of Changing Platforms (From Hyten, 2011)

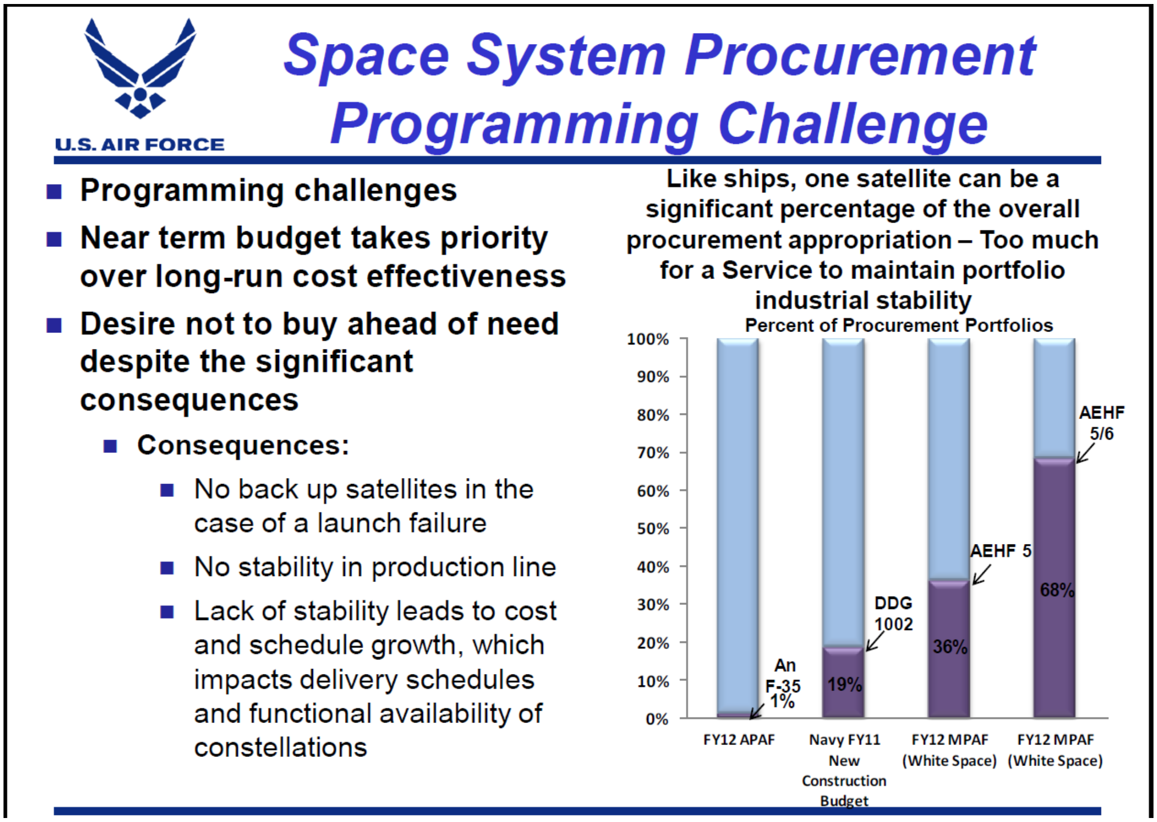


Figure 22. Space System Challenges and Consequences (From Hyten, 2011)

EASE is made up of four basic tenets: block satellite buys, established stable research and development investments, fixed price contracting, and ensured full finding over multiple years through advanced appropriations. (Tobias, 2011) The premise is, with block satellite buys, DoD can capitalize on "economy of scales" and procure critical parts, especially because most component parts are used in batches, to build subsystems and systems. Block buys will enable production lines to be run more efficiently while reducing non-recurring engineering costs. Next, by establishing stable research and development investments result in efficiencies being achieved because this re-investment leads to downstream performance increase and lower system cost for follow-on systems. Those dollars are used to fund technological improvements via a Capability and Affordability Insertion Program (CAIP). This process will essentially lower the costs for follow-on systems while improving their quality. The next tenet of EASE is to use fixed priced contracting. Those programs most affected are in the post development phase, where the bulk of the acquisition dollars are spent. In these post development phase acquisitions, many uncertainties should have been worked out of the systems, requirements should be approved and inviolable to minimize risk for the contractor. Lastly, the commitment for full funding is needed through multiple fiscal years using advanced appropriations to spread the cost over several years. Multi-year appropriations help provide the funding stability that nearly all programs lack (Tobias, 2011). So essentially, three types of funding are needed: advanced procurement, procurement, and advanced appropriation dollars. For the EASE process to work efficiently all aspects of funding, program management, and systems engineering must be executed in the manner they were intended and at the right time. This is similar to the FIST approach. "EASE is intended to help stabilize funding, staffing, and subtier suppliers; help ensure mission continuity; reduce the impacts associated with obsolescence and production breaks; and increase long-term affordability with cost savings of over 10 percent" (GAO, 2011, May)

The initial DMSP Block I program met at least three of the four basic EASE tenets. It was a block buy of four satellites; used a fixed price, fixed delivery contract that proved itself; and had a small fixed budget for its 22 month schedule that appeared to have been fully funded. The second tenant, i.e., stable research and development investments, may or may not have occurred at that time, based on being implemented at the beginning of the space technology development era. Whether this tenant was satisfied is undetermined, as sufficient information does not exist to make that determination. However, with clear indications that at least three of the four tenants were satisfied, this shows that the initial DMSP Block I program essentially followed the EASE acquisition approach.

The DoD's plan for first official use of EASE is in FY2012 and to test it against the buys for AEHF SV 5 and 6, and Space-Based Infrared Satellite (SBIRS) GEO SV 5 and 6. Using AEHF SV 5 and 6 as examples, Figure 23 shows a comparison of today's model against a block buy approach and illustrates how today's model does not foster cost efficiency. For example, in 2008 when Congress mandated the purchase of AEHF 4, the cost to restart the production line was significantly higher versus if they had followed an incremental acquisition approach.

> The first two AEHF spacecraft cost roughly $6.4 billion, which includes non-recurring engineering work dating back to early this decade. The third spacecraft tallies $939 million, and the cost for adding the fourth is about $2 billion…the spacecraft's high price is due to the expense associated with restarting Lockheed Martin's production line. The contract for the third AEHF satellite was drawn up four years earlier. (Aviation Week, 2011)

Theoretically, the unit cost for SVs 4, 5, and 6 could have been the same amount or even less than SV 3 ($939 million) if an evolutionary incremental approach was used for AEHF instead of the planned jump to TSAT. Those decisions have cost the tax payers significantly because the costs for AEHF 5 and 6 are going to be significantly higher than $939 million each, based on the fact that AEHF 4 costs about $2 billion.

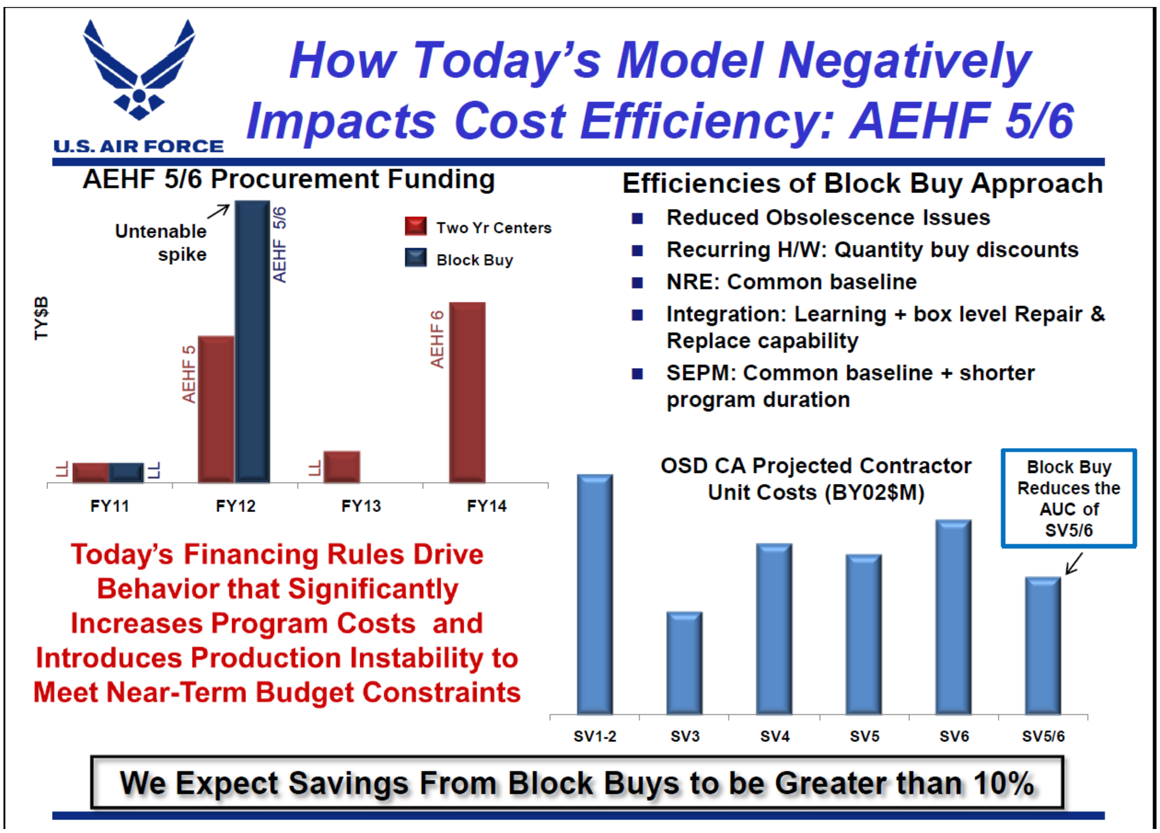


Figure 23. Comparison of Today's Acquisition Model against Block Buy Approach (From Hyten, 2011)

Figure 24 shows how exact replica satellites, "Clones," are currently bought on an as-needed basis. It shows the impacts of obsolescence, production breaks, insufficient use of labor and small lot material buys that leads to instability in the acquisition process.

This causes a domino effect that result in increased unit costs, no increase in capability, and exponential increase in Risk, to the point of a potential gap in service. These are all unintended consequences of the current space acquisition process.

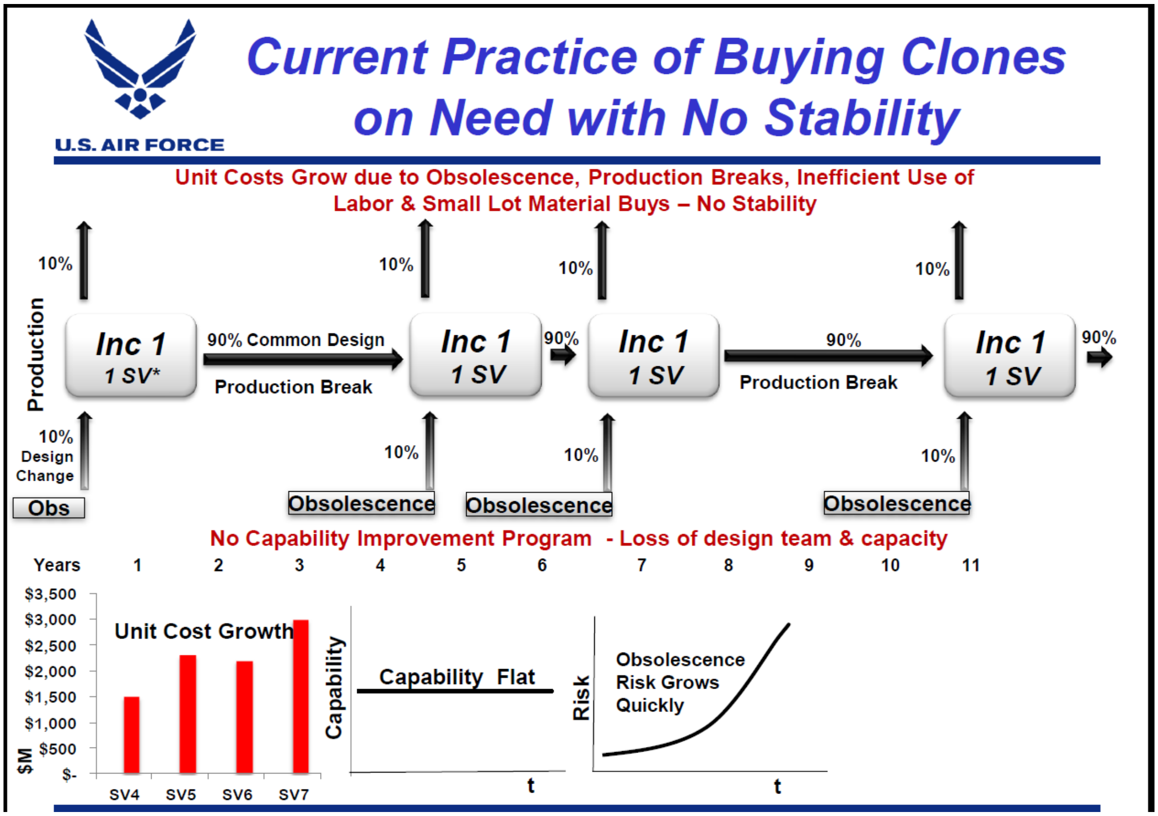


Figure 24. Current Practice of Buying Clones (From Hyten, 2011)

However, Figure 25 shows what EASE is expected to produce. The capability of the satellites are expected to continually increase because newer technology is deliberately injected at specific intervals, once matured and proven under Capability and Affordability Insertion Programs (CAIPs). The elements of CAIPs are shown in Figure 30. The expectation is to have a controlled 20 percent design change (thus 80 percent common design remains) from one increment to the next, an increase from 10 percent which was only as a result of obsolescence issues. The additional 10 percent design change is a result of the CAIP program which accounts for the continual capability increase, instead of remaining constant as in the case in Figure 24. Buying two satellites at a time would also ensure there would be no break in production for the building of the two satellites as there are thought of as a block, with purchases, resources, and budget assured for both satellites. Because of the constant interjection of new technologies at suitable moments, the obsolescence Risk remains constant instead of growing exponentially as in the case of buying clones. This model is predicated on steadier funding being available.

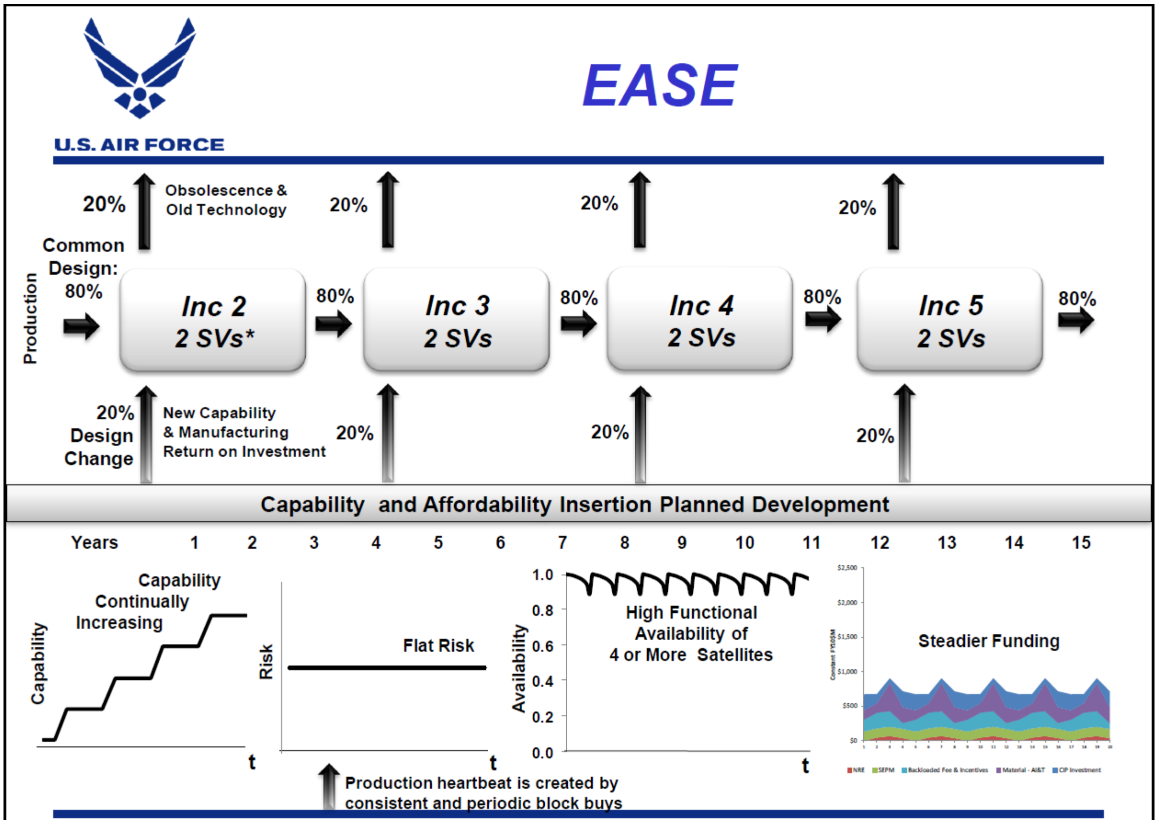


Figure 25. EASE Expected Results for AEHF Program (From Hyten, 2011)

Figure 26 shows a side by side comparison of the potential implementation of EASE on both the AEHF and SBIRS programs. The requirements baselines would be those of AEHF 4 and SBIRS GEO 4 and starting the block buy of two satellites each using Fixed Price Incentive Firm (FPIF) contracts. At the same time of the block buy, several activities under CAIP would begin so as to start the parallel technology development and maturation so that it can be interjected at later opportune times. Similarly, the Architecture for future blocks would have to be done in parallel so as to steer the program in the direction that the government intends to take it.

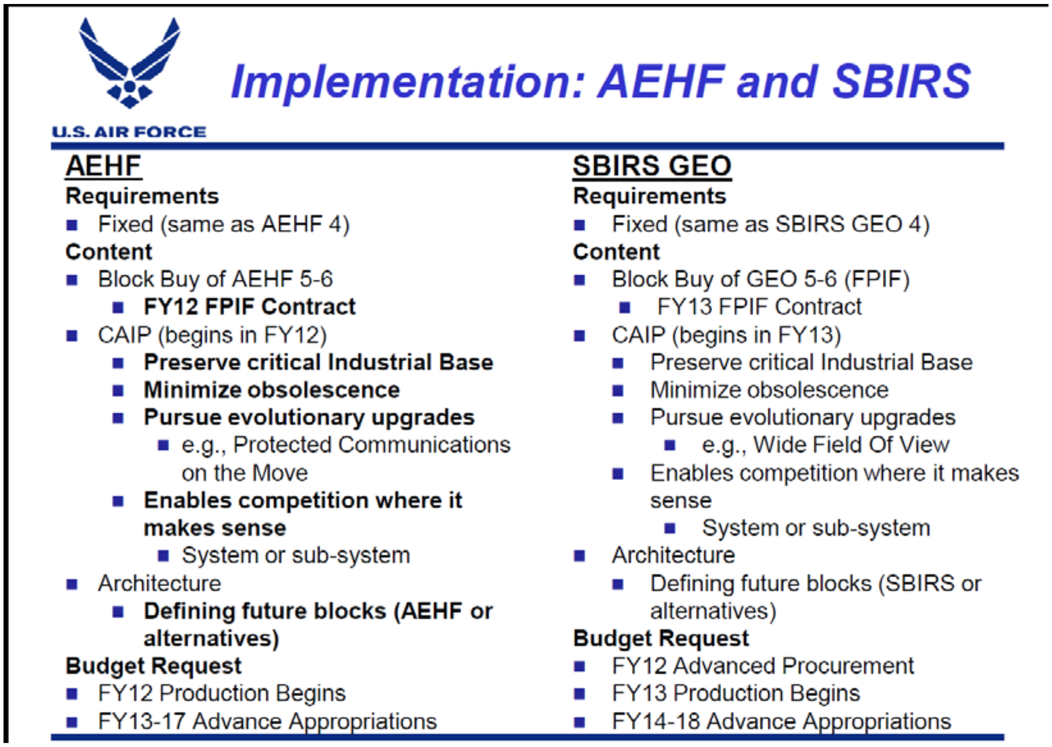


Figure 26. Comparison of EASE for AEHF and SBIRS (From Hyten, 2011)

Based on the controlled nature of the EASE initiative, the amount of funding that is needed per year to execute the acquisition program is distributed evenly. Figure 27 shows the level funding amounts that the Air Force requested in the FY 12 President Budget as needed to execute the AEHF program based on using the EASE approach. It is important to highlight the relatively stable funding that was requested across the fiscal years compared against the untenable spikes that were shown in Figure 23.

A comparison of Pre and Post EASE funding requirements revealed approximately $900M of efficiencies that are expected to be gained and would be reinvested into the evolutionary capability upgrades for AEHF 7 and 8 as shown in Figure 28.

U.S. AIR FORCE

AEHF Investment Funding FY12PB EASE Profile

RDT&E ($M)	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY12-17
EMD*	351.8	279.5	160.3	64.4	37.9	0.0	0.0	542.1
RADHARD		20.0						20.0
CAIP 7-8		110.7	209.2	273.0	281.4			874.4
CAIP 9-10						188.0	310.5	498.5
Arch Planning		11.5	23.4	23.6	24.1	27.9	31.9	142.4
Total	351.8	**421.7**	**392.9**	**361.0**	**343.5**	**215.9**	**342.4**	**2077.3**

MPAF ($M)	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY12-17
SV 3-8	38.1	77.5	85.5	88.1	90.6	105.9	113.1	560.7
SV 5 Adv Proc	208.5							0.0
SV 5-6 Block Buy		475.3	469.9	454.3	395.8	358.2	716.7	2870.2
SV 7-8 Block Buy						222.4	613.8	836.2
Total	246.6	**552.8**	**555.4**	**542.4**	**486.4**	**686.5**	**1443.6**	**4267.1**
RDTE + MPAF	598.4	**974.5**	**948.3**	**903.4**	**829.9**	**902.4**	**1786.0**	**6344.5**

***EMD: SVs 1-2 + MCS**

Figure 27. EASE Funding Profile for AEHF (From Hyten, 2011)

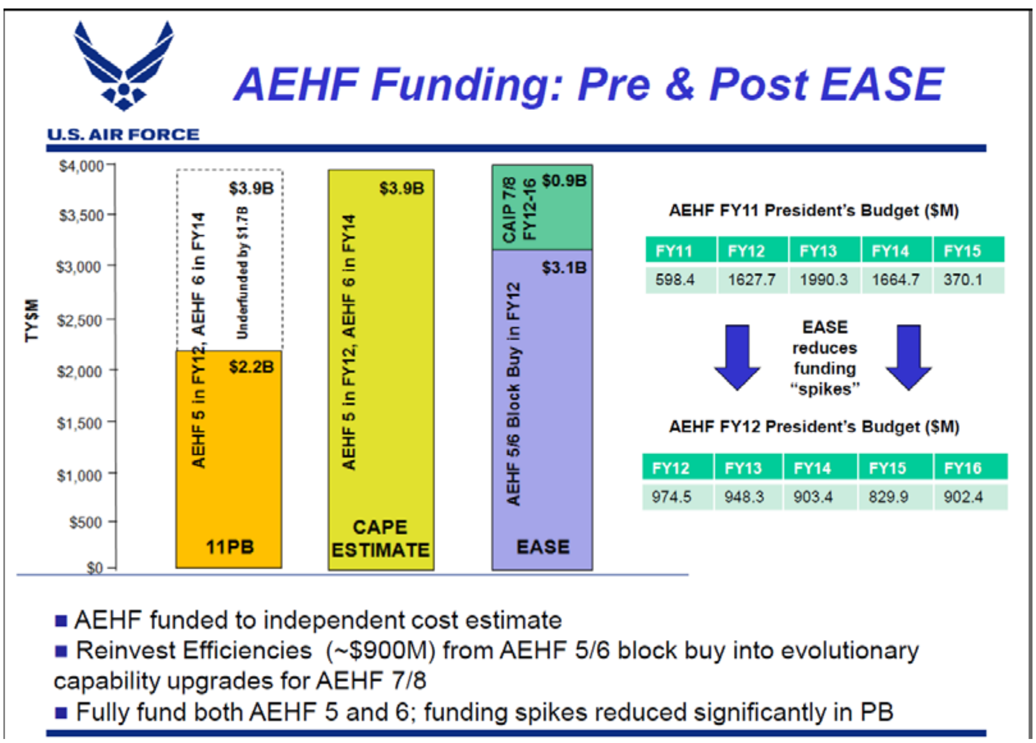


Figure 28. Comparison of Pre & Post EASE AEHF Funding (From Hyten, 2011)

Figure 29 shows the various option paths based on the CAIP. The Defense Acquisition Executive (DAE) would make the decision on which path to choose, based on the CAIP activities, taking into account factors such as maturity of technology at the time. For the EASE approach to effectively work, the CAIP activities must be sufficiently funded so as to buy down technological risks to the programs, thereby giving the DAE more options to choose from at the opportune moment.

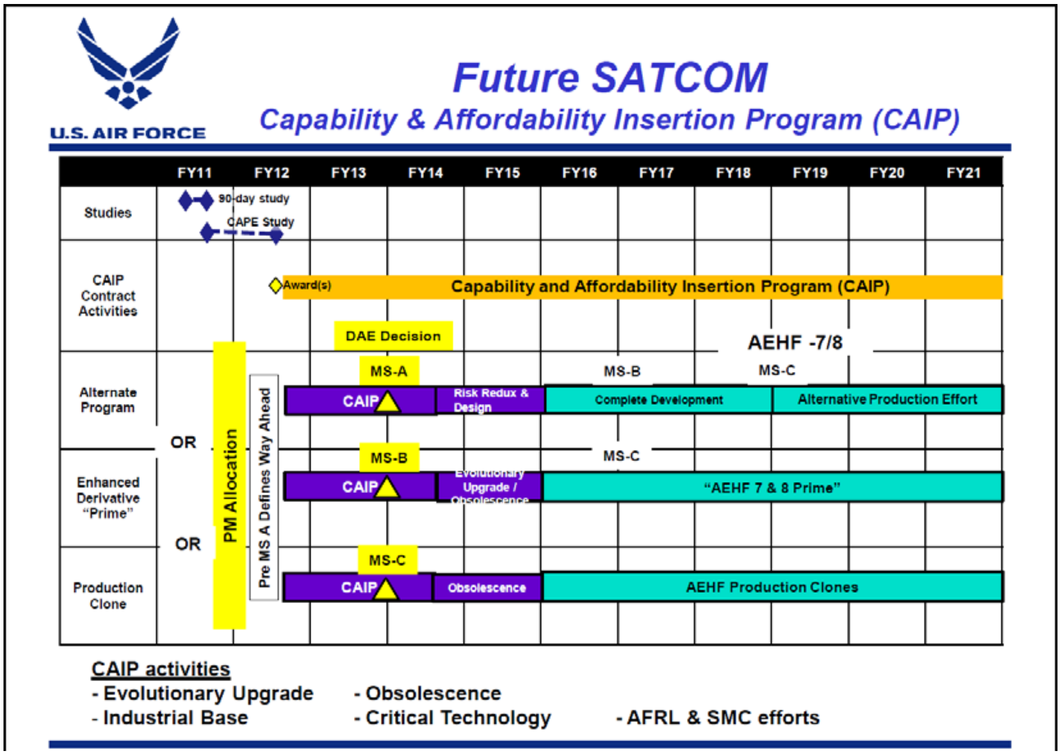


Figure 29. Roadmap for CAIP (From Hyten, 2011)

The four elements of the various CAIP programs that are available to be utilized are shown in Figure 30. Each of these elements share several similarities with the 14 Toyota Way Principles identified in Chapter II. Figure 31 shows a summary of EASE's challenges and opportunities and how they intersect. Successful execution of EASE depends on converting these challenges into opportunities.

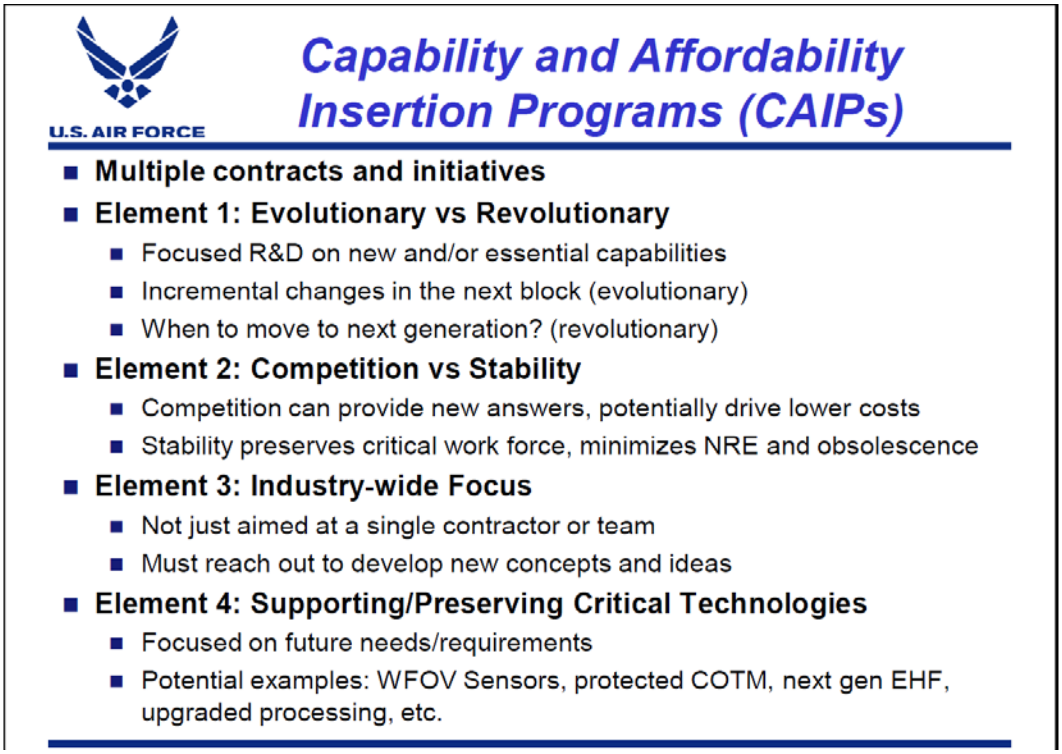


Figure 30. CAIP Options (From Hyten, 2011)

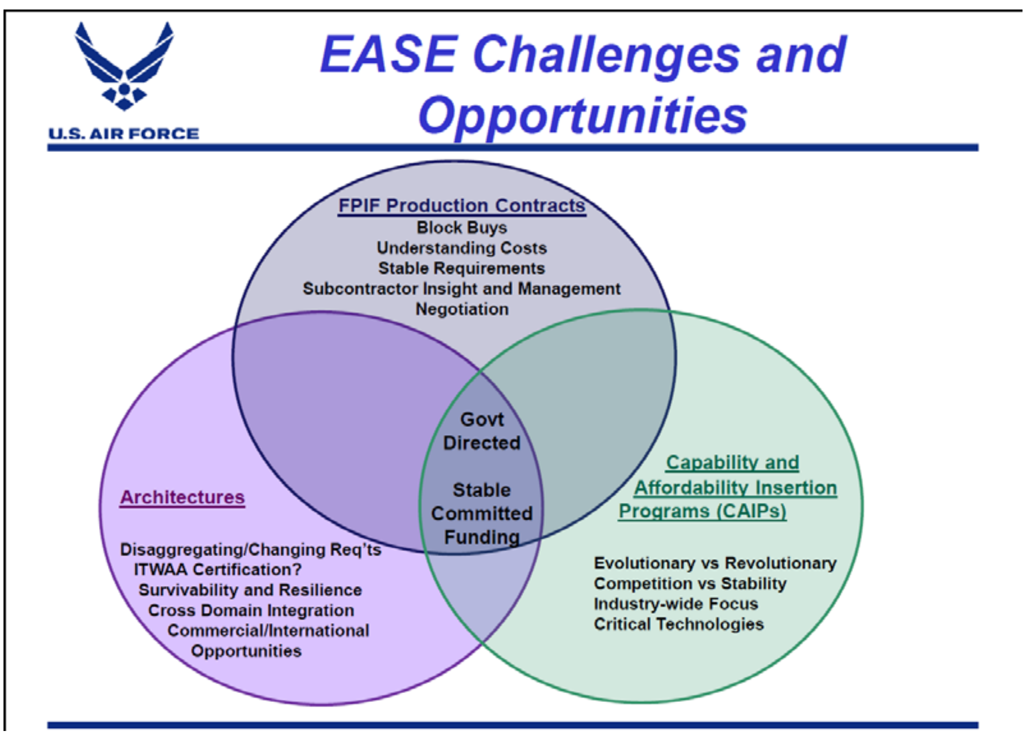


Figure 31. EASE Challenges and Opportunities (From Hyten, 2011)

D. APPLICATION OF THE TOYOTA WAY PRINCIPLES TO SPACE ACQUISITIONS

To better understand the relations between the Toyota Way principles and space acquisitions, a comparison of each of the 14 principles to space development/ manufacturing is required, as seen in Tables 17 through 19.

Table 17. Comparison of the Toyota Way Principles 1 through 5 to Space Acquisitions

The Toyota Way Principles	Similarities and Relation to Space Program Activities
Principle 1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.	This principle is very similar to the philosophy used in Space Acquisitions, such as the planning that occurs up front for the entire life cycle for the system, i.e., from Cradle to Grave. If done properly, in the end, the total ownership cost should be less for new satellite systems. It is crucial to get it right for space systems because there is not a lot that can be done to change the systems once they are launched into orbit.
Principle 2. Create continuous process flow to bring problems to the surface	This principle is also done in Space Acquisitions. Events such as Lean, Six Sigma, Total Quality Management, and Air Force Smart Operations for the 21st Century are some of the processes that are used to bring problems to the surface.
Principle 3. Use "pull" systems to avoid overproduction.	Currently, overproduction for new systems is not a problem in space acquisitions, in fact, it may be the contrary. However, it could be postulated that the current DMSP 5D-3 satellite block was in an overproduction situation because satellites still to be launched (F-19 & F-20) were produced nearly 20 years ago. Conversely, by having these two satellites available to launch has given DoD flexibility before its first satellite is needed in light of NPOESS & DWSS cancellation.
Principle 4. Level out the workload (*heijunka*). (Work like the tortoise, not the hare.)	Historically Space Acquisitions have struggled with this principle, having problems with finding the balance. For example, instead of building several satellites in blocks and put them in storage such as what DMSP has done, which resulted in a break in production line and numerous other unintended consequences, an approach that enables a slower but constant production line to produce satellites when needed is recommended. Such approach will prevent situations such as spending several millions of dollars on service life extension programs on satellites yet to be launched because of issues such as parts obsolescence and degradation issues.
Principle 5. Build a culture of stopping to fix problems, to get quality right the first time.	Currently, this is not considered to be a problem in space acquisitions because many of the systems are considered to be over-engineered because of the concern that once launched, they cannot be recovered for major repairs and only the possibility of software uploads to fix certain problems.

Table 18. Comparison of the Toyota Way Principles 6 through 12 to Space Acquisitions

The Toyota Way Principles	Similarities and Relation to Space Program Activities
Principle 6. Standardize tasks are the foundation for continuous improvement and employee empowerment.	The goal of trying to keep satellite production lines ongoing enables the standardization of tasks, instead of starting and stopping production lines for each satellite or block of satellites, which is very costly as illustrated with the cost increase from AEHF 3 to 4 of $939 million to $2 billion. Additionally, standardizing satellite builds is recommended in Chapter V as an area for further space acquisitions research.
Principle 7. Use visual control so no problems are hidden	This principle is applicable to the reporting chain for how information gets reported to leadership about the status of the acquisition. It can be applicable to production lines for both automobiles and satellites.
Principle 8. Use only reliable, thoroughly tested technology that serves your people and processes.	In general, space acquisitions have had problems with complying with this principle. This has been evident with several programs, such as NPOESS, that takes immature technology into the system acquisition and not able to solve problems timely. This principle is similar to the 6th FIST Practice in Table 15 “Designs must only include mature technologies” and the 2nd EASE Tenet “establish stable research and development investments” and will be a recommendation of this thesis.
Principle 9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.	While this thesis focused less on the personnel aspect of programs, this principle is very applicable to space acquisitions as demonstrated in Table 3 that shows Workforce improvement initiatives are part of the Air Force’s acquisition improvement plan.
Principle 10. Develop exceptional people and teams who follow your company’s philosophy.	While this principle is generally done in space programs there is much room for improvement especially as policies change for how systems are to be acquired.
Principle 11. Respect your extended network of partners and suppliers by challenging them and helping them improve.	This principle is related to space programs because space programs have an extended network of system prime contractors, subcontractors, and parts manufacturers, similar to the automotive industry.
Principle 12. Go and see for yourself to thoroughly understand the situation (*genchi genbutsu)*	This principle can be applied to any number of space acquisition areas, such as viewing work done on the production line and in the program offices.

Table 19. Comparison of the Toyota Way Principles 13 and 14 to Space Acquisitions

The Toyota Way Principles	Similarities and Relation to Space Program Activities
Principle 13. Make decisions slowly by consensus, thoroughly considering all options, implement decisions rapidly.	While this principle is great in theory, in practice it is difficult to implement on space programs because there are several stakeholders and virtually impossible to get consensus by all. This was one of the major down falls of the NPOESS program. However, Integrated Product Teams (IPTs) in space acquisitions would benefit greatly from this principle.
Principle 14. Become a learning organization through relentless reflection (*hansei)* and continuous improvement (*kaizen)*	Similar to Principle 2, this principle shares similarity with space program activities, for example, methods such as Lean, Six Sigma, Total Quality Management, and Air Force Smart Operations for the 21st Century that focus on continuous improvements are used in Space acquisitions.

E. CHAPTER SUMMARY

This chapter began with the examination of two new acquisition methodologies, FIST and EASE, their application to space acquisitions and how they can help improve it. FIST is a values based approach that gives program managers a “tool kit” of eight Practices and eleven Principles as guidance to use for making decisions. The original DMSP Block I program was used as an example of how to apply FIST to a space acquisition program and simultaneously proving that it qualified as a FIST program by performing a Rubric score calculation.

EASE is a new initiative developed by the DoD specifically for Satellite procurements. Its four basic tenets: block satellite buys, establish stable research and development investments, fixed price contracting, and ensure full finding over multiple years through advanced appropriations, were examined. The DMSP Block I program, AEHF, and SBIRS GEO were used to demonstrate the application of the EASE process to space acquisitions and the potential benefits that the taxpayer can expect to see from such an approach. These benefits include reduced obsolescence issues, lower overall program costs, capability continually increasing as time passes, and less risky programs.

This chapter concluded with a mapping of the 14 Toyota Way principles to space acquisition, showing the similarities and relations to space program activities. In particular, ten of the fourteen Toyota Way Principles (1, 2, 3, 4, 6, 8, 9, 11, 13, and 14), show direct relevance and similarity to space acquisitions, as seen in Tables 17 through 19, and will be compared to the FIST and EASE principles in Chapter IV.

In Chapters IV and V, these three tools will be used to help define what a possible solution for what the DoD's follow-on Weather program could be.

IV. DISCUSSIONS AND ANALYSIS

A. INTRODUCTION

Based on the three approaches: FIST, EASE, and the 14 Toyota Way Principles as discussed in Chapter III, this chapter begins with a mapping between them that serves to show a comparison and the connections of their applicable aspects to space systems acquisitions. These connections will be used later in this chapter to help make recommendations for what should be done for a follow-on Weather Satellite program. However, before any recommendations are made, a summary of the initial and current plans for the program needs to be accomplished. Several findings for the follow-on program are highlighted and discussed in this chapter and were based on information from the previous chapters.

B. COMPARISON AND CONNECTIONS AMONG FIST, EASE, AND TOYOTA WAY PRINCIPLES APPLICABLE TO DEFINING NEW SPACE SYSTEMS

As should be expected, FIST and EASE are very applicable to space systems acquisitions because they were both developed by analyzing years of DoD systems acquisitions with the goal to improve it. However, at least ten of the fourteen Toyota Way Principles can also be applied to DoD space systems although their development was based on non-DoD acquisitions, i.e., Toyota's automotive industry way. These comparisons are shown in Table 20 by way of mapping related elements to each other. As seen in Table 20, there are several similarities and related connections among them.

Table 20. Comparison and Connections Among FIST, EASE, and Toyota Way Principles

FIST (Fast, Inexpensive, Simple, & Tiny)	EASE	Applicable Toyota Way Principle
1. Minimize team size, maximize team talent.	1. Block Satellite buys with incremental changes in next block – capitalize on economy of scales, buy in batches, efficiency gained because of buying in bulk, reduce NRE costs	#1. Base management decisions on long-term philosophy, even at expense of short-term goals.
2. Use schedules & budgets to constrain the design.		#2. Create continuous process flow to bring problems to the surface.
3. Insist on simplicity in organizations, processes & technologies.		#3. Use "pull" systems to avoid overproduction.
4. Incentivize and reward under-runs.	2. Establish stable research & development investments – fund CAIPs, lower costs for follow-on system	#4. Level out the workload
5. Requirements must be achievable within short time horizons.		#6. Standardize tasks are the foundation for continuous improvement & employee empowerment
6. Designs must only include mature technologies.		#8. Use only reliable, thoroughly tested technology that servers your people and process
7. Documents & meetings must be short. Have as many as necessary, as few as possible.	3. Fixed price contracting – for post development phase, stable requirements,	#9. Grow leaders who thoroughly understand the work, live the philosophy, & teach it to others.
8. Delivering useful capabilities is the only measure of success.		#11. Respect your extended network of partners and suppliers by challenging them & helping them improve.
9. Fixed funding & floating requirements are better than fixed requirements and & floating funding.		#13. Make decisions slowly by consensus, thoroughly considering all options, implement decision rapidly.
10. Complexity is a cost.	4. Full funding over multiple years – use advanced appropriations to spread cost over several years, provides funding stability	#14. Become a learning organization through relentless reflection & continuous improvement
11. Complexity reduces reliability.		
12. Simplicity scales, Complexity doesn't.		
13. Iterative approach, not one-shot deal.		

C. ASSESSMENT OF THE INITIAL STARTING POINT FOR THE FOLLOW-ON SYSTEM

At the time of the September 2011 Senate Appropriations Committee's recommendations for termination of the DWSS program, two of three major aspects to the follow-on program's acquisition were known to a certain level of fidelity. Specifically, performance and schedule requirements were known as discussed in Chapter II. DoD's performance requirements have now been reduced to providing environmental monitoring coverage only in the early-morning polar orbit and with an initial launch capability (ILC) no earlier than (NET) 2018. Essentially, DoD needed to be prepared to launch one satellite in 2018 to meet its weather requirements which are the same observations that were planned for the second and fourth NPOESS satellites, specifically, the VIIRS and Microwave Imager/Sounder (MIS) as shown in Table 11. However, with the recent cancellation of DWSS, a 2018 ILC is no longer feasible because as seen in Figure 6 from comparable programs, history has shown that it takes more than five years before a large scale space acquisition program launches its first satellite. The earliest for a recent acquisition program shown in Figure 6 is seven years.

Also included in Chapter II was the discussion that the Senate Appropriations Committee provided $250M in September 2011 for continued senor development, requirements definition, and source selection activities for a the competitive source selection for the follow-on program. The initial acquisition plan was for the first DWSS spacecraft to carry three sensors: Visible/Infrared Imager Radiometer Suite (VIIRS) sensor, Microwave Sensor based on legacy requirements, and a Space Environmental Monitor (SEM) sensor suite. Similarly, recall that $150M was provided for the current NGC contract termination liability and for the government to figure out how much of the prior work can be leveraged for the new program.

The notional program schedule that Mr. John Baldonado presented at the American Meteorological Society on January 25, 2011 shows DMSP F-19 ILC in early FY13 to replace F-17 (Baldonado, 2011). If F-19 is launched in FY 2013 and with a reasonable expectation of at least five years of on-orbit performance, that would enable the current DMSP program to provide weather coverage until 2018. However, even an optimistic seven year acquisition timeline for a new satellite will not allow meeting the 2018 NET ILC for the first follow-on program's satellite. So, the 2018 ILC date will need to be changed. With the DoD still having one satellite remaining to be launched, F-20, and no longer responsible for the midmorning orbit where it was slated to replace F-18 in 2014, F-20 now becomes available to bridge the time between F-19's expected end of life and the follow-on program's ILC. This ILC date realistically should be set to no later than 2020, a date derived by looking at the date F-20 was initially built (which was around 1998, and would make it over 20 years old by the time it is launched making it a high risk for on-orbit failure) and the fact that any number of situations could occur such as F-19 premature failure on orbit or F-20 launch or on orbit failure. These timeline are depicted in Figure 32. So, F-20 should be kept in a "launch on demand" status to give DoD more options should in case any of the aforementioned situations were to occur otherwise DoD could end up in a situation that leads to poor or no weather coverage until the follow-on program's first satellite is launched. This situation is a real possibility especially because such situation occurred twice in DMSP's history in 1976 and 1980 with the failures of DMSP Block 5C-3's F-34 satellite and DMSP Block 5D-2's F-5 satellite. Both satellites were the last in their respective block and series (as would be the case for F-20), and their launch failures led to poor and no military weather coverage capabilities between 1975 to 1977, and 1980 to 1982, respectively.

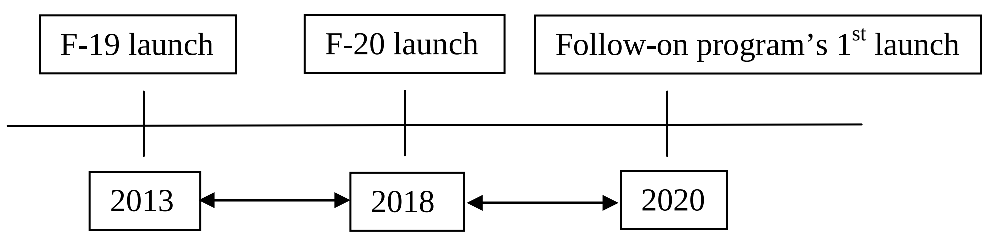


Figure 32. Recommended Launch dates until Follow-on Program's 1st Launch

D. FIST, EASE, AND THE TOYOTA WAY APPLIED TO DMSP FOLLOW-ON PROGRAM

Below, the four elements of FIST, in conjunction with its practices and principles, simultaneously with the four tenets of EASE and 16 Principles of The Toyota Way, as discussed in Chapter III, are used to define a series of steps that the program office for the DMSP follow-on system should undertake to develop an executable program that meets its cost, schedule, and performance requirements. The tenets of EASE and applicable Toyota Way principles are incorporated into the discussions under the appropriate FIST elements below to justify the finding.

1. First FIST Element: Fast

Decisions made for the new program should embrace commitment to speed, not just program schedule but also with timely decision making. With the 2012 order to stop work on the DWSS program, time is of the essence for the program office to figure out what can be salvaged from both the original NPOESS and initial DWSS programs and develop an executable plan that puts the new program on a path to success. It is vital that all stakeholders are part of the decision making process and agree with the recommended path forward. With the DoD relying on aging on-orbit satellites and two satellites yet to be launched that will be approximately 15 and 20 years old, respectively, by the time they are launched, schedule is paramount and emphasis should be placed on it and reflected in every decision that is made. As the 13th Toyota Way principle states, "Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly." While seven years may appear to be sufficient time to acquire a satellite, history has shown that none of the current major space acquisition programs have been able to meet this timeline, as shown in Figure 6. So, the program office should consider this schedule a high risk and implement decisions rapidly. One way to achieve a fast schedule is to ensure that mature technologies are utilized, which is the eighth principle of The Toyota Way, "use only reliable, thoroughly tested technology that serves your people and process."

2. Second FIST Element: Inexpensive

To ensure that the follow-on program remains affordable, realistic requirements have to be generated to prevent a similar situation of over promising and under delivering that has occurred on nearly every recent space program as shown in Figure 5. A key issue focuses on what the true requirements for the follow-on program are: not just accepting the legendary NPOESS Initial Operational Requirements Document (IORD)–II as the definitive set of requirements because it contained both DoD and DoC requirements. So, it is imperative to ensure that only the DoD's requirements are extracted and drive the new acquisition, because, DoC is now responsible for their own requirements and acquisition. There are numerous ways to achieve inexpensive solutions. One way is to start from a proven baseline, such as the legacy DMSP Block 5D-3 satellites, particularly F19 and F20 satellites that underwent slight modernization. So, the DMSP System Operational Requirements Document (SORD) would be a recommended starting point for a requirements document.

To ensure the acquisition program remains inexpensive, "buy in bulk" and buy utilizing contracts such as FPIF that incentivize adherence to cost and ensure that there is sufficient funding to pay for the entire block buy. This step of ensuring an inexpensive "buy" incorporates the first, third, and fourth basic tenets of EASE (Block satellite buys, fixed priced contracting, and ensuring full funding). The Block buy should be for only two satellites at a time, due to the reduced DoD requirement to fly in one orbit. If the requirement was to revert to the two orbits as currently flown, then the block buy should be for four satellites, similar to the aforementioned proposed AEHF EASE approach (Chapter III, Figure 26). The goal is to get a production line started that is sustainable, very similar to the GPS or Toyota production line philosophy (Chapters II and III). While this production line would contain only two satellites in production at any given time and being built at a much slower pace, as compared to the automotive industry, the principles remains the same – do not fall into the trap of customizing every satellite that is built, but instead standardize the satellites to fit the production line and processes. The findings in this paragraph are in line with The Toyota Way Principles 1, 2, 3, 4, 6, and 8, which are "base your management decisions on a long-term philosophy, even at the expense of short-term financial goals, continuous process flow, use the "pull" system to avoid overproduction, level out the workload, standardize tasks and processes, use only reliable, and thoroughly tested technology," respectively.

While the norm is for the government to use Cost contracts to acquire the first two satellites in most new acquisitions, in this case, the use of FPIF contracts should be the preferred approach because of a number of reasons unique to this acquisitions such as the more matured program requirements (resulting from the recommendation to scale back to legacy DMSP requirements), while leveraging the billions of dollars that have been spent on developing newer technologies for NPOESS. Therefore, the requirements and technologies should be mature for both spacecrafts and sensors. A compelling reason would be needed to justify why an FPIF contract could not be used, especially since it was the contract vehicle effectively used in the initial DMSP Block I acquisitions in 1961, a period which did not have existing technology to leverage, in contrast to what currently exists today. Another reason why an FPIF contract is recommended for the spacecraft procurement is because several spacecrafts on the market are commercially available or have already been modified for usage in another DoD programs. The requirements for the spacecraft should be readily identifiable because, as shown in Chapter II, DoD has flown 42 DMSP satellites during the past 50 years in the same orbits. So orbit unique requirements such as additional onboard power storage are known.

With the information known today from legacy weather sensors and modernized ones from those on NPP or others currently in industry, the program office should be able to define the Size, Weight, and Power (SWaP) required for each sensor and generate clearly defined interface requirements for the spacecraft. Knowing this fidelity with the sensors requirements also compliments the use of FPIF contracts for sensor procurement. While sensor integration is normally done via a cost contract, a separate FPIF contract for sensor integration is also advocated and recommended that it is awarded to the prime contractor for the spacecraft and not the senor vendor(s) or a third integration contractor. The reason for this recommendation is because it will reduce complexity by not having a third contractor involved. The incentive should be written at a high level so as to give the government the flexibility needed and reduce contract modifications. For these reasons, the use of FPIF contracts to incentivize contractors to meet DoD’s needs such as cost efficiency is recommended. The use of fixed price contracting to the maximum extent will enable the program to meet the inexpensive element of FIST and coincides with the third element of EASE.

Finally, it is imperative to ensure there is full funding for each block of two satellites that are to be procured. That is the only way to provide assured skills, resources, and lower costs. Delays in funding will result in corresponding delays to the program meeting its goals. This finding is the same as the fourth element of EASE.

3. Third FIST Element: Simple

To meet the first two FIST elements, it is imperative to keep the program simple and set realistic goals. As mentioned in the second element, the requirements should be based on the proven technology, such as the legacy DMSP Block 5D-3 spacecraft requirements, specifically those of the updated F19/F20 satellites. Although some aspects of these satellites may be obsolete, there are other aspects not obsolete, such as how the sensors and subsystem of the spacecraft integrate and work efficiently. In addition, information should be rapidly gained from NPP which was recently launched and which is based on modern technology. The DMSP follow-on program manager needs to ensure that there is no delay in the first 2 satellites builds because of the desire to mature technology that is not yet proven. So, every effort should be made to leverage proven technology that has been developed and proven on NPP and the NPOESS program. Any unproven technology needs to be deferred for implementation on the third and subsequent SVs, once they are proven; so essentially an incremental approach to acquisitions. This technology maturation would be part of a CAIP for the DMSP follow-on program as defined in Figure 26. The previous findings are consistent with EASE's second tenet of "establishing stable research and development" and Principle 8 of The Toyota Way "Use only reliable, thoroughly tested technology that serves your people and processes." The goal is to get away from trying to acquire the "next best thing," which should be left to the research labs and developmental planning organizations to first be thoroughly proven before moving such technology to the program offices where operational system acquisitions occur.

In keeping with the "Simple" element of FIST, the program office should verify that three initial sensors per satellite (VIIRS, SEM-N, Microwave Sensor with legacy DMSP performance or greater) are absolutely needed to be on the first two satellites.

Since the VIIRS sensor is built and proven, DoD should sole source an FFIP contract to the sensor vendor, for 2 units, with a requirement that by buying 2 units, the cost of the second unit will be considerably less expensive than the first, otherwise do a competitive source selection. Similar processes should be followed for the other two sensors. Each of the sensors should be prioritized, classifying them as either primary, secondary, and/or tertiary. Based on their priority, the program office should set strict rules for how any of their cost, schedule, and/or performance impacts will affect the overall program. For example, in the event that an issue develop with a lower priority sensor, the course of action is clear if that sensor will be flown on the particular spacecraft that it was initially planned for or if instead it will be flown on the next spacecraft. To keep a program simple, at times, tough decisions like these have to be made. As principle 13 of the Toyota way states, "make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly."

The program office should leverage as much of the common ground system architecture that is currently being used for the DMSP operational satellites via NOAA's Satellite Operations Facility (NSOF), instead of looking to acquire their own command and control facilities to support its new satellites. As the ground system ages, an incremental modernization approach, in conjunction with NOAA should be undertaken.

4. Fourth FIST Element: Tiny

For the FIST and EASE models to be effective in lowering costs and improving scheduled deliveries, acquired systems need to adhere to the model and be optimally sized. Prior to the Senate's recommendation to cancel the DWSS program, the initial acquisition plan was for a modified NPOESS C spacecraft that is 40% smaller. Because of the high cost to launch satellites, SWaP factors are extremely important and are constantly being traded-off in space acquisitions. Therefore, an assessment needs to be conducted into the use of a smaller spacecraft, even smaller than the current Block 5D-3 spacecraft. Advances in technology have allowed for the reduction in size of several electronics and the integration of various piece parts, to produce overall smaller form, fit, and functional multipurpose products; for example, a smart phone. As a result, instead of launching on Atlas V or Delta IV rockets as done for the current DMSP satellites, the new satellites could potentially be launched on smaller rockets such as the Minotaur IV.

E CHAPTER SUMMARY

This chapter began with comparing and showing connections among FIST, EASE and Toyota Way principles that are applicable to defining new space systems. Then, an assessment of where the DMSP follow-on program currently stands based on the September 2011 Senate Appropriations Committee's recommendations for termination of the DWSS program and the subsequent stop work in January 2012. The four elements of FIST, along with the four tenets of EASE and 16 Principles of the Toyota Way were assessed and shown to be applicable and appropriate for consideration for the DMSP follow-on program based on current known information. This assessment resulted in a series of findings for the program office to pursue for their new follow-on program.

The results of this chapter shows that meeting production schedules for a 2018 ILC is no longer feasible especially because of the recent DWSS cancellation. A 2020 ILC date was recommended after evaluating launch dates for the two remaining satellites taking into account their ages by then, and a seven year acquisition timeline. Based on the time it takes to acquire similar systems, a 2020 ILC is optimistic and remains a high risk to the program. However, if the program office uses the findings of this chapter, the principles of FIST, EASE, and The Toyota Way, and adopt best practices from other current programs such as GPS IIIA's incremental developmental approach as discussed in Chapter II, it should be able to meet the new ILC, minimizing the possibility of a break in DoD weather coverage and placing the follow-on program on a sustainable path for the future.

V. CONCLUSION

A. CONCLUSION

The research questions from Chapter I are restated below with concise answers to them and references to applicable sections of this thesis that covered them.

1. **What are some of the acquisition challenges facing current Space systems?** The high cost of space systems and unstable funding are the two greatest challenges currently affecting it. Others include risk aversion, introducing immature technology to systems acquisitions, and trying to satisfy all requirements in a single step and on fewer platforms that leads to very complex systems. These challenges were discussed in Chapter II.

2. **What acquisition approach is best suited for Space systems? Single Step, Incremental/Block, Spiral, or a combination?** Based on the research conducted in this Thesis (DMSP, GPS, FIST, EASE, Toyota's approach, etc.), a combination approach is best suited. Specifically, a Block approach with Spiral increase in capabilities interjected at opportune times within the block acquisitions, as intended with the CAIP process within EASE. These reviews and applications were covered in Chapters II and III.

3. **What is a possible solution for the new DMSP follow-on program if FIST, EASE, and Toyota's approaches were used to help define it?** A Block/spiral combination acquisition approach for two satellites at a time with CAIP results interjected between every 2 satellite builds, utilizing fixed price incentive contracts where feasible and a 2020 ILC. See Chapter IV, sections C and D, for details of the solution.

4. **What lessons, if any, can Space System acquisition leverage from other acquisition approaches such as those used in the automotive industry?** There are several lessons to be learned but ones identified are Principles 1 through 14 that are shown in Tables 17 through 19. For example, how

standardize tasks are the foundation for continuous improvement. See section C of this chapter for recommendation for further study on this topic.

The research conducted in this thesis suggests that if a strong modernization effort had occurred in parallel with the acquisition of the current DMSP Block 5D-3 satellites, the combination would have resulted in an affordable transition to the next generation of weather satellites. For example, if during the years when the first three of the current block's five satellites were being launched and operated, such parallel modernization efforts were occurring, there would have been sufficient time to demonstrate the newer technology on the final one or two satellites to be launched in this block thereby smoothing the "technological hurdle ramp" to the next generation weather satellites. Consider it an incremental increase in capability, demonstrated on the current block, for implementation on the next block acquisition. If this incremental process was to be continuously repeated (as long as the requirements exists for these satellites) there would be more of gradual increase in capability and theoretically should result in lower overall costs and more compact scheduled deliveries of capability to the warfighter. The key is disciplined, concurrent, mature technology insertion occurring during the life of program and hence the importance of the CAIP discussed in Chapter III. Basing the acquisitions strategy of a future program on the next best technology can delay development and force immature technology into production line systems that end up in costly rework and disruption of work flow. This gradual continuous improvement cycle is the goal of EASE as discussed in Chapters III and IV.

The three approached described in this thesis pose the same underlying notion that greater efficiency is attainable in DoD acquisitions. With limited funding available to procure new systems, DoD must be more efficient in the way it acquires satellites. Essentially, DoD needs to transition to a system of procurement "on-demand" to meet its requirements. Parts degradation and obsolescence makes it costly to block buy several satellites at once and then place them in storage for a significant number of years, as in the case of the current DMSP 5D-3 block, and it is significantly more costly to buy one satellite at a time. So, DoD needs to find the balance between the two approaches. This thesis recommends a combined approach, based on the research that was conducted.

Specifically, a Block approach with Spiral increase in capabilities interjected at opportune times within the block acquisitions.

B. RECOMMENDATIONS

To ensure that the findings presented in Chapter IV remains valid, the DMSP follow-on program office should ensure that DoD's requirement still remains as one orbit, and has not changed since DWSS' cancellation. This is because the acquisition approach defined in Chapter IV would require the number of satellites acquired in each block be doubled if the requirement was to revert to providing coverage in the two orbits that DMSP satellites have flown for over 46 years, since March 18, 1965. Another recommendation is to continue the tradition of DMSP program and name this new block of satellites Block 6, so as to continue the historical legacy of the DMSP satellites as discussed in Chapter II. With current DMSP satellites surpassing on average 60 months on orbit and with the current advances in technology, it is reasonable to require at least 7 years of on-orbit performance for the follow-on program's satellites. As the EASE approach is implemented, DoD should seize the opportunity to standardize the production process for spacecrafts and acquire payloads to match standard interfaces with satellites and not the opposite where each Satellite is a custom design based on the payload characteristics.

C. AREAS TO CONDUCT FURTHER RESEARCH

Further research should be conducted on what it would take for DoD to define standard size (e.g., small, medium, and large) satellites and have standard production lines for them. In addition, it would be interesting to explore ways for DoD to own the production lines and pay industry or research laboratories to interject technology when mature, essentially the reverse of the current process. As satellites go through these standard production lines, they could be tailored based on their missions (e.g., surveillance, communications, meteorology, and navigation) and orbits (e.g., LEO, HEO, or GEO) they are slated to fly in. This approach potentially could further lower the cost of space system acquisitions while ensuring that the warfighter receive the capabilities when needed.

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APPENDIX A: DEFINITION OF TERMS

This thesis contains acronyms for sensors that were not defined. See below for a more detailed definition and explanation for each DMSP sensor in the Block 5D series. This was courtesy of Bohlson, 2007. In addition, Table 21 contains definitions for the sensors that were going to be flown on the NPOESS spacecrafts.

Primary Sensor: OLS - Operational Linescan System

The OLS measures visible and thermal infrared bands, thus obtaining cloud cover and some temperature information. The main portion of the OLS is an oscillating telescope device driven in a sinusoidal motion by counter-reacting coiled springs and a pulsed motor. The motion moves the instantaneous field of view (IFOV) of the detectors across the satellite subtract, with maximum scanning velocity at nadir and reversals at the end of each scan. Detector size is dynamically changed to reduce angular IFOV as it approaches each end of scan, thereby maintaining an approximately constant footprint size on earth. The swath width is 2963 km from the nominal 833 km orbital altitude. New bearings and lubricant were incorporated into the OLS beginning with F-12.

The OLS provides global coverage in both visible (L data) and infrared (T data) modes. Fine resolution data with a nominal linear resolution of 0.56 km are collected as needed, day and night, by the IR detector (TF data), and as needed, during daytime only, by a segmented, silicon diode detector (LF data). A high resolution photomultiplier tube is used for nighttime visible imagery.

For Block 5D spacecraft, tape recorder storage capacity limited the quantity of fine resolution data (LF or TF) which can be down linked from the stored data fine (SDF) mode to each ground station readout. Data smoothing permits global coverage in both the IR (TS) and visible (LS) spectrum to be stored on the tape recorders in the stored data smoothed (SDS) mode. Smoothing is accomplished by electrically reducing the sensor resolution to 2.78 km in the along scan direction, then digitally averaging five such 0.56 x 2.78 km samples in the along track direction. A nominal linear resolution of 2.78 km results. An additional detector allows collection of visible data (LS) with a 2.78 km nominal linear resolution under low light level conditions. These data are used for nighttime cloud cover and aurora equator ward boundary determination. The visible daytime response of the OLS is from 0.4 to 1.1 microns, chosen to provide maximum contrast between earth, sea, and cloud elements of the image field. The visible fine mode is provided for day scenes only.

The IR detector consists of two segments and is switched along scan to provide approximately constant ground footprint and image denotation. The detector is tri-metal (HgCdTe), passively cooled, and operates at approximately 110°K. The OLS IR spectral response of 10.5 to 12.8 um was chosen to optimize detection of both water and ice crystal clouds. The dynamic range of the sensor is from 190°K to 310°K with an accuracy of 1°K NE T from 210°K to 310°K.

The OLS data processing subsystem performs command, control, data manipulation, storage, and management functions for the entire sensor suite. The OLS receives and stores commands from the ground station and then processes them according to time codes. The OLS executes commands, accomplishes the smoothing of fine resolution data, derives gain commands from orbital parameters for normalization of visual data and dynamic signal control, and outputs the data to the spacecraft communications system. All data are processed, stored, and transmitted in digital format. The OLS also provides the data management functions to process, record, and output data from up to 12 additional environmental sensors. All DMSP transmissions (telemetry monitoring, satellite command and control, and sensor data) are encrypted. The encrypted data can be output simultaneously with playback of two channels of stored data.

A combination of either fine resolution data and the complementary smoothed resolution data (i.e., LF and TS or TF and LS) can be provided in the direct digital transmission mode (RTD). For RTD, the size of the pixel for the fine data is 0.56 x 0.56 km and 0.56 x 2.78 km for the smooth data. The OLS system includes and controls four digital tape recorders and each one can record at any one of three data rates and play back at either of two data rates. The recorders for spacecraft through S-15 have the capacity for storage of at least 400 minutes of SDS (TS and LS) data, or at least 40 minutes of SDF (LF or TF) data, or at least 20 minutes of SDF (LF and TF) data. For spacecraft S-16 through S-20, added channels will decrease these figures (and increase the mission sensor data) to at least 300 minutes of SDS (TS and LS) data, or at least 30 minutes of SDF (LF or TF) data, or at least 20 minutes of SDF (LF and TF) data. All tape recorders are interchangeable in function to provide operational redundancy and enhanced system life expectancy.

<u>Mission Sensors -</u>

<u>SSB</u> - Gamma Tracker

The SSB was supplied by Sandia National Lab and was used to track fallout and nuclear debris entrained in the atmosphere above 10 to 15 kilometers. The sensor detected the fission gammas emitted by the debris.

<u>SSB/A</u> - X-Ray Spectrometer

The SSB/A detected x-rays and gammas from bomb debris or those x-rays produced by the bremsstrahlung process when electrons precipitate from the earth's radiation belts. By sensing these x-rays, the SSB/A provided location of the aurora as it orbits the earth.

<u>SSB/O</u> - Omnidirectional Gamma Detector

The SSB/O was an experiment to determine if more accurate atmospheric measurements could be obtained by measuring the co-orbiting particles and.the upward flux and subtracting it from the sub-satellite scene. The experiment was extremely successful. The SSB/O was sensitive to X-rays in the energy range of approximately 1.S key.

<u>SSB/S</u> - Scanning X-Ray Detector

The SSB/S detected the location, intensity and spectrum of x-rays emitted from the earth's atmosphere. The detector consisted of three sensors. The first two each consisted of an array of four 1 cm diameter mercury iodide (HgI) crystals collimated to a 10° wide radial field of view. The third was a 0.635 cm x 7.62 cm diameter sodium iodide scintillator collimated to a 10° wide radial field of view.

<u>SSB/X, SSBIX-M, and SSB/X-2</u> - Gamma Ray Detectors

The SSB/X is an array-based system which detects the location, intensity, and spectrum of x-rays emitted from the earth's atmosphere. The array consists of four identical and independent directional detectors. The SSB/X-M and SSB/X-2 follow from the SSB/X and are also gamma-ray and particle detectors. The SSB/X-M and SSB/X-2 consist of two identical and independent gamma ray detectors and three particle detectors. The SSB/X-M and SSB/X-2 are also capable of detecting gamma ray bursts.

SSC - Snow Cloud Discriminator

The SSC was a 1.6 micron channel instrument. It was used to determine the presence of snow versus clouds. It was a proof-of-concept sensor intended to help determine if machine processing could make the snow/cloud determination.

SSD - Atmospheric Density Sensor

The SSD was designed to provide a measure of major atmospheric constituents (Nitrogen, Oxygen, and Ozone) in the earth's thermosphere by making earth-limb observations of the ultraviolet radiation from the thermosphere. The sensor measured radiation emitted from excitation of molecular nitrogen by impinging solar radiation.

SSE - Temperature Sounder

The SSE was an eight channel scanning filter radiometer. Six of the channels were in the IS um carbon dioxide band, one was in the 12 um window, and the last was in the rotational water vapor band near 20 um. Radiance measurements of the earth's atmosphere data were processed to obtain vertical temperature profiles. The sensor weighed about 8.2 kg. Subsystems included a Chopper Filter Assembly, a Scanner Subsystem, and an Electronics Subsystem. In general, the SSE was capable of measuring the energy from scenes between O and 330°K, but data were usually run between 150 and 330°K. A prototype SSE was flown on F30. The sensor was built by Barnes Engineering.

SSF – Laser Threat Detection

The SSF is an operational version of the SSZ. It monitors electromagnetic radiation.

SSH - Infrared Spectrometer

The IR Spectrometer (SSH) was an infrared multispectral sounder for humidity, temperature, and ozone measurements. The SSH provided soundings of temperature and humidity and a single measurement of ozone for vertical and slant paths lying under and to the side of the sub-satellite track.

The SSH made a set of radiance measurements in narrow spectral channels lying in the absorption bands of carbon dioxide, water vapor, and ozone. The radiance measurements were mathematically inverted to yield vertical temperature profiles of temperature, water vapor, and the total ozone content. For temperature sounding, radiances were measured in narrow channels in the wing of the 15 up Carbon dioxide absorption band. For humidity sounding, channels were selected to provide a range of absorption coefficients in the rotational water vapor band. Inversion yielded the vertical humidity profile.

SSH-2 - Infrared Temperature and Moisture Sounder

The SSH-2 provided soundings of temperature and humidity for vertical and slant paths lying under and to the side of the sub-satellite track. It was physically identical to the SSH, with different (and tighter) filter bands.

SSI/E Topside Ionospheric Plasma Monitor

The SSI/E measured the ambient electron density and temperatures, the ambient ion density, and the average ion temperature and molecular weight at the DMSP orbital altitude. The instrument consisted of an electron sensor (Langmuir probe) and an ion sensor mounted on a 2.5 meter boom. The ion sensor is a planar aperture, planar collector sensor oriented to face into the spacecraft velocity vector at all times.

SSI/ES Ionospheric Plasma Drift/Scintillation Meter

The SSI/ES is an improved version of the SSI/E. In addition to the Langmuir probe and planar collector which make up the SSI/E, the SSI/ES has a plasma drift meter and a scintillation meter.

SSI/ES-2 Special Sensor Ionospheric Plasma Drift/Scintillation Monitor

The SSI/ES-2 is a package of four sensors that measure in situ ionospheric parameters such as ion and electron temperatures, densities, and plasma irregularities, as well as ion drift velocity vectors for characterizing the high-latitude space environment. The data volume of SSI/ES-2 is 12 MByte/satellite-day.

SSI/ES-3 Enhanced Ionospheric Plasma Drift/Scintillation Monitor An upgrade of the SSI/ES-2 sensor. The data supports a variety of HF and UHF communications missions, and is used for atmospheric drag calculations for low Earth orbit satellites.

SSI/P - Passive Ionosonde

The SSI/P was a scanning radio receiver. It mapped the man-made radio spectrum to determine the critical (breakthrough) frequency of the F-layer of the ionosphere. The sensor automatically scanned from 1 MHz to 10 MHz in 20 KHz steps at a rate of one step per second.

SSJ - Space Radiation Dosimeter

The SSJ. measured the accumulated radiation dose produced by electrons in the 1 to 10 MeV energy range, protons of greater than 20 MeV, and the effects of the occasional nuclear interactions produced by energetic protons. Accumulated dose was measured over a period of time (one year minimum).

SSJ/2 - Precipitating Electron Spectrometer

The SSJl2 was the next generation SSJ. It consisted of a single stepping channel with six energy ranges. Nominally, the channels were 0.30, 0.68, 1.60, 3.50, 7.90, and 18.00 key. The sampling rate was 0.0922 seconds per energy step and the FOV was 30° in an ant,-earth cone. The sensor was built by the Aerospace Corporation.

SSJ/3 Auroral Electron and Ion Spectrometers.
The SSJ/3 is a next generation sensor of the SSJ. The SSJ/3 was flown on all Block 5D-1 spacecraft with the exception of F-1. Objective: Measurement of transfer energy, mass, and momentum through the magnetosphere-ionosphere in the Earth's magnetic field.

SSJ/4 Precipitation Electron/Proton Spectrometer

The SSJ/4 is a next generation sensor of the SSJ/3. Objective: Measurement of transfer energy, mass, and momentum of charged particles through the magnetosphere-ionosphere in the Earth's magnetic field. The instrument looks toward the satellite zenith. - The SSJ/4 sensor consists of four electrostatic analyzers that record the flux of precipitating ions or electrons at 20 fixed energy channels between 30 eV and 30 keV. The curved plate detectors allow precipitating electrons and ions to enter through an aperture of about 20 x 10 (FWHM). Electrons and ions of the selected energy are deflected toward the target by an imposed electric field applied across the two plates. The two low energy detectors consist of 10 channels centered at 34, 49, 71, 101, 150, 218, 320, 460, 670, and 960 eV. The high energy detector measures particles in 10 channels centered at 1.0, 1.4, 2.1, 3.0, 4.4, 6.5, 9.5, 14.0, 20.5 and 29.5 KeV. Each detector integrates each channel for 0.09 s from high energy channel to low. A complete cycle is sampled each second. The primary sources of the particles precipitating into the upper atmosphere are the northern and southern auroral zones. The daily data volume is approximately 1 Mbyte per satellite. The sensor data also supports missions which require knowledge of the polar and high-latitude ionosphere, such as communications, surveillance, and detection systems that propagate energy off or through the ionosphere.

SSJ/5 Precipitation Electron/Proton Spectrometer
Upgrade of SSJ/4. Detects and analyzes electrons and ions that precipitate

in the ionosphere to produce an aurora display. The sensor data also supports missions which require knowledge of the polar and high-latitude ionosphere, such as communications, surveillance, and detection systems that propagate energy off or through the ionosphere.

SSK - (Classified Sensor)

The SSK is a static earth-viewing sensor. It monitors electromagnetic radiation.

SSL - Lightning Detector

The SSL was a “one-of-a-kind” experiment. It operated at night to detect lightning flashes in the 0.4 to 1.1 um range. The peak response was near 0.8 um. The FOV was 2222 x 2963 km (due to the silicon photodiodes arrangement in the sensor).

SSM Triaxial Fluxgate Magnetometer

The SSM measures geomagnetic fluctuations associated with geophysical phenomena (i.e., ionospheric currents flowing at high latitudes). In combination with the SSI/ES (or SSI/ES-2) and the SSJ/4, the SSM provides heating and electron density profiles in the high-latitude ionosphere. A new Astromast boom was added on Block 5D-3 to isolate the sensor from spacecraft effects.

SSM/I - Microwave Imager

The SSM/I is a passive microwave radiometer. It detects thermal energy emitted by the earth-atmosphere system in the microwave portion of the electromagnetic spectrum. AFGWC and FNMOC meteorologists and oceanographers and certain tactical sites use the SSM/I to measure ocean surface wind speed, ice coverage and age, areas and intensity of precipitation, cloud water content, and land surface moisture. The data obtained are used for tropical storm reconnaissance, ship routing in polar regions, agricultural weather, aircraft routing and refueling, estimates of trafficability for Army support, communications management, and other missions.

The instrument is a conically scanned imager having a swath width of 1395 km. The sensor rotates with a nominal 1.9 second period and collects data during 102 degrees of each rotation. During the periods of the rotation that data are not being collected, the SSM/I collects calibration readings from both hot and cold sources. The SSM/I provides seven data channels of information. The resolution and the major environmental response of each channel depends upon its wavelength as indicated in Table 2.4.3-1. The channels make it possible to judge several environmental elements when the channels are processed multispectrally using three principles:

SSMIS Special Sensor Microwave Imager Sounder

SSMIS = SSM/I + SSM/T-1 + SSM/T-2 (Block 5D-3 sensor). In the Block 5D-3 satellite era, the Block 5D-2 passive microwave sensor suite is combined into a single new sensor package - the SSMIS (see Ref. 3). Improvements include 24 channels of data which are all coincident, increased resolution range, increased FOV, and enhanced ground processing software. The sensor adds one additional channel over the SSM/T to improve the measurement of the tropopause temperature and height. The frequencies chosen (channels 1-7 and 24) provide near uniform coverage in height to about 32 km. With the addition of five more channels (channels 19-23), the temperature retrievals are extended up to about 80 km.

The scene spacing for the sounder channels has been improved from 120 km to 480 km of the earlier instruments to 50 km for the lower atmosphere and to 75 km altitude for the upper atmosphere measurements. SSMIS uses almost the same channels as SSM/I for the environmental parameter extraction. The frequency of 85 GHz was changed to 91 GHz to save an extra channel in the system. SSMIS augments the rain retrieval and cloud amounts with channel 8 at 150 GHz.

SSM/T - Temperature Radiometer

The SSM/T is a seven channel microwave sounder. It measures atmospheric emission in the 50 to 60 GHz oxygen (O2) band. The SSM/T is designed to provide temperature soundings over previously inaccessible cloudy regions and at higher altitudes than those attainable with IR sounders such as the SSH and the SSH-2 flown on satellites F-1 through F-6.

The SSM/T is a cross-track nadir scanning radiometer having FOV of 14.4°. At the nominal 833 km altitude, the subtrack spatial resolution is an approximate circle of 174 km diameter at nadir. There are seven total cross-track scan positions separated by 12° with a maximum cross-track scan angle of 36°. At the far end of each scan resolution degrades to an ellipse of 213 x 304 km size. The SSM/T data swath is about 1500 km; therefore, there is a data coverage gap between successive orbits over much of the earth.

SSM/T-2 - Microwave Water Vapor Profiler

The SSM/T-2 is a modification of the SSM/T for water vapor sounding. This sensor has channels at 91.5 GHz, 150 GHz and the 183 GHz water vapor resonance line and has a resolution that ranges between 46 and 120 km. The system uses the same modular construction as the SSM/T. The sensor is packaged separately from the SSM/T to ease integration.

SSR and IFM (Integrated Flux Monitor) - (Classified Sensors)

The SSR and IFM were forerunners of the SSZ.

SSULI Special Sensor Ultraviolet Limb Imager
The optical instrument is a spectrograph with the objective to measure extreme and far ultraviolet radiation (vertical profiles) from the Earth's limb. The primary observations, ranging from 80 - 170 nm, with 1.5 nm resolution, are of radiation from atomic oxygen and nitrogen, and molecular nitrogen, resulting in direct measurements of the electron density vertical profile as well as ion and neutral densities. The vertical profiles in the upper atmosphere and ionosphere are obtained by viewing the Earth's limb at a tangent altitude of approximately 50 km to 750 km. The LORAAS (Low Resolution Airglow/Aurora Spectrograph) instrument on ARGOS (Launch Feb. 23, 1999) is a SSULI prototype instrument. LORAAS data of ARGOS is being used to validate SSULI algorithms that convert raw measurements into useful environmental parameters that characterize the upper atmosphere.

SSUSI Special Sensor Ultraviolet Spectrographic Imager

SSUSI is a nadir-pointing instrument that measures UV radiation from the Earth's atmosphere and ionosphere, it also measures visible radiation (airglow and terrestrial albedo). The instrument consists of three subassemblies: SIS (Scanning Imaging Spectrometer), NPS (Nadir-looking Photometer System), and the support module. SIS in turn consists of a cross-track scanning mirror at the input to the telescope (folded design) and spectrograph optics. There are redundant 2-D photon-counting detectors at the focal plane (detector size: 16 pixels in along-track and 160 pixels in the cross-track direction). The detectors employ a position sensitive anode to determine the photon event location. The scan mirror sweeps the 16 pixel footprint from horizon to horizon, producing one frame in 22 seconds. The imaging mode performs simultaneous measurements in five wavelength bands from 115 - 180 nm. The imaging mode scan cycle consists of a limb-viewing section followed by an Earth viewing (nadir) section. Limb-viewing imagery is collected from -72.8º from nadir to -63.2º from nadir. The limb-viewing section has a cross-track resolution of 0.4º per pixel, it consists of 24 cross-track pixels and 8 along-track pixels (at five bands). The Earth-viewing section has a cross-track resolution of 0.8º. - NPS consists of three nadir-looking photometers. It operates in the visible portion of the electromagnetic spectrum, monitoring airglow at 427.8nm and 630nm and the terrestrial albedo near 630nm. NPS operates only on the nightside of the orbit. Its data determine the auroral oval location and provide information to help determine electron densities in the F-layer, energy deposition in the auroral region (day and night), photoelectrons, neutral composition, and equatorial electrojet. Each photometer unit includes an integrated detector package consisting of a photomultiplier tube, high voltage power supply, and pulse amplitude discriminator electronics.

SSY - Classified Sensor)

The SSY is a package of state-of-health sensors.

SSZ – Laser Threat Detection

The SSZ is a prototype static earth-viewing sensor. It monitors electromagnetic radiation. (Bohlson, 2007)

Table 21. Description of Expected NPP and NPOESS Sensors, as of May 2008

Sensor	Description
Advanced Technology Microwave Sounder	Measures microwave energy released and scattered by the atmosphere and is to be used with infrared sounding data from the Cross-track Infrared Sounder to produce daily global atmospheric temperature, humidity, and pressure profiles.
Microwave Imager/Sounder	Collects microwave images and data needed to determine sea ice characterization and measure rain rate, ocean surface wind speed and direction, amount of water in the clouds, and soil moisture, as well as temperature and humidity at different atmospheric levels.
Cross-track Infrared Sounder (CrIS)	Collects measurements of the earth's radiation to determine the vertical distribution of temperature, moisture, and pressure in the atmosphere.
Clouds and the Earth's Radiant Energy System sensor	Measures solar short-wave radiation and long-wave radiation released by the earth back into space on a worldwide scale to enhance long-term climate studies.
Ozone Mapping and Profiler Suite (OMPS)	Collects data needed to measure the amount and distribution of ozone in the earth's atmosphere. Consists of two components (limb and nadir) that can be provided separately.
Space Environment Monitor	Collects data to identify, reduce, and predict the effects of space weather on technological systems, including satellites and radio links.
Total and Spectral Solar Irradiance Sensor	Monitors and captures total and spectral solar irradiance data.
Visible/Infrared Imager/Radiometer Suite (VIIRS)	Collects images and radiometric data used to provide information on the earth's clouds, atmosphere, ocean, and land surfaces.

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APPENDIX B: FIST RUBRIC

Table 22. FIST Rubric (From Ward, 2009)

FIST Rubric				
	High **10 pts**	**Medium** **5 pts**	**Low/No** **0 pts**	**Opposite** **-5 pts**
Fast Is Good	Strong, explicit affirmation of the importance of speed. Formal commitment to maintaining deadline (contractual, etc). Contractual incentives to reward early delivery. Concrete steps taken to actually reduce development timeline. Accepts significant risks in order to maintain schedule.	Modest, occasional affirmation of the importance of speed, with caveats. Modest, informal commitment to maintain or reduce deadline. Contractual incentives to reward on-time delivery. Few steps taken to reduce timeline. Accepts moderate risks in order to maintain schedule	Little to no mention of the importance of speed. No commitment (beyond the ordinary) to maintain deadline. No steps taken to reduce timeline or reward on-time / early delivery.	Ambivalence or antipathy towards speed. Explicit support for "taking as much time as we need" Active attempts to increase timeline. Accepts schedule delays rather than accept risks.
Inexpensive Is Good	Strong, explicit affirmation of the importance of low-cost. Formal commitment to maintain budget (contractual, etc) Contractual incentives to reward cost under-runs. Concrete steps taken to actually reduce development cost. Accepts significant risks in order to reduce costs.	Modest, occasional affirmation of the importance of low-cost, with caveats. Modest, informal commitment to maintain or reduce budget. Few concrete steps taken to reduce cost. Accepts moderate risks in order to maintain costs.	Little to no mention of the importance of low cost. No commitment (beyond the ordinary) to maintain budget. No steps taken to reduce cost.	Ambivalence or antipathy towards low-cost. Explicit support for "spending as much money as we need to" Active attempts to increase budget. Accepts cost increases rather than accept risks.
Simple Is Good	Strong, explicit and frequent affirmation of the importance of simplicity. Deliberate steps taken to actually reduce complexity in many	Modest, occasional affirmation of the importance of simplicity, with caveats. Modest attempts to reduce complexity in	Little to no mention of the importance of simplicity. No mention of steps taken to reduce complexity.	Ambivalence or antipathy towards simplicity. Explicit support for / pride in complexity. Active attempts to

Table 23. FIST Rubric continued (From Ward, 2009)

	areas (organization, technology, communication, etc). Heavy reliance on existing, mature, proven technology (TRL 7+). System capability less than previous systems. Frequent emphasis on the importance of and reliance on talent.	some areas. Primarily relies on mature technologies, with some new developments. System capability moderately less than previous systems. Occasional mention of the importance of and reliance on talent.	No mention of technology maturity levels. No mention of the importance of and reliance on talent. System capabilities match or moderately exceed previous systems.	increase complexity. Heavy reliance on new developments and technology breakthroughs System capabilities significantly exceed previous systems. Explicit reliance on formal, structured process, control and compliance.
Tiny Is Good	Strong, explicit affirmation of the importance of small. Formal commitment to maintain or reduce size. Concrete steps taken to actually reduce size (of org, process, sys, documentation, etc).	Modest, occasional affirmation of the importance of small, with caveats. Modest, informal commitment to maintain or reduce size. Few steps taken to reduce size.	Little to no mention of the importance of small. No commitment (beyond the ordinary) to maintain size. No steps taken to reduce size.	Ambivalence or antipathy towards small, lean or streamlined approaches. Explicit support for / pride in bigness. Active attempts to increase size.

Outcome	**A** Met or surpassed all or most operational requirements, including maintainability and reliability Delivered operational capability Users expressed satisfaction Delivered within a reasonable margin of original cost and schedule baseline Program replicated or imitated by subsequent projects	**F** Mission failed to meet or surpass a significant number of requirements System rejected by users Program cancelled before delivery Delivered after adding substantial funding and substantial schedule increase Operational use is severely restricted to a subset of original operational vision or requirement set.

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