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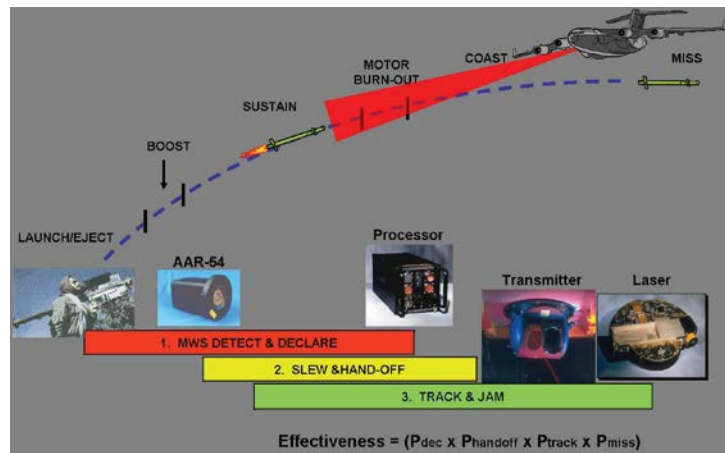
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Large Aircraft Infrared Countermeasures (LAIRCM) SYSTEMS ENGINEERING CASE STUDY

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Foreword

At the direction of the former Secretary of the Air Force, Dr. James G. Roche, the Air Force Institute of Technology (AFIT) established the Air Force Center for Systems Engineering (AF CSE) at its Wright Patterson AFB campus in 2003. With academic oversight by a subcommittee on systems engineering, chaired by then-Air Force Chief Scientist Dr. Alex Levis, the AF CSE was tasked to develop case studies of SE implementation during concept definition, acquisition, and sustainment. The committee drafted an initial case outline and learning objectives, and suggested the use of the Friedman-Sage Framework to guide overall analysis.

The Department of Defense is exponentially increasing the acquisition of joint complex systems that deliver needed capabilities demanded by our warfighter. Systems engineering is the technical and technical management process that focuses explicitly on delivering and sustaining robust, high-quality, affordable solutions. The Air Force leadership has collectively stated the need to mature a sound systems engineering process throughout the Air Force. Gaining an understanding of the past and distilling learning principles that are then shared with others through our formal education and practitioner support are critical to achieving continuous improvement.

The AF CSE has published eleven case studies thus far including the A-10, KC-135 Simulator, Global Hawk, C-5A, F-111, Hubble Telescope, Theater Battle Management Core System, International Space Station, Global Positioning System (GPS), the HH/MH-53, and the E-10A. All case studies are available on the AF CSE website, <http://www.afit.edu/cse>. These cases support academic instruction on SE within military service academies, civilian and military graduate schools, industry continuing education programs, and those practicing SE in the field. Each of the case studies is comprised of elements of success as well as examples of SE decisions that, in hindsight, were not optimal. Both types of examples are useful for learning.

Along with discovering historical facts, we have conducted key interviews with program managers and chief engineers, both within the government and those working for the various prime and subcontractors. From this information, we have concluded that the discipline needed to implement SE and the political and acquisition environment surrounding programs continue to challenge our ability to provide balanced technical solutions. We look forward to your comments on this case study and our other AF CSE published studies.

Thomas F Christian, SES, DAF
Director, Air Force Center for Systems Engineering
Air Force Institute of Technology

The views expressed in this Case Study are those of the author(s) and do not reflect the official policy or position of the United States Air Force, the Department of Defense, or the United States Government.

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1 Systems Engineering Principles

1.1 General Systems Engineering Process

The Department of Defense continues to develop and acquire joint systems and to deliver needed capabilities to the warfighter. With a constant objective to improve and mature the acquisition process, it continues to pursue new and creative methodologies to purchase these technically complex systems. A sound systems engineering process focused explicitly on delivering and sustaining robust, high-quality, affordable products that meet the needs of customers and stake holders must continue to evolve and mature. Systems engineering is the technical and technical management process that results in delivered products and systems that exhibit the best balance of cost and performance. The process must operate effectively with desired mission-level capabilities, establish system-level requirements, allocate these down to the lowest level of the design, and ensure validation and verification of performance, meeting cost and schedule constraints. The systems engineering process changes as the program progresses from one phase to the next, as do the tools and procedures. The process also changes over the decades, maturing, expanding, growing, and evolving from the base established during the conduct of past programs. Systems engineering has a long history. Examples can be found demonstrating a systemic application of effective engineering and engineering management, as well as poorly applied, but well-defined processes. Throughout the many decades during which systems engineering has emerged as a discipline, many practices, processes, heuristics, and tools have been developed, documented, and applied.

Several core lifecycle stages have surfaced as consistently and continually challenging during any system program development. First, system development must proceed from a well-developed set of requirements. Second, regardless of the evolutionary acquisition approach, the system requirements must flow down to all subsystems and lower level components. And third, the system requirements need to be stable, balanced and must properly reflect all activities in all intended environments. However, system requirements are not unchangeable. As the system design proceeds, if a requirement or set of requirements is proving excessively expensive to satisfy, the process must rebalance schedule, cost, and performance by changing or modifying the requirements or set of requirements.

Systems engineering includes making key system and design trades early in the process to establish the system architecture. These architectural artifacts can depict any new system, legacy system, modifications thereto, introduction of new technologies, and overall system-level behavior and performance. Modeling and simulation are generally employed to organize and assess architectural alternatives at this introductory stage. System and subsystem design follows the functional architecture. System architectures are modified if the elements are too risky, expensive or time-consuming. Both newer object-oriented analysis and design and classic structured analysis using functional decomposition and information flows/data modeling occurs. Design proceeds logically using key design reviews, tradeoff analysis, and prototyping to reduce any high-risk technology areas.

Important to the efficient decomposition and creation of the functional and physical architectural designs are the management of interfaces and integration of subsystems. This is applied to subsystems within a system, or across large, complex system of systems. Once a solution is planned, analyzed, designed, and constructed, validation and verification take place to

ensure satisfaction of requirements. Definition of test criteria, measures of effectiveness (MOEs), and measures of performance (MOPs), established as part of the requirements process, takes place well before any component/subsystem assembly design and construction occurs.

There are several excellent representations of the systems engineering process presented in the literature. These depictions present the current state of the art in the maturity and evolution of the systems engineering process. One can find systems engineering process definitions, guides, and handbooks from the International Council on Systems Engineering Electronic Industries Association, Institute of Electrical and Electronics Engineers, and various Department of Defense (DoD) agencies and organizations. They show the process as it should be applied by today's experienced practitioner. One of these processes, long used by the Defense Acquisition University (DAU), is depicted by Figure 1-1. It should be noted that this model is not accomplished in a single pass. This iterative and nested process gets repeated to the lowest level of definition of the design and its interfaces.

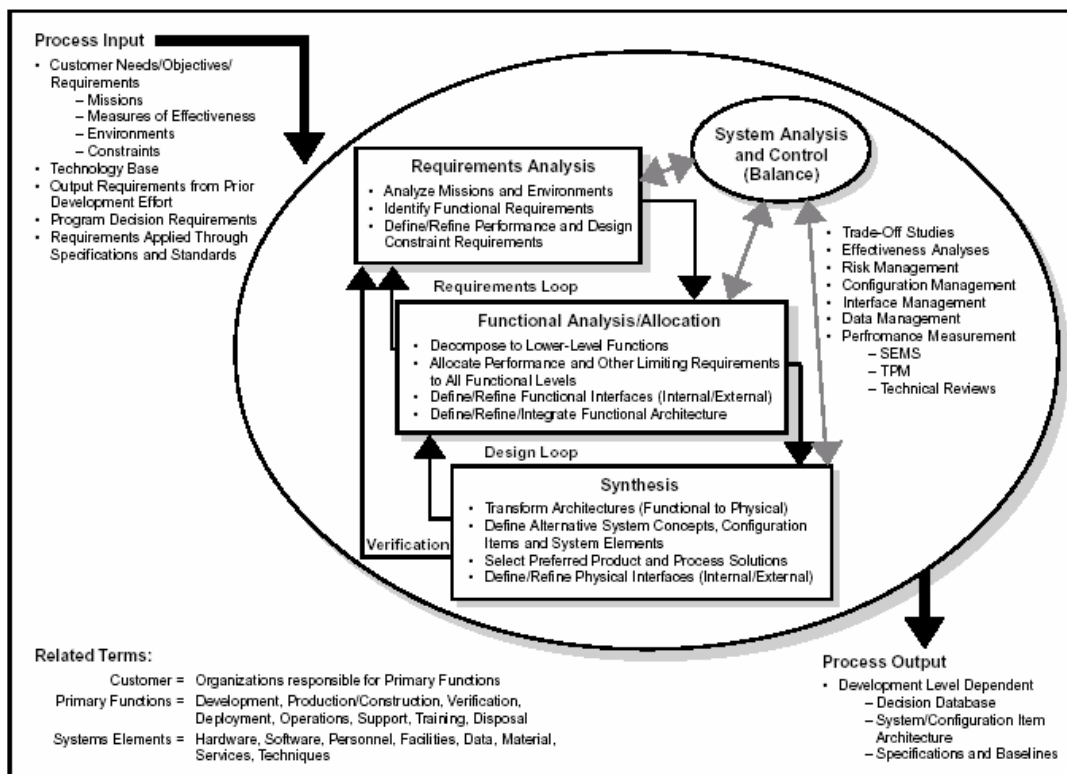


Figure 1-1 The Systems Engineering Process as Presented by DAU

1.2 DoD Directive 5000 Series

During President Richard Nixon's first term, Secretary of Defense Melvin Laird faced congressional attempts to lower defense spending. The cause was the Vietnam War and the rising cost of defense acquisition, as well as emerging energy and environmental programs. Laird and David Packard, his deputy, recognized the need for a mechanism to control and manage spending especially with the coming fiscal constraint. In May 1969, Packard formed the Defense Systems Acquisition Review Council to give advice on the acquisition of major weapon systems. It was chartered to review major milestones as well as conduct occasional management reviews. One year later in 1970, Packard issued a policy memorandum that was to become the foundation

for the DoD 5000 series of documents which were first issued in 1971, and as of January 2008 have been reissued 10 times. The original purpose of the DoD 5000 series was to improve the management of acquisition programs and include policy to streamline management, decentralize execution, and use appropriate management structures. The 1971 issue of the DoD 5000 series established the following program considerations (abbreviated here) pertaining to progression of a program through the acquisition process.

1. System need shall be clearly established in operational terms, with appropriate limits, and shall be challenged throughout the acquisition process ... Wherever feasible, operational needs shall be satisfied through the use of existing military or commercial hardware ...
2. Cost parameters shall be established which consider the cost of acquisition and ownership ... Practical tradeoffs shall be made between system capability, cost and schedule ...
3. Logistic support shall also be considered as a principle design parameter ...
4. Programs shall be structured and resources allocated to assure that the demonstration of actual achievement is the pacing function ... Schedules and funding profiles shall be structured to accommodate unforeseen problems and permit task accomplishment without unnecessary overlapping or concurrency.
5. Technical uncertainty shall be continually assessed ... Models, mock-ups, and system hardware will be used to the greatest possible extent to increase confidence level.
6. Test and evaluation shall commence as early as possible. A determination of operational suitability, including logistics support requirements, will be made prior to large scale production commitments ...
7. Contract type shall be consistent with all program characteristics, including risk ...
8. The source selection decision shall take into account the contractor's capability to develop a necessary defense system on a timely and cost-effective basis ...
9. Management information/program control requirements shall provide information which is essential to effective management control ... Documentation shall be generated in the minimum amount to satisfy necessary and specific management needs.

1.3 Evolving Systems Engineering Process

The DAU model, like all others, has been documented in the last two decades, and has expanded and developed to reflect a changing environment. Systems are becoming increasingly complex internally and more interconnected externally. The process used to develop the aircraft and systems of the past was a process effective at the time. It served the needs of the practitioners and resulted in many successful systems in our inventory. Notwithstanding, the cost and schedule performance of the past programs are fraught with examples of some well-managed programs and ones with less-than-stellar execution. As the nation entered the 1980s and 1990s, large DoD and commercial acquisitions were overrunning costs and behind schedule. Aerospace industry primes were becoming larger and more geographically and culturally distributed and worked diligently to establish common systems engineering practices across their enterprises. However, these common practices must be understood and be useful both within the enterprise and across multiple corporations and vendor companies because of the mega-trend of teaming in large (and some small) programs. It is essential that the systems engineering process effect

integration, balance, allocation, and verification and be useful to the entire program team down to the design and interface level.

Today, many factors overshadow new acquisition, including system-of-systems (SoS) context, network-centric warfare and operations, an increased attention to human systems integration, and the rapid growth in information technology. These factors are driving a more sophisticated systems engineering process with more complex and capable features, along with new tools and procedures. One area of increased focus of the systems engineering process is the informational systems architectural definitions used during system analysis. This process, described in the DoD Architectural Framework (DoDAF), emphasizes greater reliance on reusable architectural views describing the system context and concept of operations, interoperability, information and data flows, and network service-oriented characteristics.

1.4 Case Studies

The systems engineering process to be used in today's complex system and system-of-systems projects is a process matured and founded on principles developed in the past. Examination of systems engineering principles used on programs, both past and present, can provide a wealth of lessons to be used in applying and understanding today's process. It was this thinking that led to the initiation of the Air Force Center for Systems Engineering case study effort, as well as the present continuation of that effort.

The purpose of developing detailed case studies is to support the teaching of systems engineering principles. They will facilitate learning by emphasizing to the student the long-term consequences of the systems engineering and programmatic decisions on program success. The systems engineering case studies will assist in discussion of both successful and unsuccessful methodologies, processes, principles, tools, and decision material to assess the outcome of alternatives at the program/system level. In addition, the importance of using skills from multiple professions and engineering disciplines and collecting, assessing, and integrating varied functional data will be emphasized. When they are taken together, the student is provided real-world, detailed examples of how the process attempts to balance cost, schedule, and performance.

The utilization and misutilization of systems engineering principles will be highlighted, with special emphasis on the conditions that foster and impede good systems engineering practices. Case studies should be used to illustrate both good and bad examples of acquisition management and learning principles, to include whether:

- every system provides a satisfactory balanced and effective product to a customer;
- effective requirements analysis was applied;
- consistent and rigorous application of systems engineering management standards was applied;
- effective test planning was accomplished;
- there were effective major technical program reviews;
- continuous risk assessments and management was implemented;
- there were reliable cost estimates and policies;
- they used disciplined application of configuration management;

- a well-defined system boundary was defined;
- they used disciplined methodologies for complex systems ;
- human systems integration was accomplished;
- problem solving incorporated understanding of the system within the larger operational environment.

The systems engineering process transforms an operational need into a system or system-of-systems. Architectural elements of the system are allocated and translated into detailed design requirements. The systems engineering process, from the identification of the need to the development and utilization of the product, must continuously integrate and balance the requirements, cost, and schedule to provide an operationally effective system throughout its life cycle. Systems engineering case studies highlight the various interfaces and communications to achieve this balance, which include:

- The program manager/systems engineering interface between the operational user and developer (acquirer) essential to translate the needs into the performance requirements for the system and subsystems.
- The government/contractor interface essential for the practice of systems engineering to translate and allocate the performance requirements into detailed requirements.
- The developer (acquirer)/user interface within the project, essential for the systems engineering practice of integration and balance.

The systems engineering process must manage risk, both known and unknown, as well as both internal and external. This objective will specifically capture those external factors and the impact of these uncontrollable influences, such as actions of Congress, changes in funding, new instructions/policies, changing stakeholders or user requirements, or contractor and government staffing levels.

1.5 Framework for Analysis

The Air Force Center for Systems Engineering case studies will present learning principles specific to each program, but will utilize the Friedman-Sage framework to organize the assessment of the application of the systems engineering process. The Systems Engineering case studies published by the Air Force Institute of Technology employed the Friedman-Sage construct and matrix as the baseline assessment tool to evaluate the conduct of the systems engineering process for the topic program.

The framework and the derived matrix can play an important role in developing case studies in systems engineering and systems management, especially case studies that involve systems acquisition. The Friedman-Sage framework is a nine row by three column matrix shown in Table 1-1.

Table 1-1 A Framework of Key Systems Engineering Concepts and Responsibilities

| Concept Domain | Responsibility Domain | | |
|--|-------------------------------------|---------------------------------|-------------------------------------|
| | 1. Contractor Responsibility | 2. Shared Responsibility | 3. Government Responsibility |
| A. Requirements Definition and Management | | | |
| B. Systems Architecting and Conceptual Design | | | |
| C. System and Subsystem Detailed Design and Implementation | | | |
| D. Systems and Interface Integration | | | |
| E. Validation and Verification | | | |
| F. Deployment and Post Deployment | | | |
| G. Life Cycle Support | | | |
| H. Risk Assessment and Management | | | |
| I. System and Program Management | | | |

Six of the nine concept domain areas in Table 1 represent phases in the Systems Engineering lifecycle:

- A. Requirements definition and management;
- B. Systems architecting and conceptual design;
- C. System and subsystem detailed design and implementation;
- D. Systems and interface integration;
- E. Verification and validation;
- F. Deployment and post deployment.

Three of the nine concept areas represent necessary process and systems management support:

- G. Life cycle support;
- H. Risk assessment and management;
- I. System and program management.

While other concepts could have been identified, the Friedman–Sage framework suggests these nine are the most relevant to systems engineering in that they cover the essential life cycle processes in systems acquisition and the systems management support in the conduct of the process. Most other concept areas that were identified during the development of the matrix appear to be subsets of one of these. The three columns of this two-dimensional framework represent the responsibilities and perspectives of government and contractor, and the shared responsibilities between the government and the contractor. In teaching systems engineering in DoD, there has previously been little distinction between duties and responsibilities of the government and industry activities. While the government has responsibility in all nine concept domains, its primary objective is establishing mission requirements.



Figure 1-2 Artist's concept of the LAIRCM

2 Large Aircraft Infrared Countermeasures (LAIRCM) System Description

2.1 LAIRCM System Description

The LAIRCM system autonomously detects and declares Infrared (IR) threat missiles, tracks the missiles and jams the missiles to create a miss, resulting in aircrew and aircraft protection. The system has no interoperability requirements outside the platform on which it is installed. The LAIRCM system consists of five basic subsystem components, all related technical orders (TOs), support equipment, training systems, related facilities, materiel, software, services, and personnel required to ensure the system can perform its intended operational function. The specific quantity of LAIRCM system components is platform dependent; the platform will also determine if they will use the Phase I or Phase II components as follows:

1. System Processor (SP)
2. Control Indicator Unit (CIU)
3. Missile Warning Sensor (MWS) subsystem
4. Laser Transmitter Assembly (LTA) subsystem
5. Viper™ Multi-band Laser subsystem (VL)

As shown in Figure 2-2, the LAIRCM system has three small laser transmitter assemblies (SLTAs), which are mounted on the aircraft, as well as five missile warning transmitters at various points on the aircraft. The three LTAs are mounted with two in the front and one under the tail. A processor located on the flight deck of the aircraft collects the data and transmits information to the aircrew. The laser transmitters are the heart of the system, they basically work to interrupt the infrared signal, or heat. The lasers "blind" the missile's eyeball, so it disables the missile's ability to follow the heat source from the plane.



Figure 2-1 LAIRCM System



Figure 2-2 LAIRCM mounted C-17

2.2 LAIRCM System Components (from LAIRCM Test and Evaluation Master Plan, 2010)

2.2.1 System Processor (SP)

The SP provides overall control and monitoring of the system (Figure 2-3). It accepts aircrew or maintenance commands and data from the CIU to determine system mode and operation. It also controls and receives data from the MWS and transmitters for threat acquisition, tracking, and jamming. LAIRCM Phase I is a federated system on the aircraft. No data are shared between the LAIRCM processor and the mission computer of the aircraft upon which it is installed. As shown in Figure 2-11, the LAIRCM processor receives discrete (nonserialized) signals from the aircraft for Weight on Wheels (WoW) as a safety interlock to prevent laser emissions or flare pulses while the aircraft is on the ground. The LAIRCM processor directly interfaces with the ALE-47 flare dispenser via a discrete line to control the dispensing of flares if a laser turret is not available to address an attacking threat missile. The LAIRCM processor utilizes discrete lines to illuminate the Group A Supplemental Crew Alert light in accordance with system logic. These lights, typically installed by the aircraft modification (Group A) contractor within the field of view of the pilot, enables the pilot to rapidly determine if the system has detected a missile threat, or has dispensed flares. LAIRCM Phase II retains all the Phase I Group A interfaces and adds an Inertial Navigation System (INS) interface for the Next Generation (NexGen) MWS subsystem as depicted in Figure 2-11.



Figure 2-3 System Processor

The LAIRCM system has a built in attitude reference unit (part of the countermeasures processor) and does not require aircraft inertial navigation system data. It does require information from the WoW switch to instruct the system to disengage the laser while on the ground. The LAIRCM system has the capability to electrically interface with the ALE-47 countermeasures dispenser system and is connected to the ALE-47 on aircraft that have the flare dispenser installed. The aircrew can select either the LAIRCM system or the AAR-47 for automatic flare dispense via the ALE-47 in accordance with user tactics and procedures. LAIRCM does not affect current AAR-47 and ALE-47 operation when AAR-47 is selected by the aircrew.

2.2.2 Control Indicator Unit (CIU)



Figure 2-4 CIU

The CIU provides the operator interface to program the LAIRCM system for control of the various modes (off, standby, operate) to initiate built-in-test (BIT), to display system status, and provide the crew with bearing to threat missile launch (Figure 2-4). The system is programmed by inserting a smart card user data module into the CIU. The CIU has a mode that enables the flare system to be used as a backup in case the LAIRCM system encounters problems. The LAIRCM system has the capability to alert the aircrew of a missile engagement. The CIU provides threat



Figure 2-5 CIUR

warning aural and visual cues. The display and backlighting may be used under normal cockpit illumination or with night vision systems. The CIU utilizes a discrete (non-serialized) control line to illuminate the Master Caution Warning light if the system fails. This light is normally installed by the aircraft modification (Group A) contractor within the pilot field of view to alert the aircrew if the system fails. The replacement CIU is shown in Figure 2-5.

2.2.3 Missile Warning Sensor (MWS) Subsystem

The MWS detects and declares threat missiles prior to motor burnout (Figure 2-6). The current MWS is the Northrop Grumman Corporation (NGC) DIRCM AAR-54 (V) Ultraviolet (UV) Missile Warning Subsystem and associated processor card located within the system processor. UV sensors mounted on the aircraft provide azimuth and elevation coverage to comply with requirements contained in the LAIRCM ORD.



Figure 2-6 AAR-54 Ultraviolet MWS subsystem

2.2.3.1 NexGen MWS

The LAIRCM Phase II NexGen MWS is designed to replace the AAR-54 (Figure 2-7). The NexGen MWS upgrade will improve the existing LAIRCM system's probability of declaring threat missiles beyond the AMC ORD Annex requirements to meet the basic Multi-Command ORD 314-92 requirements. Two contractors, NGC and Lockheed Martin, were carried through SDD and NGC was selected as the single production contractor.

Incorporation of the NexGen MWS into the LAIRCM system will require Inertial Navigation System (INS) information to be provided to the LAIRCM processor. A new Group A interface is required to accomplish this task. The LAIRCM system will become a bus monitor on the aircraft 1553 data bus so these data can be provided to the NexGen MWS subsystem. This Phase II change in system architecture is portrayed in Figure 2-11.



Figure 2-7 NexGen MWS

2.2.4 Laser Transmitter Pointer/Tracker subsystem

The Laser Transmitter Pointer/Tracker subsystem, originally fielded with the LAIRCM system, is known as the Small Laser Transmitter Assembly (SLTA). In 2007 the ASC LAIRCM Program Office began procuring the Guardian Laser Transmitter Assembly (GLTA) as a replacement to the SLTA on some AMC-identified platforms.

2.2.4.1 Small Laser Transmitter Assembly (SLTA)

The SLTA is comprised of the NGC ViperTM countermeasures laser and the small transmitter (Figure 2-8). The pointer-tracker is designed to track the inbound threat missile and point the laser jam source at the missile's seeker. Threat location information is provided to the transmitter by the MWS. The transmitter is the most complex subsystem, and consists of an IR fine track sensor (FTS), pointing turret subsystem, and associated communication and control functions. The transmitter is equipped with a two-axis gimbal for steering the overall transmitter and an additional two-axis mirror system for finer pointing accuracy of the FTS and laser. The laser is boresighted to the center of the FTS field of regard. The ViperTM laser subsystem has completed development under a USSOCOM contract and is in production. All ViperTM components fit into

a 13-inch diameter by 2-inch high chassis, weighing less than 10 lb, the lightest laser available for IRCM applications.



Figure 2-8 SLTA

2.2.4.2 Guardian Laser Transmitter Assembly (GLTA)



Figure 2-9 GLTA

The GLTA initial production order was placed in May 07 with deliveries beginning in 2008 (Figure 2-9). The GLTA spiral builds on NGC independent research and development (IRAD) for the pointer-tracker program and provides increased supportability, reduced production costs, and improved effectiveness compared to the SLTA. The LAIRCM GLTA with the Viper™ Laser is a replacement for the SLTA on certain platforms, and is compatible with the current MWS and the NexGen MWS (LAIRCM Phase II). The LAIRCM processor software is also updated within this program to ensure interoperability with the GLTA. The objectives of this LAIRCM GLTA program (versus SLTA) are:

- Reduced turret procurement cost
- Significant reliability improvement
- 25% weight reduction
- 2.5/1 drag reduction

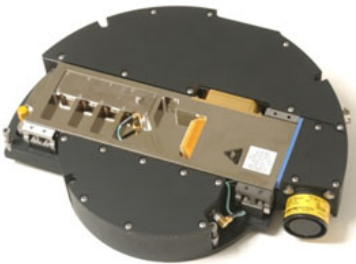


Figure 2-10 Viper Laser

2.3 Specifications (LAIRCM)

The specifications for LAIRCM are provided below in Table 2-1 and the system view shown in Figure 2-11.

Table 2-1 Support Requirements Criteria Requirement

| Support Requirement | Requirement | Actual |
|--|--------------------|------------|
| Will perform its mission | 95 percent of time | 95 percent |
| Mean Time Between Maintenance | 130 hours | >130 hours |
| Mean Time Between Removal | 1500 hours | 650 hours |
| Mean Time to Repair | NTE 60 minutes | 30 minutes |
| BIT Accuracy to Correct Subsystem | 95 percent | 98 percent |
| Two levels of maintenance (organizational and depot) | 2-level | 2-level |

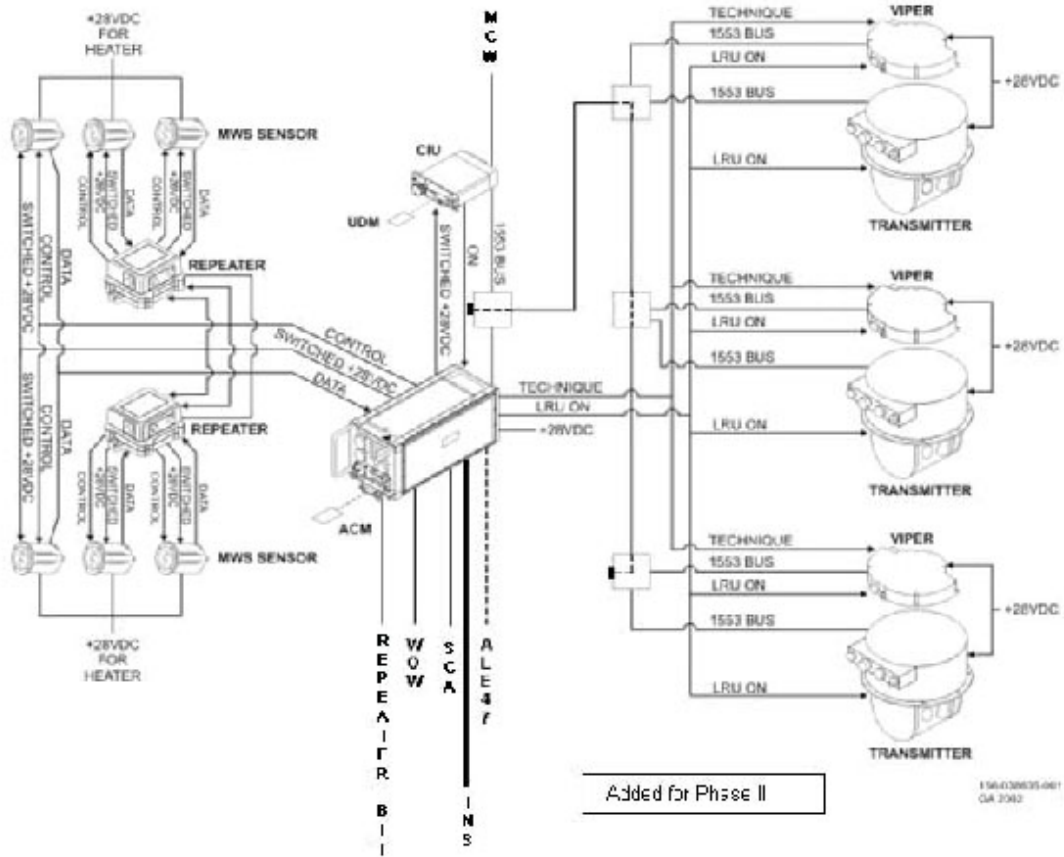


Figure 2-11 LAIRCM System View (from LAIRCM Systems Engineering Plan)

3 The LAIRCM Story – the Family of IR Countermeasures

A blacked-out C-130 climbed into the night sky over Baghdad in January 2006 and headed toward Kuwait carrying six members of the House Armed Services Committee. Suddenly, a shoulder-fired missile streaked toward the plane. “Fortunately the C-130’s onboard countermeasures system was one of the most capable available,” an Air Force pilot wrote in a report about the incident. It may well be that the lawmakers are alive today because the C-130 was equipped with LAIRCM—the large-aircraft infrared countermeasure— one of a family of IR Countermeasure systems (Figure 3-1). The LAIRCM’s laser “deflected the missile” and the attack failed, the pilot reported.

The threat, meanwhile, continues to grow. During the early months of the Iraq war, Gen. John Handy, then chief of the Air Mobility Command, said U.S. military cargo planes were being fired on with shoulder-fired missiles and anti-aircraft artillery “on almost a daily basis.” At that time, Air Guard planes were equipped with flares and metallic chaff as countermeasures. The flares are burning bits of metal that create hot spots in the sky to lure heat-seeking missiles away from the hot exhaust of aircraft engines. Chaff is used to confuse missile system radars. Those defenses and evasive maneuvering by pilots are enough to keep planes safe from less sophisticated MANPADS, as shoulder-fired missiles are often called. But flares are less effective against the more sophisticated missiles that have begun showing up in Iraq and Afghanistan.

Pilots have adopted other defenses as well. Flying just above treetop level, for example, gives insurgents less time to aim and fire. That tactic reportedly was used to protect former Defense Secretary Donald Rumsfeld when he flew into Baghdad aboard an MC-130 Combat Talon in 2003. And instead of making a gradual descent into Baghdad’s or Kabul’s main airport, C-130 and C-17 pilots often drop into a tight, gut-wrenching corkscrew to avoid becoming targets for shoulder-fired missiles and rocket-propelled grenades.

Nonetheless, at least three large cargo planes have been hit. A commercial cargo plane operated by freight carrier DHL was badly damaged in November 2003 while taking off from Baghdad. An Air Force C-17 was hit in December 2003, and a C-5 was hit in January 2004. The C-17 and the C-5 were hit despite their defensive flares, says Jack Pledger, who is the head of infrared countermeasures development at Northrop Grumman. Fortunately, each plane was able to land safely. Perhaps U.S. forces have been lucky. The threat of shoulder-fired missiles “has outpaced current strategy and available countermeasures,” wrote Air Force Reserve Maj. James Whitmire, who analyzed the growing danger to commercial airliners and military planes. Thousands of shoulder-fired-missiles “are available on the black market at affordable prices. Multiple sources corroborate the fact that these missiles are well within the reach of terrorists,” Whitmire wrote.

The family of IR countermeasure (IRCM) includes flares, jammers, warning systems, and composite IRCM systems (Figure 3-1).

| Systems | Jammers | Flares | Warning Systems |
|----------------|-----------------------|-----------------|-----------------------|
| <u>DIRCM</u> | <u>AN/AAQ-24</u> | <u>DIRCM</u> | <u>AN/AAR-44</u> |
| <u>LAIRCM</u> | <u>AN/ALQ-144</u> | <u>CMS</u> | <u>AN/AAR-47</u> |
| <u>SIIRCM</u> | <u>AN/ALQ-156</u> | <u>MAWS</u> | <u>AN/AAR-54</u> |
| <u>TADIRCM</u> | <u>AN/ALQ-157</u> | <u>IRCM</u> | <u>AN/AAR-57 CMWS</u> |
| <u>WIPPS</u> | <u>AN/ALQ-204</u> | <u>Matador</u> | |
| | <u>AN/ALQ-211</u> | <u>SIRFC</u> | |
| | <u>AN/ALQ-212</u> | <u>ATIRCM</u> | |
| | <u>AN/QRC-81</u> | <u>IRCM</u> | |
| | <u>AN/QRC-84 IRCM</u> | | |
| | | <u>ASTE</u> | |
| | | <u>Comet</u> | |
| | | <u>M211</u> | <u>AIRCMM</u> |
| | | <u>M212</u> | <u>AIRCMM</u> |
| | | <u>MK</u> | <u>flare</u> |
| | | <u>MJU-7A/B</u> | <u>flare</u> |
| | | <u>MJU-27/B</u> | <u>flare</u> |
| | | <u>MJU-32/B</u> | <u>flare</u> |
| | | <u>MJU-47/B</u> | <u>ASTE</u> |
| | | <u>MJU-48/B</u> | <u>ASTE</u> |
| | | <u>MJU-49/B</u> | <u>flare</u> |
| | | <u>MJU-50/B</u> | <u>AIRCMM</u> |
| | | <u>MJU-51/B</u> | <u>AIRCMM</u> |
| | | <u>MJU-52/B</u> | <u>BOL-IR</u> |
| | | <u>MJU-53/B</u> | <u>ASTE</u> |

Figure 3-1 The family of IR Countermeasures

The US military has recognized the increasing threat to its tactical aircraft from anti-aircraft IR guided missiles.

By one estimate more than 1,000,000 shoulder-fired surface-to-air missiles exist and are available on the worldwide market. The lethality and proliferation of IR surface-to-air missiles (SAMS) was demonstrated during the Desert Storm conflict. Approximately 80% of U.S. fixed-wing aircraft losses in Desert Storm were from ground based Iraqi defensive systems using IR SAMS. Both IR SAMS and IR air-to-air missiles have seekers with improved Counter-Countermeasures (CCM) capabilities that seriously degrade the effectiveness of current expendable decoys. MANPADS are the most serious threat to our large, predictable, and slow flying air mobility aircraft. These systems are lethal, affordable, easy to use, and difficult to track and counter. According to a CIA Report, MANPADS have proliferated worldwide, accounting for over 400 casualties in 27 incidents involving civil aircraft over the previous 19 years. This proliferation has forced air mobility planners to frequently select less than optimal mission routes due to lack of defensive systems on airlift aircraft.

When an aircraft has been detected, targeted, locked-on, and the missile fired, the emphasis has to shift to defeating the in-flight missile. Of course, except in the case of autonomously guided missiles, countermeasures against the ground (or hostile aircraft) tracking and command guidance system could still be effective (as in the case of conventional RF countermeasures). There are already a number of countermeasures against RF seekers.

MANPADS are shoulder launched missile systems typically include heat seeking or IR missiles and are a threat to aircraft and other types of transportation. IR missiles include an IR detector, which allows the IR missile to detect and track a target. More particularly, IR missiles detect the heat signature (i.e., infrared light) which is emitted by hot structures, for example, engines of the aircraft, to track the aircraft in an attack.

Pyrotechnic flares (Figure 3-1) are used traditionally for this purpose, but have short effective time durations. Routinely dispensing flares to draw possible MANPAD missiles away from a transport is clearly unacceptable. Dispensing flares or recoverable decoys when an attack is detected requires a sophisticated and costly missile attack sensing system. Recurring false alarms would likely cause unacceptable hazards from flares to people and property. Tethered decoys have also been proposed. Non-predeployed recoverable decoys must be deployed quickly after

receiving a warning, which places stringent requirements on the tether line and requires a complex release and recovery system. Decoys must also radiate considerable IR power, which limits operating duration or requires significant power-carrying capacity by the tether. Fueled decoys must be refueled and battery-operated decoys need to be recharged or replaced, requiring costly and time-consuming ground operations. Another issue is handling potentially hazardous materials at passenger terminals. To be effective, a passive decoy must radiate IR energy at levels comparable to or exceeding that of an airliner.

Conventional MANPAD-launched missiles include an infrared sensor that is sensitive to heat, for example the heat emitted from an aircraft engine. The missile is programmed to home in on the infrared heat signal using a steering system. Using a rotating reticule as a shutter for the sensor, the incoming heat signal is modulated, and, using the modulated signal, an on-board processor performs the calculations necessary to steer the missile to its target. Owing to its portable size, MANPAD missiles have a limited range, and a burn time of a few seconds from launch to extinguishing.

In recent years, missile guidance systems have become increasingly sophisticated, and, as a result, there are a number of different types of missiles in existence. In some embodiments, the missile is outfitted with multiple sensors that detect infrared radiation at multiple wavelengths, using reticules that are encoded at different patterns.

In view of the threat, various countermeasure techniques have become popular. A missile warning system scans the region for rocket launch signals, such as the infrared or ultraviolet signature of a rocket tail. Upon the detection of a missile launch, various countermeasure systems are activated. In one example, hot flares or chaff are released from the aircraft to confuse the infrared or radar system of the launched missile.

Other approaches broadcast light energy in order to confuse the missile infrared sensors. In one example, light energy emitted by non-coherent flashlamps is directed toward the missile sensors, in order to confuse them and render them ineffective ("jamming"). (See Jammers, Figure 3-1). IR missiles are vulnerable to IR signals which blind the IR detector of the incoming IR missile.

Conventional countermeasures to an IR missile threat include jamming systems which confuse or blind the IR missile using either IR lamps and/or IR lasers. These jamming systems transmit either a IR signal to blind the IR detector of the incoming IR missile.

The IR lamp and/or IR laser jamming systems are heavy, complex, consume a great deal of power, and require significant space. Real estate in airborne platforms, as well as in most other transportation is typically at a premium or may not be available. Further, systems using IR lasers include precise pointing and tracking devices, which are hard to implement and produce drag on an aircraft platform. Owing to their extremely high cost, such countermeasure systems have enjoyed only limited use, primarily on military aircraft. The countermeasure systems are commonly integrated into the aircraft, for example, in the fuselage, wing, or nose of the aircraft, or fixed onto an outer portion of the aircraft. Depending on where the countermeasure systems are mounted to the aircraft, they can lead to an increase in drag, reducing flight performance and increasing operating costs. Also, servicing, maintenance, upgrading and testing of the systems are expensive and time consuming procedures. In addition, such procedures require grounding of each aircraft for a period of time. What is needed is a system that may jam IR missiles and that may have reduced size, weight and power (SWAP) requirements. Also needed is a system with a

reduced time for pointing and having increased reliability and reduced drag on the aircraft platform.

The real challenge is posed by the shoulder-launched "fire and forget" type of IR guided missiles. In most cases, such missiles require lock-on prior to launch; they do not have autonomous reacquisition capability. Given an adequate hemispheric missile warning system, it is quite conceivable that the missile can be defeated in flight. One approach is to use an RF weapon (directed from the aircraft under attack, or counter-launched) to defeat the guidance electronics. For optical or IR seekers that are obviously not "in-band" to the RF weapons, a "back-door" means of coupling the RF energy into the attacking missile must be used. Such back-door mechanisms exist; however, they are notoriously unpredictable and statistically diverse, differing by orders of magnitude from missile to missile, even those of the same class, depending on the missile's maintenance history.

Rather than simply providing a second bright IR source in an attempt to draw an approaching missile away from a targeted aircraft, Directed Infrared Countermeasures systems (DIRCM) systems use beams of light, produced by a variety of means such as flashlamps, to defeat their homing mechanisms (Figure 3-2). In many MANPADS, a reticule within the seeker causes pulses of light from the target aircraft to "shine" on the missile's infrared detector. The IR detector senses the IR radiation and sends an electric signal to the guidance package, which determines the target location and allows the missile to track the target aircraft's location and movement through the sky. By shining a light towards the seeker, an IRCM system provides the infrared detector with energy and "jams" the missile, causing it to miss its intended victim. Northrop Grumman's Nemesis system is a widely-utilized flashlamp-based DIRCM system. There are more than 3,000 IRCM systems deployed world-wide that protect against infrared guided missile threats.



Figure 3-2 DIRCM (Directed Infrared Countermeasures system)

Despite the advantages that DIRCM systems have over flares, these systems have limitations that have prompted a move towards laser-based systems, such as the Navy's TADIRCM system and the Air Force's LAIRCM system. LAIRCM builds upon the NEMESIS platform but replaces the flashlamp source of IR radiation with a laser source Figure 3-3.



Figure 3-3 Viper™ laser replacement for the SLTA flash system

Another approach is to use a laser to attack the threat. For highly dynamic aircraft that can maneuver to avoid the threat, it may suffice to simply blind the missile and assume it can be avoided. Current systems confuse missiles with IR energy, making the missile wobble in flight, but not necessarily break lock.

Whereas susceptibility reduction (hit avoidance) should be regarded as the primary means of aircraft defense, optimal survivability can be achieved through an integration of susceptibility and vulnerability reduction (hit survival) techniques. Vulnerability reduction techniques are particularly important for commercial aircraft in that the use of flares and rapid G-maneuvers is not appropriate. However, some solutions may prove applicable to all aircraft and threats encountered.

The application of well thought out Modeling and Simulation can balance requirements and mitigate risks associated with complex systems. In 1995 NG engineers knew the laser was coming along; however it was not at a Technology Readiness Level of 9 (actual system “flight proven” through successful mission operations). NG built in the laser channel and in 1999-2000 the laser technology matured; by 2001 they were integrating the laser into the turret and auto bore sight. The system was fully integrated by the summer of 2002. Similar Modeling and Simulation occurred on the transition from UV to IR. Another Modeling and Simulation success story was in the development of the Viper™ laser. NG was able to show via Modeling and Simulation the 10lb Viper™ could protect the C-17 compared to a competitor’s 65lb device that was three times the cost. Without sound Modeling and Simulation, these data could not have been produced without actually building and demonstrating the devices.

3.1 Program History

| Table 3-1 LAIRCM History of Significant Events | |
|---|------|
| USAF identifies requirement to improve protection of large aircraft against IR-guided missile threats | 1998 |
| LAIRCM Phase I acquisition strategy approved by Aeronautical Systems Center ASC Commander | 2000 |
| ASC/CC approved the LAIRCM Milestone B Acquisition Decision Memorandum | 2001 |
| Award of the LAIRCM Group B contract on 28 Sep 01 to NGC for the LAIRCM Phase I program | 2001 |
| NGC to perform aircraft modification (Group A) development and integration of the LAIRCM system on C-130 aircraft | 2002 |
| AMC issued a Combat Mission Needs Statement (CMNS) for accelerated IRCM capability | 2002 |
| SAF/AQQ issued program direction to execute a LAIRCM “Lite” installation on 12 C-17 aircraft | 2002 |
| AMC identified a need to equip as many C-17s with LAIRCM protection as soon as possible | 2004 |
| SAF/AQ issued interim program direction to equip up to an additional 59 C-17s with LAIRCM “Lite” | 2004 |
| SAF/AQ approved LAIRCM Guardian™ Laser Trans Assembly (GLTA) sole source award to NGC | 2004 |
| LAIRCM SPO was designated as the LAIRCM Program Office under 516 th ASW Aeronautical Systems Wing. | 2005 |
| Air Force Acquisition Executive (AFAE) provided direction to proceed with production of the GLTA | 2007 |
| NexGen MWS Milestone C decision was made | 2008 |
| LAIRCM unfunded PDM III Study identified operational requirement for the Mobility Air Forces (MAF) | 2009 |
| Viper™ Laser 2.1 service life projected to 3500 hr MTBR | 2011 |
| LAIRCM evaluated on KC-135; pod does not interfere with refueling probe dynamics (Figure 3-4) | 2011 |



Figure 3-4 KC-135R with Aerial Refueling Boom and LAIRCM (mounted on under belly)

3.2 Evolutionary Phases

The United States Special Operations Command (USSOCOM) developed the DIRCM system to protect C-130 sized and smaller aircraft against Infrared (IR)-guided missiles. This system uses a pointer/tracker (P/T) assembly to direct flash-lamp light energy on IR-guided threat missile seekers. This technique allows for significantly higher levels of IR jam energy compared to aircraft signature to be directed on IR threats and has resulted in increased technique effectiveness. LAIRCM is shown below (Figure 3-5) on a C-17.



Figure 3-5 LAIRCM mounted on the underside of a C-17

The USSOCOM/United Kingdom (UK) DIRCM program incorporated a laser transmit path in the DIRCM P/T. With a laser installed in the DIRCM, significantly higher levels of jam energy became available. The LAIRCM program leverages and improves upon the DIRCM program by incorporating a laser onto the DIRCM small transmitter and providing the energy required for large aircraft protection. LAIRCM also uses other DIRCM components including the processor, the Control Indicator Unit, and the AAR-54 Missile Warning System (MWS). Leveraging the USSOCOM DIRCM solution enabled a near-term solution to Air Mobility Command (AMC) requirements. The LAIRCM system is a common solution for both C-17 and C-130 aircraft, providing both supportability and interchangeability benefits. LAIRCM offers increased effectiveness and growth for C-130 aircraft that could be leveraged by USSOCOM in improving the current DIRCM flash-lamp capabilities.

LAIRCM is an evolutionary acquisition program. The LAIRCM Phase I acquisition strategy was approved by the Aeronautical Systems Center Commander (ASC/CC) on 16 Aug 00, as the LAIRCM Designated Acquisition Commander (DAC) at the LAIRCM Acquisition Strategy Panel. The approved strategy included conducting a full and open competition for award of a single LAIRCM Group B system integration contract with production and sustainment options.

The LAIRCM evolutionary acquisition strategy balances AMC's documented urgent and compelling need with the ultimate goal of increased effectiveness and affordability. To accomplish this balance, the LAIRCM program is comprised of three phases:

1. Phase I is a system comprised of proven and available subsystems, previously developed under the UK/USSOCOM DIRCM program to satisfy AMC's urgent and compelling need.
2. The Phase II program provides a solution to the evolutionary requirements not fully addressed during the Phase I program. The Phase II improvements will be accomplished through spiral development to satisfy the need for increased effectiveness with improved missile warning and new jamming techniques.

3. Implementation of Phase III capabilities will be authorized as funded and directed by operational commands and SAF/AQQ. Phase III is a reliability improvement and Life Cycle Cost (LCC) reduction phase. Projects funded are the CIUR, Viper™ 2.1 and LSPR. The LAIRCM Phase I system is a derivative of the AN/AAQ-24 (V) DIRCM that was jointly developed by the UK and USSOCOM. The current LAIRCM Phase I system is being installed on AMC, AFRC, and ANG C-5/C-130/C-17/C-20/C-40, Federal Aviation Administration (FAA) Challenger, United States Army (USA) C-37 and Air Force Special Operations Command (AFSOC) CV-22/AC-130/MC-130 platforms.

The Next Generation (NexGen) MWS Phase II spiral is aimed at improving AN/AAQ-24 (V) system effectiveness by developing a new MWS. Since improved missile warning is a common requirement for both the United States Air Force (USAF) and USSOCOM, the NexGen MWS development was accomplished as a cooperative program with both agencies contributing funding. The MWS upgrade was accomplished with a competitive System Development & Demonstration (SDD) using a simulation-based acquisition approach to plan for Modeling and Simulation throughout the acquisition life cycle. As a result of a source selection, SDD contracts were awarded to both NGC and Lockheed Martin. Choosing two contractors mitigated performance and cost risk and provided potential competition for follow on production.

3.3 Acquisition History

Subsequent to Operational Requirements Document approval, AMC submitted a \$6.8 million FY01 Program Objective Memorandum initiative for LAIRCM. In Jul 99, the Chief of Staff of the Air Force (CSAF) tasked AMC and AFMC to investigate and provide an affordable solution to protect AMC aircraft. In Oct 99, ASC/CC presented a proposed LAIRCM program development and acquisition approach balancing urgency with affordability to the Secretary of the Air Force (SECAF), CSAF, and SAF/AQ. SECAF supported this proposal and presented it to the Deputy Secretary of Defense in Nov 99. In Dec 99, the Deputy Secretary of Defense approved Program Budget Decision 743, funding the first 20 AMC aircraft. In Feb 00, the President's FY01 budget included funding for LAIRCM.

The LAIRCM program was initiated as an FY01 New Start. Congressional notification occurred through the President's FY01 budget submission with inclusion of the LAIRCM program in the Research Development Test and Evaluation budget item justification for Program Element 0401130F, C-17 aircraft, Project 4886. The Source Selection Authority approved the basis for contract award, selection factors, and scope of evaluation by approving the LAIRCM Source Selection Plan (SSP) on 22 Oct 00 (further amended by SSP amendments 1 and 2 on 20 Jan 01 and 2 Sep 01, respectively).

At the 26 Mar 01 CSAF Quarterly Acquisition Program Review, CSAF expressed concern over LAIRCM affordability. CSAF tasked a reexamination of LAIRCM requirements and affordability. On 30 Mar 01, as a means to address the CSAF tasking, ASAF(A) directed a modification to the LAIRCM RFP allowing LAIRCM offerors the opportunity to submit separate alternate proposals for performance-based solutions. On 7 May 01, the LAIRCM team issued an RFP amendment authorizing offerors to submit separate alternate proposals. The Source Selection Evaluation Team completed evaluations of all baseline and alternate proposals on 7 Sep 01. On 27 Sep 01, the LAIRCM Milestone Decision Authority (MDA), ASC/CC approved the LAIRCM Milestone B Acquisition Decision Memorandum, authorizing entry into SDD. This

decision enabled award of the LAIRCM Group B contract on 28 Sep 01 to NGC for the LAIRCM Phase I program. The scope of the development effort under the NGC LAIRCM contract included developing, integrating, testing and supporting installation of LAIRCM systems on two C-17 and one C-130 aircraft during the SDD acquisition phase. The contract also included production options for LAIRCM shipsets (which are complete systems ready to be installed), spares, support equipment, C-130 modifications and installations, C-17 installation support, program management, engineering support and interim contractor support. This change to the original LAIRCM strategy was approved by the LAIRCM DAC on 15 Mar 02. The LAIRCM alternate solution was chosen by the LAIRCM DAC because it offers a high degree of commonality with the USSOCOM DIRCM program.

A separate contract modification to NGC, signed 7 Jun 02, tasked NGC to perform aircraft modification (Group A) development and integration of the LAIRCM system on C-130 aircraft. This modification took advantage of the existing C-130 design and installation performed by NGC on the DIRCM program for AFSOC C-130 aircraft. NGC subcontracted the Group A design work to Lockheed-Martin Owego, with the installations to be accomplished at Crestview Aerospace in Crestview, Florida. Crestview Aerospace, a small business concern, is Lockheed Martin's subcontractor for the C-130 LAIRCM modification. C-17 Group A development and integration of the LAIRCM system is performed by The Boeing Company Long Beach under contract to the C-17 program office Mobility Directorate (ASC/ WLM), C-17 Division, Mobility Directorate. NGC, in accordance with their Associate Contractor Agreement (ACA) with Boeing, provides C-17 installation support on a Time and Material (T&M) basis.

As part of the LAIRCM Milestone C decision, 22 Aug 02, the LAIRCM PM received MDA approval to increase the total Low Rate Initial Production (LRIP) quantity by one additional system, bringing the LRIP total to 13 LAIRCM systems. This single shipset increase was necessary to support the accelerated LAIRCM installs on the C-17. On 7 Nov 02, AMC issued a Combat Mission Needs Statement (CMNS) for accelerated IRCM capability. This mission need was approved by CSAF on 27 Nov 02.

SAF/AQQ then issued program direction to execute a LAIRCM "Lite" installation on C-17 aircraft on 13 Dec 02. LAIRCM-Lite is a C-17 program that uses a combination of laser jammers and flares due to the limited availability of LAIRCM components.

During 2003-2004, 12 C-17s were modified and fielded in the C-17 LAIRCM "Lite" configuration. In Jan 04, AMC identified a need to equip as many C-17s with LAIRCM protection as soon as possible. In May 04, the LAIRCM System Program Office (SPO) proposed an extension to the existing Quick Reaction Capability being fielded under the Nov 02 CMNS. This extension proposed equipping up to 59 additional C-17s with LAIRCM "Lite." SAF/AQ and CSAF concurred with this plan. In Nov 04, SAF/AQ issued interim program direction to equip up to an additional 59 C-17s with LAIRCM "Lite" using a combination of existing C-17 funds and other funds that might be made available and directed for this purpose. In Sep 04, Congress approved an above threshold reprogramming to field 18 additional C-17 LAIRCM "Lite" systems.

On 9 Nov 04, SAF/AQ approved LAIRCM Guardian™ Laser Transmitter Assembly (GLTA) Class Justification and Authorization for other than Full and Open Competition for the GLTA acquisition program to award sole source contracts to NGC, Defense Systems Division,

Rolling Meadows, IL. On 18 May 07, the Air Force Acquisition Executive (AFAE) provided direction to proceed with production of the GLTA and to have this effort managed by the Air Force Program Executive Officer for Aircraft (AFPEO/AC). Within 1 week, the LAIRCM Program Office) awarded NGC an initial production contract for 56 GLTAs.

In Dec 04, ASC/CC was designated as the Air Force Program Executive Officer for Aircraft (AFPEO/AC), reporting directly to ASAF (A) for management of the LAIRCM program. In Feb 05, the LAIRCM SPO was designated as the LAIRCM Program Office under the 516th Aeronautical Systems Wing. On 18 Apr 05, AFPEO/AC approved entrance of LAIRCM Phase I into FRP. Phase I production by LAIRCM Program Office includes installation on AMC C-17, C-130, C-5, and C-40 aircraft; AFSOC MC-130; AFRC and ANG C-130s; FAA and Foreign Military Sales aircraft; and other aircraft as directed and funded. In addition, derivative LAIRCM systems are being acquired by other procurement agencies for USA C-37, USSOCOM CV-22 and MH-53, UK C-17, and Australian AF Wedgetail (DIRCM Direct Commercial Sales) aircraft.

The NexGen MWS Milestone B decision was made in Jun 04 and the NexGen MWS Milestone C decision was made May 08. The NexGen sensor achieved a FRP decision under the DoN LAIRCM program no further milestone decisions are required by the Air Force. On 11 May 06, LAIRCM Program Office awarded a 5-year, \$3.2 billion Indefinite Delivery Indefinite Quantity (IDIQ) contract to NGC. The IDIQ contract includes Firm Fixed Price (FFP), Cost Plus Fixed Fee, T&M, and Cost Reimbursement (CR) type contract line items in support of acquisitions for the following: LAIRCM systems, aircraft modification kits, aircraft modifications and system installations, aircraft integration support, studies and analyses, spares, support equipment, technical data, training courses, field support, repairs, contractor systems engineering/program management, hardware and software design, and engineering changes including production incorporation of spiral developments. The type of contract utilized is appropriate for the efforts involved (e.g., high-risk and development activities will use CR, production will use FFP, investigative studies and support activities such as interim contractor support will use T&M contract types).

3.4 Test and Evaluation (T&E) Overview

The baseline Phase I LAIRCM system Developmental Test & Evaluation (DT&E) has been successfully completed. These test results provided the data needed to perform an Operational Assessment (OA) in FY02 and to certify readiness for Initial Operational Test and Evaluation (IOT&E) in FY04. LAIRCM Phase I IOT&E was completed by the Air Force Operational Test and Evaluation Center (AFOTEC) on C-17 aircraft (Feb-Mar 04) and on C-130 aircraft (Jun-Jul 04). The AFOTEC final report rated LAIRCM as “Effective and Suitable” with all Critical Operational Issues rated as Satisfactory. The GLTA successfully accomplished live missile fire tests between May-Jun 06 and flight tests between Sep-Oct 06 on a C-17. AFOTEC performed an OA and submitted a report in early 07.

Throughout NexGen MWS SDD performance, assessments were accomplished using a variety of test assets with the overall effectiveness evaluation being digital simulation. A live missile firing test (May-Jun 06) and a C-130 flight test (Aug-Sep 06) were successfully completed for both SDD systems. A production NexGen system has been selected and installed on a C-17; this aircraft has undergone integration testing at Edwards AFB (Sep-Oct 09). In an effort to determine whether to use active cooling or passive cooling of the NexGen MWS sensors, a C-17 thermal test was conducted at Yuma Marine Corps Air Station (MCAS), Yuma,

AZ in Jul07 and Jul 09. Based on analysis of test results, LAIRCM Engineering has elected to accept the low risk associated with passive cooling options.

3.5 Interfaces with Other Programs

During Phase I, the LAIRCM system was being installed on C-17 and C-130 aircraft. The aircraft Group A provisions designed and developed to accommodate the LAIRCM Group B components must be properly interfaced with and integrated. Cockpit Working Groups (CWG) were established for both the C-17 and C-130. In the case of the C-17, "Boeing performed install locations (of the LAIRCM display) before NGC was under contract and didn't really know where things belonged and how they were used," according to NGC's Dave Snodgrass. As a result, the LAIRCM control indicator unit display in the C-17 had to be mounted down and to the left of the pilot in the C-17. The pilot cannot see it directly without turning and looking down. In addition, because of its design (the top surface had a raised knob and a flap that opened and accepted the User Data Module card) and location, flight deck personnel often stepped on the unit which affected its reliability and operation. The CIU has now been redesigned (see Figure 2-5), the surface is flat and it incorporates texted information incorporated on a small screen.

Currently in the C-17 there is an indication with a tiny display just beneath the glare shield that simply lights the word acronym MSL (which stands for "missile") on both the pilot's and the co-pilot's sides of the flight deck. This indicates to the pilots that LAIRCM has been activated and performing its function. Also, some aircraft, like the C-130 have elected to have an audio alert that says "missile launched" to give further indication, but the C-17 community has elected to not use that feature, according to the ASC LAIRCM Program Office.

The C-17 Group A design and development portion of the program was accomplished by the C-17 original equipment manufacturer, The Boeing Company. The C-17 Division placed Boeing under contract for this activity in Jan 02. Two C-17 aircraft were modified and tested with the LAIRCM system as part of this contract. A C-17 Group A modification and installation contract was awarded to Boeing in FY03 to modify and install the LAIRCM system on 10 additional C-17 aircraft and in FY05 Boeing was awarded another contract to install LAIRCM on an additional 18 aircraft (total C-17 installs). The LAIRCM Program Office continues to contract for and execute procurement of additional LAIRCM systems and support equipment for C-17 aircraft as LAIRCM Program Office receives funds from the C-17 Division. The C-17 Division continues to contract for C-17 Group A and aircraft modifications.

Since the C-17 Group A development was contracted separately to The Boeing Company (C-17 manufacturer), a strong relationship between NGC (the LAIRCM Group B developer) and The Boeing Company was built through an Associate Contractor Agreement (ACA). This is a contract requirement in both contracts, ensuring the LAIRCM Group B and C-17 Group A contractors share interface and integration information, and builds a high degree of confidence that installed LAIRCM performance will meet AMC operational needs. This approach also builds strong IPT relationships.

The LAIRCM C-130 Group A acquisition strategy changed to contract with NGC for accomplishing the C-130 Group A design and development, with options for production installation since NGC was responsible for the original C-130 DIRCM design and installation. This strategy change offered significant cost and schedule savings and reduced risk for the LAIRCM program.

NGC performed the C-130 Group A design and development effort for LAIRCM. This approach was chosen due to the commonality with USSOCOM ongoing design and installation on similar C-130 aircraft. This commonality enables the LAIRCM Program Office to leverage existing C-130 installation designs developed by NGC for the USSOCOM DIRCM program and apply them to the C-130 LAIRCM installation. This strategy change saved the USAF \$12.5 million, completed the C-130 design and trial installation portion of the LAIRCM program 22 months earlier, and offered significantly lower risk due to use of an existing, approved, and proven design.

For all future aircraft types, the LAIRCM acquisition strategy is for the aircraft modification contractor (Group A) and the LAIRCM Group B contractor to establish an ACA, share aircraft interface and integration data, and jointly plan the aircraft ground, flight, and acceptance tests. This approach was used with the C-5. In Jan 05, LAIRCM Program Office began working to integrate LAIRCM onto the C-5 using a similar approach as C-17 integration, utilizing an ACA between Lockheed-Martin (C-5 manufacturer) and NGC (the LAIRCM Group A developer).

The ASC/WL Mobility Directorate and USSOCOM Special Operations Acquisition and Logistics Center Program Executive Officer (PEO) for Fixed Wing have a Program Specific Memorandum of Agreement (PSMOA) for the NexGen Acquisition Program. Under this PSMOA, NexGen will be jointly funded and LAIRCM Program Office will lead this joint team in the development, test, and acquisition of NexGen MWS.

To motivate the contractor during the Phase I development program, the contract with NGC successfully employed an incentive fee profit arrangement. As the program has evolved to a production-oriented phase with a stable baseline configuration, these incentives are no longer required. In addition, on-going upgrades and enhancements to the technical baseline of the system are modest in scope, when compared to the development program, with clearly understood objectives and low-to-moderate technical risk. This type of development is suitable for other than incentive fee profit strategies; to include both fixed-fee and award-fee structured contracts. Contractor performance is motivated through the Contractor Performance Assessment Report and continued justifiable opportunities for sole-source contracts.

3.6 NexGen MWS Business Strategy

For the Phase II NexGen MWS effort, LAIRCM Program Office awarded two SDD contracts—one to NGC and one to Lockheed Martin respectively. Choosing two offerors mitigated cost, schedule and performance risk, and provided potential competition for the follow-on production phase. The SDD contract type was Cost-Plus Incentive Fee (CPIF) for both. CPIF contracts were appropriate for this acquisition considering the desired outcome and the risks identified to achieving that outcome while providing each contractor with some level of cost control incentive.

The LAIRCM DT&E for GLTA and NexGen MWS and future programs consists of Analysis, Measurements, M&S, Production Qualification Testing, Performance Verification Testing, HITL testing, uninstalled SIL testing, open-air range testing, live missile fire testing, and acceptance testing. The integrated tests are designed to identify any anomalies in the system and to establish LAIRCM installed performance. Developmental testing (DT) includes SIL, HITL, live missile fire, and installed LAIRCM performance.

The LAIRCM Phase I program has completed Milestone C and is in FRP. Spiral developments will be accomplished in parallel with FRP. Changes will be phased into production as they become available.

3.7 Evolutionary Acquisition Objectives

LAIRCM Phase I program objectives include:

- Maximize use of non-developmental items to field a self-protection capability as soon as possible.
- Meet AMC ORD Annex (a subset of LAIRCM ORD) requirements for a Phase I LAIRCM system.
- Develop, test, and integrate the Phase I LAIRCM system on two C-17 and one C-130 aircraft during an SDD acquisition phase.
- Produce, support, modify, and deliver additional C-17 and C-130 LAIRCM protected aircraft as soon as possible following the SDD acquisition phase until Phase II production begins.
- Reduce cost and improve reliability of the LAIRCM Laser Transmitter Assembly.
- Plan an affordable, incremental upgrade path (Phase II) to protect additional AMC aircraft and meet remaining ORD requirements.
- The procurement of Group B hardware to support installation on the C-5, C-17, C-37, C-40, C-130, C-130J, AMC, AFRC, ANG, and FAA aircraft, and to accomplish installation of Group B onto FMS and C-130 aircraft based upon approved funding and direction.

LAIRCM Phase II program objectives include incremental upgrades to:

- Improve the LAIRCM system's probability of declaring threat missiles beyond the AMC ORD Annex requirements to meet the basic Multi-Command ORD 314-92 requirements.
- Develop, test, and integrate additional techniques for the LAIRCM Phase I and Phase II systems to extend countermeasure capability beyond the AMC ORD Annex Tier I threat requirements to meet the basic Multi-Command ORD 314-92 requirements.
- Develop, test, and integrate the Phase II LAIRCM system onto additional aircraft as directed by AMC, USSOCOM/AFSOC and other appropriate agencies (i.e., USA, USN, DHS, etc).
- Group B hardware to support installation on the C-5, C-17, C-37, C-40, C-130, C-130J, AMC, AFRC, ANG, FAA and FMS aircraft based upon approved funding.

3.8 Source Selection Strategy

3.8.1 FRP-Indefinite Delivery Indefinite Quantity (IDIQ)

For follow-on production, ASC/WLYE has direction from SAF/AQQ to install LAIRCM on up to 444 AMC aircraft as congressional funding is appropriated. ASC/WLYE will execute contracts to procure LAIRCM configurations for the approved LAIRCM configuration baseline for LAIRCM installations on platforms to include: C-17, C-130 variants, C-130J, C-5, C-40, C-37, KC-135, KC-10, RC-135, E-8C, Army, Navy, Marine Corps (platforms as specified and funded by the services), and FMS aircraft. ASC/WYL will procure LAIRCM equipment for

other government agencies, as approved by the Program Executive Officer (PEO), to include the DHS and FAA.

This contract with NGC has been negotiated and provides for acquisitions in support of the overall AN/AAQ-24(V) LAIRCM program on an IDIQ basis for a 5 year period. The IDIQ contract has a ceiling value of \$3.2B. This IDIQ contract is the primary vehicle used to acquire the items set forth in the Justification and Approval (J&A) for Other Than Full and Open Competition.

IDIQ acquisitions provided for include the following: LAIRCM systems/subsystems, aircraft modification kits, hardware and software design, aircraft modification design, aircraft modification, system installation, aircraft integration support, studies and analyses, spares, support equipment, technical data, logistics support, training courses, contractor systems engineering/program management support, hardware and software design, and engineering changes including production incorporation of spiral developments. The predominant contracting activity under the IDIQ contract is expected to be procurement of LAIRCM Group B hardware.

3.8.2 Phase III

Phase III will implement modernization activities driven by reliability and LCC issues.

3.9 Risk Management

The LAIRCM program office Risk Management Process is documented in an RMP. This replaces an informal process that included reviews of program risks associated with cost, schedule, and performance. The RMP includes a process to check status and to track program risks and to establish risk management metrics.

The RMP serves to identify possible risk items early and to aid in developing mitigation plans. Once identified, technical risks will be closely monitored and closure plans assessed to ensure proper, cost-effective risk management, mitigation, or elimination. Risks will be cross correlated into the categories of cost, schedule, and performance where the impact is most likely to occur.

Once risks are identified, rated, and categorized, mitigation metrics will be prepared and progress will be periodically measured.

ASC/CC policy memorandum #06-016, 3 Oct 06, requires performance of an annual integrated risk assessment and that all serious or high risk hazards be reported to the PEO or AFAE. There are no serious or high risk hazards identified for the LAIRCM program, as confirmed by the annual assessment.

3.9.1 LAIRCM Program Risk

The LAIRCM program has already overcome the originally predicted program risks with laser development and aircraft integration. The major technical risks remaining concern the performance and integration of the Phase II development efforts.

3.9.1.1 Laser Development Risk

During FY02, USSOCOM experienced cost growth due to the need to resolve performance issues traceable to the ViperTM laser design. To mitigate risk to the LAIRCM contract and program, ASC/WLYE transferred \$2M to USSOCOM's DIRCM program office to help fund the

cost growth proposal to complete the Viper™ laser development. In addition, the LAIRCM contract modification for reliability growth testing of the Viper™ laser to identify inherent design, process, or parts problems reduced the risk of the laser development and production transition. Finally, through monitoring NGC Laser Systems efforts to continue to improve the manufacturing processes associated with the Viper™ laser, the LAIRCM program office significantly reduced risk in this area. These efforts have mitigated the cost and schedule risk of Viper™ laser development and production risk.

3.9.1.2 Aircraft Integration Risk

The primary technical risk the program overcame was LAIRCM integration on the C-17; this risk did not exist on the C-130 since NGC had already accomplished DIRCM installation on the C-130. The C-17 installation was a new design and the key risk in the integration was the location of the LAIRCM CIU, or Control Indicator Unit (Fig 2-4). As discussed in Section 3.5, LAIRCM came along after the cockpit displays had already been designed and installed in the C-17. There was no readily available real estate for the CIU. A small indicator under the glare shield of both the pilot and co-pilot indicates when a missile has been detected by LAIRCM. Another design risk involves the C-17 vibration environment, particularly for the tail cone installation of the LAIRCM SLTA.

Vibration risk reduction testing on a C-17 was conducted in Jun 02; all vibration levels and increased drag were found acceptable. Integration risks remain for integration of subsequent platforms (e.g. C-5, C-40, and C-130J).

3.9.2 NexGen MWS Program Risk

The overall risks associated with the NexGen MWS acquisition are assessed as low, based on extensive market research, and multiple testing opportunities included in the SDD program. The AIRCM program team participated in a Risk Assessment Workshop in 2003 with ASC Acquisition Center of Excellence personnel, senior center advisors, a cross-functional team from the program office, and the operational customer. Of the 103 potential risks identified during the workshop, no risks were identified as high and only three risk areas were identified as issues requiring mitigation. The primary program risk drivers include:

- Development of a NexGen MWS DSM and integration of the DSM with environment models resulting in digital simulations – now complete.
- The installed NexGen MWS system meets aircraft spatial coverage requirements without the need for additional sensors and additional aircraft modifications.

3.9.3 GLTA Program Risk

The overall risks associated with the GLTA acquisition are assessed as low since the GLTA is currently in production.

3.9.4 Engineering and Technical Risk Mitigation

3.9.4.1 Systems Engineering Approach

As stated in the foreword to this Case Study, systems engineering includes making key system and design trades early in the process to establish the system architecture. In the case of the displaced CIU for LAIRCM in the C-17, the technology simply came along after the controls and panels had been designed for the aircraft. As a result, the display is not in direct sight of the

pilot. Not everything can be placed front and center of the pilots. This has been somewhat resolved by the installation of a small missile indicator display under the glare shield which the pilots may perceive depending on their cockpit workload.

Modeling and simulation are generally employed to organize and assess architectural alternatives at the introductory stage of a program. The ViperTM laser was modeled, simulated, and then demonstrated by NGC that it could successfully protect the C-17. Good systems engineering was also demonstrated when NGC “pre-plumbed” the laser channel for LAIRCM prior to the completed development of the laser module, anticipating its integration into LAIRCM at a future date. This forward planning resulted in cost and schedule savings while meeting performance standards.

Important to the efficient decomposition and creation of the functional and physical architectural designs of a system like LAIRCM are the management of interfaces and integration of subsystems. However, successful design, development and production are not always enough to sustain a system throughout its life cycle. Sound Human Systems Integration applied early in the program can help mitigate disasters later on. Sound systems engineering was applied to the upgrade of the transmitter/tracker system. In 1995 NG engineers knew the ViperTM laser was coming along however it was not at a TRL of 9. NG built in the laser channel and in 1999-2000 the laser technology matured and by 2001 they were integrating the laser into the turret and auto bore sight. The A kits fit into the old B slots. NG had both function and fit. There was no cost to modify the aircraft for their kit to fit in the slot provided. NG’s secret was they built their system to stand alone so it did not have to interface with the a/c mission computer. The system was fully integrated by the summer of 2002. Similar planning occurred on the transition of the MWS from UV to IR.

Excessive turnover of Air Force Systems Program Office personnel lead to a breakdown of communications with AMC and NGC and led to impacts to the program cost, schedule, and performance. In the LAIRCM program, the constant Air Force turnover was dramatic in the eyes of the contractor. There was a gradual degradation of the relationship NGC had with the SPO. Because of the inefficiency in the SPO due to constant personnel turnover, NGC felt SOCOM funding for LAIRCM was jeopardized. The new SPO team lost about 1-yr of executing the program due to schooling up time and learning the ropes. Since 2009 the LAIRCM technical philosophy is one of having a government/contractor team functioning under a single, unified system engineering approach. This approach is centered on the following premises:

- NGC is responsible for development of the LAIRCM system as documented in the LAIRCM system specification. NGC is also responsible for minimizing any impacts to other aircraft subsystems/systems when integrated.
- The Boeing Company, Long Beach is responsible for design and development of LAIRCM Group A provisions on the C-17 aircraft in accordance with the LAIRCM Group B ICD. They are also responsible for minimizing any Group A impacts to the LAIRCM Group B performance, as tested and verified against the LAIRCM system specification.
- NGC is responsible for design and development of LAIRCM Group A provisions on the C-130 aircraft in accordance with the LAIRCM Group B ICD. NGC is responsible for minimizing any Group A impacts to the LAIRCM Group B performance, as tested and verified against the LAIRCM system specification.

- Lockheed-Martin is responsible for design and development of LAIRCM Group A provisions on the C-5 aircraft in accordance with the LAIRCM Group B ICD. They are also responsible for minimizing any Group A impacts to the LAIRCM Group B performance, as tested and verified against the LAIRCM system specification.
- Comprehensive subsystem/system-level testing to verify system performance and ensure qualification to the aircraft operating environments.

The IPT will use the contractor's technical performance measures to assess progress and manage the requirements established in the system specification.

Installed LAIRCM functional performance was verified and validated by the contractor/government test team, including Boeing for the C-17 and NGC for the C-130, during C-17 and C-130 ground and flight testing. Once the C-5/LAIRCM design is established, the necessary installation and performance characteristics will be verified and validated. The C-5, C17, and C-130 program offices are responsible for weapon system OSS&E on their respective platforms.

3.9.4.2 Configuration Management

ASC/WLYE controls the configuration of LAIRCM at the system specification level. Each aircraft platform (i.e., C-17, C-130) maintains aircraft configuration management. The LAIRCM contractor managed the configuration and controlled the allocated and product baselines during development and continues to do so during production. During on-aircraft integration and test activities, the Government retains approval authority for all configuration changes. Sustainment accomplished by contractor depot support will continue for the foreseeable future. Efforts are underway to determine the long-term strategy for sustainment as discussed in paragraph 3.9.4.4 below.

3.9.4.3 Modeling and Simulation (M&S)

M&S has been the principal means of verification of LAIRCM subsystem and system performance. Reliance on HITL simulation facilities is the primary means to verify the performance of the laser jamming subsystem against the system specification. Facilities such as the Air Force Electronic Warfare Evaluation Simulator in Fort Worth TX and the Guided Weapons Evaluation Facility at Eglin AFB FL allow thousands of missile engagements to be performed, in a cost effective manner, using actual LAIRCM laser hardware in these HITL facilities, results in statistically relevant verification testing, not possible or affordable in any other method of test. The performance verification of the LAIRCM missile warning subsystems will rely on contractor digital models used in design verification tests (DVT) and HITL tests. Reliance on the LAIRCM Group B contractor's SIL validates missile warning handoff accuracy and tracking accuracy prior to flight testing.

3.9.4.4 Sustaining the LAIRCM

The sustainment of the LAIRCM will be formally transitioned to WR-ALC Robins AFB, GA, in 2016. The Air Force's plan for sustainment differs from that of the Navy. The Navy has a "cradle-to-grave" philosophy on a system's lifecycle. One advantage of this approach, according to contacts at WR-ALC, is the Navy plans the sustainment of a weapon system up front during the initial planning for a program. The Air Force philosophy of transitioning systems to the sustainers after Milestone C is proper planning and funding to sustain the system has been problematic in that the sustainers have been left out of the early planning and funding to sustain

the system being short-changed. The WR-ALC personnel saw an advantage to the Navy's single manager concept especially after Milestone C. The private/public 50/50 sharing of depot level maintenance (10 USC 2466) was also discussed at the WR-ALC with respect to LAIRCM. This rule requires doing at least 50 percent depot maintenance in-house using organic government organizations. As a result, contractors can then perform only the remaining 50 percent. The purpose of the code is to assure a core logistics capability for the government. The rule has led to some awkward arrangements at WR-ALC. In one case, government personnel have to be escorted by NGC personnel into areas of NGC-proprietary equipment at WR-ALC.

Data rights and data possession for LAIRCM sustainers was also discussed. The USAF requested data rights but not data possession on LAIRCM. As a result, the Air Force does not own the data and then must go sole source to NGC for the data it never requested from the program start which drives up the cost. In addition, LAIRCM data provided to WR-ALC is not at a Level III which is what is required to perform depot maintenance. Early planning by the stakeholders could have alleviated many of these problems.

3.9.4.5 Program Management

As mentioned in 3.9.4.1 excessive turnover of SPO personnel can lead to a breakdown of communications with the customer and contractor and lead to program impacts. The LAIRCM program is now on a 5-yr IDIQ. Estimates are the latest SPO team lost about 1-yr of executing the program due to schooling up time and learning the ropes. In addition, FMS programs (e.g. with Germany) have jeopardized the program schedule.

3.10 Summary/Conclusion

The requirement for LAIRCM surfaced in 1998 (LAIRCM ORD AMC/ACC/AFSOC #314-92 3 Aug 98). The Air Force identified a requirement to protect its large vulnerable aircraft from IR-guided missile threats. LAIRCM is the primary DoD system for protecting large aircraft from the widespread and growing threat of MANPADS, shoulder-fired and mobile launched surface-to-air missiles. LAIRCM provides an effective solution to defeating IR threats which saves aircraft and, more importantly, lives. Major customers include AMC, ANG, AFRC, AFSOC, C-5, C-17, C-20, C-37, C-40, C-130 variants, the Navy, CV-22, SOCOM, and FMS.

The LAIRCM program has been a spiral development with Phase I delivering a laser-based system developed by the UK in concert with USSOCOM that met AMC's urgent need. Phase II resulted in an improved system that was highly effective in countering MANPADS. LAIRCM is a MANPADS/IR SAM solution, not universal IR missiles, which is a much larger spectrum.

Well applied Modeling and Simulation demonstrated LAIRCM's ability to counter IR threats. NGC was able to demonstrate the laser-based LAIRCM before the first Viper™ system was ever produced. NGC employed sound systems engineering in its spiral development of LAIRCM. They were able to design and fit their Viper™ laser-based system into the same hole in the aircraft older generation flash-lamp based system was housed. NGC also installed common LAIRCM units on different aircraft which allowed maintainers the ability to "scab" units from one aircraft for use on a higher priority aircraft, for example.

Human Systems Integration of LAIRCM came about long after the C-17 had been designed and developed. As a result, the cockpit display for LAIRCM had to be installed out-of-view of the pilots. The LAIRCM system is autonomous. The C-17 pilots do receive an indication of its operation on small indicators under the glare shield; however, the cockpit indicator display is not

front-and-center since it came about long after the instrument panel had been designed. C-130 pilots rely on an audible warning of missile launch.

Excessive turnover of the Air Force Systems Program Office (SPO) personnel led to a breakdown of communications with the customers and contractors and led to impacts to program cost, schedule, and performance. The nuisance effect of the constant Air Force personnel turnover was dramatic in the eyes of the contractor. There was a gradual degradation of the relationship NGC had with the SPO. Because of the inefficiency in the SPO due to constant personnel turnover, NGC felt SOCOM funding for LAIRCM was jeopardized.

LAIRCM is now operational on over 500 aircraft in the USAF, Navy, Army, FAA, and Foreign Air Forces. Current plans are to install it on over 900 AMC aircraft (by FY 2020). LAIRCM continues to defeat threats posed against AMC aircraft. Modernization efforts are ongoing to support reliability and maintainability improvements with lower ownership costs. The system will continue to be improved and provide protection to both materiel and lives.

Appendix A: A Framework for Systems Engineering Concept and Responsibility Domains

| Concept Domain | Responsibility Domain | | |
|--|------------------------------|--------------------------|------------------------------|
| | 1. Contractor Responsibility | 2. Shared Responsibility | 3. Government Responsibility |
| A. Requirements Definition and Management | | | |
| B. Systems Architecting and Conceptual Design | | | |
| C. System and Subsystem Detailed Design and Implementation | | | |
| D. Systems and Interface Integration | | | |
| E. Validation and Verification | | | |
| F. Deployment and Post Deployment | | | |
| G. Life Cycle Support | | | |
| H. Risk Assessment and Management | | | |
| I. System and Program Management | | | |

This Friedman-Sage matrix is included as an exercise for the student. Following the explanation in Section 1.5 of this Case Study develop 4-6 systems engineering learning principles from the case study and then insert them into the matrix based on whether they were a contractor responsibility, a government responsibility, or a shared responsibility between the government and the contractor.

Appendix B: Author Biography

William Albery, Ph.D. is the Chief Scientist of Innovative Technologies Corporation (ITC) in Dayton, Ohio. He is a retired 36-year civilian (U.S. Air Force) who technically managed the Wright Patterson AFB human centrifuge facility. From 2005-2008, he was the Crew Interface Systems Engineer on the Air Force Research Laboratory's Rotary-Wing Brownout (RWB) study. In 2007, he organized and led a North Atlantic Treaty Organization (NATO) RTO Task Group on RWB that has 9 countries and 20 scientists/engineers and pilots participating. He received his Bachelor of Science degree in Systems Engineering from Wright State University (WSU) in 1971, his Masters Degree in Biomedical Engineering from The Ohio State University (OSU) in 1976 and his Doctorate (PhD) in Biomedical Sciences from WSU in 1987. He is an Associate Professor in the WSU School of Medicine, a Fellow of the Aerospace Medical Association, a Fellow of the Aerospace Human Factors Association, current President of the Aerospace Human Factors Association and past President of the SAFE Association. Dr. Albery was a co-author for the AFIT MQ-1/9 Case Study and the author of a Case Study for the C-17. He was the lead author on the MH-53J/M Case Study <http://www.afit.edu/cse/cases.cfm?case=26&a=detail> and the E-10 Case Study <http://www.afit.edu/cse/cases.cfm?case=28&%20a=detail> also for the AFIT Center for Systems Engineering.

Appendix C: Acronyms

| | |
|----------|--|
| ACA | Associate Contractor Agreement |
| ACAT | Acquisition Category |
| ACM | Aircraft Characterization Module |
| ADM | Acquisition Decision Memorandum |
| AESG | Aeronautical Systems Group |
| AESS | Aeronautical Systems Squadron |
| AESW | Aeronautical Systems Wing |
| AF | Air Force |
| AFAE | Air Force Acquisition Executive |
| AFCAA | Air Force Cost Analysis Agency |
| AFFTC | Air Force Flight Test Center |
| AFI | Air Force Instruction |
| AFMC | Air Force Materiel Command |
| AFOTEC | Air Force Operational Test and Evaluation Center |
| AFPEO/AC | Air Force Program Executive Officer for Aircraft |
| AFRC | Air Force Reserve Command |
| AFROC | Air Force Requirements Oversight Council |
| AFRL | Air Force Research Laboratory |
| AFSOC | Air Force Special Operations Command |
| AMC | Air Mobility Command |
| AMC/A5 | Air Mobility Command Requirements Group |
| ANG | Air National Guard |
| APB | Acquisition Program Baseline |
| ASAF (A) | Assistant Secretary of the Air Force for Acquisition |
| ASC | Aeronautical Systems Center |
| ASE | Aircraft Survivability Equipment |
| ATIRCM | Advanced Threat Infrared Countermeasure |
| BIT | Built-in-Test |
| CBSG | Combat Sustainment Group |
| CBSS | Combat Sustainment Squadron |
| CCB | Configuration Control Board |

| | |
|-----------|--|
| C-E LCMC | Communications-Electronics Life Cycle Management Command |
| CFR | Code of Federal Regulation |
| CIU | Control Indicator Unit |
| CIUR | Control Interface Unit Replacement |
| C-MANPADS | Counter Man Portable Air Defensive Systems |
| CMNS | Combat Mission Needs Statement |
| CMWS | Common Missile Warning System |
| CPFF | Cost Plus Fixed Fee |
| CPI | Critical Program Information |
| CPIF | Cost-Plus Incentive Fee |
| CR | Cost Reimbursement |
| CSAF | Chief of Staff of the Air Force |
| CTA | Center Test Authority |
| DAC | Designated Acquisition Commander |
| DRB | Deficiency Review Board |
| DCMA | Defense Contract Management Agency |
| DES | Directed Energy Solutions |
| DHS | Department of Homeland Security |
| DIRCM | Directional Infrared Countermeasures |
| DMSMS | Diminishing Manufacturing Sources and Material Shortage |
| DMS/OPR | Diminished Manufacturing Source/Obsolete Parts Replacement |
| DoD | Department of Defense |
| DoS | Department of State |
| DOT&E | Director of Operational Test & Evaluation |
| DT | Developmental Testing |
| DT&E | Developmental Test & Evaluation |
| DVT | Design Verification Test |
| ECP | Engineering Change Proposal |
| EOM | Electro-optical Modules |
| ESOH | Environmental, Safety, and Occupational Health |
| EVMS | Earned Value Management System |
| EW | Electronic Warfare |
| FAA | Federal Aviation Administration |

| | |
|--------|---|
| FAR | Federal Acquisition Regulation |
| FCA | Functional Configuration Audit |
| FMS | Foreign Military Sales |
| FFP | Firm Fixed Price |
| FRACAS | Failure Reporting and Corrective Action System |
| FRP | Full Rate Production |
| FTS | Fine Track Sensor |
| FY | Fiscal Year |
| GFE | Government Furnished Equipment |
| GFP | Government Furnished Property |
| GLTA | Guardian™ Laser Tracker Assembly |
| HAZMAT | Hazardous Material |
| HITL | Hardware in-the-Loop |
| HMMPP | Hazardous Material Management Program Plan |
| HoS | Head of State |
| HSI | Human System Integration |
| IBIT | Initiated Built-in-Test |
| IBO | Industrial Base Office |
| ICE | Independent Cost Estimate |
| ICS | Interim Contractor Support |
| ID/IQ | Indefinite Delivery/Indefinite Quantity |
| IMP | Integrated Master Plan |
| IMS | Integrated Master Schedule |
| IOT&E | Initial Operational Test and Evaluation |
| IPT | Integrated Product Team |
| IR | Infrared |
| IRCM | Infrared Countermeasures |
| ISO | International Organization for Standardization |
| ISP | Intelligence Support Plan |
| ITA | Integrated Threat Assessment |
| ITT | Integrated Test Team |
| IUID | Item Unique Identification |
| JRMET | Joint Reliability Maintainability Evaluation Team |

| | |
|--------|--|
| KPP | Key Performance Parameter |
| LAF | LAIRCM Acquisition Follow-on |
| LAIRCM | Large Aircraft Infrared Countermeasures |
| LCC | Life Cycle Cost |
| LCMP | Life Cycle Management Plan |
| LIDAR | Light Detection and Ranging |
| LOA | Letter of Offer and Acceptance |
| LOD | Letter of Determination |
| LRIP | Low Rate Initial Production |
| LRU | Line Replaceable Unit |
| LSPR | LAIRCM System Processor Replacement |
| L/TA | Laser Transmitter Assembly |
| M&S | Modeling and Simulation |
| MAF | Mobility Air Forces |
| MDA | Milestone Decision Authority |
| MEON | Multi-Role Electro-Optical End-To-End |
| M-Sig | Missile Signature |
| MIR | Medium Infrared |
| MTBR | Mean Time Between Removal |
| MUDM | Maintenance User Data Module |
| MWS | Missile Warning System |
| MXW | Maintenance Wing |
| NAIC | National Air Intelligence Center |
| NATO | North Atlantic Treaty Organization |
| NexGen | Next Generation |
| NGC | Northrop Grumman Corporation |
| NSN | National Stock Number |
| OA | Operational Assessment |
| OEM | Original Equipment Manufacturer |
| ORD | Operational Requirements Document |
| OSD | Office of the Secretary of Defense |
| OSS&E | Operational Safety, Suitability, and Effectiveness |
| OT | Operational Testing |

| | |
|--------|---|
| OT&E | Operational Test and Evaluation |
| PBL | Performance Based Logistics |
| PCMCIA | Personal Computer Memory Card International Association |
| PEO | Program Executive Officer |
| PESHE | Programmatic Environment, Health Evaluation |
| PM | Program Manager |
| PMD | Program Management Document |
| POM | Program Objective Memorandum |
| POE | Program Office Estimate |
| PPP | Program Protection Plan |
| PSMOA | Program Specific Memorandum of Agreement |
| P/T | Pointer/Tracker |
| PTA | Pointer Tracker Assembly |
| PTO | Participating Test Organization |
| OPF | Operational Flight Program |
| QCL | Quantum Cascade Lasers |
| QE | Quiet Eyes™ |
| R&D | Research and Development |
| RAM | Reliability, Availability, and Maintainability |
| RDT&E | Research, Development, Test & Evaluation |
| RF | Radio Frequency |
| RFP | Request for Proposal |
| RMP | Risk Management Process |
| SAF | Secretary of the Air Force |
| SBIR | Small Business Innovative Research |
| SCG | Security Classification Guide |
| SDD | System Development & Demonstration |
| SECAF | Secretary of the Air Force |
| SEP | Systems Engineering Plan |
| SERD | Support Equipment Requirement Document |
| SIL | Software Integration Laboratory |
| SLTA | Small Laser Transmitter Assembly |
| SOCOM | Special Operations Command |

| | |
|------------|---|
| SORAP | Source of Repair Assignment Process |
| SP | System Processor |
| SPO | System Program Office |
| SRU | Shop Replaceable Unit |
| SSEWG | System Security Engineering Working Group |
| SSM | System Support Manager |
| SSP | Source Selection Plan |
| STC | Supplemental Type Certificate (FAA) |
| SWEAP | Secure Web-based Electronic Acquisition Program |
| T&E | Test and Evaluation |
| T&M | Time and Material |
| TED | Threat Environment Description |
| TEMP | Test and Evaluation Master Plan |
| TO | Technical Order |
| TPWG | Test Planning Working Group |
| TSP | Transition Support Plan |
| TW | Test Wing |
| UDM | User Data Module |
| UID | Unique Identification |
| UK | United Kingdom |
| US | United States |
| USA | United States Army |
| USAF | United States Air Force |
| USD (AT&L) | Office of Secretary of Defense for Acquisition Technology and Logistics |
| USG | United States Government |
| USN | United States Navy |
| USSOCOM | United States Special Operations Command |
| UV | Ultraviolet |
| VDATS | Versatile Depot Automated Test Stations |
| WR-ALC | Warner Robins Air Logistics Center |

Appendix D: References

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