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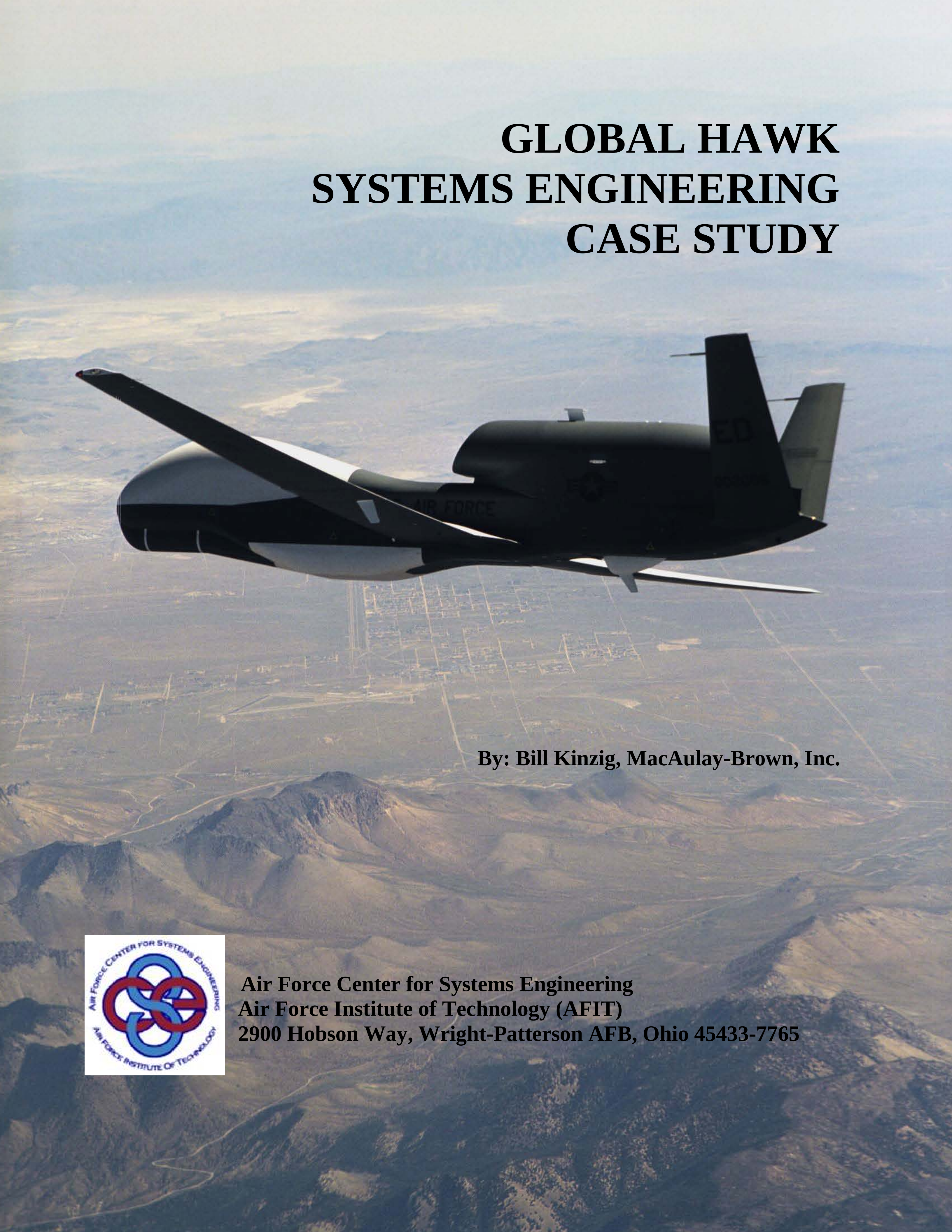
Global Hawk Systems Engineering Case Study

Air Force Center for Systems Engineering

Bill Kinzig
MacAulay-Brown, Inc.



GLOBAL HAWK SYSTEMS ENGINEERING CASE STUDY

By: Bill Kinzig, MacAulay-Brown, Inc.

Air Force Center for Systems Engineering
Air Force Institute of Technology (AFIT)
2900 Hobson Way, Wright-Patterson AFB, Ohio 45433-7765

FORWARD

At the direction of the former Secretary of the Air Force (SAF), Dr. James G. Roche, the Air Force Institute of Technology (AFIT) established an Air Force Center for Systems Engineering (AFCSE) at its Wright-Patterson Air Force Base (WPAFB), Ohio, campus in 2002. The AFCSE was tasked to develop case studies focusing on the application of systems engineering principles within various aerospace programs. The intent of these case studies was to examine a broad spectrum of program types and a variety of learning principles using the Friedman-Sage Framework to guide overall analysis. In addition to this case, many other studies are available at the AFCSE web site, such as:

- Global Positioning System (GPS) (space system)
- Hubble Telescope (space system)
- Theater Battle Management Core System (TBMCS) (complex software development)
- F-111 Fighter (joint program with significant involvement by the Office of the Secretary of Defense [OSD])
- C-5 Cargo Airlifter (very large, complex aircraft)
- B-2 Bomber (cutting edge stealth, structures, and flight controls)
- A-10 Attack Aircraft (competitive development of critical technologies)
- Peacekeeper (Intercontinental Ballistic Missile [ICBM])

These cases support academic instruction on systems engineering within military service academies and at both civilian and military graduate schools, as well as training programs in industry. Each case study is comprised of elements of success, as well as examples of systems engineering decisions that, in hindsight, were not optimal. Both types of examples are useful for learning. Plans exist for future case studies focusing on various space systems, additional aircraft programs, munitions programs, joint Service programs, logistics-led programs, science and technology/laboratory efforts, and a variety of commercial systems.

The Department of Defense (DoD) continues to develop and acquire joint complex systems that deliver needed capabilities to our warfighters. Systems engineering is the technical and technical management process that focuses explicitly on delivering and sustaining robust, high-quality, affordable products. The Air Force leadership has collectively stated the need to mature a sound systems engineering process throughout the Air Force.

As we uncovered historical facts and conducted key interviews with program managers and chief engineers, both within the Government and those working for the various prime and subcontractors, we concluded that today's systems programs face similar challenges. Applicable systems engineering principles and the effects of communication and the environment continue to challenge our ability to provide a balanced technical solution. We look forward to your comments on this case study and the others that follow.

GEORGE E. MOONEY, SES
Director, Air Force Center for Systems Engineering
Air Force Institute of Technology

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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 Stated Government.

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Bill Kinzig

TABLE OF CONTENTS

LIST OF FIGURES

1. SYSTEMS ENGINEERING PRINCIPLES

1.1 General Systems Engineering Process

1.1.1 Introduction

The Department of Defense (DoD) continues to develop and acquire joint military service weapon systems and deliver the 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 stakeholders 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 from identified gaps in mission-level capabilities to 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 disciplined 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 life-cycle 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. Secondly, 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 and balanced and 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 systems 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 (INCOSE), Electronics Industrial Association (EIA), Institute of Electrical and Electronics Engineers (IEEE), and various 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. 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.

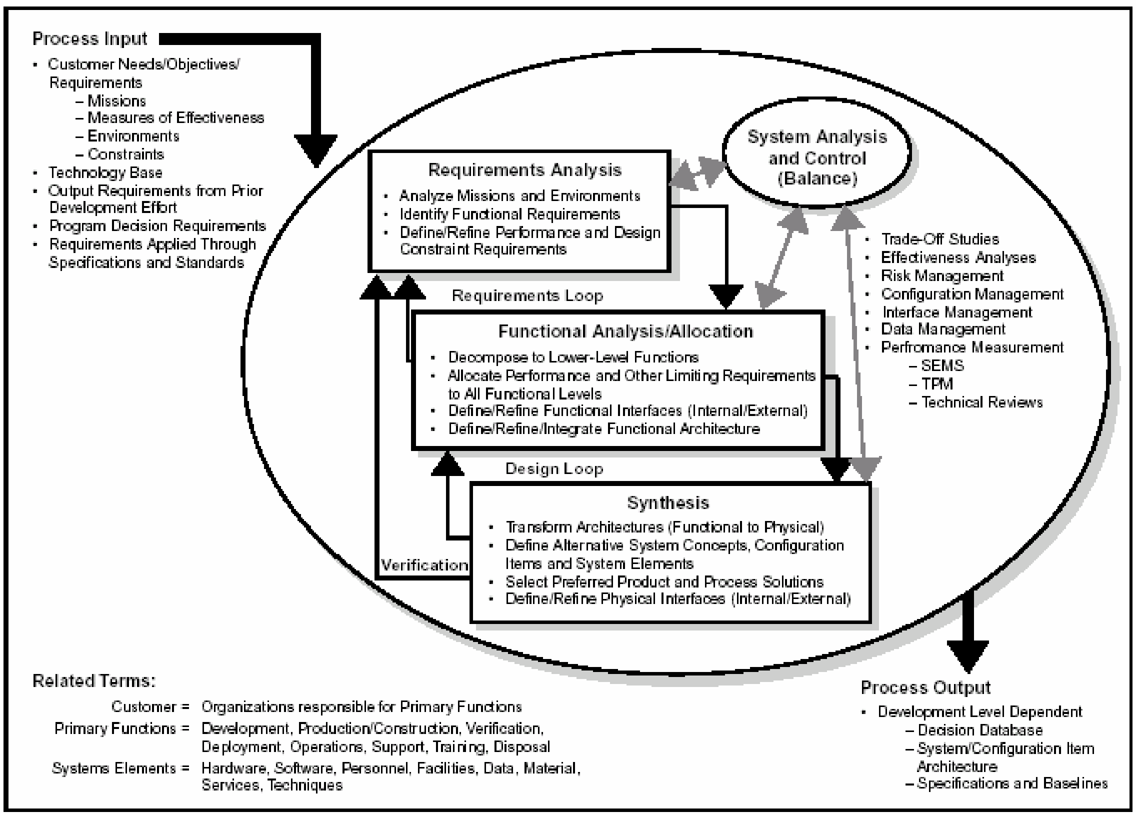


Figure 1. *The Systems Engineering Process as presented by the Defense Acquisition University.*

1.1.2 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 aircraft and other weapons 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. However, the cost and schedule performance records of the past programs are fraught with examples of some well-managed programs and programs with less than stellar execution. As the nation entered the 1980s and 1990s, large DoD and commercial acquisitions were overrunning costs and running behind schedule. The aerospace industry and its organizations were becoming larger and more geographically and culturally distributed. The systems engineering process, as applied within the confines of a single system or single company, was no longer the norm.

Today, many factors overshadow new acquisitions, including system-of-systems (SoS) context, network-centric warfare and operations, and rapid growth in information technology (IT). For example, with SoS, a group of independently operated systems are interdependently related within and across all lanes of the interoperability to effectively support an overarching objective. These factors have driven a new form of emergent systems engineering, which focuses on certain aspects of our current process. One of these increased areas of focus resides in the architectural definitions used during system analysis. This process is differentiated by greater reliance on reusable architectural views describing the system context and Concept of Operations (CONOPS), interoperability, information and data flows, and network service-oriented characteristics. The DoD has recently made these architectural products, described in the DoD Architectural Framework (DoDAF), mandatory to enforce this new architecture-driven, systems engineering process throughout the acquisition life-cycle.

1.1.3 Case Studies

The systems engineering process to be used in today's complex SoS projects is a process matured and founded on the principles of systems developed in the past. The examples of systems engineering used in other programs, both past and present, provide a wealth of lessons to be used in applying and understanding today's process.

The purpose of developing detailed case studies is to support the teaching of systems engineering principles. Case studies 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 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 is emphasized. Analysis of these aspects will provide the student with real-world, detailed examples of how the process plays a significant role in balancing cost, schedule, and performance.

The utilization and misutilization of systems engineering principles are 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, including determining if:

- Every system provides a balanced and optimized 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.
- Effective major technical program reviews were conducted.
- Continuous risk assessments and management was implemented.
- Reliable cost estimates and policies were developed.
- Disciplined application of configuration management was demonstrated.
- System boundaries were well-defined.
- Disciplined methodologies were developed for complex systems.
- Problem-solving methods incorporated understanding of the system within a bigger environment (customer's customer).

The systems engineering process translates an operational need into a set of system elements. These system elements are allocated and translated by the systems engineering process into detailed requirements. The systems engineering process, from the identification of the need to the development and utilization of the product, must continuously integrate and optimize system and subsystem performance within cost and schedule to provide an operationally effective system throughout its life cycle. Case studies highlight the various interfaces and communications to achieve this optimization, which include:

- The program manager/systems engineering interface, which is essential between the operational user and developer (acquirer) 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, and
- 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, known and unknown, as well as internal and external. This objective specifically focuses on external factors and the impact of uncontrollable influences, such as actions of Congress, changes in funding, new instructions/policies, changing stakeholders or user requirements, or contractor and Government staffing levels.

Lastly, the systems engineering process must respond to mega-trends in the systems engineering discipline itself, as the nature of systems engineering and related practices vary with time.

1.1.4 Framework for Analysis

This case study is presented in a format that follows the learning principles specifically derived for the program, using the Friedman-Sage Framework to organize the assessment of the application of the systems engineering process. The framework and 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 framework presents a nine-row by three-column matrix shown in Figure 2.

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			

Figure 2. *Framework of Key Systems Engineering Concepts and Responsibilities.*

Six of the nine concept domain areas in Figure 2 represent phases in the systems engineering life cycle:

Requirements Definition and Management

Systems Architecting and Conceptual Design

Detailed System and Subsystem Design and Implementation

Systems and Interface Integration

Validation and Verification

System Deployment and Post Deployment

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

Life-cycle Support

Risk Management

System and Program Management

While other concepts could have been identified, the Friedman-Sage Framework suggests that these nine are the most relevant to systems engineering in that they cover the essential life-cycle processes in systems acquisition and systems management support in the conduct of the process. Most other concept areas identified during the development of the matrix appear to be subsets of one of these areas. 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 contractor.

The Friedman-Sage Matrix is not a unique systems engineering applications tool, but rather a disciplined approach to evaluate the systems engineering process, tools, and procedures as applied to a program. The Friedman-Sage Matrix is based on two major premises as the founding objectives:

1. In teaching systems engineering, case studies can be instructive in that they relate aspects of the real world to the student to provide valuable program experience and professional practice to academic theory.

2. In teaching systems engineering in DoD, there has previously been little distinction between duties and responsibilities of the Government and industry activities. More often than not, the Government role in systems engineering is the role of the requirements developer.

1.2 Global Hawk Major Learning Principles and Friedman-Sage Matrix

The authors' selection of learning principles and Friedman-Sage Matrix are reflected in the Executive Summary of this case (separate attachment).

2. Global Hawk Descriptions

2.1 Mission

The Global Hawk is an advanced intelligence, surveillance, and reconnaissance air system composed of a high-altitude, long-endurance unmanned air vehicle (UAV) and a common ground segment (CGS) for command, control, and data collection. Its primary mission is to provide overt, continuous, long-endurance, all-weather, day/night, and near-real-time, wide-area reconnaissance and surveillance. The air vehicle is coupled with an integrated ground-based Mission Control Element (MCE) and Launch and Recovery Element (LRE) that monitors autonomous flight and facilitates-aided control of the air vehicle, when required.

The Global Hawk system consists of the aircraft, payloads, data links, ground stations, and logistics support package. The ground stations have the ability to provide command and control (C2) of up to three vehicles and at least one air vehicle payload from a single ground station.

The Global Hawk system is to be employed at the Joint Forces Command request for a variety of missions according to the Air Force-developed CONOPS. The system is capable of near-real-time transmission of collected data, meaning that information is delayed only by the time required for electronic processing, communication, and vehicle mechanical response. The air vehicles are supported by transportable ground stations equipped with both line-of-sight (LOS) and beyond-LOS communications for vehicle C2, health and status monitoring, and sensor data transmissions. Collected data are transmitted to a Common Imagery Ground Surface System (CIGSS) for archiving, post-processing, exploitation, and dissemination via direct transmission or terrestrial networks. Once deployed in-theater, the Joint Forces Air Component Commander apportions the Global Hawk, as required. Figure 3 depicts a top-level overview of the system's operational architecture.

2.2 Global Hawk System

The Global Hawk system is comprised of three elements: Air Vehicle, Common Ground Station, and Support System. The production Global Hawk system has been evolved using a spiral development approach that feeds a block build approach. The prime contractor for the Global Hawk system is Northrop Grumman. As this study will show, the configuration of the Global Hawk system has changed significantly over time.

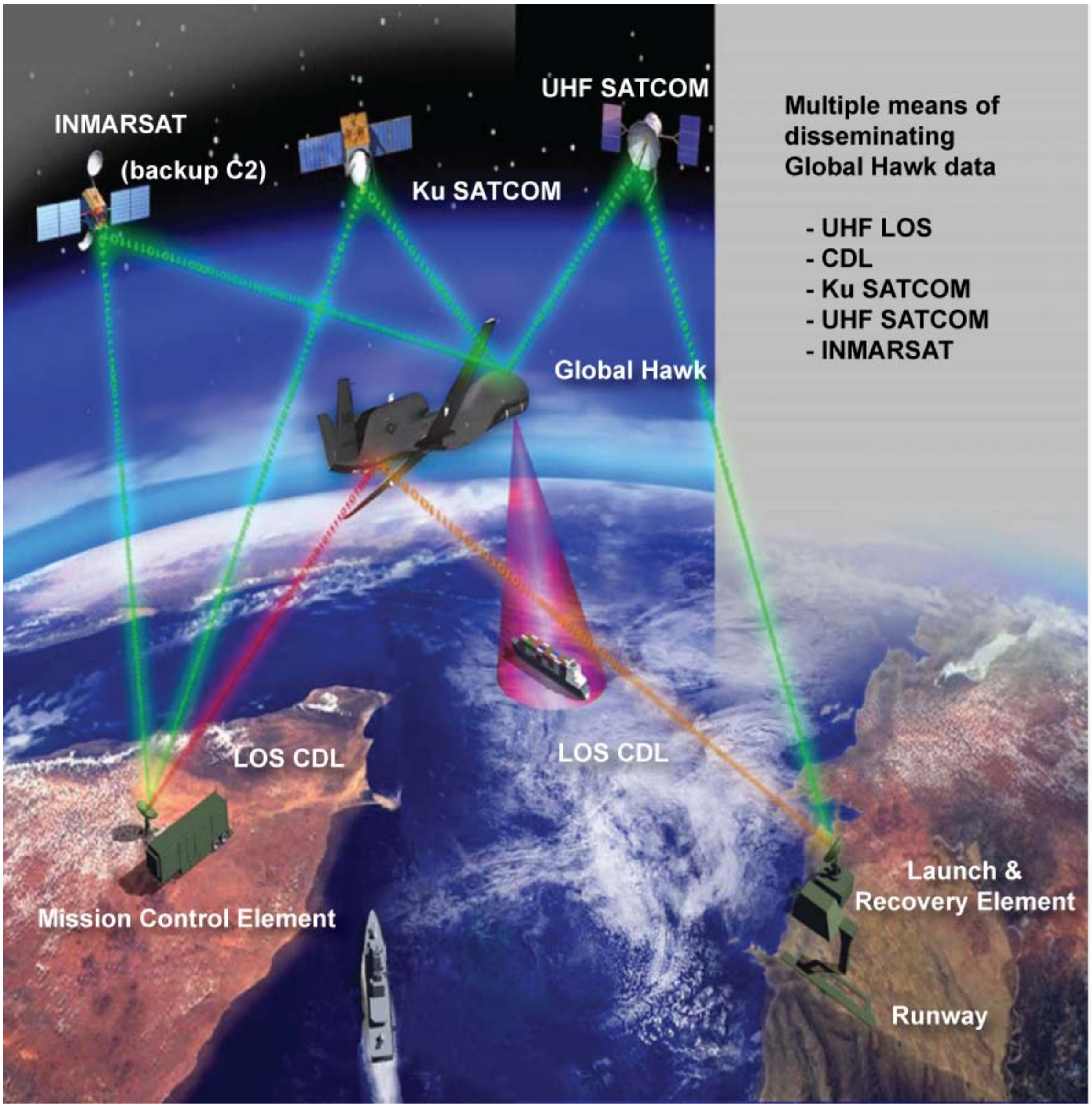


Figure 3. Global Hawk Integrated System[1]

2.2.1 Air Vehicle

The Air Vehicle consists of the airframe and avionics/flight control elements. In addition, the Air Vehicle contains an Airborne Integrated Communication System that enables C2 of the air vehicle and its payload, health and status monitoring, raw data and product transfer, and other communication functions, such as those required by the Global Air Traffic Management (GATM) mandates.

[1] Global Hawk Concept to Combat, Bob Ettinger, National Defense Industry Association 24thAnnual National Test & Evaluation Conference, 28 February 2008, Chart 5

2.2.1.1 *Airframe*

The wings and tail of the Global Hawk are made of graphite composite material. The V-configuration of the tail provides a reduced radar and infrared signature. The wings have structural hard points for external stores. The aluminum fuselage contains pressurized payload and avionics compartments.

The nose gear, which is a derivative of the F-5 design, is height adjustable to suit the runway characteristics. The landing gear automatically retracts at an altitude of 4,000 feet. An electric generator system supplies 25 kilo-volt-amperes (KVA) of AC electrical power.

Each Global Hawk is equipped with a single AE 3007H turbofan engine supplied by Rolls-Royce North America. The engine is mounted on the top surface of the rear fuselage section with the engine exhaust between the V-shaped tails.

One of the more significant changes to the RQ-4A (Block 10) Global Hawk configuration involved increasing the air vehicle payload from 2,000 lbs to 3,000 lbs. The reason was to incorporate increased capabilities associated with the sensor system. This change, which was put on contract in March 2002, resulted in a larger air vehicle. The larger air vehicle was dubbed the RQ-4B and was incorporated as part of Block 20. Figures 4 and 5 compare the differences between the two air vehicles.

Figure 4. *External Configuration of RQ-4A versus RQ-4B.*

Characteristics	RQ-4A	RQ-4B
Wingspan	116 ft	130.9 ft
Length	44 ft	47.6 ft
Height	15.2 ft	15.3 ft
Weight	11,350 lbs	14,950 lbs
Maximum Takeoff Weight	26,750 lbs	32,250 lbs
Fuel Capacity	15,400 lbs	17,300
Payload	2,000 lbs	3,000 lbs
Speed	340 knots	310 knots
Range	9,500 nautical miles	8,700 nautical miles

Figure 5. *Major Differences between RQ-4A and RQ-4B*[2]*.*

2.2.1.2 *Sensors*

The main thrust of the air vehicle changes over time has involved the sensors. Figure 6 depicts the major sensor evolution. Block 0 refers to the Advanced Concept Technology Development (ACTD) air vehicles; Block 10 to the initial production air vehicles; and Block 20 through 40 to the larger production air vehicles with the increased payload.

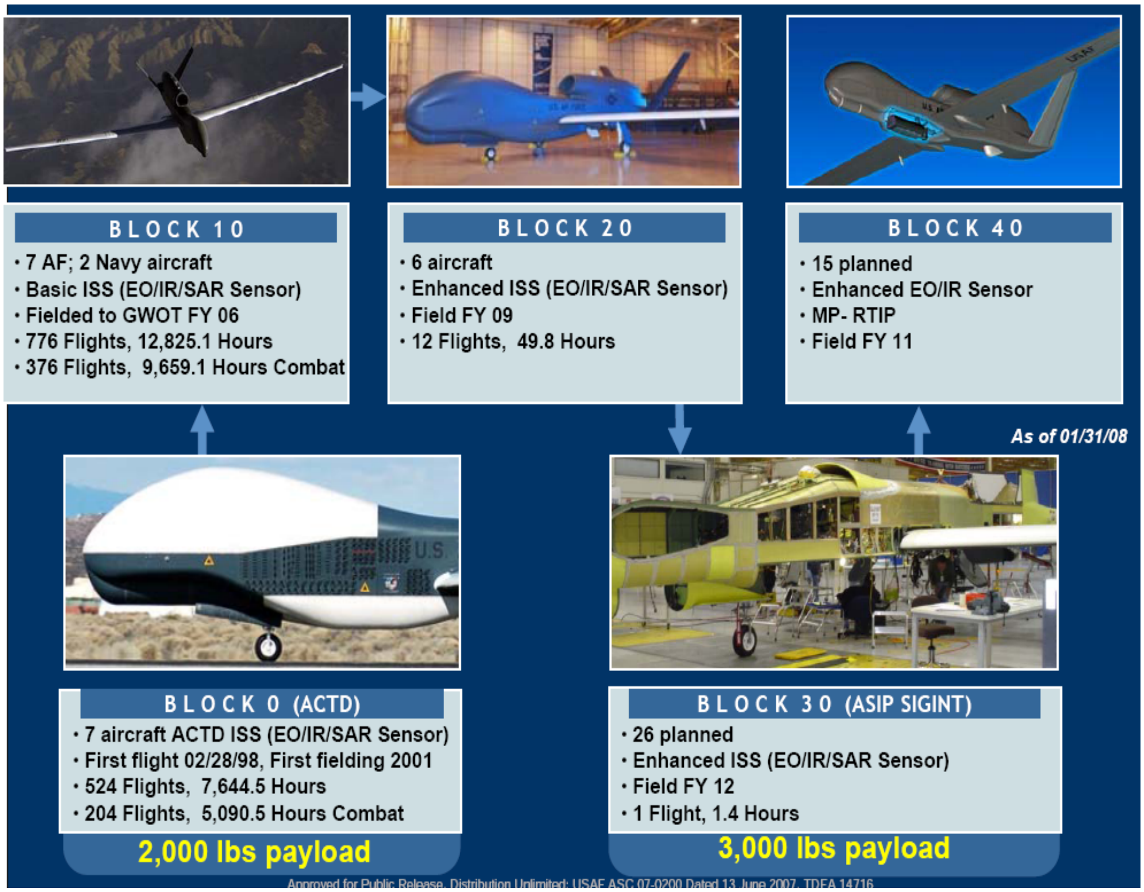


Figure 6. *Sensor Development.*[3]

[2] Factsheets: RQ-4 Global Hawk Unmanned Aircraft System, Air Force Link, October 2008
[3] Global Hawk Concept to Combat, Bob Ettinger, National Defense Industry Association 24th Annual National Test and Evaluation Conference, 28 February 2008, Chart 3

Raytheon Space and Airborne Systems supplies the Global Hawk Integrated Sensor Suite (ISS) that includes the Synthetic Aperture Radar (SAR) and infrared sensor system.

Raytheon also supplies the Enhanced Integrated Sensor Suite (EISS), which improves the range of both the SAR and infrared system by approximately 50 percent. Figure 7 is a cutaway of the air vehicle, showing the ISS locations.

Northrop Grumman is the prime contractor, with Raytheon as the major subcontractor, for the Air Force Multi-Platform Radar Technology Insertion Program (MP-RTIP). MP-RTIP is an active, electronically scanned array radar that can be scaled in size for different platforms. Three MP-RTIP systems are being built for Global Hawk and three for the E-10A Multi-sensor Command and Control Aircraft (MC2A). The first Global Hawk with the MP-RTIP is scheduled for delivery in 2011.

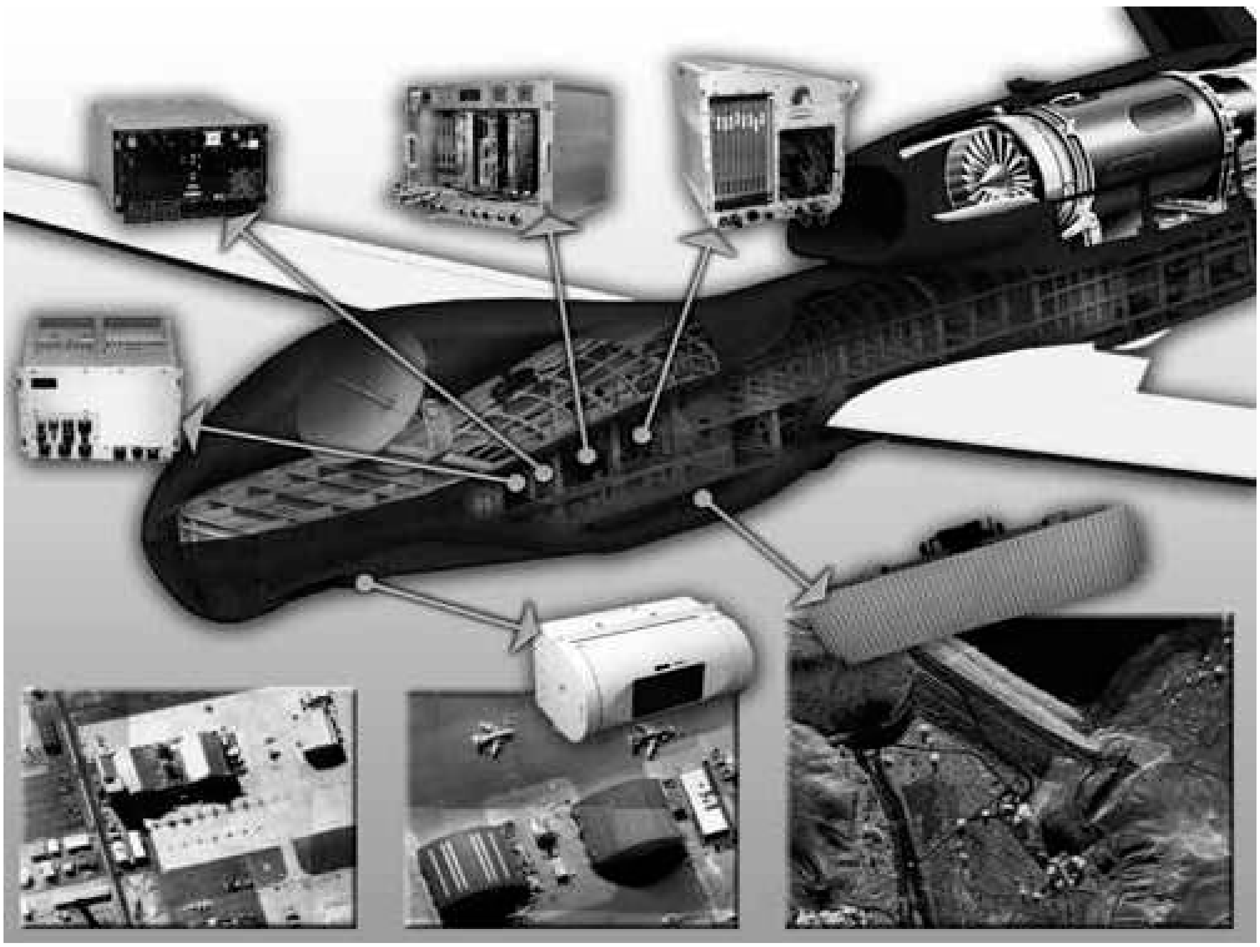


Figure 7. *Cutaway of Global Hawk Showing Integrated Sensor Suite Locations*[4]

[4] Transitioning an ACTD to an Acquisition Program, Col. G. Scott Coale, Defense AT&L, September-October 2006, Page 9

2.2.1.3 *Flight and Navigational Control*

The air vehicle's flight control and navigation functions are managed by two Integrated Mission Management Computers that integrate data from the navigation system. The prime navigation and control system consists of two Inertial Navigation System/Global Positioning System (INS/GPS) systems. The aircraft is flown by entering specific way points into the mission plan. Way points can be changed in flight, as necessary. No joystick is used in flying the air vehicle. A computer mouse is used to modify the flight control mode to alter flight operation.

2.2.2 Common Ground Segment

The CGS coordinates data requests for the mission, prepares and executes the mission plan, and performs any mission re-tasking during a flight. It supplies digital near-real-time, high-quality imagery to the warfighter for combat situational awareness. The CGS consists of two elements: LRE and MCE (see Figure 8).

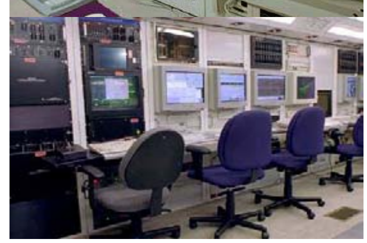
Mission Control Element (MCE)

Launch and Recovery Element (LRE)

CGS = MCE & LRE

Figure 8. Common Ground Segment

The LRE is located at the air vehicle base. It launches and recovers the air vehicle and verifies the health and status of the various onboard systems. During launch and recovery, it is responsible for air vehicle control, coordination with local and en route traffic facilities, and handoff of the air vehicle to the MCE. The element has the capability to C2 multiple air vehicles.



The MCE serves as the cockpit during the operational portion of a mission. C2 data links provide the ground crew with complete control of the air vehicle. From this station, the pilot can communicate with outside entities, such as air traffic controllers, airborne controllers, and ground controllers, to coordinate the mission. The MCE is responsible for the mission elements that include flight, communication, sensor processing, and mission payload control. If necessary, the pilot can land the aircraft at any location provided in the mission plan.

2.2.3 Support Segment

The Support Segment provides the resources to: a) prepare the Global Hawk system for operation; b) accomplish post-operation refurbishment; c) maintain the system to conduct training exercises; d) package the system for deployment; and e) set up the system at a deployed location. It includes the spares, support equipment, training systems, technical orders (TOs), etc., which are required to maintain the aircraft, train the personnel, and operate the air vehicle.

3. Global Hawk Program

3.1 Historical Background

Much of the 20th century is dotted with examples of UAVs. UAVs were first mentioned in *Jane's All the World's Aircraft* in 1920. The earliest noteworthy UAV was the A. M. Low's Aerial Target first tested on July 6, 1917. The vehicle was intended to be a target drone used for anti-aircraft training. It was very basic but provided an example of the potential value of unmanned vehicles. Unfortunately, testing was prone to mechanical failures, and the program was canceled before its true usefulness could be demonstrated.


RADIOPLANE OQ-2A (GVG / PD)

UAVs were tested during World War I but were never used by the United States. However, the technology progressed, and UAVs did play a role in World War II with the OQ-2 Radioplane being the first mass produced UAV for the United States military. Reginald Denny and his partners began designing the OQ-2 target drone in 1938, and, in 1940, the Army awarded them a contract. By war's end, 15,000 had been delivered and promptly destroyed during anti-aircraft training.[5] Likewise, Germany's use of the V-1 "flying bomb" laid the groundwork for post-war concept exploration.

The first real use of UAVs by the United States in a combat reconnaissance role began during the Vietnam War. UAVs, such as the AQM-34 Firebee developed by Teledyne Ryan, were used for a wide-range of missions, such as intelligence gathering, decoys, and leaflet dropping. Even though the loss rate of the UAVs was reasonably high, they were still preferred over the use of manned vehicles.


Ryan BQM-34 "Firebee"
USAF Museum

The Israeli Air Force pioneered several UAVs in the late 1970s and 1980s. In 1982, United States observers noted Israel's use of UAVs in Lebanon and persuaded then Navy Secretary John Lehman to acquire a UAV capability for the Navy. Interest continued to grow in other elements of the Pentagon, and the Reagan Administration increased the UAV procurement in the fiscal year (FY)87 budget submission. This act marked the transition of UAVs in the United States from experimental to acquisition. One of the UAVs acquired by the Navy was the RQ-2 Pioneer. It was developed jointly by AAI Corporation and Israeli Aircraft Industries and became a very useful air vehicle


RQ-2 Pioneer

[5] Unmanned Aerial Vehicles in the US Military, Donald Myers, Illinois Institute of Technology

during Desert Storm for collecting tactical intelligence. The Navy battleships used the Pioneer to locate Iraqi targets for their 16-inch guns.

Figure 9 is a brief summary of the UAV evolution over the course of the 20th century. By the early 1990s, UAVs had shown their worth and began earning a tactical role in our military plans of operation. However, past UAV programs were historically plagued by cost growth, schedule slips, and technical shortfalls. Examples included the Army's Lockheed Aquila that was canceled in the late 1980s and the Teledyne Ryan BQM-145A that was canceled in 1993. The cause of the poor track record in the United States is unclear. One theory is that the UAVs never had the universal support of the operational user ("silk scarf syndrome"). If you couple this with the cost overruns and lack of an integrated DoD vision, UAVs had a difficult path forward.

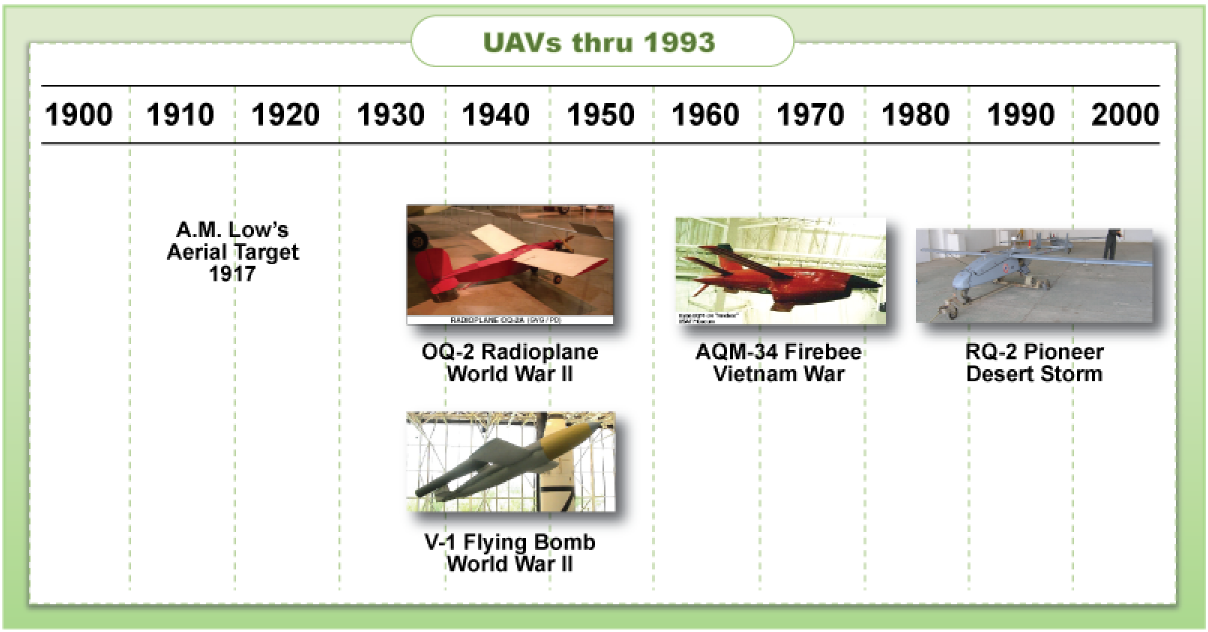


Figure 9. *Noteworthy Unmanned Air Vehicles (UAVs) Through 1993*

In 1988, Congress directed the consolidation of DoD UAV program management and formed the UAV Joint Program Office (JPO). In July 1993, the Joint Requirements Oversight Council (JROC) endorsed a three-tier approach in acquiring UAVs:

Tier I	Quick Reaction Capability
Tier II	Medium Altitude Endurance
Tier III	Full Satisfaction of the Mission Need Statement

Tier I and II were pursued through the Gnat 750 and Predator programs. After a brief study, the Defense Airborne Reconnaissance Office (DARO) replaced the Tier III approach with a parallel Tier II+/Tier III- approach. Tier II+ would be a conventional high-altitude endurance vehicle, while Tier III- would be a low observable vehicle.

3.2 Advanced Concept Technology Development (ACTD) Phase

3.2.1 Original Acquisition Strategy

The requirement for a Global Hawk type of system grew out of Operation Desert Storm and the Air Force's need to find mobile SCUD missiles. The Services all agreed that an air vehicle was needed that could loiter at high altitude and provide extended surveillance of a given target area. This need was substantiated by several post-Desert Storm reviews, including those conducted by the Air Force Scientific Advisory Board and Defense Science Board. In response to the JROC three-tier approach for developing UAVs, the DARO formed the High Altitude Endurance (HAE) UAV Program Office. The office was chartered with developing a family of unmanned reconnaissance vehicles meeting the objectives of the modified Tier II+/Tier III- approach discussed in Paragraph. 3.1 above.

DARO sponsored the program but assigned program management responsibility to the Defense Advanced Research Projects Agency (DARPA) for the initial phases of ACTD. The Air Force was a participating organization with the intent of assuming program management responsibility for the final phases. The Memorandum of Understanding (MOU), which established the program, clearly stated that the effort would focus not only on development of the two systems (Tier II+ and Tier III-) but also on management issues that often plagued past programs. The MOU also required that the program be managed by a JPO having a DARPA Program Director supported by both an Air Force and Navy Deputy Director. The intent was to ensure the buy-in of both the Air Force and Navy, thus integrating the development efforts, a concern previously expressed by Congress. Later within ACTD, an Army Deputy Director was also included in the JPO. The United States Atlantic Command (USACOM) was identified as the user and was responsible for assessing military utility before the start of Phase III. USACOM was also designated as a participant in program reviews and a partner in developing the CONOPS.

The HAE program was comprised of two separate air vehicles designated as Tier II+ and Tier III-. The Tier II+ configuration would be a conventional UAV capable of simultaneously carrying both a SAR and Electro-Optical/Infrared (EO/IR) sensor suite. It was intended to compliment or replace the aging U-2 fleet. The Tier III- would be a low observable configuration capable of carrying either a SAR or EO/IR suite. Figure 10 is a summary of the performance objectives for each configuration, as defined in the initial HAE ACTD management plan.

As this case study unfolds, it will be shown that the Tier II+ program became known as the Global Hawk, and the Tier III- became known as DarkStar. Since this case study focuses on the Global Hawk, the study will address DarkStar only as it impacts the Global Hawk program.

Characteristics	Tier II+	Tier III-
On-Station Lotier (hours)	24	>8
Operating Radius (miles)	2000 – 3000	>500
Loiter Altitude (ft msl)	60,000 – 65,000	>45,000
True Air Speed (knots)	300 – 375	>250
Takeoff Weight (lb)	15,000 – 27,000	8500
Survivability Measures	Threat Warning, ECM, Decoys	Low Observable
Sensor Payload	SAR, GMTI and EO/IR	SAR or EO
Sensor Payload Weight (lb)	1000 – 1500	1000

Figure 10. *High Altitude Endurance (HAE) Performance Objectives*[6]

The strategy for the HAE UAV Tier II+ program involved four phases, as depicted in Figure 11. Phases I through III represented the ACTD program which was to be completed between October 1994 and December 1999, with Phases II and III running concurrently for six months in 1997. Phase IV represented production. No Engineering and Manufacturing Development (EMD) was originally planned.

> **Phase I:** A six-month effort in which three teams conducted a System Objective Review and Preliminary System Specification Review
>
> **Phase II:** A 27-month effort in which two teams designed and developed the UAV configuration, complete with a System Specification and interfaces. The prototype system would then be built and undergo initial flight testing. The products for each team included two prototype air vehicles, one set of sensors, one ground segment, and one support segment capable of demonstrating the overall, integrated system performance
>
> **Phase III:** A 36-month effort in which a single team would demonstrate their integrated system operational utility. The products included eight fully integrated, pre-production air vehicles (except for two EO/IR sensors), two ground segments, and the logistics support necessary for a two-year field demonstration
>
> **Phase IV:** Open-ended serial production of Air Vehicle (A/V) #11 and beyond, as well as Ground Segment #4 and beyond

In establishing the HAE program, DARPA recognized the failures of past UAV programs because of unit costs far exceeding what the user was willing to fund. In an attempt to overcome the historical problems, DARPA, with congressional support, implemented a new acquisition strategy significantly different from past DoD strategies. The strategies involved the following:

[6] HAE UAV ACTD Management Plan, Version 1.0, December 94 (draft), Table 1

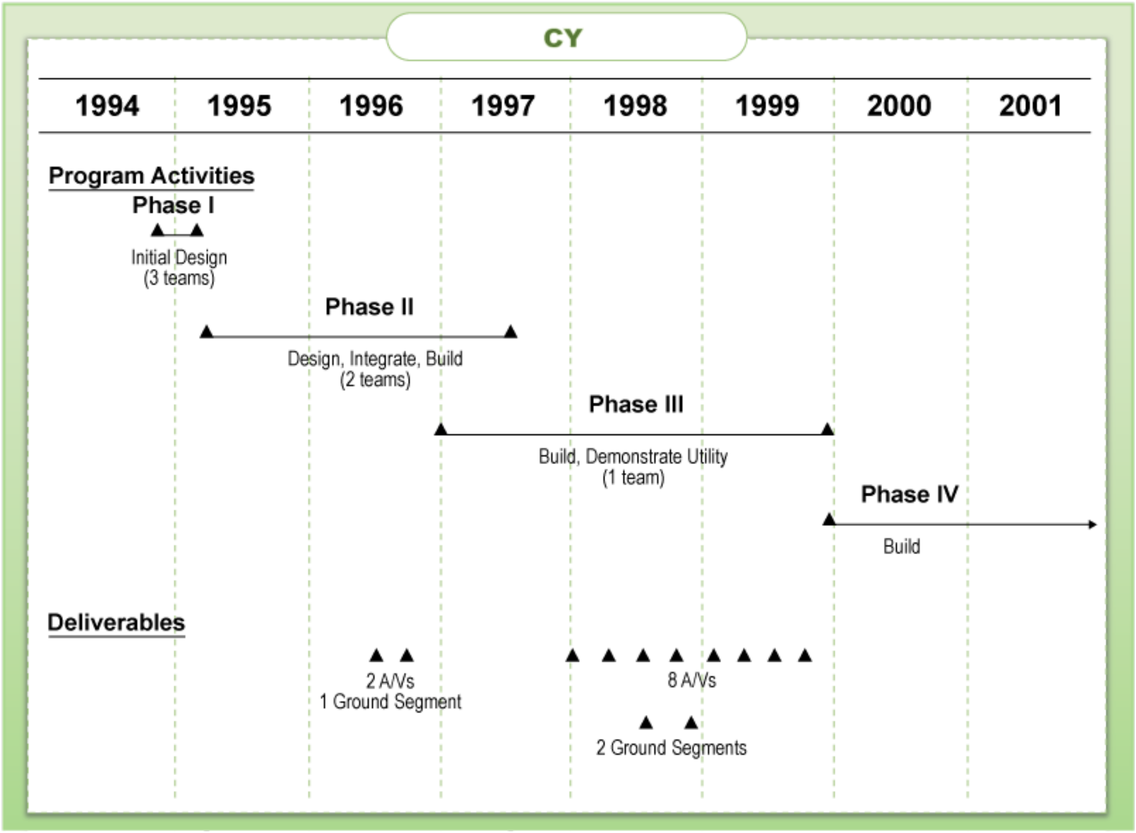


Figure 11. *Original Tier II+ Schedule*

ACTD: The ACTD concept was initiated coincidentally with development of the Tier II+ program strategy. In 1994, the ACTD process evolved in response to the recommendations of the Packard Commission (1986) and Defense Science Board (1987, 1990, and 1991). The concept was developed to provide a rapid, cost-effective means to introduce new capabilities into the military services. The core elements of the ACTD initiative, according to Dr. Kaminski, Under Secretary of Defense for Acquisition and Technology (USD [A&T]), were as follows:

> "There are three characteristics…which are the hallmark of the program. The first is that there is usually joint service involvement in an ACTD. Second, ACTDs allow our warfighter to perform a very early operational assessment of a system concept before we've invested a lot of money in the concept. And third, there is usually some residual operational capability left in the field at the completion of an ACTD, even if we haven't decided to put the program into a full development phase." [7]

The ACTD process was intended to be unique from other acquisition reform efforts. It was distinct by virtue of its emphasis on heavy user involvement. It provided an opportunity for new concepts to be developed through a process whereby operational tactics were developed concurrently with the hardware. The overall system would not be judged until an operational demonstration.

[7] DoD News Briefing, 28 June 1995

The entire ACTD process, including source selection and funding, was overseen by the ACTD Steering Group chaired by the Vice Chairman of the Joint Chiefs of Staff. In addition, the selection of ACTDs was reviewed by the JROC through the Joint Warfare Capability Assessment groups. The technologies to be evaluated were selected by a small group of Army, Navy, Air Force, Marine Corps, and Office of the Secretary of Defense (OSD) officials fondly dubbed the "Breakfast Club." There were three possible outcomes for an ACTD program:

1. Concept fails and is discarded
2. Concept works but needs additional development and proceeds into Engineering and Manufacturing Development
3. Concept works and bypasses EMD

Since the basic acquisition strategy of the HAE program evolved during the same time period as the ACTD process, there was close coordination between the principles of both activities during the 1993-1994 time period. This allowed the HAE to be accepted as an ACTD program and allowed the JPO to move forward with their solicitation to industry in April 1994 before the ACTD process was formally introduced.

Pilot Acquisition Provisions of Public Law

Another significant strategy implemented was the use of a newly adopted legislation that permitted the removal of many oversight and management processes typically required by Government acquisitions. The authority granted by this provision was known as Section 845 Other Transactions Authority (OTA). The HAE program had been classified as a Pilot Acquisition Program under Public Law 101-189, Section 2371, Title 10, United States Code (USC), and under Section 845 of the 1994 National Defense Authorization Act (NDAA) (Public Law 103-160). This not only released the contractor from complying with Military Specifications (MIL-SPECs) but also released them from a series of Government rules and regulations, such as the Federal Acquisition Regulations (FARs); Defense FAR Supplement; Armed Services Procurement Act; Competition in Contracting Act; and Truth in Negotiations Act. It also freed the contractor from the requirement to undergo Defense Contract Audit Agency (DCAA) audits, thus allowing the use of commercial auditors. In essence, all procurement system regulations were non-applicable. However, this waiver was initially granted only through Phase II. Extension of the waiver into Phase III was not a given and thus represented a program risk. If the program transitioned into Phase IV, there was a good chance that the program would return to the "standard" acquisition process.

Section 845 OTA allowed DARPA to operate under an "agreement" instead of a contract. Two key differences between a typical contract and an "agreement" are defined in Article IV and VII. For an "agreement," Article IV, Payable Event Schedule, permits the parties to agree to changes in payable milestones based on program events, and Article VII, Disputes, designates the DARPA director as the ultimate arbiter of disputes. Section 845 OTA also transferred significant management and design responsibility to the contractor. This allowed the contractor to operate under few obligations, gave the contractor the ability to cease work at any time without penalty, limited Government direction, and required no formal reporting or tracking. In essence, the agreement gave the JPO limited influence as reflected by the following section of the agreement:

> "This agreement gives extraordinary responsibility and authority to Teledyne Ryan Aeronautical (TRA) The Government will not unilaterally direct

> performance within or outside the scope of the work. Thus the government must be able to convince TRA of the need for change."

Design Requirements: One of the more radical strategies of the program was the emphasis on Unit Flyaway Price (UFP). Programs in the demonstration phase typically establish a set of system-level performance requirements that they convey to the contractor in a form, such as a System Requirements Document. There would also be some method of unit procurement cost control established to help set production boundaries. However, history has shown that the cost control measure seldom worked. Past UAV programs were no exception, with costs sometimes escalating to the point that the user was no longer willing to fund the program. Over the years, several cost control initiatives were pursued. During the 1970s, the concept of Design to Cost (DTC) was implemented. The concept was "to set a cost goal early on, similar to the way a performance goal is set, and then design to that goal."[8] However, an Institute for Defense Analyses (IDA) study concluded that the DTC approach did not result in any significant improvement to cost control. Another concept was the fixed price development that was typically incorporated with the broader concept of total package procurement. Here, the initial development contract would typically define a set of system descriptors, performance specifications, and a fixed cost requirement. As usual, estimates were inevitably optimistic, and the concept failed. In the early 1990s, Cost As an Independent Variable (CAIV) was developed with the idea that the user would play a stronger role in establishing the initial balance between cost and other system performance parameters. However, no specific application of this approach was known at the start of the Tier II+ program. With no evidence of a successful cost control strategy, the JPO, in concert with DoD, developed a new strategy that treated cost as the sole design requirement with all performance objectives subject to trade. Before Phase I contract award, a $10 million (FY94 dollars) UFP cap was imposed by the Deputy Under Secretary of Defense for Advanced Technology.

Consistent with the strategy of specifying only one firm requirement, the $10 million UFP, the program developed a set of desired performance characteristics that were defined in terms of a range of values considered acceptable. The parameters were labeled as goals, either as Primary Objective, Objective, or Desired. This approach gave the contractor the latitude and responsibility to define the balance among the desired performance parameters, so the user would receive the "biggest bang for the buck." This freed the JPO from closely tracking the contractor's progress in meeting a large number of individual performance specifications. The JPO even tried hard to avoid giving the impression that they valued one specific performance goal over another.

Integrated Product and Process Development

An additional element of the JPO strategy was the use of Integrated Product and Process Development (IPPD) and associated Integrated Product Teams (IPTs). IPPD is a management technique that integrates all the essential acquisition activities into multidisciplinary teams organized according to product areas, not discipline. These IPTs are characterized by participants empowered to make decisions and commitments for the functional areas they represent. The Government program members work closely with the contractor IPTs, operating in an atmosphere of teamwork and mutual trust. The goal is to optimize design, manufacturing, and

[8] Acquiring Major Systems: Cost and Schedule Trends and Acquisition Initiative Effectiveness, Karen W. Tyson et al, Institute for Defense Analyses, Paper P-2201, March 1989

supportability. It is a concept that evolved from the concurrent engineering practice and was first implemented in the DoD on the F-22. On May 10, 1995, the Secretary of Defense directed that IPPD and IPTs be applied to the acquisition process to the maximum extent possible. Even though the Tier II+ program was exempt from the standard procurement regulations, the JPO supported the concept and strongly encouraged its use. The contractor complied.

Design for Low Program Risk

Traditional DARPA programs tend to emphasize high system performance goals that increase the risk of failure. However, the JPO truly wanted the Tier II+ program to succeed. Thus, they tried to design a program that would have a relatively low risk of serious failure. In essence, they equated a program with high technical risk to a program that would not meet its cost requirements. One tactic used by the JPO was to convey to the contractor that the development funds were limited to a specific amount and that no additional funds would be made available. This strategy was particularly emphasized during the later phases of the program.

Small JPO Staff

The JPO was a very small, austere organization, purposely sized that way to ensure minimal oversight by the Government and provide a significant degree of autonomy to the contractors.

3.2.2 Phase I

The solicitation for Phase I was released in April 1994. The solicitation made it perfectly clear that the $10 million (FY94 dollars) UFP was the only program requirement. The solicitation gave the contractor total control in defining the configuration based on the performance goals defined in the Systems Capability Document and required $10 million UFP. A Task Description Document, Integrated Master Schedule (IMS), and Integrated Master Plan (IMP) were required for insight into all the systems and UFP allocation. The solicitation suggested a management approach involving IPTs, maximum use of commercial systems, streamlined processes, and contractor responsibility.

The original intent, as defined in Paragraph 3.2.1 above, was to award competitive contracts to three separate teams. There was an unexpectedly large response to the solicitation because of the acquisition waivers that now facilitated the participation by nontraditional DoD contractors, such as Aurora and Grob. Fourteen teams responded. The bids submitted covered a wide-range of size and performance for a $10 million UFP, causing the Government to question the credibility of some of the estimates. When DARPA assessed the breadth and quality of the responses, they elected to select five teams. Each team was funded at a “not to exceed” $4 million, with payments to be made upon successful completion of contractually specified milestones. The five teams awarded contracts in October 1994 were:

- Loral Systems with Frontier Systems
- Northrop Grumman Aerospace with Westinghouse Electric
- Orbital Sciences with Westinghouse Electric
- Raytheon Missile Systems with Lockheed Advanced Development
- TRA with E-Systems

Little information is available concerning the contractors' performance during Phase I of the program. This is largely because of the "Competition Sensitive" nature of the phase, coupled with the short duration (six months). However, it can be concluded that the contractors did instill a degree of confidence that a reconnaissance-type UAV could be developed that would meet the user's needs.

During Phase I, DARPA formed a small JPO at Ballston, Virginia, with personnel assigned from the Aeronautical Systems Center (ASC) and Naval Air Systems Command (NAVAIR). The JPO was also supported by a small cadre at Wright-Patterson Air Force Base (WPAFB), Ohio. This was consistent with the strategy of a small Government staff. The JPO supported both the Tier II+ and Tier III- programs. In some cases, personnel were dedicated to one program, and, in other cases, personnel were shared between the two programs. The exact staffing level at the DARPA JPO during Phase I fluctuated but, on average, consisted of a core group of about 12 people with half being engineers. Specialists were called in, as needed, from the various agencies.

During Phase I, the JPO was busy preparing for the next phase. The JPO was forced to revise its acquisition strategy for Phase II because of funding constraints. Between release of the draft Phase I Solicitation on April 29, 1994, and the release of a revised version on June 1, 1994, the funding profile for Phase II/Phase III was reduced by $10 million. By release of the Phase II Solicitation on February 15, 1995, the funding profile was further reduced by another $88 million. Figure 12 shows the funding profile as a function of time and phase. This funding reduction forced the JPO to choose between canceling the program, changing the Phase II activity content, or selecting a single Phase II contractor. The JPO chose the last option. When the change was announced midway through Phase I, the early elimination of competition became controversial both with the competing contractors and Capitol Hill. This was particularly true for the four contractors who eventually were not selected for Phase II. In their minds, TRA was the clear favorite, and, thus, they were competing for the runner-up contract.

	29 Apr 94	1 Jun 94	15 Feb 95
Phase I	$12M	$20M	$20M
Phase II	$235M	$230M	$164M
Phase III	$275M	$270M	$248M

Figure 12. *Funding Changes*

In early February 1995, the Evaluation Factors were finalized for judging the upcoming Phase II proposals. The factors encompassed four areas as defined below:

- **System capability**: How close is the proposed system to meeting the System Capability Document (SCD) objectives? How effective and suitable will the final system be, as a whole, in the operational environment? How stable is the proposed design and technical approach throughout the phases of the program? How well does the system design support growth and flexibility? (All these questions were addressed within the context of the $10 million UFP.)
- **Technical approach**: Is the technical approach low-risk, and has the use of off-the-shelf technology been maximized? Is the design, development, and manufacturing approach adequate for each phase of the program? Are the technical processes described in the Process IMP adequate for their intended use?

- **Management approach**: Does the IMP depict a well-defined program that can be tracked easily? Does it propose a system that can be delivered within the resources provided? (Specific management functions evaluated included planning processes, program control, and organization; past performance was also evaluated.)
- **Financial approach**: Will the offeror be able to execute the proposed program within the financial resources provided? Are those resources consistent with the UFP? (Specific criteria were reasonableness, realism, and completeness of cost estimates.) [9]

On February 15, 1995, the Phase II solicitation was released. Source Selection followed shortly thereafter.

3.2.3 Phase II

TRA was selected for the Phase II contract in May 1995. The JPO viewed TRA's approach to be relatively low risk. TRA proposed a relatively conservative design with the technical risk envisioned to be associated with the flight test program. Their design was at the high end of the weight scale, implying less technical risk but more cost risk should certain performance parameters miss their goals significantly. This was consistent with the JPO's objective of a low-risk program.

The technical content contracted in Phase II remained as initially planned, i.e., design and build two air vehicles and one ground segment, followed by flight testing sufficient to demonstrate the technical performance consistent with a $10 million (FY94 dollars) UFP. In order to ensure that all the technical characteristics would be fully addressed, TRA converted all the technical performance objectives into requirements. Trade-offs could then be made later, if required, to meet the UFP requirement. The Phase II schedule, however, was expanded with the agreement of the contractor from the originally planned 27 months to 33 months. The additional six months was added to the flight test program. At the same time, Phase III was shortened from 36 months to 24 months.

A successful end to Phase II required the following:

- "Thumbs-up" by the user to continue
- System Specification that all participants agreed would lead to a $10 million UFP.

The key milestone dates for Phase II were:

- First Flight December 1996
- Phase II End December 1997

At Phase II contract award, the original Tier II+ schedule depicted in Figure 11 remained essentially intact. The only significant change involved the notion of a CGS that could serve both

[9] The Global Hawk Unmanned Aerial Vehicle Acquisition Process, A Summary of Phase I Experience, Geoffrey Sommer, Giles K. Smith, John L. Birkler and James R. Chiesa, RAND Corporation, 7 December 2007, Pages 7 and 8

the Tier II+ and Tier III-. Figure 13 shows the revision and will serve as the baseline for discussing future schedule changes.

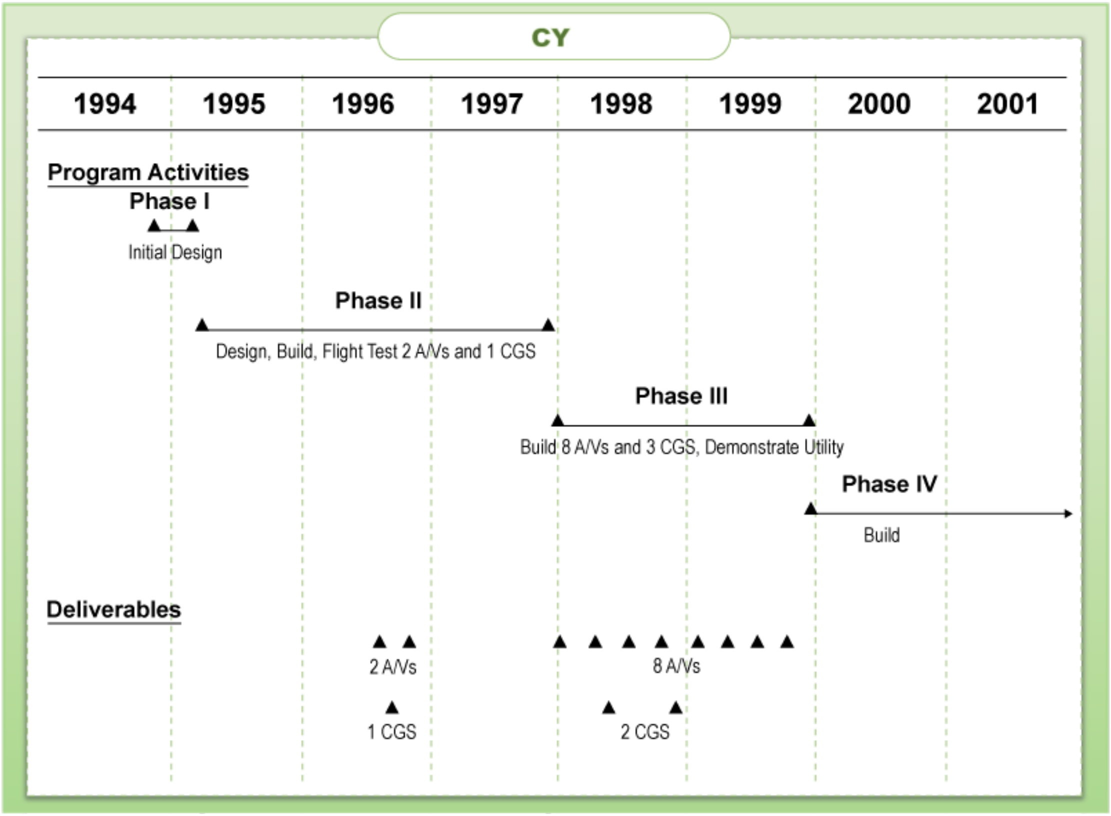


Figure 13. *Global Hawk Schedule as of Mid-1995*

Program Name

Early in Phase II, DARPA held a contest to establish the names for both the Tier II+ and Tier III- programs. Many names were submitted, and Gen Ralston, then Air Combat Command (ACC)/CC, selected the winning names. The Tier II+ program was dubbed Global Hawk, and the Tier III- was dubbed DarkStar. Program documentation continued to use the term Tier II+ throughout ACTD, but the term was dropped in favor of the Global Hawk once the program entered EMD/Production.

Phase II Agreement, dated August 3, 1995

Consistent with the latitude granted by Section 845 OTA, a Phase II Agreement was executed on August 3, 1995, with an effective date of April 6, 1995. The agreement added, by reference, a System Specification, Task Description Document, IMS, and IMP. The vision was that these documents combined would describe the system capability goals and how the Phase II activities would be organized. TRA also included in the agreement the following list of guidelines and processes aimed at ensuring low development risk and high military utility:

- Early testing
- Compatibility with existing military systems

- Integrated product development philosophies
- Trade-offs to maximize military utility
- Built-in growth path
- Maximized use of off-the-shelf equipment
- Maximized use of open architectures
- Minimized system life-cycle cost
- Required supplier participation in the IPT structure
- Invited customer participation in the IPT structure [10]

The negotiated Cost Plus Incentive Fee (CPIF) was $157,348,000. An additional Cost Plus Fixed Fee (CPFF) was included for other tasks.

TRA Organization

As prime contractor, TRA was responsible for the development and integration of three system segments: Air Vehicle Segment, Ground Segment (MRE and LRE), and Support Segment. This responsibility led to the formation of the following IPTs:

- Air Vehicle Segment
- Payload Segment
- Ground Segment
- Support Segment
- Systems Engineering/Program Management
- System Test

The TRA engineering organization was roughly characterized by two groups: the young engineers, some with experience on guided missiles, and the older, experienced "Elder Statesmen" that had worked on TRA's high flying drones (Compass Cope and Compass Arrow). The Chief Engineer was responsible for creating his organization. He personally did much of the hiring and approvals. First and foremost, he followed the philosophy that each IPT lead needed to be an excellent engineer who liked people and had good interpersonal skills. Each IPT lead formally signed an agreement that he would be responsible for his product from "womb to tomb." There was no such thing as throwing an issue over the wall to hide it. In some instances, small Tiger Teams were constituted for a short period of time for tasks that required intense multi-disciplinary involvement. Everyone within each IPT inherently liked empowerment and understood that individual responsibility came along with the empowerment. It also meant that they had to own up to their mistakes, so the mistakes could be corrected quickly without recrimination. The team instituted a Toyota approach, which allowed anyone on the team to stop the project if he saw something terribly wrong. The Chief Engineer reviewed and, in some cases, co-wrote, amended, and approved each and every system/subsystem document.

[10] Innovative Management in the DARPA High Altitude Endurance Unmanned Aerial Vehicle Program, Jeffrey A. Drezner, Geoffrey Sommer, Robert S. Leonard, RAND Corporation, 7 December 2007, Pages 43 and 44

The Global Hawk program also had a small designated systems engineering organization, as well as systems engineers located within each of the IPTs. The contractor integrated the systems engineering function partly into the technical management structure where some of the IPT leads were experienced in the systems engineering discipline. The Chief Engineer created this organization and chose the IPT leads based on leadership capability, interpersonal skills, and technical excellence in their area of expertise (systems engineering, design, analysis, manufacturing/assembly, logistics, cost, ground segment, communications, payloads, etc.). In this concept, the Chief Engineer was the individual with primary responsibility to define and execute the systems engineering process. The Systems Engineering IPT lead and his small staff on the program worked with the Chief Engineer to define many of the processes and procedures to be used.

JPO Organization

The JPO formed a much smaller, mirror image of the TRA organization, so, in theory, there was a JPO segment lead to work directly with each TRA segment IPT lead. The JPO remained true to the strategy of maintaining a small JPO staff. This sometimes resulted in criticism that the JPO was understaffed and that it hindered its ability to interact with the contractor. At the start of Phase II, there was a combined total of about 15 full-time people supporting both Global Hawk and DarkStar, with about half being engineers. One Systems Engineer was included on the team. Similar to Phase I, specialists were called in, as needed, from the various agencies. The size of the JPO grew with time but remained small throughout the ACTD phase. The total JPO never exceeded about 30 full-time people with 10 of them being engineers.

TRA/JPO Relationship

One of the consistent remarks made by both TRA and JPO involved the excellent working relationship between the two groups (TRA and JPO). Everyone wanted to make the ACTD a success. In areas where one group was weak, the other group rolled up their sleeves, pitched in, and contributed greatly. There was no “beating around the bush;” just “let’s work together and get the job done.”

The underlying Government strategy was to eliminate oversight but maximize insight. Consequently, program leadership stayed in regular contact, resolving issues in real-time. This approach meant that everyone on both sides was value-added, and the concept of multiple formal milestone reviews was considered irrelevant, since everyone who needed to know was fully in the loop. Both TRA and JPO worked extremely hard, and their availability was not limited to the standard 8:00 to 5:00 weekday. If flight testing, or a problem occurred on a Saturday or Sunday, people were always willing to support the need. The success of the ACTD program can be attributed to the team’s hard work, dedicated people, and strong leadership.

ACC

ACC had a Requirements Directorate for both the Global Hawk and Predator. This function was subsequently moved to the Air Force Command and Control, Intelligence, Surveillance, and Reconnaissance (AFC2ISR) Center. The Directorate generated the Operational Requirements Document (ORD) and was involved with the JPO in generating the Capability Development Document (CDD), terms that were used somewhat interchangeably.

Common Ground Station

An amendment to the agreement for Phase II of the Global Hawk program, dated July 1995, included support for a CGS that would be used by both the Global Hawk and DarkStar. Within the Global Hawk program, the ground segment was the responsibility of one of TRA's subcontractors, E-Systems. By October 1995, E-Systems had created an integrated set of requirements, and by year's end, they proposed a CGS concept. "Sometime in mid-1996 the JPO realized that progress would be enhanced if TRA was relieved of management responsibility for development and integration of the common ground system."[11] This would allow TRA to focus strictly on the Global Hawk system. Consequently the JPO assumed management of the CGS and contracted directly to E-Systems. E-Systems committed to a schedule that would deliver the CGS by mid-1999, a time sufficient to support both Phase III demonstrations. In the interim, this change in strategy left each of the two air vehicle companies free to develop unique ground segments consistent with their specific development and demonstration strategies and schedules.

Engineering Development

As activities progressed from concept to engineering development, the complexity of the activities increased. The RAND Corporation, which was contracted by DARPA to assess how the innovative strategies affected the program outcome, concluded that the main events and conditions listed below impacted the Global Hawk program during Phase II:

- "Reduction in budget led to a loss of the competitive environment in Phase II. While the budget cut occurred in Phase I, it affected Phase II execution by radically changing the contractual and management environment from one that relied on competition to ensure contractor performance to a single-source best-effort arrangement with weak incentives and limited mechanism for government intervention.
- Integration risk was underestimated. Inadequate emphasis was placed on the risks of software development and systems integration.
- The lead contractor (TRA) was a relatively small organization with good experience in small UAV programs but little experience in large, complex programs. TRA's primary expertise was in the air-vehicle system; it had inadequate capabilities in key software and integration areas. Being small, it had limited resources to apply to problems. It also had relatively weak management processes that, at least initially, were driven by personalities."[12]

As noted, the major technical challenges were the software development and systems integration. During the first year of the program, TRA did not recognize the need for the significant software development that would follow. As the development progressed, it also became clear that the other critical challenge was in system integration, not air vehicle design. For example, the acquisition strategy emphasized the use of commercial off-the-shelf (COTS) as a method to reduce cost. However, the risks and problems associated with integrating COTS into a complex system were underestimated. In some instances, such as the mission computer, the COTS equipment had to be redesigned. An additional explanation for some of the technical difficulties is that the technologies used for the air vehicle and electronic systems were not as mature as the

[11] Ibid, Page 91

[12] ibid, Pages 48 and 49

team believed. Finally, in the second year of Phase II, TRA recognized the challenges and applied the additional resources. The challenges then began to come under control.

Crash of the First DarkStar

Darkstar hanging in the Smithsonian Institution's National Air and Space

In April 1996, the first DarkStar crashed during takeoff on its second flight. Although the two projects were independent of each other, the DarkStar crash heightened the risk aversion on the Global Hawk program. This resulted in more conservative design decisions, increased reviews, unplanned single point failure analysis, and increased testing in the System Integration Laboratory (SIL) before first flight. One specific program consequence is that DARPA decided to delay first flight until the contractor completed a lengthy joint evaluation of all the software, flight control laws, and other flight critical subsystems. That effort delayed first flight by 8-10 months. All of this was consistent with the JPO's acquisition strategy to Design for Low Program Risk.

IMP and IMS

Early in Phase II, the IMP and IMS tended not to be integrated and up-to-date. The IPTs worked to the schedule and cost targets but did not record their progress adequately. In April 1997, TRA implemented a process that fully integrated the cost and schedule status into their earned-value system. Likewise, the IMP and IMS were updated to reflect their current status, and greater emphasis was placed in maintaining and using these tools.

Renegotiated Phase II Agreement, dated August 4, 1997

Consistent with the latitude provided by Section 845 OTA, TRA and DARPA renegotiated the Phase II agreement to accommodate problems encountered to date. The agreement was summarized as follows: "The original agreement followed a CPIF contract approach. The new agreement requires cost-sharing at a threshold of $206 million of program cost at a ratio of 30 percent TRA, 70 percent government, until a value of $228 million is reached, where the program is capped. Previously earned fees must begin to be paid back to the government at that point. TRA's subcontractors begin participating in the cost share at $218 million. TRA is not obligated to continue to perform when the limit is reached unless the Agreement is further modified. The renegotiation also required that TRA and its team members invest $3.1 million in the SIL, above the value of the Agreement." [13]

Phase IIB Amendment, dated March 31, 1998

Less than a year later, TRA and DARPA amended the Renegotiated Phase II Agreement to accommodate Phase III. The amendment definitized the tasks associated with manufacturing of AV-3, AV-4, and long-lead items for AV-5; authorized certain Contractor Acquired Property; provided incremental funding; and revised other affected Agreement Articles. The amendment also addressed the activities associated with building an ISS and performing Integrated Logistics Support tasks, such as providing technical manuals, spares, training, and software maintenance, all of which were not addressed by the previous agreements.

[13] ibid, Page 59

Program Cost Growth and Schedule Slip

Technical issues resulted in a cost growth and schedule slip. First, there were the issues associated with software development (e.g., Integrated Mission Management Computer software) and system integration. Then, there was the DarkStar crash. The investigation indicated that problems in the flight control software were the major cause. As a result, the JPO insisted that the flight control software be fully demonstrated on the SIL before first flight. To compound the tightening schedule, problems in developing the software delayed the full demonstration in the SIL.

The result of these technical problems was an additional nine-month slip to the end of Phase II. Since the program was only funded through December 1999, the JPO was forced to offset the impact by shortening the 24-month user evaluation to 12 months (January 1999 to December 1999). Likewise, the duration of Phase III was reduced to 15 months. This was necessary to maintain timing of the production decision.

With all of this happening, the nonrecurring engineering costs increased. In a program review, the USD (A&T) directed that the program remain within the available funding. Ultimately, the quantity of vehicles procured during ACTD was reduced from 10 to five. Figure 14 depicts the new schedule as of mid-1998.

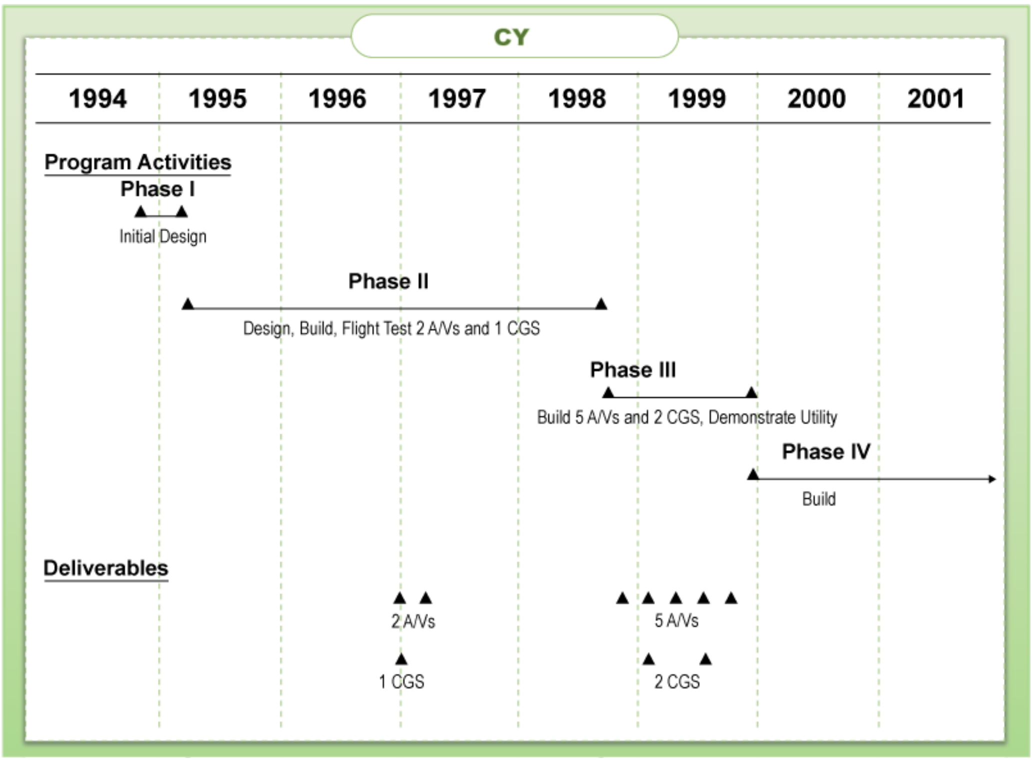


Figure 14. *Revised Global Hawk Schedules as of Mid-1998*

UFP Cost Growth

Both the JPO and TRA believed that the UFP requirement was a viable way to control cost and encourage trade-offs. However, the amount of analysis that was used to define the $10 million (FY94 dollars) cap was unclear. A RAND Report which did an extensive study on the ACTD phase of the program concluded: "We believe that the $10 million UFP was selected because it was judged to be high enough to provide a system with meaningful capability if adhered to, yet at the same time low enough that the Air Force would be willing to pay for it."[14] By the end of Phase II, both the JPO and TRA surmised that the $10 million UFP was unachievable and would be exceeded by $1 million to $3 million. The information was widely briefed amongst the participating organizations, but the Government did not make it publicly known. There were several reasons for the increase. According to a RAND Report, "Assumptions underlying the UFP have been violated, including production gaps and transitions to subsequent phases, subsystem initial costs, and cost improvement."[15] Likewise, TRA avoided the trade-offs of some functionality because of the fear of dropping a capability that the user wanted most. In other cases, the Government was accused of imposing "requirements creep." However, the RAND study concluded that "The government was not adding superfluous systems; rather, they enabled or enhanced operational capabilities that DARPA did not understand well."[16] The issue of DARPA, the user, and the Air Force not clearly communicating requirements and their implications was a problem that occurred periodically throughout the program. This is perhaps one of the fallouts of not having a clearly defined set of requirements.

Performance Objectives

As the design of the system matured, the performance parameters became better defined. Key characteristics, such as operating radius, loiter altitude, takeoff weight, and payload weight were expected to be at the high end of the spectrum. Figure 15 shows how the parameters evolved over time.

Characteristics	December '94	December '99
On-Station Loiter (hours)	24	Same
Operating Radius (miles)	2000 – 3000	3000
Loiter Altitude (ft msl)	60,000 – 65,000	>60,000
True Air Speed (knots)	300 – 375	300 - 350
Takeoff Weight (lb)	15,000 – 27,000	25,600
Survivability Measures	Threat Warning, ECM, Decoys	Same
Sensor Payload	SAR, GMTI and EO/IR	Same
Sensor Payload Weight (lb)	1000 – 1500	1800

Figure 15. *ACTD Performance Objectives*

3.2.3.1 *Flight Test Planning*

Initial program planning called for flight testing to occur as part of the Phase II development and Phase III user evaluation. Phase II included a 12-month flight test program using the two engineering development models of the air vehicle and one CGS. Phase III was originally planned as a 24-month field demonstration with heavy participation from the user. Eight air vehicles were to be used with two additional CGSs. Demonstrations were intended to include combined Global Hawk/DarkStar participation and DoD training exercises. The plan for a

[14] Innovative Development, Global Hawk and DarkStar - Their Advanced Concept Technology Demonstrator Program Experience, Executive Summary, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Page 16

[15] Innovative Management in the DARPA High Altitude Endurance Unmanned Aerial Vehicle Program, Jeffrey A. Drezner, Geoffrey Sommer, Robert S. Leonard, RAND Corporation, 7 December 2007, Pages 43 and 44, Page107

[16] ibid, Page 108

combined Global Hawk/DarkStar demonstration ended abruptly in January 1999 when the DarkStar program was terminated.

The HAE UAV ACTD Management Plan, dated December 15, 1994, clearly conveyed the expectation that all 10 Global Hawk test vehicles (two Phase II and eight Phase III) and all three CGSs (one Phase II and two Phase III) would be identical, supporting a direct transition into production. DARO, the sponsoring agency, would provide the program funds though the end of Phase III, and the Air Force, the lead agency, would provide the operations and support funds. The ACTD Management Plan did not specify the expected number of flight hours. However, it did make clear the importance of the flight test program and introduced the concept that the contractor was responsible for the flight test program.

The primary objective of Phase II testing was to validate the system's technical performance against the contractor's System Specification. The Technical Performance Measures (TPMs) and System Maturity Matrix (SMM) goals were established and cross-referenced to the Preliminary System Specification. "The TPMs were related to the technical and payload incentives embodied in Attachment 5 of the Ryan Agreement."[17] The flight test program was structured as a steady progression in learning with each flight generating more confidence in the system performance and a better characterization of the TPMs and SSM. Tracking of the TPMs were particularly important since the ACTD program had no contractual performance requirements.

A test plan was written to support the flight test program. It addressed not only the flight test but also the ground-based system and subsystem testing necessary to demonstrate readiness for first flight. The test plan specified only 16 flights because of the relatively small flight envelope inherent to the aircraft. The test plan called for every flight to demonstrate essentially the identical time duration, vehicle speed, and altitude profile.

Version 7 of the HAE UAV ACTD Management Plan provided more detail. Phase II testing would begin in mid FY97 and would last through the end of FY98. The Air Force Flight Test Center (AFFTC) would be responsible for coordinating airspace usage. The Phase II development tests would consist of seven airworthiness flights and nine payload flights over a 12-month period. The Phase III demonstration was to start in the last quarter of FY98 and continue through the end of FY99. Exercises would be established by the commanders with the objective of identifying tasks that would demonstrate the Global Hawk's contribution. The number of exercises would be determined based on the number deemed necessary to characterize the system's utility.

3.2.3.2 *First Flight*

AV-1 rolled out of the TRA facility on February 20, 1997. While at Lindbergh Field in San Diego, California, the air vehicle guidance and navigation system was statically tested. There was the opportunity to perform taxi tests at Lindbergh Field, but its delivery to Edwards AFB, California, was already late. Thus, the air vehicle was disassembled and trucked to Edwards AFB on August 28, 1997. Taxi tests began that October. The B-2 facility at South Base was used for the flight test program. It was fully equipped,

[17] Innovative Development, Global Hawk and DarkStar – Flight Test in the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Page 7

including a control room and access to a runway that was reasonably secluded; although, early operations were all off the main runway at Edwards AFB. The First-Flight Readiness Review (FFRR) occurred on February 9, 1998, followed by an additional week of software confidence testing. Poor weather caused additional delays, and the Global Hawk finally flew for the first time on February 28, 1998. Below is the official DoD news release that followed:

> "Global Hawk, the Department of Defense's newest reconnaissance aircraft, successfully flew for the first time at Edwards Air Force Base, Calif., on Saturday, February 28.
>
> Global Hawk air vehicle number one, a high-altitude, long-endurance unmanned air vehicle (UAV), took off from the Edwards Air Force Base main runway at 7:43 a.m. (PST) and flew for 56 minutes. The UAV reached altitudes up to 32,000 feet before landing on the base's main runway. Global Hawk, with a 116-foot wingspan, navigated along a "bow tie" track within restricted air space. The entire mission, including the take-off and landing, was performed autonomously by the aircraft based on its mission plan. The Launch and Recovery Element of the system's ground segment continuously monitored the status of the flight.
>
> The flight was the first of numerous air worthiness evaluation and payload demonstration flights planned. The Defense Advanced Research Projects Agency (DARPA) is developing Global Hawk to provide military field commanders with a high-altitude, long-endurance system that can obtain high-resolution, near-real-time imagery of large geographic areas."
>
> "Today's flight was an exceptional accomplishment for the Global Hawk team. This is a key milestone towards giving warfighters a powerful new capability," said DARPA's program manager Col Doug Carlson, USAF. "Not only did Global Hawk perform beautifully, but the successful flight demonstrated how government, military, and contractor personnel can work together on a challenging development program. I am especially pleased with the excellent support we have received from the Edwards Air Force Base team, and I look forward to working with them as the program proceeds."
>
> The new aircraft has been designed to operate with a range of 13,500 nautical miles, at altitudes up to 65,000 feet and with an endurance of 40 hours. During a typical reconnaissance mission, the aircraft can fly 3,000 miles to an area of interest, remain on station for 24 hours, survey an area the size of the state of Illinois (40,000 square nautical miles), and then return 3,000 miles to its operating base. During a typical mission, a Synthetic Aperture Radar/Moving Target Indicator and Electro-Optical and Infrared sensors onboard the aircraft can provide near-real-time imagery of the area of interest to the battlefield commander via world-wide satellite communication links and the system's ground segment.
>
> Global Hawk air vehicle number one has been located at Edwards Air Force Base since August 1997. Air vehicle number two, which is nearing completion, will be flown primarily to validate the performance of the system's sensors and

communication systems; its testing will begin at Edwards Air Force Base later this year.

The Global Hawk program is managed by DARPA for the Defense Airborne Reconnaissance Office. Teledyne Ryan Aeronautical is the prime contractor. Principal suppliers on the contractor team include Raytheon Systems, which is developing the ground segment and sensors; Allison Engine Co., which builds the aircraft's turbofan engine; Boeing North American, which builds the carbon fiber wing; and L3 Com, which is developing the communication systems." [18]

3.2.3.3 *Flight Test Program*

The Flight Test Plan initially called for just 16 flights during Phase II because of the relatively small flight envelope inherent to the aircraft. In reality, 21 sorties were conducted over 16 months using two air vehicles. 158 total flight hours were accumulated between February 28, 1998, and June 11, 1999. AV-1 primarily flew airworthiness sorties, accumulating 12 sorties for 103 hours. AV-2 primarily flew payload checkout sorties, accumulating nine sorties for a total of 55 hours. Figure 16 shows the buildup of flight hours.

Even though the flight envelope of the Global Hawk was fairly small, there were concerns that had to be carefully addressed. The Global Hawk is unique relative to the extended amount of time that the subsystems are cold soaked at high altitude. Some of these subsystems were COTS and were not qualified to the long dwell times at these temperature extremes. Even though the Environmental Control System was designed to maintain the temperature and pressure within a normal operating environment, a buildup of flight tests involving 1, 2, 4, 8, 12, and 20 hours were conducted to verify that the Environmental Control System was adequate to compensate for the long dwell times at the pressure and temperature extremes of high altitude.

Relative to the overall flight test program, objectives were not met in four of the 21 flights. Of the four flights, one dealt with airworthiness and three with payload. In cases where objectives were not met, the mission was typically re-flown. In those cases where only a couple of the objectives were not met, those objectives were often added to the next mission.

[18] News Release, U.S. Department of Defense, Office of the Assistant Secretary of Defense (Public Affairs), 2 March 1998

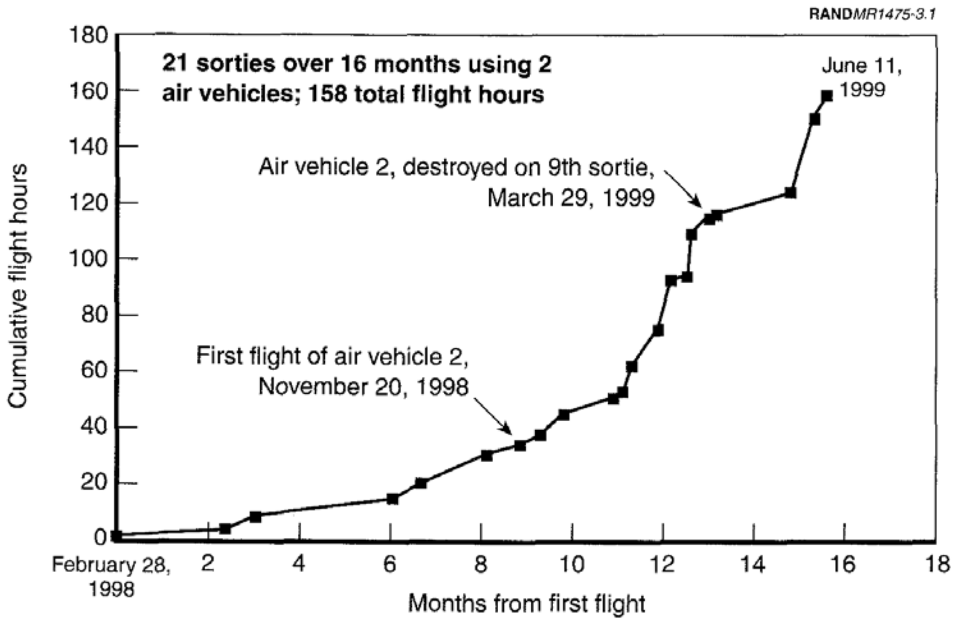


Figure 16. *Phase II Flight Program*[19]

Test Responsibilities

Consistent with the new authority resulting from the Section 845 OTA, TRA was given significantly increased responsibility over the flight test program. TRA was responsible for test planning, test execution, and designation of the Test Director. AFFTC provided assistance for safety issues, and ACC provided technical support.

To ensure an operational flavor in the test program, which was a key element of the ACTD, the Test Director at TRA involved the user (31st Test and Evaluation Squadron [TES]) in nearly all aspects of the program. He also involved the JPO in the test planning.

CGS

The CGS consists of the LRE and MCE. LRE 1 was delivered to TRA in November 1996 for air vehicle integration testing and then sent to Edwards AFB in October 1997 to support Phase II flight testing. MCE 1 was delivered to TRA in October 1997. Subsequently, LRE 2 was delivered to TRA in June 1999 and MCE 2 in September 1999.

CGS performance was always a major concern to the flight test program, since much of the Global Hawk capability was embedded into the ground segment. The performance of both the LRE and MCE was satisfactory with no significant problems being uncovered. However, because of lack of trained personnel and lack of spares, the CGS was never given the opportunity to demonstrate its ability to simultaneously control multiple air vehicles.

[19] Innovative Development, Global Hawk and DarkStar, Flight Tests in the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Page 21

Mission Control Element (MCE)

Launch and Recovery Element (LRE)

CGS = MCE & LRE

Comparison to U-2

In 1997, Air Staff performed a comparison between the Global Hawk and U-2 systems. It was already known that the Global Hawk had one significant advantage in that it was designed for a minimum loiter time of 24 hours; whereas, the U-2 was only capable of missions in the range of 8-10 hours. As part of the comparison, Air Staff reviewed the 1997 mission decks for the U-2. It was concluded that the Global Hawk could perform 100 percent of all U-2 missions except one. For that one case, the Global Hawk could perform about 60 percent of the mission because of sensor limitations. The study found that the Global Hawk was better suited for the broad-area surveillance mission (of primary concern to DARO) than was the manned U-2 aircraft. The U-2 required a smaller fleet and had better range on their radar. However, Global Hawk was far cheaper, and its lesser sensor capabilities were deemed to meet the needs of the "exploitation" community. The Global Hawk sensors, both EO/IR and SAR, were new developments, not Government-furnished equipment (GFE). They were much smaller and required much less power than the U-2 sensors. However, the Global Hawk sensors were "custom fit," making the sensors harder to replace. The user was pleased with the results and decided that they would upgrade the Global Hawk sensor capability later in the program.

Loss of Air Vehicle 2

In some ways, the loss of AV-2 never should have occurred. The accident was truly the result of multiple coincidences. AV-2 was scheduled to fly the program's 18th sortie on Friday, March 26, 1999. Unfortunately, the flight had to be aborted. As test lead, TRA elected to re-fly the mission on Monday, March 29, 1999. The aircraft experienced an uneventful liftoff from the runway at Edwards AFB. As it climbed through 40,000 feet, the air vehicle suddenly and unexpectedly flipped over on its back, shut down its engine, and locked the flight controls into a death spin. It is reported that the chase plane kept yelling "pull up, pull up," but nothing could be done. For some unknown reason, the air vehicle was given a termination command, and, per design, there was no over-ride. The aircraft executed the termination command perfectly and crashed. The loss of the air vehicle, including payload, was estimated at $45 million.

The investigation that followed concluded that the crash was because of lack of proper coordination between Nellis AFB, Nevada, and Edwards AFB, California. The official news release that followed stated:

> "The Air Force accident investigation board has released its results concerning the possible causes of the March 29 crash of the Global Hawk Unmanned Aerial Vehicle No. 2.
>
> The mishap occurred when Global Hawk inadvertently received a test signal for flight termination from a test range on Nellis Air Force Base, NV, which was outside the frequency coordination zone in which the UAV's mission was being flown. This caused Global Hawk to go into a termination maneuver involving a pre-programmed, rolling, vertical descent from an altitude of 41,000 feet.
>
> Global Hawk No. 2, valued at approximately $45 million, crashed at 10:14 a.m. PST at the South Range at China Lake Naval Weapons Center, California. When it crashed, there was no fire, and China Lake personnel secured the site.
>
> "While this incident was unfortunate, and caused a temporary delay in our flight test program, we resumed flying May 18 from Edwards," said Col Craig McPherson, director, Global Hawk System Office, Reconnaissance Systems Program Office at Aeronautical Systems Center here. "The flight termination approach for Global Hawk has now been modified to prelude the type of incident experienced on March 29." [20]

As coincidences sometimes happen, Nellis AFB was preparing for an upcoming exercise involving the Global Hawk. By design, the Global Hawk has its own internal termination system. However, there was also the capability for an independent termination command transmitted from the ground station. As part of the preparation, Nellis AFB was performing a checkout that involved sending an independent termination command. When the independent termination command was transmitted, it worked flawlessly, and the air vehicle immediately went into a controlled crash.

Ironically, the flight resulting in loss of the air vehicle was the last flight scheduled with the independent termination system. Had the sortie taken place any time after Monday morning, the mishap would never have occurred. Needless to say, the additional independent termination system was permanently removed from the air vehicles immediately following that flight. The test program did not resume flights until May 18, 1999.

Some people have questioned whether the test authority given TRA under the Section 845 OTA was a factor in this accident. The RAND Corporation, in its contract to assess how the acquisition strategy affected program execution and outcome, offered the following insight:

> "One circumstance leading to the destruction of air vehicle 2 was the contractor's decision to re-fly on Monday the sortie that had been aborted three days before. Some participants believe that the flexibility to execute the re-flight so quickly stemmed from the contractor's status as lead for test program execution. Others believe that the Air Force would have made the same decision and executed the same quick turnaround. Most participants stated that the destruction of air vehicle 2 was not a result of the contractor involvement in the test program because Ryan relied on AFFTC for test support in any case. However, the incident report states that Ryan did not follow established notification procedures for the revised

[20] Results of Global Hawk Accident Investigation Board Released, Air Force News, Sue Baker, Aeronautical Systems Center Public Affairs, 23 December 1999

mission. Some participants further noted that Ryan had in fact followed these procedures and had provided the necessary information to the appropriate office at Edwards AFB. Unfortunately, the person who normally handles frequency management coordination at Edwards was on leave that day. Other participants noted that had the Air Force Flight Test Center (AFFTC) been the Responsible Test Organization (RTO), it might not have approved the Saturday workload that was required to support a Monday flight owing to manning and flight operational tempo issues. Considering all of these views, it is not clear if the contractor's designation as lead for test program execution played a role in the loss of air vehicle 2." [21]

Conclusion of Phase II

Duration of the Phase II flight test program did end up slipping by four months. What was originally a 12-month program ended up taking 16 months. Loss of AV- 2 was certainly a player in the program slip, but it was not the only source, since the accident actually occurred at the 13-month point of the flight test program. Earlier problems with sorties not always meeting flight test objectives, aborts because of air vehicle failures, etc., all contributed to the slip. As a result, Phase II finished in June 1999, 24 months later than the original schedule. The flight test program did accomplish the majority of its objectives, demonstrating the airworthiness of the system and providing initial characterization of both the air vehicle and its SAR. However, the program did not demonstrate the ability of the CGS to simultaneously control multiple air vehicles. Likewise, it was unable to perform sufficient tests to characterize the EO/IR sensors, since AV-2, which crashed before completing its test objectives, was the only vehicle with the EO/IR subsystem installed.

Change in Program Management Responsibility

Program Management responsibility was originally planned to transition from DARPA to the Air Force at completion of Phase II, which was originally scheduled for July 1997. However, delays in completing Phase II resulted in the transition being delayed until October 1998.

3.2.4 Phase III

Overview

The Global Hawk program entered Phase III, the Demonstration and Evaluation (D&E) Phase, in January 1999. Phase III focused on obtaining the information necessary for the user to make a sound military utility assessment. The bulk of this phase centered on planning and executing the D&E exercises. However, some flights were still conducted to support engineering needs. Thirteen flights totaling 152 hours were conducted for functional checkout of the air vehicles: four flights for AV-3, five flights for AV-4, and four flights for AV-5. In addition, three flights totaling 21 hours were conducted for several other engineering purposes, such as validating the wing pressure.

[21] Innovative Development, Global Hawk and DarkStar, Flight Tests in the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Page 23

D&E Planning

The D&E IPT Operations Plan was released in September 1997, which documented the envisioned Military Utility Assessment process. Both USACOM (the user) and ACC (the TES) participated in the IPT. Effectiveness, suitability, and interoperability were the top three measures of performance. From these measures, operational issues were derived, exercises were defined, and assessment plans were developed. The entire process was documented in the Integrated Assessment Plan dated June 1998.

When Phase III was shortened because of schedule slips in Phase II, USACOM expressed concern over the adequacy of the user demonstration, which was now reduced to 12 months. It was feared that sufficient information would not be collected to make a definitive military utility assessment.

3.2.4.1 *Northrop Grumman Acquires TRA*

TRA was a relatively small aeronautical company. It had its roots in 1934 when T. Claude Ryan founded the Ryan Aeronautical Company. Its first aircraft was the Ryan ST or Sport Trainer, a low-wing, tandem seat monoplane. In 1937, a second civilian model was introduced, the Ryan SCW-145. This was a larger, three-seater aircraft. Interest from the Army Corps followed, resulting in the PT-16 (15 built); PT-20 (30 built); PT-21 (200 built); and, finally, the PT-22 (1298 built). Following World War II, Ryan expanded its business base to include missiles and unmanned aircraft. Some of the more significant unmanned vehicles include the Ryan Firebee unmanned target drone and Ryan Firebird (first air-to-air missile). In the 1950s, Ryan became a pioneer in jet vertical flight, developing the X-13 Vertijet and, in the early 1960s, the XV-5 Vertifan. In 1968, the company was acquired by Teledyne for $128 million, and T. Claude Ryan retired.

In the late 1990s, Northrop Grumman decided to expand their military aerospace business base into the area of UAVs. They viewed the acquisition of Teledyne Ryan as a logical choice. Teledyne Ryan had a history rich in UAVs, starting with target drones and then progressing into missiles. They also had one of the major, up-and-coming Air Force military contracts with the Global Hawk. In July 1999, Northrop Grumman finalized a $140 million buy of Teledyne Ryan. The acquisition was logically viewed by many as a move designed to bolster Northrop Grumman's presence in the UAV business. Figure 17 is a summary of Northrop Grumman's organizational history. Regarding the buy, Northrop Grumman chairman, Kent Kresa, called the acquisition "an excellent strategic fit with many of Northrop Grumman's business areas and strengthens our surveillance and precision strike capabilities."[22]

[22] Northrop Grumman Scoops Up Ryan, Flight International, 6 February 1999

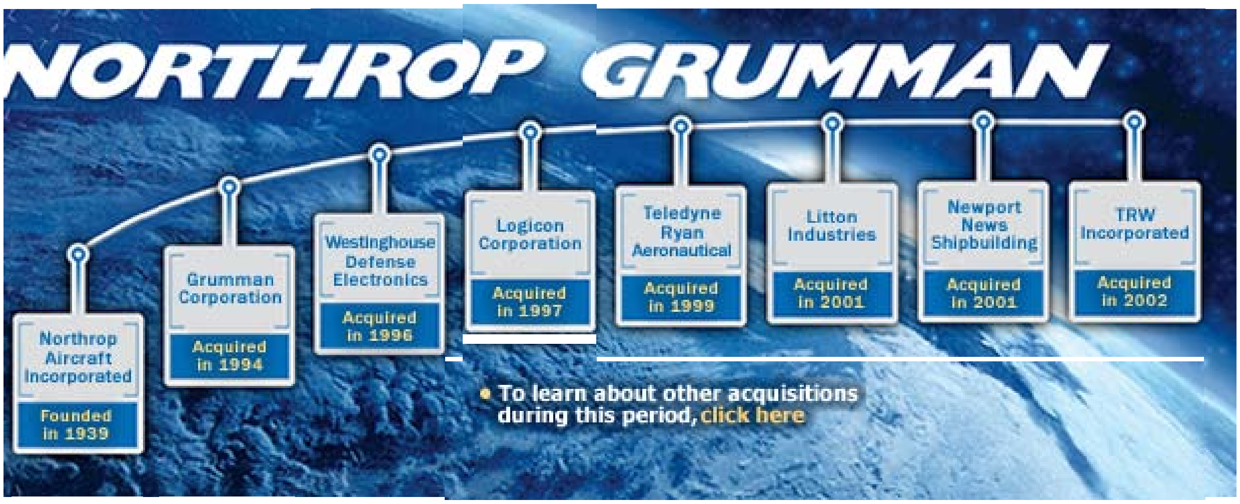


Figure 17. *Northrop Grumman History*[23]

Northrop Grumman was a much larger company with a rich history in larger aircraft programs. Some of the more significant post-World War II programs included the F-5, T-38, F/A-18, F-20, and B-2. One of the criticisms of TRA was that it was a small company geared to small drone contracts and large contracts where they served as a subcontractor. Some viewed TRA as not having the experience and engineering tools required to support a large-scale development/ production program the size of Global Hawk. Thus, many within the Air Force viewed the timing of the acquisition as a major plus, that the buy-out would strengthen the overall acquisition process. Unfortunately, the acquisition did have some negative consequences. Cost increased, and the program slowed as new people and processes were introduced. Both engineering and production moved into new facilities. With the new production facilities, came changes in production processes and tooling. All of this resulted in unavoidable disruption to the program.

3.2.4.2 *Class A Mishap*

In December 1999, an AV-3 experienced a post-flight Class A Mishap, which is defined as "an accident that results in fatality or total permanent disability, loss of an aircraft, or property damage of $1 million or more."[24] Below are the findings of the Accident Investigation Board, which is available to the general public at "http://usaf.aib.law.af.mil/index.html." The site contains the Executive Summary for each of the Aircraft Accident Investigations starting with FY00. Thus, the site does not contain the summary for loss of AV-2.

> "On 6 December 1999, at 1617 (0017 Zulu), Air Vehicle RQ-4A Global Hawk UAV, S/N 95-2003, accelerated to an excessive taxi speed after a successful, full stop landing. The air vehicle departed the paved surface and received extensive damage to the electro-optical/infra-red (EO/IR) sensor when the nose gear collapsed. Air vehicle came to rest 150 yards south of runway 22 on Edwards AFB. No damage to government or private property, other than the air vehicle,

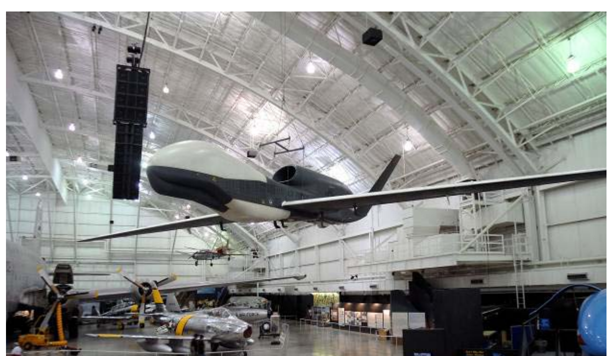
[23] http:/www.northropgrumman.com/heritage/index.html

[24] USAF Accident Investigation Boards, USAF Judge Advocate General's Corps, http://usaf.aib.law.af.mil/ AIB_Info.html, Page 1

> was sustained. The damage to the air vehicle, including the sensor package, is estimated at $5.3 million. Global Hawk AV-3 returned from its ninth flight prematurely due to a low temperature condition in the forward avionics bay. The most likely cause of this low temperature condition is the fuel bypass valve being too far open, cooling the avionics below their design limit. The air vehicle transitioned to a preplanned contingency route and returned to base. After the air vehicle landed and stopped on the runway, the command and control officer commanded the vehicle to taxi. The air vehicle accelerated in an attempt to attain the preprogrammed commanded ground speed of 155 knots.
>
> There is clear and convincing evidence that the primary cause of this mishap was the execution of a commanded ground speed of 155 knots for a taxi waypoint on the contingency mission plan. The excessive commanded ground speed was introduced by a combination of known Air Force Mission Support System and Global Hawk Aircraft/Weapon/Electronic software problems. Once the erroneous taxi speed was introduced, the mission planning and mission validation processes failed to recognize or correct the error.
>
> The air vehicle autonomously executed the taxi portion of the mission plan, ultimately causing it to depart the paved surface. Due to limitations in the Launch and Recovery Element, there was insufficient time for the test team to recognize the situation and stop the air vehicle prior to it departing the paved surface."

The AV-3 mishap, coupled with loss of AV-2, had three significant impacts on the flight test program: 1) both mishaps involved loss of the EO/IR sensor, resulting in no representative EO/IR imagery being generated during the demonstrations; 2) the demonstration program never had two flyable aircraft available at a given time, thus, never permitting multiple air vehicles to participate in a given exercise; and 3) the flight test program was shut down for three months.

AV-3 was repaired and returned to flight status. It became a workhorse of the Global Hawk fleet, amassing many sorties. On August 12, 2008, AV-3 was put on display at the National Museum of the United States Air Force (NMUSAF) near Dayton, Ohio. According to George Guerra, Northrop Grumman Vice President for High-Altitude, Long-Endurance Systems, "The Global Hawk UAV-3 provided unprecedented intelligence information to battlefield commanders almost continuously since being pressed into service in 2001, deploying three times in support of the global war on terrorism … The men and women who built and operated this aircraft take great pride in its historical performance, logging more than 4,800 flight hours, 167 missions and hundreds of thousands of images." [25]



AV-3 Hanging in Museum at Wright-Patterson AFB

[25] New Global Hawk Exhibit Opens at Museum, Air Force Link, 15 August 2008

3.2.4.3 Change in Flight Test Responsibility

Initially, all program participants accepted the arrangement that TRA would be the RTO, while the JPO would accept accident liability and responsibility for contingency planning and accident investigation. This arrangement was consistent with Section 845 OTA, whereby the contractors are given broader responsibility. However, the AV-3 post-flight taxi accident changed the Air Force's attitude. AFFTC believed that it could no longer ensure safety without being designated as the RTO. The Commander of Edwards AFB would not agree to continue flight testing under the original structure. Eventually, the issue was resolved at the three-star officer level (EAF/CC and ASC/CC), and, on February 7, 2000, AFFTC was designated as the RTO.

3.2.4.4 Configuration Changes

As typical of any development program, the Global Hawk design changed as the result of flight testing. Generally speaking, the changes were small and did not impact the D&E program. Block 1 modifications were incorporated into the delivery of AV-4 and AV-5. These included the addition of a second radio, as well as improvements to the navigational and fuel systems. AV-1 was also given the upgrade, as well as AV-3 during its repair following the post-flight taxi accident.

3.2.4.5 Military Utility Assessment (June 1999 through June 2000)

The Military Utility Assessment was a key element of Phase III. Simply speaking, the purpose of the assessment was to determine whether or not the Global Hawk system would provide the military commanders with the ability to significantly impact the outcome of combat operations. The assessment was conducted by the United States Joint Forces Command (USJFCOM) during the time period of June 19, 1999, through June 19, 2000. The process included the collection, analysis, interpretation, and reporting of data obtained during operational exercises and demonstrations. Detachment 1 Air Force Operational Test and Evaluation Center (AFOTEC) collected the data and provided the results directly to USJFCOM. Representatives from ACC's 31 TES participated in the operations and assisted in the collection of data.

The year-long schedule of events was divided into three progressive stages: crawl, walk, and run. The crawl stage was intended to demonstrate the Global Hawk system basic capability. The walk stage was designed to begin stressing the system by increasing the operational tempo, number of scenes collected, and sortie duration. The run stage was designed to demonstrate the Global Hawk's ability to influence a battle. The demonstration included four air vehicles, three LREs, and two MCE stations. All sorties originated from and ended at either, Edwards AFB or Eglin AFB, Florida. The primary task during a sortie was to fly the pre-planned mission duration and collect imagery data of the target areas identified in the collection plan.

The Military Utility Assessment consisted of 21 sorties supporting 11 exercises that totaled 381 flight hours. The exercises supported follow:

- Roving Sands 1 (June 19, 1999)
- Roving Sands 2 (June 26, 1999)
- Roving Sands 2B (June 27, 1999)
- Extended Range 1-1 (July 15, 1999)
- Extended Range 1-2 (July 27, 1999)

- Extended Range 2/JFEX-Combined Arms Exercise (CAX) (August 30, 1999)
- CAX 99 – Marine Corps Exercise (September 9, 1999)
- Extended Range 3-01 Navy Seals (October 4, 1999)
- Extended Range 3-02 Navy Seals and Close Air Support (October 8, 1999)
- Extended Range 4-01 Alaska (October 19, 1999)
- Extended Range 4-02 Alaska (October 25, 1999)
- Desert Lightning II (November 9, 1999)
- Desert Lightning II (November 13, 1999)
- Desert Lightning II (November 17, 1999)
- Joint Task Force (JTF)-6 Sortie 1 (December 3, 1999)
- JTF-6 Sortie 2 (December 6, 1999)
- D&E Deployment to Eglin AFB (April 20, 2000)
- Linked Seas-1 (May 8, 2000)
- Linked Seas-2 (May 11, 2000)
- JTF Exercise (JTFEX)00-1 (May 18, 2000)
- JTFEX00-2 (May 19, 2000)

Figure 18 represents the distribution of sorties over time. December 1999 to March 2000 represents the stand-down time resulting from the AV-3 post-flight accident.

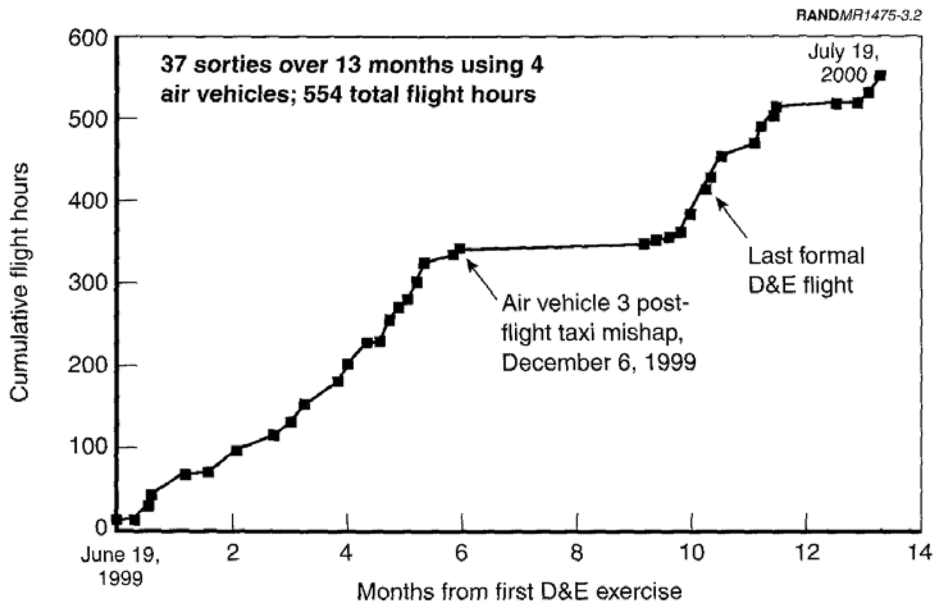


Figure 18. *Phase III Light Test Program*[26]

Eglin Deployment

The deployment to Eglin AFB and the subsequent participation in the Link Seas and JTF exercises were the most eventful sorties of the assessment. The flight to Eglin AFB on April 20, 2000, provided the Global Hawk with the opportunity to demonstrate to the Coast Guard the ability to generate images of the shipping activity in the Gulf of Mexico. It also represented the first time that the Global Hawk flew in national airspace. To do so, the JPO worked closely with the Federal Aviation Administration (FAA) to gain their permission. The FAA had significant concerns with a UAV flying over populated areas. Thus, the JPO and Northrop Grumman worked closely together to define flight paths that avoided populated areas.

During the ferry flight from Edwards AFB to Eglin AFB, the air vehicle encountered cold temperature problems with fuel in the wing. Since there was no active cooling system on the plane, avionics used the fuel in the wing as a heat sink. Unfortunately, the avionics was not generating sufficient heat to keep the fuel warm on the extended high-altitude mission. Consequently, the team closely monitored the fuel temperature real-time, and the air vehicle was just able to complete the flight. To support the subsequent trans-Atlantic flight, the team analyzed the fuel temperature as a function of time. One of the interesting facts of science is that the cooler the ground temperature, the warmer the temperature at altitude. Since the flight profile to Portugal was further from the equator, fuel temperature was not an issue.

The two exercises that followed the Eglin AFB deployment represented the first trans-oceanic flight to Europe and the first mission flown in one theatre of operation while under control from another.

During the Linked Seas exercise, the Global Hawk flew northward from Eglin AFB along the east coast, transmitting radar images directly to a ground station located in Fort Bragg, North

[26] Innovative Development, Global Hawk and DarkStar, Flight Tests in the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Page 26

Carolina, and to the aircraft carrier USS George Washington stationed in Norfolk, Virginia. One of the pictures taken was that of an earthen dam. There is a widely used expression that the program was subsequently sold on that one "dam picture." The air vehicle then continued its flight across the Atlantic where it monitored shipping movements. Above Portugal, it gathered radar images of an amphibious landing operation near Setubal. The exercise involved the joint Services; North Atlantic Treaty Organization's (NATO's) Supreme Allied Command Atlantic; its regional command SOUTHLANT; and several NATO countries, including Portugal. The air vehicle returned to Eglin AFB 28 hours later.

During the JTFEX exercise, the Global Hawk flew through three air traffic control zones above the Atlantic. It provided direct support for the joint maritime mission of a Navy Carrier Battle Group and Marine Expeditionary Unit in a land-sea environment. The Global Hawk returned to Edwards AFB on June 19, 2000, concluding the 13-month user demonstration program.

Conclusions and Recommendations of the Assessment

The military utility assessment provided very positive conclusions and recommendations. It concluded that the Global Hawk did demonstrate a military utility and that it could fly 32-plus-hour sorties, collect high-quality SAR images, and complete almost any type of operational mission. The assessment recommended the following:

- Expeditiously field an operational version of the ACTD system
- Enter the formal acquisition system with Milestone II and Low Rate Initial Production (LRIP) decisions
- Use spiral development to upgrade capabilities over time
- Improve mission planning
- Provide robust worldwide satellite communications (SATCOM)
- Aggressively coordinate efforts with the FAA to expand UAV operations.

The assessment went a long way to convince the naysayers of the potential value of the unmanned Global Hawk. The Global Hawk was now seen as a legitimate compliment to, or replacement for, the aging U-2. The Global Hawk had demonstrated some advantages over the U-2, such as range, endurance and not exposing a pilot to danger. However, as presently designed, it did not match 100 percent of the U-2 capabilities. The Air Force was now planning to upgrade the second generation of Global Hawks, so the system would be more similar in capabilities.

3.2.5 Phase IV

The original expectation was that the Global Hawk design would be ready for immediate production and operational use at the conclusion of Phase III. However, it was eventually realized that the program schedule, budget, and acquisition implementation did not accommodate the kind of detailed engineering necessary to support a production go-ahead. For example, sufficient flight testing was not conducted to properly characterize the aerodynamic properties of the air vehicle. Static and fatigue article testing was not conducted to characterize the airframe life. Durability and damage tolerance testing was not conducted to characterize the life of the components. Environmental test data were not available to substantiate the component performance for extended periods of time at altitude.

As a result, sufficient data were not available to define and verify many of the requirements necessary for a production decision. The ACTD phase did not result in a validated System Specification and corresponding lower-tiered specifications, as required by the Air Force to procure and accept future air vehicles. Consequently, a congressional decision was made not to pursue production immediately following the conclusion of ACTD. Therefore, Phase IV never materialized.

3.2.6 Summary of ACTD

Program Cost. Over the duration of the ACTD, the costs associated with specific activities grew significantly, but the program took steps to limit the total cost impact to the Air Force. In December 1994, the estimate for the Global Hawk portion of the ACTD program, through completion of Phase III, was $512 million. The actual cost to the Government was $963 million. However, the figures can be misleading in that cost growth was minimized by changing program content. For example, of the 10 originally planned air vehicles, only seven were purchased. Likewise, fewer sensor payloads were procured, and significantly fewer flight hours were accumulated.

Schedule

There is no clear, unambiguous end date for ACTD. In reality, there are four possibilities:

1. Final Phase III flight (July 9, 2000)
2. Release of the Military Utility Assessment Report (September 2000)
3. Conclusion of activities put on contract during the ACTD program (February 2001)
4. Milestone II decision for transition to the formal acquisition process (March 6, 2001)

Depending on which date is used, the total duration of ACTD was between 69 months (October 1994 through July 2000) and 77 months (October 1994 through March 2001). Since Phase III was originally planned for completion in December 1999, the total slip in final schedule was between seven and 15 months.

Practically speaking, one may argue that the ACTD ended with completion of the flight test program, which provided the data necessary for proceeding forward. If one chooses that date, then Figure 19 depicts how the key milestones slipped throughout the ACTD.

Milestone	May 94	Jun 95	Mar 98	Jul 00
Phase I				
Contract Award	Oct 94	Oct 94	Oct 94	Oct 94
End Date	Apr 95	Apr 95	Apr 95	Apr 95
Phase II				
Contract Award	Apr 95	May 95	May 95	May 95
First Flight	Dec 96	Dec 96	Feb 98	Feb 98
Duration of Flight Test	Dec 96-Dec 97	Dec 96-Dec 97	Nov 97-Nov 98	Feb 98-Jun 99
Phase II End	Jul 97	Dec 97	Oct 98	Jun 99
Phase III				
Start	Jul 97	Dec 97	Oct 98	Jan 99
Military Utility Assessment	Dec 97-Dec 99	Dec 97-Dec 99	Dec 98-Dec 99	Jun 99-Jun 00
End	Dec 99	Dec 99	Dec 99	Jul 00

Figure 19. *Evolution of Key Milestones during ACTD*

Flight Test

Figure 20 provides a summary of the ACTD flight test program. Of the 21 sorties flown in Phase II, 17 fully meet their objectives. Of the 37 sorties flown during Phase III, 26 fully met their objectives, five partially met their objectives, and six did not meet their objectives. When objectives were not met, the flights were either re-flown, or the objectives were integrated into already planned flights.

Phase	AV-1	AV-2	AV-3	AV-4	AV-5	Total
II	12/103	9/55				21/158
III	13/225		9/122	11/168	4/39	37/554
Total	25/328	9/55	9/122	11/168	4/39	58/712

Figure 20. *Summary of Sorties/Flight Test Hours by Air Vehicle and Program Phase*

Acquisition Strategy

The RAND Corporation, in its study of the ACTD program, attributes six program outcomes to the novel acquisition approach. Below is a summary of their findings:

- “The mission planning was cumbersome and time consuming. The contractors knew at the time of the Phase II bid that significantly more funds would be required to make the mission planning system suitable for sustained operations. However, because the focus of the ACTD was on demonstrating military utility, which at the time was not well defined and did not specify timely sortie generation, a conscious decision was made to defer this investment.
- The program lacked sufficient resources both for training personnel and for providing adequate spares. This was attributable in part to the reallocation of resources within the program to cover increased nonrecurring engineering activity, and in part to a highly constrained budget throughout the duration of the ACTD.

- The pace of the flight test program was too fast given its cumbersome mission planning process and limited resources. Test personnel were clearly overburdened, which appears to have been a contributing factor in the air vehicle 3 taxi mishap.
- The designation of contractors as the lead for flight test direction, planning, and execution could have resulted in a failed program. Contractors may not have the necessary capabilities, experience, and perspective (culture) to run all aspects of a military test program….
- The differences in perspective between the ACTD and post-ACTD user communities regarding the CONOPS proved to be a serious impediment to the program's transition into the Major Defense Acquisition Program (MDAP) process….
- Differences between the ACTD and post-ACTD user in operational requirements definition are also inhibiting the program’s transition to an MDAP. The extent to which the capabilities of the ACTD configuration - demonstrated through testing - should determine the requirements for a post-ACTD system is the underlying issue. The spiral development concept planned for use in the post-ACTD development implies that requirements will evolve along with the system’s configuration and block upgrades. As a result of this process, early configurations will not have the full capability that ACC, the force provider, desires. Initial drafts of the ORD that is required for all MDAPs were not wholly reflective of the system’s demonstrated capabilities and subsequent evolution based on known shortfalls.”[27]

UFP

The $10 million UFP covered only the recurring cost of what actually “took to the air.” It was in 1994 dollars and excluded sustaining engineering, program management, and a host of other costs. By the end of Phase II, both the JPO and TRA knew that the $10 million UFP was unachievable and would be exceeded by $1 million to $3 million. The program’s sole requirement of a $10 million UFP was ultimately abandoned. The reasons for not meeting the UFP are numerous, but the following are the dominant ones:

- There was little or no analytical basis for the UFP. Instead, it was based on what the user was willing to pay.
- The UFP was based on very optimistic assumptions. For example, assumptions relative to supplier and manufacturing costs proved unrealistic.
- The unwillingness of the JPO to strictly enforce the $10 million UFP. In reality, the JPO was unwilling to sacrifice major system capability.
- The $10 million was for a 10-vehicle production of Air Vehicles 11 through 20 and assumed a buy of eight vehicles (3 through 10) had been exercised very early in the ACTD program. That did not occur. DARPA delayed the program, introduced a gap, and effectively abandoned the $10 million plan.

[27] Innovative Development, Global Hawk and DarkStar, Flight Tests in the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Pages37-40

According to one of the RAND reports, "No serious analysis underlay the UFP. To our knowledge, this number was not connected to desired Tier II+ or Tier III- capabilities in any analytical sense. Instead, we believe that the $10 million UFP was selected because it was judged to be high enough to provide a system with meaningful capability if adhered to, yet at the same time low enough that the Air Force would be willing to pay for it. The originators of the program believed that the price must be set at an artificially low level or the program would be abandoned even before it began. The DoD was compelled to use this tactic because of the false notion embedded in the Air Force culture that UAVs are inherently less complicated to develop and build than manned aircraft with similar capabilities."[28]

In reality, the cost of AV1 and the learning curve for AV2 showed the contractor on a reasonable track to achieving the $10 million requirement had the Government stuck to the original plan (e.g., aircraft buy, requirements, etc.).

Baseline Definition

The ACTD phase did an excellent job in developing and demonstrating the military utility of the Global Hawk system. It participated in 11 combat-type exercises involving 21 sorties and 381 flight hours. The subsequent Military Utility Assessment Report was very positive and endorsed continuation of the program. However, the acquisition strategy called for production immediately following Phase III, and the information generated during ACTD did not support this approach. System development activities conducted during ACTD were robust and supported the objectives of this phase. Pre-flight analyses and tests were comprehensive and allowed entry into the flight demonstration phase with acceptable risk. Subsequent flying activities demonstrated the considerable performance capabilities of the system. All of the contractor-defined design requirements were successfully demonstrated except for engine out landing, which was not demonstrated because of a high risk of vehicle loss. This did not necessarily mean, however, that a full quantitative engineering characterization of the system had been accomplished. For example, a proof test of the wing structure (flight article) to 100 percent design limit load (DLL) was conducted; this provided limited substantiation of the design and verification of the "as built" product integrity of this specific flight article. However, budget considerations did not allow for the conduct of static load testing of a fully instrumented dedicated test article to ultimate load (1.25 x DLL) to fully validate the design; nor did they permit durability/life testing of the airframe structure or individual components. Likewise, the ACTD flights demonstrated the ability of the vehicles to survive and function successfully in extreme environmental conditions (e.g., very low air temperatures at high altitude), but no service life qualification of subsystems and components using the defined environments was accomplished for the same reason. In reality, the contractor wanted to do more testing. For example, they submitted a proposal to conduct structural testing to ultimate load, especially on the wing, but DARPA was forced to reject it because of lack of funding. As a result of programmatic decisions, Phase II and Phase III did not produce a verified set of specifications necessary to completely define the product baseline for production; there were no validated System Specification, Air Vehicle Specification, or lower-tiered specifications produced in the

[28] Innovative Development, Global Hawk and DarkStar - Their Advanced Concept Technology Demonstrator Program Experience, Executive Summary, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Page 16

ACTD phase. In essence, the successful outcome of the program was impacted by inadequate upfront funding.

Conclusion

The ACTD phase was categorized as successful. It demonstrated the technology of a UAV whose primary mission is to provide overt, continuous, long-endurance, all-weather, day/night, and near-real-time wide area reconnaissance and surveillance. However, it did not result in a system that was ready to enter production. This was primarily because of customer decisions to reduce ACTD program scope and content to stay within cost targets.

3.2.7 Collier Trophy

The Robert J. Collier Trophy was established in 1911 with Glenn H. Curtiss being the first recipient for his successful development of the hydro-aeroplane. In 1929, the Collier Trophy was designated as a national award honoring those who have made significant achievements in the advancement of aviation. The name became official in 1944, with the award being presented once a year by the President of the United States. The trophy is on permanent display at the National Air and Space Museum.

The Global Hawk Program was awarded the 2000 Collier Trophy. The trophy was presented on May 8, 2001, by Don Koranda, President of the National Aeronautic Association, to the Northrop Grumman Corporation, Rolls-Royce, Raytheon Company, L-3 Communications, Air Force, and DARPA "for designing, building, testing, and operating Global Hawk, the first fully autonomous, operationally demonstrated, and most capable surveillance and reconnaissance unmanned aerial vehicle in the world."

3.3 Engineering and Manufacturing Development (EMD)/Production Phase

3.3.1 EMD

3.3.1.1 *Acquisition Strategy*

Definition of Spiral Development

Spiral development, as the wording implies, addresses the incremental development of a capability. Other terms, such as blocks and lots, address the production of the system. Air Force Instruction (AFI) 63-123, Evolutionary Acquisition for C2 Systems, Paragraph 4.1, dated April 1, 2000, describes spiral developments as follows:

> "The spiral development process is an iterative set of sub-processes that may include: establish performance objectives; design; code, fabricate, and integrate; experiment; test; assess operational utility; make tradeoffs; and deliver. Other sub-processes may be added as needed. Spiral development characteristics include: a team of stakeholders motivated to collaborate and mitigate risk; a development plan and decision process; a process to refine requirements; a firm schedule per increment; continued negotiation of performance and cost goals; test/experimentation; and a user decision to field, continue development, or terminate any portion of the increment. Experimentation, which includes simulation and exercises, allows all concept stakeholders to solidify their understanding of a concept beyond paper studies or ideas. When strung together, spirals facilitate more precise and rapid maturation of new technologies and

> refinement of user requirements with high operational utility into a complete capability for one increment. The key intent is for the system and the fidelity of its requirements to evolve together with iterative feedback. Feedback can originate from multiple sources including experiments, test and evaluation, the Air Force Modernization Planning Process (MPP), radio frequency management, operational experience, and user participation."

Col. Wayne M. Johnson, Director of the Global Hawk program at the start of EMD, provides a simpler definition:

> "But for practical purposes, a spiral acquisition could also be defined as a set of acquisition activities incrementally incorporated into an evolving baseline. Each increment or spiral increases capability and does so in a rapid pace, with each spiral building on the previous spiral and spreading risk and development costs over a longer period of time. Each spiral is made up of one or more projects developed independently to the maximum extent possible. When each of the developments is ready, it is dropped into the production baseline. Testing, both internal to the program (DT&E) and external (IOT&E) is done incrementally." [29]

Post-ACTD Planning

Cancellation of the DarkStar program had been discussed by the OSD and Air Force since early 1998. Post-ACTD planning for the HAE program (Global Hawk and DarkStar) was specifically delayed until the fate of DarkStar was decided. Once the DarkStar contractors were ordered to cease activity on January 29, 1999, the Global Hawk Program Office was given permission to proceed with post-ACTD planning. The planned start date for the next phase coincided with release of the Military Utility Assessment and completion of Phase III, which were both scheduled for June 2000.

Guidance for the post-ACTD activities were documented in the Single Acquisition Management Plan (SAMP). The initial May 1999 draft did not address many of the programmatic issues, such as identifying further development activities, procurement buys (quantities and schedule), and continued use of Section 845 OTA. Global Hawk planning as of July 1999 included $420 million in the current Five-Year Defense Plan (FYDP) and $25 million reallocated by Congress to cover fourth quarter FY00 post-ACTD activities.

The post-ACTD activities included a one-year EMD program. This was required to comply with the congressional direction contained in the FY99 Authorization Conference Report, which required that the Global Hawk complete an EMD phase before entering production.

Post-ACTD options were requested by both OSD and Secretary of the Air Force (SAF)/AQ. In preparation for a July 1999 USD (A&T) program review, the Program Office developed 10 different options, eight of which were presented at the program review. The options presented ranged from buying the existing ACTD configuration with no additional funds beyond those already programmed, to a two-year EMD program that would develop and deliver a Block 10 configuration with a budget increase of $690 million.

[29] The Promise and Perils of Special Acquisition: A Practical Approach to Evolutionary Acquisition, Col. Wayne M. Johnson, USAF (ret) and Carl O. Johnson, Acquisition Review Quarterly, Summer 2002, Page 177

The program review provided a broad outline of the post-ACTD acquisition strategy. However, it did not define the specific structure. Instead, planning would continue with a focus on the three options outlined in Figure 21. The review did give the Program Office the approval and authority to proceed in defining the details associated with the EMD activities. Unfortunately the Program Office had only one year to finalize the details and prepare the required documentation.

On August 20, 1999, the Intelligence Program Decision Memorandum 1 was released, which provided some specific guidance for future program planning. As part of the overall strategy, the memorandum required the program to:

- Buy two air vehicles (AV-6 and AV-7) in FY01 in order to protect the industrial base.
- Initiate a one-year EMD program in FY01.
- Initiate production in FY02 at the rate of two air vehicles per year.
- Use spiral development to satisfy the ORD and address issues identified in the Military Utility Assessment.

	Option 5	Option 6	Option 7
Cost Increase over FY 2001 POM	$450M	$510M	$390M
Duration of EMD	1 year	2 year leading to Block 10	2 year
Block 5	8 A/Vs + 2 CGSs within FYDP	2 A/Vs Concurrent development & production	N/A
Block 10	Deferred beyond FYDP	6 A/Vs + 2 CGS within FYDP	2 A/Vs per year starting in FY 03 with 1 A/V prior to production units. 1 CGS within DYDP
Draft ORD Compliant	Block 5 would not meet many requirements	Block 10 would satisfy requirements	Block 10 would satisfy most requirements
Risk	Low-to-Moderate	Low-to-Moderate	Moderate

Figure 21. *Options Resulting from Decision Memorandum signed July 11, 1999*

In September 1999, the Deputy USD (A&T) proposed a $510 million FYDP plus-up to the program to cover a) a one-year EMD program leading to production of Block 5 air vehicles; b) production of Block 5 air vehicles; and c) a follow-on EMD program leading to production of Block 10 air vehicles. The Air Force was unhappy with the plus-up, because it would come at the expense of other programs. Consequently, the Air Force Vice Chief of Staff asked for only an additional $390 million to the Program Objective Memorandum (POM) line for the Global Hawk, promising to accomplish the same program content. This decrease in funding would haunt the program in the upcoming years.

The specific configuration of Block 5 and Block 10 remained undefined. The plan was to baseline the configuration at the conclusion of EMD, using spiral development. Capability would be improved in each subsequent block or spiral upgrade.

The Analysis of Alternatives (AoA) was soon developed and briefed to senior Air Force decision makers on January 14, 2000. The AoA recommended upgrades to the radar, mission planning, common data link, ultra-wideband SATCOM, survivability suite, and supportability. A draft ORD was released immediately thereafter, incorporating the AoA recommendations.

As of March 2000, the following program risks still remained:

- "All requirements had not yet been defined;
- Resource constraints allowed either EMD or contingency deployments, but not both;
- Funding was insufficient to support concurrent EMD and production;
- Facility constraints remained in terms of ramping up production rates;
- Insufficient funding was programmed beyond Spiral 1 (Block 5);
- Technical training and data may not be complete by Initial Operational Test and Evaluation (IOT&E);
- Program faced potential unavailability of parts due to vanishing vendors; and
- Systems available for IOT&E might not be production representative." [30]

In November 2000, the Program Office released an approved SAMP for the post-ACTD program as depicted in Figure 22. The SAMP included much of the detail previously lacking in earlier versions. Several important aspects are as follows:

- Northrop Grumman was given Total System Program Responsibility with Raytheon being a subcontractor for the ground segment.
- Contracts for EMD, Production, and Logistics would be according to the Federal Acquisition Regulations (FARs), not OTA.
- Spiral development would be used at least for Block 5 and Block 10 and would begin in FY02.
- Block 10 would be ORD-compliant and include active electronically scanned array technology and signals intelligence (SIGINT) capabilities.

By changing to a traditional FAR-based contract, an extensive list of program documents were now required. Below is a list of the more significant documents:

- ORD
- Program Management Directive (PMD)
- Systems Engineering Master Plan (SEMP)
- Test and Evaluation Master Plan (TEMP)
- SAMP
- Defense Acquisition Executive Summary (DAES)
- Selected Acquisition Report (SAR)
- Acquisition Decision Memorandum (ADM)
- System Requirements Document (SRD)

[30] ASC/RAV Early Strategies and Issues Session Briefing, March 2000

- System Performance Specification
- Monthly Acquisition Report (MAR)
- Cost Performance Report (CPR)
- Contract Funds Status Report (CFSR)
- Contractor Cost Data Report (CCDR)

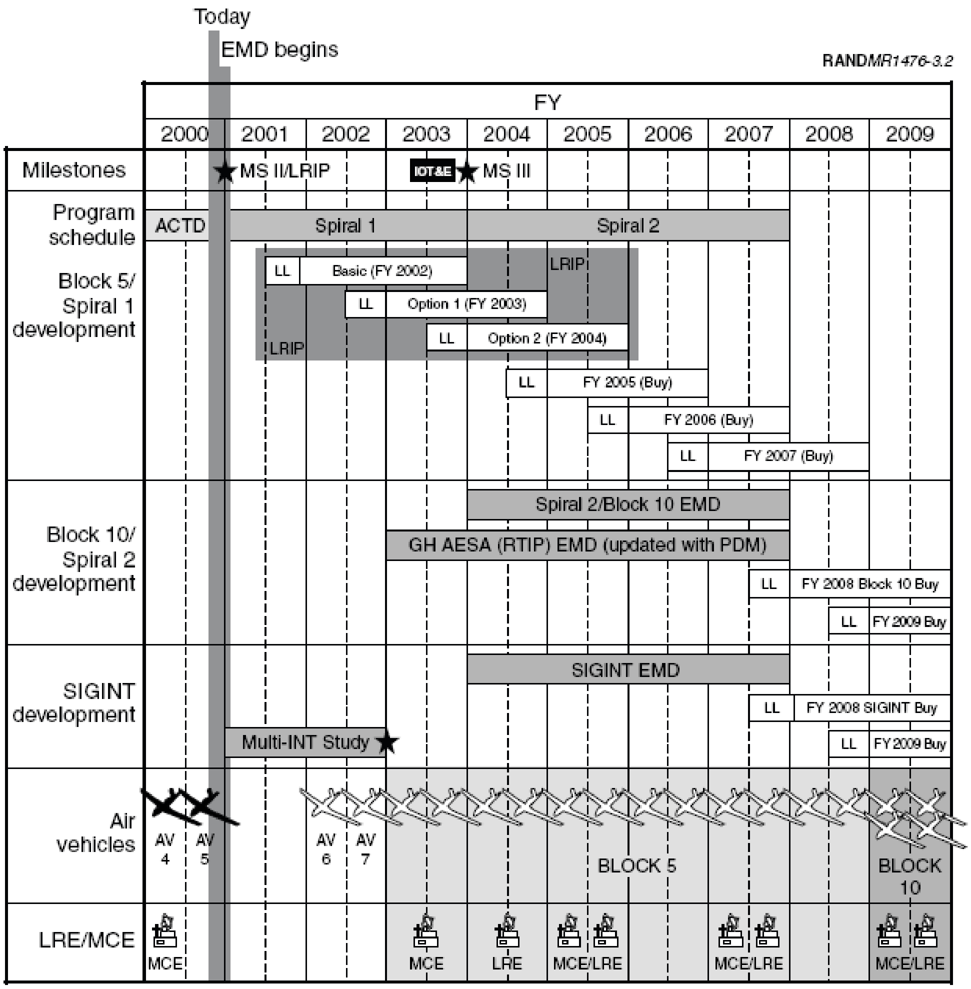


Figure 22. *Global Hawk Baseline Program circa December 2000*[31]

Configuration Changes

The Block 1 configuration was that of AV-4 and AV-5. The Block 2 aircraft, AV-6 and AV-7, were put on contract in December 1999 and were scheduled to be delivered in FY02.

Spiral 1 (Block 5) aircraft were now scheduled to be delivered in FY03 at a production rate of two aircraft per year through FY06. The Spiral 1 upgrades were to include GATM compliance;

[31] Innovative Development, Global Hawk and DarkStar, Transition Within and Out of the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002, Page 39

upgrade of processors for the Integrated Mission Management Computer and SAR; replacement of vanishing vendor items; enhanced mission planning to reduce the planning cycle to 12 hours; and an open system common data link. By March 2002, ACC identified their Block 5 "must dos." These included a ground moving target indicator, EO/IR sensor characterization, ground safety camera, and see-and-avoid/detect-and-avoid equipment.

Spiral 2 (Block 10) aircraft included major upgrades not funded until the FY01 POM. Block 10 included a survivability suite, weather detection, electrical power improvements, and sensor improvements.

3.3.1.2 *EMD Contract Award*

The Milestone II decision continued to slip for a variety reasons. Finally, in February 2001, a favorable decision was rendered. ASC at WPAFB then awarded Northrop Grumman the EMD contract for Spiral 1 in March 2001, about five months later than the baseline schedule shown in Figure 22.

Some form of an EMD program was congressionally mandated by the direction contained in the FY99 Authorization Conference Report. The Air Force's approach was to keep EMD to a minimum, completing Spiral 1 in just one year. The overall program strategy was to let each configuration remain undefined at the start of its EMD and define the baseline at the conclusion of its EMD. Capability would be improved in each subsequent block or spiral upgrade. To convey some basic set of requirements at the start of the Spiral 1 EMD, a Draft EMD SRD was included in the contract. It was a four-page draft document that basically addressed the following overall system requirements:

- Minimum endurance capability to transit 1,200 nautical miles, remain on station for 24 hours, and return to base
- Worldwide operation in all classes of airspace
- Near-real-time mission control, mission monitoring, and mission updates/modifications
- Capability to satisfy 100 percent of the top-level Information Exchange Requirements
- ORD requirements for reliability, maintainability, and sustainability

Because of limited funding and schedule, not all of the ORD requirements were incorporated into Spiral 1. One example was the requirement for a single-point refueling system. This requirement was subsequently incorporated into Block 20. Unfortunately, delaying incorporation of ORD requirements extended throughout the program as requirements originally identified (and sometimes funded) for particular Blocks, such as the Weapon System Trainer, were forced to be deferred. To address this issue, ACC eventually partnered with the Program Office to form the Requirements Planning Working Group. ACC makes the point that they have been accused at times of "requirements creep," but the reality is that they were merely advocating incorporation of long-deferred requirements.

The program's approach to defining and managing the technical requirements continued to be unique. The EMD contract included a draft SRD instead of a System Specification, and the SRD did not contain the normal level of detail associated with a System Specification. The intent was to evolve to the baseline technical requirements at completion of EMD, thus, providing the contractor with greater contractual latitude. Normally, a program would use the contractual

System Specification as a basis for the system design and verification accompanying EMD. The contractual System Specification is a double-edged sword in that it establishes the minimum set of design requirements that the Air Force will use to judge the program's success/compliance, and it protects the contractor against requirements creep. With the baseline not being defined until completion of the EMD phase, program risk increases in that either the technical performance or cost expectations may not be met.

Statement of Work (SOW)

The SOW designated Northrop Grumman as the prime contractor with Total System Performance Responsibility (TSPR) for the Global Hawk system, including the air, ground, and support elements. It further stated that spiral development was to be used to develop the key system improvements, and IPTs would be used in the program management of the tasks. The specific non-recurring engineering tasks identified in the SOW included:

- Worldwide Operations with areas to include tailored GATM requirements and See and Avoid requirements
- Mission updates
- Capability to retrofit AV-7 in support of testing and validation

The SOW specifically addressed many of the products directly related to a FAR-based contract. For example, the SOW included a requirement for the contractor to prepare and submit a Contractor Work Breakdown Structure (CWBS); a CPR, using Northrop Grumman's Earned Value Management System (EVMS); and a CFSR. Also included in the SOW were requirements for:

- An IMS that detailed all activities for the Global Hawk system, including the Air Vehicle, Ground, and Support Segments
- Reliability Analysis
- Aircraft Structural Integrity Program (ASIP) Master Plan
- TOs

The SOW also contained a requirement for Northrop Grumman to support demonstrations and exercises at the direction of the Contracting Officer. Northrop Grumman was required to maintain all available air vehicles, ground segments, and support segments in a condition suitable for the unspecified flight operations.

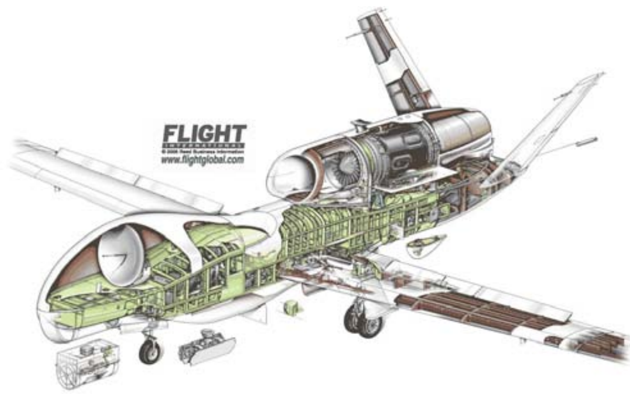
Many of the typical engineering activities associated with a program of this magnitude were not specifically mentioned in the SOW. However, some were implied under the Configuration Management section, which required that specific documentation be provided in the Program Document Library or hard copy. Some of the more significant documents to be included in the Program Document Library were:

- System, Segment, and available lower-tier specifications
- Interface Control Documents (ICDs) and Interface Definition Documents (IDDs)
- Software Requirement Specifications (SRSs), Software Design Documents (SDDs), and Version Description Documents (VDDs)

- System Integration Plans, Subsystem Integration Procedures, and UAV Level Acceptance Test Procedures
- IMP and EVMS Metrics
- Integrated Logistics Support Data

Airworthiness Certification, a new Air Force requirement just established in October 2000, was only indirectly mentioned through its inclusion in the list of Applicable Documents.

3.3.2 Production



In June 2001, just three months after EMD contract award, Northrop Grumman was awarded a contract for LRIP of two air vehicles (P1 and P2) and one MCE. The completion date was December 2003. The start date represented a three-month slip to the schedule shown in Figure 22 and was because of a five-month slip in both the Milestone II decision and start of EMD. The most significant aspect of the acquisition strategy was the concurrency of EMD and Production. This obviously injected additional program risk and would require careful execution and monitoring.

The production process followed by the Global Hawk program involved the terms “blocks” and “lots.” Simply speaking, the relationship between block, lot, and spiral can be explained as follows:

- Spiral refers to the incremental development of a system capability.
- Block represents a series of aircraft with the same capability. Thus, a given block contains a specific spiral (or set of spirals).
- Lot represents a series of aircraft procured under a given authorization. A lot can involve one or multiple blocks of aircraft.

Figure 23 shows the relationship between blocks, lots, and spirals as ultimately implemented on the Global Hawk program. Note that the program dropped the term Block 5 and replaced it with Block 10; i.e., Spiral 1 now refers to the capabilities incorporated into Block 10.

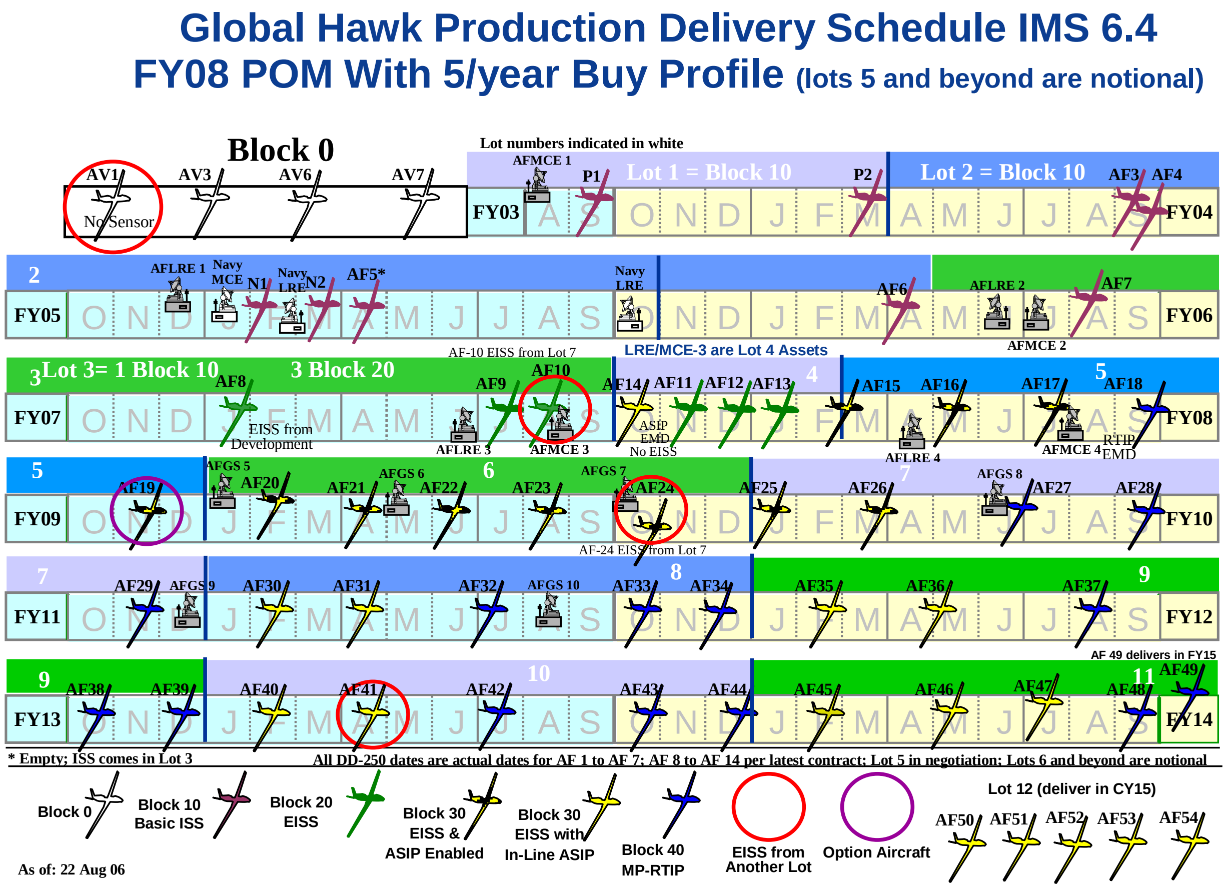


Figure 23. *Relationship between Spirals, Blocks, and Lots*[32]

3.3.3 Supporting Contractors

As with any large contract, Northrop Grumman forged contractual relationships with a multitude of subcontractors. The principal subcontractors were as follows:

- Raytheon Systems for the ground segment and sensors
- Rolls-Royce for the turbofan engine
- Vought Aircraft for the carbon-fiber wing
- L-3 Communications for the communications system

3.3.4 Australian Deployment

The EMD contract required that Northrop Grumman support demonstrations and exercises at the direction of the Contracting Officer. The first of the demonstrations was a deployment to Australia. AV5 made aviation history on April 22-23, 2001, when it flew 7,500 miles non-stop from Edwards AFB to the Royal Australian Air Force (RAAF) Base in Edinburgh, Australia. This new endurance record for UAVs was completed in just 22 hours.

To support the deployment, a ground station and assessment team from the AFOTEC located at Kirtland AFB, New Mexico, was also sent to Australia. During the deployment, the Global

[32] Global Hawk Systems Engineering Plan, Version 1, October 2006, Page 5

Hawk flew 11 sorties around the country to demonstrate its reconnaissance and surveillance capabilities. The sorties included participation in the Tandem Thrust military exercise in Queensland, sorties over Australia's northwest coast, and sorties over Cape York and the Northern Territory.

The RAAF, the Australian Defense Science and Technology Organization, and AFOTEC jointly assessed the military utility of the Global Hawk. The assessment focused on interoperability, as well as the potential to fundamentally alter the force structure of the Australian Defense Force in a cost-effective manner.

The Global Hawk successfully demonstrated its ability to search large areas and detect/classify marine targets. Australian officials also determined that it would be useful for peacetime tasks, such as detecting illegal fishing, detecting illegal immigrants, and supporting national disasters. After six weeks of operations, the Global Hawk returned to Edwards AFB. The result of the deployment was a four-year agreement called Project Agreement 13 to develop the Global Hawk as a replacement for Australia's aging fleet of P-3C Orions.

3.3.5 Combat Deployments to Southwest Asia

Operation Enduring Freedom (November 11, 2001, to September 28, 2002)

9/11 had both a very positive impact in determining the future of the Global Hawk program and a negative impact to maintaining cost and schedule. The deployment to Southwest Asia allowed the Global Hawk to demonstrate its true value to the warfighter in a real-world scenario. On the other hand, it robbed the EMD program of a valuable asset, ultimately costing the program non-planned dollars and schedule time.

Immediately following the devastation of the two World Trade Center towers on September 11, 2001, the Program Office at WPAFB was requested to identify how the Global Hawk could support the War on Terrorism. The Program Office, in concert with Northrop Grumman, identified how the system could provide an advantage. As a result, AV-3 was deployed to Afghanistan in November 2001 to support Central Command's request for persistent, broad area reconnaissance and surveillance. Several members of the Program Office, both military and civilian, accompanied the deployment. During Operation Enduring Freedom, the "Global Hawk provided the Air Force and joint war-fighting commanders more than 17,000 near-real-time, high-resolution intelligence, surveillance and reconnaissance images, flying more than 60 combat missions and logging more than 1,200 combat hours." [33]

To keep the ACTD aircraft functioning, parts for AV-3 were cannibalized from AV-6. The ground station segment performed extremely well, giving the commanders a continuous wide-angle view of the battlefield that was instantly beamed to our Combined Air Operations Center in Saudi Arabia. Enemy positions would then be sent to the field commanders and pilots to destroy the targets.

In assessing its contribution to the war on terrorism, Lt Col Thomas Buckner, 12th Expeditionary Reconnaissance Director of Operations, is quoted as saying, "To know it was a technology

[33] HALE Program Overview, History and Accomplishments, Northrop Grumman Website, www.northropgrumman.com/ unmanned/globalhawk/overview.html, Page 3

demonstrator and then to (see) it sent to war is amazing….Global Hawks are in huge demand by combatant commanders. We are able to respond and be flexible for the users on the ground."[34]

Figure 24. *Electro-Optical (EO) Imagery*[35]

Operation Iraqi Freedom (March 18 to April 23, 2003)

During Operation Iraqi Freedom, the Global Hawk flew 15 missions, collecting over 4,800 images. Even though this represented only 3 percent of all the image collection missions flown, it represented 55 percent of the time-critical data on air defense targets. The sole Global Hawk "located at least 13 surface-to-air missile batteries, 50 SAM launchers, 300 canisters and 70 missile transporters; it also imaged 300 tanks, 38 percent of Iraqi's armored force—a remarkable display of the air vehicle's capability. The Joint Forces Air Component Commander credited the Global Hawk with accelerating the defeat of the Iraqi Republican Guard, shortening the duration of the war and reducing causalities, exceeding the combatant commander's expectations." [36]

During Operation Iraqi Freedom, the Air Force used a reach-back capability whereby the UAV and its sensors were remotely operated from Beale AFB, California. This was estimated to

[34] Prototype Global Hawk Flies Home after 4,000 Combat Hours, Tech. Sgt. Andrew Leonard, 380th Air Expeditionary Wing Public Affairs, Air Force Link, 14 February 2006
[35] Global Hawk Concept to Combat, Bob Ettinger, National Defense Industry Association 24th Annual National Test and Evaluation Conference, 28 February 2008, Chart 16
[36] HALE Program Overview, History and Accomplishments, Northrop Grumman Website, www.northropgrumman.com/ unmanned/globalhawk/overview.html, Page 3

reduce the Global Hawk logistics footprint by more than 50 percent. The crew used Internet-style chat rooms to provide effective C2 over a system that was spread across the globe.

Figure 25. *EO Imagery*[37]

3.3.6 Combat Losses

The contribution of the Global Hawk system to the war on terrorism was significant. This was amazing considering that the air vehicles were prototypes. However, the fact that they were prototypes meant that the system had not been subjected to the normal engineering development and test process leading to a production aircraft. Consequently, it was not surprising that two of the air vehicles were lost during the deployment. The first loss (AV-5) occurred on December 30, 2001, and was attributed to a structural failure of the right V-tail and ruddervator assembly because of a massive delamination of the main spar in the right V-tail. The second loss (AV-4) occurred on July 10, 2002, and was attributed to a fuel nozzle failure in the high flow position that eventually led to an engine failure. Below are the findings of the Accident Investigation Board, which are available to the general public at "http://usaf.aib.law.af.mil/index.html."

AV-5 Accident, December 30, 2001

"On 30 December 2001, at 1222 Local (0822 Zulu), the Mishap Air Vehicle (MAV), RQ-4 Global Hawk Unmanned Aerial Vehicle Serial Number 98-2005, was returning from a truncated operational mission in support of Operation Enduring Freedom when it departed controlled

[37] Global Hawk Concept to Combat, Bob Ettinger, National Defense Industry Association 24th Annual National Test and Evaluation Conference, 28 February 2008, Chart 23

flight, entering a right spin. There is no spin recovery capability for Global Hawk air vehicles, and the MAV came to rest in an uninhabited area approximately 80 miles south of the classified Forward Operating Location landing site. No damage to government or private property, other than the air vehicle, was sustained. The damage to the air vehicle, including the sensor package, is estimated at $40.6 million.

There is clear and convincing evidence that the primary cause of this mishap was structural failure of the right V-tail and ruddervator assembly due to massive delamination of the main spar in the right V-tail.

During the return flight, the right outboard ruddervator actuator control rod failed, allowing the ruddervator to travel unrestrained beyond its normal range. The control rod failure was a metal fatigue failure induced by a bend in the rod that occurred when it contacted an improperly installed actuator nut plate bolt. At 0822Z, while the MAV was descending through approximately 54,000 feet above sea level during the second of three 90 degree planned left turns, the lift spoilers were fully deployed to assist the descent. Twenty-nine seconds later, the MAV departed controlled flight, entering a right spin.

Once the four lift spoilers were raised to the maximum 45 degree deflection at this altitude, the ensuring turbulent air induced violent oscillations and vibrations (flutter) on the unconstrained right outboard ruddervator. The energy of the resultant flutter was absorbed by the right V-tail main spar, and quickly resulted in delamination of the spar caps and center webbing from the root to over one-third the length of the spar. The flexing of the spar and continuing flutter eventually caused failure of the double torsion box construction of the right V-tail, further subjecting the V-tail to increasing torsion (twisting) loading. The overall result was the structural failure of the right V-tail inducing the right spin."

AV-4 Accident, July 10, 2002

"On 10 July 2002, at 704 local (0404 Zulu), the Mishap Aircraft (MA), RQ-4A Global Hawk Unmanned Aerial Vehicle Serial Number 98-2004, was flying an operational mission in support of Operation Enduring Freedom when it experience catastrophic engine failure and impacted the ground. The MA came to rest in an uninhabited friendly area in the Central Command AOR. No damage to government or private property, other than the air vehicle, was sustained. The damage to the air vehicle, including the sensor package, is estimated at $40.6 million.

There is clear and convincing evidence that the primary cause of this mishap was a single fuel nozzle failing in the high flow position that eventually caused internal failure of the engine. A review of the performance of the engine experienced during the incident flight with the design analysis of the combustor with a single fuel nozzle stuck in the open takeoff flow metered position is consistent with the hardware distress observed.

The preflight through the first seven hours of flight was normal. At seven hours and two minutes into the mission the air intake fan speed decreased from 90% to 74% and the first fault message was received from the on-board computers monitoring the MA. The MA began to descend. Multiple Engine Core vibration faults followed and cleared. Approximately 15 minutes later Mishap Pilot (MP) 1 directed the MA to return to base when he received a fault message indicating that the navigation systems were functioning below acceptable limits. During the return to base, MP2 received a status brief and took command from MP1. Two hours and 10 minutes (0330Z) after the initial fault message, the MA experienced a catastrophic engine failure. The MA glided for another 34 minutes. MP2 attempted to find a suitable landing area and executed an emergency landing gear extension. The MA impacted the ground during the attempted emergency landing."

3.3.7 Spiral 2

The Global Hawk was viewed as a complement to the U-2 and perhaps even as a replacement. The RQ-4A had more range and endurance than the U-2 but less sensor performance based on the goal of a low-cost system. In order to enhance the value of the Global Hawk to the warfighter, senior Air Force leadership decided that Global Hawk should achieve U-2 parity to the maximum extent possible. A decision was made to proceed with a new Block 20 configuration that would carry both the Imagery Intelligence (IMINT) and SIGINT packages simultaneously. The Block 10 configuration would remain as an IMINT-only vehicle. As a result, the program launched into the Spiral 2 development without a full definition of the design requirements for the air vehicle and sensors; that definition would evolve at the end of Spiral 2 EMD. This represented a radical departure from the original acquisition strategy.

In 2001, a General Officer Steering Group (GOSG) recommended developing a larger aircraft in order to increase the payload from 2,000 to 3,000 pounds. Later that same year, DoD and Gen Jumper, then Chief of Staff, Headquarters (HQ) Air Force, designated the Global Hawk as a Transformational System, meaning that its capabilities were so revolutionary that it would be "fast tracked" into production. A one-page list of requirements was quickly established. The new and larger RQ-4B was to cruise at 60,000 feet for 28 hours and carry a 3,000-pound payload.

Marvin Sambur Speaking on Pathfinder Program

In early calendar year (CY)02, the Air Force awarded Northrop Grumman two new EMD contracts totaling nearly $300 million. According to Northrop Grumman, "The contracts, one for $247 million and the other for $52.8 million, awarded by the U.S. Air Force will increase weight and power in order to enhance Global Hawk's surveillance capabilities. They will cover Stage IIA and Stage IIB engineering and manufacturing development." [38]

Coincidently with the finalization of the Spiral 2 acquisition strategy, the Air Force held a series of senior management meetings in the fall and winter of 2001/2002. The meetings were focused on jump starting the acquisition process. Then SAF, James Roche, wanted to foster a culture of innovation and reasonable risk taking that would result in the shortening of acquisition cycle times. The objective was to deliver today's technology today. Secretary Roche wanted a flexible system that would allow the rapid insertion of new technologies throughout a system's life-cycle. His ultimate goal was to build credibility with the customer, the warfighter. Then Assistant SAF for Acquisition, Marvin Sambur, was given the responsibility for implementing the concept. Mr.

[38] Northrop Grumman Awarded Two Contracts for Global Hawk totaling $300 Million, Northrop Grumman News Release, 1 April 2002

Sambur established what was called the Agile Acquisition Initiative that was based on the simple premise of the responsible parties working together. The four parties were the requirers, the technologists, the testers, and the acquirers. There were three sub-initiatives that comprised the Agile Acquisition Initiative:

1. Collaborative requirements process whereby the warfighter would no longer toss their requirements over the wall and let the other team members try to translate their needs into a contractual document. Instead, the four parties would work as a team from the start, with the technologists and acquirers providing immediate feedback to the requirer on technology and development issues. The testers would be involved to ensure that the requirements could be verified.
2. Focused technology transfer would address whether or not the required supporting technology was available. The objective was to have the laboratories realign their limited resources to focus on bringing high-value technology to a higher technology readiness level in a time consistent with the new weapon systems.
3. Seamless verification whereby the testers were engaged early, so they could provide their expertise on testability of requirements was used. The objective was to remove the "seams" between development testing and operational testing.

In order to test the Agile Acquisition Initiative, Mr. Sambur established the Pathfinder program in March 2002.[39] There were six programs chosen "that could blaze a path for others to follow, very much like our Pathfinder forefathers…all with a bottom line goal of building credibility within and outside the acquisition community and reducing cycle time by a ratio of 4:1." [40]

The Global Hawk was one of the six Pathfinder programs selected. In an effort to deliver the Global Hawk capability to the warfighter in the shortest time possible, the Air Force restructured the program, expanding development by five years, while compressing production by nine years. Originally, program funding was spread almost evenly across 20 years. With the restructured program, funding was compressed into roughly half the time, sometimes tripling the budgetary requirements in specific years. Figure 26 shows the funding profile. This restructuring resulted in significant concurrency between development and production during FY04 through FY10 (see Figure 27). The concurrency meant that the Air Force would invest in almost half of the new, larger air vehicles before the production configuration was validated through flight testing. Likewise, full rate production would begin before the SIGINT (Block 30) and multiplatform radar (Block 40) configurations completed development and flight testing.

[39] Interview with Marvin Sambur, Assistant Secretary of the Air Force (Acquisition): Pathfinder Program Testing the Potential of Spiral Arms Development, P. L. Croise, PM, July-August 2003, Page 6
[40] Ibid, Page 6

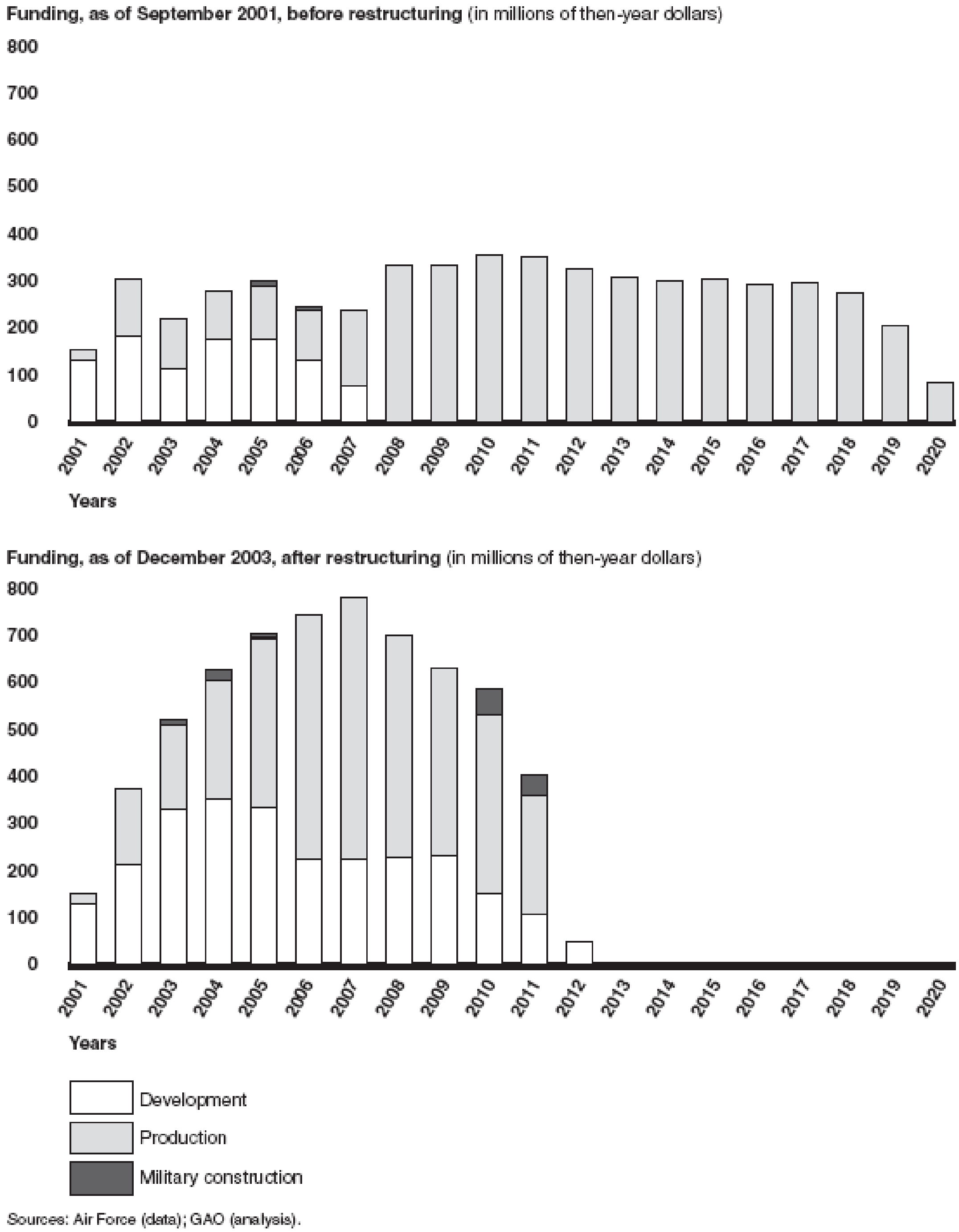


Figure 26. *Global Hawk's Annual Funding Requirements*[41]

[41] GAO-05-6, Unmanned Aerial Vehicles: Changes in Global Hawk's Acquisition Strategy Are Needed to Reduce Program Risks, Government Accountability Office, November 2004, Page 8

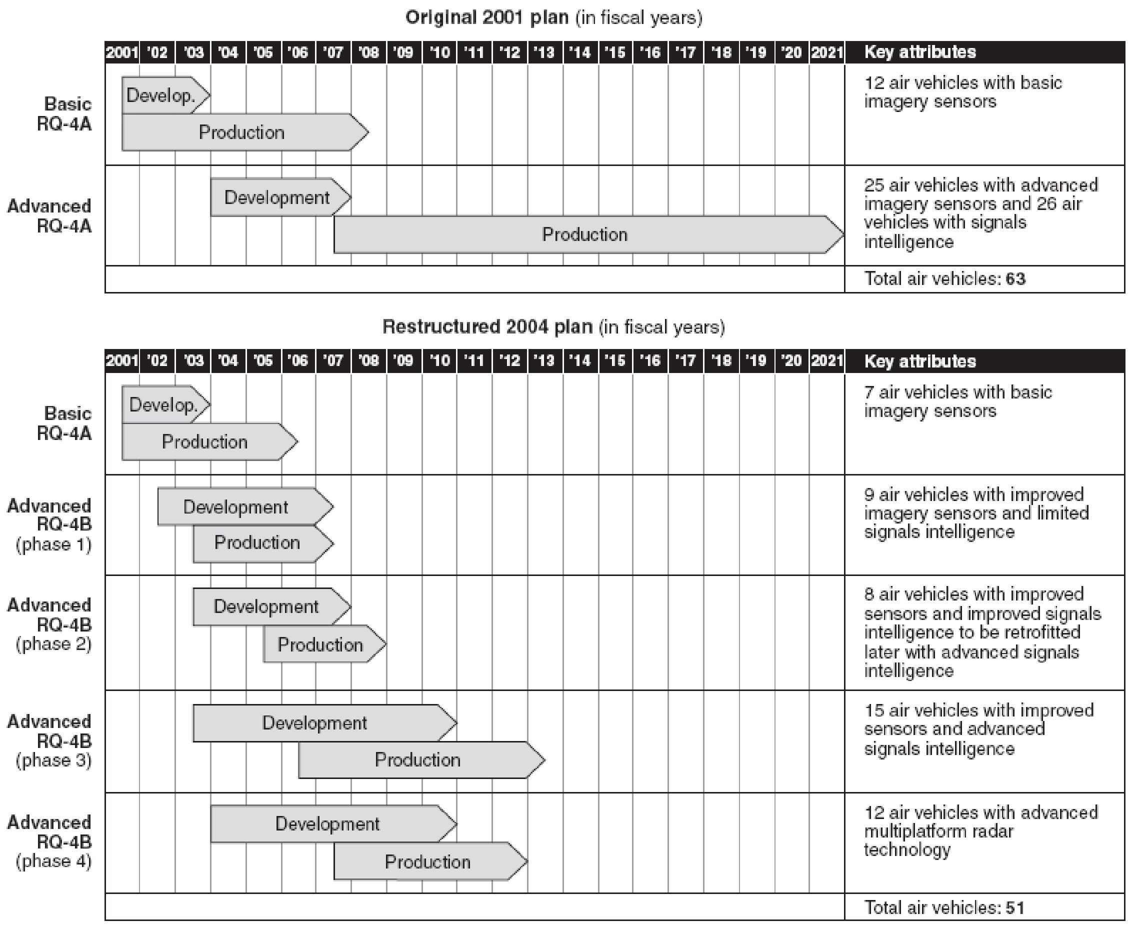


Figure 27. *Concurrency of Development and Production*[42]

The first contract, dated February 28, 2002, was for the lesser amount ($52.8 million) and addressed Spiral 2A. The updates in air vehicle capability, which were targeted for Lot 2, included:

- 25 KVA ac generator, replacing the existing hydraulically powered motor generator
- Increased capacity Environmental Control System to support increased payload capability and additional electrical power generation
- Rain Intrusion System to inhibit rain penetration into the interior compartments of the air vehicle

The second contract, dated March 25, 2002, was for $247 million and addressed Spiral 2B. It was also targeted for Lot 2. This spiral added an EISS (EO/IR/SAR sensor) and focused on the air vehicle changes necessary to support the larger 3,000-pound payload. For example, the fuselage was made larger, and equipment was rearranged, so the air vehicle could carry six of the seven Airborne Signals Intelligence Payload (ASIP) avionics boxes that the U-2 can carry. To offset the loss in stability and control from the increased fuselage volume, vertical fin size was increased. To retain air vehicle performance, additional fuel was added, and the span of the wing

[42] ibid, Page 11

was increased. To improve laminar flow over the wing, manufacturing processes were modified to maintain tighter tolerances on curvature of the airfoil. The COTS engine was upgraded with improved turbine materials to provide either more thrust or a longer duty cycle before teardown and refurbishment. The performance gains hoped for were not fully realized, and aircraft performance suffered. Maximum altitude was reduced from 65,000 feet to 60,000 feet, but endurance remained at about 30 hours, which was comparable to the Block 10.

Figure 28 is a performance comparison of the two Global Hawk configurations, while Figure 29 provides a physical comparison.

Characteristics	RQ-4A	RQ-4B
Payload	2000 pounds	3000 pounds
Take-Off Weight	26,750 pounds	32,250 pounds
Endurance	31 hours	33 hours
Time at 60,000 feet	14 hours	4 hours
Average Speed @ 60,000 feet	340 knots	310 knots
Approximate Range	10,000 nautical miles	10,000 nautical miles

Figure 28. *Performance Comparison*

Figure 29. *Physical Comparison of RQ-4A (Block 10) and RQ-4B (Block 20)*

The SOW contained in Spiral 2B did include two significant additions. First, it included a specific task for Airworthiness Certification. The second significant addition was the requirement to develop and qualify an architecture that would provide functional and physical separation of flight and mission critical functions, including software. This change is one that would be critical to obtaining Airworthiness Certification.

Airworthiness Certification

In 1994, then Secretary of Defense William Perry directed the military services to begin reinventing the acquisition process. A key element of the "Perry Initiatives" was a major reduction in the use of MIL-SPECs and military standards (MIL-STDs) in the acquisition process. Up to this point in time, the military qualified their weapon systems to an extensive set of contractual MIL-SPECs and MIL-STDs. Once qualified, the system was considered airworthy. However, with the major reduction in the use of specifications and standards, there was no comprehensive set of requirements to judge that an aircraft was safe to fly. This void in our acquisition process led to the formulation and release of Air Force Policy Directive (AFPD) 62-6, USAF Aircraft Airworthiness Certification, dated October 1, 2000. This AFPD established the requirement that each aircraft configuration undergo a formal airworthiness certification process. On October 1, 2002, the Air Force released Military Handbook (MIL-HDBK-516), Airworthiness Certification Criteria, which established the criteria to be used in determining the airworthiness of a given aircraft.

The Air Force airworthiness process can be summarized as a three-step process:

1. Development and approval of a Tailored Airworthiness Certification Criteria (TACC) document for use as the basis of certification. MIL-HDBK-516 defines the criteria to be tailored.
2. Design evaluated against the criteria contained in the TACC, using a combination of analysis, laboratory, simulator, flight, and demonstration data to verify compliance.
3. All non-compliances assessed for operational safety risks and all identified risks accepted by the appropriate authority.

The process is controlled by the ASC Airworthiness Board at WPAFB, and the TACC requires coordination of the functional experts within the ASC Engineering Directorate.

Unfortunately, Spiral 1 contract award was 19 months before release of MIL-HDBK-516. To complicate things even further, the sole reference in the Spiral 1 SOW to Airworthiness Certification was in the list of Applicable Documents, where the AFPD was simply referenced. Consequently, the SOW failed to include any specific taskings for airworthiness certification, and the corresponding systems engineering effort was never costed. This resulted in the necessary steps not being adequately reflected in the initial program planning.

The program learned from its error, and the Spiral 2 SOW did include a taking for Airworthiness Certification, which was a step in the right direction. However, the SOW tasking only required that the effort satisfy "the airworthiness criteria as specified in the tailored airworthiness criteria document." There was no mention of MIL-HDBK-516 or the specific document revision. In reality, the contract could not specify MIL-HDBK-516, since the Spiral 2B contract was signed on March 25, 2002, which was six months before release of MIL-HDBK-516.

When the program began to prepare their TACC document for the Block 20 configuration, MIL-HDBK-516B Expanded was in effect. However, the program was using the initial version of MIL-HDBK-516 for Block 10 certification. Northrop Grumman warned the Program Office several times that the airworthiness criteria and verifications had sometimes changed from the Block 10 TACC and that it would result in a cost risk. Driven by Air Force policy, the Program Office remained firm in the use of MIL-HDBK-516B Expanded. It was not until the design was about 80 percent complete that the issue was finally resolved; that MIL-HDBK-516B would be used as the basis for Airworthiness Certification. This issue could have been avoided had there been a contractual System Specification that defined the specifics for airworthiness certification.

Functional and Physical Separation of Flight and Mission Critical Functions

This addition attacked only a portion of the systemic problem associated with software. The Northrop Grumman Team did not have the experience with the standard software process required by typical Air Force programs. The Air Force has defined a series of best practices deemed necessary to efficiently and successfully develop, manage, and deliver a software package. The processes have been documented in various forms over the years. Some of the sources include:

- DoD 5000.2, Part 6-D, Computer Resources, which addresses Computer Resources Life-cycle Management Plan, Integrated System Development, software metrics, software test management, and software engineering practices
- Air Force Regulation 800-14, Life-cycle Management of Computer Resources in Systems
- ASC Pamphlets on Software Integration, Verification and Validation, Software Risk Abatement, Review of Software Requirements and Interface Requirements Specification, Software Management Indicators, Software Quality Measurement, and Software Development Capability Assessment
- SAF/AQ Memos on Software Engineering, Software Maturity Assessment, Metrics, Software Estimating, Software Reuse, and Best Practices
- Development Standards, such as DoD-STD-2167/2168, MIL-STD-498, and MIL-STD-1803

The criticality of the flight control system, both the hardware and software, had always been an issue between the Program Office and Northrop Grumman. The Air Force always classifies the flight control system, including both the hardware and software, as Safety Critical. As a result, the flight control system of most Air Force air systems is typically multiple redundant, whereas it is only single redundant on the Global Hawk. When the Program Office challenged the contractor on the issue of how they treated the flight control software, the contractor responded by stating that they treated everything the same. However, that approach did not reflect the Air Force's established process for safety critical functions. Even though the SOW tasking to separate the flight critical functions from the non-flight critical functions was a step in the right direction; little changed. Also, the update to the SOW did not address the systemic problem of requiring the contractor to develop an approach consistent with current Air Force practices. The team's lack of a sound process contributed to both cost and schedule overruns.

Even though the software process did not meet the Air Force's recommended practices, Northrop Grumman did have a consistent process within their company team. However, the processes differed between the prime and each of the suppliers. There was no one Northrop Grumman lead for overall software development on the Global Hawk system; there was a lead at Northrop Grumman and a lead at each of the subcontractors. This was a carryover of the ACTD culture, which hurt the development of an integrated product.

Relative to software validation, testing was never automated. Thus, qualification of a full Operational Flight Program (OFP) software package would take over three months. Northrop Grumman did emphasize System Integration Testing, and they did it quite well. They emphasized this testing, since the software process was lacking. Unfortunately, because of funding constraints, the suppliers did not have the test assets necessary to perform integration testing. Therefore, many of the supplier software deficiencies were not caught until they were tested at Northrop Grumman at the overall system level. When that happened, the software would typically be returned to the supplier for correction, thus, delaying the testing. In 2005, the program did implement Integrated Functional Capability (IFC). IFC now defines the functionality of the hardware/software associated with a given software release. This was an initial step in implementing the Air Force "best practices" for software development.

Late in 2004, the Program Office conducted a quick program review by recalculating their cost estimate based on an identification of known risks. In performing the cost estimate, the Review Team ascertained that the software was grossly underestimated in terms of both cost and schedule. Consequently, in April 2005, the Program Office conducted a Software Executability Review, with participation from ASC/EN at WPAFB. The team addressed the contractor's cost estimating practices, schedules, etc., and confirmed the earlier findings.

3.3.8 Organizational Structure

About two years into EMD/Production, Northrop Grumman reorganized. The program managers were aligned by major contract (e.g., Development, Production, Supportability, and Sustainment), while the Technical IPTs became the execution teams responsible for building the system. The program managers apportioned funds to these IPTs to work a particular task related to their contract. The Technical IPTs were aligned by Air Vehicle, CGS, and Payload. There were also sub-IPTs, e.g., Software, Test, Systems Engineering, Product Support, Ground Segment, etc. Each IPT had a designated Government counterpart. With the reorganization, the systems engineers were all centralized in a Systems Engineering Integration Team (SEIT). Removing the systems engineers from the IPTs was perhaps the result of a combination of several factors: a desire on the part of the Air Force to field the system as quickly as possible, a perception that very little additional development was required because of the success of the ACTD program, and a reluctance on the part of the user to fund tasks that were viewed as not contributing directly to operational capability development. As a consequence, the Government did not provide the necessary program definition and funding for these aspects of an EMD systems engineering program, and the contractor had little choice but to follow the customer-mandated approach. The result was that the SEIT was viewed by the IPTs as a "non-value added" activity and as a watch dog that imposed workload that detracted from the IPT's ability to accomplish required tasks; consequently, the SEIT had very limited ability to successfully impact the conduct of the program. This is supported by the point that, when funding problems drove program cutbacks, systems engineering proved to be an easy target.

The System Program Office (SPO) IPTs were aligned according to the contract. Consequently, there was a Development IPT, a Production IPT, and an Integration IPT, which included the SEIT. The Government IPT structure resembled how the contractor's program managers were aligned, not how their technical IPTs were aligned. This mismatch hindered SPO involvement with the contractor IPTs. Generally speaking, the SPO did participate on the contractor's IPTs, but differences between the IPT alignments made counterpart relationships difficult at times.

3.3.9 Navy Global Hawk

Even though the Global Hawk was an Air Force-managed program, there was always the expectation that the system might also fill a critical role with the Navy. During ACTD, the Navy was a member of the JPO. As the Air Force program progressed, the value to the Navy was seen to increase. Thus, in February 2003, the Navy awarded Northrop Grumman a contract for the Global Hawk Maritime Demonstration (GHMD) program. The contract involved modifying two Global Hawk air vehicles, as well as the associated ground and support segments. The contract was awarded and managed by ASC at WPAFB on behalf of the Navy. The objective of the contract was to integrate maritime sensors into two Block 10 Global Hawk air vehicles and demonstrate that the resultant system would provide a high-altitude, long-endurance surveillance capability that met the Navy's critical requirements. The program was designed to leverage off the Air Force contract in the procurement of the air vehicles and associated ground control and support segments.

The Navy took delivery of their system in CY05. The naval configuration was originally tested at Edwards AFB for several months and then ferried to the Naval Air Station (NAS), Patuxent River, Maryland, for the GHMD program.

In the spring of 2006, the system participated in a maritime drug interdiction surveillance demonstration, completing four sorties over the Caribbean and the coast of Florida. It located and identified numerous airborne and surface targets. The aircraft then flew in the Rim of the Pacific exercise in July. Although the operations were in the vicinity of Hawaii, the aircraft was operated from Edwards AFB, requiring flights to and from California for each demonstration. Four different sorties were involved, resulting in over 24 hours of maritime surveillance coordinated with the USS Abraham Lincoln and Bonhomme Richard. The sorties involved maritime situational awareness, contact tracking, and imagery support of various exercises. The imagery was transmitted to Patuxent River for processing and forwarded to the fleet operations off Hawaii. (See RQ-4N) [43]

Ultimately, Northrop Grumman entered a version of the RQ-4B into the Navy Broad Area Maritime Surveillance UAV contract competition. On April 22, 2008, the Navy awarded Northrop Grumman the contract worth $1.16 billion.

3.3.10 Production Lots 2 and 3

In February 2003, Northrop Grumman was awarded a $302.9 million fixed-price-incentive-fee contract for LRIP of Block 10 aircraft. The contract included delivery of four Block 10 air vehicles, three ISSs, two EO/IR sensors, and one LRE. Also included were two Block 10 air vehicles, two ISSs, two LREs, and one MCE for a planned 2005 maritime demonstration by the Navy. The last Lot 2 air vehicle was delivered in April 2006.

In June 2003, the Air Force awarded Northrop Grumman a $30.1 million follow-on contract to provide the long-lead parts and advanced procurement necessary to support a subsequent Lot 3. Work was scheduled for completion in February 2004. In April 2004, the Air Force awarded

[43] Northrop Grumman to Demonstrate Global Hawks for Maritime Watch, Space Daily, 13 February 2003

Northrop Grumman the subsequent $202 million contract for Lot 3 LRIP. Lot 3 was a mixed buy involving one Block 10 air vehicle with sensor suite, one Block 20 air vehicle with sensor suite and SIGINT clip-in kit, two Block 20 air vehicles with SIGINT clip-in kit, one LCE, one MCE, and one basic sensor suite.

3.3.11 German Demonstration

During the ACTD phase, Germany followed the development of the Global Hawk system closely. Their aging fleet of Brequet Atlantique SIGINT aircraft based at Nordholz was due for replacement by 2008. The success of the ACTD program led the European Aeronautical Defense and Space (EADS) Company to sign an agreement with Northrop Grumman in July 2000 to develop an unmanned wide area surveillance and reconnaissance air vehicle.

In July 2002, the Air Force and German Ministry of Defense (MoD) successfully completed preliminary compatibility testing of the EADS electronic intelligence (ELINT) payload with the Global Hawk at Northrop Grumman's Integrated Systems facility in San Diego. This was followed by a flight demonstration in November 2002 at Edwards AFB. During the flights, the ELINT sensor detected radar transmissions from emitters located at the Naval Air Warfare Center (NAWC) at China Lake, California. Transmissions were sent through the line-of-sight communications link to a German ground station temporarily located at Edwards AFB.

The successful integration of ELINT into the Global Hawk led Northrop Grumman to conduct a series of demonstration flights in Germany for the German MoD. On October 15, 2003, the first prototype Block 10 flew a 21-hour trans-Atlantic flight from Edwards AFB to Nordholz, Germany. The air vehicle was then based at Nordholz from October 15 to November 6, 2003, flying six demonstration sorties over the North Sea for a total of 29 flight hours. The ELINT sensor successfully enabled the Global Hawk to detect and classify electromagnetic signals from aircraft, ships, and land-based systems. The air vehicle was able to detect the type of radar emitting from each source.

The highly successful demonstration led to a decision by the German MoD to award a $430 million contract to EuroHawk GmbH, a joint venture company formed by EADS and Northrop Grumman Corporation. The contract, which was awarded on January 31, 2007, was for the development, test, and support of the Euro Hawk unmanned signal SIGINT system. The system will provide stand-off capability to detect electronic ELINT radar emitters and communications intelligence emitters. EADS will provide the ground stations required to receive and analyze the data from the Euro Hawk. Delivery of the first demonstrator is scheduled for 2010 with the next four scheduled between 2011 and 2014.

3.3.12 Block 10 Flight Test

Rollout of the first production Block 10 air vehicle took place at the Northrop Grumman manufacturing facility in Palmdale, California, on August 1, 2003. The air vehicle made its maiden flight the following summer (July 2004) when it flew from Palmdale to the Flight Test Center at Edwards AFB. The four-hour flight went flawlessly.

One interesting program note is that it was not until about a month before the Air Force took possession of the first Block 10 air vehicle that the Program Office took action to develop an Air Vehicle Specification. The air vehicle had been designed to a set of requirements, but they were fluid and non-contractual. For the Air Force to accept the air vehicle, the Program Office needed a specification to base its acceptance. Thus, an Air Vehicle Specification was written to match what the current configuration was capable of achieving.

Since the program was now ready to move beyond the advanced concept demonstrator phase, the program decided to pursue a Certificate of Authorization (COA) for operation in national airspace. In August 2003, the FAA granted the Air Force a COA to routinely operate the Global Hawk in national airspace. Before the COA, the FAA would grant the Global Hawk access to national airspace only in several FAA regions in order to support specific exercises. This certification was significant, since it represented the first national COA granted for a UAV.

The Block 10 air vehicle began its 15-month-long operational flight test in August 2005. Testing was conducted at Edwards AFB by AFOTEC Detachment 5, 31 TES, and 452nd Flight Test Squadron (FLTS). The purpose of the tests was to determine if the Block 10 configuration was ready for deployment.

The test program began with a Pre-Deployment Assessment, which was conducted on August 22-28, 2005, at Beale AFB. Capabilities evaluated included flying operations; EO, IR, and SAR sensor functionality; and quality, timeliness, and usefulness of sensor imagery. Representative sorties were flown to emulate the types of sorties to be flown in a real-world combat environment. The first two sorties lasted more than 28 hours each, while the final sortie lasted almost 14 hours. The test team then proceeded with the deployment phase of the operational test program in April 2006. The Global Hawk system, along with the test team, deployed to various locations worldwide. Deployments included locations with the Army and Marine Corps units in theater to assess how well the Global Hawk system would satisfy the warfighter’s needs. The test program also included a deployment to the east coast to evaluate sensor performance in dense foliage and evaluate the system interoperability with ground units involving the Army’s 513th Military Intelligence Brigade.

At completion of the operational test program on November 17, 2006, Maj Gerhardt, Global Hawk Test Director with AFOTEC Detachment 5, concluded the following: “Global Hawk is the premier unmanned intelligence, surveillance and reconnaissance aircraft for this generation warfighter. This assessment will lay the ground work for future Global Hawk testing of Blocks 20, 30, and 40.” [44]

[44] AFOTEC Det. 5 Leads Conclusion of First Global Hawk Operational Testing, Airman 1st Class Julius Delos Reyes, 95th Air Base Wing Public Affairs, 1 December 2006

3.3.13 Airworthiness Certification of Block 10

Being the first program to seek Airworthiness Certification of a UAV was no easy task. The situation was compounded by the fact that Airworthiness as a distinct task separate from the typical system development/performance verification activity was a new concept with AFPD 62-6 just established in October 2000. AFPD 62-6, USAF Aircraft Airworthiness Certification, was not released until October 1, 2000, just five months before Spiral 1 EMD contract award. MIL-HDBK-516, which established the criteria to be met, was not released until October 1, 2002, 19 months after Spiral 1 contract award.

In developing the TACC, the Program Office used the original version of MIL-HDBK-516. Approximately 560 criteria contained in MIL-HDBK-516 were deemed applicable. Since a comprehensive effort to fully characterize the system performance and characteristics was not included in the EMD contract, the program had to rely on the limited set of activities accomplished during the ACTD phase. This resulted in 70 of the 560 criteria being assessed as non-compliant. To address the non-compliances, the Program Office placed the 70 non-compliances into 40 different “buckets” of risk. Less than 20 of these “buckets” were classified as Moderate Risk per MIL-STD-882 (Department of Defense Standard Practice for System Safety). As a result, Block 10 was given a Restricted Certificate of Airworthiness on January 25, 2006. The restriction involved avoiding populated areas to the maximum extent possible. In a News Release, Northrop Grumman stated, “RQ-4A Global Hawk reconnaissance system is the first unmanned aerial vehicle (UAV) to achieve a military airworthiness certification…The military airworthiness certification process is very rigorous and has taken three years and 77,000 man-hours to achieve.” [45]

3.3.14 Nunn-McCurdy Breach and Recertification

The Nunn-McCurdy Amendment was first introduced in the 1982 Defense Authorization Act and was made permanent in 1983. The amendment was designed to curtail cost growth in our military weapon procurements. Appendix 3 of this case study contains a copy of the amendment.

Simply speaking, the amendment requires that the Pentagon notify Congress when cost growth on a major acquisition program reaches 15 percent. If the cost growth reaches 25 percent, then the Pentagon must recertify the program based on the following criteria:

1. System is essential to the national security,
2. There are no alternatives to the system that will provide equal or greater military capability at less cost,
3. New estimates of total program unit cost or procurement unit cost are reasonable and/or,
4. Management structure for the system is adequate to manage and control the total program acquisition unit cost or procurement unit cost.

Rarely is a program cancelled under this law. However, the recertification results in numerous program improvements and Congress typically accepts the Secretary of Defense’s recertification.

[45] Northrop Grumman RQ-4A Global Hawk UAV Achieves Military Airworthiness Certification: A First for Unmanned Aerial Vehicles, Revelle Anderson, Northrop Grumman News Release, 13 February 2006

3.3.14.1 *Circumstances Leading to Breach*

As the saying goes, hindsight is 20-20. In retrospect, there were a number of factors that ultimately contributed to the breach. The prominent ones as defined by the interviewees in this study include the following:

1. The seed for the breach on the Global Hawk program was the Air Force decision to develop the larger Block 20 aircraft. The user identified the need for additional capabilities, which resulted in a larger payload aircraft. When the decision was made to pursue the larger aircraft, no one fully appreciated the extensiveness of the change, and this led to cost increases. For example, the decision-makers did not realize that the wing needed to be larger, the empennage redesigned, and the landing gear strengthened to accommodate the heavier take-off and landing loads. Likewise, only about 20 percent of the RQ-4A drawings were applicable as opposed to 80 percent as originally projected. These discrepancies were largely because of the contracts containing no pre-EMD engineering development activities for the next spiral.
2. The user had specific performance requirements that needed to be met, and these were not necessarily consistent with available funding. The result was a choice of "the devil's alternative": either breach the program cost ceiling or fail to meet the user requirements. The program chose to meet the user requirements.
3. Customer direction and funding did not support the conduct of Spiral 1/Block 10 development of full engineering characterization activities, which had not been accomplished during ACTD.
4. The program lacked a single IMS. There was a SOW tasking to create and maintain an IMS that depicts program interdependencies and critical paths. Implementation of this tasking resulted in a multitude of IMSs: one for each Spiral and one for each of the Tier 2 IPTs. In some cases, the IMSs were merely created and maintained in PowerPoint, while others were created and maintained in Microsoft (MS) Project. The IMSs were typically independent of each other, and there was no overall program attempt to integrate the IMSs through a single IMS that showed the interdependencies and critical paths.
5. TRA was an excellent choice for an ACTD type of program where there were few Government rules and regulations resulting from the use of Section 845 OTA. However, the EMD and Production contracts were FAR-based, requiring implementation of the extensive set of Government rules and regulations governing a military acquisition program. TRA did not have the experience associated with a much larger EMD program accompanied by these types of controls. The appropriate processes were not in place, and this contributed to cost overruns.
6. Concurrency was a major contributor to the problem. Production contracts were awarded based on the design currently available without any effort allotted to refine and validate the design. For example, the EMD initial contract was awarded in March 2001, and the contract for the first two Block 10 LRIP air vehicles were awarded just three months later. The user's attitude was: "We want what is out there." There was no well-defined baseline for each block of aircraft and no rigor for identifying and correcting shortfalls. In essence, the team was proceeding with an air vehicle configuration whose foundation was not truly understood.

7. The program was not prepared for the logistics support associated with the multitude of air vehicle configurations.
8. Airworthiness as a distinct task separate from typical system development/performance verification was a new concept with the AFPD just established in October 2000 and the corresponding MIL-HDBK-516 not released until October 2002. For Spiral 1, no airworthiness tasking was included in the SOW, and the cost of the effort was not projected. For Spiral 2, the contractor assumed that the same initial version of MIL-HDBK-516 used for Block 10 would also be used for Block 20. However, Air Force policy required that the latest version be used. The resultant ambiguity led to a late resolution that MIL-HDBK-516B Expanded would be used for the Block 20 certification. This required Northrop Grumman to generate or provide documentation that was not in their database and, in some cases, redesign components or structure to comply with the new handbook.
9. The contractual performance requirements that existed were minimal (more typical of an ACTD program) and were documented in the SOW. The SOW is a program document defining tasks to be performed, not a specification. The program failed to require a contractual System Specification typical of a military acquisition program. As a result, requirements were loosely defined, and new requirements were added based on operational experience. The result was a serial approach to the design of the RQ-4B that increased cost significantly.
10. Formal engineering reviews were lacking. To minimize the cost impact, there was little preparation, and the attitude was "come as you are." Consequently, reviews lacked detail; risks were often not identified; and, when risks were identified, the closure plans were often missing. This shortfall was specifically noted in the Block 20 "Critical Design Review (CDR)" and January 2006 Design Review for Block 30.
11. In many cases, proper test/validation resources were not available at the different levels, including the subcontractors. For example, hardware and software changes were not tested properly at the subcontractor facilities because of lack of test equipment. Deficiencies would not be found until they entered testing on the hot bench at Northrop Grumman. The software or hardware would then have to be returned to the subcontractor for corrective action. Another example is that there were no test units procured for sensor development; only production test units, and this sometimes led to delays in the delivery of units to the aircraft.
12. Initially, the contractor was responsible for the flight test program. When the decision was made at the three-star level to transfer responsibility to the Air Force, the Combined Test Force was behind the power curve relative to preparing Flight Test Plans, developing a flight test schedule, etc. The Program Office had an inadequate appreciation for the associated cost in developing the Combined Test Force. However, as noted earlier, the decision to transfer test responsibility was made at the three-star level to correct an operational problem, not address a cost issue.
13. Many of the traditional disciplined engineering processes were neither included in the contract nor funded and, thus, were not part of the development/verification process. Both the Program Office and Northrop Grumman preferred to implement a better systems engineering program, but inadequate funding drove cutbacks, and systems engineering was an easy target. As a result, there were no integrity programs for the engine, subsystems, and avionics. Even though the ASIP was included in the SOW, it

was inadequately implemented. For example, there was no fatigue article, and the EMD air vehicle was never redesigned to the standard gust load margin of 1.5. Likewise, the standard Air Force software management processes were not followed; Computer Software Configuration Items (CSCIs) were not identified, proper test processes for CSCIs were not established, proper regression testing did not always take place, etc. When contractors/subcontractors would encounter problems with safety critical software, they would make a fix and then continue testing without performing the necessary regression testing.

14. The software development/verification process was significantly underestimated. There was no one person at either the Program Office or Northrop Grumman overseeing the entire software process. Northrop Grumman had formed a Software IPT, but it did not monitor the subcontractor software closely. Likewise, a Software Executeability Review found that the cost-estimating technique was inadequate.
15. There were multiple spirals occurring simultaneously, and few, if any, knew how the "pieces" fit together. The spirals tended to be fluid with changes occurring until the very end of a spiral. The contractor tried to be responsive per the objectives of Agile Acquisition, but the changes led to overruns.
16. The Verification Cross-Reference Index used by the program merely designated analysis, demonstration, test, and inspection for verification of the requirements. There was no explanation of the deliverables necessary to show compliance. This led to increased time and cost to generate more data and generate unplanned reports necessary to convince the Air Force that a particular requirement was satisfied.
17. The need for technical documentation was not emphasized in the ACTD program, so the people on the program often became the repository of information. There were numerous personnel changes during EMD/Production. When individuals left, their corporate knowledge of the program was lost. Data would sometimes have to be re-generated, and new people would have to be trained.

2003 Report for Congress

In an April 2003 Report for Congress, it was concluded that "The Air Force is striving to meet its $48 million goal for unit cost, with research and development costs increasing the price of the unit to as high as $73 million."[46] It also noted that there was a concern among Air Force and DoD officials that the continual addition of new features and capabilities was making the program unaffordable.

This view was further echoed by the Permanent Select Committee on Intelligence, which noted that, what was once a $10 million (FY94 dollars) air vehicle "has become at least $30-40 million aircraft, and the cost will increase substantially further as additional and improved sensors, and corresponding power/payload upgrades, are added."[47] This statement was obviously referring to the changes associated with the Spiral 2A and 2B upgrades. The Committee was further quoted as saying that there is "now an effort to flood the Global Hawk program with money, there are ad hoc

[46] Report for Congress: Unmanned Aerial Vehicles: Background and Issues for Congress, Elizabeth Bone and Christopher Bolkcom, Library of Congress, Order Code RL31872, 25 April 2003, Page CRS-35
[47] ibid, Page CRS-36

plans for rapid, major upgrades before requirements have been established, and no sign of serious examination of where and how Global Hawk fits into an overall collection architecture." [48]

2004 Government Accountability Office (GAO) Report to the Chairman, Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representative

In November 2004, the GAO reported to Congress that the Global Hawk program was in need of change to reduce overall program risk. The report noted that, originally, program funding was spread almost evenly across 20 years. However, with the larger RQ-4B, funding was now compressed to roughly half the time, sometimes tripling the budgetary requirements in specific years (see Figure 3-10 in Paragraph 3.3.7). The program restructuring expanded the development by five years, while compressing the production by nine years. This restructuring resulted in significant concurrency between development and production during FY04 through FY10 (see Figure 3-11 in Paragraph 3.3.7). This concurrency meant that the Air Force would invest in almost half of the new, larger air vehicles before the production configuration would be validated through flight testing. Likewise, full rate production would begin before the SIGINT (Block 30) and multiplatform radar (Block 40) configurations completed development and flight testing.

The GAO Report also criticized the program's cost growth. It stated that "The program's total cost estimates have increased by nearly $900 million, driven by a threefold increase in development costs to pay for the development of a new and larger air vehicle. As a result, the program acquisition cost increased 44 percent since the program started." [49] Figure 30 depicts the program cost growth as a function of time.

	March 2001 (original plan)	March 2002 (1st restructuring)	March 2003 (2nd restructuring)	March 2004 (status this year)
Total cost[a]				
Development	$906.2	$2,311.0	$2,395.6	$2,587.9
Procurement	4,459.8	4,388.9	3,278.5	3,552.2
Military construction	28.0	146.7	140.8	140.8
Total program	**$5,394.0**	**$6,846.6**	**$5,814.9**	**$6,280.9**
Quantity				
Air vehicles	63	51	51	51
Ground stations	14	10	10	10
Unit costs[a,b]				
Total program	**$85.6**	**$134.2**	**$114.0**	**$123.2**
Procurement only	$70.8	$86.0	$64.2	$69.6

Sources: Air Force (data); GAO (analysis).

Figure 30. *Global Hawk Program's Cost, Quantity, and Unit Costs*[50]

The original March 2001 plan referenced in Figure 30 involved acquiring the basic system very similar to the successful ACTD configuration and then incrementally developing and procuring systems with more advanced sensors as the critical technologies were demonstrated on the same platform. The *original* plan included 63 RQ-4A air vehicles and 14 ground stations.

[48] ibid, Page CRS-36
[49] GAO-05-6, Unmanned Aerial Vehicles: Changes in Global Hawk's Acquisition Strategy Are Needed to Reduce Program Risks, Government Accountability Office, November 2004, Page 3
[50] ibid, Page 12

The first restructuring in March 2002 was because of introduction of the RQ-4B. Development costs increased as the result of the desire to develop the capability quickly. To help offset costs, the user revised his requirements to include only 51 air vehicles and 10 ground stations. Even with these reductions, the total procurement costs increased because of the higher air vehicle unit cost and the plan to equip all larger platforms with the multi-intelligence mission capability.

The second restructuring was for affordability reasons. In December 2002, DoD decided to switch from all multi-mission capabilities to a mix of multi-mission and single mission RQ-4Bs. This switch lowered the procurement costs by decreasing the required number of sensors.

The report concluded that the new Global Hawk strategy associated with the larger RQ-4B did not fully embrace the knowledge-based approach expressed by the DoD's acquisition guidance and best practices. It stated that "While the original acquisition strategy more closely adhered to this approach, the restructured strategy has caused gaps in knowledge about technology, design, and manufacturing at major investment decision points. These actions changed the underpinnings of the program's original business case and increased likelihood of future cost increases and schedule delays in delivering the capabilities expected by the warfighter."[51]

The report recommended that the Secretary of Defense direct the Air Force to a) revisit the decision for concurrent development and production, and b) develop a new business case that defines the warfighter needs consistent with available technology, engineering capability, time, and money. To manage risk, the report also recommended that the Secretary delay further procurement of the RQ-4B, other than the test units, until a new business case was embraced that reduced risk and justified further investments. DoD disagreed with both recommendations, contending that risks were indeed being managed effectively and that the GAO approach would require additional time and money.

Announcement of Breach in Excess of 15 Percent

In April 2005, the Air Force reported to Congress a breach of 18 percent in procurement unit cost over the 2002 approved baseline. In the Air Force letter to Congress, the breach was primarily attributed to the increase of air vehicle capacity to accommodate requirements for a more sophisticated, integrated imagery and SIGINT sensor suite. The letter referred to the 2002 program restructuring that added a new, larger, and more capable air vehicle. It noted that the 2002 baseline planned to procure only the smaller RQ-4A but the new, larger RQ-4B required more extensive changes to the fuselage, tail, and landing gear. As a result of this letter to Congress, the program came under closer scrutiny, particularly by the GAO. Everything was now being examined with many additional items being included in the estimate, even some items associated with future spirals.

Announcement of Breach in Excess of 25 Percent

In December 2005, the GAO reported that the Air Force had failed to report $401 million in procurement costs. Program officials stated that the unreported costs were for items needed to meet the warfighter requirements and bring the RQ-4B to a common configuration. This included items, such as SIGINT sensors and ground station enhancements that would require retrofit after the air vehicle or ground station left the production line. Likewise, development and procurement cost increases and schedule slips resulted in deferring some items until later in the

[51] ibid. Page 4

program and reclassifying costs. For example, the approved 2002 baseline called for 25 SIGINT sensors to be installed on the production line, but cost pressures and schedule changes caused the program to move the cost for 10 of the sensors worth $123 million to a different account targeted for modifications following delivery. Because historic DoD practices did not include modifications in the program baseline, the Air Force stated that they did not include these modification costs in the report. OSD officials responsible for the SARs stated that, historically, modification costs were not included in these reports to Congress, because modifications were typically for new capabilities or changes following delivery of a fully capable system. Both OSD and the Air Force did agree on one thing: "…a factor contributing to uncertainty is that DoD policies and practices have been increasingly streamlined to provide less detailed guidance and may need to be updated to keep pace with new business practices such as evolutionary and spiral development."[52]

Figure 31 shows the impact of adding the $401 million for modification costs. The result is a 31 percent breach over the approved December 2002 baseline. The 2005 GAO Report also concluded that adding the modification costs would also result in a breach of program acquisition unit cost growth of 19 percent compared to the 11 percent reported in the SAR.

Table 1: Global Hawk Procurement Unit Cost (in millions of dollars)

	Baseline estimate (Dec 2002)	Program estimate (Mar 2005)	Percent change reported to Congress	Retrofit costs not reported	GAO estimate including retrofit costs	Percent change, including retrofit costs
Procurement Cost	$2,904.6	$3,416.1		$400.6	$3,816.7	
Quantity	51	51			51	
Unit cost & Change	$57.0	$67.0	18%		$74.8	31%

Note: Costs expressed in base year 2000 dollars.

Source: Air Force (data); GAO (analysis).

Figure 31. *Procurement Unit Cost (in millions of dollars)*[53]

DoD only partially agreed with the GAO findings. They agreed that the retrofit costs for the 10 SIGINT sensors and one radar sensor were in the approved baseline and should have been included in the procurement unit cost reporting. Including these items increased the unit cost to 22.5 percent over the baseline versus the 18 percent previously reported to Congress and included in the annual SAR. DoD did not agree that the other remaining modifications were also reportable, since they were outside the scope of the historical reporting practice.

Despite DoD's position, the GAO Report made the following recommendation: "We recommend that the Secretary of Defense direct the Under Secretary of Defense for Acquisition, Technology, and Logistics to revise the Global Hawk report and take the necessary actions to comply with the legislation for reporting and certification." [54]

As a result, the Air Force re-notified Congress in December 2005 that "…if these additional costs were included, the procurement unit cost had actually increased by over 25 percent and that program acquisition unit costs (including development and military construction costs in addition

[52] GAO-06-222R, Unmanned Aircraft Systems: Global Hawk Cost Increase Understated in Report, Government Accountability Office, 15 December 2005, Page 4

[53] ibid, Page 5

[54] ibid, Page 5

to procurement) had also breached the thresholds established in the law."[55] The SAR for the quarter ending December 31, 2005, was submitted to Congress on April 6, 2006. It stated that the Global Hawk program had experienced a unit cost breach of more than 25 percent to the current baseline estimate. It further stated that notification and unit cost breach information would be provided to the Congress and that the USD (Acquisition, Technology, and Logistics [AT&L]) would consider whether or not to recertify the program. The result was that DoD now had 60 days to recertify the program.

3.3.14.2 *Recertification*

As part of the recertification process, the OSD conducted a review of the Global Hawk program. A management evaluation was conducted in the following seven areas: Schedule, EVMS, Management Reserves (MR), Contract Strategy, Personnel, Systems Engineering Practices, Sustainment/Supportability, and Operational Testing Strategy.

Some of the more significant findings of the seven areas listed above include:

1. Requirements definition and decomposition were the major root cause of program issues. Requirements tended to be unstable, traceability to components and modules lacking, flow down of requirements to subcontractors often missing, and validation of systems/subsystems missing.
2. Schedule management tools were now just being matured, and the outlook was optimistic. Until recently, there had not been a method to analyze schedules at the program level, particularly across contracts.
3. IMS lacked the necessary detailed schedules for subcontracted effort and Government activities. The contractor needed to move towards automated updates of the IMS database.
4. IMP was not incorporated into the contract to define contractual responsibility for planned events.
5. Weekly EVM had only been in place for several weeks, and the program needed a plan for using the EVM and MR data.
6. The Development, Test, and Evaluation (DT&E) strategy was insufficient to reduce program risk and support decisions. Lower-level development tests were typically not used as a building block to system test, entry and exit criteria were typically missing, test planning and test procedures were inadequate, critical test parameters were not verified, test assets were lacking, and systems were not assessed against its intended environment.
7. Adequate operational test and evaluation (OT&E) was planned too late in the acquisition cycle.
8. The current depot activation plan did not support activation by Initial Operational Capability (IOC)+4.

[55] GAO-06-447, Unmanned Aircraft Systems: New DOD Programs Can Learn from Past Efforts to Craft Better and Less Risky Acquisition Strategies, Government Accountability Office, March 2006, Page 7

9. Systems engineering planning, processes, and staffing had improved significantly since summer 2005.

The review also considered the findings of an Air Force Independent Review Team (IRT) Assessment completed in January 2005, a review of the Government management structure, and a review of the primary systems integrator management structure. In reviewing the January 2005 IRT findings, the OSD noted that software development, systems engineering, and cost growth were areas of high risk. However, they concluded that recommendations from the earlier IRT were being implemented, but metrics were just beginning to show progress.

Based on the review findings, the OSD restructured the program, developed a new cost estimate that was deemed reasonable, and established a set of recommendations that the Air Force agreed to implement. On June 5, 2006, The Honorable Kenneth J. Krieg, USD (AT&L), sent various members of Congress a letter justifying continuation of the program. In the letter, he certified the restructured Global Hawk program that:

1. The Global Hawk program was essential to national security.
2. There were no alternatives to the Global Hawk program that would provide equal or greater military capability at less cost.
3. The new estimates of program acquisition unit cost and procurement unit cost were reasonable.
4. The management structure was adequate to manage and control acquisition unit cost and procurement unit cost.

The restructured program was defined as a system comprised of aircraft, payloads, ground elements, and support elements. The program was limited to production of no more than five aircraft per year until Block 20/30 IOT&E was accomplished, which was planned for fall 2008. The restructuring extended production from 2011 to 2015. The LRIP quantity was limited to one Block 10 system, one Block 20 system, three Block 30 systems, and one Block 40 system.

In justifying that the new estimates of program acquisition unit cost and procurement unit cost were reasonable, the OSD used the Cost Analysis Improvement Group (CAIG), since they were viewed as an independent assessor. Based on their findings, the program acquisition unit cost and procurement unit cost were estimated as shown in Figure 32.

	BY00$M	TY$M
Program Acquisition Unit Cost		
Cost	7988	9491
Unit Cost	148	176
Procurement Unit Cost		
Cost	4842	5857
Unit Cost	90	108

Figure 32. *Restructured Program Cost as of May 2006*

OSD also concluded that the management structure was adequate to manage and control program acquisition unit cost and procurement unit cost if the following recommendations directed in the June 2006 Acquisition Decision Memorandum were implemented:

- Conduct a risk evaluation of design and planning for material readiness.

- Integrate the Defense Contract Management Agency (DCMA) into the management process.
- Improve the Award Fee process to incentivize Northrop Grumman.
- Complete a Depot Activation Plan, Source of Repair Assignment Process (SORAP), and Depot Maintenance Inter-service Process.
- Review and update, if necessary, the new IMS/IMP, with attention given to improvements in electronic updates from subcontractors and incorporation of Government events.
- Review systems engineering implementation and management (including software, risk, subcontractor specifications, subcontractor drawings, and quality assurance).
- Update the TEMP to provide an event-driven OT&E strategy consistent with planned production decisions.

The USD (AT&L), Kenneth Krieg, sent letters containing the above justification to the appropriate members of Congress on June 5, 2006. Congress concurred with the recertification, and the Air Force moved forward, implementing the recommendations outlined in the letters.

3.3.14.3 *Resultant Actions Taken by the Program*

Based on the findings of the OSD review and letters sent to Congress, the Program Office implemented a number of actions to improve their overall program management. Those noted during the case study interview process include:

1. More structured approach to requirements management. Requirements resided in various non-contractual documents and notebooks, and the only single source for requirements was the Requirements Management Specification (RMS). The program had recently focused on adding traceability to the RMS, and the RMS had been placed in the Data Object-Oriented Repository System (DOORS). Also, Technical Review Boards have been established to help ensure traceability of requirements.
2. Creation of a single IMS.
3. Increased focus on software development and verification. The software qualification process has been more thoroughly defined, better configuration control has been established for units in test, and improved Acceptance Test Procedures have been implemented.
4. Improved Airworthiness Certification Process. ASC/EN has been more integrated into the certification process, since they must ultimately approve the TACC and coordinate on the final certification.
5. Development and implementation of a Systems Engineering Plan. The Program Office authored a tailored Systems Engineering Plan and is now executing to that plan.
6. Elimination of spirals. The program now uses blocks instead of spirals. Previously, participants knew when a spiral started but not always when it ended. This sometimes resulted in disputes between the contractor and Air Force relative to whether or not certain overruns were attributed to a specific contract.

7. More timely use of EVMS. Technical performance and schedule performance data are now transferred electronically into the EVMS.
8. Initiation of a Materiel Improvement Project Review Board (MIPRB) with emphasis on user involvement.
9. More traditional Preliminary Design Reviews (PDRs) and CDRs.
10. Refocus of the systems engineering management team and increased scope of their reviews. Previously, the systems engineering management team dealt mostly with air vehicle issues and considered very few specification changes, in-work changes, or changes to test procedures. Northrop Grumman increased the technical scope of the reviews and instituted a Technical Review Board. Any changes to the baseline at the system level is now reviewed by the Technical Review Board, so all IPTs are aware of and concur that the changes are appropriate, executable, and verifiable.

4. SUMMARY

The Global Hawk program was founded on the concept of providing the user with a system that was relatively inexpensive and quick to field. This provided the warfighter with a vehicle that could more readily be sent into high risk areas to obtain valuable intelligence information. If the unit was shot down, there was no loss of a pilot, and there was no major loss of dollars. The Global Hawk program was unique in many ways. For example:

a. It was the first ACTD program that emphasized heavy user involvement.
b. The ACTD program strategy used a provision of a newly adopted legislation that permitted the removal of many oversight rules and regulations typically required by Government acquisitions. The authority granted by this provision was known as Section 845 OTA.
c. The ACTD program was one of the few that truly focused on unit cost. The only requirement communicated to the contractor was a $10 million (FY94 dollars) UFP. All technical performance objectives were tradable.
d. With the latitude granted by Section 845, the contractor was initially designated as the RTO for the flight testing at Edwards AFB.
e. The Global Hawk was one of the few prototypes to be deployed into combat, participating in both Operation Enduring Freedom and Operation Iraqi Freedom.

Because of the numerous successes of the ACTD program, the Global Hawk won the 2000 Collier Trophy. The following year, it made aviation history by flying 7,500 miles non-stop from Edwards AFB to the RAAF Base in Edinburgh. This new distance record for a UAV was completed in just 22 hours.

Because of the successful demonstrations, Northrop Grumman received additional contracts with the Navy, Germany, and Australia. As a result of the joint Air Force/Australian exercise, Australia established a four-year agreement called Project Agreement 13 to develop the Global Hawk as a replacement for Australia's aging fleet of P-3C Orions. As a result of the highly successful German demonstration, the German MoD awarded a contract to EuroHawk GmbH, a joint venture company formed by EADS and Northrop Grumman, for the development, test, and support of the Euro Hawk system. It is also safe to say that the GHMD contributed to Northrop Grumman winning the Navy contract for the Navy Broad Area Maritime Surveillance UAV.

The ACTD program was highly successful with the program ultimately demonstrating the military utility of an unmanned system in an operational environment. The prototype aircraft even participated in combat, supporting the war on terrorism. However, the ACTD phase did have several shortcomings. First, the program requirements changed over the period of the ACTD phase, resulting in a more expensive air vehicle. Also, the ACTD program evolved to eliminate the elements necessary to demonstrate that the system was ready for production, as planned in the original strategy.

As a production program, the Global Hawk continued to use innovative acquisition strategies. Spiral development was used to incrementally develop capabilities that, when ready, would be incorporated into a production baseline. The concept was to deliver an operational capability to the user in a shorter period of time. This approach was consistent with the new acquisition strategies being developed by the senior management within the Air Force. In 2002, Dr. Marvin Sambur, then Assistant SAF for Acquisition, designated the Global Hawk as one of his six Pathfinder programs designed to deliver a needed capability to the warfighter in the shortest time possible. As a result, the schedules for the Block 20 and beyond air vehicles were compressed by nine years. To achieve scheduled milestones, significant concurrency was imposed between the development and production programs. This concurrency, coupled with an underestimation of the changes associated with the larger Block 20 aircraft, contributed to cost overruns resulting in a Nunn-McCurdy breach. The result was that the program was forced to recertify, adding realism to cost and schedule, as well as implementing some changes to how the program is managed. The Global Hawk now continues as a viable, stronger program. It has revolutionized the conduct of military combat by providing the warfighter with the ability to make decisions based on persistent and continuous near-real-time simultaneous EO/IR and on-board processed SAR imagery, thus providing the warfighter with a capability that is changing the face of modern aviation.

5. REFERENCES

Acquiring Major Systems: Cost and Schedule Trends and Acquisition Initiative Effectiveness, Karen W. Tyson et al, Institute for Defense Analyses, March 1989

AFOTEC Det. 5 Leads Conclusion of First Global Hawk Operational Testing, Airman 1st Class Julius Delos Reyes, 95th Air Base Wing Public Affairs, December 1, 2006

DoD News Briefing, June 28, 1995

Edwards Test Production Global Hawk for Possible Deployment, Tech Sgt Eric M. Grill, 95th Air Base Wing Public Affairs, September 8, 2005

EuroHawk, www.eads.com/1024/en/businet/defence/mas/uav/eurohawk.html

Factsheets: RQ-4 Global Hawk Unmanned Aircraft System, Air Force Link, October 2008

GAO-05-6, Unmanned Aerial Vehicles: Changes in Global Hawk's Acquisition Strategy Are Needed to Reduce Program Risks, Government Accountability Office, November 2004

GAO-06-222R, Unmanned Aircraft Systems: Global Hawk Cost Increase Understated in Report, Government Accountability Office, December 15, 2005

GAO-06-447, Unmanned Aircraft Systems: New DoD Programs Can Learn from Past Efforts to Craft Better and Less Risky Acquisition Strategies, Government Accountability Office, March 2006

Global Hawk Concept to Combat, Bob Ettinger, National Defense Industry Association 24th Annual National Test and Evaluation Conference, February 28, 2008

Global Hawk Systems Engineering Plan, Version 1, October 2006

HAE UAV ACTD Management Plan, Version 1.0, December 1994 (draft)

HALE Program Overview, History and Accomplishments, Northrop Grumman web site, www.northropgrumman.com/ unmanned/globalhawk/overview.html

Innovative Development, Global Hawk and DarkStar – Flight Test in the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002

Innovative Development, Global Hawk and DarkStar – HAE UAV ACTD Program Description and Comparative Analysis, Robert S. Leonard and Jeffrey A. Drezner, RAND Corporation, last modified December 7, 2007

Innovative Development, Global Hawk and DarkStar – Their Advanced Concept Technology Demonstrator Program Experience, Executive Summary, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002

Innovative Development, Global Hawk and DarkStar, Transition Within and Out of the HAE UAV ACTD Program, Jeffrey A. Drezner and Robert S. Leonard, RAND Corporation, 2002

Innovative Management in the DARPA High Altitude Endurance Unmanned Aerial Vehicle Program, Jeffrey A. Drezner, Geoffrey Sommer, and Robert S. Leonard, RAND Corporation, last modified December 7, 2007

Interview with Marvin Sambur, Assistant Secretary of the Air Force (Acquisition): Pathfinder Program Testing the Potential of Spiral Arms Development, P. L. Croise, PM, July – August 2003

Letter from Kenneth J. Krieg, Under Secretary of Defense for Acquisition, Technology, and Logistics, to Richard B. Cheney, President of the Senate, on Global Hawk Program Recertification, June 5, 2006

News Release, United States Department of Defense, Office of the Assistant Secretary of Defense (Public Affairs), March 2, 1998

Northrop Grumman RQ-4A Global Hawk UAV Achieves Military Airworthiness Certification: A First for Unmanned Aerial Vehicles, Revelle Anderson, Northrop Grumman News Release, February 13, 2006

Northrop Grumman to Demonstrate Global Hawks for Maritime Watch, Space Daily, February 13, 2003

Photo Release – Northrop Grumman First Production Air Vehicle of Global Hawk Unmanned Reconnaissance System, Jim Hart, Northrop Grumman, August 1, 2003

Prototype Global Hawk Flies Home after 4,000 Combat Hours, Tech Sgt Andrew Leonard, 380th Air Expeditionary Wing Public Affairs, Air Force Link, February 14, 2006

Report for Congress: Unmanned Aerial Vehicles: Background and Issues for Congress, Elizabeth Bone and Christopher Bolkcom, Library of Congress, Order Code RL31872, April 25, 2003

Results of Global Hawk Accident Investigation Board Released, Air Force News, Sue Baker, Aeronautical Systems Center Public Affairs, December 23, 1999

RQ-4 Global Hawk, http://www.absoluteastronomy.com/topics/RQ-4_Global_Hawk

The Global Hawk Unmanned Aerial Vehicle Acquisition Process, A Summary of Phase I Experience, Geoffrey Sommer, Giles K. Smith, John L. Birkler, and James R. Chiesa, RAND Corporation, last modified December 7, 2007

Transitioning an ACTD to an Acquisition Program, Col G. Scott Coale and George Guerra, Defense AT&L, September – October 2006

Unmanned Aerial Vehicles in the US Military, Donald Myers, Illinois Institute of Technology

USAF Accident Investigation Boards, USAF Judge Advocate General’s Corps, http://usaf.aib.law.af.mil/AIB_Info.html

6. APPENDICES

Appendix A. AUTHOR BIOGRAPHY

Bill Kinzig joined MacAulay-Brown, Inc., as a Senior Systems Engineer in 2006, providing flight systems and systems engineering support to Government and industry clients. He has over 38 years of leadership and management experience in acquisition and sustainment of Air Force weapon systems. While working at MacAulay-Brown, he has conducted several research studies for the KC-X Program Office; led an E-10 airworthiness certification effort for the Electronic Systems Center (ESC) at Hanscom AFB, Massachusetts; consulted with ESC on developing an airworthiness certification approach for the E-8; and rewrote the ASC Guidance Document for Systems Engineering Plans at WPAFB.

Before his employment at MacAulay-Brown, Mr. Kinzig spent 35 years at ASC/EN, working aircraft acquisition. He began his career in the Subsystems Branch, supporting a myriad of aircraft, such as the E-3, F-4, A-7K, F-16, B-2, and KC-10. He expanded his responsibilities while working on the F-22, eventually leading the Aircraft Systems IPT. From there, he was assigned as Technical Advisor for Air Vehicle Subsystems and ended his career as Technical Director for Flight Systems Engineering. While serving as Technical Director, he was a Senior Member of the Airworthiness Control Board, Senior Member of the Air Force Fleet Viability Board, and Senior Air Force Representative to the biyearly Airworthiness Summits.

Mr. Kinzig earned a B.S. in Mechanical Engineering from the University of Dayton in 1970 and an M.S. in Mechanical Engineering from the University of Dayton in 1978.

Appendix B. ACRONYMS

ACC	Air Combat Command
ACTD	Advanced Concept Technology Demonstration
ADM	Acquisition Decision Memorandum
AFB	Air Force Base
AFC2ISR	Air Force Command and Control, Intelligence, Surveillance, and Reconnaissance
AFCSE	Air Force Center for Systems Engineering
AFFTC	Air Force Flight Test Center
AFI	Air Force Instruction
AFIT	Air Force Institute of Technology
AFOTEC	Air Force Operational Test and Evaluation Center
AFPD	Air Force Policy Directive
AoA	Analysis of Alternatives
ASC	Aeronautical Systems Center
ASIP	Airborne Signals Intelligence Payload
A/V	Air Vehicle
C2	Command and Control
CAIG	Cost Analysis Improvement Group
CAIV	Cost As an Independent Variable
CAX	Combined Arms Exercise
CCDR	Contractor Cost Data Report
CDR	Critical Design Review
CFSR	Contract Funds Status Report
CGS	Common Ground Segment
CIGSS	Common Imagery Ground Surface System
COA	Certificate of Authorization
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
CPFF	Cost Plus Fixed Fee
CPIF	Cost Plus Incentive Fee
CPR	Cost Performance Report
CSCI	Computer Software Configuration Item

CWBS	Contractor Work Breakdown Structure
CY	Calendar Year
D&E	Demonstration and Evaluation
DAES	Defense Acquisition Executive Summary
DARO	Defense Airborne Reconnaissance Office
DARPA	Defense Advanced Research Projects Agency
DAU	Defense Acquisition University
DCAA	Defense Contract Audit Agency
DCMA	Defense Contract Management Agency
DLL	Design Limit Load
DoD	Department of Defense
DoDAF	DoD Architectural Framework
DOORS	Data Object-Oriented Repository System
DT&E	Development, Test, and Evaluation
DTC	Design To Cost
EADS	European Aeronautical Defense and Space
EIA	Electronics Industrial Association
EISS	Enhanced Integrated Sensor Suite
ELINT	Electronic Intelligence
EMD	Engineering and Manufacturing Development
EO	Electro-Optical
ESC	Electronic Systems Center
EVM	Earned Value Management
EVMS	Earned Value Management System
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FFRR	First-Flight Readiness Review
FLTS	Flight Test Squadron
FY	Fiscal Year
FYDP	Five-Year Defense Plan
GAO	Government Accountability Office
GATM	Global Air Traffic Management

GFE	Government-furnished Equipment
GHMD	Global Hawk Maritime Demonstration
GMTI	Ground Moving Target Indicator
GOSG	General Officer Steering Group
GPS	Global Positioning System
HAE	High Altitude Endurance
HQ	Headquarters
ICBM	Intercontinental Ballistic Missile
ICD	Interface Control Document
IDA	Institute for Defense Analyses
IDD	Interface Definition Document
IEEE	Institute of Electrical and Electronics Engineers
IFC	Integrated Functional Capability
IMINT	Imagery Intelligence
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
INCOSE	International Council on Systems Engineering
INS	Inertial Navigation System
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
IR	Infrared
IRT	Independent Review Team
ISS	Integrated Sensor Suite
IT	Information Technology
JFCOM	Joint Forces Command
JPO	Joint Program Office
JROC	Joint Requirements Oversight Council
JTF	Joint Task Force
JTFEX	Joint Task Force Exercise
KVA	Kilo-Volt-Amperes

LOS	Line of Sight
LRE	Launch and Recovery Element
LRIP	Low Rate Initial Production
MA	Mishap Aircraft
MAR	Monthly Acquisition Report
MAV	Mishap Air Vehicle
MC2A	Multi-sensor Command and Control Aircraft
MCE	Mission Control Element
MDAP	Major Defense Acquisition Program
MIL-HDBK	Military Handbook
MIL-SPEC	Military Specification
MIL-STD	Military Standard
MIPRB	Material Improvement Project Review Board
MoD	Ministry of Defense
MOE	Measure of Effectiveness
MOP	Measure of Performance
MoU	Memorandum of Understanding
MP	Mishap Pilot
MPP	Modernization Planning Process
MP-RTIP	Multi-Platform Radar Technology Insertion Program
MR	Management Reserve
MS	Microsoft
NAS	Naval Air Station
NATO	North Atlantic Treaty Organization
NAVAIR	Naval Air Systems Command
NAWC	Naval Air Warfare Center
NDAA	National Defense Authorization Act
NMUSAF	National Museum of the United States Air Force
OFP	Operational Flight Program
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OTA	Other Transactions Authority

OT&E	Operational Test and Evaluation
PDR	Preliminary Design Review
PMD	Program Management Directive
POM	Program Objective Memorandum
RAAF	Royal Australian Air Force
RFP	Request for Proposal
RMS	Requirements Management Specification
RTO	Responsible Test Organization
SAF	Secretary of the Air Force
SAMP	Single Acquisition Management Plan
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SCD	System Capability Document
SDD	Software Design Document
SEIT	Systems Engineering Integration Team
SEMP	Systems Engineering Master Plan
SIGINT	Signals Intelligence
SIL	System Integration Laboratory
SMM	System Maturity Matrix
SORAP	Source of Repair Assignment Process
SoS	System-of Systems
SOW	Statement of Work
SPO	System Program Office
SRD	System Requirements Document
SRS	Software Requirements Specification
TACC	Tailored Airworthiness Certification Criteria
TBMCS	Theater Battle Management Core System
TEMP	Test and Evaluation Master Plan
TES	Test and Evaluation Squadron
TO	Technical Order
TPM	Technical Performance Measure
TRA	Teledyne Ryan Aeronautical

TSPR	Total System Performance Responsibility
UAV	Unmanned Air Vehicle
UFP	Unit Flyaway Price
USACOM	United States Atlantic Command
USC	United States Code
USD (A&T)	Under Secretary of Defense for Acquisition and Technology
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USJFCOM	United States Joint Forces Command
VDD	Version Description Document
WPAFB	Wright-Patterson Air Force Base

Appendix C. AMENDMENT

Amendment

Report No. 97-311

DEPARTMENT OF DEFENSE AUTHORIZATION ACT, 1982

November 3, 1981. – Ordered to be printed.

CONFERENCE REPORT

(To accompany S.815)

TITLE IX—GENERAL PROVISIONS

REPORTS ON UNIT COSTS OF MAJOR DEFENSE SYSTEMS

Sec. 917 (a)(1) The program manager (as designated by the Secretary concerned) for each major defense system included in the Selected Acquisition Report dated March 31, 1981, and submitted to Congress pursuant to section 811 of the Department of Defense Appropriation Authorization Act, 1976 (Public Law 94-106; 10 U.S.C. 139 note), shall submit to the Secretary concerned, within seven days after the end of each quarter of fiscal year 1982, a written report on the major defense system included in such selected acquisition report for which such manager has responsibility. The program manager shall include in each such report --

(A) the total program acquisition unit cost for such major defense system as of the last day of such quarter; and

(B) in the case of a major defense system for which procurement funds are authorized to be appropriated by this Act, the current procurement unit cost for such major defense system as of the last day of such quarter.

2) If at any time during any quarter of fiscal year 1982, the program manager of a major defense system referred to in paragraph (1) has reasonable cause to believe that (A) the total program acquisition unit cost, or (B) in the case of a major defense system for which procurement funds are authorized to be appropriated by this Act, the current procurement unit cost has exceeded the applicable percentage increase specified in subsection (b), such manager shall immediately submit to the Secretary concerned a report containing the information, as of the date of such report, required by paragraph (1).

3) The program manager shall also include in each report submitted pursuant to paragraph (1) or (2) any change from the Selection Acquisition Report of March 31, 1981, in schedule milestones or system performances with respect to such system that are known, expected, or anticipated by such manager.

(b)(1) If the Secretary concerned determines, on the basis of any report submitted to him pursuant to subsection (a), that the total program acquisition unit cost (including any increase for expected inflation) for any major defense system for which no procurement funds are authorized to be appropriated by this Act has increased by more than 15 percent over the total program acquisition unit cost for such system reflected in the Selected Acquisition Report of March 31, 1981, then (except as provided in paragraph (3)) no additional funds may be obligated in connection with such system after the end of the 30-day period beginning on the day on which the Secretary makes such determination. The Secretary shall notify the Congress promptly in writing of such increase upon making such a determination with respect to any such major defense system and shall include in such notice the date on which such determination was made.

(2) If the Secretary concerned determines, on the basis of a report submitted to him pursuant to subsection (a), that –

(A) the procurement unit cost of a major defense system for which procurement funds are authorized to be appropriated by this Act has increased by more than 15 percent over the procurement unit cost derived from the Selected Acquisition Report of March 31, 1981, or

(B) the total program acquisition unit cost (including any increase for expected inflation) of such system has increased by more than 15 percent over the total program acquisition unit cost for such system as reflected in the Selected Acquisition Report of March 31, 1981, or

then (except as provided in paragraph (3)) no additional funds may be obligated in connection with such system after the end of the 30-day period on the day which the Secretary makes such determination. The Secretary shall notify the Congress promptly in writing of such increase upon making such a determination with respect to any such major defense system and shall include in such notice the date on which such determination was made.

(3) The prohibition contained in paragraphs (1) and (2) on the obligation of funds shall not apply in the case of any major defense system to which such prohibition would otherwise apply if the Secretary concerned submits to the Congress, before the end of the 30-day period referred to in paragraph (1) or (2), a written report which includes –

(A) a statement of the reasons for such increase in total program acquisition unit cost or procurement unit cost;

(B) the identities of the military and civilian officers responsible for program management and cost control of the major defense system;

(C) the action taken and proposed to be taken to control future cost growth of such system;

(D) any changes made in the performance or schedule milestones of such system and the degree to which such changes have contributed to the increase in total program acquisition unit cost or procurement unit cost;

(E) the identities of the principal contractors for the major defense system; and

(F) an index of all testimony and documents formally provided to the Congress on the estimated cost of such system.

(c)(1) If the Secretary concerned **–**

(A) on the basis of a report submitted to him pursuant to subsection (a), determines (i) that the total program acquisition unit cost (including an increase for expected inflation) for a major defense system has increased by more than 25 percent over the total program acquisition unit cost or such system reflected in the Selected Acquisition Report of March 31, 1981, or (ii) in the case of any such system for which procurement funds are authorized to be appropriated by this Act, that the current procurement unit cost of such system has increased by more than 25 percent over the procurement unit cost derived from the Selected Acquisition Report of March 31, 1981, and

(B) has submitted a report to the Congress with respect to such system pursuant to subsection (b)(3),

then (except as provided in paragraph (2)) no additional funds may be obligated in connection with such system after the end of the 60-day period beginning on the day on which the Secretary makes such determination.

(2) The prohibition contained in paragraph (1) on the obligation of funds shall not apply in the case of a major defense system to which such prohibition would otherwise apply if the Secretary of Defense submits to the Congress, before the end of the 60-day period referred to in such paragraph, a written certification stating that -

(A) such system is essential to the national security;

(B) there are no alternatives to such system which will provide equal or greater military capability at less cost;

(C) the new estimates of the total program acquisition unit cost or procurement unit cost are reasonable; and

(D) the management structure for such major defense system is adequate to manage and control total program acquisition unit cost or procurement unit cost.

(d) As used in this section:

(1) The term "total program acquisition unit cost" means, in the case of a major defense system, the amount equal to (A) the total cost for development and procurement of, and system-specific military construction for, such system, divided by (B) the number of fully configured end items to be produced for such a system.

(2) The term "procurement unit cost" means, in the case of a major defense system, the amount equal to (A) the total of all procurement funds available for such system in any fiscal year, divided by (B) the number of fully-configured end items to be procured with such funds during such fiscal year.

(3) The term "Secretary concerned" has the same meaning as provided in section 101(8) of title 10, United States Code.

(e) Section 811 of the Department of Defense Appropriation Authorization Act, 1976 (Public Law 94-106; 10 U.S.C. 139 note), is amended by addition at the end thereof the following new subsection:

"(c)(1) Each report required to be submitted under subsection (a) shall include the history of the total program acquisition unit cost of each major defense system from the date on which funds were first authorized to be appropriated for such system.

"(2) As used in this subsection, the term 'total program acquisition unit cost' means the amount equal to (A) the total cost for development and procurement of, and system-specific military construction for, a major defense system, divided by (B) the number of fully configured end items to be produced for such a system."