DarkStar - High Altitude Endurance UAV

by

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ABSTRACT

This paper describes the U.S. program to develop, test, and demonstrate the Tier 3-, DarkStar, High Altitude Endurance Unmanned Aerial Vehicle (HAE UAV). DarkStar is designed to provide continuous, timely, high resolution imagery products to the Warfighter. DarkStar is uniquely capable of extended surveillance over heavily defended territory. DarkStar is part of the HAE UAV program which also includes the Global Hawk UAV and a common ground segment which is interoperable with both UAVs. It is the combination of DarkStar, Global Hawk and other intelligence, surveillance and reconnaissance assets which will provide U.S. forces with the information dominance, central to future warfighting plans. DARPA is executing the program under Section 845 contracting authority. Air vehicle #1 completed one successful flight and had an accident on the takeoff of flight #2. The accident causes are now well understood. Subsystems and test procedure modifications are being implemented on air vehicle #2. Planning for the programs demonstration phase, FY99-00, is well underway. The United States Atlantic Command has been designated the lead CINC for the system's military evaluation. Specific demonstration exercises are being identified and specific data collection requirements are being developed. The entire DarkStar team is confident that it will

demonstrate the performance characteristics which make this a unique and valuable system for protecting and preserving the nation's interests.

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Introduction

On May 20, 1994, the United States Department of Defense entered into a Section 845 Agreement with Lockheed Martin Skunk Works and Boeing Military Airplane Division to develop and demonstrate a radically new system. The DarkStar unmanned air vehicle is designed to provide assured, high resolution, surveillance over heavily defended territory, day or night, at the direction of the theater commander. Several firsts are being attempted: a) a new way of doing system acquisition within DoD, b) a focus on the ultimate cost of procuring the system rather than a rigid set of performance requirements, and c) a rapid development of a low observable, autonomous, unmanned system at a development price which is deemed affordable.

The need for high resolution, wide area imagery was highlighted in the Gulf War. Theater commanders identified the following objectives: timely information, increased revisit rate or refresh of information, synoptic battlefield coverage, and cooperative use of all intelligence, surveillance and reconnaissance (ISR) assets. A "system of systems" study was completed during the summer of 1993 which attempted to quantify these objectives. The study results yielded: an emphasis on making strategic systems more responsive to tactical information requests; the Tier 2 (Predator) system; the High Altitude Endurance (HAE) Unmanned Air Vehicle (UAV) programs; and several other initiatives aimed at improved processing, exploitation and distribution of information.

The HAE UAV program is not trying to solve all of the tactical commanders' requirements. It is the collection of all ISR assets which is believed to optimally address the overall objectives. The HAE UAV program has three elements: the Tier 2+, Global Hawk, the Tier 3-, DarkStar, and the Common Ground Segment (CGS). The airborne platforms are complementary systems controlled by a CGS for takeoff, landing, mission tasking, image receipt, and dissemination. Global Hawk provides long endurance and synoptic coverage of the battlefield in low to medium threat environments. DarkStar provides comparable image quality and collection rates; but, its primary emphasis is on assured imagery collection in high threat environments. This workload distribution avoids the unnecessary expense of a single large platform capable of doing both jobs.

Programmatic Structure - DARPA Agreement

The DARPA "Agreements authority" was enacted as Section 251, Public Law 101-189, in the FY 1990 National Defense Authorization Act (codified in 10 U.S.C. §

2371) as a way to allow commercial and government entities to jointly fund research and development activities. Subsequently, 10 U.S.C. § 2371, Section 845 of the 1994 National Defense Authorizations Act was enacted to allow DARPA, on a pilot basis, to use non-procurement agreements for purely military Research and Development and, prototype projects and technology demonstrations of hardware directly relevant to weapon systems. The primary benefit of this authority is that DARPA can tailor the contracting process to each project rather than conforming to predetermined contracting rules such as the Federal Acquisition Regulations (FARS), Departmental FARS, Truth in Negotiation Act (TINA), Competition in Contracting Act (CICA), Military Specifications (MILSPECS). It also allows the use of commercial manufacturing and auditing practices without the often burdensome government audit inspections. The use of the Agreements Authority by the HAE UAV program has shortened development time and enhanced affordability. Section 845 Authority allows DARPA to implement streamlined acquisition and focus on goals and objectives rather than acquisition regulations.

In point of fact, DARPA has not thrown out all of these regulations; but, has judiciously chosen which regulations to implement. The Tier 3- Agreement gave Lockheed and Boeing tremendous flexibility in the organization of the program, selection of subcontractors, use of mil-spec equipment, cost reporting and day to day program management. Historically, as R&D contract costs grow, all of the risk is born by the Government. DARPA is trying to change the mindset that as development costs increase the Government is always counted on to make up all shortfalls. Several tacks were taken on the Tier 3- program to make this happen:

- the Government minimized reporting and formal meeting requirements,
- a target cost was established, with a fee structure incentivizing cost control and system performance,
- and if the contractor exceeded a predetermined cost, a 50/50 cost share between the Government and Contractor team became effective.

Development risks are shared by all parties and everyone is incentivised to manage to a fixed set of goals, objectives and requirements.

The Government program office is structured to support all three HAE UAV program elements: Tier 2+, Tier 3- and CGS. Many individuals support multiple elements within the program. This helps in the cross flow of information; particularly, lessons learned. Specifically, the Tier 3- program is staffed by a highly experienced group of technical experts covering a broad range of technical disciplines. It is important that the technical specialists recognize they are part of a larger systems program and are encouraged to identify and solve problems in a systems context. A central tenet of trying to make this organization work in the DARPA Agreement context is to seek insight into what the contractor is doing rather than providing Government oversight. Good communication among all the parties is critical since the "normal" massive documentation does not exist in a Mil-Spec sense. Critical documents are developed and maintained in order to execute the program; but, additional documents which are for documentation only are bypassed. The team has been successful with 10-20 people supporting the development effort at any given time. When issues arise additional experts are brought in to provide advice and solutions; but, they do not remain with the program after the issue is resolved. With a small team the interchange of information is mandatory and readily achieved. Developing any airplane is very much a systems problem; it should not be approached by a large number of individualists solely concerned with their technical area.

Requirements, Goals and the Unit Flyaway Price

Historically, the U.S. DoD specifies a large number of performance, process, reporting and management requirements when procuring a system. These requirements are used by the contractor to design the system and by the Government to judge the success or failure of the project. The incremental cost of those requirements is rarely assessed at the beginning of the program and the number of requirements often grows after a contract has been signed. The usual result is that large sums of money are spent trying to satisfy the last 5 percent of the requirements and the requirements growth leads to significant overall development growth in both dollars and time. There is only one requirement on this program, $10M unit flyaway price (UFP) for the airplane system. Essentially this is the cost of everything that leaves the ground. All of the system performance measures are goals. All of the documentation is in contractor format. The contractor is free to trade off system performance in an effort to satisfy the $10M UFP while maintaining military utility.

The $10M UFP requirement for the airborne system remains a central focus of the program. The airborne system is composed of the: airframe, on-board communications, and sensors. All other performance related measures are goals, Figure 1. The cost will be assessed as the average cost of units 11 to 20 in FY94 dollars. This point in the fabrication cycle was selected to allow the contractors to come down the learning curve on assembly and insure that the lessons learned from early flight test are incorporated into the system. Based on Government and contractor studies DARPA believes that a system with very good military utility can be procured for that price. The contractor was given complete freedom in the design and fabrication of the system in order to maximize achievement of the goals and maintain the ability to meet the $10M UFP. Lessons learned from the Tier 2, Predator, program were looked at as the statement of work for air vehicles 3 and 4 was developed. Several minor modifications will be made: addition of navigation lights, addition of a voice relay capability for communications with the FAA and a few others of similar ilk. Air vehicle #2 will be updated with as many of these changes as practical in the FY99 time frame. These changes represent the maturation of Service use of UAVs in operational environments.

Figure 1. DarkStar System Goals

• Endurance	Greater than 8 hours at 500nmi radius
• Command and Control	Via line of sight and SATCOM (UHF)
• Mission Route Planning	Demonstrate capability
• Autonomous Flight	Takeoff through landing
• Radar wide are search	
– via CDL	1,688 sq.nmi/hr at 1 m resolution
– via T1 SATCOM	288 sq.nmi/hr at 1 m resolution
• Radar spot mode	
– via CDL	75 spots / hr at 1 ft resolution (1nmi x 1 nmi)
– via T1 SATCOM	75 spots /hr at 1 ft resolution (.43nmi x .43 nmi)
• EO wide area search	
– via CDL	1,600 sqnmi/hr at IIRS >5.5
– via T1 SATCOM	25 sqnmi/hr at IIRS >5.5
• EO spot mode	
– via CDL	1,280 spots/hr at IIRS >5.5 (1nmi x 1 nmi)
– via T1 SATCOM	20 spots/hr at IIRS >5.5 (1nmi x 1 nmi)

DARPA is intent on changing the status quo and have the contractor share in the risk of development cost growth. The Tier 3- contractors agreed to share the development costs above a threshold value. This was an attempt by the Government to accomplish several things: a.) insure the initial estimate was realistic, b.) share the risk between all parties, and c.) change the paradigm of DoD R&D development.

ACTD Concept

Tier 3- was designated as an Advanced Concept Technology Demonstration (ACTD) program. That designation implies: the military users would be brought into the program early in the development process, and they will have the loudest voice in assessing the utility of the system. The HAE UAV system will be assessed in a series of Service and Joint demonstrations in FY99 and FY00. Three outcomes are possible at the end of the ACTD:

- the system demonstrates its value and a production decision is made,
- the system is useful; but, no further systems are desired and a residual capability remains, and,
- the system does not perform and the DoD investment is minimized in arriving at that conclusion.

United States Atlantic Command (USACOM) was designated as the lead CINC for the HAE UAV systems assessment. Several military officers have been assigned to the program to develop the demonstration and evaluation plan and a concept of operations.

This plan will identify the specific military exercises to participate in, the data to be collected, and the system assessment criteria. USACOM and the program office are trying to identify a series of exercises beginning with very straight forward non-real-time participation to full integration into an exercises primary objectives. There is a strong desire by USACOM to demonstrate several system deployments to various theaters, worldwide. These deployments will begin to answer several questions:

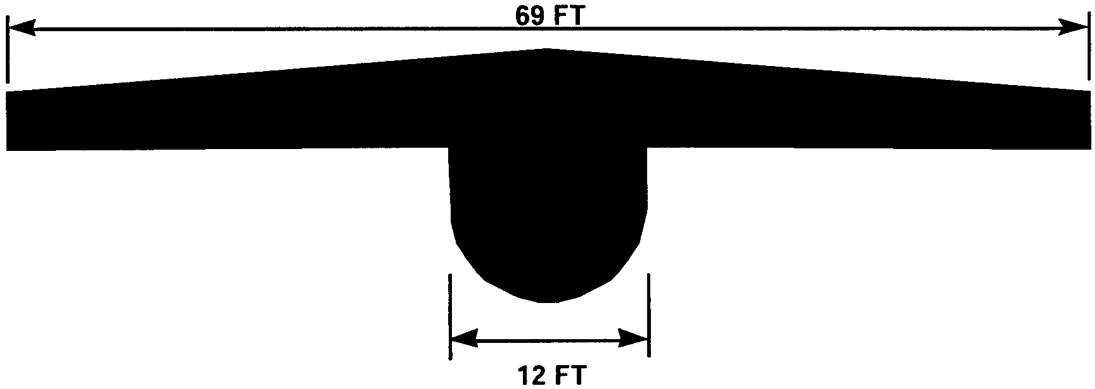
- What is the logistics trail required to support these systems ?
- How much airlift is required ?
- How well do the systems integrate with theater command and control structures ?
- Are there peculiar basing issues associated with these UAVs ?
- Can data from the systems be rapidly disseminated within the theater ?
- What is the quality of the data product(s) ?
- What availability rate is the system able to maintain ?
- How reliable are the systems and components ?
- How does the system integrate with other theater air assets ?
- Is the system responsive to tasking ?

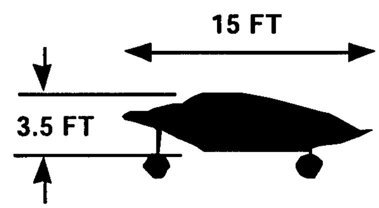
This does not represent all interesting questions; nor do we expect to have complete answers to all of these questions. The overarching goal is to gather as much information as possible, within program time and budget constraints, to enable a decision on program continuation beyond the ACTD.

System Description

DarkStar is a low observable aircraft designed to provide the theater commander with wide area, high resolution coverage when the battlefield is heavily defended. DarkStar is capable of greater than 8 hours of endurance at a radius of 500 nmi., with a payload of one thousand pounds. Figure 2 shows the physical dimensions of the aircraft. The engine is a Williams FJ-44-1 which is used commercially on the Citation business jet.

Figure 2. Tier III Minus
Unique Flight Vehicle Shape





• DESIGN GROSS WEIGHT	8,600 LB
• DESIGN ZERO FUEL WEIGHT	5,639 LB
• DESIGN PAYLOAD WEIGHT	1,081 LB
• ENGINES (1)	WILLIAMS FJ-44

Command and control of the aircraft is a redundant system using: a line of sight (LOS) UHF link, UHF SATCOM or one of the sub-channels on the LOS Common Data Link (CDL). The system has been designed to operate even if the primary link is lost. Nominally, the system will continue on its mission for a preset amount of time and try and reestablish communications with the operating base over each of the links in sequence. If communication is not reestablished, the mission plan will dictate whether the aircraft continues its mission or returns to base. If upon return to base the system is still unable to establish communications; it will proceed according to the mission plan to attempt a landing.

The DarkStar sensor is either a synthetic appeture radar (SAR) or an electro-optical (EO) system. The SAR is supplied by Northrop-Grumman Electronics Systems, Baltimore, MD. Northrop-Grumman modified existing parts from the canceled Navy A12 SAR program and significantly expanded on the technology developed for the Predator radar. In one hour the system is capable of collecting 1700 square nautical miles of imagery at 1 meter resolution or over 75 spot images, 1 nmi. x 1 nmi., at one foot resolution. The radar is a 2-D electronically scanning antenna mounted in the left payload bay of the airplane. The entire system is contained on a pallet which can be easily lowered, disconnected, and replaced with an EO payload pallet. The system was specifically designed to minimize the number of connections between the pallet and the aircraft to facilitate rapid change out.

The EO sensor is supplied by Recon-Optical Incorporated, ROI, Chicago, IL. This system is a modification of other line scanning systems developed by ROI. In one hour the EO system is capable of collecting 1600 square nautical miles of wide area imagery or over 1200 spot images, 1 nmi. x 1 nmi, at approximately 1 meter resolution. Since this system is in the visible spectrum only, at this time, the window technology is relatively straight forward.

The sensor imagery is disseminated via one of two communications links:

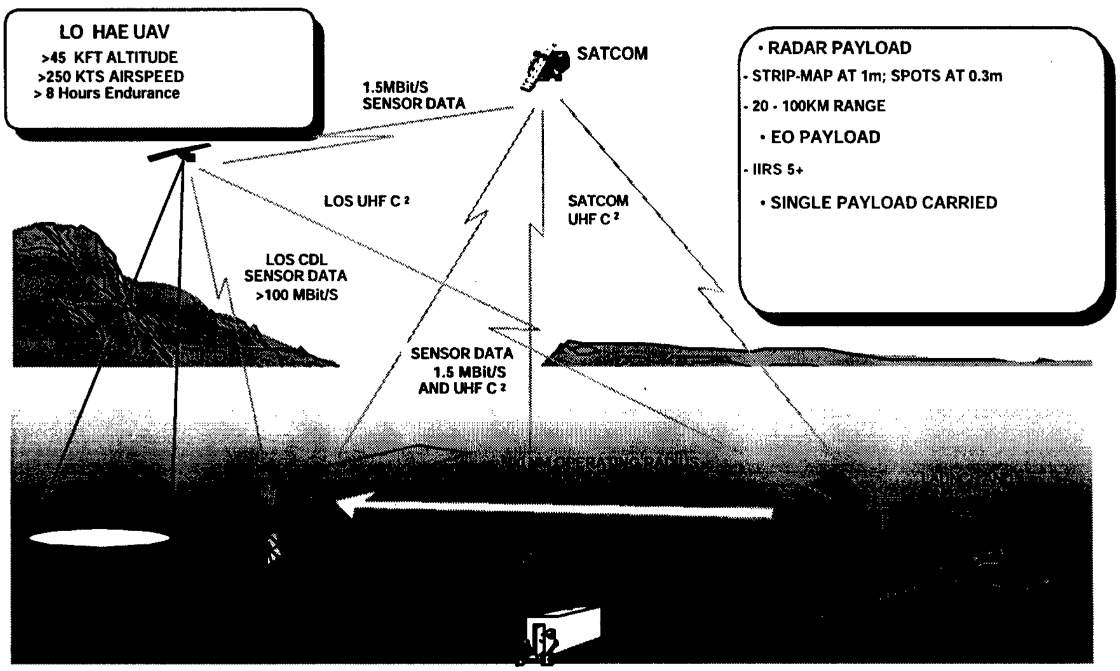
- LOS common data link CDL capable of 137 megabits per second, or
- Ku band SATCOM system at 1.5 megabits per second.

The LOS imagery is processed on the ground and then disseminated to existing image exploitation systems (IES) such as CARS, ETRAC or JSIPS. Imagery sent via SATCOM is processed on board the airplane and is disseminated to the IES. The area collected by the payloads using each of the links is described in Figure 1.

The DarkStar control and dissemination architecture is shown in Figure 3. It is identical to the Global Hawk's architecture. The CGS is being developed by Raytheon E-Systems. The CGS is composed of two elements: the launch and recovery element, LRE, and the mission control element, MCE. As its name indicates, the LRE is responsible for aircraft preflight and the takeoff and landing mission phases. The Mission Control Element will receive tasking instructions from theater operational forces; and develop the flight, communications, and sensor collection plans. In addition, during the mission, the MCE will: control the vehicle and sensors, interact with air traffic control authorities, dynamically retask the air vehicles and sensors, format the imagery and store or disseminate it in real time to an IES. The MCE will also perform any sensor data processing not done on-board the aircraft; and monitor platform and sensor health and status. The theater commander will have direct HAE UAV system control and be the first to receive the imagery products.

The CGS elements may be collocated or dispersed as the mission requires. While there is no need for the LRE and MCE to be collocated; there are clear advantages to having the MCE and an IES in close proximity. The amount of data generated by the HAE UAV systems requires sufficient communications bandwidth to move the imagery from the MCE to the IES. The closer they are, the easier it is to establish a high bandwidth communications link. The image exploitation systems can then take advantage of their secondary distribution channels to promulgate the information to the appropriate echelon.

Figure 3. Tier III Minus Architecture

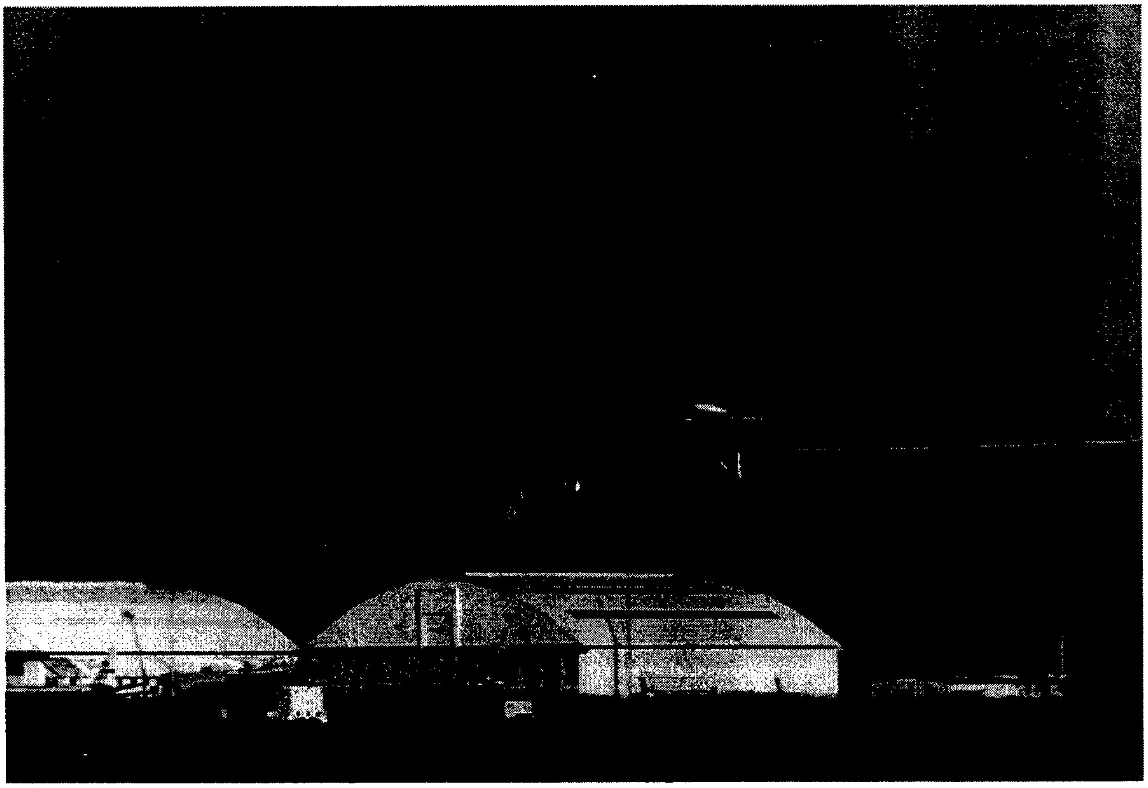


A critical DarkStar system element is the mission planning element. Using the Air Force Mission Support System (AFMSS) and the Common Low Observable Auto-Router (CLOAR) DarkStar missions are carefully planned to exploit the system's low observable attributes. The CGS will allow the theater commander to control multiple DarkStar and Global Hawk vehicles and receive synoptic battlefield imagery in near-real-time.

Program Status

The Tier 3- Agreement was signed on 20 June, 1994. Twelve months later the first of two air vehicles was rolled out at the Lockheed plant in Palmdale, California. On 29 March, 1996 DarkStar first flight was accomplished. In twenty one months, Lockheed and Boeing were able to demonstrate the first fully autonomous system using differential GPS for takeoff and landing. The first flight lasted approximately twenty minutes and demonstrated the basic system flight characteristics, Figure 4.

Figure 4. First Flight of Air Vehicle #1



On 22 April, 1996 DarkStar air vehicle #1 crashed on its second flight. A thorough investigation by the Air Force, DARPA and an independent review team identified the accident's cause. It was determined to be caused by interactions between the landing gear and the vehicle inertia which caused an undamped vehicle oscillation. This behavior was not correctly predicted by the system simulation available at the time. UAV's are not forgiving of mans inattention to detail. Manned aircraft are known to have the same temperament, as is evidenced by early program accidents of the F-14, B-1A, Have Blue, F-117, X-31 and YF-22.

Lockheed, Boeing and the Government team have worked for twelve months to understand the primary and secondary causes of the air vehicle #1 accident and to develop system adjustments. These adjustments have taken many forms:

- changes to the system simulation,
- changes to the landing gear,
- changes to the takeoff methodology,
- changes to the communications system,
- and changes to the crew training syllabus to focus more on emergency procedures.

While the team was exploring the accident causes and solutions several other program risk reduction tasks were completed. Air vehicle #2 was sent to Lockheed's radar cross section range at Hellendale, CA. The system performed excellently. The Lockheed and Boeing engineers were able to identify and solve problems real-time using the latest computational tools. All test objectives were achieved. At the same time, the radar system was completing its integration and risk reduction testing aboard a Northrop-Grumman BAC-111 system test aircraft. The radar demonstrated the collection rates, resolution and field of regard required to meet its performance goals. The EO system risk reduction testing was conducted on-board a Pacer Coin C-130 aircraft. (Results of this testing were not available in time for inclusion in this paper; but, will be discussed at the Conference.)

Air vehicle (A/V) #2 is currently at NASA Dryden Flight Research Center preparing for a return to flight. Several tests need to be completed before the system returns to the air:

- system ground testing (comms, landing gear, EMI....),
- taxi testing over a range of speeds, and,
- verification of measured system performance versus the system simulation.

Looking Ahead

In 1997-1998 the Tier 3- program has several goals:

- complete A/V #2 airworthiness and sensor performance testing,
- initiate fabrication and testing of air vehicles #3 and 4,
- qualification of the production, flush port, air data system, and
- detailed planning for the ACTD system demonstration phase.

A/V #2 flight testing will begin late this summer. The airplane will be flying on the Edwards Air Force Base ranges during this program phase. The testing will be conducted in two phases: airworthiness testing and payload testing. The primary objective of the airworthiness testing is to clear enough of the flight envelope to be able to safely conduct the payload testing. This will not be a complete envelope expansion test program. The objective of the payload testing is to demonstrate the resolution, collection rate and dissemination capability of the system.

Fabrication of air vehicles 3 & 4 will began in May 1997. These airplanes will incorporate a number of enhancements to improve overall system reliability. These changes are focused on the subsystems and will not effect the system performance goals. The two subsystems most likely to change are the fuel and electrical systems. Studies of these systems and lessons learned from A/V #1 indicate that substantial improvement in overall system reliability can be achieved with moderate design changes. Lessons learned during the flight test of A/V #2 will be rolled into these aircraft if at all possible.

All of the initial flight testing of A/V #2 will use a conventional air data boom as depicted in Figure 4. The production, low observable, flush port air data system has already been built into the airplane. During the initial air vehicle #2 flight testing data will be gathered to begin the calibration process for the flush port system. A concentrated effort will be undertaken during the spring and summer of 1998 to qualify the production air data system. This flight test segment will explore much larger portions of the overall flight envelope than was done during the initial airworthiness flights. Air vehicles 3 and 4 will go through acceptance testing, first with the boom and then transition rapidly to the flush port system.

In 1999-2000 the focus of the program will change from development to system demonstration. The type, location and scope of the demonstrations are being coordinated by USACOM. At this time, demonstrations are planned in the Southwest U.S. and probably one overseas location. These demonstrations are the ACTD culmination. The fundamental question to be answered is: Does the DarkStar system offer a substantial benefit to the conduct of the intelligence, surveillance, reconnaissance mission area ? A substantial effort has already begun with USACOM and the Services to identify: exercises to participate in, data collection requirements, and metrics against which the system will be assessed.

Summary

The Persian Gulf War demonstrated many things to both sides. A paramount lesson was that information about the status and intentions of the enemy can provide forces with a tactical and strategic advantage. In 400 B.C. Sun Tzu, the great Chinese general said, "So it is said that if you know others and know yourself, you will not be imperiled in a hundred battles; if you do not know others but know yourself, you win one and lose one; if you do not know others and do not know yourself, you will be imperiled in every single battle."[1] . The HAE UAV program along with other intelligence, surveillance, and reconnaissance systems will provide the warfighter with dominant situational awareness. The entire DarkStar team is confident that it will demonstrate the performance characteristics which make this a unique and valuable asset for protecting and preserving the nation's interests.

1 The Art of War, Sun Tzu, Translated by Thomas Cleary. Shambhala Pocket Classics. Boston, 1991.

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