Part One

Introduction

Part One provides a general background for an introduction to the technology of unmanned aerial vehicle systems, called “UAV systems” or “unmanned aerial systems” (UAS).

Chapter 1 presents a brief history of UAVs. It then identifies and describes the functions of the major elements (subsystems) that may be present in a generic UAS. Finally, it presents a short history of a major UAV development program that failed to produce a fielded UAS, despite significant success in many of the individual subsystems, and teaches useful lessons about the importance of understanding the inter-relationship and interactions of the subsystems of the UAS and the implications of system performance requirements at a total-systems level. This story is told here to emphasize the importance of the word “system” in the terms “UAV System” and “UAS.”

Chapter 2 contains a survey of UAS that have been or presently are in use and discusses various schemes that are used to classify UAV systems according to their size, endurance, and/or mission. The information in this chapter is subject to becoming dated because the technology of many of the subsystems of a UAS is evolving rapidly as they become more and more part of the mainstream after many years of being on the fringes of the aeronautical engineering world. Nonetheless, some feeling for the wide variety of UAS concepts and types is needed to put the later discussion of design and system integration issues into context.
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History and Overview

1.1 Overview

The first portion of the chapter reviews the history of UAV systems from the earliest and crudest “flying objects” through the events of the last decade, which has been a momentous period for UAV systems.

The second portion of the chapter describes the subsystems that comprise a complete UAV system configuration to provide a framework for the subsequent treatment of the various individual technologies that contribute to a complete UAS. The air vehicle itself is a complicated system including structures, aerodynamic elements (wings and control surfaces), propulsion systems, and control systems. The complete system includes, in addition, sensors and other payloads, communication packages, and launch and recovery subsystems.

Finally, a cautionary tale is presented to illustrate why it is important to consider the UAV system as a whole rather than to concentrate only on individual components and subsystems. This is the story of a UAS that was developed between about 1975 and 1985 and that may be the most ambitious attempt at completeness, from a system standpoint, that has so far been undertaken in the UAS community. It included every key UAS element in a totally self-contained form, all designed from scratch to work together as a portable system that required no local infrastructure beyond a relatively small open field in which a catapult launcher and a net recovery system could be located. This system, called the Aquila remotely piloted vehicle (RPV) system, was developed and tested over a period of about a decade at a cost that approached a billion dollars. It eventually could meet most of its operational requirements. The Aquila UAS turned out to be very expensive and required a large convoy of 5-ton trucks for transportation. Most importantly, it did not fully meet some unrealistic expectations that had been built up over the decade during which it was being developed. It was never put in production or fielded. Nonetheless, it remains the only UAS of which the authors are aware that attempted to be complete unto itself and it is worth understanding what that ambition implied and how it drove costs and complexity in a way that eventually led the system to be abandoned in favor of less complete, self-sufficient, and capable UAV systems that cost less and required less ground support equipment.
1.2 History

1.2.1 Early History

Throughout their history, UAV systems have tended to be driven by military applications, as is true of many areas of technology, with civilian applications tending to follow once the development and testing had been accomplished in the military arena.

One could say that the first UAV was a stone thrown by a caveman in prehistoric times or perhaps a Chinese rocket launched in the thirteenth century. These “vehicles” had little or no control and essentially followed a ballistic trajectory. If we restrict ourselves to vehicles that generate aerodynamic lift and/or have a modicum of control, the kite would probably fit the definition of the first UAV.

In 1883, an Englishman named Douglas Archibald attached an anemometer to the line of a kite and measured wind velocity at altitudes up to 1,200 ft. Mr. Archibald attached cameras to kites in 1887, providing one of the world’s first reconnaissance UAVs. William Eddy took hundreds of photographs from kites during the Spanish-American war, which may have been one of the first uses of UAVs in combat.

It was not until the World War I, however, that UAVs became recognized systems. Charles Kettering (of General Motors fame) developed a biplane UAV for the Army Signal Corps. It took about 3 years to develop and was called the Kettering Aerial Torpedo, but is better known as the “Kettering Bug” or just plain “Bug.” The Bug could fly nearly 40 mi at 55 mi/h and carry 180 lb of high explosives. The air vehicle was guided to the target by preset controls and had detachable wings that were released when over the target allowing the fuselage to plunge to the ground as a bomb. Also in 1917, Lawrence Sperry developed a UAV, similar to Kettering’s, for the Navy called the Sperry-Curtis Aerial Torpedo. It made several successful flights out of Sperry’s Long Island airfield, but was not used in the war.

We often hear of the UAV pioneers who developed the early aircraft but other pioneers were instrumental in inventing or developing important parts of the system. One was Archibald Montgomery Low, who developed data links. Professor Low, born in England in 1888, was known as the “Father of Radio Guidance Systems.” He developed the first data link and solved interference problems caused by the UAV engine. His first UAVs crashed, but on September 3, 1924, he made the world’s first successful radio controlled flight. He was a prolific writer and inventor and died in 1956.

In 1933, the British flew three refurbished Fairey Queen biplanes by remote control from a ship. Two crashed, but the third flew successfully making Great Britain the first country to fully appreciate the value of UAVs, especially after they decided to use one as a target and couldn’t shoot it down.

In 1937 another Englishman, Reginald Leigh Denny, and two Americans, Walter Righter and Kenneth Case, developed a series of UAVs called RP-1, RP-2, RP-3, and RP-4. They formed a company in 1939 called the Radioplane Company, which later became part of Northrop-Ventura Division. Radioplane built thousands of target drones during World War II. (One of their early assemblers was Norma Jean Daugherty, later known as Marilyn Monroe.) Of course the Germans used lethal UAVs (V-1’s and V-2’s) during the later years of the war, but it was not until the Vietnam-War era that UAVs were successfully used for reconnaissance.
1.2.2 The Vietnam War

During the Vietnam-War era, UAVs were used extensively in combat, but for reconnaissance missions only. The air vehicles were usually air launched from C-130’s and recovered by parachute. The air vehicles were what might be called deep penetrators and were developed from existing target drones.

The impetus to operations in Southeast Asia came from activities during the Cuban Missile Crisis when UAVs were developed for reconnaissance but not used because the crisis ended before they became available. One of the first contracts was between Ryan and the Air Force, known as 147A, for vehicles based on the Ryan Firebee target drone (stretched versions). This was in 1962 and they were called Fireflies. Although the Fireflies were not operational during the Cuban crisis, they set the stage for Vietnam. Northrop also improved their early designs, which were essentially model airplanes, to jet propelled deep penetrators, but stuck mostly to target drones. The Ryan Firefly was the primary air vehicle used in Southeast Asia.

A total of 3,435 sorties were flown, and most of these (2,873, or nearly 84%) were recovered. One air vehicle, the TOMCAT, successfully completed 68 missions before it was lost. Another vehicle completed 97.3% of its missions of low altitude, real-time photography. By the end of the Vietnam War in 1972, air vehicles were experiencing 90% success rates [1].

1.2.3 Resurgence

At the end of the Vietnam War, general interest in UAVs dwindled until the Israelis neutralized the Syrian air defense system in the Bekaa Valley in 1982 using UAVs for reconnaissance, jamming and decoys. Actually, the Israeli UAVs were not as technically successful as many people believe, with much of their operational success being achieved through the element of surprise rather than technical sophistication. The air vehicle was basically unreliable and couldn’t fly at night, and the data-link transmissions interfered with the manned fighter communications. However, they proved that UAVs could perform valuable, real-time combat service in an operational environment.

The United States began to work again on UAVs in August 1971 when the Defense Science Board recommended mini-RPVs for artillery target spotting and laser designation. In February 1974, the Army’s Materiel Command established an RPV weapons system management office and by the end of that year (December) a “Systems Technology Demonstration” contract was awarded to Lockheed Aircraft Company, with the air vehicle subcontracted to Developmental Sciences Incorporated (later DSC, Lear Astronics, Ontario, CA). The launcher was manufactured by All American Engineering (later ESCO-Datron), and the recovery net system by Dornier of the then still-partitioned West Germany. Ten bidders competed for the program. The demonstration was highly successful, proving the concept to be feasible. The system was flown by Army personnel and accumulated more than 300 flight hours.

In September 1978, the so-called Target Acquisition/Designation and Aerial Reconnaissance System (TADARS) required operational capability (ROC) was approved, and approximately 1 year later, in August 1979, a 43-month Full Scale Engineering Development (FSED) contract was awarded to Lockheed sole source. The system was given the name “Aquila” and is discussed in more detail at the end of this chapter. For a number of reasons that provide
important lessons to UAV system developers, Aquila development stretched out for many years and the system was never fielded.

In 1984, partly as a result of an urgent need and partly because the Army desired some competition for Aquila, the Army started a program called Gray Wolf, which demonstrated, for the first time for a UAV, hundreds of hours of night operations in what could be called “combat conditions.” This program, still partly classified, was discontinued because of inadequate funding.

1.2.4 Joint Operations

The US Navy and Marine Corps entered the UAV arena in 1985 by purchasing the Mazlat/Israeli Aircraft Industries (IAI) and AAI Pioneer system, which suffered considerable growing pains but still remains in service. However, the Congress by this time became restless and demanded that a joint project office (JPO) be formed so that commonality and interoperability among the services would be maximized. The JPO was put under the administrative control of the Department of the Navy. This office has developed a master plan that not only defines the missions but also describes the desirable features for each kind of system needed by the services. Some elements of this plan will be discussed in Chapter 2 in the section called “Classes of UAV Systems.”

The US Air Force was initially reluctant to embrace UAVs, notwithstanding their wealth of experience with target-drone unmanned aircraft. However, this attitude changed significantly during the 1990s and the Air Force not only has been very active in developing and using UAVs for a variety of purposes but also has been the most active of the four US services in attempting to take control of all UAV programs and assets within the US military.

1.2.5 Desert Storm

The Kuwait/Iraq war allowed military planners an opportunity to use UAVs in combat conditions. They found them to be a highly desirable asset even though the performance of the systems then available was less than satisfactory in many ways. Five UAV systems were used in the operation: (1) the Pioneer by US forces, (2) the Ex-Drone by US forces, (3) the Pointer by US forces, (4) the “Mini Avion de Reconnaissance Telepilot” (MART) by French forces, and (5) the CL 89, a helicopter UAV, by British forces.

Although numerous anecdotal stories and descriptions of great accomplishments have been cited, the facts are that the UAVs did not play a decisive or a pivotal role in the war. For example, the Marines did not fire upon a single UAV-acquired target during the ground offensive according to a Naval Proceedings article published November 1991 [2]. What was accomplished, however, was the awakening in the mind of the military community of a realization of “what could have been.” What was learned in Desert Storm was that UAVs were potentially a key weapon system, which assured their continuing development.

1.2.6 Bosnia

The NATO UAV operation in Bosnia was one of surveillance and reconnaissance. Bomb-damage assessment was successfully accomplished after NATO’s 1995 air attacks on
Bosnian-Serb military facilities. Clearly shown in aerial photographs are Serbian tanks and bomb damaged buildings. Night reconnaissance was particularly important as it was under the cover of darkness that most clandestine operations took place. The Predator was the primary UAV used in Bosnia, flying from an airbase in Hungary.

1.2.7 Afghanistan and Iraq

The war in Iraq has transformed the status of UAVs from a potential key weapons system searching for proponents and missions to their rightful place as key weapon systems performing many roles that are central to the operations of all four services. At the beginning of the war, UAVs were still under development and somewhat “iffy,” but many developmental UAVs were committed to Operation Iraqi Freedom. The Global Hawk was effectively used during the first year despite being in the early stages of developmental. The Pioneer, the Shadow, the Hunter, and the Pointer were used extensively.

The Marines flew hundreds of missions using Pioneers during the battle for Fallujah to locate and mark targets and keep track of insurgent forces. They were especially effective at night and could be considered one of the decisive weapons in that battle.

The armed version of the Predator, mini-UAVs such as the Dragon Eye, and a wide range of other UAV systems have been used on the battlefields of Afghanistan and Iraq and have proven the military value of UAVs.

1.3 Overview of UAV Systems

There are three kinds of aircraft, excluding missiles, that fly without pilots. They are unmanned aerial vehicles (UAVs), remotely piloted vehicles (RPVs), and drones. All, of course, are unmanned so the name “unmanned aerial vehicle” or UAV can be thought of as the generic title. Some people use the terms RPV and UAV interchangeably, but to the purist the “remotely piloted vehicle” is piloted or steered (controlled) from a remotely located position so an RPV is always a UAV, but a UAV, which may perform autonomous or preprogrammed missions, need not always be an RPV.

In the past, these aircraft were all called drones, that is, a “pilotless airplane controlled by radio signals,” according to Webster’s Dictionary. Today the UAV developer and user community does not use the term drone except for vehicles that have limited flexibility for accomplishing sophisticated missions and fly in a persistently dull, monotonous, and indifferent manner, such as a target drone. This has not prevented the press and the general public from adopting the word drone as a convenient, if technically incorrect, general term for UAVs. Thus, even the most sophisticated air vehicle with extensive semiautonomous functions is likely to be headlined as a “drone” in the morning paper or on the evening news.

Whether the UAV is controlled manually or via a preprogrammed navigation system, it should not necessarily be thought of as having to be “flown;” that is, controlled by someone that has piloting skills. UAVs used by the military usually have autopilots and navigation systems that maintain attitude, altitude, and ground track automatically.

Manual control usually means controlling the position of the UAV by manually adjusting the heading, altitude, speed, etc. through switches, a joy stick, or some kind of pointing device (mouse or trackball) located in the ground control station, but allowing the autopilot to stabilize
the vehicle and assume control when the desired course is reached. Navigation systems of various types (global positioning system (GPS), radio, inertial) allow for preprogrammed missions, which may or may not be overridden manually.

As a minimum, a typical UAV system is composed of air vehicles, one or more ground control station (GCS) and/or mission planning and control stations (MPCS), payload, and data link. In addition, many systems include launch and recovery subsystems, air-vehicle carriers, and other ground handling and maintenance equipment. A very simple generic UAV system is shown in Figure 1.1.

1.3.1 Air Vehicle

The air vehicle is the airborne part of the system that includes the airframe, propulsion unit, flight controls, and electric power system. The air data terminal is mounted in the air vehicle, and is the airborne portion of the communications data link. The payload is also onboard the air vehicle, but it is recognized as an independent subsystem that often is easily interchanged with different air vehicles and uniquely designed to accomplish one or more of a variety of missions. The air vehicle can be a fixed-wing airplane, rotary wing, or a ducted fan. Lighter-than-air vehicles are also eligible to be termed UAVs.

1.3.2 Mission Planning and Control Station

The MPCS, also called the GCS, is the operational control center of the UAV system where video, command, and telemetry data from the air vehicle are processed and displayed. These data are usually relayed through a ground terminal, which is the ground portion of the data link. The MPCS shelter incorporates a mission planning facility, control and display consoles, video and telemetry instrumentation, a computer and signal processing group, the ground data terminal, communications equipment, and environmental control and survivability protection equipment.
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Figure 1.2  Mission planning and control station

The MPCS can also serve as the command post for the person who performs mission planning, receives mission assignments from supported headquarters, and reports acquired data and information to the appropriate unit, be it weapon fire direction, intelligence, or command and control, for example, the mission commander. The station usually has positions for both the air vehicle and mission payload operators to perform monitoring and mission execution functions.

In some small UAS, the ground control station is contained in a case that can be carried around in a back-pack and set up on the ground, and consists of little more than a remote control and some sort of display, probably augmented by embedded microprocessors or hosted on a ruggedized laptop computer.

At the other extreme, some ground stations are located in permanent structures thousands of miles away from where the air vehicle is flying, using satellite relays to maintain communications with the air vehicle. In this case, the operator’s consoles might be located in an internal room of a large building, connected to satellite dishes on the roof.

A cut-away view of a typical field MPCS is shown in Figure 1.2.

1.3.3 Launch and Recovery Equipment

Launch and recovery can be accomplished by a number of techniques ranging from conventional takeoff and landing on prepared sites to vertical descent using rotary wing or fan systems. Catapults using either pyrotechnic (rocket) or a combination of pneumatic/hydraulic arrangements are also popular methods for launching air vehicles. Some small UAVs are launched by hand, essentially thrown into the air like a toy glider.
Nets and arresting gear are used to capture fixed-wing air vehicles in small spaces. Parachutes and parafoils are used for landing in small areas for point recoveries. One advantage of a rotary-wing or fan-powered vehicle is that elaborate launch and recovery equipment usually is not necessary. However, operations from the deck of a pitching ship, even with a rotary-wing vehicle, will require hold-down equipment unless the ship motion is minimal.

1.3.4 Payloads

Carrying a payload is the ultimate reason for having a UAV system, and the payload usually is the most expensive subsystem of the UAV. Payloads often include video cameras, either daylight or night (image-intensifiers or thermal infrared), for reconnaissance and surveillance missions. Film cameras were widely used with UAV systems in the past, but are largely replaced today with electronic image collection and storage, as has happened in all areas in which video images are used.

If target designation is required, a laser is added to the imaging device and the cost increases dramatically. Radar sensors, often using Moving Target Indicator (MTI) and/or synthetic aperture radar (SAR) technology, are also important payloads for UAVs conducting reconnaissance missions. Another major category of payloads is electronic warfare (EW) systems. They include the full spectrum of signal intelligence (SIGINT) and jammer equipment. Other sensors such as meteorological and chemical sensing devices have been proposed as UAV payloads.

Armed UAVs carry weapons to be fired, dropped, or launched. “Lethal” UAVs carry explosive or other types of warheads and may be deliberately crashed into targets. As discussed elsewhere in this book, there is a significant overlap between UAVs, cruise missiles, and other types of missiles. The design issues for missiles, which are “one-shot” systems intended to destroy themselves at the end of one flight, are different from those of reusable UAVs and this book concentrates on the reusable systems, although much that is said about them applies as well to the expendable systems.

Another use of UAVs is as a platform for data and communications relays to extend the coverage and range of line-of-sight radio-frequency systems, including the data links used to control UAVs and to return data to the UAV users.

1.3.5 Data Links

The data link is a key subsystem for any UAV. The data link for a UAV system provides two-way communication, either upon demand or on a continuous basis. An uplink with a data rate of a few kHz provides control of the air-vehicle flight path and commands to its payload. The downlink provides both a low data-rate channel to acknowledge commands and transmit status information about the air vehicle and a high data-rate channel (1–10 MHz) for sensor data such as video and radar. The data link may also be called upon to measure the position of the air vehicle by determining its azimuth and range from the ground-station antenna. This information is used to assist in navigation and accurately determining air-vehicle location. Data links require some kind of anti-jam and anti-deception capability if they are to be sure of effectiveness in combat.

The ground data terminal is usually a microwave electronic system and antenna that provides line-of-sight communications, sometimes via satellite or other relays, between the MPCS and
the air vehicle. It can be co-located with the MPCS shelter or remote from it. In the case of the remote location, it is usually connected to the MPCS by hard wire (often fiber-optic cables). The ground terminal transmits guidance and payload commands and receives flight status information (altitude, speed, direction, etc.) and mission payload sensor data (video imagery, target range, lines of bearing, etc.)

The air data terminal is the airborne part of the data link. It includes the transmitter and antenna for transmitting video and air-vehicle data and the receiver for receiving commands from the ground.

1.3.6 Ground Support Equipment

Ground support equipment (GSE) is becoming increasingly important because UAV systems are electronically sophisticated and mechanically complex systems. GSE may include: test and maintenance equipment, a supply of spare parts and other expendables, a fuel supply and any refueling equipment required by a particular air vehicle, handling equipment to move air vehicles around on the ground if they are not man-portable or intended to roll around on landing gear, and generators to power all of the other support equipment.

If the UAS ground systems are to have mobility on the ground, rather than being a fixed ground station located in buildings, the GSE must include transportation for all of the things listed earlier, as well as transportation for spare air vehicles and for the personnel who make up the ground crew, including their living and working shelters and food, clothing, and other personal gear.

As can be seen, a completely self-contained, mobile UAS can require a lot of support equipment and trucks of various types. This can be true even for an air vehicle that is designed to be lifted and carried by three or four men.

1.4 The Aquila

The American UAS called the Aquila was a unique early development of a total integrated system. It was one of the first UAV systems to be planned and designed having unique components for launch, recovery, and tactical operation. The Aquila was an example of a system that contained all of the components of the generic system described previously. It also is a good example of why it is essential to consider how all the parts of a UAS fit together and work together and collectively drive the cost, complexity, and support costs of the system. Its story is briefly discussed here. Throughout this book, we will use lessons learned at great cost during the Aquila program to illustrate issues that still are important for those involved in setting requirements for UAS and in the design and integration of the systems intended to meet those requirements.

In 1971, more than a decade before the Israeli success in the Bekaa Valley, the US Army had successfully launched a demonstration UAV program, and had expanded it to include a high-technology sensor and data link. The sensor and data-link technology broke new ground in detection, communication, and control capability. The program moved to formal development in 1978 with a 43-month schedule to produce a production-ready system. The program was extended to 52 months because the super-sophisticated MICNS (Modular Integrated Communication and Navigation System) data link experienced troubles and was delayed. Then, for reasons unknown to industry, the Army shut the program down altogether.
It was subsequently restarted by Congress (about 1982), but at the cost of extending it to a 70-month program. From then on everything went downhill.

In 1985, a Red Team formed to review the system came to the conclusion that not only had the system not demonstrated the necessary maturity to continue to production, but also that the systems engineering did not properly account for deficiencies in the integration of the data link, control system, and payload and it probably would not work anyway. After two more years of intensive effort by the government and contractor, many of the problems were fixed, but nevertheless it failed to demonstrate all of the by then required capabilities during operational testing (OT) II and was never put into production.

The lessons learned in the Aquila program still are important for anyone involved in specifying operational requirement, designing, or integrating a UAS. This book refers to them in the chapters describing reconnaissance and surveillance payloads and data links in particular, because the system-level problems of Aquila were largely in the area of understanding those subsystems and how they interacted with each other, with the outside world, and with basic underlying processes such as the control loop that connects the ground controller to the air vehicle and its subsystems.

1.4.1 Aquila Mission and Requirements

The Aquila system was designed to acquire targets and combat information in real time, beyond the line-of-sight of supported ground forces. During any single mission, the Aquila was capable of performing airborne target acquisition and location, laser designation for precision-guided munitions (PGM), target damage assessment, and battlefield reconnaissance (day or night). This is quite an elaborate requirement.

To accomplish this, an Aquila battery needed 95 men, 25 five-ton trucks, 9 smaller trucks, and a number of trailers and other equipment, requiring several C-5 sorties for deployment by air. All of this allowed operation and control of 13 air vehicles. The operational concept utilized a central launch and recovery section (CLRS) where launch, recovery, and maintenance were conducted. The air vehicle was flown toward the Forward Line of Own Troops (FLOT), and handed off to a forward control section (FCS), consisting mainly of a ground control station, from which combat operations were conducted. It was planned that eventually the ground control station with the FCS would be miniaturized and be transported by a High Mobility Multipurpose Wheeled Vehicle (HMMWV) to provide more mobility and to reduce target size when operating close to the FLOT. The Aquila battery belonged to an Army Corps. The CLRS was attached to Division Artillery because the battery supported a division. The FCS was attached to a maneuver brigade.

1.4.2 Air Vehicle

The Aquila air vehicle, was a tailless flying wing with a rear-mounted 26-horsepower, two-cycle engine, and a pusher propeller. Figure 1.3 shows the Aquila air vehicle. The fuselage was about 2 m long and the wingspan was 3.9 m. The airframe was constructed of kevlar-epoxy material, but metalized to prevent radar waves from penetrating the skin and reflecting off of the square electronic boxes inside. The gross takeoff weight was about 265 lb and it could fly between 90 and 180 km/h up to about 12,000 ft.
1.4.3 Ground Control Station

The Aquila ground control station contained three control and display consoles, video and telemetry instrumentation, a computer and signal processing group, internal/external communications equipment, ground data terminal control equipment, and survivability protection equipment.

The GCS was the command post for the mission commander and had the display and control consoles for the vehicle operator, payload operator, and mission commander. The GCS was powered by a 30-kW generator. A second 30-kW generator was provided as a backup. Attached to the GCS by 750 m of fiber-optic cable was the remote ground terminal (RGT). The RGT consisted of a tracking dish antenna, transmitter, receiver, and other electronics, all trailer-mounted as a single unit. The RGT received downlink data from the air vehicle in the form of flight status information, payload sensor data, and video. The RGT transmitted both guidance commands and mission payload commands to the air vehicle. The RGT had to maintain line-of-sight contact with the air vehicle. It also had to measure the range and azimuth to the air vehicle for navigation purposes, and the overall accuracy of the system depends on the stability of its mounting.

1.4.4 Launch and Recovery

The Aquila launch system contained an initializer that was linked to the RGT and controlled the sequence of the launch procedure including initializing the inertial platform. The catapult was a pneumatic/hydraulic system that launched the air vehicle into the air with the appropriate airspeed.

The air vehicle was recovered in a net barrier mounted on a 5-ton truck. The net was supported by hydraulic-driven, foldout arms, which also contained the guidance equipment to automatically guide the air vehicle into the net.

1.4.5 Payload

The Aquila payload was a day video camera with a boresighted laser for designating targets. Once locked on to a target, moving or stationary, it would seldom miss. The laser rangefinder/designator was optically aligned and automatically boresighted with the video camera. Scene and feature track modes provided line-of-sight stabilization and autotracking.
for accurate location and tracking of moving and stationary targets. An infrared night payload was also under development for use with Aquila.

### 1.4.6 Other Equipment

An air-vehicle handling truck was part of the battery ground support equipment and included a lifting crane. The lifting crane was necessary, not because the air vehicle was extremely heavy, but because the box in which it was transported contained lead to resist nuclear radiation. In addition a maintenance shelter, also on a 5-ton truck, was used for unit-level maintenance and was a part of the battery.

### 1.4.7 Summary

The Aquila system had everything imaginable in what one could call “The Complete UAV System;” “zero-length” launcher, “zero-length” automatic recovery with a net, anti-jam data link, and day and night payload with designator. This came at very high cost, however—not only in dollars but also in terms of manpower, trucks, and equipment. The complete system became large and unwieldy, which contributed to its downfall. All of this equipment was necessary to meet the elaborate operational and design requirements placed on the Aquila system by the Army, including a level of nuclear blast and radiation survivability (a significant contributor to the size and weight of shelters and the RGT mount). Eventually, it was determined that many of the components of the system could be made smaller and lighter and mounted on HMMWVs instead of 5-ton trucks, but by that time the whole system had gotten a bad reputation for:

- having been in development for over 10 years;
- being very expensive;
- requiring a great deal of manpower, a large convoy of heavy trucks for mobility, and extensive support;
- what was widely perceived to be a poor reliability record (driven by the complexity of the data link, air-vehicle subsystems, and the zero-length recovery system);
- failure to meet some operational expectations that were unrealistic, but had been allowed to build up during the development program because the system developers did not understand the limitations of the system.

Foremost among the operational “disappointments” was that Aquila turned out to be unable to carry out large-area searches for small groups of infiltrating vehicles, let alone personnel on foot. This failing was due to limitations on the sensor fields of view and resolution and on shortcomings in the system-level implementation of the search capability. It also was partly driven by the failure to understand that searching for things using an imaging sensor on a UAV required personnel with special training in techniques for searching and interpretation of the images provided. The sources of these problems and some ways to reduce this problem by a better system-level implementation of area searches are addressed in the discussions of imaging sensors in Part Four and data links in Part Five.

The Aquila program was terminated as a failure, despite having succeeded in producing many subsystems and components that individually met all of their requirements. The US
Army Red Team concluded that there had been a pervasive lack of system engineering during the definition and design phases of the program. This failure set back US efforts to field a tactical UAS on an Army-wide basis, but opened the door for a series of small-scale “experiments” using less expensive, less-sophisticated air vehicles developed and offered by a growing “cottage industry” of UAV suppliers.

These air vehicles were generally conventionally configured oversized model airplanes or undersized light aircraft that tended to land and takeoff from runways if based on land, did not have any attempt at reduced radar signatures and little if any reduced infrared or acoustical signatures, and rarely had laser designators or any other way to actively participate in guidance of weapons.

They generally did not explicitly include a large support structure. Although they required most of the same support as an Aquila system, they often got that support from contractor personnel deployed with the systems in an ad hoc manner.

UAV requirements that have followed Aquila have acknowledged the cost of a “complete” stand-alone system by relaxing some of the requirements for self-sufficiency that helped drive the Aquila design to extremes. In particular, many land-based UAVs now are either small enough to be hand launched and recovered in a soft crash landing or designed to take off and land on runways. All or most use the global positioning system (GPS) for navigation. Many use data transmission via satellites to allow the ground station to be located at fixed installations far from the operational area and eliminate the data link as a subsystem that is counted as part of the UAS.

However, the issues of limited fields-of-view and resolution for imaging sensors, data-rate restrictions on downlinks, and latencies and delays in the ground-to-air control loop that were central to the Aquila problems are still present and can be exacerbated by use of satellite data transmission and control loops that circle the globe. Introducing UAV program managers, designers, system integrators, and users to the basics of these and other similarly universal issues in UAV system design and integration is one of the objectives of this textbook.

References