2

Classes and Missions of UAVs

2.1 Overview

This chapter provides general classes and missions of Unmanned Aerial Vehicles (UAV). It also describes a representative sample of unmanned aerial systems (UAS), including some of the earlier designs that had a large impact on current systems. The range of UAS sizes and types now runs from air vehicles (AVs) small enough to land on the palm of your hand to large lighter-than-air vehicles. This chapter mainly concentrates on those in the range from model[1] airplanes up to medium-sized aircraft, as does the rest of this book, where "unmanned aerial systems" and "UAV Systems" are utilized interchangeably.

Much of the early development of UAS was driven by government and military requirements, and the bureaucracies that manage such programs have made repeated efforts to establish a standard terminology for describing various types of UAS in terms of the capabilities of the air vehicles. While the "standard" terminology constantly evolves and occasionally changes abruptly, some of it has come into general use in the UAV community and is briefly described.

Finally, the chapter also attempts to summarize the applications for which UAS have been or are being considered, which provides a context for the system requirements that drive the design tradeoffs that are the primary topic of this book.

2.2 Classes of UAV Systems

2.2.1 Classification Criteria

There are a number of criteria for classification of UAVs. It is convenient to have a generally agreed upon scheme for classifying UAVs rather like the classification of military aircraft in general into such classes as transport, observation, fighter, attack, cargo, and so on. Table 2.1 provides some criteria for classification of UAVs, and their related classes.

Parts 48 and 107 of FAR regulate the application of small UAVs. For instance, you may not operate an sUAS at night, which is defined in the US (except Alaska) as the time between the end of

1 Model airplane – generally known collectively as the sport and pastime of aeromodelling – here is not an aircraft model for the wind tunnel application. It is a small remotely controlled (RC) plane that is often designed by non-aeroengineer traditional airplane enthusiasts and is usually built in a garage.

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Table 2.1 Criteria for classification of UAVs

No.	Classification Criterion	Class
1	Manufacturing location	1. Home-made (Model), 2. Industrial
2	User	1. Civil, 2. Military
3	Mission	1. Filming, 2. Package delivery, 3. Intelligence, Surveillance, and Reconnaissance (ISR), 4. Precision strike, 5. Combat (UCAV), 6. Teaming, 7. Meteorological measurements, 8. High-altitude platform, 9. Search and observation
4	Size	1. Micro, 2. Mini, 3. Very small, 4. Small, 5. Medium, 6. Large
5	Wing configuration	1. Fixed-wing, 2. Rotary-wing (includes multi-copter), 3. Hybrid
6	FAA [5]	Small UAVs (under FAR Parts 48 and 107)
7	Altitude/Range/Endurance	1. Very low-cost close range, 2. Close range, 3. Short range, 4. Mid-range, 5. Long range, 6. Medium-altitude, long endurance (MALE), 7. High-altitude, long endurance (HALE)
8	Number of uses	1. Reusable, 2. Expendable

evening civil twilight and beginning of morning civil twilight. This is due to the fact that, at night, there is no sufficient visibility to the remote pilot. A small unmanned aircraft is defined as an unmanned aircraft weighing more than 0.55 lb and less than 55 pounds on takeoff, including everything that is on board or otherwise attached to the aircraft.

In the following sections, three specific classifications based on: (1) range and endurance, (2) mission, and (3) tier (for US Air Force, Marine Corps, and Army) are presented.

2.2.2 Classification by Range and Endurance

Shortly after being appointed the central manager of US military UAV programs, the Joint UAV Program Office (JPO) defined classes of UAVs as a step toward providing some measure of standardization to UAV terminology. They were:

- *Very Low-Cost, Close-Range*: Required by the Marine Corps and perhaps the Army to have a range of about 5 km (3 miles) and cost about $10,000 per air vehicle. This UAV system fits into what could be called the "model airplane" type of system and its feasibility with regard to both performance and cost had not been proven but since has been demonstrated by systems such as the Raven and Dragon Eye.
- *Close Range*: Required by all of the services but its concept of operation varied greatly depending on the service. The Air Force usage would be in the role of airfield damage assessment and would operate over its own airfields. The Army and Marine Corps would use it to look over the next hill, and desired a system that was easy to move and operate on the battlefield. The Navy wanted it to operate from small ships such as frigates. It was to have a range of 50 km (31 miles), with 30 km (19 miles) forward of the FLOT. The required endurance was from 1 to 6 h depending on the mission. All services agreed that the priority mission was reconnaissance and surveillance, day and night.
- *Short Range*: The Short-Range UAV was also required by all of the services and, like the Close-Range UAV, had the day/night, reconnaissance, and surveillance mission as a top priority. It had a required range of 150 km (93 miles) beyond the FLOT, but 300 km (186 miles) was desired. The endurance time was to be 8–12 h. The Navy required the system to be capable of launch and recovery from larger ships of the Amphibious Assault Ship and Battleship class.

- *Mid-Range*: The Mid-Range UAV was required by all the services except the Army. It required the capability of being ground or air launched and was not required to loiter. The latter requirement suggested that the air vehicle was a high-speed deep penetrator and, in fact, the velocity requirement was high subsonic. The radius of action was 650 km (404 miles) and it was to be used for day/night reconnaissance and surveillance. A secondary mission for the mid-Range was the gathering of meteorological data.
- *Endurance*: The Endurance UAV was required by all services and, as the name suggested, was to have a loiter capability of at least 36 h. The air vehicle had to be able to operate from land or sea and have a radius of action of approximately 300 km (186 miles). The mission was day/night reconnaissance first and communications relay second. Speed was not specified, but it had to be able to maintain station in the high winds that would be experienced at high altitudes. The altitude requirement was not specified, but it was thought probably to be 30,000 ft (9.14 km) or higher.
- *Long range:* This class of UAVs was not defined by JPO. However, an endurance UAV is capable of flying in a long range (e.g., thousands of miles) mission.

This classification system has been superseded. However, some of the terminology and concepts, particularly the use of a mix of range and mission to define a class of UAVs, persist today and it is useful for anyone working in the field to have a general knowledge of the terminology that has become part of the jargon of the UAV community.

The following sections outline some of the more recent terminology used to classify UAVs. Any government-dictated classification scheme is likely to change over time to meet the changing needs of program managers, and the reader is advised to search the literature and other references if the current standard of government classification is needed. Operation and certification of small unmanned aircraft systems is regulated [5] by Federal Aviation Administration under Part 107.

2.2.3 Classification by Missions

Defining the missions for UAVs is a difficult task because (1) there are so many possibilities and (2) there have never been enough systems in the field to develop all of the possibilities. This is not to say that the subject has not been thought about, because there have been repeated efforts to come up with comprehensive lists as part of classification schemes. All such lists tend to become unique to the part of the UAV community that generates them, and all tend to become out of date as new mission concepts continually arise.

Two major divisions of missions for UAVs are civilian and military, but there is significant overlap between these two in the area of reconnaissance and surveillance, which a civilian might call search and surveillance or observation, which is the largest single application of UAVs in both the civilian and military worlds.

The development of UAVs has been led by the military and there are other areas long recognized as potential military missions that also have civilian equivalents. These include atmospheric sampling for radiation and/or chemical agents, providing relays for line-of-sight communications systems, and meteorological measurements.

An area of interest to both the military and civilian worlds is to provide a high-altitude platform capable of lingering indefinitely over some point on the Earth that can perform many of the functions of a satellite at lower cost and with the capability of landing for maintenance or upgrade and of being re-deployed to serve a different part of the world whenever needed.

Within the military arena, another division of missions has become prominent during the last decade. An increasing mission for military UAVs is the delivery of lethal weapons (i.e., precision strike). This mission has a number of significant distinctions from nonlethal missions in the areas of AV design and raises new issues related to the level of human control over the actions of the AV.

Of course, all missiles are “unmanned aerial vehicles.” However, we consider systems that are designed to deliver an internal warhead to a target and destroy themselves while destroying that target as flying weapons (e.g., a missile), and distinguish them from vehicles that are intended to be recoverable and reused for many flights (i.e., UAV). As discussed later in this book, although there are areas in common between flying weapons and reusable aircraft, there are also many areas in which the design tradeoffs for weapons differ from those for the aircraft.

As of this writing, the primary form of active armed UAV is an unmanned platform, such as the MQ-1 Predator (see Figure 11.1) and MQ-9 Reaper (see Figure 1.5) carrying precision-guided munitions and the associated target acquisition and fire-control systems such as imaging sensors and laser designators. This is evolving to include the delivery of small guided bombs and other forms of dispensed munitions. These systems can be considered unmanned ground attack aircraft and unmanned combat aerial vehicle (UCAV). The future seems to hold unmanned fighters and bombers, either as supplements to manned aircraft or as substitutes.

DOD and Boeing have – in the past few years – developed and tested a number of UCAVs such as Boeing X-45, Northrop Grumman X-47, and Kratos XQ-58 Valkyrie. Moreover, some European countries are currently developing UCAVs. Under development are: BAE Corax (also known as Raven), EADS Barracuda (Germany), Dassault nEUROn (France), Elbit Hermes 450 (Israel), BAE Taranis (UK), Boeing X-45A, and EADS Surveyor (Multinational). Furthermore, Chengdu Wing Loong (Chinese title, GJ-2) – a long range UAV with a strike capability and a satellite data link – has been developed by China in 2018.

There is an ambiguous class of military missions in which the UAV does not carry or launch any weapons, but provides the guidance that allows the weapons to hit a target. This is accomplished using laser designators on the AV that “point out” the target to a laser-guided weapon launched from a manned aircraft or delivered by artillery. As we have seen, this mission was a primary driver for the resurgence of interest in UAVs in the US Army in the late 1970s. It remains a major mission for many of the smaller tactical UAVs in use by the military.

The classes of UAVs – Close-Range, Short-Range, Mid-Range, and Endurance – imply missions by virtue of their names, but the services often employ them in such unique ways that it is impossible to say that there is only one mission associated with each name. For example, the Air Force’s airfield battle damage assessment mission and the Army’s target designation mission both could utilize similar airframes (e.g., having the same weight and shape), but would require an entirely different range, endurance, speed, and payload capabilities. Some missions appear to be common to all the services such as reconnaissance, but the Army wants “close” reconnaissance to go out to 30 km, and the Marine Corps believes that 5 km is about right.

Among the core missions of UAVs for both military and civilian use are ISR, Intelligence, Surveillance, and Reconnaissance (search), which often are combined, but are different is important ways, as seen in the following definitions:

- *Intelligence*: The activity to obtain – by visual or other detection methods – information about what is present or happening at some point or in some area.
- *Surveillance*: The systematic observation of aerospace, surface or subsurface areas, places, persons, or things by visual, aural, electronic, photographic, or other means.
- *Reconnaissance*: The activity to identify a target (e.g., individual, car, or building) by visual or other detection methods at some point or in some area via comparing the obtained information with the reference data.

Thus, surveillance implies long endurance and, for the military, somewhat stealthy operations that will allow the UAV to remain overhead for long periods of time. Because of the interrelationship between intelligence, surveillance, and reconnaissance, the same assets are usually used to accomplish all three missions.

Insitu ScanEagle missions include ISR, as well as special services operations, escort operations, sea-lane and convoy protection, protection of high-value and secure installations, and high-speed wireless voice, video, and data communications relay.

These missions imply the detection and identification of stationary and moving targets both day and night – quite a formidable task, as we will see when discussing payloads and data links. The hardware requirements for the detection and identification capabilities impact almost every subsystem in the air vehicle as well as the ground station. Each UAV user may have requirements for the range from the UAV base to the area to be searched, the size of the area that must be searched, and the time on station required for surveillance, so intelligence/surveillance /reconnaissance missions and hardware can vary significantly.

There are both land- and air-based missions in both the military and civilian worlds. A land-based operational base may be fixed or may need to be transportable. If it is transportable, the level of mobility may vary from being able to be carried in a backpack to something that can be packed up and shipped in large trucks or on a train and then reassembled at a new site over a period of days or even of weeks. Each of these levels affects the tradeoffs between various approaches to AV size, launch, and recovery methods, and almost every other part of the system design.

Ship-based operations almost always add upper limits to AV size. If the ship is an aircraft carrier, the size restrictions are not too limiting, but may include a requirement to be able to remove or fold the long, thin wings that, as we will see later, are typical of long-endurance aircraft.

Associated with the military reconnaissance mission is target or artillery spotting. After a particular target is found, it can be fired upon while being designated with a laser to help guide a precision-guided munition. For conventional (unguided) artillery, the fire can be adjusted so that each succeeding round will come closer to, or hit, the target. Accurate artillery, naval gunfire, and close air support can be accomplished using UAVs in this manner. All of these missions can be conducted with the reconnaissance and surveillance payloads, except that a laser designator feature must be added if one is to control precision-guided munitions. This added feature raises the cost of the payload significantly.

An important mission in the military and intelligence area is Electronic Warfare (EW). Listening to an enemy transmission (communication or radar) and then either jamming it or analyzing its transmission characteristics falls under the category of EW.

Although developing and flight testing a number of experimental combat UAVs such as X-58 in the past 10 years, UCAVs are still not operational. As the latest development, in 2021, Singapore-based Kelley Aerospace [3] has developed and flight-tested the first supersonic UCAV, called Arrow. The plan is to reach speeds up to Mach 2.1.

In 2020, the Air Force awarded [3] contracts to Kratos, Boeing, Northrop Grumman, General Atomics, and Voly Defense Solutions authorizing the companies to compete for the Skyborg project, an effort to field an unmanned wingman cheap enough to sustain losses in combat but capable of supporting manned fighters in hostile environments.

The XQ-58 Valkyrie (Figure 2.1), with a wing span of 22 ft and stealth features, has 8 hardpoints (2 weapon bays with 4 in each) with a capacity of up to 550 lb (250 kg) bombs. The UCAV has a maximum speed of Mach 0.85, a range of 2,449 miles, and a service ceiling of 45,000 ft. The XQ-58 was designed to act as a "loyal wingman" that is controlled by a manned aircraft (a team of manned–unmanned aircraft) to accomplish tasks such as scouting and attracting enemy fire, if attacked.

Figure 2.1 The Kratos XQ-58 Valkyrie (Source: 88 Air Base Wing Public Affairs / Wikimedia Commons / Public Domain)

To summarize, the intelligence/surveillance/reconnaissance mission accounts for most of the UAV activity to date, and its sensors and data-links are the focus of much of today's development. Target spotting follows closely, with EW third. However, in terms of visibility and criticality, weapon delivery has become the most highly watched application and is a major focus of future development. Other missions will come into their own in time, with their way paved by success in the applications and missions now being actively carried out.

2.2.4 The Tier System

A set of definitions that has become pervasive in the UAV community stems from an attempt to define a hierarchy of UAV requirements in each of the US services. The levels in these hierarchies were called "tiers" and terms such as "tier II" are often used to classify a particular UAV or to describe a whole class of UAVs.

The tiers are different in each US service, which can lead to some confusion. These tiers are tabulated with brief descriptions in Tables 2.2 through 2.4 for US Air Force, Marine Corps, and Army respectively.

Table 2.2 US Air Force tiers

No.	Tier	Mission/Group	Example
1	N/A	Small/micro-UAV	
2	I	Low altitude, long endurance	
3	II	Medium altitude, long endurance (MALE)	MQ-1 Predator
4	II+	High altitude, long endurance (HALE) conventional UAV. Altitude: 60,000–65,000 ft (19,800 miles), less than 300 knots (560 km/h) airspeed, 3,000 nautical-miles (6,000 km) radius, 24 h time-on-station capability. Tier II is complementary to the Tier III aircraft.	RQ-4 Global Hawk
5	III−	HALE low-observable (LO) UAV. Same as the Tier II+ aircraft with the addition of LO.	RQ-3 DarkStar

Table 2.3 Marine Corps tiers

No.	Tier	Mission/Group	Example
1	N/A	Micro-UAV	Wasp
2	Tier I	Mini-UAV	Dragon Eye
3	Tier II	Small	RQ-2 Pioneer
4	Tier III	Medium	Shadow

Table 2.4 Army tiers

No.	Tier	Mission/Group	Example
1	Tier I	Small UAV	RQ-11A/B Raven
2	Tier II	Short-Range Tactical UAV	Role filled by the RQ-7A/B Shadow 200
3	Tier III	Medium-Range Tactical UAV	

The most recent classification of systems in use in the United States is related to missions although the old Tier system is still in existence. Eighteen missions relate to four general classes of UAVs – small, tactical, theater, and combat. It is quite specific to US military requirements and is not presented in this book.

2.3 Examples of UAVs by Size Group

We attempt here to provide a broad survey of the many types of UAVs that have been or are being designed, tested, and fielded throughout the world. The intent of this survey is to introduce those who are new to the UAV world to the wide variety of systems that have appeared over the few decades since the revival of interest in UAVs began in the 1980s.

There are a variety of guides to UAVs available and a great deal of information is posted on the Internet. We use *The Concise Global Industry Guide* [6] as a source for quantitative characteristics of current UAVs and a variety of open-source postings and our own personal files for information on systems no longer in production.

As a general organizing principle, we will start with the smallest UAVs and proceed to some that are the size of a corporate jet. The initial efforts on UAVs in the 1980s concentrated on AVs that had typical dimensions of 2 or 3 m (6.6–9.8 ft), partly driven by the need to carry sensors and electronics that at that time had not reached the advanced state of miniaturization that has since become possible. In more recent years, there has been a growing interest in extending the size range of UAVs down to insect-sized devices at one extreme and up to medium air transport sizes at the other end.

Some of the motivation for smaller UAVs is to make them man portable so that a soldier or a border guard can carry, launch, and control a model-airplane-sized UAV that allows him or her to take a look over the next hill or behind the buildings that are in front of him or her. Further miniaturization, to the size of a small bird or even an insect, is intended to allow a UAV to fly inside a building or perch unnoticed on a window sill or roof gutter and provide a look inside the building or into a narrow street.

The realm of small UAVs is one in which there is no competition from manned vehicles. It is unique to vehicles that take advantage of the micro-miniaturization of sensors and electronics to allow humans to view the world from a flying vehicle that could land and take off from the palm of their hand and can go places that are not accessible to anything on a human scale.

The motivation for larger UAVs is to provide long endurance at high altitudes with the ability to fly long distances from a base and then loiter over an area for many hours using a larger array of sensors to search for something or keep watch over some area. Increasingly, in the military arena, the larger UAVs also provide a capability to carry a large weapons payload a long distance and then deliver it to the destination area.

There now is increasing talk about performing missions such as heavy air transportation, bombers, and even passenger transportation with unmanned systems. Whatever may be the outcome of those discussions, it is likely that there eventually will be unmanned systems of all sizes.

In the following sections, we use intuitive-size classes that are not in any sense standardized but are convenient for this discussion. In the next six sections, general features of micro, mini, very small, small, medium, and large UAVs are presented.

2.3.1 Micro-UAVs

A new class of UAVs called micro-UAVs is of growing interest, which have the attributes of large insects and very small birds. This is a term for a class of UAVs that are, as of this writing, still largely in the conceptual or early stages of development. They are envisioned to range in size from a large insect to a model airplane with a one-inch wingspan. The advent of the micro-UAV produces a whole new series of challenges associated with scale factors, particularly micro-autopilot and control in atmospheric phenomena such as wind and gust.

Although there are still no active micro-UAVs in existence, DARPA have attempted a program to develop micro-UAVs including a flapping wing. The world's smallest and lightest micro-helicopter UAV was experimented and demonstrated by Japanese Epson Corporation – with a prop diameter of 130 mm and a mass of 8.9 g. Insight into the art of bird-size UAVs may be obtained from Hank Tennekes' book, *The Simple Science of Flight from Insects to Jumbo Jets* [7].

Assuming that payload and power-plant problems can be solved, the low wing loading of these types of air vehicles may prohibit operation in all except the most benign environmental conditions (e.g., no wind). Some of these problems, and solutions, will be discussed in Part Two of this book.

2.3.2 Mini-UAVs

This category stems from the old expendable definition and includes hand-launched as well as small UAVs that have some type of launcher (could be hand-launched). It is not officially defined by the JPO as a class of UAVs, but numerous demonstrations and experiments have been conducted over the past ten years.

These UAVs are exemplified by the electric-powered Raven and Bayraktar mini-UAVs in the selection of UAV examples earlier in this chapter. The Wasp UAV described among the previous examples is another example of a UAV at the upper limit of what might be called a "mini"-UAV. The ANAFI Parrot can be considered as a mini-UAV where it has a mass of about 0.5 kg, equipped with two 4K 21-megapixel cameras, and can fly for about 32 minutes.

Another example for this class is the HR quadcopter, which has four electric engines, dimensions of 7.1 in × 6.7 in × 1.5 in, and a takeoff mass/weight of about 120 g (4.23 oz). It is equipped with a 1080P HD Camera and can take aerial photos/videos, with the built-in WiFi module to broadcast a live video on a mobile device.

2.3.3 Very Small UAVs

For the purposes of this discussion, "very small UAVs" range from "micro" sized, which are about the size of a large insect, up to an AV with dimensions of the order of a 30–50 cm (12–20 in). There are two major types of small UAVs. One type uses flapping wings to fly like an insect or a bird and the other one uses a more or less conventional aircraft configuration, usually rotary wing for the micro size range. The choice of flapping wings or rotary wings often is influenced by the desire to be able to hover and land/perch on small surfaces to allow surveillance to continue without having to expend the energy to hover. Another advantage of flapping wings is covertness, as the UAV may look a lot like a bird or insect and be able to fly around very close to the subjects of its surveillance or perch in plan-view without giving away the fact that it is actually a sensor platform.

At the small end of this range and for flapping wings, there are many special issues related to the aerodynamics that allow the small UAVs to fly. However, in all cases the basic aerodynamic principles and equations apply, and one needs to understand them before proceeding to the special conditions related to very small size or flapping wings. Part Two of this book introduces the basic aerodynamics and some discussion to the issues for small size and flapping wings.

Examples of very small UAVs include the Chinese DJI mini 2, which is a quadcopter that can hover (i.e., vertically takeoff and land); the Israeli IAI Malat Mosquito, which is an oval flying wing with a single tractor propeller; the US Aurora Flight Sciences Skate, which is a rectangular flying wing with twin tractor engine/propeller combinations that can be tilted to provide "thrust vectoring" for control; and the Australian Cyber Technology CyberQuad Mini, which has four ducted fans in a square arrangement.

The Mosquito wing/fuselage is 35 cm (14.8 in) long and 35 cm (14.8 in) in total span. It uses an electric motor with batteries and has an endurance of 40 minutes, and claims a radius of action of about 1.2 km (0.75 mile). It is hand or bungee launched and can deploy a parachute for recovery.

The DJI Phantom 4 Pro quadcopter has four electric engines, dimensions of 9.9 in × 15.7 in × 6.75 in, and a takeoff weight of about 3 lb. It is equipped with an electro-optic camera and autopilot that allows fully autonomous waypoint navigation. It can be controlled via a smart phone as a ground control station using a Wi-Fi connection, by which the live videos are received.

The Skate wing/fuselage has a wingspan of about 60 cm (24 in) and length of 33 cm (13 in). It folds in half along its centerline for transport and storage. It has twin electric motors on the leading edge that can be tilted up or down and allow vertical takeoff and landing (VTOL) and transition to efficient horizontal flight. There are no control surfaces, with all control being accomplished by tilting the motor/propeller assemblies and controlling the speed of the two propellers. It can carry a payload of 227 g (8 oz) with a total takeoff weight of about 1.1 kg (2 lb).

The CyberQuad Mini has four ducted fans, each with a diameter of somewhat less than 20 cm (7.8 in), mounted so that the total outside dimensions that include the fan shrouds are about 42 cm by 42 cm (16.5 in). The total height including the payload and batteries, which are located in a fuselage at the center of the square, is 20 cm (7.8 in).

The CyberQuad Mini includes a low-light level electro-optic camera or thermal camera and a control system that allows fully autonomous waypoint navigation. The toy has two onboard cameras, one facing forward and one facing down, and is controlled much like a video game from a

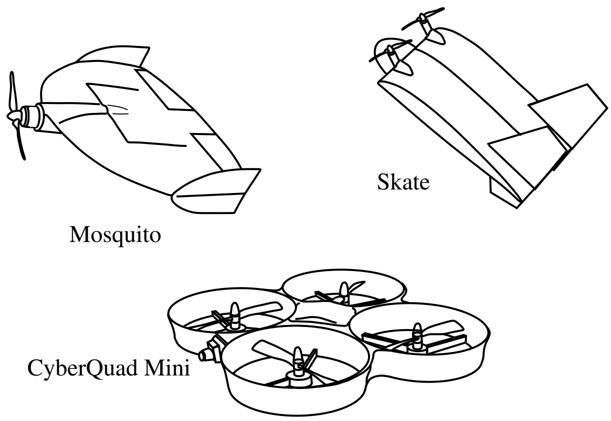

Figure 2.2 Very small UAVs

portable digital device such as a tablet computer or a smart phone. Drawings of these UAVs are shown in Figure 2.2.

2.3.4 Small UAVs

What we will call "small UAVs" have at least one dimension of greater than 50 cm (19.7 in) and go up to dimensions of a meter or two. Many of these UAVs have the configuration of a fixed-wing model airplane and are hand-launched by their operator by throwing them into the air much as we launch a toy glider. In the past ten years, the quadcopters for this class – with VTOL capability – have been operational and gained a significant market.

Examples of small UAVs include the US AeroVironment Raven and the Turkish Byraktar Mini, both conventional fixed-wing vehicles. There are also a number of rotary-wing and multi-copter UAVs in this size grouping, but they are basically scaled-down versions of the medium rotary-wing systems discussed in the following section and we do not offer an example in this group.

The RQ-11A Raven is an example of a UAV that is in the "model airplane" size range. It has a 1.4-m (4.6-ft) wingspan and is about 1 m (3.3 ft) long. It weighs only a little less than 4.4 lb (mass of 2 kg) and is launched by being thrown into the air by its operator in much the same way that a toy glider is put into flight. It uses electrical propulsion and can fly for nearly an hour and a half. The Raven and its control "station" can be carried around by its operator on his/her back. It carries gimbaled visible, near-infrared (NIR), and thermal imaging systems for reconnaissance as well as a "laser illuminator" to point out target to personnel on the ground. (Note that this is not a laser for guiding laser-guided weapons, but more like a laser pointer, operating in the NIR to point things out to people using image-intensifier night-vision devices.)

The latest model, the RQ-11B Raven, was added to the US Army's Small UAV (SUAV) program in a competition that started in 2005. Built by AeroVironment, the Raven B includes a number of improvements from the earlier Raven A, including improved sensors, a lighter Ground Control System, and the addition of the onboard laser illuminator. Endurance was improved, as was interoperability with battlefield communication networks.

The Bayraktar small UAV was developed by Baykar Makina, a Turkish company. It is a conventionally configured, electrically powered AV somewhat larger than the Raven, with a length of

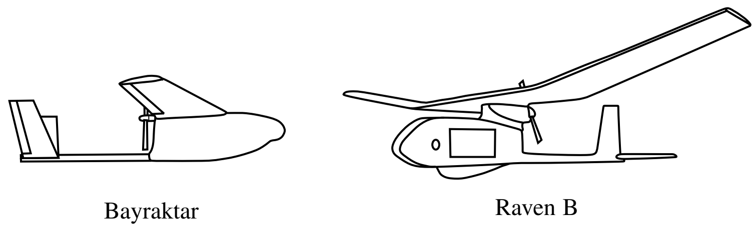

Figure 2.3 Small UAVs

Figure 2.4 Boeing-Insitu ScanEagle (Source: U.S. Navy / Wikimedia Commons / Public Domain)

1.2 m (3.86 ft), wingspan of 2 m (5.22 ft), and weight of 5 kg (105 lb) at takeoff. It is advertised to have a spread-spectrum, encrypted data link, which is a highly desirable, but unusual, feature in an off-the-shelf UAV. The data link has a range of 20 km (12.4 miles), which would limit the operations to that range, although it may depend on the local geography and where the ground antenna is located, as discussed in detail in Part Five of this book (Data Links).

The Bayraktar has a gimbaled day or night camera. It offers waypoint navigation with GPS or other radio navigation systems. Despite its slightly greater size and weight, it is launched much like the Raven. It can be recovered by a skidding landing on its belly or with an internal parachute. It is fielded with small army units and has been heavily used by the Turkish Army since it was fielded in about 2006. Drawings of these examples are shown in Figure 2.3.

The Boeing-Insitu ScanEagle (Figure 2.4) with a wing span of 3.11 m (10.2 ft) and a maximum takeoff weight of 58 lb (mass of 26.5 kg) is also classified as a small UAV. Insitu has produced about 3,000 EcanEagle air vehicles, which had a total of about 140,000 land and maritime sorties. The UAV carries a maximum of 5 kg of payload (EO/IR and ViDar sensors) for day/night and maritime surface search missions. The vehicle performance is: (1) maximum speed: 80 knots, (2) endurance: 18 hours, and (3) ceiling: 19,500 ft.

The ScanEagle can provide daytime and night-time intelligence, surveillance, and reconnaissance (ISR) – including high-resolution digital full motion video – in extreme environments.

2.3.5 Medium UAVs

We call a UAV "medium" if it is too large to be carried around by one person and still smaller than a light aircraft. (As with all of these informal size descriptions, we do not claim rigorousness in this definition. Some attempts at standardized and universal classifications of UAVs are described later in this chapter.)

The UAVs that sparked the present resurgence of interest, such as the Pioneer and Skyeye, are in the medium class. They have typical wingspans of the order of 5–10 m (16–32 ft) and carry payloads of from 100 to about 200 kg (220–440 lb). There are a large number of UAVs that fall into this size group. The Israeli–US Hunter (retired!!) and the UK Watchkeeper are more recent examples of medium-sized, fixed-wing UAVs.

There are also a large number of rotary-wing UAVs in this size class. A series of conventional helicopters with rotor diameters of the order of 2 m (6.4 ft) have been developed in the United Kingdom by Advanced UAV Technologies. There are also a number of ducted-fan systems configured much like the CyberQuad Mini but having dimensions measured in meters instead of centimeters. Finally, we mention the US Boeing Eagle Eye, which is a medium-sized VTOL system that is notable for using tilt-wing technology.

The RQ-2 Pioneer is an example of an AV that is smaller than a light manned aircraft, but larger than what we normally think of as a model airplane. It was for many years the workhorse of the stable of US tactical UAVs. Originally designed by the Israelis and built by AAI in the United States, it was purchased by the US Navy in 1985. The Pioneer provided real-time reconnaissance and intelligence for ground commanders. High-quality day and night imagery for artillery and naval gunfire adjust and damage assessment were its prime operational missions.

The 205-kg (452-lb), 5.2-m (17-ft) wingspan AV had a conventional aircraft configuration. It cruised at 200 km/h and carried a 220-kg (485-lb) payload. Maximum altitude was 15,000 ft (4.6 km) and endurance was 5.5 hours. The ground control station could be housed in a shelter on a High Mobility Multipurpose Wheeled Vehicle (HMMWV) or truck. The fiberglass air vehicle had a 26-hp engine and was shipboard capable. It had piston and rotary engine options.

The Pioneer could be launched from a pneumatic or rocket launcher or by conventional wheeled takeoff from a prepared runway. Recovery was accomplished by conventional wheeled landing with arrestment or into a net. Shipboard recovery used a net system.

The BAE Systems Skyeye R4E UAV system was fielded in the 1980s and is roughly contemporary with the Pioneer, with which it has some common features, but the air vehicle is significantly larger in size, which allows expanded overall capability. It uses launchers similar to the Pioneer but does not have a net-recovery capability. It uses a ground control station similar in principle to that of the Pioneer. It is still in service with Egypt and Morocco.

The Skyeye air vehicle is constructed of lightweight composite materials and was easy to assemble and disassemble for ground transport because of its modular construction. It has a 7.32-m (24-ft) wingspan and is 4.1 m (13.4 ft) long. It is powered by a 52-hp rotary engine (Teledyne Continental Motors) providing high reliability and low vibration. The maximum launch weight is 570 kg (1,257 lb) and it can fly for 8–10 h and at altitudes up to 4,600 m (14,803 ft). The maximum payload weight is about 80 kg (176 lb).

Perhaps the most unique feature of the Skyeye when it was fielded was the various ways in which it could be recovered. The Skyeye has no landing gear to provide large radar echoes or obstruct the view of the payload. The avoidance of a nose wheel is particularly significant as a nose gear often obstructs the view of a payload camera looking directly forward, precluding landing based on the view through the eyes of the camera. However, it can land on a semi-prepared surface by means of a retractable skid located behind the payload. This requires the landing to be controlled by observing the air vehicle externally during its final approach. This is particularly dangerous during night operations.

The landing rollout, or perhaps more accurately the "skid-out," is about 100 m (322 ft). The Skyeye also carries either a parafoil or a parachute as an alternative recovery system. The parafoil essentially is a soft wing that is deployed in the recovery area to allow the air vehicle to land much more slowly. The parafoil recovery can be effective for landing on moving platforms such as ships or barges. The parachute can be used as an alternative means of landing or as an emergency device. However, using the parachute leaves one at the mercy of the vagaries of the wind, and it primarily is intended for emergency recoveries. All of these recovery approaches are now offered in various fixed-wing UAVs, but having all of them as options in one system still would be unusual.

The RQ-5A Hunter was the first UAS to replace the terminated Aquila system as the standard "Short Range" UAS for the US Army. The Hunter does not require a recovery net or launcher, which significantly simplifies the overall minimum deployable configuration and eliminates the launcher required by the Skyeye. Under the appropriate conditions, it can take off and land on a road or runway. It utilizes an arresting cable system when landing, with a parachute recovery for emergencies. It is not capable of net recovery because it has a tractor ("puller") propeller that would be damaged or broken or would damage any net that was used to catch it. It also has a rocket-assisted takeoff option to allow the launch to occur when no suitable road or runway is available.

The Hunter is constructed of lightweight composite materials, which afford ease of repair. It has a 10.2-m (32.8-ft) wingspan and is 6.9 m (22.2 ft) long. It is powered by two four-stroke, two-cylinder (v-type), air-cooled Moroguzzi engines, which utilize fuel injection and individual computer control. The engines are mounted in-line – tractor and pusher – giving the air vehicle twin engine reliability without the problem of unsymmetrical control when operating with a single engine. The air vehicle weighs approximately 885 kg (1,951 lb) at takeoff (maximum), has an endurance of about 12 h, and a cruise speed of 120 knots.

The Hermes 450/Watchkeeper is an all-weather, intelligence, surveillance, target acquisition and reconnaissance UAV. Its dimensions are similar to the Hunter. The Watchkeeper is manufactured in the United Kingdom by a joint venture of the French company Thales and the Israeli company Elbit Systems. It has a weight of 450 kg (992 lb) including a payload capacity of 150 kg (331 lb). The Watchkeeper was in service in Afghanistan with British forces late in 2011.

A series of rotary-wing UAVs called the AT10, AT20, AT100, AT200, AT300, and AT1000 have been developed by the UK firm Advanced UAV Technology. They are all conventionally configured helicopters with a single main rotor and a tail boom with a tail rotor for yaw stability and control. The rotor diameters vary from 1.7 m (5.5 ft) in the AT10 to about 2.3 m (7.4 ft) for the AT1000. Speed and ceiling increase as one moves up the series, as does the payload capacity and payload options. All are intended to be launched by vertical takeoff and all claim the ability for autonomous landings on moving vehicles.

The Northrop Grumman MQ-8B Fire Scout is an example of a conventionally configured VTOL UAV. It looks much like a typical light helicopter. It has a length of 9.2 m (30 ft) (with the blades folded so that they do not add to the total length), height of 2.9 m (9.5 ft), and a rotor diameter of 8.4 m (27.5 ft). It is powered by a 420 hp turbine engine. The Fire Scout is roughly the same size as an OH-58 Kiowa light observation helicopter, which has a two-man crew and two passenger seats.

The Kiowa has a maximum payload of about 630 kg (1,389 lb), compared to the 270 kg (595 lb) maximum payload of the Fire Scout, but if one takes out the weight of the crew and other things associated with the crew, the net payload capability of the Fire Scout is similar to that of the manned helicopter. The Fire Scout is being tested by the US Army and Navy for a variety of missions that are similar to those performed by manned helicopters of a similar size.

The tilt-rotor Bell Eagle Eye was developed during the 1990s. It uses "tilt-wing" technology, which means that the propellers are located on the leading edge of the wing and can be pointed up for takeoff and landing and then rotated forward for level flight. This allows a tilt-wing aircraft to utilize wing-generated lift for cruising, which is more efficient than rotor-generated lift, but still to operate like a helicopter for VTOL capability.

The Eagle Eye has a length of 5.2 m (16.7 ft) and weighs about 1,300 kg (2,626 lb). It can cruise at up to about 345 km/h (knots) and at altitudes up to 6,000 m (19,308 ft). Some of these UAVs are shown in Figure 2.5.

The Bayraktar TB2 – as a precision strike MALE UAV – is developed by Baykar Makina, a Turkish company. It has a length of 6.5 m (21 ft), a wingspan of 12 m (39 ft), and a maximum takeoff weight of 1430 lb. The UAV is equipped with a 100 hp piston engine, carries a 330 lb payload (EO/IR/LD imaging and targeting sensor), and features four hardpoints for laser-guided smart munition (missiles/rockets). The performance includes: (1) maximum speed of 120 knots, (2) range of 150 km, (3) service ceiling of 27,000 feet, and (4) endurance of 27 hours. As of July 2021, the TB2 UAV has completed 300,000 flight-hours globally.

2.3.6 Large UAVs

Our informal size groupings are not finely divided, and we will discuss all UAVs that are larger than a typical light manned aircraft in the group called "large." This includes, in particular, a

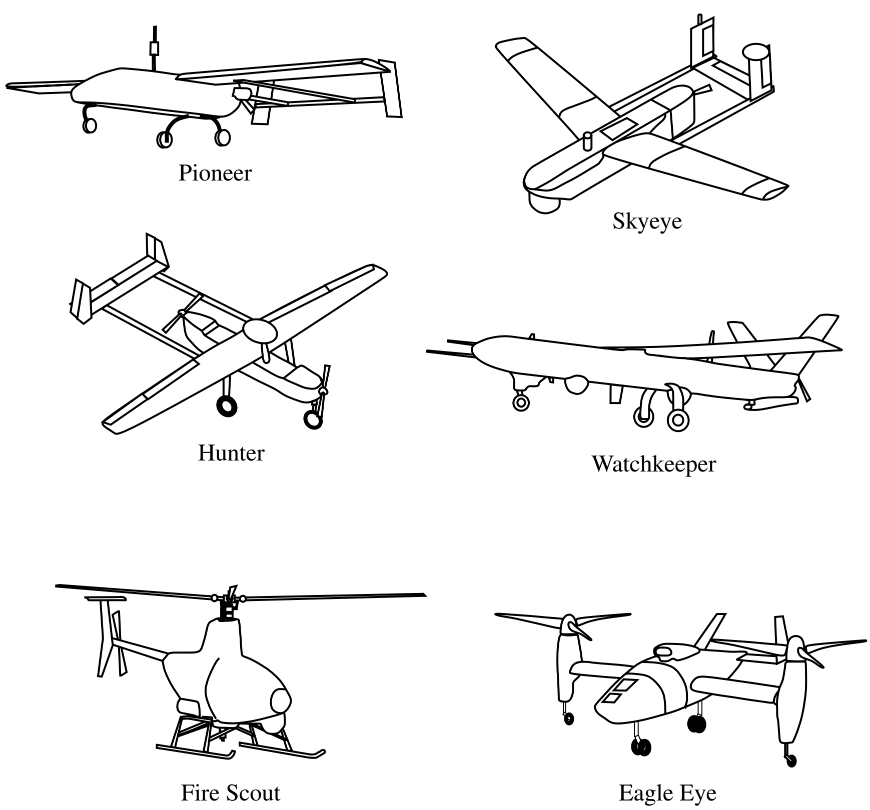

Figure 2.5 Medium UAVs

group of UAVs that can fly long distances from their bases and loiter for extended periods to perform surveillance functions. They also are large enough to carry weapons in significant quantities. The lower range of such systems includes the US General Atomics Predator A, which has a significant range and endurance, but can carry only two missiles of the weight presently being used.

The limitation to two missiles is serious as it means that after firing the two missiles that are onboard, the UAV either has lost the ability to deliver weapons or must be flown back to its base to be rearmed. For this reason, a second generation of UAVs designed for missions similar to that of the Predator, including a Predator B model (i.e., Reaper), is now appearing that is larger and able to carry many more weapons on a single sortie.

The Cassidian Harfang is an example of a system much like the Predator A and the Talarion, also by Cassidian, is an example of the emerging successors to the Predator A.

At the high end of this size group, an example is an even larger UAV designed for very long range and endurance and capable of flying anywhere in the world on its own, the US Northrop Grumman Global Hawk (see Figure 1.4).

There are a number of specialized military and intelligence systems for which information available to the public is very limited. An example of this is the US Lockheed Martin RQ-170 Sentinel. The RQ-170 Sentinel is reported to be a stealthy AV manufactured by Lockheed Martin, but limited performance data are available. It is a flying wing configuration much like the Northrop B-2 Spirit bomber and is in the medium-to-large size class, with a wingspan of around 20 m (65 ft) and a length of 4.5 m. This UAV is equipped with a single turbofan engine with 41.26 kN of thrust. In 2011, Iran stated that its Army's electronic warfare unit had downed an RQ-170 that violated Iranian airspace along its eastern border through overriding its controls, and had captured the lightly damaged UAV.

The MQ-1 Predator A is larger than a light single-engine private aircraft and provides medium altitude, real-time surveillance using high-resolution video, infrared imaging, and synthetic aperture radar. It has a wingspan of 17 m (55 ft) and a length of 8 m (26 ft). It adds a significantly higher ceiling (7,620 m or 24,521 ft) and longer endurance (40 h) to the capabilities of the smaller UAVs. GPS and inertial systems provide navigation, and remote control can be via satellite. Cruise speed is 220 km/h (119 knots) and the air vehicle can remain on station for 24 h, 925 km (575 mi) from the operating base. It can carry an internal payload of 200 kg (441 lb) plus an external payload (hung under the wings) of 136 kg (300 lb).

The Harfang UAV is produced by Cassidian, which is a subsidiary of the French company EADS. It is about the same size as the Predator and is designed for similar missions. The configuration is different, using a twin-boom tail structure. There are a variety of possible payloads. Its stated performance is similar to that of the Predator, but it has a shorter endurance of 24 h. It takes off and lands conventionally on wheels on a runway. Remote control can be via satellite.

Talarion is under development by Cassidian as a second-generation successor to the Predator/Harfang class of UAVs. It uses two turbojet engines and can carry up to 800 kg (1,764 lb) of internal payload and 1,000 kg (2,205 lb) of external payload with a ceiling of over 15,000 m (49,215 ft) and speeds around 550 km/h (297 knots).

The RQ-4 Global Hawk (see Figure 1.4) is manufactured by Northrop Grumman Aerospace Systems. It flies at high altitude and utilizes radar, electro-optical, and infrared sensors for surveillance applications. It uses a turbofan engine and appears to have a shape that reduces its radar signature, but is not a "stealth" aircraft. It is 14.5 m (47 ft) long with a 40 m (129 ft) wingspan and has a maximum weight at takeoff of 1,460 kg (3,219 lb). It can loiter at 575 km/h (310 knots) and has an endurance of 32 h. It has a full set of potential payloads and it appears that it is routinely

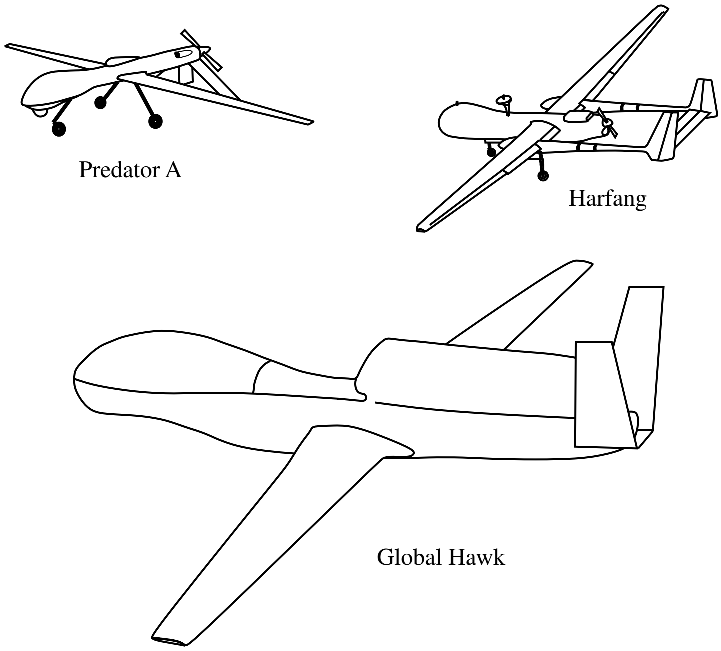

Figure 2.6 Large UAVs

controlled via satellite links. More information about the Global Hawk is presented in Section 5 of Chapter 1.

Some of these large UAVs are illustrated in Figure 2.6.

2.4 Expendable UAVs

Expendable UAVs are not designed to return after accomplishing their mission. In the military world, this often means that they contain an internal warhead and are intended to be crashed into a target destroying it and themselves. This type of expendable is discussed further in Chapter 11 and we make the argument there that it is not really a UAV, but rather a missile of some sort. There is a considerable area of overlap between guided missiles and UAVs, as illustrated by the fact that the first "UAVs" of the aviation era were mostly guided weapons. An alternative definition of an expendable is that it can (and should) be recovered if possible, but can have a very high loss rate.

The electric-motor-powered Raven, described in Section 2.3.4, is an example of an expendable, but recoverable, UAV. It is hand launched and uses a hand-carried ground control station. The Raven is used to conduct reconnaissance missions out to about 5 km and is recoverable, but if it does not return or crashes during landing, the loss is considered acceptable.

However, in the past few years, a new type of lethal UAVs (as loitering munition) has emerged. This precision-guided loitering munition is a relatively new concept and technology and generates a low (or very low) collateral damage. As example is Switchblade 300 (Figure 2.7), designed and manufactured by AeroVironment. This UAV – which was first fielded by the US Army and Marine Corp in 2011 – utilizes a small munition to break apart prior to impact and has a low acoustic, thermal, and radar signature. Switchblade 300 is interoperable with current Puma, Raven, and Wasp UAV control stations.

Figure 2.7 Switchblade UAV (Source: Business Wire, Inc.)

This UAV – with a mass of 2.7 kg (weight of 6 lb), a length of 2 ft, and a pusher electric motor – carries a small munition with a range of 10 km; it can be in the air for about 10 minutes. The operating altitude is 500 ft AGL (above ground level) and 15,000 ft MSL (mean sea level), with a cruise speed of 63 mph and a dash of 98 mph. Its tubular fuselage contains the battery, motor, avionics, and a payload (gimbaled nose camera). The UAV is folded inside a tube with wing sections unfolding once it gets airborne. The two wing sections are spring loaded, low-mounted, and sweep out upon launching.

Switchblade – armed with a 40-mm grenade-like warhead – is meant to strike targets beyond the range – or shielded from the line of sight – of the rifles, machine guns, and other weapons of an infantry platoon or squad. Switchblade was fielded on an emergency basis in Afghanistan beginning in 2012.

There are a number of similar UAVs developed by other companies. Examples are Lockheed Martin Terminator, Mistral HERO-30SF, Textron Systems BattleHawk, SAAB AT4 CS, Booz Allen Hamilton Vampire, Prox Dynamics Black Hornet, and Area-I Air-Launched, Tube-Integrated, Unmanned System, or ALTIUS-600.

Questions

1) What do HALE, MALE, UCAV, FLOT, AGL, MSL, and EW stand for?
2) Write classes of UAVs based on manufacturing location.
3) Write classes of UAVs based on user.
4) Write classes of UAVs based on mission.

5) Write classes of UAVs based on size.
6) Write classes of UAVs based on wing configuration.
7) Write classes of UAVs based on number of uses.
8) Write classes of UAVs based on altitude/range/endurance.
9) Which FAR part governs small UAVs?
10) What group of aircraft are often referred to as “model airplane”?
11) What is the definition of very low-cost close-range required by the Marine Corps?
12) What is the definition of close-range in this chapter?
13) What is the definition of short-range in this chapter?
14) What is the definition of mid-range in this chapter?
15) What is the loiter capability of an endurance UAV?
16) How do we distinguish missiles from “unmanned aerial vehicles”?
17) Define intelligence as the mission for a UAV.
18) Define surveillance as the mission for a UAV.
19) Define reconnaissance as the mission for a UAV.
20) What is the mission for tier I UAVs in the US Air Force? Provide an example.
21) What is the mission for tier II UAVs in the US Air Force? Provide an example.
22) What is the mission for tier II+ UAVs in the US Air Force? Provide an example.
23) What is the mission for tier III− UAVs in the US Air Force? Provide an example.
24) What is the weight group for tier I UAVs in the US Marine Corps? Provide an example.
25) What is the weight group for tier II UAVs in the US Marine Corps? Provide an example.
26) Provide an example for tier III UAVs in the US Marine Corps.
27) What is the weight group for tier I UAVs in the US Army? Provide an example.
28) What is the mission for tier II UAVs in the US Army? Provide an example.
29) What is the mission for tier III UAVs in the US Army? Provide an example.
30) What mission accounts for most of the UAV activity to date?
31) What is tier in UAV classification?
32) List size classes of UAVs that are presented in this chapter.
33) What is the typical size range for very small UAVs?
34) Briefly describe the characteristics of DJI Phantom 4 Pro.
35) Briefly describe the characteristics of RQ-11A Raven.
36) What is the range of data link for Bayraktar UAV?
37) Write typical wingspan and payload weight for medium UAVs.
38) Write three examples of air vehicles for the class of medium UAVs.
39) What were prime operational missions of RQ-2 Pioneer?
40) Briefly describe the characteristics of BAE Systems Skyeye R4E UAV.
41) Write four UAVs that are equipped with a rotary or piston engine.
42) What is the most unique feature of the Skyeye, when it was fielded? Discuss.
43) Write two disadvantages of a nose gear when the camera payload is located under the fuselage nose?
44) Which UAS was the first one to replace the terminated Aquila system as the standard “Short Range” UAS for the US Army?
45) Write names of three UAVs that were made of composite materials.
46) Briefly describe the characteristics of RQ-5A Hunter.
47) What was the mission of Hermes 450/Watchkeeper?
48) Write length, height, and engine power of Northrop Grumman MQ-8B Fire Scout.
49) Write the name of a UAV with a tilt-rotor configuration.

50) What are the maximum cruise speed and ceiling of Bell Eagle Eye?
51) Write two example UAVs (one for the lower range and one for the high end) of the large UAV group.
52) Write: (1) wingspan, (2) length, and (3) total payload weight of the MQ-1 Predator A.
53) Write cruise speed and endurance of the MQ-1 Predator A.
54) What can an MQ-1 Predator A provide as its mission?
55) What are the payload sensors for surveillance applications in the RQ-4 Global Hawk?
56) What is an expendable UAV?
57) What is the type and mission of the Switchblade 300?
58) Write features of the wing and fuselage of the Switchblade 300.
59) What are the cruise speed and ceiling of the Switchblade 300?
60) What are two payloads of the Switchblade 300?
61) Write the maximum speed, endurance, and ceiling of ScanEagle.
62) For ScanEagle, what are: (1) the maximum takeoff weight and (2) weight of payload?
63) What are sensors of Boeing-Insitu ScanEagle?
64) According to FAR Parts 48 and 107, may you operate an sUAS at night in the US? Why?
65) What UAV is defined as a small unmanned aircraft by FAR?
66) Name four expendable UAVs and their manufacturers.
67) List missions of Insitu ScanEagle.
68) Describe the performance of the XQ-58 Valkyrie.
69) What is the capacity of bombs in the XQ-58 Valkyrie?
70) Write: (1) wingspan, (2) length, and (3) total payload weight of the Bayraktar TB2.
71) Write the maximum speed and endurance of the Bayraktar TB2.
72) What can a Bayraktar TB2 provide as its mission?
73) What is the payload of Bayraktar TB2?