
Introduction to Quadcopters

A Brief History of Multirotor Helicopters

The multirotor helicopter also known as a *quadrotor* or *quadcopter* is equipped with four rotors to create lift. It is a true helicopter in that lift force is created by narrow-chord horizontally rotating air foils. The quadcopter design has been in existence since the 1920s when an early manned version named the De Bothezat helicopter was built and successfully flown. First developed and prototyped under a U.S. Army contract, the De Bothezat helicopter is pictured in Figure 1.1.

It first flew in October 1922 at what is now known as Wright Field in Dayton, Ohio. The helicopter actually started with six rotors, but eventually two were deemed unnecessary and were eliminated. It made more than 100 flights over a period of years but never flew more than 5 meters into the air and never with any lateral movement. This was due to the complexity and difficulty of simply trying to maintain level flight, never mind moving in a lateral direction. This lateral movement control was to be the bane of multirotor helicopters until the invention and use of computer-assisted flight-control systems that would lessen the pilot workload. The U.S. Army eventually lost interest in the De Bothezat project and discontinued it in the early 1930s, after spending more than \$200,000 on the program.

Helicopter development languished, at least in the United States, from the early 1930s to the mid 1940s. With the ending of World War II, development work did resume, but the focus was on more conventional designs that employed a main rotor with a tail rotor or the use of coaxial main rotors. The armed forces that initially funded helicopter development apparently believed that any possible advantages of using quad rotors were far outweighed by their complexity and ill-mannered flight characteristics.

The U.S. Army eventually developed and successfully fielded a heavy-lift, tandem-rotor helicopter named the Chinook, model CH-47, which despite being designed in the 1960s, is still in wide use today. It has undergone many updates and upgrades to keep it fully compatible with today's environment.

The U.S. Department of Defense also sponsored the development and production of a hybrid, dual-tilt-rotor aircraft named the Osprey, model V-22. It takes off and lands as a dual rotor helicopter, but flies as a traditional airplane with the wings tilted to a level position while it is operating in cruise mode. Figure 1.2 is a picture of the pilot's station in the V-22, showing all the incredible technology available to the pilot.



FIGURE 1.1 De Bothezat helicopter.

Both the Chinook and Osprey take advantage of computer-assisted flight-control systems that significantly reduce pilot workload and make it practical to safely fly aircraft that would otherwise be nearly impossible to fly.

The development of true quad-rotor helicopters turned out to be delayed until the early 1990s when a small-scale, *radio-controlled* (R/C) system named the Gyro Saucer 1 was developed and marketed in Japan. This is the earliest instance that I could find in my research for the appearance of a practical quadcopter, with or without an onboard pilot. It used mechanical gyros for stability and fairly small electrical motors to turn the props. Unfortunately, the props were made of Styrofoam and had a habit of disintegrating if they came in contact with anything, including light fabric curtains. The Gyro Saucer had an operating flight time of approximately three minutes, was never exported from Japan, and hence, was a relatively unknown system. Figure 1.3 is a picture of this early quadcopter.

The first modern, widely available multirotor system was the Draganflyer, which was designed and manufactured in the early 2000s by Draganfly Innovations Inc. Draganfly has



FIGURE 1.2 V-22 pilot's station.



FIGURE 1.3 Gyro Saucer 1 system.

since superseded that early design with later models that are much more sophisticated and come equipped with a variety of functional capabilities. Figure 1.4 is a picture of their X-8 model, which is quite a remarkable and stable platform.

The X-8 quadcopter has four booms with a motor attached to each one and a pair of propellers attached to each motor, thus making for a total of eight propellers on the craft. This quadcopter is just one of dozens of models available for purchase at the time this book is being written.

Most small-scale, R/C multicopter helicopters have four rotors; however, there are models with as few as three to as many as eight, with a few outliers with even more. There is also a start-up company named *e-volo* that plans to build a manned aircraft with 18 rotors named the *Volocopter*.

This book will focus only on building and flying an R/C small-scale quadcopter because it is the most representative and reasonably priced of the current selection of multicopter helicopters.



FIGURE 1.4 Draganflyer X-8.

A Matter of Definition

There are a variety of descriptors associated with quadcopters that I would like to briefly examine. Probably the most general description of a quadcopter is an *unmanned aerial vehicle* (UAV). UAV has also been interpreted as an *uninhabited aerial vehicle*, which is precisely the same meaning as unmanned aerial vehicle. Two descriptions that are more specific would be those of *remotely operated aircraft* (ROA) and *remotely piloted vehicle* (RPV). The last two descriptions mean that no pilot is physically carried by the aerial vehicle and all vehicle control is accomplished either by a pilot using a remote ground station or autonomously by the vehicle. A related definition for this type of operation is *autonomous aerial vehicle* (AAV). It is often used to describe a UAV that is controlling its own operation, independent of any ground station. However, it should be pointed out that all AAVs should have some kind of autonomous override command available from a ground station, just in case something goes wrong with the onboard flight-control system. Having a fail-safe mode should always be a paramount design decision in any AAV project.

UAV, ROA, and RPV are the most popular and well-known descriptions for the quadcopter type of vehicle. There is also one other popular descriptor: *micro aerial vehicle* (MAV), which refers to any very small-sized UAV with all length, width, or height dimensions of 15 cm or less. MAVs are actively being developed along with swarming control techniques in a variety of research projects. Developers of some of these projects hope to implement insect biomimicry into their MAVs in an attempt to achieve the performance and capabilities of their real-world counterparts.

How Are Quadcopters Used?

The answer to the question of how quadcopters are used depends on whether one is viewing them from a military or a civilian perspective. Military use of quadcopters lies mainly in the intelligence, surveillance, and reconnaissance (ISR) field, and to a lesser extent, in tactical deployments. Quadcopters are excellent ISR assets that nicely complement fixed-wing UAVs that are extensively employed by many worldwide military organizations. Currently all tactical deployments where weapons-carrying UAVs are deployed in actual combat are still the domain of fixed wing UAVs, such as the U.S. Air Force MQ-9 Reaper, which is shown in Figure 1.5.

The quadcopter, as of this writing, still cannot carry a heavy payload, such as a missile or cannon, although it is likely that there are ongoing military research projects attempting to overcome this limitation. There would be an obvious tactical advantage for a combat unit to be able to deploy a small, airborne weapons platform that could hover over a battlefield and engage enemy targets upon command. The old military adage of “gain the high ground for tactical advantage” would definitely take on a new meaning with the use of a tactical quadcopter.

Civilian uses for quadcopters are far more numerous than military ones at this time. Some of these are listed in Table 1.1.

There are some legal restrictions in the United States regarding the civilian use of quadcopter UAVs, including the FAA requirements that they not be flown any more than 400 feet above ground level and not near any airport. I am sure that similar restrictions are in place in other countries, so I would urge you to research the laws and regulations that are applicable in your country.

U.S. residents should also be aware that the airspace above their domiciles is *not* exclusive for their use. In the 1946 decision, [United States v. Causby 328 US 256 1946](#), the U.S. Supreme Court held that only the landowner’s airspace that may be reasonably occupied or



FIGURE 1.5 US Air Force MQ-9 Reaper UAV.

used in connection with the land residence is exclusive to the landowner. The precise court wording is shown below:

Cujus est solum ejus est usque ad coelum et ad inferos has no legal authority in the United States when pertaining to the sky. A man does not have control and ownership over the airspace of their property except within reasonable limits to utilize their property. Airspace above a set minimum height is property of the Masses and no one man can accuse airplanes or other such craft of trespassing on what they own.

Law enforcement
Security patrols on private property
Agricultural surveying
Communications relay
Incident command support
Aerial mapping
Aerial photography
Severe weather telemetry
University research projects
Search and rescue

TABLE 1.1 Civilian Uses of Quadcopters

The Latin words at the start of the court's decision refer to English common law where it was held that a landowner had exclusive rights to all space "from the depths to the heavens." Obviously, the court held that this specificity did not apply in the United States. Otherwise, one could imagine the resulting chaos if airlines had to obtain landowners permission to fly into airspace that projected from the ground. As mentioned earlier, it would be wise to check with the appropriate authorities before flying your quadcopter in a country other than the United States. You might find yourself inadvertently trespassing in someone's airspace.

Other limitations or constraints related to real-time video surveillance are more problematic. All quadcopters with video capability, whether onboard capture or real-time transmission, should be operated with prudence. In other words, it is definitely *not* a good idea to fly the quadcopter (even without video) over to your neighbor's house and attempt to peer in their windows. Flying over your neighbors' houses, while legal, should be done with an abundance of caution. I would definitely talk with my neighbors prior to making any flights above or close to their homes.

Design of the Elev-8 Quadcopter

According to Ken Gracey, President of Parallax Inc., the Elev-8 project began after a visit to his company by some folks from the Hoverfly Company. Hoverfly manufactures sophisticated quad and hex copters that can optionally be equipped with camera systems. Hoverfly also designs and manufactures flight-control boards, which was one of the main reasons they visited Parallax. It turns out that some very bright Parallax engineers designed an unusual and very clever eight-core microcontroller they aptly named *Propeller*. The designers decided to call their cores "cogs," which I suppose was to emphasize a more collaborative computing approach as compared to traditional multicore processors. (In a later chapter, I will explore the Propeller chip in much greater depth.) Designers and engineers at Hoverfly recognized the unique capabilities of the Propeller chip and decided to incorporate it into their flight-controller boards. Thus, the reason for the visit to Parallax headquarters was to demonstrate their quadcopter. Ken was fascinated with their demonstration and quickly realized that he and his company had to be involved in a like-minded project, which is the genesis of the Elev-8. Ken also realized that it made much more sense to provide a kit of parts in lieu of a fully assembled quadcopter. This idea fit with the Parallax company specialty, which is centered on providing builders and users with components and subassemblies in lieu of fully assembled products. At times, they have provided fully assembled products, but that seems mostly outside of their modus operandi.

Creating the basic Elev-8 kit was in itself a bit of a problem: Ken and two of his engineers, Kevin Cook and Nick Ernst, had to determine suitable components that would enable builders to successfully make their own Elev-8 without excessive costs or complexity. Many of the problems and design decisions they encountered will be discussed in later chapters to provide you with an understanding of the decisions that are required in a project of this complexity.

It was an easy decision for Ken to simply incorporate a fully assembled HoverflySPORT controller board into the kit. The flight-controller board is the key element that enables a user with an R/C transmitter to fly a quadcopter as directed. Figure 1.6 shows the HoverflySPORT controller board.

Chapter 2 delves into the complexities of quadcopter flight dynamics, and it soon will become apparent that designing and building a flight-control board is best left to professionals.

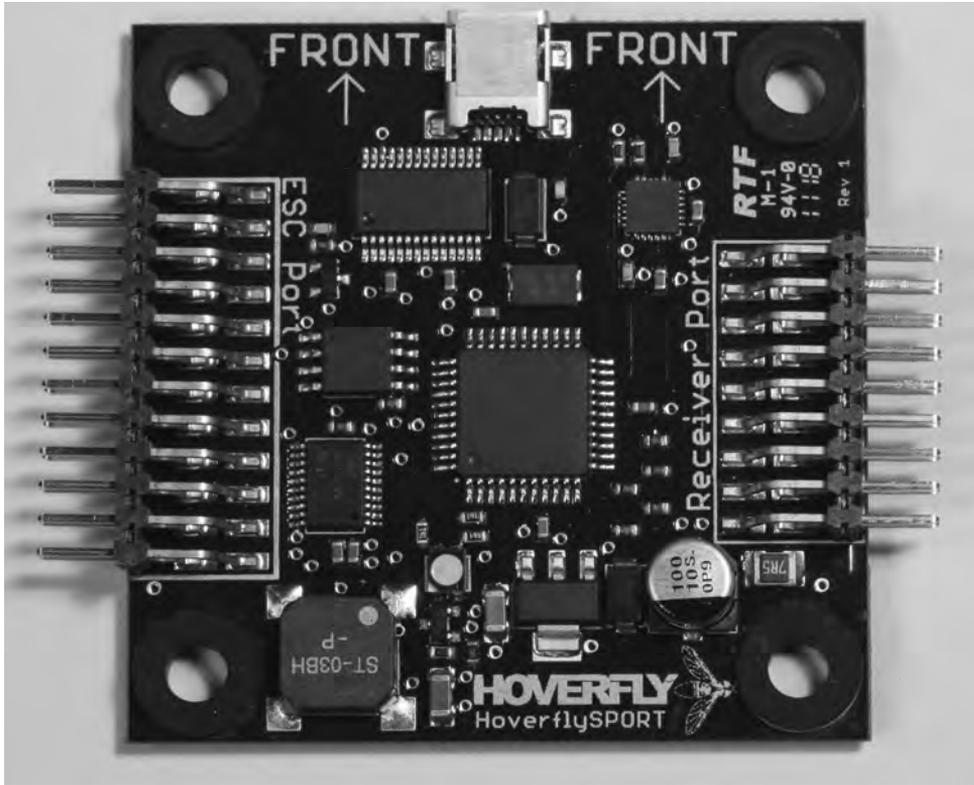


FIGURE 1.6 HoverflySPORT controller board.

Having said that, it turns out that current Elev-8 kits now contain the HoverflyOPEN controller board, which gives knowledgeable users the opportunity to add their own control programs in lieu of using the default software. Figure 1.7 shows the HoverflyOPEN board In Chapter 2, I will also address the pros and cons of creating your own flight-control software.

Main Electrical/Electronic Elev-8 Components

The main electrical/electronic components that make up the Elev-8 system are shown in Figure 1.8. There are only 11 essential components, not counting wires, connectors, or any optional components such as telemetry and LED display components.

With only 11 components, the Elev-8 is not a very complex aircraft due mainly to the automated control provided by the HoverflyOPEN control board. A fully assembled, basic Elev-8 is shown in Figure 1.9.

The HoverflyOPEN control board and a Spektrum AR8000 receiver are clearly visible mounted on the top of the quadcopter. The LiPo battery is disconnected, as shown by the unconnected power cables that are visible in the front of the quadcopter. Red checkerboard pattern decals have been applied on each of the two aluminum tubes attached to the right side of the quadcopter. In addition, black checkerboard pattern decals are on the tubes

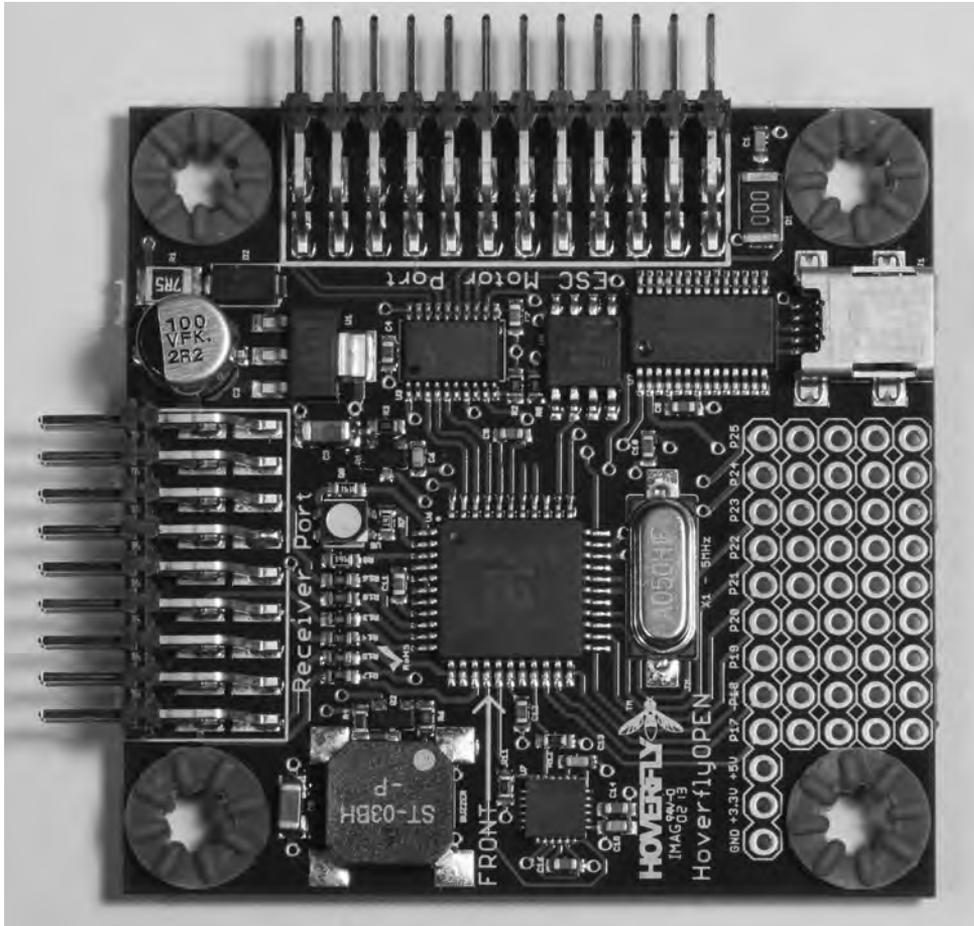


FIGURE 1.7 HoverflyOPEN controller board.

attached on the left. The red decals serve a very important purpose: they show the forward travel direction for an X configuration quadcopter. Forward is always between the red checkered tubes. The X configuration as well as other configurations will be discussed in Chapter 2.

Figure 1.10 is a picture of the first Elev-8 that I built in early 2012.

Every Elev-8 built will be unique to some degree. They all start from a basic kit of parts available for purchase from Parallax Inc., Rocklin, CA. Users can, and probably should, modify their kits to suit their personal preferences. Modifications can include adding items such as LED lights, video cameras, GPS trackers, and so on. For example, I added a separate Basic Stamp II microcontroller on my first quadcopter, which allowed me to independently program the display operation of the four LED strips attached to the underside of each of the four boom tubes. Figure 1.11 is a picture of a Basic Stamp II development board mounted

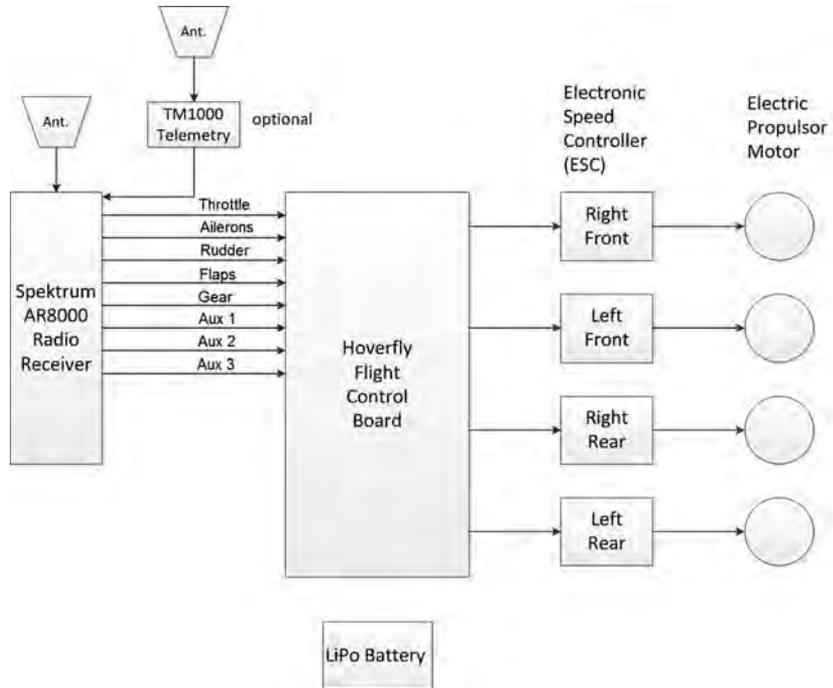


FIGURE 1.8 Main electrical/electronic Elev-8 components.

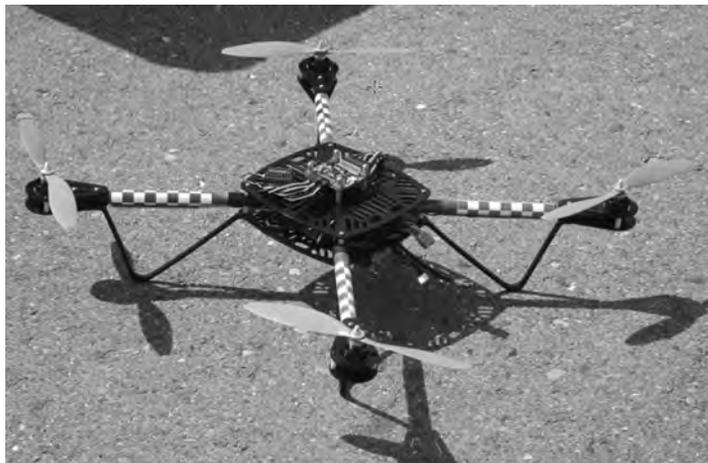


FIGURE 1.9 Basic Elev-8 quadcopter.



FIGURE 1.10 My first Elev-8 quadcopter.

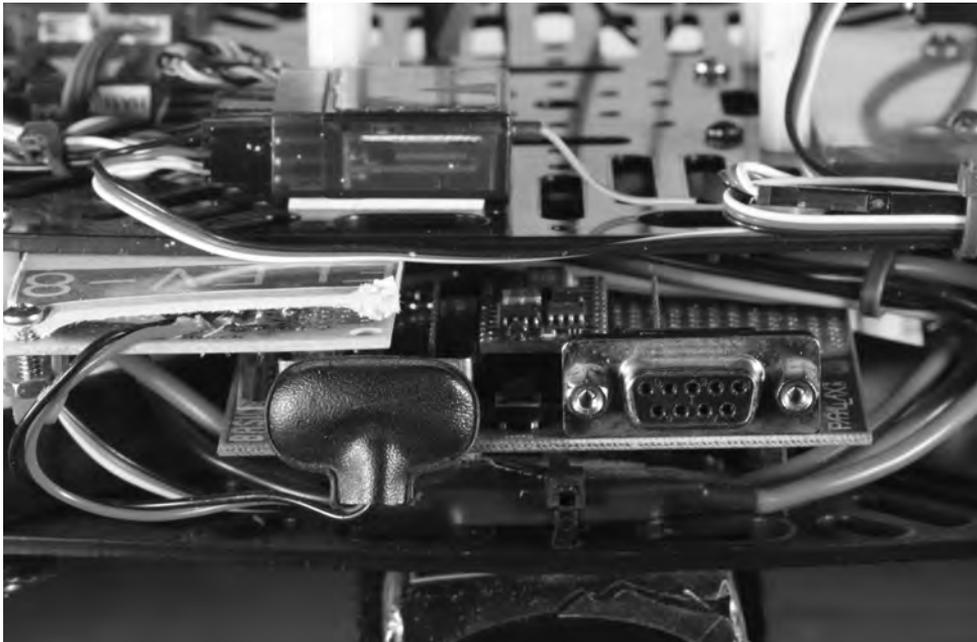


FIGURE 1.11 LED control Basic Stamp II development board.

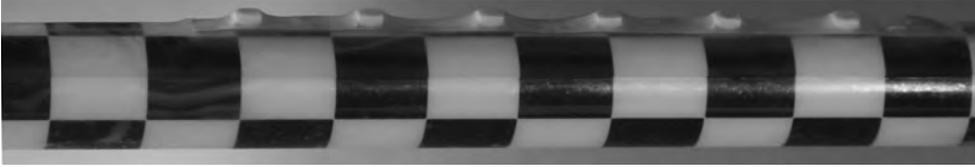


FIGURE 1.12 LED strip.

between the two Delrin boards that comprise the main structural boards of the Elev-8. The LED power distribution prototype board is located beneath a small cardboard piece with Elev-8 printed on it.

The DB-9 connector visible in the photo is used only to program the Stamp chip and is not needed during normal operation.

One of the LED strips mounted on the bottom of a boom tube is shown in Figure 1.12. Each strip has six LEDs mounted on an integral plastic backing strip that needs only two wires to power and control it.

I also added an R/C servo-control kill switch that was the ultimate fail-safe feature, just in case the quadcopter went out of control. This servo-control switch is shown in Figure 1.13.

Remotely activating this switch immediately cuts off all power to the quadcopter and causes it to drop to the ground. Remember, it is always preferable, and a lot less expensive, to accept damage to the quadcopter than to cause personal injury and/or property damage to an innocent party.

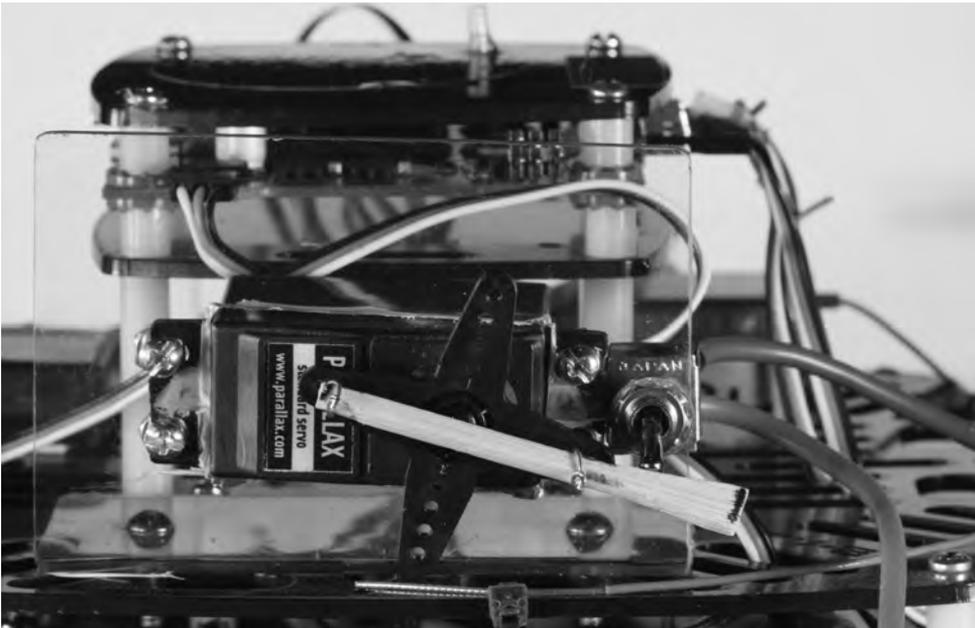


FIGURE 1.13 Servo-control kill switch.

Summary

I began this chapter with a brief history of multirotor development that started in the 1920s with a large manned aircraft, the De Bothezat helicopter. It turned out that safely controlling the flight path for this type of aircraft was much too demanding for human pilots. This fact delayed development until computer technologies were created that enabled the requisite supplemental control for safe flight. Two significant paths of development then led to more advances: (1) amply funded military projects in the 1970s yielded the design and production of manned multirotor aircraft, and (2) small unmanned R/C multirotors were built in Japan in the 1990s.

Next, I discussed a variety of definitions to help clarify the confusion that seems to surround these aircraft. The term unmanned aerial vehicle (UAV) appears to be the most appropriate descriptor for the quadcopter.

The section on military and civilian uses of quadcopters revealed that there are far more civilian applications than military ones. I also discussed some legalities that you should be aware of and obey as required.

The Elev-8 quadcopter kit origins began when the Hoverfly Company used the Parallax Propeller chip in the design of their flight controllers. The president of Parallax decided to create a parts kit, including a Hoverfly control board that would enable users to build their own highly capable quadcopter at a reasonable cost. Remarkably, there are only 11 main electrical/electronic components that make up the basic Elev-8.

I finished the chapter by showing some of the add-ons and enhancements that can be incorporated into the basic Elev-8. A real-time video add-on will also be discussed in detail in a later chapter.

Chapter 2 provides a thorough discussion of the quadcopter flight dynamics. I strongly urge you to carefully study the next chapter in order to achieve a good understanding of the physics that allows a quadcopter to fly. This knowledge will improve your control skills. Additionally, a good understanding of the basics of quadcopter control will also help you to create your own software, if you are so inclined.