Multi-rotor mania!

Multicopters have enjoyed an unprecedented burst in popularity in recent years, not only for recreational purposes but also for commercial and military applications. From search & rescue to TV, film and even managing livestock. It's a diverse aerial platform that can be used for almost anything.

From quadcopter to dodecacopter, multicopters offer a different flying experience. As a commercial film and TV pilot, Shahid Banglawala should know!

FORMAT

In a nutshell, multicopters are vertical take-off and landing (VTOL) aircraft that use multiple motors and propellers to provide thrust and manoeuvrability. They come in all shapes and sizes, from the typical four-motor quadcopter to huge octocopters or even dodecacopters (12 motors), and cost from as little as £30, which is the asking price for a Hubsan X4 ready-to-fly quadrotor that fits in the palm of your hand and can be flown around your living room. At the other end of the spectrum you'll find professional machines used for filming feature films and TV programs that measure over a metre across and cost in excess of £10,000. Beyond these, there's even been a full-size manned multicopter! My interest in this field is more than hobby-based as I design, build and operate multicopters that capture aerial video for film and TV. I have, therefore, become somewhat involved with them and have begun to understand how they can provide a real advantage in my field. More on that later, but first let's take a look at some of the reasons why multicopters have taken off (pun intended!).

ADVANTAGE

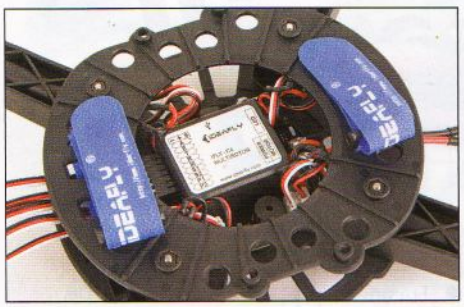
What makes multicopters appealing is their simplicity. No matter how big or complex a multicopter looks, the only moving parts are the motors and propellers (excluding any specialist equipment that may be fitted, such as a gimbal for carrying a camera, or retracts).

What you have is a machine capable of vertical take-off and landing, but without the mechanical complexity of a helicopter. There are no swash plates, ball links, belts, torque tubes or servos to install and set up, so in theory there's less to go wrong. Multicopters are also generally quieter as there are no big helicopter blades spinning around or tail belts and gears whirring away, which means that they're less intimidating. And as a multicopter uses multiple propellers instead of one big rotor blade, there's less energy in each rotor so the damage to persons or property in the event of contact can be reduced. It doesn't stop there: Thanks to the lack of moving parts, multicopters are smooth with low vibration levels, making them ideal for carrying cameras.

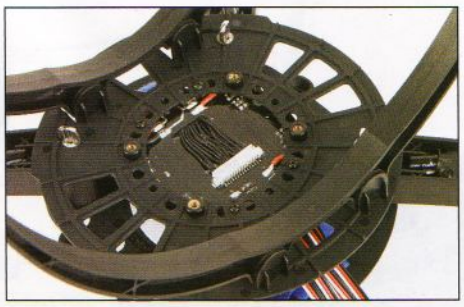
Multicopters with six or more motors offer redundancy, so theoretically if a motor or propeller fails, the craft can still fly safely. Lose a rotor blade on a helicopter and you've had it! These machines have a simple layout, so they're easy and quick to make from a range of materials.

Even at this end of the spectrum, RTF quadcopters like this Twister are clever little machines.

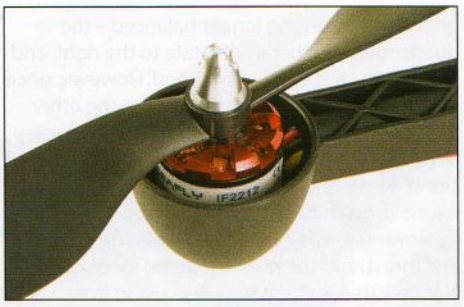
words » **Shahid Banglawala** | photos » **David Ashby & Shahid Banglawala**



A step up from the introductory level machines, this iFly4 provides the power to carry a camera.



The iFly4 is an RTF machine requiring only your Rx and 3s Li-Po battery.



Cups protect the outrunners from ground strikes.

The large legs provide clearance for the camera harness and, of course, the low C of G aids stability.

All you need is something to mount the radio equipment on and a few booms sticking out for the motors to sit on. I've seen frames made from fibreglass, metal, plastic, carbon fibre and even wood. My partner in crime, Simon Mills, built the frame for his first quadcopter from aluminium channel and fibreglass board for around £15, and it was pretty much indestructible, too. Don't be fooled into thinking a cheap frame like this won't perform as well as a carbon job. Far from it, Simon's custom frame was very stiff (exactly the property a good quality frame should have), more durable and cheaper to repair than a posh alternative.

FUNCTION

So, how do these weird-looking things actually work? The secret is in the multiple rotors (I term the combination of a motor and propeller a 'rotor'). Quadcopters are the simplest and most common configuration of multicopter, so we'll see how one functions.

Let's first label the motors from 1 to 4. Motors 1 and 3 rotate anti-clockwise, whilst motors 2 and 4 rotate clockwise (I'll explain why later). To take off, all four rotors speed up in unison, and as the propellers turn faster and generate thrust, the machine lifts into the air. Simple! To descend, the opposite occurs; the rotors slow down, less thrust is generated and, thanks to gravity, the aircraft descends back down to earth. That's simple enough, but what about pitch, roll and yaw?

Control of a quadcopter is achieved by changing the rpm of a single rotor independently of the others, altering both the thrust and torque reaction of that rotor and hence manoeuvring the aircraft. Sounds tricky, but it's actually quite straightforward.

I mentioned above that the motors don't all rotate the same way; the fact that two turn clockwise and the other two anti-clockwise ensures that the aircraft doesn't yaw as the opposing directions of rotation cancel each other out. Isaac Newton's third law of motion applies here: 'For every action there is an opposite and equal reaction'. If you lean against a wall, you push on the wall and the wall pushes back at you. If we apply this to a quadcopter, if a rotor spins one way then it simultaneously tries to turn the quadcopter the other way; this is the 'torque reaction' of the rotor. So, by having two motors turning one way and two the other, the combined torque reactions of all the rotors cancel out and the quadcopter doesn't rotate. The faster a rotor turns, the greater the torque reaction – see Figure 1 (page 18).

PITCH AND ROLL

Okay, so now we know how to control altitude and why multirotors use motors that rotate in both directions. Let's move on to controlling pitch and roll.

We'll assume rotor 1 represents the quadcopter's nose. In order to pitch the nose down, rotor 3 accelerates and rotor 1 decelerates, causing a thrust imbalance that will tilt the quadrotor forward. Conversely, if rotor 1 decelerates and rotor 3 accelerates, the machine will tilt back.

Roll control is pretty much the same; to roll to the left, rotor 2 accelerates and rotor 4 decelerates, and vice versa to roll to the right.

So, in pitch and roll, the acceleration / deceleration relationship between rotors keeps the torque in balance and prevents yaw.

YAW

In order to yaw, our quadcopter requires an imbalance of torque. To yaw to the right, accelerate rotors 1 and 3. As these are both turning anti-clockwise they generate a torque reaction that's trying to turn the machine to the right. And because they're spinning faster than the other two rotors the overall torque

DJI's Phantom is another plug 'n' play offering that's ready for your GoPro camera.

on the machine is no longer balanced – the quadcopter will therefore rotate to the right, and yaw control has been established. However, since rotors 1 and 3 are turning faster than the other two, this torque imbalance also brings an excess of thrust and would cause the quadcopter to climb. As we only want to yaw and not climb, the excess thrust has to be negated. This is achieved by slowing rotors 2 and 4. They then generate less thrust, and the quadcopter no longer climbs. Not only that, but the torque reaction from 2 and 4 (which was trying to turn the machine left) has also reduced; this adds to the right yaw that we want, so that's a bonus! To yaw to the left, simply do the opposite, i.e. accelerate rotors 2 and 4 and decelerate 1 and 3 – see Fig.2.

That's the basic motions covered, but what if we want to do something more complex such as yaw whilst climbing, or roll whilst flying forward? This requires complex mixing of the individual rotor speeds which, thankfully, is sorted out for you by a clever box of electronics called a flight controller. Flying a multicopter is very similar to flying a helicopter in that you tilt the aircraft in the desired direction of flight and use the rudder stick to point the nose where you want it to go.

Though the above describes how a quadcopter works, hexactopers, octocopters and almost every other type of multicopter work in the same way, although with six or more rotors, multiple rotors carry out the pitch and roll functions rather than just one.

ODDS OUT

The reason you never see multicopters with an odd number of rotors is because the torque reaction wouldn't cancel out, and the machine would rotate. There is an exception to this, however: the tricopter! As the name suggests this uses 3 rotors, plus a servo to tilt one of the rotors to achieve yaw control.

BREAKDOWN

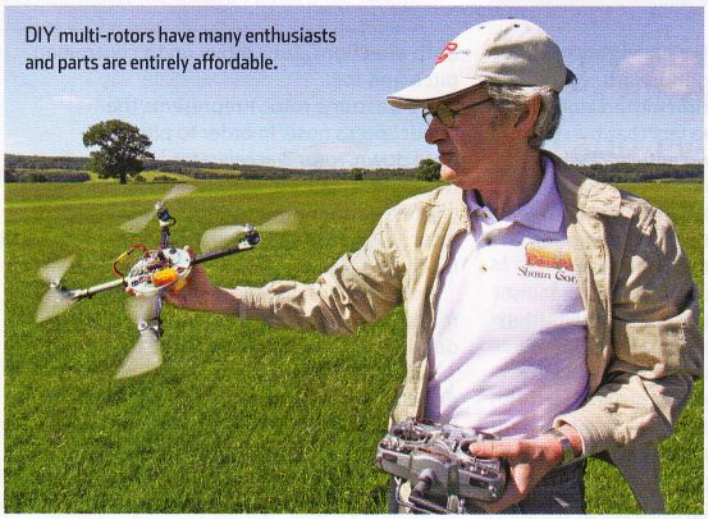
The main components required to assemble a multicopter are as follows:

- Frame
- Motors
- Speed controllers (ESCs)
- Propellers (tractor and pusher)
- Flight controller
- Battery
- Receiver
- LED lights for orientation (optional)

Each motor has its own ESC, each of which needs to be wired up to the battery. The signal wires from the ESCs plug into the flight controller along with connections from the Rx. Fig. 3 shows the arrangement. Okay, let's take a closer look at some of the components.

FRAME

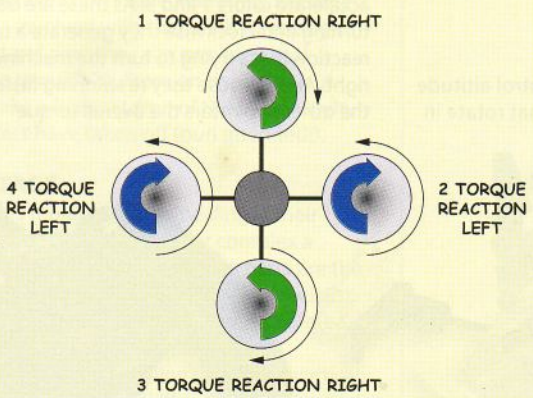
The frame forms the foundation of a multicopter and is what all the other equipment is bolted to. The main requirement is that



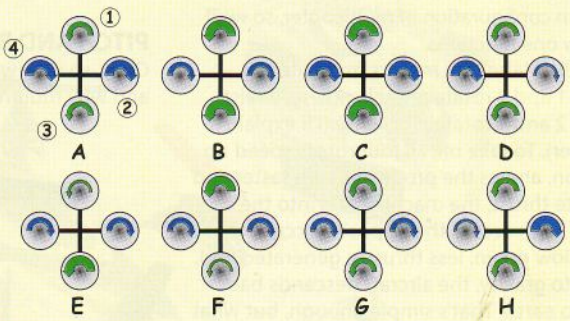
DIY multi-rotors have many enthusiasts and parts are entirely affordable.

My latest build, a Y6 machine, Y6 denoting frame shape and motor count.

Fig.1

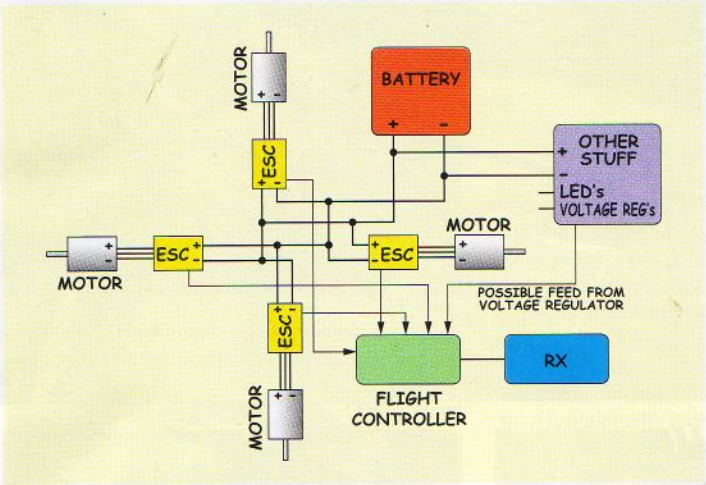


IN A STEADY HOVER ALL TORQUES ARE BALANCED



A	YAW LEFT	E	PITCH NOSE DOWN
B	YAW RIGHT	F	PITCH NOSE UP
C	TAKE OFF	G	LAND
D	ROLL RIGHT	H	ROLL LEFT

Fig.2



it should be stiff, since any flex could cause control issues. There are lots of frames available commercially, some are made from plastic, others from a mixture of metal and fibreglass, and a couple of examples are made from wood.

A frame is made up of centre plate(s) and booms. The centre plates are typically where the R/C gear and flight battery are located, and are often stacked on top of one another. For example, one plate would host all the ESCs, a second plate the flight controller, and so on. This helps to keep things neat and can offer some protection to the components in the event of a crash. Other items are sometimes mounted on the booms, such as a magnetic compass or GPS receiver.

To begin with, I'd recommend you get a cheap, readily available frame like a DJI Flamewheel. Or, if you prefer a more DIY approach, nip down to your nearest hardware shop, grab some aluminium channel or square section for the booms plus some fibreglass sheet or similar for the centre plates, and get crafting.

Carbon fibre a-plenty is used on professional aerial filming rigs and the like, and is used extensively in such multicopters because of its stiffness, low weight and appearance. But it's not the 'be all and end all'; just like Simon Mills' example mentioned earlier, you can make a frame that's equally as stiff from other materials. Carbon isn't cheap in a crash! That said, if you do fancy a carbon frame, be wary of vastly overpriced suppliers. CarbonCore (www.carboncore.co.uk) does a great range of all-carbon frames at reasonable prices.

Lights are essential to aid orientation.

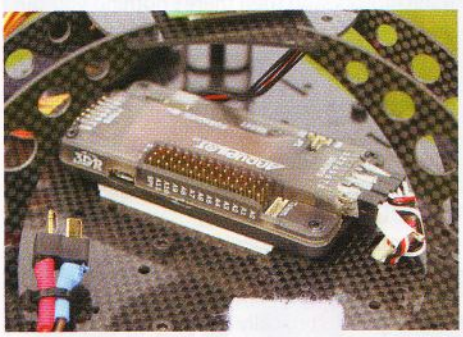
MOTORS

Picking out a motor for a multicopter is the same as picking out a motor for any other electric-powered model aircraft and it goes without saying that your choice needs to be of good quality. I use AXi motors, have done so for a number of years, and I've never had one fail.

Some brands offer multicopter-specific motors – not that there's anything fancy or special about their internals. Generally speaking, the key difference is usually that the shaft comes out of one side only, and the wires are quite long in order to travel along the booms and reach the speed controllers. Wires on AXi multicopter motors, for example, are 700mm long. To select the right size of motor for your frame, the best approach is to see what others are using and go from there, or you could use an online calculator (such as www.ecalc.ch) to get you in the right ballpark.

ELECTRONIC SPEED CONTROLLERS

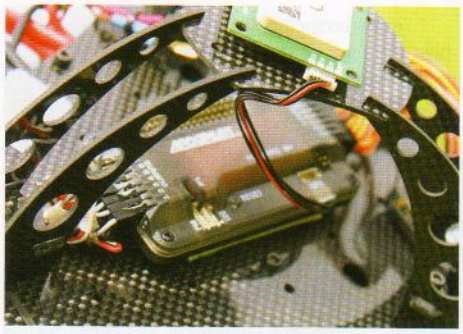
A curious fact is that in the early days of multicopters, the cheap ESCs that poured out of China were preferred for use rather than established premium brands. This was because these cheapies had a much faster update rate, sending more signals per second to the motors. The motors, therefore, reacted faster and the multicopter flew better as a result. This isn't the case nowadays as some big names, such



The flight controller is the brain, this unit by Arducopter.

Low pitch props (such as these 14 x 4.5s) are required as they generate more thrust at low airspeeds.

Early flights with my Y6 have been positive although its payload carrying ability has yet to be explored.



Carbon frame components are available off-the-shelf.

as Castle Creations and Jeti, have wised up and are now manufacturing ESCs that are more multicopter-friendly.

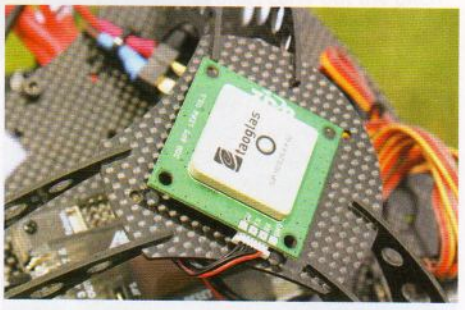
A good refresh rate is what's needed, with 400Hz being the benchmark. If you don't fancy a Castle or Jeti controller, then check out ZTW, Hobbywing or Turnigy Plush controllers, all of which have been used in multicopters with good results. There are plenty of suppliers on eBay, too; type 'multicopter ESC' into the search bar and there's a good choice to be had.

A rather smart chap known as 'SimonK' designed some excellent firmware specifically for multicopter use, however loading this onto ESCs meant using fiddly jumper pins. Thankfully you can now buy a range of ESCs with the SimonK firmware already installed, and I've had good results with Proflight UK SimonK controllers from www.proflightuk.co.uk.

Something to bear in mind when programming ESCs for multicopter use is that if the motors stop then there's nothing you can do to save the model, so many people disable the brake and turn the low voltage cut-off right down or remove it altogether. It's a good idea to use a timer, standalone battery alarm or some form of telemetry to ensure the battery doesn't get run down too low.

PROPELLERS

Since multicopters spend a lot of time hovering and at low airspeeds, low pitch propellers are ideal, because they generate more thrust at low airspeed. I typically run propellers between 4 and 5" in pitch, sometimes slightly more or less, but I certainly don't run anything like 7 or 8" pitch. Some folk advise running higher pitch



The Y6's GPS unit means height and position can be held with no input from the pilot.

Good quality motors are essential. I've always used AXi and have never had one fail.

props because it aids stability, but I can't for the life of me see why.

Multicopters are sensitive to any vibration or imbalance, so prop balancing is very important indeed; don't neglect it! I balance both blades and hubs, and I also check blade tracking, i.e. checking that both blades are identical and not warped or twisted. Warping is more of a problem on plastic or nylon-based propellers (e.g. APC) and less of an issue on machined wooden props or good quality carbon examples.

There's no need to splash out crazy money on propellers, indeed I've used a variety of brands without any problems but none have been used without first being balanced and checked. Generally speaking, if you have two identical size props that are both balanced and true, but one is lighter than the other, the lighter prop is better suited to multicopter use. Because it's lighter the motor will be able to change speed quicker, which gives better response.

Don't forget, you need propellers for both clockwise and anti-clockwise (pusher and tractor) rotations and for this very reason some manufacturers and retailers sell propellers in pairs, one of each type.

FLIGHT CONTROLLER

The flight controller is the multicopter's brain, its most basic function being to take your commands and turn them into motion by sending signals to the appropriate motors. Those equipped with built-in accelerometers and gyroscopes can self-level the machine should you become disorientated, and by making use of compasses and GPS, height and position can be maintained with no input from the pilot. In fact on some systems you can create a flight plan on a laptop, click a button, and the multicopter will fly it all by itself!

A clever fail-safe feature found on most flight controllers equipped with GPS is that if the radio signal is lost, the aircraft will automatically fly back and land from where it took off. In fact, there are so many different functions available that I can't mention them all here. The range of capabilities offered by

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ESCs with a high refresh rate are essential although, surprisingly, they're often not the most expensive.

Costing some £20 – 30k, RED cameras are broadcast standard units worth more than the flying machine itself.

flight controllers is truly staggering, and new ones are being added all the time.

The most popular flight controller at the moment is produced by DJI and comes in two forms: the Naza-M, which is aimed more at hobbyists, and the Wookong-M, for professional use. Both carry out similar functions in terms of stabilising multirotors, GPS support etc., but the Wookong can be upgraded with extra features such as autonomous flight and ground station support. Whilst DJI units are renowned for their 'plug and play' capability, ease of use and minimal setup time, I felt the DJI WKM that I fitted to an octocopter didn't offer as much control over the settings as I'd have liked. I felt it could fly better if there was access to more tuning parameters.

I started looking around and came across Arducopter, an open-source project – in other words the flight controller software is available in its entirety for free, and it can be sourced from the internet. Anyone can see how it works and make changes, improvements and additions. Thus there are thousands of people around the world working together on Arducopter to continually develop it. All you have to do is purchase an Ardupilot Mega, which is the physical electronic board, and load the software on with a PC. Each software release is thoroughly tested to ensure there are no problems or software bugs.

Because so many people work on it, Arducopter offers quite possibly the biggest range of features of any of the flight controllers out there, and at a low price. It's safe to say the total functionality is greater than DJI has to offer.

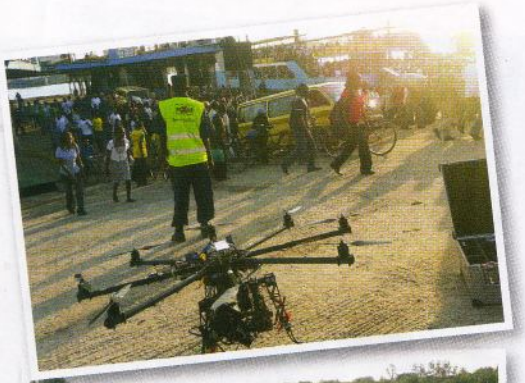
But wait a minute, if Arducopter is so good, why isn't everyone using it? Well, it requires more tuning and setup to get right, and if you've never tuned a multicopter before it can be pretty daunting. Thankfully there are lots of knowledgeable folk online and lots of good examples to help you along. However if you purchase a frame that's supported by Arducopter, such as the Arducopter 3DR kits, then you don't have to do any tuning as you can download pre-tuned settings off the internet.

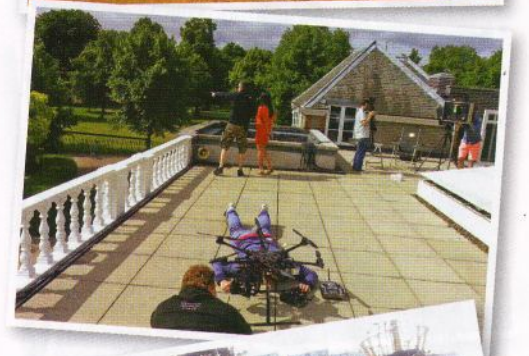
In the end I did manage to tune that octocopter to fly better than I could on DJI, however I'm still working on getting the advanced functionality, like the GPS mode, to work properly. With DJI they work straight out of the box.

Having experienced both DJI and Arducopter systems, which would I chose? It really depends on what you want to do. If you want to get up and flying in next-to-no time with something that'll likely work quite well, go the DJI route. On the other hand if you don't mind spending extra time tuning and tweaking and want to save some cash, go Arducopter. This is just my view, though; I strongly suggest you research both thoroughly before taking the plunge.

Use strong, double-sided foam tape when mounting a flight controller to a frame, as this will help isolate the controller from airframe vibrations. Excessive vibrations can cause the controller to become confused, with poor control or even a crash being the end result.

My Y6 should be able to carry a good DSLR and camera mount aloft.





In 55-degree temperatures, desert filming in Dubai last month revealed one weakness in that the picture transmitters overheated! ESCs etc. were fine.

There are a whole host of other flight controllers out there, which all vary in their plug and play capability, setup times, overall capability and costs. I've not tried them personally, but KK Multicopter, XAircraft, MultiWii, Mikrokopter, Zero UAV, Hoverfly and Rabbit are all worth looking at.

LED LIGHTS

It's quite common to see LED strip lights fitted to multicopters to help with orientation. Green LEDs on the forward boom and red on the rear boom are especially useful when flying something with a high 'arm' count, such as an octocopter. Other orientation aids used by some include fitting flags, or attaching bright tape to the booms.

PROFESSIONAL AERIAL FILMING

Earlier on I mentioned my aerial filming involvement within the film and TV industry using multicopters. I use a variety of frames for this, typically octocopters and hexacopters ranging from 800mm to 1250mm diameter. Octos and hex' are favoured because they have the lifting power to carry a camera and offer some redundancy should a motor fail. No-one wants to put an expensive camera into the sky without some sort of backup!

You can't just grab a multicopter and start charging people for aerial filming, however – that's illegal. I had to first get a special BNUC-S license, which allows the holder to operate unmanned systems up to 20kg for commercial gain. I then had to get permission to operate from the Civil Aviation Authority, who looked at how I would conduct my flying operations with regard to safety. With all this to hand I then had to arrange third party insurance, specifically designed for those carrying out aerial photography.

To date I've worked on TV programmes such as Restoration Home and Grand Designs, and I've also worked on commercial and promotional videos, too. It's not as glamorous as it seems, though; many-a time I've been stuck in a muddy field in the middle of nowhere! Oh, and I've not been involved with any big Hollywood blockbusters yet, but I'm working on it!

The sort of camera used depends on the client. For example on Restoration Home, a Panasonic GH3 was preferred. Essentially a stills camera it's also capable of producing excellent quality HD video that's suitable for broadcast. Some jobs require a much more comprehensive camera

Pictures are transmitted via video downlink.

such as the Red Epic, a full-on professional camera costing around £30,000! For that I use a very powerful octocopter that can lift payloads up to around 7kg. The octo alone weighs 7kg, so that's a total of 14kg in the air.

The cameras are attached to a specialised gimbal that contains accelerometers and gyros. The gimbal keeps the camera perfectly still and pointed in the same direction no matter what the aircraft does and is controlled by a transmitter; the camera operator can see what the camera sees on a screen that's connected to a special video downlink.

I work with professional camera operators, and it makes all the difference. Anyone with the cash could buy a professional aerial filming rig with a fancy camera, but if they don't know proper camera technique then it's pointless; all the director or producer is interested in is the quality of the shot.

A typical day 'on set' will start with the producer or director, the camera operator and myself surveying the site. I'll identify any obstacles or issues that may arise from flying, and make abundantly clear anything that I can or cannot do. As a pilot, it's imperative not to feel pressured into doing something that's dangerous or you're not comfortable with.