March 9th 2011/Leif Nygaard Eilertsen
Version 1.0

DESCRIPTION OF A MULTICOPTER FOR 360° PANORAMA PHOTOGRAPHY

This description is used for the construction of a multicopter for 360° panorama (spherical panorama) and video photography. The multicopter (a remote controlled helicopter with 6 or 8 arms) will be equipped with a special, remote controlled gimbal on which a digital camera will be mounted.

Panorama by Jakub Jewula (www.kkmulticopter.com)

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1 INTRODUCTION

After collecting a lot of information from various sources, I have settled on a hexacopter design – a helicopter with 6 propellers.

Jakub Jewula from KKMultiCopter told me the secret of safe flying: Redundancy. A hexacopter will offer a balance between complexity and safety (the choice was between quad-, hexa- and octocopters). The key principle is: *More and smaller motors equal higher redundancy*. The multicopter should be able to land safely even if a motor or propeller fails.

Other benefits are lower thrust per motor, even at higher payloads, resulting in less vibration. In this case the payload needs to be more than 1500 grams in order to carry my current Nikon DSLR.

Let's get the show on the road with some examples.

Left to right: Hexacopter from Jakub (Poland). Kestrel 3 hexacopter. Complete frame from Mikrocopter.de.

1.1 Appendices

The shopping list and payload/flying-time calculator is attached as separate Excel spreadsheets.

2 ABOUT PANORAMA PHOTOGRAPHY

2.1 Equipment

I use a DSLR for both panorama and video photography – being a gigapixel fanatic. My current panorama setup is a *Nikon D90* with a *Nikkor 10.5mm fish-eye lens*. The Nikon 12.3 Mp. sensor results in panoramas with a resolution up to 12.000 x 6.000 pixels – and video in 720p (1280 x 720 pixels).

In the near future I plan to replace the Nikon D90 body for the newer Nikon D7000 with a 16 Mp. sensor and 1080p video.

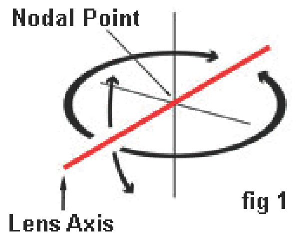
2.2 The work process

Spherical panoramas are made by taking a number of overlapping photographs. My current setup (Nikon D90) require that I take 6 photos at 60° intervals, then a photo of the Zenith (up) and finally a photo of the Nadir (down).

These photographs are stitched using special stitching software (*Autopano Giga*, *PTGui* or *Hugin*), which will result in a panorama giving the illusion of standing inside a sphere when displayed using an Adobe Flash-based viewer (in this case the *KrPano* viewer).

2.3 Fundamental requirements

An absolutely vital requirement in order to make a spherical panorama is that the lens rotates exactly around the "*nodal point*". Nothing is more important!



The nodal point is the point, where light breaks inside the lens – not the front glass; not the center of the camera. Exactly at the middle axis of the lens where the light breaks.

This point can be difficult to determine. Consequently, the gimbal must be equipped with various adjustments in the X- and Y-axis.

A gimbal must ensure 2 things:

1. Allow the camera to be positioned with the nodal point at the point of rotation vertically and horizontally.
2. Allow the camera to rotate around the nodal point.

On a Nikkor 10,5mm fish-eye lens the nodal point is located at the golden ring close to the front lens. But adjustment must be possible if I buy another lens.

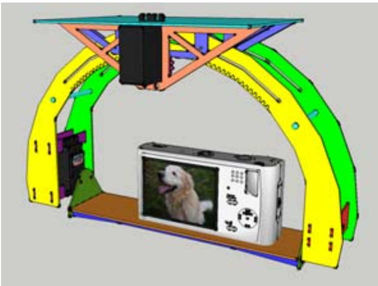
2.4 Aerial photography requirements

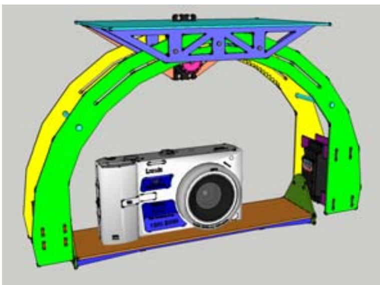
The gimbal will be mounted on a multicopter. The camera can be triggered remotely, either by a separate wireless camera trigger or integrated into the remote flight control. The last solution is the best, as it will reduce the number of gadgets to handle while flying. However it will require a more expensive remote control, probably with 6 or 7 channels.

A special problem is how to rotate the gimbal. The gimbal must have built-in servo motors in order to be able to rotate around 2 axes.
Drawings or photos can be found on the Internet.

Another problem is vibration. The gimbal must have some form of vibration reduction.

The photo to the left shows one solution on how to mount the camera in portrait position for spherical panorama photography.





The diagrams at the right (made with Google Sketchup) show the principle, but the design must be improved.

The construction of a gimbal is a minor concern. Let’s build the multicopter first.

3 PROJECT GOALS

The project goals are the driving factors behind the design, and fall into two groups. The first group is a list of qualitative goals (that can be observed) and are integral to the functionality of the system. The second group is a list of quantitative goals (that can be measured) and optimized to improve the performance of the system.

3.1 Qualitative goals

The first major qualitative goal is to achieve autonomous hover. This goal is clearly satisfying the main characteristic of the hexacopter. Without autonomous hover, the purpose of creating such a design is irrelevant and all subsequent goals are unimportant.

The second qualitative goal is to provide full 3-axes maneuverability. By satisfying this goal, full spatial control can be provided within a set flight area. The 3 axes specified are two axes of horizontal translation and one axes of vertical translation. This goal also include being able to control the angle with respect to the horizontal plane for the purpose of commanding and controlling horizontal translation of the system.

The third goal is to provide an adaptable design. This will allow design changes to be made late during development of the prototype and help with optimizing the length of the arms on the hexacopter.

3.2 Quantitative goals

The first quantitative goal with a measurable outcome is the size and weight restrictions. A size limitation of 65 cm. x 65 cm. is imposed, primarily due to lack of experience with aerial photography and R/C flying. The second limitation is a weight restriction, where a maximum weight (hardware and payload) of 2 kg. is set as a design criteria for selection of motors and propellers.

The second quantitative goal is to model and simulate the flight of the hexacopter. This goal will involve an iterative process geared towards constantly adding complexity to a simplified model until a solution is eventually converged upon. An accurate yet efficient model is also important for testing the controller gains and the usefulness of the sensor feedback.

The next quantitative goal is to minimize sensor noise. This goal is necessary for the formulation of an accurate model for simulation and for providing a clear and filtered signal for the controller.

The last quantitative goal is to design a system and controller that would achieve a fast settling time (time from start until stable flight). An appropriate settling time will be less than 5 seconds.

4 REQUIREMENT SPECIFICATION

4.1 Fundamental requirements

#	Requirement	Description
1	Payload	Payload must not be below 1.4 kg. - calculated as camera with lens, gimbal, battery and landing gear. Weight of camera and lens: 700 + 300 grams. Weight of gimbal: 400 grams (depending on servos and material).
2	Size	The diameter should be 620-720 mm. – measured between 2 motors mounted opposite each other (2-motor diameter).
3	Weight	The weight of the airframe must be below 400 gram, without battery, landing gear and photo equipment. Total weight including battery, motors, propellers and electronic must be appr. 1.5 kg.
4	Materials	Preferably reinforced glass fiber. Aluminium is an alternative. Steel, plastic and carbon fiber is not a solution due to either weight, lack of strength or price.
5	Transport	The multicopter must be compact since it probably will be transported on my bicycle. The arms should preferably be able to rotate or be taken off.  The solution shown in the photo will add complexity and is not. Jakub's SexyCopter is not foldable and must be changed to use a quick-release plastic bolt.
6	Noise	The multicopter should be silent (no need to scare anyone or make them look up).

4.2 Multicopter

#	Requirement	Description
1	Simplicity	The multicopter must be easy to maintain (as few parts as possible).
2	Least amount of fabrication	The parts should be off-the-shelf – for example 10x10mm aluminium square tubes or prefabricated reinforced glass fiber.
3	Lowest price	Off-the-shelf parts readily available.
4	Position	The multicopter must be able to maintain its position with ease along all 3 axes (height, sideways, forward/backward) as well as pitch, yaw and roll.
5	Motors	Brushless motors must fit the purpose. There are differences between using a motor for aerial photography and aerobatics. Motors below 1000kV are recommended for aerial photography due to the slower RPM giving less vibration. A comparison chart can be found below.

#	Requirement	Description
6	ESC	The Electronic Speed Controllers must match the Amp requirements of the motors. A 25 Amp ESC is recommended for heavy-duty use with 10 inch propellers.
7	Propellers	 APC1047 Counter Rotating Propellers. Should be 8x3.8 or 10x4.7 inch Slow Flyer. Larger propellers will result in wobbling.
		 EPP1045 Counter Rotating Propellers.
8	Flight Controller	 An electronic flight controller is required in order to control the motors as well as keeping the multicopter level during flight. The Spectrum DX8 seen here is reasonably cheap and can be used for several models. Price: 2850 DKR in Holte Modelhobby.
9	Battery	The Zippy FlightMax 3 cell (11.1V, 20C, 4000mAh) seems to be the preferred choice by many due to the high output.
10	Battery Alarm	 A Lipo Battery Low Voltage alarm in order to avoid unnecessary crashes due to a exhausted battery. Can be purchased on eBay or HobbyKing for 3-5 US$.
11	Landing gear	The gimbal must be mounted below the multicopter. This requires a landing gear with sufficient height and suspension. Examples of landing gears with gimbals:   
12	Protection	The motors and electronic parts should be protected (taking the added weight into account). An example can be seen in the photo of Jakub's SexyCopter.
13	Charger	Charger with balancer.

4.3 Gimbal and photo equipment

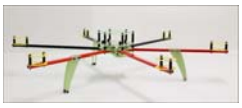
#	Requirement	Description

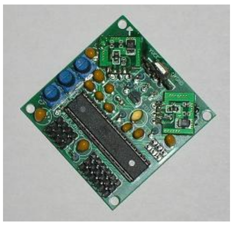
#	Requirement	Description
1	Camera	 Current camera: Nikon D90 (with battery grip).
		 Probable upgrade of my current Nikon D90 to Nikon D7000 with a 16.2 Megapixel sensor. Weight: 774 grams (with battery and sd card).
		 Panasonic Lumix DMC-FX700 have Full HD and a 14.1 Megapixel sensor. Seen at Amazon and B&H at 334 US$. Weight: ???
2	Horizontal rotation:	360° (all the way) at 10° intervals.
3	Vertical rotation:	180° (from Zenith to Nadir) at 10° intervals. This requirement is unrealistic. A photo taken at Zenith will photograph the bottom of the multicopter.
4	Position:	 The camera must be mounted vertically (portrait position) while photographing panoramas.  The camera must be mounted horizontally when recording video.
5	Vibration	The gimbal must be attached using some form of suspension in order to reduce vibration.
6	Dimensions	Dimensions of a Nikon D90 camera are: Height: 77mm. Width: 132mm Depth: 103mm (with lens?)

5 PARTS LIST

5.1 Multicopter key parts (need to have)

Purchased items are enhanced in **bold** letters with green background color.

Item	Pcs.	Image	Description
Remote Control	1		The type of remote control must be determined when I know more about the number of channels required. Spectrum DX8 with AR6200 receiver (7-channel) can be found at Holte Modelhobby for 2.850 DKR.
Motors	6		Turnigy 2217 20turn 860kv. Weight 71 grams.
Propeller	3		Clockwise. GWS 10x3.7 propeller, priced at 9 US$ for 6 propellers at TowerHobbies.
Propeller, pusher	3		Counter-clockwise
ESC	6		Turnigy Plush 25 Amp (12 US$ at HobbyKing).
Airframe	1		The Jakub SexyCopter v2 (released November 2010). The landing gear needs to be replaced, but it will do while learning to fly.
Battery	2		Zippy FlightMax 3 cell (11.1V, 20C, 4000mAh). Price: 20 US$ at HobbyKing. *Consider a 4 cell battery for longer flights (will increase weight).*
Battery Monitor	1		Low battery battery monitor. Must be loud. HobbyKing, price 4 US$.
Shield	1		For protection of electronics (must fit the chosen center plate).
Charger	1		Turnigy Accucel-6 50W 5A Balancer/Charger. Price: 25 US$ at HobbyKing.

Item	Pcs.	Image	Description
Electronic Flight Controller	1		Jakub's KK Multicontroller flight controller with 3 built-in gyros. Price 100 US$ from the classified section at www.kkmulticopter.com.
Bolts etc.			3mm bullit connectors. Preferably in plastic (due to weight concern)
Cables			18 gauge wire.
			Servo extension cables (female to female).
Protection (landing gear)	1		

5.2 Multicopter supplementary (nice-to-have)

Item	Pcs.	Image	Description
Motors	2		Turnigy 2217 20turn 860kv. Weight 71 grams.
Propellers (cw)	5		
Propellers (ccw)	5		
ESC	1		Turnigy Plush 25 Amp
Battery	2		Zippy FlightMax 3 cell (11.1V, 20C, 4000mAh).
Lights	1		Recommended for easier detection of the multicopter (in the dark).
GPS	1		While it would be nice to have a GPS, it is not necessary in order to achieve a stable flight.

5.3 Gimbal key parts (need-to-have)

Item	Pcs.	Image	Description
Gimbal	1		ALware 3-axis gyro stand for Gaui 330X quadkopter. Maximum camera dimensions: 60x110x50mm (HxLxW).

6 CONSTRUCTION

6.1 Calculation of maximum payload

A payload calculator can be found in a separate Excel spreadsheet.

6.2 Calculation of flying time

A flying time calculator can be found in a separate Excel spreadsheet. Flying time will depend on weight, engine thrust and battery power. A spreadsheet is included.

6.3 Motor Comparison Chart

The following information is used to determine the type of motor. Key Performance Indicators for aeriel photography are low thrust. Motor thrust and propeller size/pitch must be taken into account. The table is sorted by Kv.

Photo	Description	Weight (gr)	Volt	Kv RPM/V	Thrust
	KDA 20-22L.			?	
	The Emax 2830-14 motor is recommended by Jakub forum users for aerial photography, but does not take the high payload into account.	52	11.1V (3S)	750	
	Turnigy 2217 20turn, priced at 14 US$ at HobbyKing.	71	11	860	
	BP A2217-9 950kv motor, described as heavy-duty, priced at 21 US$ at TowerHobbies.	73,4	?	950	550? 30 g/oz
	Turnigy 2217 16turn 1050kv, priced at 14 US$ at HobbyKing.	71	?	1050	
	Turnigy 28-30-azj	57,9	14 (4S)	1100	
	The FC 28-22 motor will deliver higher thrust and is recommended for aerobatics by Jakub users.	39	11.1V (3S)	1200	

6.4 ESC Comparison Chart

Photo	Description	Weight (gr)	Cont. curr.	Max. curr.	Amp
	Turnigy Plush 10 Amp ESC	9	10A	12A	10
	Hobbywing Pentium 18 Amp ESC.	19	18A	22A	18
	Turnigy Plush 18 Amp ESC. User programmable.	19	18A	22A	18
	Turnigy Plush 25 Amp ESC. User programmable.	22	25A	35A	25

6.5 To Be Determined

- Protection of motors and landing gear like Jakub's QuadroKopter?

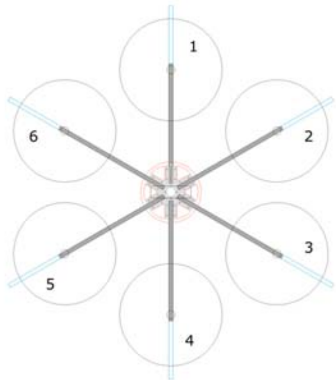
7 FUTURE PLANS

It would not be as difficult to build a multicopter from carbon fiber as I expected. The company DragonPlate can supply most items prefabricated.

The next step would be to build a carbon fiber octocopter.

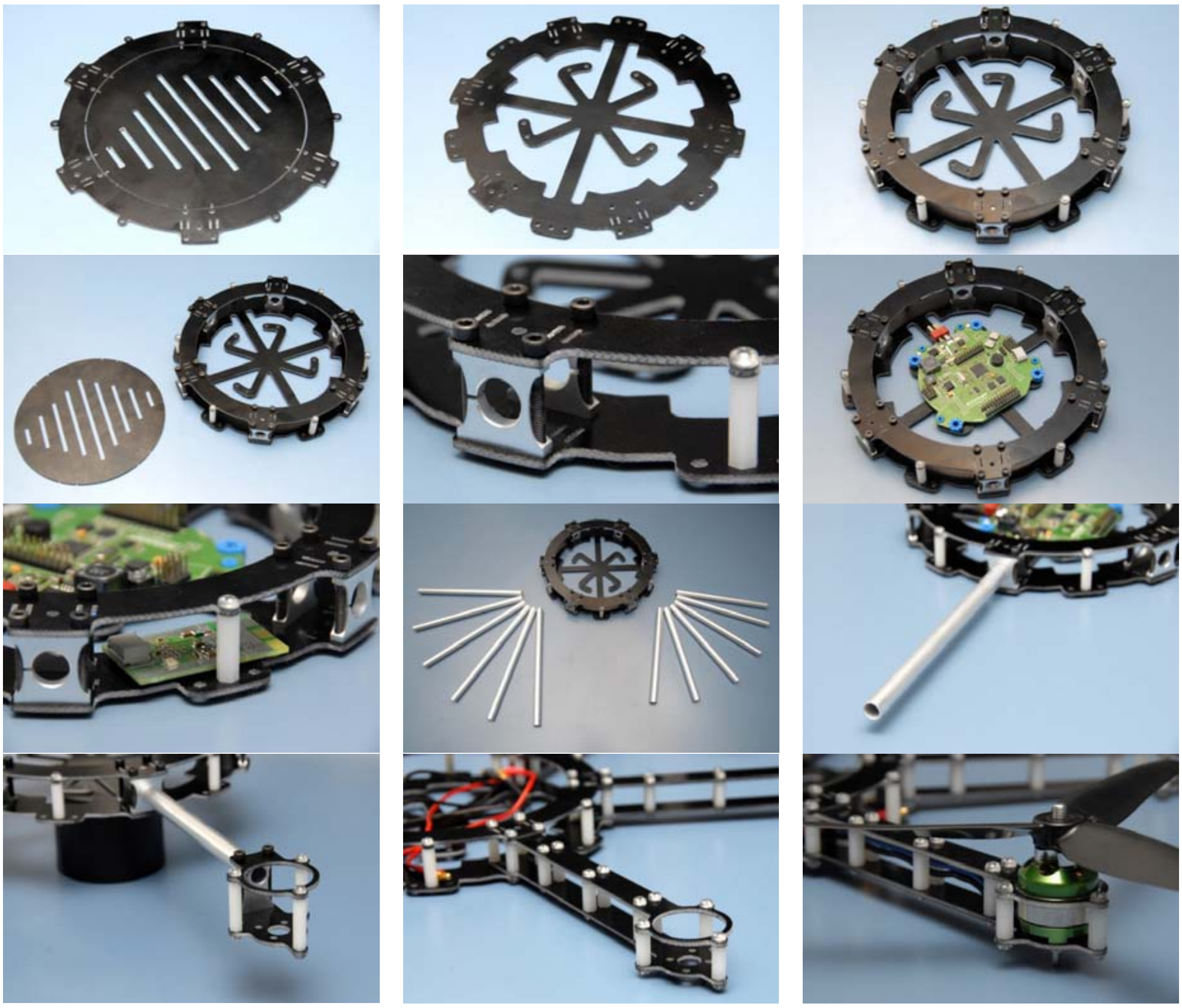
7.1 Homemade construction

The information here is kept for future reference only (if I decide to build a multicopter from scratch).

Item	Pcs.	Description
Construction diagrams		Diagrams are hard to come by. If they exist they must be found at forums like rcgroups. Other possibilities are at the designers sites such as www.mikrokopter.de.  
Center plates	2	If homemade, you will need at least 2 center plates for mounting arms and electronics (and a shield to match the size of the chosen center plates). Examples of center plates (left to right: Mikrokopter, KK Multicopter (Korea), Rusty's Rev-8 from AGL Hobbies). The most versatile seems to be the Rusty's Rev-8 kit allowing for up to 12 arms.   
Tubes		 Carbon fiber square and rounded tubes can be purchased from DragonPlate. The price for a ¾ inch tube is appr. 20 US$.

7.2 Polish hexacopter

The images below show a homemade hexacopter that seem promising – grabbed from a polish forum. The images are listed in sequence (left to right, top to bottom).



8 APPENDIX 1 - USEFUL LINKS

8.1 Shops etc.

Link	Description
www.hobbyking.com	One of the largest shops for RC equipment
www.holte-modelhobby.dk	Holte Modelhobby: The Danish specialist (with very decent prices inside EU).
www.kkmikrocopter.com	Jakub produces several frames and other equipment, but is probably best known for his KKMulticontroller (a flight controller with built-in gyro). Many parts require electronic expertise.
www.kkmikrocopter.kr	A Korean site with almost the same name as Jakub's original site, but no affiliation. The shop can be used for purchasing a number of parts. Beside parts they offer a lot of tutorials.
www.mikrocopter.de	A german site offering a lot of spare parts, among which some excellent center plates.
www.nghobbies.com	Canadian outlet for Mikrocopter parts.
www.photoshipone.com	PhotoShipOne offers a perfect gimbal in carbon fibre for 360° panoramas. However, the price is outside my price range: From 400 US$ for a 2-axis model to 1500 US$ for the top model VR360.
www.quadframe.com	Jakub's new commercial site.
www.readymaderc.com	ReadyMadeRC offer some complete FPV systems.
www.quadroufo.com	Specializes in quadcopter setups.

8.2 Clubs

Link	Description
www.aplanding.com	General forum for R/C aeroplane and helicopter hob-by.

9 APPENDIX 2 - GLOSSARY

Assorted

TBD: To Be Done (not determined; not decided).
G10: Epoxy reinforced glass fiber.
Payload: Lifting weight.
PCB: Printed Circuit Board.
UAW: Unmanned Airplane Weight.

9.1 Motors

Brushed motor

This is the original type of DC motor that used carbon brushes on a comutator – which produces a lot of sparks and is prone to make a lot of electric noise and wear out quickly.

These types of motors are very inefficient, typically in the region of 50-65 %. You can only use a brushed ESC with a brushed motor.

You can tell a brushed ESC from a brushless ESC as a brushed ESC has 2 wires in (normally one black and one red) and 2 wires to the motor (both are usually of the same color). The direction of rotation can be changed by swapping the wires on the motor.

Brushless motor

This is the modern type of electric motor. It doesn't use any brushes and consequently quieter electrically speaking. It is actually a 3 phase AC motor. Only a brushless ESC can be used to power this type of motor. A brushless ESC converts the DC voltage from the battery into 3 phase AC voltage.

Brushless ESC's can be identified by 2 wires in (normally one black and one red) and 3 wires that go to the motor (all 3 are normally the same color).

Brushless motors are a lot more efficient, generally in the range of 85-92 % which means that more of the power is converted into rotation and less into heat. This higher efficiency allows them to handle higher amps/power and have longer flight times. As the only moving parts are bearings, brushless motors are very reliable. The direction of rotation can be changed by swapping any 2 of the 3 wires to the motor. Brushless motors come in 2 types: Inrunners and Outrunners.

Brushless Inrunner motor

Inrunner motors are a type of brushless motor. The outer case is stationary and the central shaft spins. Inrunner motors are suited to high speed, low torque applications like high speed aircraft, EDF's, geared applications and helicopters.

Brushless Outrunner motor

Outrunner motors are some times referred to as "rotating can" motors. In this design the back part of the motor (where the wires come out) is stationary and the outer can and shaft rotates. Outrunners are suited to high torque, lower RPM applications like shocky's, park fliers, general sport and scale models. They throw large propellers at lower RPM which are a lot more efficient than smaller propellers at higher RPM's.

9.2 Propellers

10x4.7: Example of propeller syntax (a 10 inch propeller with 4.7 inch pitch).
CCW: Counter Clockwise.
CW: Clockwise.

9.3 Electronic Speed Controllers

Electronic Speed Controller (ESC)

An ESC is an Electronic Speed Controller. An ESC is placed between the battery and the electric motor with an additional wire to the throttle channel on the receiver. ESC's controls the speed of the electric motor.

ESC's come in two types: Brushed and brushless. A brushed ESC can only be used with a brushed motor – and a brushless ESC can only be used with a brushless motor. Additional circuitry in the ESC will cut power to the motor when the battery voltage drops to a preset level to stop damaging the battery.

BEC (UBEC, SBEC)

BEC is short for Battery Eliminator Circuit (UBEC: Universal BEC, SBEC: Switching BEC). The BEC part of an ESC is completely separate from the circuitry which controls the speed of your electric motor.

Contrary to popular belief it does NOT cut power to the motor when the battery voltage drops below a set level. Other circuitry within your ESC controls this function. The BEC's only job is to supply the receiver and servos with power which it converts from the battery that supplies your motor, eliminating the need for a separate battery to power your receiver and servos.

Your ESC may or may not have a BEC built in. It is best to check before hand to make sure and also check the maximum number of servos it can supply – to ensure you are not going to draw too much current and blow the BEC (this would cause a loss of power to your receiver and servos, which in turn would cause an expensive crash). If you don't trust your expensive model to a BEC then fit a separate receiver battery.

9.4 Electronics

Volts (V)

Volts are very important in electric flights as motors have a RPM per Volt figure. The more Volts the higher the RPM.

Amps (Ampere)

Ah: Ampere/hour.

Amps are also important in electric flight as we need to know how many Amps our electric motor is using. We need to make sure that our ESC, battery and motor can handle the current (expressed in Amps).

mAh

Short for Milli Amperes per Hour – mAh is a measure of storage capacity of batteries. 1000 mAh is equal to 1 Ah.

AC/DC

AC: Short for Alternating Current.
DC: Short for Direct Current.

Watts

Watts is the measurement of “Power”. Power is a function of Volts and Amps, i.e. Watts = Volts x Amps. Most motors have a maximum Watts rating.

9.5 Batteries

LiPo / Li-Poly / Lithium Polymer

This is a type of modern battery with a high voltage per cell. Nominal voltage is 3.7 Volts per cell. Maximum voltage is 4.2 Volts per cell. Minimum voltage per cell before serious damage results is 3.0 Volts per cell under load.

For the same physical size as NiCad’s or NiMi’s, LiPo cells have a h8igher voltage, larger storage capacity and are 30-50 % lighter. They are capable of delivering high power. On the down side, they are relatively fragile, cost more and can burst into fire if abused, damaged in a crash or over charged.

As they are a lot lighter, have a higher voltage and can store more energy they have transformed electric flight along with brushless motors.

Li-ion / Lithium Ion

This is another type of modern battery with a high voltage per cell. Nominal voltage is 3.6 per cell. Maximum charged voltage is 4.1 per cell. They do not have the storage capacity and density of LiPo cells and are heavier, but can resist a crash or two.

NiCd / Ni-Cad

NiCd’s – or to give them their full name Nickel-Cadmium – batteries have a nomimal voltage of 1.2V per cell. Ni-Cad is a trademark of the SAFT Corporation.

NiCd’s are heavy, have a low energy storage density compared to LiPo cells and suffer from memory effect. Due to the poisonous effect of Cadmium, NiCd cells are no longer manufactured within Europe and have been replaced by either Ni-MH, Li-ion or LiPo cells/batteries.

Ni-MH

Ni-MH (Nickel Metal Hybride) batteries have a nominal voltage of 1.2V per cell. Ni-MH’s are heavy, but have 2-3 times the energy storage capacity of Ni-Cd’s. Ni-MH’s do not suffer from memory effect.

9.6 Assorted abbreviations

RPM/V

Short for Revolutions per Minute per Volt, usually measured without any load. Also known as “kv”.

EDF

Short for Electric Ducted Fan. EDF’s are mini jets. They have an impeller (contained within the airframe) opposed to a propeller (on the outside of the airframe).

Shock Flyer (Shocky)

A small profile model normally flown indoors, but can be flown outside in very calm conditions.

Memory Effect

An effect that Ni-Cd (Nickel Cadmium) batteries suffer from. If Ni-Cd batteries are not fully discharged before recharging they will suffer from a reduced storage capacity.

Suppression Capacitators

These are fitted on brushed motors in order to reduce electrical noise generated by the brushes rubbing on the commutator of the motor. Brushless motors do not need capacitators.

Photography related abbreviations

DSLR:	Digital Single Lens Reflex (camera).
Gimbal:	Panorama head for mounting a camera.
Gp.:	Gigapixel.
Mp.:	Megapixel.

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