DIY Drone and Quadcopter Projects: A Collection of

From the Editors of Make:


Make:
DIY Drone and Quadcopter Projects
A Collection of Drone-Based Essays, Tutorials, and Projects
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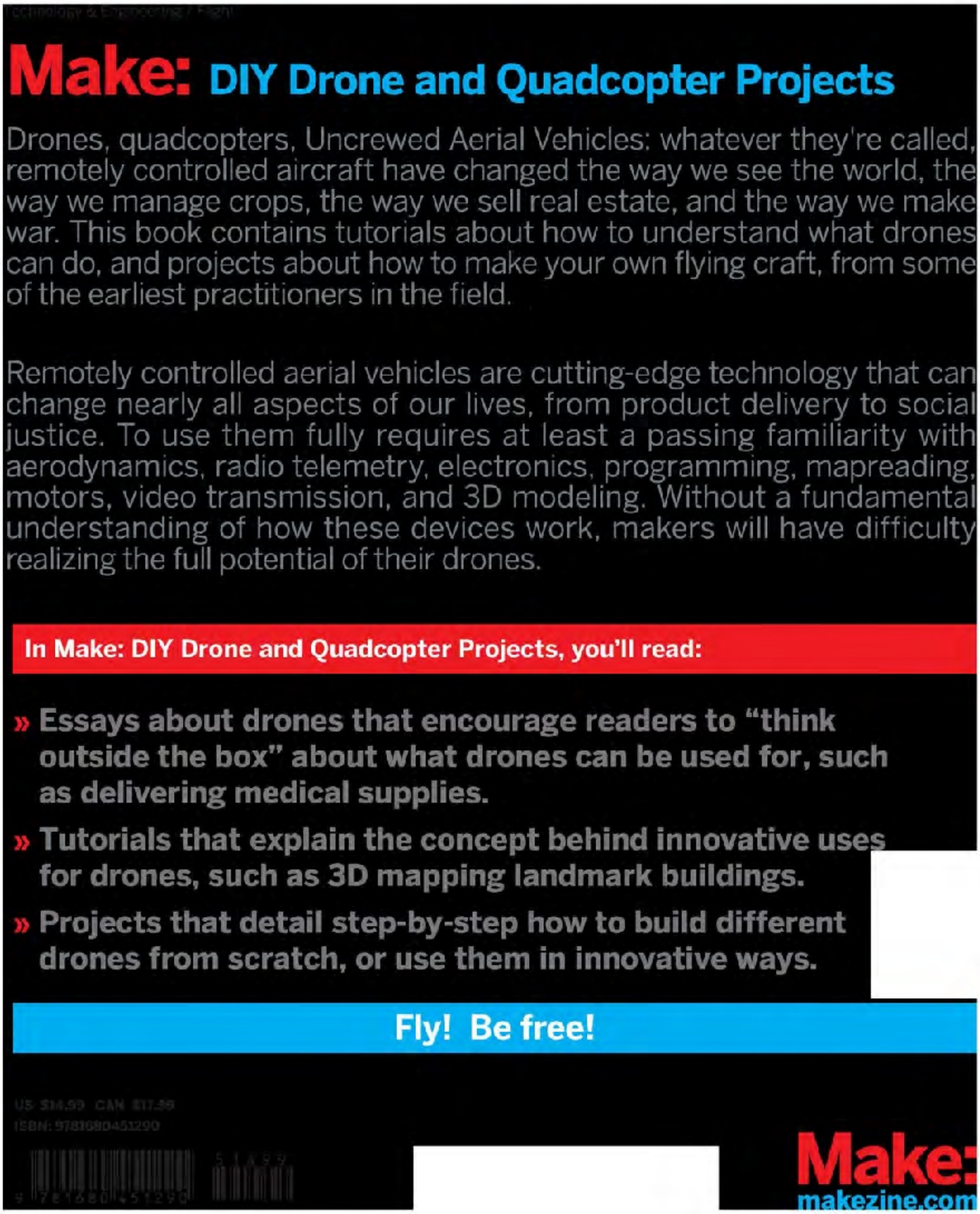
Technology & Engineering / Flight

Make: DIY Drone and Quadcopter Projects

Drones, quadcopters, Uncrewed Aerial Vehicles: whatever they're called, remotely controlled aircraft have changed the way we see the world, the way we manage crops, the way we sell real estate, and the way we make war. This book contains tutorials about how to understand what drones can do, and projects about how to make your own flying craft, from some of the earliest practitioners in the field.

Remotely controlled aerial vehicles are cutting-edge technology that can change nearly all aspects of our lives, from product delivery to social justice. To use them fully requires at least a passing familiarity with aerodynamics, radio telemetry, electronics, programming, mapreading, motors, video transmission, and 3D modeling. Without a fundamental understanding of how these devices work, makers will have difficulty realizing the full potential of their drones.

In Make: DIY Drone and Quadcopter Projects, you'll read:

- **Essays about drones that encourage readers to "think outside the box" about what drones can be used for, such as delivering medical supplies.**
- **Tutorials that explain the concept behind innovative uses for drones, such as 3D mapping landmark buildings.**
- **Projects that detail step-by-step how to build different drones from scratch, or use them in innovative ways.**

Fly! Be free!

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Quadcopter Projects

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Table of Contents

PART I

Features

The first section of the book is a collection of

frame to its propellers, from its battery to its

feature articles from the pages of *Make:*, provid—

brain. Subsequent articles look at how drones

ing an introduction to the world of drones:

work, the positive ways drones are being used

those autonomous aerial vehicles that mostly

—as a way to drop food and other supplies to

(but not always) take the form of small quad—

refugees in war-torn places around the world,

rotor helicopters called quadcopters.

and other uses for remote flying vehicles. With

The first article looks into what exactly drones these five articles under your belt, you'll be in a

are, and more importantly, what they are not.

great position to understand and enjoy the rest

The second article provides a detailed break—

of the book!

down of the anatomy of a drone: from its air-

Not everybody likes the word drone—industry and military experts avoid using the “D

word” in public. They prefer the term “unmanned aerial system or vehicle” and associ-ated acronyms UAS or UAV. Despite plenty of misgivings about military and spy drones, the word drone has become widespread and popular, used with great enthusi-asm by hobbyists who hang out on the DIY Drones site and by professional aerial photographers like the L.A.-based Drone Dudes. So what is a drone?

—Dale Dougherty, founder of Make: Magazine and creator of Maker Faire The original meaning of drone is a male bee.

entiate drones from remote-control aircraft, but

The body of a drone is bigger than all other

it emphasizes that a human, who can be held

bees (except the queen), but what physically

responsible, is at the controls. A drone can be

distinguishes a drone is a larger pair of com—

operated manually or it can be programmed to

pound eyes. Yet drones have no real work to do

follow a fixed flight plan.

but reproduce. They make late afternoon flights

The distinguishing feature of a drone seems to

to what is called a congregation area, where

be the promise of autonomy. Today, a typical

drones gather looking to mate with a virgin

flight consists of switching between manual

queen. Once these bees succeed, however (and

flight and autopilot. How much further might it

they perform this act in midair), the drones fall

go? Given the right instrumentation and the

out of the sky, having left an essential body

ability to process that data, could a drone be

part behind. That’s all that drones do.

programmed to make context-aware decisions,

The notion that a drone doesn’t have much

particularly ones that humans are not very

work of its own leads to a secondary definition

good at? A drone might detect problems

of a drone as someone who lives off the work of

before they occur, such as responding to gusts

others—a parasite. In fact, at the end of sum—

of wind or avoiding unexpected obstacles. A

mer, the worker bees kick the remaining drones

drone might also be able to communicate with

out of the hive. They eat too much and do too

other drones.

little. They can be replaced in the spring.
Can a drone be considered a robot, able to
This helps set up the problem. We not only
obey Asimov’s Three Laws of Robotics? We
need to figure out a definition for drones, we
need drones that explicitly avoid harming
also have to figure out what they’re going to do
humans and can act to protect themselves
—and not do. While some agree that drones
from destruction. We should expect this much
are unmanned, others point out that they’re
from any fully autonomous vehicle. A drone
piloted, preferring the acronym RPA for
then might be said to have a mind of its own.
“remotely piloted aircraft.” That wouldn’t differ—
3
Until such time, however, that responsibility
For makers, the most interesting challenge isn’t
falls on the person flying the drone. When you
just building drones or flying them. It’s discov—
fly a drone, you aren’t just a user—you’re a
ering what drones are good for, what creative
pilot. You must protect your equipment, your—
uses they have, and what tough problems they
self, and most importantly, other people. A bad
might solve. Otherwise, planes and quadcop—
or incompetent pilot can injure people or
ters will be sold only as toys, not tools, and
invade their privacy. It’s not a lot different from
many people will discard them once they lose
owning a pet or a car.
interest in their playthings. We’re hoping
Good pilots, like the Drone Dudes, worry that
drones become platforms for developing com—
bad or careless pilots will garner the public’s
pelling applications that will push the technol—
attention, create a climate of fear, and cause
ogy forward and adjust the balance between
governments to restrict or eliminate drones for
the light and the dark side of drones.
commercial or recreational use. The reason we
need better technology is that few of us are

very good pilots.

Figure 1-1 *An example of how cool you can be with a drone.*

Getting Started with

2

Multicopters

Tips on how to build, buy, fly, and spy with multirotor R/C helicopters.

—From Make:31 by Frits Lyneborg

A multicopter is a flying robot resembling a

design was of a radio-controlled, self-leveling

wagon wheel—without the wheel. It has a cen—

quadrocopter (Figure 2-1).

tral hub with electronics, power, and sensors,

onto which are mounted arms that hold propellers to provide lift. The number of arms gives

the name: a tricopter (trirotor) has three arms, a

quadrocopter or quadcopter (quadrotor) has

four, a hexacopter six, and an octocopter eight.

There are other variations, but these are the

most popular setups.

They're also called multirotors, which arguably

is the correct term, but I'll stick to multicopters

because that's used more often on the Internet,

where you'll find the most information on the

Figure 2-1 *Gurdan and Doth*

topic. Why try multicopters? Perhaps you saw

one and you just have to own this cool new

In late 2004, Silverlit began production of their

gadget. Or you fly R/C planes and you'd like to

X-UFO, a simplified and cheaper version of the

try a new type of aircraft. Or you're into DIY

students' design (Figure 2-2). When this prod—

electronics or robots, or you want to do aerial

uct hit the international markets over the next

photography. Whatever your motivation,

few years, it seeded the idea of a small, remote

there's an option for you. I've flown a variety of

controlled multicopter to many people

multicopters and built three of my own, so I've

throughout the world. Today there are dozens

picked up a few tips I can share.

on the market.

Homebrew Pedigree

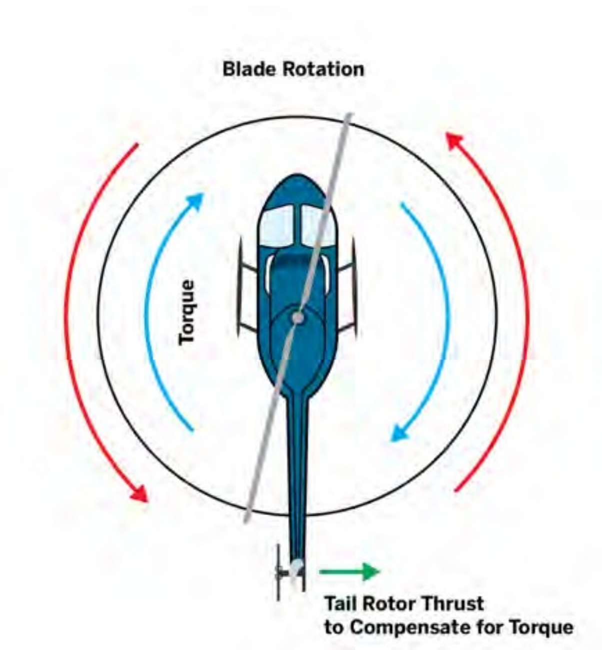
In 2003, Hong Kong-based company Silverlit

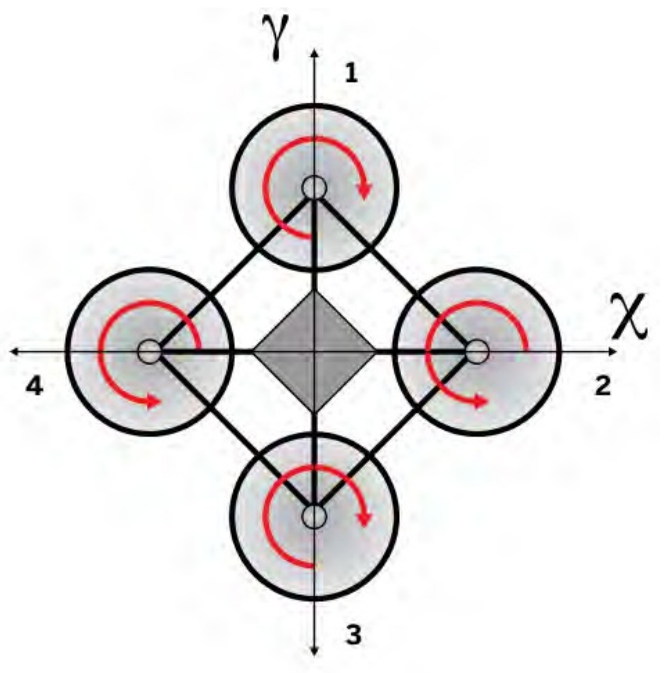
Electronics read in the newspaper about students Daniel Gurdan and Klaus M. Doth's prize—

winning entry in Germany's national Young

Scientists competition. Gurdan and Doth's

7





How They Work

counteracting the torque of the adjacent propellers.

Figure 2-2 *The Silverlit X-UFO*

How They Work

On an ordinary helicopter, the tail rotor provides horizontal thrust to counteract the main rotor's torque, in order to keep the helicopter from spinning around with the main blades

Figure 2-4 *Quadcopter propellers spin in opposite direc-*

(Figure 2-3).

tions

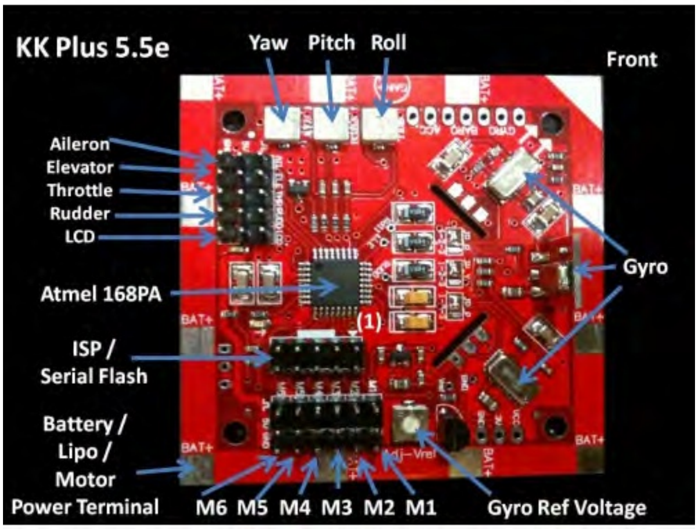
More importantly, a multicopter has an onboard computer that varies the speed on individual propellers, making possible every form of spin, tilt, yaw, and rudder control around any center and any axis, as well as flight in any direction.

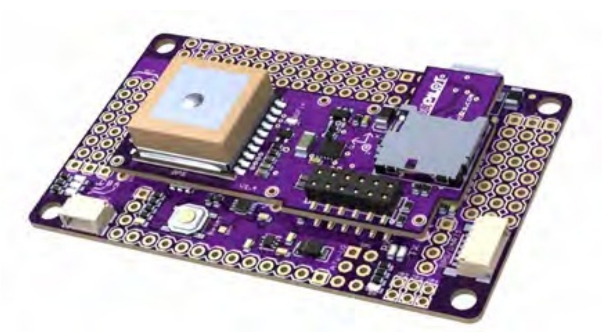
Your First Multicopter

The best starter multicopter is lightweight: the lighter the copter, the less damage to it and to the surroundings when you crash. And you will crash! The bigger they get, the more scared you'll be of flying them. Large multicopters can rip through clothes and flesh, and they cost a lot of money. The downside is that lighter versions carry less payload (read: cameras and extra sensors), and flying time is usually shorter. The upside is that they're cheaper. Ironically, it's

Figure 2-3 *How a regular helicopter works*

also a good thing that lighter copters are typi—
A multicopter works quite differently. Take for
cally harder to control, due to fewer sensors
instance a quadrocopter: every second propel—
and less-sophisticated overall construction.
ler spins in the opposite direction (Figure 2-4),
Why is this good? Because you’ll learn to fly. A
heavy, complex autonomous multicopter





might be easier to fly—or even fly by itself—
but you’ll never learn to handle a multicopter
that way. That can be a big problem the
moment something goes wrong. And something will go wrong.

Building Your Own

Multicopter

Once you’ve played with multicopters, you’ll
realize that building one is a project that you
could take on. Here are the basics.

Batteries and Motors

Figure 2-5 *The KK Plus controller*

The real magic here is the combination of the very powerful lithium polymer (LiPo) batteries

and brushless motors. These two components,

with just a normal R/C plane propeller on the

motor, can lift themselves right off the ground,

and so this combination can make virtually anything fly.

ESCs and Control Board

A multicopter's flight must be controlled and

balanced in a certain way. The motors are con-

Figure 2-6 *The ArduCopter*

trolled by little units called electronic speed

controllers (ESCs), and these need signals tell-

Body and R/C Gear

ing them how much power to pass on. In a mul—

The body of a multicopter can be made of

ticopter, that signal comes from a special

almost anything, including wood, so the only

control board. The control board is hooked up

"mysterious" thing is the control board. The rest

to a standard R/C plane receiver, and possibly

is common R/C gear: a four-channel transmitter

other peripherals such as GPS, or whatever your

and receiver, and connectors to hook up your

imagination and wallet allow. Probably the two

components. A Google search on "multicopter

most popular control boards right now are

control board" will get you started and lead you

HobbyKing's MultiRotor Control Board V2.1

to plenty of build instructions, and I recom-

(hobbyking.com) and Multi RC Shop's KK Plus

mend visiting *http://rcexplorer.se*, *http://hobbyk-*

V5.5e Multicopter Controller (multircshop.com),

ing.com, and *http://diydrones.com.*

both based on Atmel's ATmega168 microcontroller chip (Figure 2-5). Arduino-oriented mak-Video from a Multicopter
ers might prefer DIY Drones' ArduCopter

system (*http://copter.ardupilot.com/*), with its

Filming from the sky is the most common bro—

ArduPilot Mega board based on the

ken dream among multicopter users. Unfortu—

ATmega2560 (Figure 2-6).

nately a lot of people are spending a lot of

money hoping to make great professional

video from the air at a fraction of the cost of a real helicopter. Many shops out there are ready

Video from a Multicopter

to sell this dream, which I think is unfair. You

you use the medium on its own terms: accept

should think twice. Here's a test: take your cam—

the ever-moving picture, use a lightweight

era and put it on a broomstick. Hold the other

camera, and focus on action shots where the

end of the broomstick. Now try to get good

camera is moving through the air. The best vid—

footage out of that. While it may give interest—

eos I've seen use extreme wide-angle shots,

ing new angles and be "arty," in general it's

usually made with the GoPro camera brand

going to look "filmed from the end of a broom-

(Figure 2-7), which can also shoot at 60 frames stick." You'll find it hard to get the quality of per second (fps), giving a slow-motion feeling.

shots you're used to. The same is the case with

The lighter the camera, the better the flight

a multicopter. You can find cool-looking videos

performance. Think eight ounces and below.

made from multicopters on YouTube, but

Finally, your best tool is video feedback.

they're always focused on the flight experience

Actually seeing what you film, while you're

("Look, I'm flying!"), rather than a specific object

doing it, is called first-person video (FPV). There

or person being photographed. If you work

are many options for wireless video downlinks,

hard with your equipment, you can get cool

depending on the following parameters.

shots, but they'll be lucky shots, unless your

copter can transmit video back to the ground

(see the section "Cameras and Video Downlink-

ing"). If you get a picture of a house, it'll be awk-wardly framed. If you video anything other than random treetops, the subject won't be well

placed in the frame, and everything will be

moving about. It's not easy.

Gimbals and Gyros

You can purchase very expensive camera

mounts and gimbals with gyroscopic stabilization. But before you do, ask to see raw film of at

least one minute made with the equipment—

not filmed at high speed and slowed down for a

smooth look, and not edited in short clips, or

stabilized in post-production. I don't recommend two-axis gyro gimbals. In my experience

they introduce more shaking than they do

Figure 2-7 *A GoPro mounting rig for a drone*

good, even the very expensive ones. (And

Cost, weight, and power consumption

three-axis gimbals introduce even more.) Since

multicopters are extremely steady when it

How large an antenna can you carry to the

comes to holding direction, I don't think these

field? What RF bands are allowed in your coun—

are of any benefit. Your best mount is some—

try? Which are already used on your copter?

thing simple like a flexible plastic tube or soft

Transmitting power

foam. Just accept that the camera is not level at

Systems one watt or stronger may require a

all times.

ham operator's license. Frequency regulation

Cameras and Video Downlinking

information is available at http://makezine.com/go/hamradio.

You can get really cool videos and pictures from

multicopters if you've practiced flying, and if

Electromagnetic pulses

trolled by an Arduino-based autopilot devel—

Powerful transmitters can make servos and

oped by DIY Drones (Figure 2-9).

other electronics malfunction. These things

have to be experienced; there are no golden

rules that I'm aware of. Sometimes things just

interfere.

In general you're looking for lighter weight,

longer range, less power consumption, and

undisturbed frequencies. You can't expect to

use cheap, random TV transmission gear. Get

something from a shop that has experience with video downlinks from multicopters. And if

Figure 2-9 *Some ArduCopter screens*

you get a pair of video glasses for monitoring

(Figure 2-8), you can see what the camera in the There are also popular setups where cameras sky sees, even in sunlight. If nothing else, it's

film the drone, and a computer calculates its

really cool to be able to elevate your field of

flight from what the cameras see (little dots on

vision by remote control.

the copter). Perhaps you could even set up a

drone to navigate by the sun. It's all just sensors. If you do experiment with drones, never

let your autonomous machine go beyond visual contact. Most systems I know of have a

built-in maximum range of 250 meters. Once

you start playing with multicopters, you'll

notice there's no longer a sharp border

between "autonomous" or "R/C" flight. Any

multicopter is a robot that to some degree is

autonomously controlling its motors (or it

would crash). And even fully autonomous

drones have the option of killing the automa-

Figure 2-8 *Video glasses for first-person video*

tion and returning to R/C control (anything else

would be hazardous). With multicopters, it's

Going Further: Drone

always some form of R/C, and it's always some

Multicopters

kind of autonomous.

More DIY multicopters and kits: *http://scou-*

Once you've mastered R/C multicopters, you

tuav.com, *http://multiwiicopter.com*

might want to try drone multicopters. When

most people say drone they're talking about

Quadcopter FPV: *http://makezine.com/go/fpv*

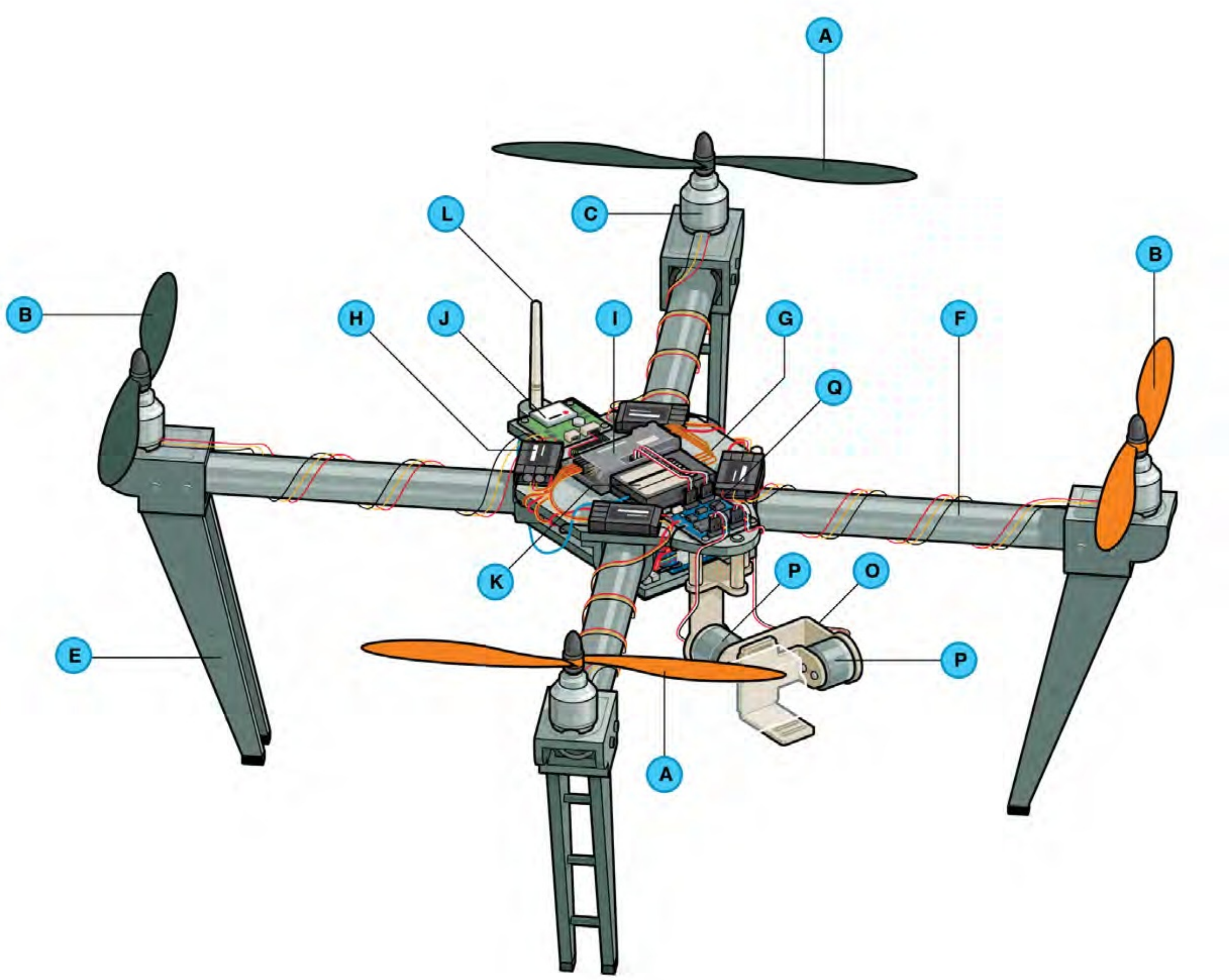
flying by GPS coordinates and waypoints in

3D-printable quad: *http://makezine.com/go/*

fully autonomous mode, and that's something

hugin

special. One example is the ArduCopter, con-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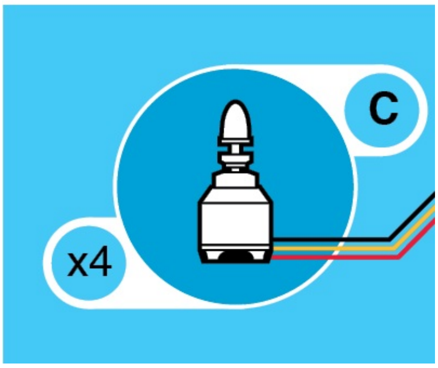
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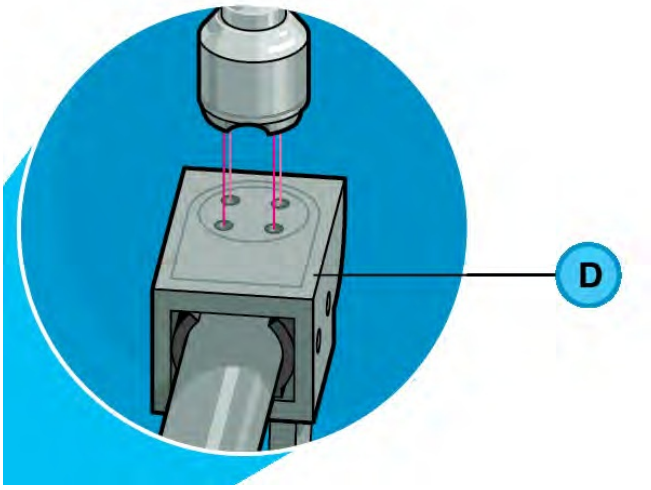


Anatomy of a Drone

3

—Multirotor UAV diagram by Rob Nance

Standard Prop

Motor Mount

The same “tractor” propeller used on standard

Sometimes built into combination fittings with

front-engine R/C airplanes. In orange in the dia-

landing struts (Figure 3-2).

gram above.

“Pusher” Prop

These contra-rotating props exactly cancel out motor torques during stationary level flight. Opposite pitch gives downdraft. In dark grey in the diagram above.

Motor

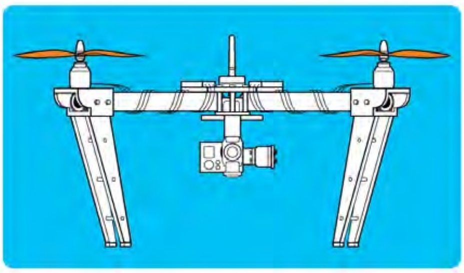
Usually a brushless electric “outrunner” type, which is more efficient, more reliable, and qui— eter than a brushed motor (Figure 3-1).

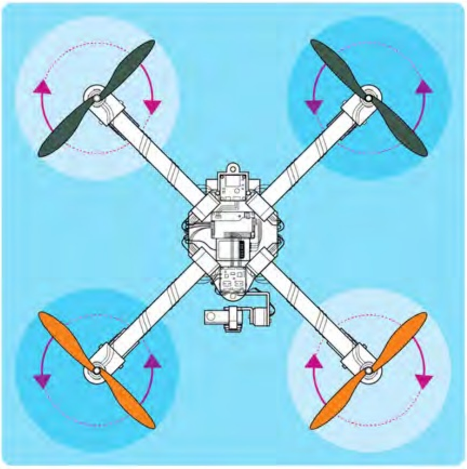
Figure 3-2 *Close-up of motor mount*

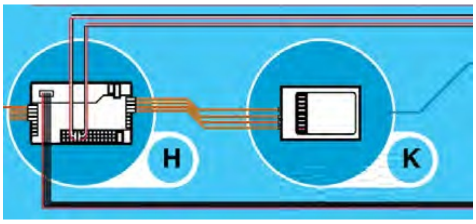
Landing Gear and Boom

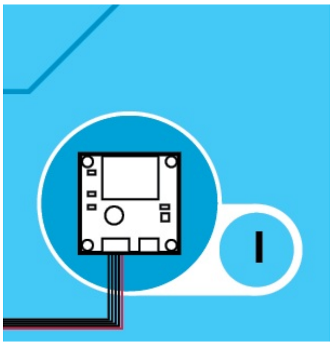
Designs that need high ground clearance may adopt helicopter-style skids mounted directly to the body, while designs with no hanging payload may omit landing gear altogether (Figure 3-3).

Figure 3-1 *Motor*









Boom

Electronic Speed Controller

(ESC)

Converts DC battery power into three-phase AC

for driving brushless motors (Figure 3-5).

Figure 3-3 *Landing gear and boom*

Boom

Shorter booms increase maneuverability, while

Figure 3-5 *Electronic speed controller (H) and radio*

longer booms increase stability. Booms must be

receiver (K)

tough to hold up in a crash while interfering

with prop downdraft as little as possible.

Flight Controller

Main Body

Interprets input from receiver, GPS module, battery monitor, and onboard sensors. Regulates

motor speeds, via ESCs, to provide steering, as

Central “hub” from which booms radiate like

well as triggering cameras or other payloads.

spokes on a wheel. Houses battery, avionics,

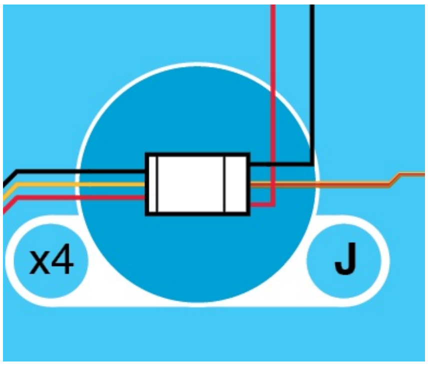
Controls autopilot and other autonomous func—

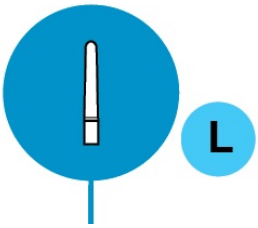
cameras, and sensors (Figure 3-4).

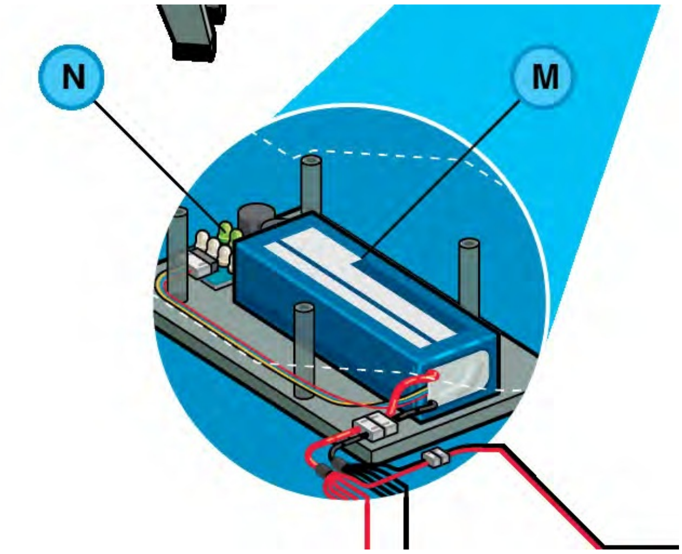
tions (Figure 3-6).

Figure 3-6 *Flight controller computer*

Figure 3-4 *The main body of the drone*







GPS Module

GPS Module

Battery

Often combines GPS receiver and magnetome—

Lithium polymer (LiPo) batteries offer the best

ter to provide latitude, longitude, elevation,

combination of energy density, power density,

and compass heading from a single device

and lifetime on the market (Figure 3-9).

(Figure 3-7).

Figure 3-7 *GPS module*

Figure 3-9 *Battery (M) and battery monitor (N)*

Receiver

Battery Monitor

Often a standard R/C radio receiver unit. The

Provides in-flight power level monitoring to

minimum number of channels needed to con—

flight controller.

trol a quad is four, but five is usually recommended (as seen in Figure 3-5).

Gimbal

Antenna

Pivoting mount that rotates about one, two, or

three axes to provide stabilization and pointing

Depending on your receiver, may be a loose

of cameras or other sensors.

wire whip or helical “rubber ducky” type

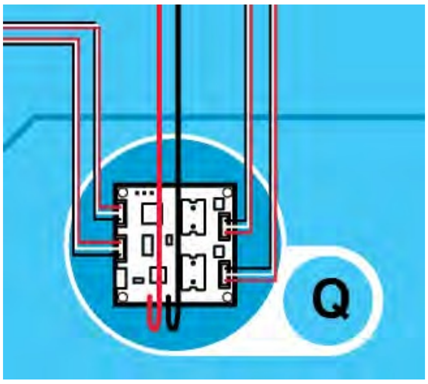
(Figure 3-8).

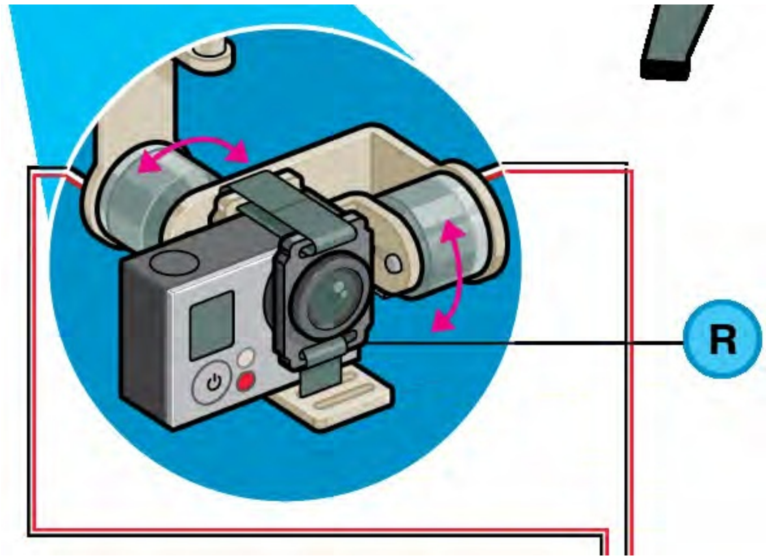
Gimbal Motor

Brushless DC motors can be used for direct-drive angular positioning, too, which requires

specially wound coils and dedicated control circuitry that have only recently become commercially available.

Figure 3-8 *Antenna*





Gimbal Controller

Gimbal Controller

Camera

Allows control of direct-drive brushless gimbal

GoPro or other compact HD video unit with

motors as if they were standard hobby servos

onboard storage. Real-time streaming is possi-

(Figure 3-10).

ble with special equipment (Figure 3-11).

Figure 3-10 *Gimbal controller*

Figure 3-11 *Camera*

Building Drones to Deliver Medicine

and Food to War-Torn Syria

4

Fixed-wing UAVs aren’t just for bombs—meet the nonprofit building drones that fly supplies to Syria.

—From Make:47 by Signe Brewster

On March 16, 2015, barrels of chlorine gas

broke out about international intervention in

rained down on the town of Sarmin in northern

the Syrian war. Since 2011’s Arab Spring, when

Syria, killing six and wounding many more—

activists came together to protest president
just one of many horrific chemical attacks in the
Bashar al-Assad and his government, at least
civil war that has consumed the country.
200,000 people have died there. More than
“Sarmin isn’t far from the border but the border
10,000 were children. A lack of medical care
is closed to all traffic,” Sasha Ghosh-Siminoff,
and food are among the government’s weap—
president of Syrian aid organization People
ons against its own people.
Demand Change, texted his Stanford
Person after person at the gathering asked the
University-based friend Mark Jacobsen, four
same question: why isn’t more being done?
hours after the attack. “If your planes were
Jacobsen, a former Air Force cargo pilot,
ready, you could have flown in emergency
explained to one attendee that you simply can’t
medicine and gear.”
fly a cargo plane into such an unpredictable
The planes Ghosh-Siminoff was referring to are
place. It’s impossible.
drones, built expressly for this purpose. Jacob—
He went back to his hotel that night feeling
sen is the executive director of Uplift Aeronau—
guilty. It didn’t seem like a good enough
tics, a nonprofit that hopes to deliver essential
answer. While speaking with his colleagues, he
medical supplies, food, and other cargo to
became fixated on the idea of sending in large
Syrians via its Syria Airlift Project. Syria recently
numbers of packages—perhaps via drone. He
closed its border to foreign aid, and any planes
took out a notebook at around 2 or 3 a.m., the
that attempt to fly over the country run a high
hope of sleep long forgotten.
chance of being shot down. Uplift has a differ-
“It seemed like I was onto something with the
ent plan: fleets of drones that could swoop in
idea of swarming small packets, but I didn’t
by night, undetected by human eyes or radar.
really know what technology could do that,
whether it would be quadcopters or planes or

Doing More

catapults or anything else. Balloons?” Jacobsen
says. “I was just trying to lay out everything I
Jacobsen, who is pursuing a Ph.D. in political
could think of.”
science, was in Istanbul about a year ago with a
group of academics when a heated discussion
19
Complications
Uplift Aeronautics and the Syria Airlift Project
election in Turkey, and the country’s air strikes
were born, and today Jacobsen and a group of
within Syria, add a new layer of complexity.
volunteers are busy flying prototype drones.
Their plan is to fly over the border from a neigh-

Farm Drones Take Flight

boring country, on missions chosen by aid part—
ners such as People Demand Change. Each
“In some ways, negotiating with the armed
drone can carry only a few pounds of supplies,
groups and the people inside Syria is easier
but their small size makes them untrackable by
than the Turkish governments,” Ghosh-Siminoff
radar and dispensable. If a chlorine bomb
says. “It’s really difficult to navigate that
explodes, medicine-carrying drones can be
bureaucracy and know you’re in the clear and
there in an hour, as opposed to days—or never.
not running afoul of some archaic rule.”
Uplift plans to train Syrian refugees and other
In Syria, the groups fighting Assad would be
people on the ground to fly and repair the
most likely to shoot down a drone. Currently,
drones. Its first destination would be Aleppo,
the resistance occupies the ground between
Syria’s largest city. The war has hit it hard. Hun—
Uplift’s launch site and Aleppo. If Uplift can
ger and disease are common.
demonstrate the planes are for aid, and will not
The drones would take about a half hour to fly
interfere with the opposition’s efforts, Ghosh—
to Aleppo. Instead of touching down, they
Siminoff said there should not be a problem
would drop their cargo in a small box attached

convincing the locals to let them pass.

to a parachute. Then they would return. Back at

In a country strapped for resources, a scenario

the launch base, the location of which would

could arise where troops start capturing drones

likely shift from day to day, volunteers could

to use for their own purposes. Uplift thought of

switch out their battery, load new cargo, and

that. The drones are equipped with a self—

launch again within minutes.

destruct device designed to fry their navigation

system if they fly too close to the ground any-

Complications

where but at the launch site. Any drone that

gets too low will never be remotely pilotable

Flying anything, let alone hundreds of drones,

again.

into a country without permission is a breach of

“We’re not planning to talk to them at all once

international law. Current sanctions bar send—

they leave the takeoff area,” says Jacobsen.

ing US goods into the country. In extreme times

“Routes will be pre-programmed. Our custom

like these, exceptions can be granted, but they

firmware on the plane actually plugs its ears

depend on various government channels.

and stops listening to incoming messages

Jacobsen isn’t exactly sure how Uplift will

while in Syrian airspace, which should make it

secure an OK from the US, though he has initi—

considerably harder to hack.”

ated conversations with officials. The drones

will likely have to be approved by the US Treas—

ury and international agreements, and will

need to comply with arms regulations and

counterterrorism laws.

Uplift will also need to talk with the governments in countries bordering Syria, such as Turkey or Jordan. They will need to prove that the

drones will be safe and beneficial. The recent

Figure 4-1 *Michael Taylor, with Uplift Aeronautics' Waliid drone mounted on a home-built PVC launcher*

Figure 4-2 *A volunteer tests the drone radio controls*

A Team of Volunteers

A Team of Volunteers

allows it to fly for an hour instead of minutes. Its

wingspan measures 5′ 7″ and is decorated in

On a hot, cloudless day in April, Jacobsen and

black, green, and red—the colors of the Syrian

four volunteers gathered at Stanford Universi—

flag.

ty’s Lake Lagunita. Engineer Michael Taylor, a
Ph.D. candidate in electrical engineering, led
two other volunteers through setting up the
drone launcher on the lake bed, which has
become a grassy field thanks to California’s
drought.

Back in the field, Taylor and aeronautics and
astronautics Ph.D. student Heather Kline had
completed the launcher—a 7-foot-long PVC
pipe skeleton that guides the drone into the air.
Tomoki Eto, a mechanical engineering under—
graduate and experienced drone pilot, anchors
On a porch overlooking the lake, Jacobsen
a bungee line to the ground several hundred
assembled and tested the “Waliid” drone. He
feet away, stretches it to the launcher, and
ran new volunteer Stuart Ginn, a medical resi—
attaches it. Upon release, the bungee will fling
dent still clad in scrubs, through the plane’s
the UAV into the air.
software and pre-flight protocol.

The team consists of five volunteers, but
expands to 15 or 50 people, depending on how
you look at it. The engineering core resides at
Stanford, but people all over the world are contributing to its design and deployment. It’s
been an informal collaboration via email,
Skype, and Dropbox, but Uplift plans to release
as much open source material as possible,
probably via Github.

Like many of the volunteers, lead engineer
Brandon Fetroe got involved with the project
after hearing about it through Stanford’s UAV
club. While the technical hurdles felt managea—
Made of foam and held together by tape, the
ble to him as an engineer, he says, its political
drone is not visually impressive. It’s shaped like
challenges were things “many Americans didn’t
a plane, as opposed to the quadcopters that
feel capable of tackling on our own.”
have taken over the consumer market, which

Figure 4-3 *Uplift Aeronautics members Heather Kline, Tomoki Eto, Mark Jacobsen, and Michael Taylor*

“The project made it clear from the start that

Open Source

each individual person who was interested in

helping out has the opportunity to contribute

With all the parts prepped, the group clusters

in ways that match their skill set and that

around the launcher on the lake bed. The

together, as a whole, the team could do things

Waliid sits on top of two metal rails that will

that the individual on their own certainly can’t,”

guide it out and up while the bungee acceler—

Fetroe says.

ates it forward.

Fetroe, a mechanical engineering Ph.D. student,

The final verbal checks ring out while a small

has been flying R/C planes since he was 12. He

crowd forms to watch.

described his expertise as a little bit of everything—something that holds true throughout

“Clear!” Jacobsen shouts.

the Uplift team. Ginn, for example, was once a

The launcher releases and the drone springs

commercial pilot; he’s now helping reach out to

forward. The bungee falls away as it coasts up

medical NGOs. And Jacobsen is leveraging his

and begins flying rectangles over Lake Lagu—

international contacts and friends in the US

nita.

government from his days in the Air Force.

Breaking New Ground

Interest in using drones for deliveries is high

around the world. Syria is just one of many

regions where broken infrastructure can make

supplies impossible to deliver by land. Drones

are already busy monitoring poachers and providing aerial intelligence in disaster situations.

But Jacobsen didn’t relate the Syria Airlift

Project to any of those efforts. Instead, he

looked back much further, to the Cold War

Uplift flies its planes with software built by 3D

when the Western Allies airlifted supplies into

Robotics. Jacobsen also runs a custom program

West Berlin. US Air Force pilot Gail Halvorsen

that measures the plane’s energy consumption

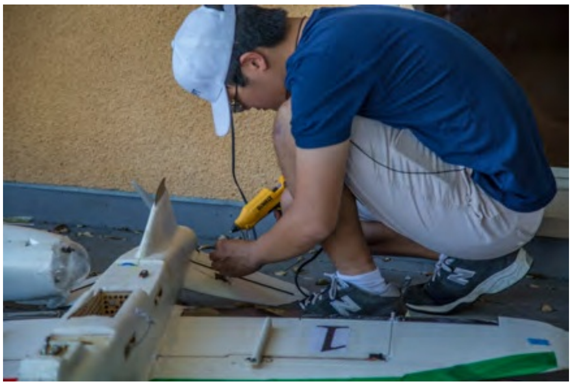
started a movement when he began dropping

at different flying speeds. Every so often, the

candy attached to handkerchief parachutes for
Waliid increases its speed by 2 miles per hour,
children. Like the Candy Bomber, as Halvorsen
gradually moving from 28 to 50 miles per hour.
became known, the drones could drop symbols
of hope and happiness.

If Uplift begins sending drones into Syria, it will
run another custom program. An app called
“People inside Syria affiliate airplanes with
Swarmify can take a single flight plan and turn
death. There are no positive memories of an air—
it into as many semi-randomized flight paths as
plane anymore,” Ghosh-Siminoff says. “It would
the team needs.

be nice to see a positive example of when a
plane came to help them instead of to kill
them. It would make them feel like they’re not
alone, that the world didn’t forget them, and
that there’s still someone out there trying to
help them.”



Open Source

“Because every flight plan is slightly different, it

Drones that can carry more than a few pounds

ensures planes don’t collide with each other,”

of cargo for an hour and cost, say, $1,000, didn’t

Jacobsen says. “It also gives you tactical surviv—

exist. Fetroe said new options are emerging,

ability, because no two planes cross the same

but most have yet to officially hit the market.

point on the ground. If somebody sees the first

For now, Uplift will carry on with its own design.

plane fly over, they won’t catch the next one.”

The project’s current hangar of vehicles cost

Much of the drone itself is made from off-the—

between $500 and $1,000 to build. The Waliid is

shelf and open source components. While

actually the $100 Talon kit made by X-UAV. Its

Uplift could someday manufacture its own

autopilot system is built by 3D Robotics. Its

drones, right now it works with inexpensive

motors, props, and servos were all picked for

hobby kits. This choice has its roots in the

their modest price, and can be found on Hobby

organization’s origins, when Jacobsen had to

King.

teach himself the basics of building and programming a drone and fund the project inexpensively.

But even as Uplift’s volunteer ranks grew, it kept

building its own drones. It turns out that there

isn’t much of an alternative.

“When we looked at different airframes, one

thing became immediately clear: the market is

really polarized as far as cost and capability is

concerned,” Fetroe says. “If you tried to put all

the planes in a line, and had the tiniest, cheap—

est one on one end, and some huge commercial or military drone on the other end, you

In its belly sits the real value—the payload. A notice there's a really big gap in the middle,

wooden box, laser cut by Fetroe, opens to

kind of where we are trying to operate."

release its cargo. It floats to Earth strapped to a

parachute made from garbage bags, or whatever other cheap plastic is available (read more about this in Chapter 13).

Syria Is Not the Finish Line

Syria Is Not the Finish Line

"My long term goal is to help build a world where the use of starvation and medical depri— vation are impossible—they just don't work Whether or not the Syria Airlift Project suc— anymore; you can always find a way to get ceeds, Uplift sees a future for its drones. What humanitarian aid through. That's a lifelong will start with just a few flights this summer

ambition," Jacobsen said. "If we can get the first

could scale to hundreds or thousands of planes

steps done, we can scale from there."

that can feed entire neighborhoods. Even just a

handful of planes can make rural medical deliveries and bring aid to disaster-stricken regions

where the political situation is more welcom—

ing.

Quad Squad

5

These expert pilots and developers are working

Going from 0-60 with APM

to make quadrotors cooler and more useful than ever.

Everyone loves a flying machine. Since launch—ing just over a decade ago, DIY quadrotors and other autonomous aerial platforms have matured rapidly, thanks to an obsessive community and access to technology advance—ments like lithium-polymer batteries, brushless motors, and increasingly small, high-powered processors and sensors. With these components, drones are now incredibly strong, stable, and capable of doing most if not all of the piloting themselves.

So if these machines fly themselves, what do enthusiasts do to stay involved and excited? To help answer that question, we assembled a diverse gathering of top UAV flyers, including Hollywood filmmakers, smash-proof airframe builders, and aerial software and component creators, to discuss and demonstrate some of the newest tools and techniques involved in the pursuit of quadrotor aerial excellence. Their

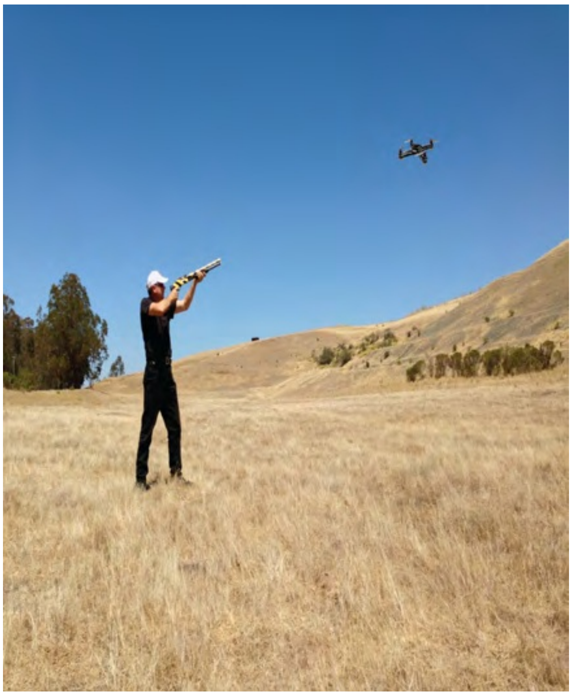
Figure 5-1 *Jason Short, Design Director, 3D Robotics,*

reports promise an exciting future in flight.

http://3drobotics.com

APM:Copter was born on October 10, 2010. The date is indelibly etched in my memory, since it was the same day my son Lukas was born. We

spent the week at the hospital while the Blue
Angels flew overhead during Fleet Week in San
31



Building the World’s Toughest Drone
Francisco. I knew my days of flying UAVs at the
The most exciting improvement is our new, full—
airfield were likely over, so I set about designing
featured Android tablet interface, which ena—
one I could fly in my backyard while my son
bles you to plan and control a drone in the air.
napped.
Community-developed apps like DroidPlanner
Adapting APM:Plane to fly multicopter drones
and Andropilot allow you to command the
was simple at first, but engineering full
drone with a simple Google Maps-like interface.
autonomy turned out to be a wicked problem.
Advanced features, such as the “Follow Me”
Multicopters stress the flight controller system.
function, allow the tablet’s position to be sent
There are over 100,000 lines of code running on
to the drone, creating your own personal flying
the Arduino-based processor, and almost noth—
camera, ready to capture your next hike up Kili—
ing can go wrong that doesn’t end in a bad out—
manjaro, surf in Maui or your son’s first success—
come, often culminating in a crash. Producing a
ful bike ride in the local park.
rock-solid flight control system and ironing out

the details took a small army of volunteer

Building the World's Toughest

developers and years of collaborative work, but

the results have been astounding.

Drone

Today, the 3DR development team is focused

on key features that will make it easier for new

users to install and configure APM on any airframe.

Our latest software release of APM:Copter

brings some new and very helpful capabilities.

Setup wizards walk you through the configuration process, and a new auto-tune function

learns how the drone flies, maximizing flight

performance and removing the burden of manual tuning. A new, highly advanced inertial navigation controller fuses GPS and internal

sensors to empower a pilot of any skill level to

fly the drone right out of the box, without the

challenges inherent to manual flight. Software—

defined "geo-fences" prevent you from flying

too far or too low. If the drone breaks the fence,

APM automatically takes control and flies back

home on its own.

A new flight mode called "drift" relies on the

intelligence of the autopilot to simplify flight

Figure 5-2 *Marque Cornblatt, Cofounder, Game of*

control to a single stick. The end result is a

Drones, http://gameofdrones.biz

drone that flies and corners more like a race car

Deep in a huge Oakland, California warehouse

than a typical multicopter. If you lose orienta—

filled with fire-breathing robots, monster

tion, just let go of the stick and the brakes will

machines, and other implements of destruc—

be automatically applied, bringing your drone

tion, a not-too-secret cabal of inventors, engi—

to a safe landing.

neers, and artists meets late at night. This

group gathers, first, to show off their latest

launched it. The magic is in the airframe con—

custom-built drones, UAVs, and robots.

struction, and it's hard to imagine any other

And, second, of course, to pit them against

type that could withstand such abuse without

each other in one-on-one airborne “fights to
becoming unflyable.
the deck.”
Besides the supertough construction, we like
The crucible of destruction is known, some—
to strip our airframes down to the bare necessi—
what informally, as “Flight Club.” The first rule of
ties. For example, rather than using four ESCs
Flight Club is that all commercially available
on separate boards, we favor a four-in-one ESC
drones and drone kits are far too fragile and
board for motor speed control. This reduces the
expensive for heavy-duty use—especially if
number of failure points significantly. The end
that use is dogfighting. But a number of inno—
result is a supertough, super-simple airframe
vative and perhaps even groundbreaking
that can survive an entire day of flying, fighting,
design concepts have evolved here, including
and crashing without a single repair.
many clever DIY methods for making drones
Because most pilots go to great lengths to
cheaper, tougher, faster, and easier to repair.
avoid collisions and crashes, most airframes—
Flight Club competition led me to team up with
though they may be carefully designed to opti—
industrial designer (and long-time aerial—
mize other factors—are mechanically fragile.
dogfighting nemesis) Eli Delia. Together we
This has created a culture of expectation in
began researching highperformance materials
which airframes that break when they crash are
and manufacturing methods from tough-duty
an accepted norm. Thus many amateur pilots
industries including aerospace, military/law
are rightly afraid to take risks and really hone
enforcement, and even medical manufacturing.
their flying skills for fear of damaging their frail,
expensive gear.
That research led us to thermoformed polymers, and we soon began designing and proto—
At Game of Drones, our approach flies directly
typing airframes using various sheet plastics
in the face of this culture. Our motto is “Fly ‘em
including styrene, polycarbonate, PET, and

hard and put ‘em away wet. They’re only
Kydex 100, the supertough plastic “alloy” we
drones.” It’s my hope that this approach will not
ultimately settled on. Launching a Kickstarter
only make it easier for beginners to enter the
let us test the market and get direct feedback
hobby, but will also inspire more people to
from UAV pilots of all skill levels and needs, and
design, build, and fly drones for aerial combat
this spark of user insight has already ignited
games, business, research, and more.
several ideas for our next project.

Drones as Aerial Access

My personal UAV—the one I fly every day—is
one of our company’s first prototypes. It’s been

Points

crashed and/or dropped from hundreds of feet
too many times to count. It has been flown
WiFi technology will make drones simpler to
through fires and landed in (and launched
control and provide the opportunity, eventu—
from) stagnant water. We’ve (deliberately)
ally, for Internet-controlled drones.
flown it through plate glass windows and shot
While the vision for drones is that they operate
it out of the sky with a 12-gauge shotgun. It
fully autonomously taking off, flying a mission
keeps coming back for more.
and landing without human intervention, of
Sure, it’s scuffed, scratched, torn, and beat, but
course we will want to be able to find out
it still flies straight and true as the day we first
where our drones are located, know whether
they are functioning properly (or not), and be

Drones as Aerial Access Points

able to change the mission or take over manual

cally sent over a long-range serial link like IEEE

control at any time. Achieving these ends will

802.15.4.

require maintaining wireless connectivity

throughout the majority of each flight.

Video

This is what gets most drone users excited—

the idea of sending back real-time video so

someone on the ground can experience what it

is like to fly. For most hobbyists the only option

for getting video from a drone is an analog

wireless video transmitter/receiver. Analog

video systems offer the advantages of being

reasonably low-cost and having very low

latency or lag.

With all three of these systems running at the

same time there is a risk for interference (with

potentially disastrous consequences), so most

operators use different frequency bands for

each system. Typically drone operators use 900

MHz for telemetry (at least in the US; 433 MHz

is standard in Europe), 2.4 GHz for control, and

5 GHz for video. Since higher frequency means

shorter range, video typically is the weakest link

and will go out before an operator loses control

or telemetry.

A better solution, however, may be to combine

Figure 5-3 *Adam Conway, VP Product Management,*

all three systems under a single wireless tech-

Aerohive Networks, http://aerohive.com

nology, one that has the range for flight but

Wireless communications for hobbyist and pro—

also the bandwidth to be able to deliver video,

level UAVs today primarily consist of three con—

control, and telemetry with a single radio. For

nection uses.

this, WiFi is the obvious choice: it's fast, inexpensive, and (if set up properly) has the neces-

Control

sary long range.

Steering a drone in manual mode, or switching

In the long view, WiFi and other TCP/IP-based

into autonomous mode, is typically accom—

networking technologies are going to be foun—

plished with a traditional R/C transmitter and

dational for creating drones that are Internet—

receiver

controlled.

Telemetry

Today there are already consumer drones, like

As a drone is flying around it has the ability to

the Parrot AR, that use WiFi for video and con—

send telemetry data back to a ground station.

trol signals. But among the more flexible open

Telemetry data typically consists of onboard

source autopilot software and hardware, sup—

sensor inputs including GPS location and diag—

port tends to fall off. However, a few eager

nostic data, but it can also be used to change

engineers and hackers have already begun

settings on the drone mid-flight and provide experimenting with adapting ArduPilot for WiFi

new mission waypoints. Telemetry data is typi—

Drones as Aerial Access Points

telemetry and control, and I think it’s only a

Our systems provide a cost-effective, safe, matter of time until all drones move to WiFi.

dynamic alternative to traditional aerial videography, making them an attractive substitute for

producers considering conventional methods

like manned helicopters and cranes.

Each UAV is designed with a different camera

weight class in mind. Our heavy lifting octocopter was built to mount high-end cameras (like

the RED Epic) that can produce the super high—

resolution imagery the film industry now

expects from professional camera operators.

The RED camera, in fact, is the industry standard and flying it was our first big goal.

Now, with pro-quality HD cameras getting

smaller and cheaper every day, we believe that

the future of cinema drone technology is in a

more compact system. Our new UAV design

(the D2) comes equipped with everything a

professional aerial video team would ever need

for a shoot: onboard GPS, a custom three-axis

brushless gimbal, full HD video downlink, wireless follow focus, and even dual parachutes for

those “oh sh*t” situations. With great agility and

Figure 5-4 *Jeffrey Blank and Andrew Petersen, Drone*

response time, we expect the D2 to find a

Dudes, http://dronedudes.com

comfy spot at the top of the cinema-drone food

We are a unique collective of filmmakers,

chain.

designers, and flying robots. Using a fleet of

We originally got into flying drones because

custom multirotor UAVs and custom camera

they can capture shots that are not practical

gimbals, we offer our services as aerial cinema—

using any other camera platform. Now we’ve

tographers for feature films, commercials,

had a glimpse of what’s possible, and are striv—

music videos, and sporting events around the

ing to constantly develop our technology. The

world. We feel fortunate to be supported by a

complex, rapidly evolving intersection between

network of amazing people and look forward to

technical development and artistic expression

seeing where this exciting new technology will is what makes this business so much fun.

take our business and our art.

Chapter 5: Quad Squad

PART II

Tutorials

How can you do some of the amazing things

years ago would have been impossible for the

people are doing with drones? The tutorial sec—

casual hobbyist to create. The third article

tion contains four articles that can get you

shows how some enthusiasts are putting

started.

drones to work, creating aerial maps of historic

The first two articles explain how drones are

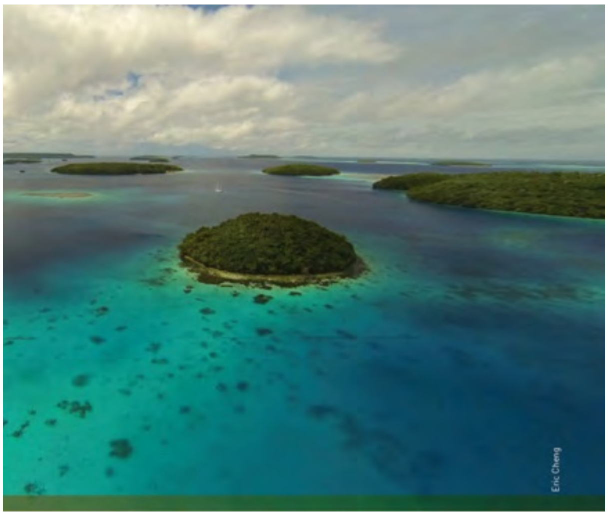
buildings in Cuba. And finally, we learn some of

used to create beautiful examples of aerial pho—

the most important rules of flight, to keep

tography and video—images that only a few

drone use safe.



Getting Started with

6

Aerial Video

How to make fantastic videos from your multicopter or drone.

—From Make:37 by Eric Cheng

The first aerial photograph was taken in 1858

Choose the Right UAV

by French photographer Gaspard-Félix Tournachon, from a hot air balloon. Since then, aerial

The vast majority of people getting into aerial

perspectives in imaging have remained elusive

videography choose a quadcopter as their first

to those without astronomical budgets. Histori—

UAV. Quadcopters' electronic flight controllers,

cally, photographers have used just about

sensors, and GPS automatically stabilize flight,

everything to get cameras up in the air, includ—

and in some instances, allow autonomous "mis—

ing balloons, birds, kites, rockets, airplanes, and

sion" flying via waypoint programming, allow—

helicopters. In the last few years, unmanned

ing for steady video platforms that can

aerial vehicles (UAV) have improved so much in

maneuver themselves into precise locations.

performance and reliability that they have

They're simpler to operate than tricopters, and

started to creep into the mainstream as the

more affordable than hexacopters.

best way for (most) people to capture aerial

images and video. These five tips will help you

The most popular quadcopter for aerial filming

to get the best aerial videos you can.

is the $679 DJI Phantom, because it's ready-to—

fly (RTF) out of the box and is designed to hold

a GoPro camera. The Phantom is a great platform, even for beginning hobbyists, because it's

easily hackable. There is a vibrant third-party

accessories market, mostly made up of enter—

prising individuals selling personally developed

mods online.

Multirotors from 3D Robotics are also a great

choice. They offer kits and RTF models (including a new Phantom competitor called the Iris),

all running their open source, open hardware

flight platform for the ultimate in hackability.

Figure 6-1 *An Aerial view of Tonga, where most of this article took place* 39

Choose the Right Camera

Figure 6-2 *The 3D Robotics Iris*

Figure 6-3 *RotorPixel gimbals are matched to the DJI Phantom and also pretuned to match the GoPro Hero3*

Adventurous makers will likely want to build

camera

their own multirotor aircraft, which have the

advantages of being (potentially) more budget

Finally, GoPros are easily protected while air—

friendly (see Chapter 11) and allowing you to

borne using their branded underwater housing

tailor components to your specific needs. A DIY or third-party lens protectors.

quadcopter or hexacopter consists of an airframe, flight controller, electronic speed con-

Stabilize Your Camera

troller (ESC), motors, propellers, batteries, radio,

and receiver. Entire kits are available for less

The smoothness of aerial video is directly corre—

than $200. Of course, to do videography, you'll

lated to its perceived quality. But multirotor

also need a camera, which leads us to…

motion isn't smooth. As a multirotor flies

around, the flight controller automatically sta-

Choose the Right Camera

bilizes the aircraft by sending power to its multiple motors. During flight maneuvers or in

Although large cameras can easily be put into

gusts of wind, a multirotor might pivot violently

the air if you configure and make your own

on multiple axes, which may keep the aircraft

multirotor aircraft, my favorite cameras for aer—

itself stabilized in space, but can wreak havoc

ial videography are GoPros, which provide the

on footage from onboard cameras. In the past,

best image quality for their size and weight.

hobbyists used servomotors to correct for this

The GoPro Hero3 Black Edition weighs only 73

sort of movement, but servos are slow and

grams and can record video at 2.7K

sloppy, unable to correct quickly enough.

(2,704×1,524 pixels) at 45Mbps (or 30fps). And

it's got built-in WiFi for downloading your foot-

Gimbals and Aircraft Motion

age.

These days, stabilized aerial video is made possible by the incorporation of gimbals that use

GoPros are also pretty much the standard in

brushless motors. A gimbal is simply a support

aerial videography, which means maximum

that allows the rotation of an object around an

compatibility with OEM and third-party acces—

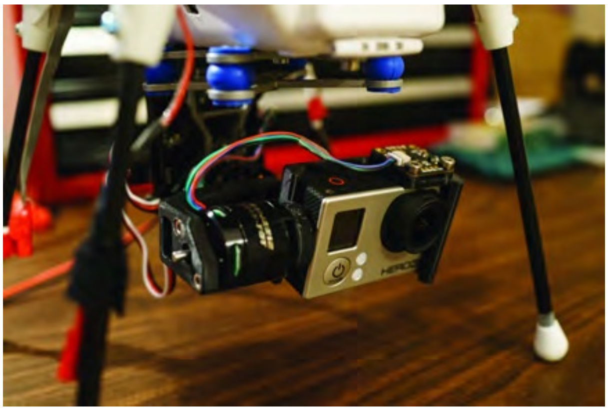
axis, and brushless motors are the same motors

sories for aerial imaging, such as vibration isola—

that revolutionized R/C model aircraft due to

tors and gimbals (covered in the next tip).

their great power-to-weight ratio (rewound for higher torque in gimbal use).



from top to bottom as they read data for each frame. If a camera is moved around during shutter sweeps, it results in horizontal spatial artifacts, more commonly known as "jello." Jello is caused in UAV footage by high—frequency vibrations introduced by rotating motors and propellers. The best way to remove it is by balancing propellers, which can come from the factory with one side heavier than the other. Balancing is facilitated by inexpensive

prop balancers, and is achieved by applying

Figure 6-4 *Author’s gimbal mount, showing the blue*

clear tape to the lighter side and/or sanding the

rubber vibration isolator

heavier side. (Sand the flats, not the leading or

trailing edges—YouTube has great tutorial vid—

A typical camera gimbal allows rotation around

eos.)

two axes: roll and pitch. A sensor on the camera

mount tells the gimbal controller, “I want to be

Balanced props, combined with the vibration

level,” and the gimbal controller sends the

isolators that are commonly used to mount

appropriate signals to the brushless motors

gimbals, should yield beautiful, jello-free, stabi—

that control pitch and roll. In practice, brushless

lized video.

gimbals yield footage from quadcopters that

looks like it was taken using a flying Steadicam

(see *http://ech.cc/aerialvid* for some of my footage). Gimbals for GoPro cameras are available for as little as $150, and can simply be bolted to

the bottom of any aerial platform.

Figure 6-6 *Inexpensive prop balancers help you reduce*

propeller vibration

Figure 6-5 *The aircraft is crooked but the camera is*

Assemble an FPV System

level, controlled by a brushless gimbal

Prop vibration and “jello”

It’s difficult to get good video if you can’t see

The second image-quality problem that needs

what you’re recording. With first-person view

to be solved is the removal of “rolling shutter”

(FPV), an analog transmitter is used on the UAV

artifacts. CMOS image sensors, which are used

to broadcast real-time video from the camera.

in most digital cameras, scan the image in rows

The pilot uses a receiver and either a monitor or

Practice, Practice, Practice

LCD glasses to see what the UAV is seeing. Experienced pilots can fly 100% using FPV without needing a line-of-sight view of the aircraft. An entry-level FPV system can be purchased for around $250. You can read my full deconstruc—tion of the Ready Made RC 5.8 GHz starter kit at http://ech.cc/quadfpv —it taps into the GoPro to use it as the FPV camera as well. (For more details on using first-person view, see Chap-

ter 8.)

Figure 6-8 *Practice your skills with toys like the Blade Nano QX and the Syma X1*

Figure 6-7 *The author pilots his video Phantom over the waters of Tonga via an FPR (first-person view) system from Ready Made RC*

I recommend honing your flying skills using

inexpensive off-the-shelf toys. The Syma X1 and

Practice, Practice, Practice

Blade Nano QX or mQX are all great toy quadcopters that cost between $36 and $90. They fly

The most important thing you can do to

using the same controls, and do not offer the

improve your aerial video footage is to become

luxury of GPS location hold. If you can master a

a skilled pilot. There is no substitute for stick

small quadcopter, the skills you learn will trans—

time, and spending all your time at a work—

late directly to larger aircraft.

bench instead of flying your UAV in an open

field will never yield great footage.

Figure 6-9 *More stick time = better video, so fly as much as you can*

Quadcopter Photogrammetry

7

How a trip to Cuba and my love of R/C aircraft aided in the restoration of historic buildings.

—From Make:37 by William Grassie

Nearing the end of my graduate program in

made electric models a more realistic proposi—

media arts and computer science, I found
tion. And so my obsession began.
myself stuck working on a thesis I no longer
had much interest in. I had lost my motivation
and feared I would end up in grad limbo with a
project I couldn't bring myself to complete and
expectations, including my own, unmet. About
this time a friend of mine had signed up for a
class that was going to Cuba. This was an
opportunity I couldn't miss, so I signed up. This
adventure led me to many others, including the
genesis of what would become my new thesis.
I've long been an R/C flying enthusiast. In my
boyhood, my dad and I built a small, gas—
powered balsa wood plane. It was tethered to a
Figure 7-1 *Grassie's first photogrammetry drone rig*
string, and you could only fly in a circle. The
It started with small helicopters. Then larger
poor plane didn't survive its maiden flight. That
helicopters built from parts. This led to air—
concluded my R/C experience for many years,
planes, which was how I began doing FPV (first—
as we couldn't afford to rebuild it. The price of
person view) flying. Soon after came tricopters
all things R/C at that time made it cost—
and quadcopters, which provided full three—
prohibitive for many.
dimensional freedom of movement and a very
A couple of years ago I discovered the hobby
stable platform for cameras.
anew. I purchased a little R/C helicopter for my
Then came Cuba, photogrammetry, and libera—
brother, and was surprised by the quality, flight
tion from my uninspired thesis. Photogramme—
time, and maneuverability. I started doing some
try is a method for creating 3D models of
research and found a whole new, more afforda—
objects by taking a series (usually hundreds) of
ble world of R/C. This revolution was mainly
photographs. The concept is as old as modern
due to the advent and proliferation of lithium
photography. What has changed is the use of

polymer batteries and brushless motors, which
digital photos and software. The software takes
replaced expensive, messy gas motors and
45

Quadcopter Photogrammetry
all of the photographs and compares them to find matching points. Then the software uses these points to calculate depth.

Through my graduate program in media arts at New Mexico Highlands University, I traveled to Cuba for photography, photogrammetry, and an exchange of ideas. One goal was to make contact with the Office of the Historian, which is responsible for restoring the buildings of Old Havana.

Highlands University had been working with

Figure 7-2 *Photogramming the Hotel Santa Isobel*

the Georgia O'Keeffe Museum for about a year developing the use of photogrammetry as a tool for conservation and preservation. We

Photogrammetry Tips

hoped to share these simple and inexpensive techniques with members of the Office of the

1. A digital camera with fixed focal length is best.

Historian. We contacted them, learned more

2. Make sure your photos overlap 60% to 80%. 3.

about what they do, and demonstrated the

Take the photos horizontal to your object and at a

methods we had developed for documenting

uniform distance. 4. Uniform lighting is important
for creating good models. 5. Process the images in
historic objects and sites using photogramme—
Agisoft PhotoScan. 6. Low-quality models can be
try. They were very excited and offered us the
generated on a laptop. High-quality models
opportunity to create photogrammetric mod—
require multi-GPU systems with 128GB of RAM. 7.
els of several buildings and structures.
For small models you can get away with 30 to 60
photos. Larger models (like buildings) may require
This was my first real opportunity to use photo—
several thousand images. The more photos, the
grammetry in the field, and I too was impressed
better detail you can achieve.
with what was possible. However, while working on documenting several structures, it
When I returned from Cuba I immediately got
became apparent that we were limited by tak—
to work. I had only recently started experimenting photos at ground level, which created gaps
ing with building quadcopters, and the one I
in the images. Once we had rendered a prelimi—
owned had seen better days. But I went ahead
nary model of Hotel Santa Isabel, I found that
and started modifying it to carry a camera for
anything above the field of view would inevita—
my proof-of-concept build. My initial test used
bly show up in the data as black holes rather
a GoPro Hero HD set for time-lapse and my
than a solid 3D model.
house as the subject. I shot 200 pictures, and
I started thinking of different ways to get a
the results, though not beautiful, were very
complete view of the building. One obvious
encouraging. I set out to create a purpose-built
method would be to rent a hydraulic lift, but
quadcopter as a stabilized camera platform to
that could be costly and impractical in tight
create photogrammetric models of large-scale
spaces. Helicopters might work, but would also
structures.
be cost-prohibitive. Then it hit me: I could use
From the outset, I was determined it would be

multirotor R/C aircraft to photograph the inac—

affordable and accessible, and I hoped my idea

cessible areas. My passion for photography and

could inspire and educate others. In its simplest

the R/C world came together in a beautiful way.

form, photogrammetry can be done with a

compact digital camera and a laptop with sur—

prisingly good results. But as the desired qual—

software, I concluded that my methodology

ity of the finished model goes up, the hardware

was sound and completely viable as a useful

requirements and processing time rise dramati—

tool for photogrammetry of large-scale struc—

cally.

tures.

In association with the field-testing, I created a

blog to help anyone who might be interested

in getting started with their own quadcopter.

The blog UAV 3-D (*http://uav3-d.info*) has articles on just about every concept of quadcopter flight so that this technology can be accessed

by even the most uninitiated.

My Setup

MULTIROTOR: Custom built using parts largely

Figure 7-3 *The resulting 3D model of Hotel Santa Isobel* from *http://rctimer.com* with an APM 2.5 controller board from *http://www.diydrones.com*. It has 30-Once I had built the new quadcopter, I began amp SimonK ESCs (electronic speed controls) and

testing and collecting data. It worked flaw—

900kV motors with 10×4.7” carbon-fiber props.

lessly. I collected hundreds of photos to be pro—

CAMERA: Canon PowerShot running CHDK cus—

cessed and turned into a complete 3D model of

tom firmware, which lets the camera take RAW

the historic multistory building that was my

photos automatically.

subject. When the photos had been processed

and a complete model had been created in

FPV Fundamentals

8

Put a camera on your ‘copter and yourself in the pilot seat.

—From Make:37 by Steve Lodefink

Watching your rotorcraft or fixed-wing R/C

cheaper models often lack. Most importantly,

plane fly is always fun, but the experience really

“Wide Dynamic Range” (WDR) exposure com—

comes to life when you get to peer directly
pensation will allow you to see skies and shad—
through the “eyes” of your aircraft, as if riding
owed ground features at the same time,
along inside it.
without blown-out highlights or underresolved
In R/C circles, this is called “first-person view,” or
shadows. This is more than just an aesthetic
more commonly, FPV. It refers to piloting a
concern; these features can make a big differ—
model aircraft from the perspective of the air—
ence in your ability to navigate.
craft itself, via an onboard video camera, wire—
Besides “board” types, any number of small
lessly linked to a ground station, streaming
lightweight commercial video cameras could
real-time video to be displayed on goggles
potentially be adapted for FPV drone use. As
worn by the pilot.
long as you can figure out power and signal
There are several ways to set up FPV on your
connections, the only really critical requirement
rig; this guide should help you understand the
is low weight.
general requirements and get you quickly up to
speed.

Mounting the Camera

Camera

As with shooting photos and video from your
drone, it is especially important to keep air—
The most popular cameras for FPV are small
frame vibrations to a minimum when flying
security-type “board cameras,” which typically
FPV. Vibrations cause blurry, nearly useless
come as caseless circuit boards, with lens
image transmissions. Balance all props, and if
assemblies screwed right to the PCBs. It may be

necessary, the bells of brushless motors. Mount

tempting to use a cheap, 480-line camera, but

cameras using foam, elastic bands, rubber

for a really satisfying experience, it’s best to

standoffs, and/or other shock-absorbing means

spend a bit more. $50 will get you a 600-line

to soak up the shakes from the motors and

board camera from a trusted brand like Sony.

props.

Not only will the higher resolution greatly

improve visibility, but these slightly pricier cameras have dynamic exposure features that

49

Ground Station

Ground Station

you can still have lots of fun, even without a 10—

mile range.

Your ground-based equipment is collectively

referred to as a “ground station,” and includes

Antennae

the video receiver, antenna, monitor or goggles, battery, and often a tripod, case, or back—

The last thing you need when flying FPV is an

pack to house everything.

unreliable video link. The little “whip” antenna

Ground station designs vary greatly. A good

that came with your video transmitter is use—

one will be easy to transport, quick to set up

less. You will want to build or buy a better one.

and take down, and difficult to trip over.

Three-or four-lobe omnidirectional “cloverleaf”

or “egg-beater” antennas are a good choice and

Frequency

are easy to build and cheap to buy.

A variety of low-cost miniature video transmitters and receivers are marketed with FPV in

mind. Common frequencies include 5.8 GHz,

2.4 GHz, 1.2 GHz, and 900 MHz. There are several factors to consider when choosing a frequency.

1) Where do you live? Different countries regu—

late the radio spectrum in different ways. You

may want to research your area’s laws to avoid

legal issues. 900 MHz has great obstacle penetration, for example, but may be reserved for

phones, as in the US.

Figure 8-1 *A true heads-up display: video from drone,*

2) Where do you fly? Different frequencies have

overlaid with flight information

different characteristics. 5.8 GHz seems to have

Many people also choose high-gain (but also

good range per watt, but is essentially line-of—

highly directional) planar “patch” antennas for

sight and will not penetrate buildings or even

ground station use, and the best-equipped sys—

trees. If you fly exclusively in open areas, 5.8

tems employ “diversity” setups that consist of

GHz might be a good choice.

two or more separate antennas, to get the best

3) What frequency do your controls use? Most

of both worlds. Special switching circuitry

R/C radios now operate at 2.4 GHz; to prevent

sends you the best available signal at any given

interference, you may want to avoid that band

time.

for your video equipment.

On-Screen Display

Power

An on-screen display (OSD) is a little video pro—

Most entry-level video transmitters radiate

cessor installed in the signal path between the
100-500 mW. If you want to fly long-range
camera and the video transmitter. It takes infor—
flights, you may have to get a more expensive,
mation from its sensors and injects a graphical
higher power unit. Unlike airplanes, FPV multi—
data display into the video stream. OSDs range
rotors tend to fly shorter-ranged missions, so
in capability and cost, with the fancy ones featuring compass, GPS, barometers, telemetry,

Video Display
multiple battery voltage monitors, *etc.* While
Some models even have a video receiver built
usually considered an “advanced” FPV system
right into the goggles. I use a pair of MyVu Crys—
component, you can get a simple OSD for
tal goggles, which are general-use video
about $10 that does one very important thing:
glasses intended for watching video from an
monitor and display the battery voltage. Know—
iPod, *etc.* I modified them by adding top and
ing when you are about to run out of juice is
bottom shades of rigid foam, and a strap from a
pretty important for any FPV rotorcraft pilot.
pair of sports goggles. As with cameras, you
need to pay attention to resolution when gog-

Video Display

gleshopping. There’s no sense using a 600-line
camera with cheap 400-line goggles. As a rule
Some FPV pilots use an LCD monitor. I’ve found
of thumb, you’ll want a pair with at least
that piloting through video goggles makes for
640×480 resolution. If you use an OSD, chances
a much better, more immersive experience.
are you won’t be able to read the text on the
There are video goggles made specifically for

display at a lower resolution.

the FPV hobby, notably those by Fat Shark.

Chapter 8: FPV Fundamentals

51

Rules of Flight

9

Flying a UAV makes you a pilot, and like any

• Keep a clear, safe zone for takeoff and

pilot, you are responsible for the safe operation
landing.
of your aircraft. The Drone Dudes, Jeffrey Blank
• Make sure your payload is perfectly
and Andrew Petersen, share their rules of
balanced on your airframe.
engagement.
• Fly safe and stay alert. Listen to your
• Know your equipment inside and out,
gut and fly within your means. Do not
and always double-check that every—
let distractions divert your attention
thing is in perfect working order before
and don't hand the controls to anyone
each flight.
without proper training.
• Charge those LiPo batteries inside fire-
• Always fly line-of-sight so you can see
proof bags in a safe location with
what's going on. Do not solely rely on
proper ventilation. Understand the
your GPS or flight controller to do the
hazards and science of LiPo battery
work for you. These tools can fail and
charging, and keep an eye on the cell
you need to be prepared for that. If you
voltages yourself as you charge or dis—
are flying in an FPV mode (first-person
charge your batteries.
view), use a spotter with binoculars to
• Choose a safe fly zone away from build—
keep visual orientation of your aircraft
ings and highly populated areas. Think
for you.
about what could happen if your air-
• It's a good idea to always fly with a
craft fails mid-flight.
telemetry module that can relay live
• Understand how changing weather
info about your aircraft. Watch your
conditions like temperature, altitude
battery voltages for any irregular per—

and wind will affect your overall flight
formance and keep your flight times
performance.
modest, always flying on the safe side.
• Check your onboard fail-safes and have
• Clear communication is essential. Make
a coordinated emergency plan with
sure you have a reliable team support—
everyone in the flight area.
ing you and that everyone knows the
predetermined flight.
• Keep a safe distance from subjects and
onlookers and always allow for unexpected drift from your plan.

PART III

Projects

Nothing helps humans to understand a topic
build a completely autonomous drone, for
better than doing hands-on projects about it.
approximately $1000. The third article covers
We close this book with a collection of project
the creation of the WAVECopter, a drone speci—
articles designed to help you get your hands
alized for flying over water! The fourth project
around the reality of building and flying your
links back to Part One of this book—it shows
own drones.
how to create a payload mechanism to drop
The first article shows how to create the Noodle
humanitarian supplies from a drone. And we
Copter, a flyable quadcopter that is about as
end the book with an entirely new type of
cheap and as sturdy as possible, since it is made
drone: a tricopter, which flies quite a bit differ—
out of foam! The second article shows how to
ently from a quadcopter.


MENU
PAGE
EXIT
TARANIS
ACCST
ENT

Noodle Copter

10

Here's a quadcopter that I designed and built in response to a CrashCast challenge to build a flyable quadcopter as cheap and as sturdy as possible.

—From Make:44 by Mark Harrison

I had seen photos of a pool noodle unit previ—

ously and wanted to try one for myself for a few

reasons:

• Pool noodles are cheap.

• It would be a good training unit when

friends wanted to try flying. I can't

imagine much you can to do break a

pool noodle!

• It would be highly visible. My main

quadcopter has really thin arms and is

hard to see at a distance.

• It would be easy to light up for night

and evening flying.

• I wanted to see how simply a working

frame could be built. For example, the

motors are simply taped to the frame.

Figure 10-1 *Structural supports for this drone are made*

• Let's face it, it's just funny to think of

from styrofoal pool noodles

flying pool noodles!

From a construction standpoint multicopters

If you build something like this, I encourage are interesting because (unlike helicopters)

you to keep to the original spirit of the thing:

they have no moving parts and (unlike air—

improvise, have fun, and don’t be afraid to try

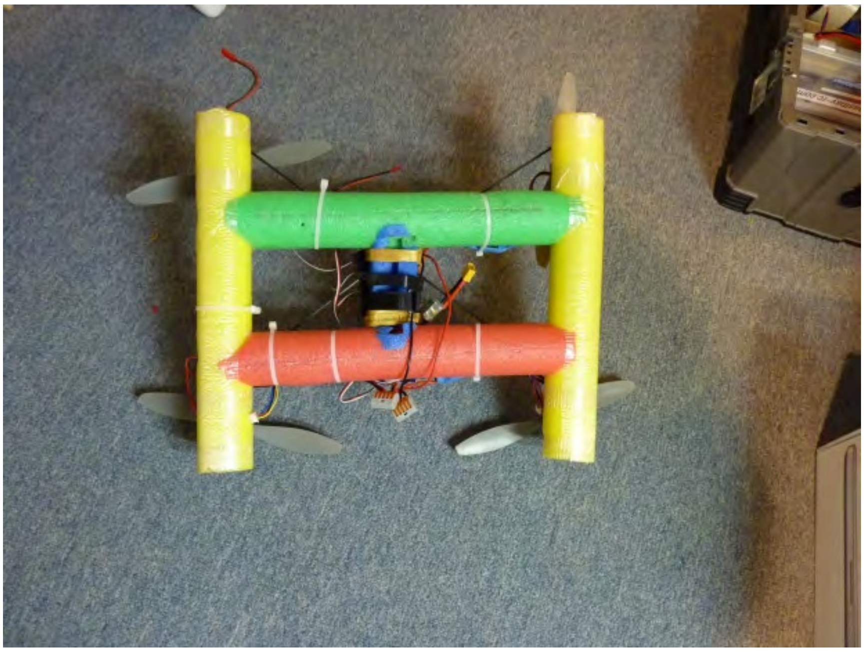
planes) do not depend on an aerodynamic

out new ideas!

body to fly. As a result, we see multicopters

made from a wide variety of materials and construction techniques.

57



Step #1: Cut the Arms to Length

Step #2: Trim the Side Arms

Figure 10-2 *Pool noodle copter lit up with internal LEDs* In keeping with the spirit of a pool noodle quadcopter, I wanted the construction to be as

simple as possible (for example, the motors are

taped to the arms). I bodged it together in an

• The side arms will be glued to the front

evening with materials that were at hand. While

and back arms, so we need the ends of

originally done as an experiment in minimal

these pieces to be curved. It will be

design and construction, I was happy enough

easiest to do this with a jig. Get a piece

with the results that I fly it regularly and use it

of thin scrap plywood and cut a two—

as a trainer when somebody wants to try flying.

inch circle, using either a hole saw or

coping saw. Cut across this hole so you

Step #1: Cut the Arms to

have a semicircle at the edge of the

Length

wood.

• Take each of the side arms and the bat-

• Cut four pieces to 15.5 inches, and one

tery mount, and cut a semicircle out of

piece to 5.5 inches. The four pieces will

the end of each piece. Be sure the ends

be the front and back arms (yellow in

of each piece are lined up. You should

the picture) and the left and right side

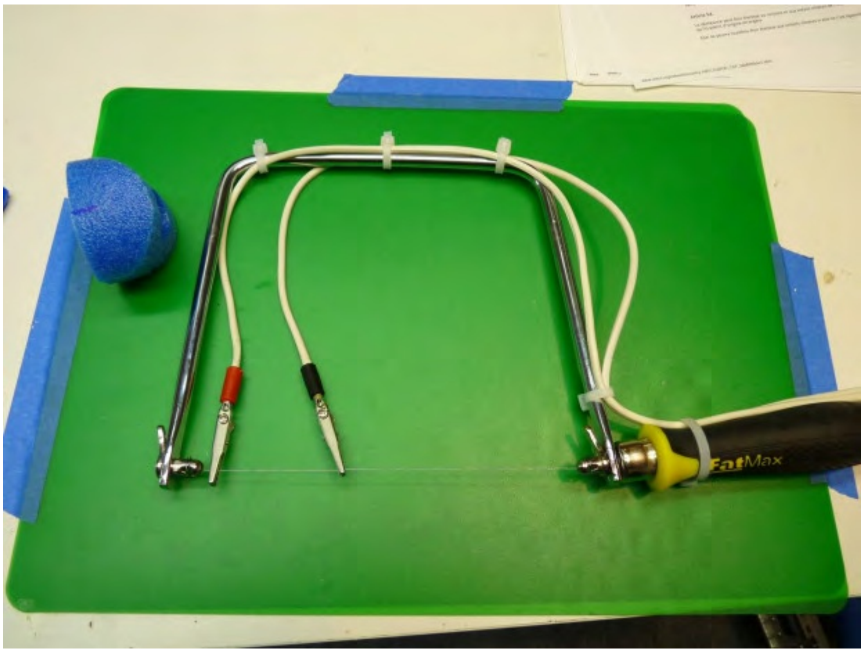
be able to dry fit the frame together

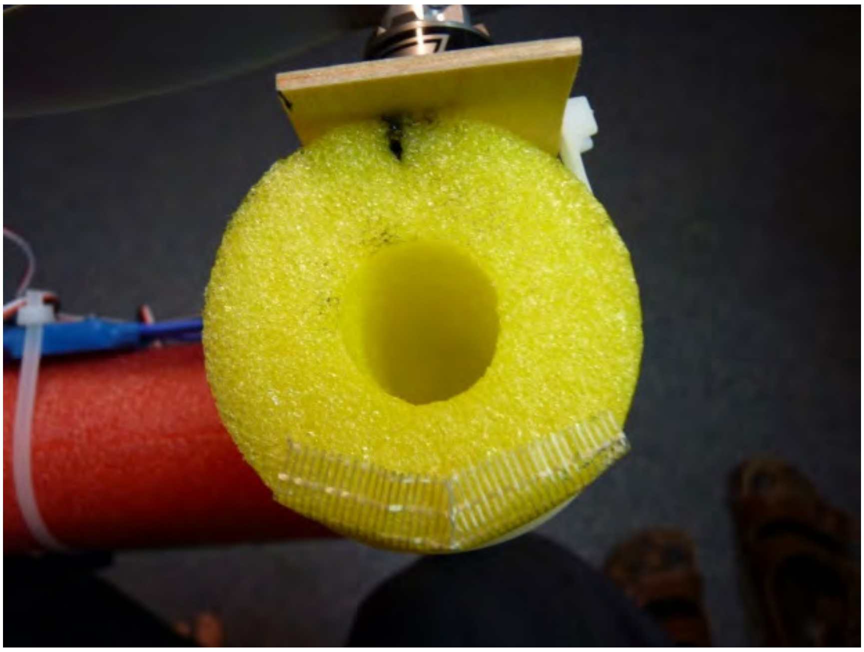
arms (red and green in the picture). The

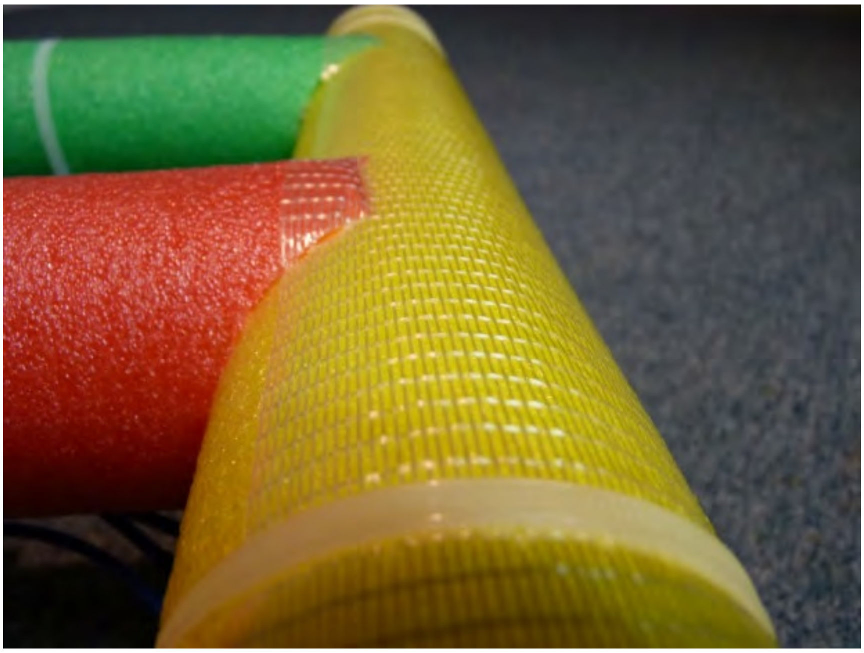
with no gaps. I had to cut a couple of

small piece will be the battery mount.

scrap pieces in order to get the feel for







Step #3: Reinforce the Arms

cutting the curve just right. You can
compensate for small gaps while gluing, but if the gaps are too big try
recutting the piece.

• Squeeze glue into the slits so that there
are no dry areas in the slit or around
the rod. This is important, as gaps in
the slit will allow the arms to flex. Allow
the glue to dry.

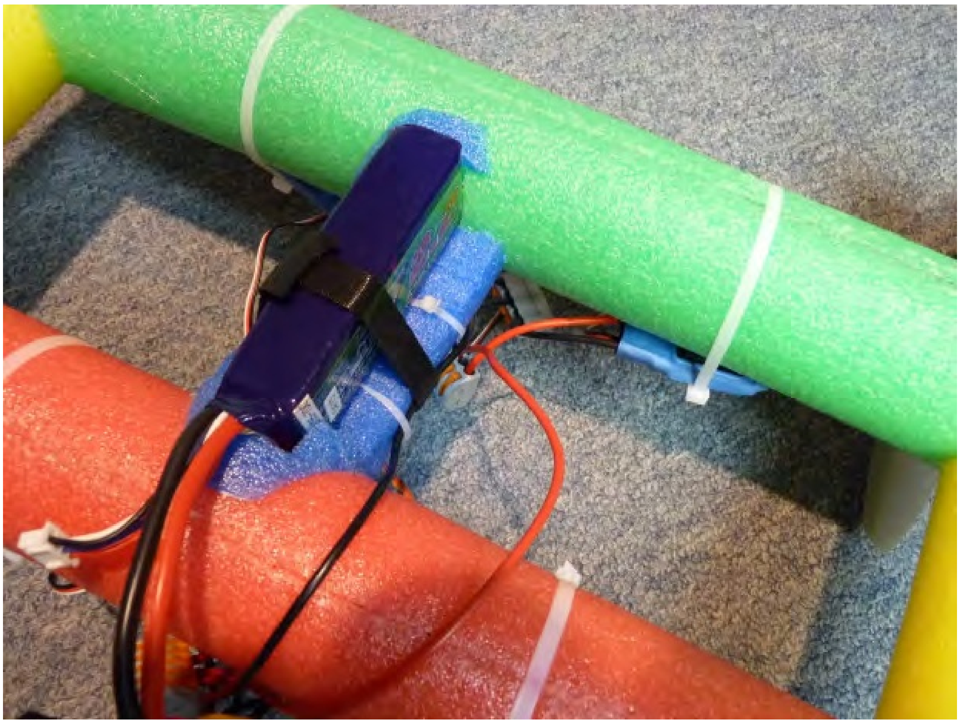
Step #3: Reinforce the Arms

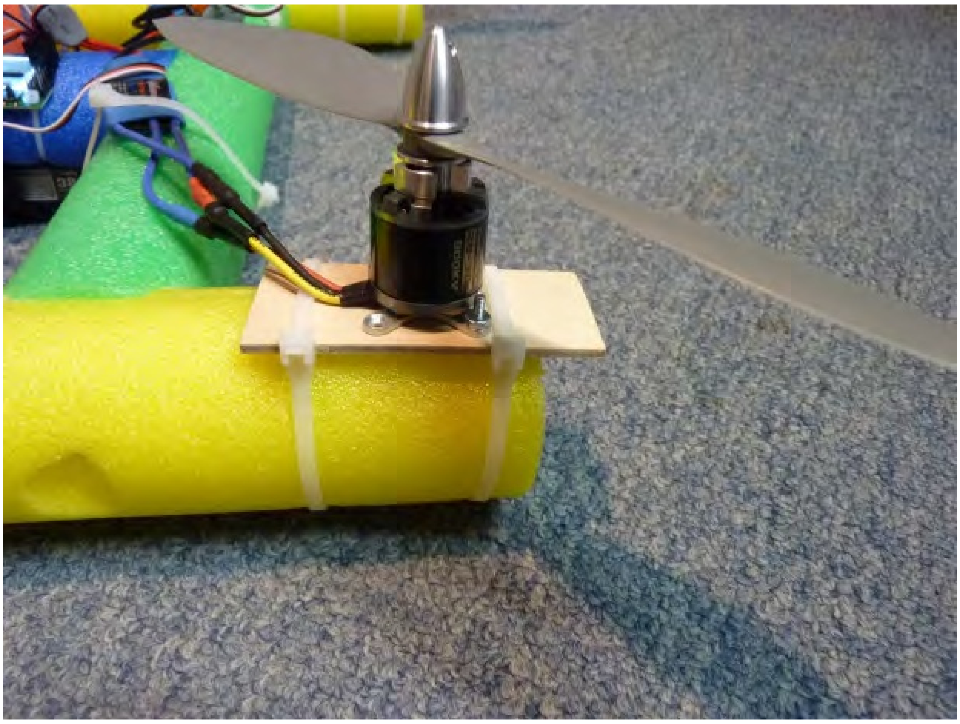
• I used Beacon Foam-Tac glue, and it
worked really well. The only requirement for the glue is that it not melt the
foam. Try gluing some scraps together
if you’re not sure.

Step #4: Attach the Arms

• Make a 1/4-inch slit along the top of
each of the four arms. Be careful not to
cut through to the center. Insert the 12—
inch carbon-fiber rods into the slits on
the left and right arms, and the 15-inch
carbon-fiber rods into the slits on the
front and back arms. I originally wanted

• Make marks on the front and back
to try 3/16-inch fiberglass kite rods, but
arms, five inches from each side. Glue
I couldn’t find a place to get them con—
the left and right arms to the front and
veniently. Some pieces of split bamboo
back arms, centering the left and right
would probably work as well.
arms on the marks you made on the





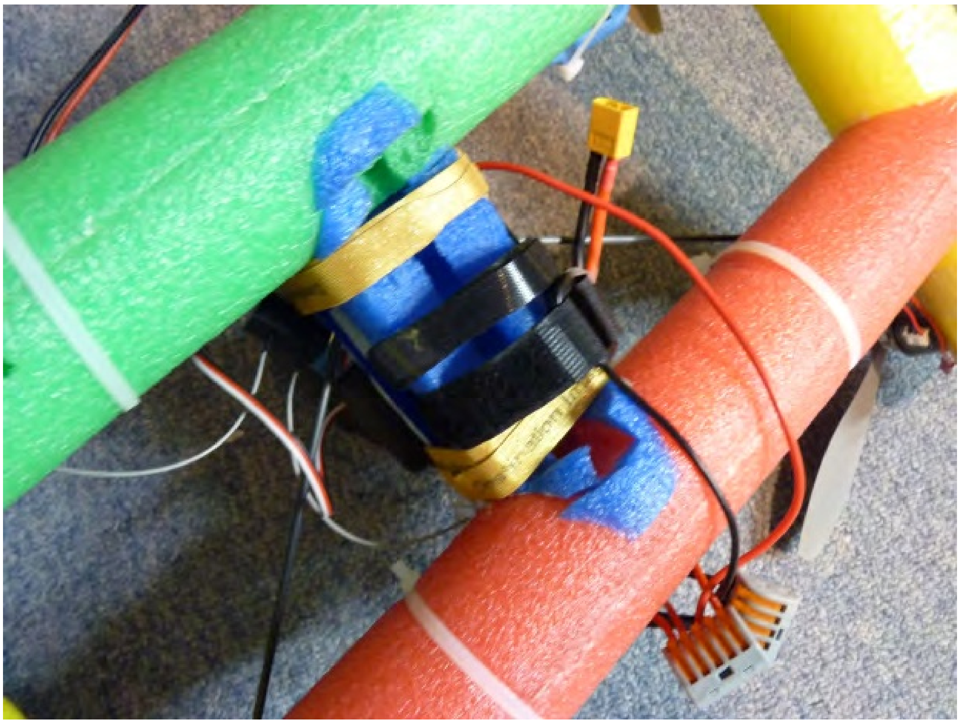
Step #5: Mount the Motors

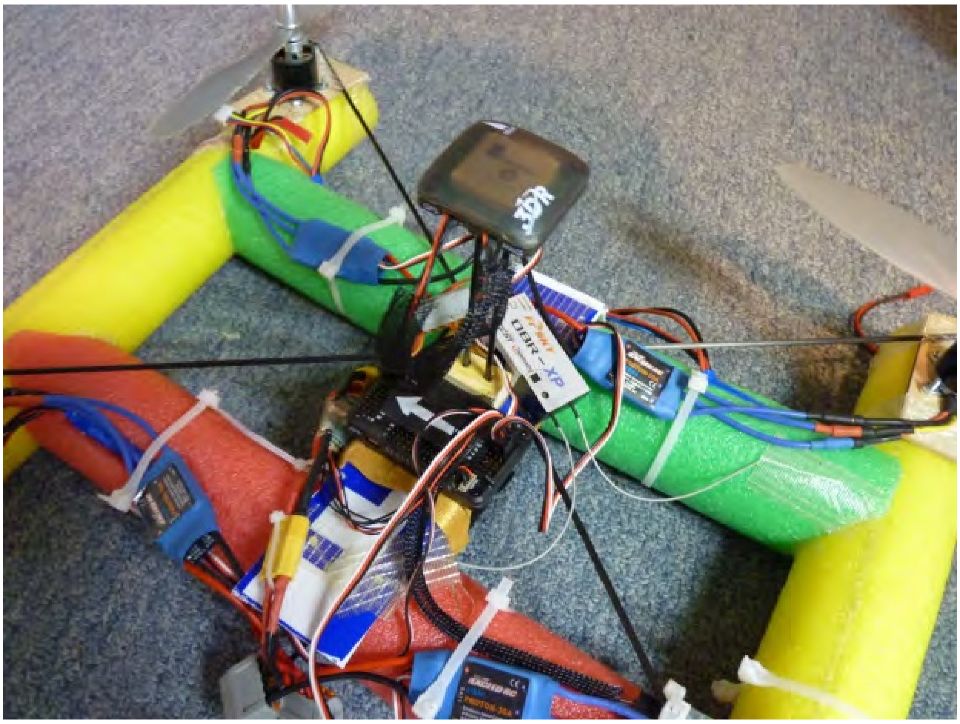
front and back arms. Be sure you’ve got

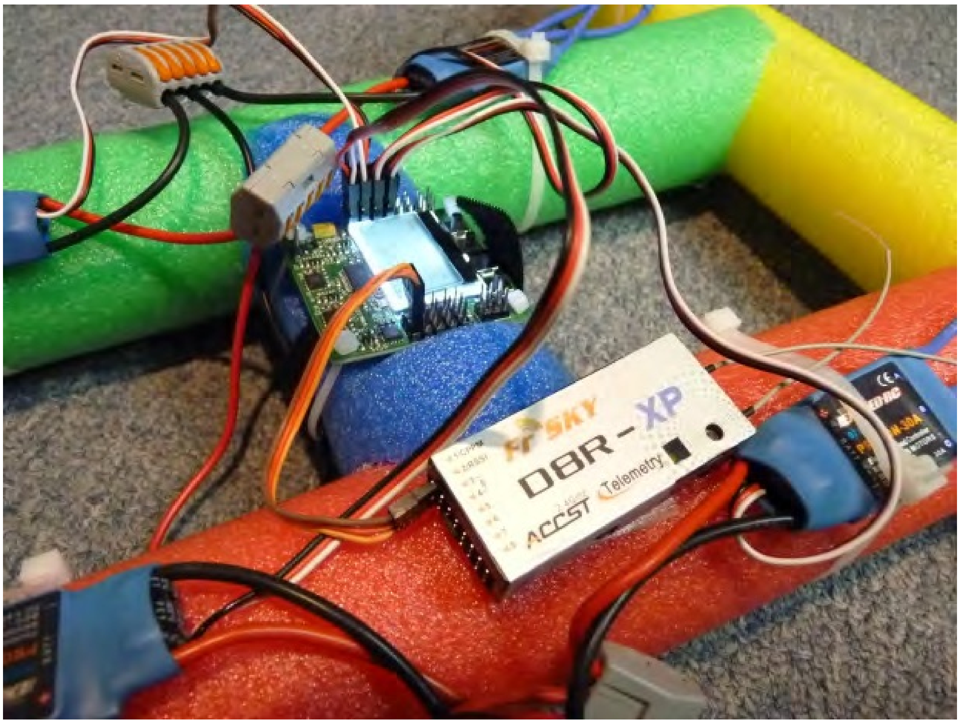
Step #5: Mount the Motors

glue over the entire curved mating surfaces. Try to eliminate all gaps, but if you’ve got some small gaps it will be fine. Check your alignment, and secure with blue tape while the glue dries.

• Do the same with the battery mount. It
fits centered between the left and right
arms.
• Cut four plywood scraps to a size that
allows you to conveniently tape your
motors to the arm. With my roll of tape,
a dimension of 1 inch by 3.5 inches
worked well. I originally tried zip ties,
but they cut into the arm and didn't
keep the motors level. Strapping tape
works perfectly.
• The frame is complete after all the glue
• Tape the four motors to each end of
has dried. Check your joints, and make
the front and back arms. Use strapping
sure they're tight and strong. The frame
tape on each side of the motor. Run the
should be relatively rigid (by pool noo—
tape all around the arm so it overlaps
dle standards, at least).
with itself. Make sure it's smooth and
• Run a length of strapping tape along
that the motors are flat on top of the
the bottoms of all four arms: front and
arms. You can adjust the motor posi—
back, and left and right. Make sure it's
tion by wiggling them a bit.
tight and smooth. This, in conjunction
with the rods in the top of the arms,
will eliminate flex.




3DR
DBR-XP



Step #6: Configure the Center Mount

Step #6: Configure the Cen-

instructions here. The Ardupilot Mega **ter Mount** is my preferred flight controller board,

but I've tested the KK2 and Flip controllers and they also worked well. Note

that everything is taped, hot-glued, or

zip-tied to the top of the unit. I did this

because I wanted to finish it quickly,

and I honestly thought I would recycle

the parts after my friends and flying

buddies had gotten a good laugh.

Cut out some of the bottom battery mount.

There should be just enough room for a 3S

2200 mAh battery to fit. I bodged the flight

control board mount by hot gluing the electronics to a piece of scrap coroplast plastic (just

about anything flat will work), and then attaching the coroplast to the top of the battery

mount with two velcro straps, one on each side.

If I make another frame, I'll try running some of

A third velcro strap holds the battery in place.

the wires, etc., either through the arm or

embedding them like the rods. Interestingly,

Step #7: Flight Electronics

while it's incredibly ugly viewed from the top, it

looks quite nice from the air since you're mainly

viewing the bottom. The farther away it is, the

nicer it looks.

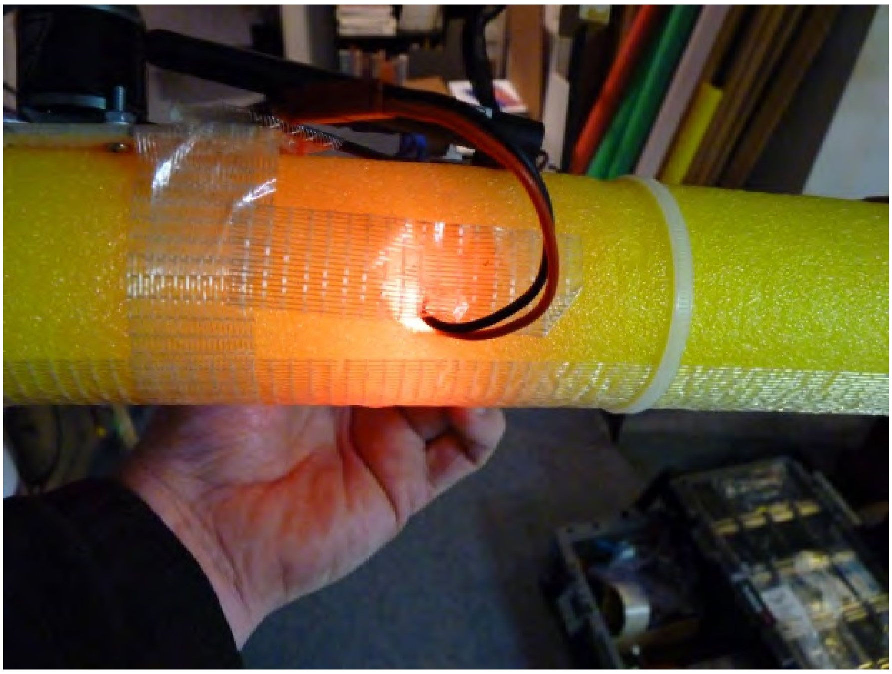
• Configuring the flight electronics is the

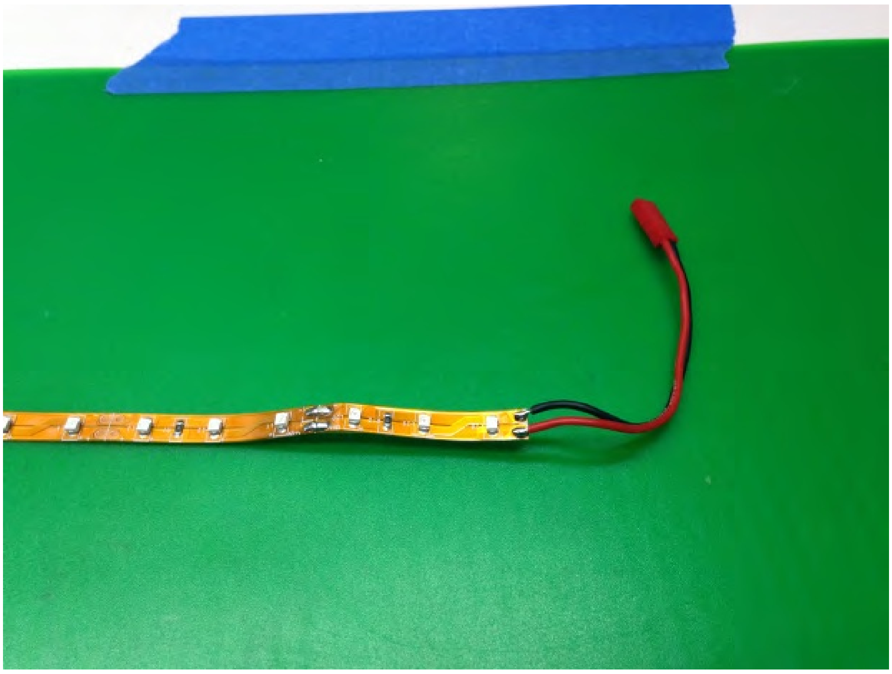
same as for any other quadcopter. You

can follow Chad Kapper's excellent

Chapter 10: Noodle Copter

61





Step #8: Adding Lights

• I didn’t have a power distribution

the rigidity of the frame. I taped a cou—

board handy, so I used Wago connec—

ple of extra carbon-fiber rods to the

tors to do this. Here are some notes on

plywood motor mounts in an X shape

[doing this: *http://eastbay-*](http://eastbay-rc.blogspot.com/2011/03/update-wago-connector-for-power.html)

to counteract this, but if you don’t cut

rc.blogspot.com/2011/03/update-wago-

into the arms that won’t be necessary.

connector-for-power.html.

Step #8: Adding Lights

• At night the yellow arms were quite a
lot brighter than the red and green
arms. I arranged it so that the yellow
arms were powered by a 2S battery
• Lights were simple to add. LED strip
and the red and green arms were pow—
lights fit perfectly into the hollow pool
ered by a 3S battery.
noodles. I used a separate battery for
the lights so I wouldn't have to run an
extra wire to the main battery.

Step #9: Test Flights and

More Information

• I make a big mistake though. I cut a slot
in the arms for the LED batteries. They
• The Noodle Copter flies quite well. The
were a perfect fit, but the cut in the
fat arms catch the wind more than
arm allows the arms to twist, reducing
other copters, but it's stable even in

Step #9: Test Flights and More Information

pretty high winds. We maidened it with

low the progress of the Noodle Copter

gust of wind up to about 15 MPH:

and other East Bay RC projects here:

http://bit.ly/1WO7qSI.

http://eastbay-rc.blogspot.com and http://bit.ly/1pLT6zS. There are a lot of tutorials on making and flying RC craft of various sorts, and on using the various electronic bits that make model

aircraft fly these days.

• Here's a few more articles on the Noodle Copter. You can get more information on the Noodle Copter here: http://

bit.ly/1q5S3e0, http://bit.ly/1T9mhrQ, and http://bit.ly/1pLSV7T. You can fol-

The Handycopter UAV

11

There are essentially two configurations for a quadcopter: the “+” frame and the “X”

frame. Here we’ve chosen to build an X frame so your onboard camera can have a clear forward view.

—From Make:37 by Chad Kapper

We’ll take you all the way from building the air-

• Liquid electrical tape

frame to adding autonomous flight capability

• Polycarbonate sheet, 0.093"×8"×10”

with ArduPilot. Once you’ve got it working, you

could program this drone, for instance, to auto-

• Zip ties, 4” (100-pack)

matically visit a series of landmarks or other

• Flexible PVC coupler, 1¼” to 1¼”

waypoints and take pictures of them.

• Aluminum bar, 1/8"×3/4"×36”

Time Required

A weekend

• Hook/loop strap, 1/2"×8” (2)

Cost

• Hook/loop tape, 3/4"×18”

Airframe

• Weatherstrip tape, foam, 3⁄8"×12”

$30–$60

• Double-sided tape, 1"×5’

Avionics

• Wire, stranded insulated, 12 AWG, 12”

$500–$800

red and 12” black

Materials

For the avionics:

• Copper pipe reducer, 1” to 1/2”

For the airframe:

• Gimbal motors (2), iPower 2208-80

• Conduit clamps, 1 1/2” (4)

• Gimbal controller, iFlight V3.0

• Square dowels, wood, 1/2"×36” (2)

• Flight controller, 3D Robotics ArduPilot

• Machine screws: flat-head M3×6mm

Mega 2.6

(8); M3×20mm (12); M3×25mm (4)

• GPS module, 3D Robotics LEA-6H

• Hex nuts, M3 (8)

• R/C transmitter, 5+ channels

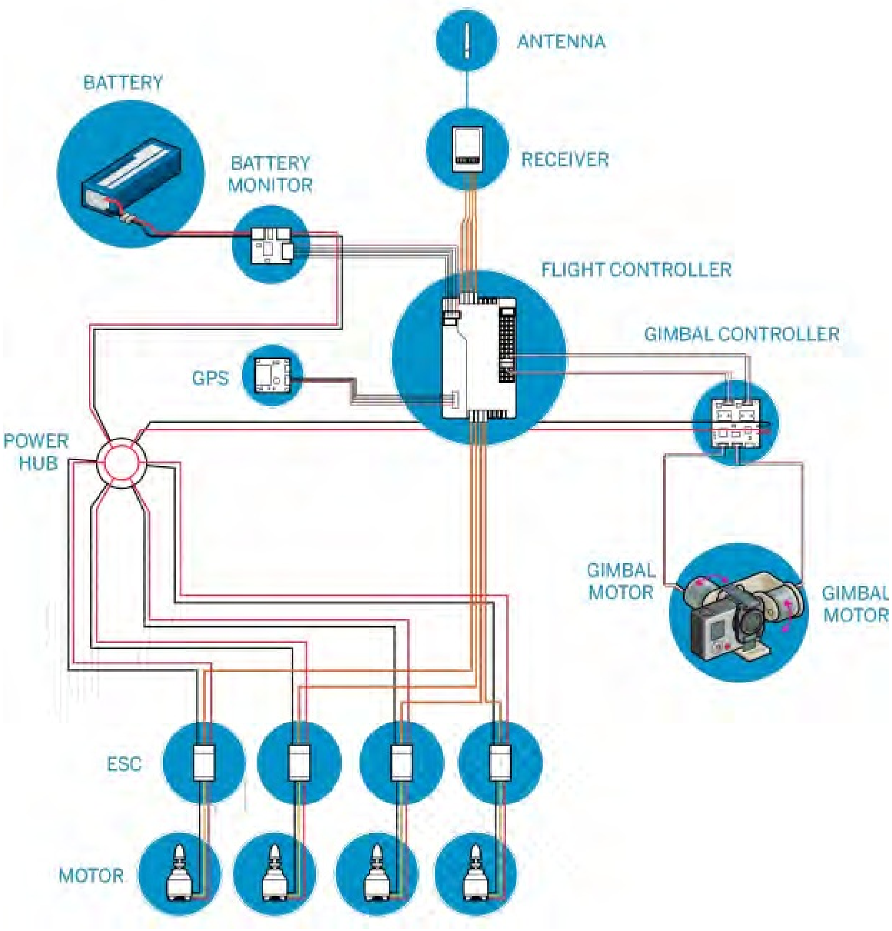
• Flat washers, M3 (4)

• R/C receiver, 5+ channels

• Thread-locking compound

• Motors, 850kV (4) AC2830

65



Tools

• Propellers, Turnigy 9047R SF (2)

• Propellers, Turnigy 9047L SF (2)

• Electronic speed controllers (4)

• M/M servo leads, 10cm (5)

• Camera, GoPro Hero3 White Edition

• LiPo battery, 2,200mAh, 3S 20C

• Battery monitor, APM Power Module

with XT60 connectors

Tools

• Computer with printer

• Straightedge

• Plastic scoring knife

Figure 11-1 *Wiring diagram for the Handycopter UAV*

• Drill and bits: 1⁄8”, 3⁄16”, 1/4”, 5⁄16”, 3⁄8”

• Wood saw

• Phillips screwdrivers: #1 and #2

• Pliers

• Wire cutters / strippers

• Hacksaw

• Soldering iron and solder

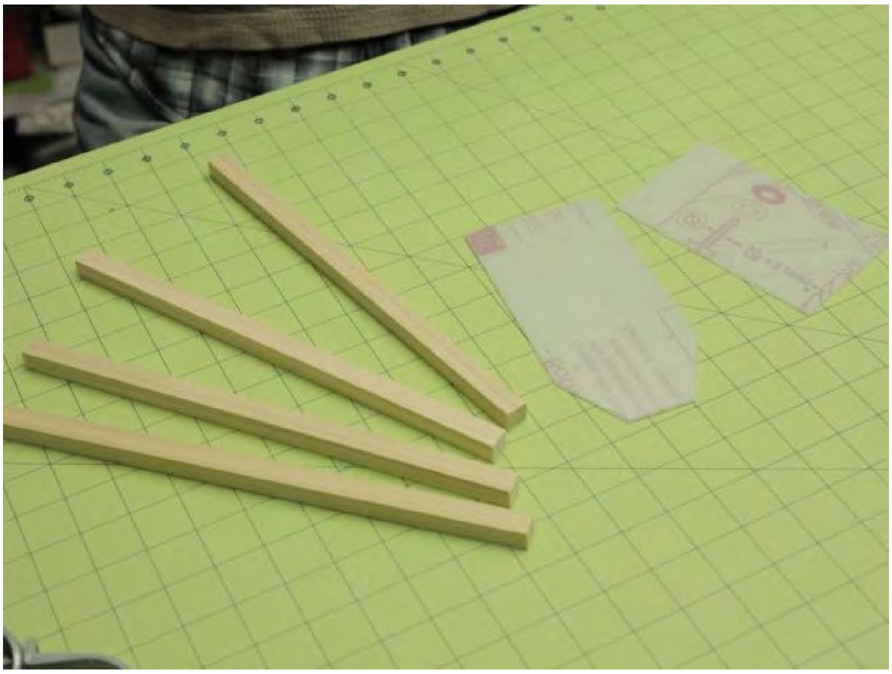
• Scissors

• Pencil

• File

• Hobby knife

Figure 11-1 is a look at the overall wiring diagram for the Handycopter UAV. We'll then take you step-by-step through the process of creating it.



Step #1: Fabricate the Body

Step #1: Fabricate the Body

• The copter’s central hub consists of two

Step #2: Cut and Drill the

polycarbonate plates. Download the

Booms

cutting and drilling templates from

[http://makezine.com/the-handycopter-](http://makezine.com/the-handycopter-uav)

*[uav, pr](http://makezine.com/the-handycopter-uav)*int them full-size, and affix them temporarily to your polycarbonate sheet.

• Saw four square dowel booms to 10"–

11” each. Shorter booms will make

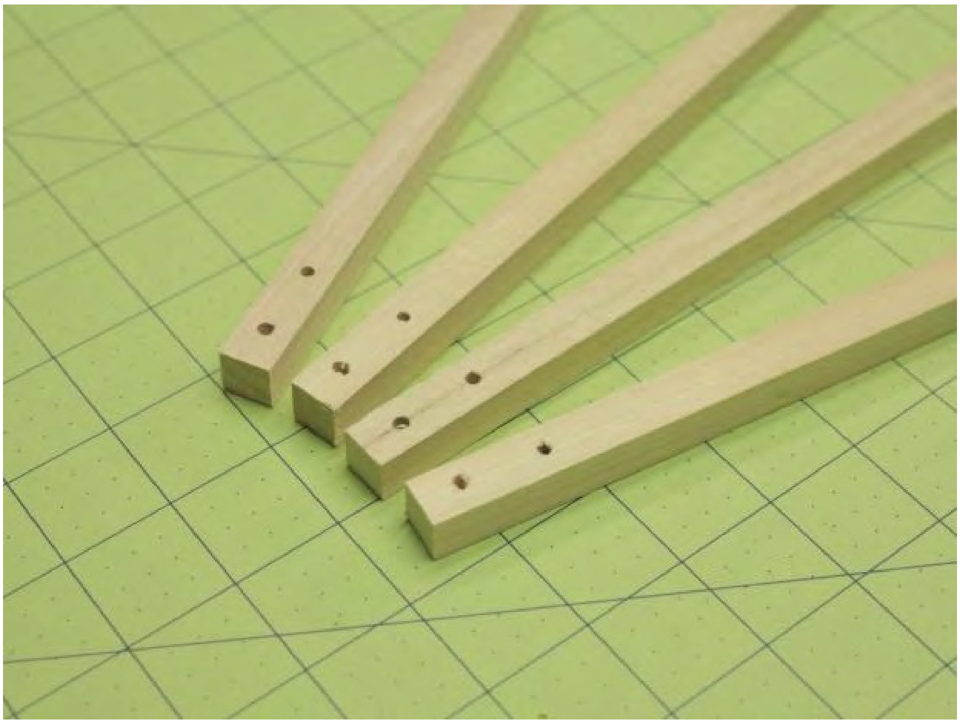
your quad more agile, and longer

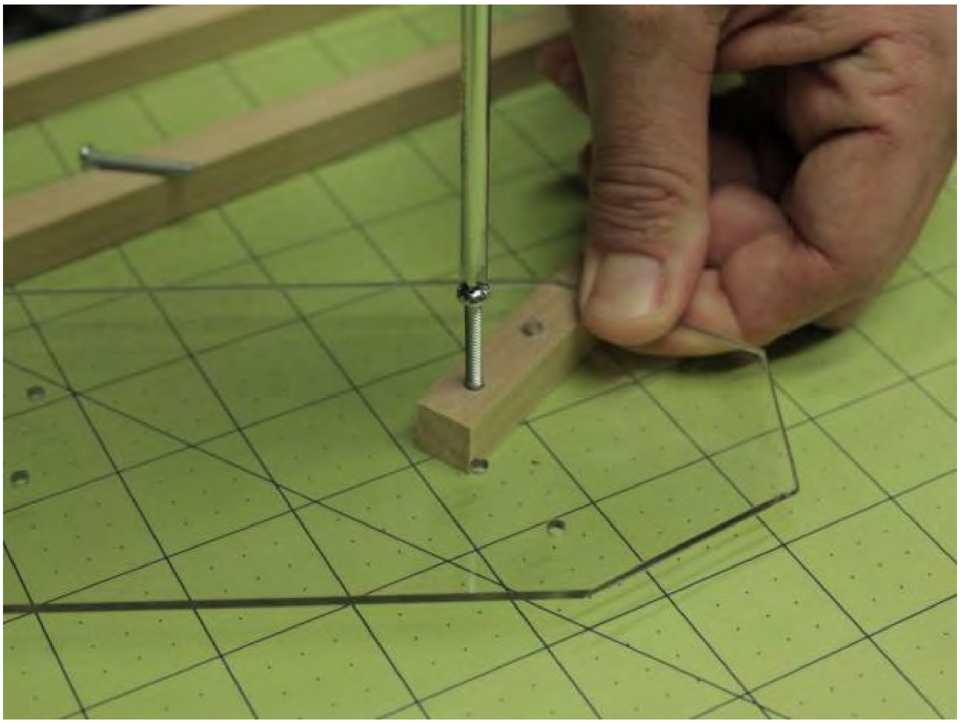
booms will make it more stable.

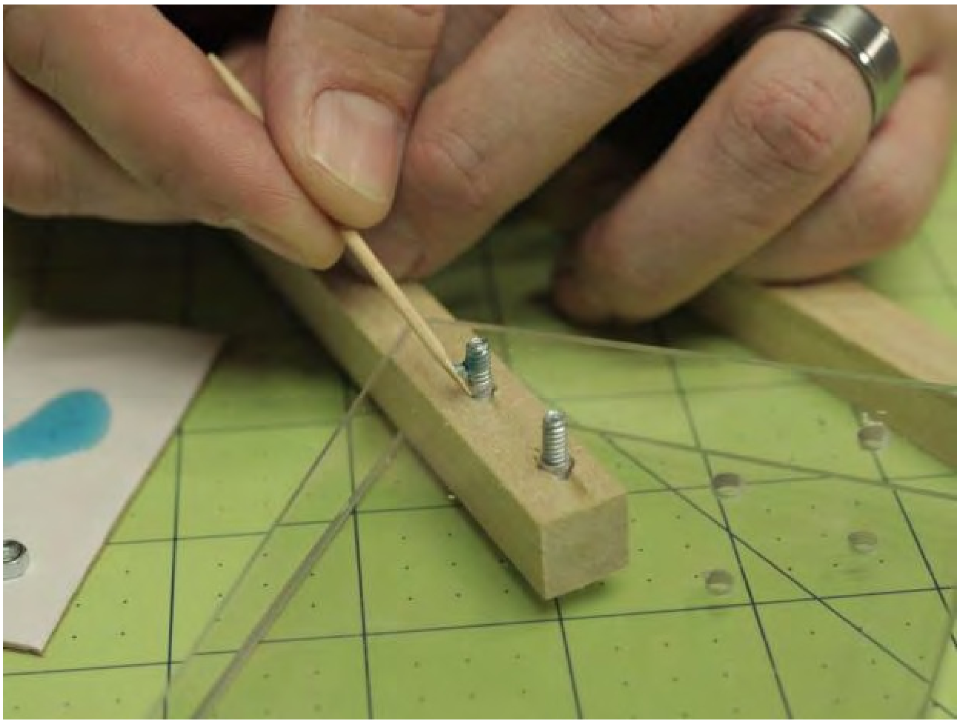
• Use a plastic cutter to score and snap each plate to shape, then drill out the holes with a 1/8” bit.

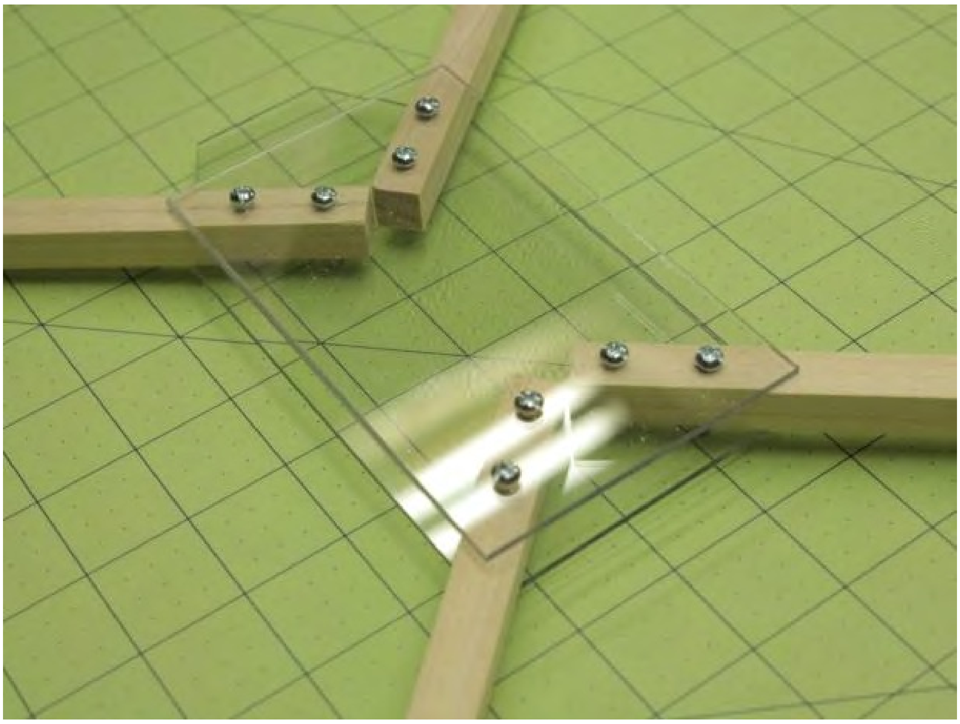
Chapter 11: The Handycopter UAV

67









Step #3: Assemble the Frame

• Secure the booms between the hub plates using four M3×25mm screws through the inner holes and four M3×20mm screws through the outer holes.

• Drill two 3mm holes, one 6mm and one 26mm (on-centers) from the end of each boom.

• Once the booms are in place and you’re happy with the fit, apply thread-locking compound to the outer screws only, add nuts, and tighten them down.

Step #3: Assemble the Frame

Thread the inner nuts on just loosely, for now.

Step #4: Wire the Power Hub

• Six components will connect to the power hub—the four electronic speed controllers (ESCs), the power module, and the gimbal controller board.

Step #5: Drill Motor Shaft Clearances

• First, cut off the male XT60 connector

• Wiring the motors and electronic

from the APM power module cable.

speed controllers together is tedious.

Then strip about 1/4” of the insulation

Store-bought distribution boards are

from each wire, red and black, on all six

convenient, but cost space and weight.

components, and tin the stripped ends.

I prefer this homemade distribution

Saw a 3/8” ring from each end of the

hub made of rings of nested copper

copper reducer, and file off any rough

pipe to keep things lean and tidy.

edges.

Step #5: Drill Motor Shaft

Clearances

• Solder each of the six red positive leads

to the smaller ring, and the corresponding six black negative leads to

the larger ring. Wrap the smaller ring in

• Here we’ll show you how to make your

3/8” foam weatherstripping tape and

own landing struts from ordinary con—

slip the outer ring over it.

duit clamps. You can also use inexpensive prefab combination landing gear /

motor mounts that simplify the process

quite a bit, and look better to boot.

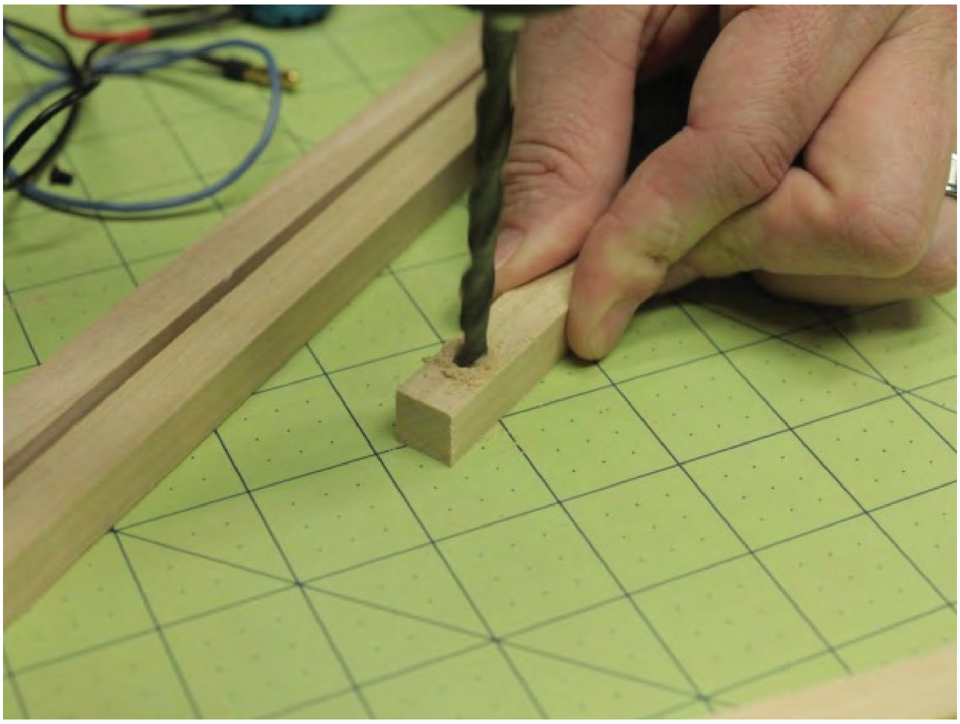
Please check out our product line at

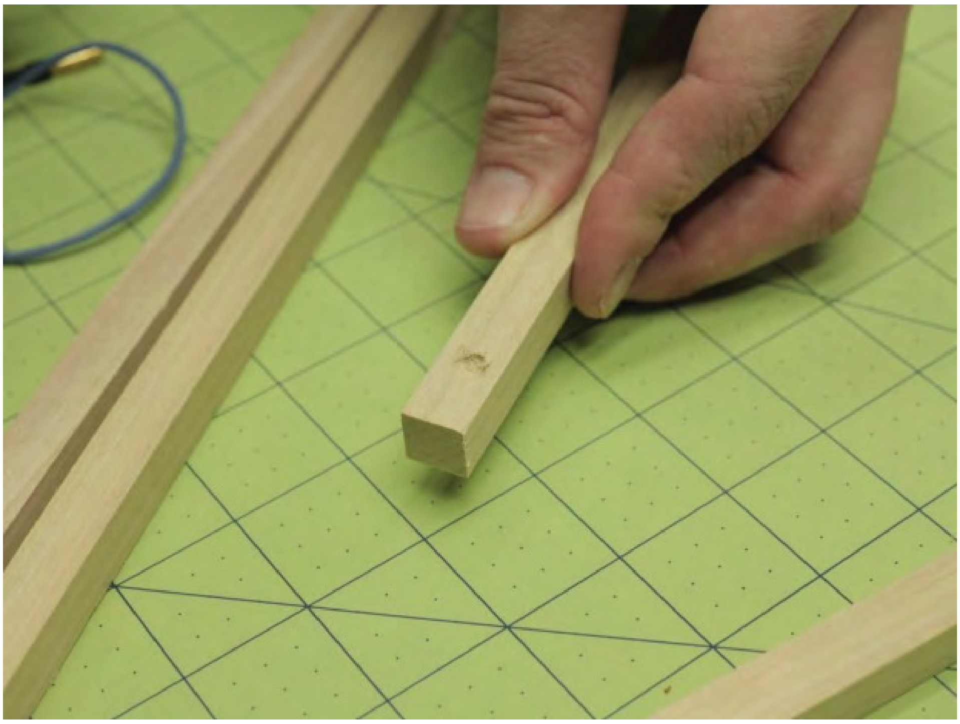
http://www.flitetest.com if you're interested in the prefab option.

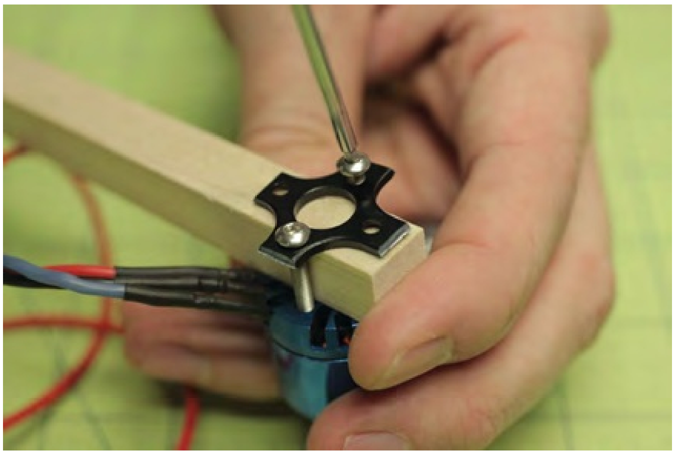
• Finally, paint the entire hub with liquid

electrical tape for insulation.

69







Step #6: Mount the Motors

Step #6: Mount the Motors

• If you go the homemade route, you'll

be mounting the motors directly to the

• Cut down the bracket that came bun—

booms. Mark and drill a shallow blind

dled with each motor and use two

recess in each, so the shaft can spin

M3×20mm screws to clamp a motor to

freely. A 5⁄16" bit works well for this.

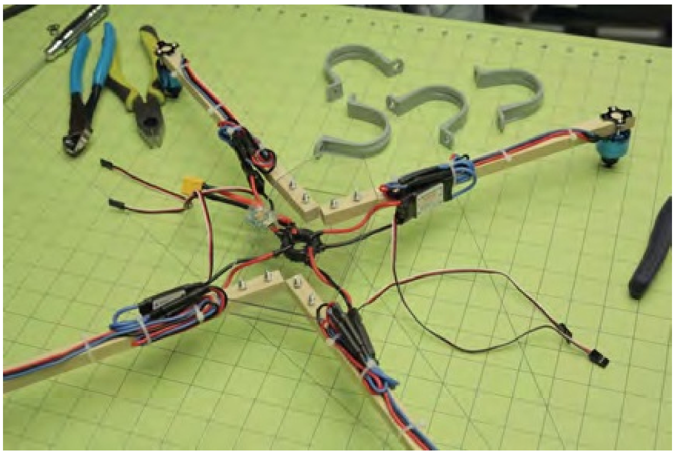
the end of each boom.

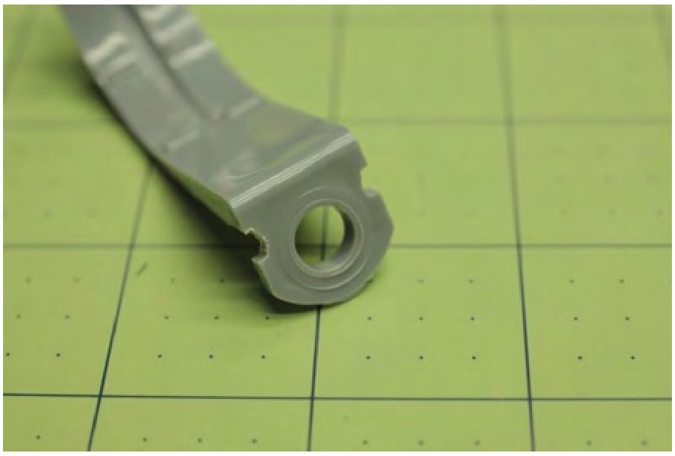
Figure 11-2 *Only two screws are used on each motor for mounting, and the factory brackets are cut down to save weight*

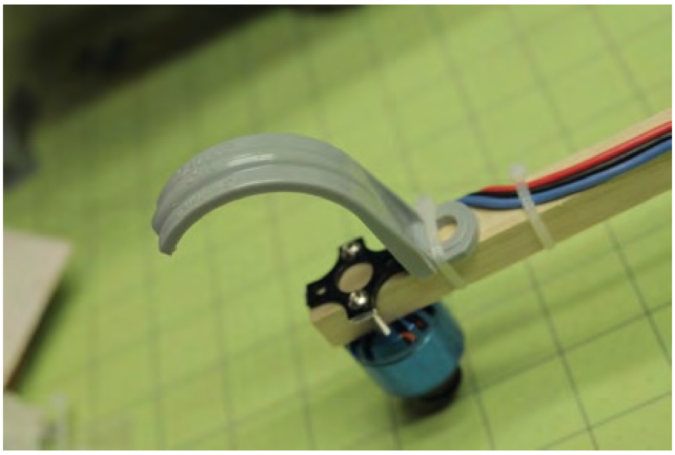
• Verify that each motor shaft spins

freely when the screws are fully tightened. If not, double-check that its

boom is properly recessed underneath.







Step #7: Add the Landing Gear

• Smooth any rough edges on the

• Use wire cutters to snip off one side of
bracket with a file.
each of four conduit clamps, leaving a
J-shaped foot behind. Smooth the cut

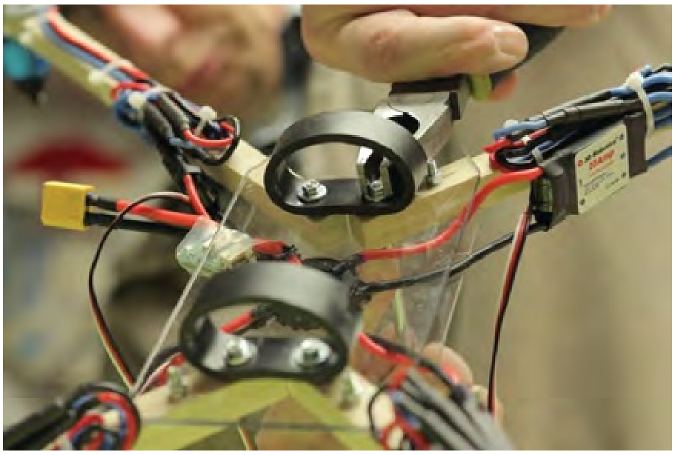
Step #7: Add the Landing

end with a file, then file or grind two

Gear

small notches beside the remaining mounting hole as shown. Attach a foot to the end of each boom, just inside the motor mount, using a zip tie run through these notches.

• Slip the power hub between the top and bottom body plates and route the ESC power leads out along the four booms. If you bought motors and ESCs from the same manufacturer, there’s a good chance they came with preinstal— led “bullet” connectors. In this case, simply plug the motor leads into the ESC leads and coil any slack under the boom. Or you can solder the motor wires directly to the ESC boards for a cleaner build. Secure the motor leads, the ESC power leads, and any leftover slack tightly against the booms with zip ties.



Step #8: Install the Shock Mounts

Step #8: Install the Shock

which helps isolate the camera from

Mounts

propeller vibrations and adds a bit of

space, above, to mount the gimbal

controller board.

• Remove the hose clamps from the flexible PVC coupler and save them for

another project. Cut two 3/4” rings

Step #9: Build the Camera/

from the coupler’s rubber body with a

Battery Mount

sharp hobby knife. Align each ring

across two of the frame’s protruding

The gimbal and battery shelf are assembled

inner screws and press down hard with

from three simple L-shaped brackets. We refer

your thumbs to mark two drilling spots.

to these as the shelf, roll, and pitch brackets.

• Drill 1/8"-diameter holes on the dents,

• Saw a 36” length of 1/8"×3/4” alumi—

through one side of the ring only.

num bar stock into two 18” sections,

Install the rings over the frame screws

then saw one of those into two 9” sec—

with M3 flat washers and nuts. Secure

tions, giving three pieces total. Make a

with thread-locking compound when

right-angle bend in each section as

you’re happy with the fit.

indicated on the templates, working

• The gimbal and battery shelf are

over a piece of wood or other scrap

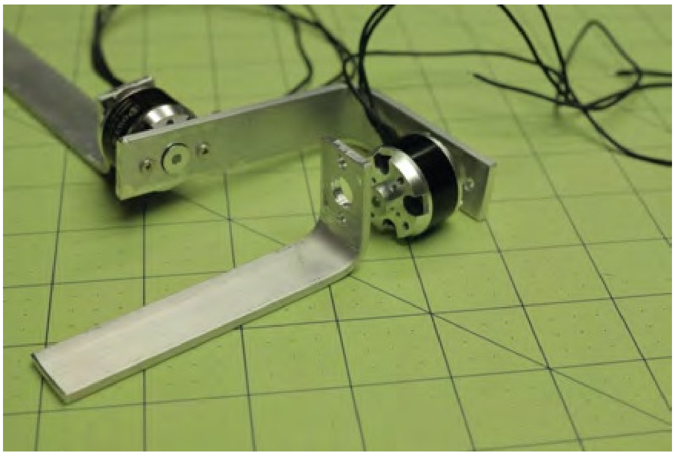
attached via two shock mounts cut

with a beveled edge to increase the

from thick flexible rubber tubing,

bend radius to about 3/8”. (Too sharp a

bend can overstress and weaken the



Step #10: Mount the Camera and Battery

aluminum.) After you've made the

• Attach the bottom of the second motor

bends, cut each bracket to final size per

to the free arm of the roll bracket, and

the templates.

its top to the pitch bracket, in just the

same way.

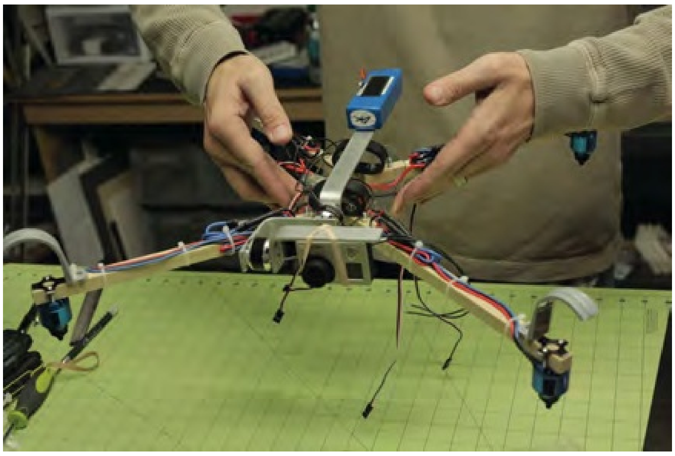
Step #10: Mount the Camera and Battery

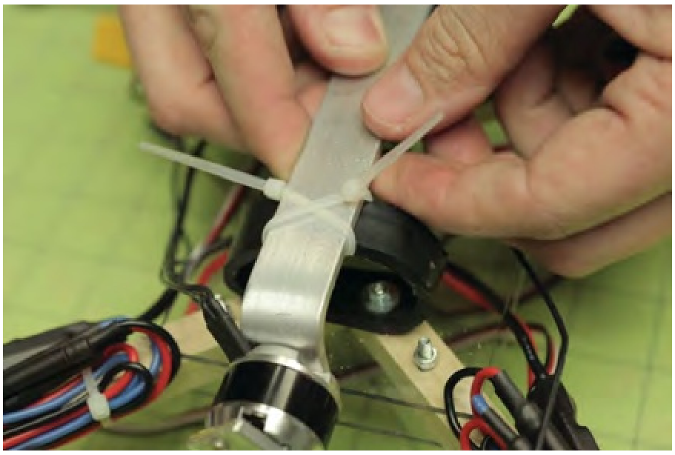
I designed this quad to balance properly with a 3S 2,200mAh LiPo battery and a GoPro Hero3 White. If you use other equipment be sure you keep the CG (center of gravity) in the middle of your airframe. Here's how to get it balanced.

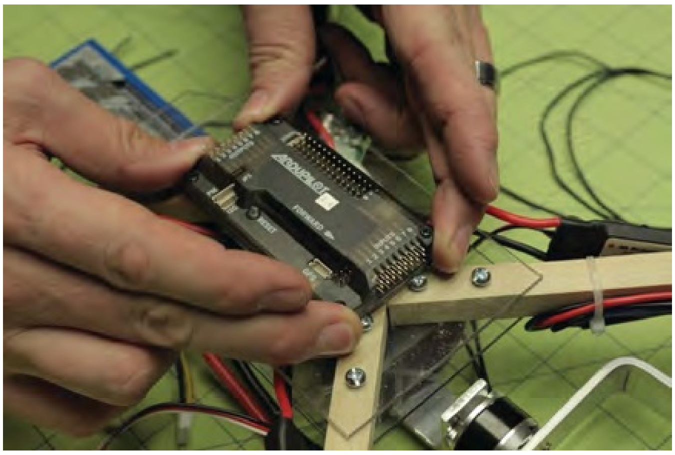
• Accurately locate, mark, and drill a centered row of three 1/8"-diameter holes on the short leg of the shelf and pitch brackets, and on both legs of the roll bracket. In each case, the outermost hole should be 3mm from the bracket end on-center, and the holes themselves 9.5mm apart on-centers. Finally, step-drill the center hole in each row up to 3/8" to provide clearance for the motor shaft.

• With the frame upside-down, balance the camera, brackets, and battery across the two shock mounts on the underside of the frame. Adjust the position of the whole assembly forward and backward along the frame until the entire quad balances evenly between your fingertips, centered on either side of the body.

• Use two M3×6mm screws to attach the bottom of a gimbal motor to the shelf bracket, and then two more to attach the top of the motor to the longer arm of the roll bracket.







Step #11: Install the Avionics

both bracket and battery as an added

precaution.

TIP

Though the GoPro is a tough

camera, you may want to build a

“dummy” version having the
same weight, and approximately
the same size, to mount during
your maiden and subsequent
shakedown flights.

• For the gimbal motors to operate
smoothly, the camera must be balanced along both axes. Weaken the
adhesive on a piece of double-sided

Step #11: Install the Avionics

tape by sticking it to your shirt and
peeling it off. Remove the backing and
apply the exposed side to the pitch
bracket, then use the weakened side to
hold your GoPro in place while you
adjust it to find the balance point. Once
you’ve got it, use an elastic band or a
velcro strap, in addition to the tape, to
hold the camera securely in place.

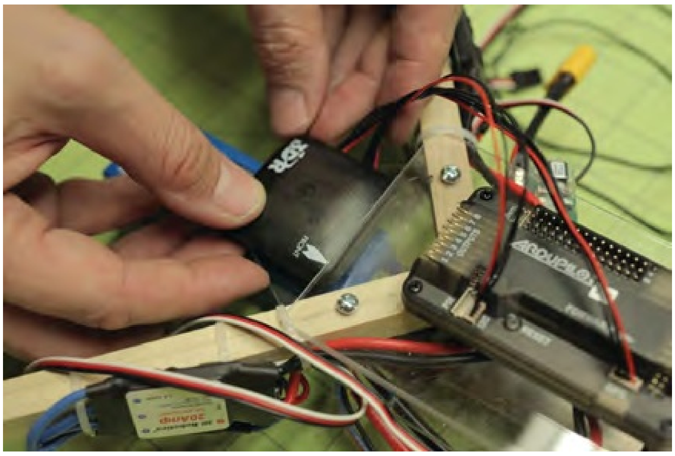
• Arrange your flight controller, receiver
and other modules before attaching
them to the airframe. Once you’re
happy with the layout, use double-sided tape to secure everything to the
frame. Download the wiring diagram
for a detailed list of all connections.

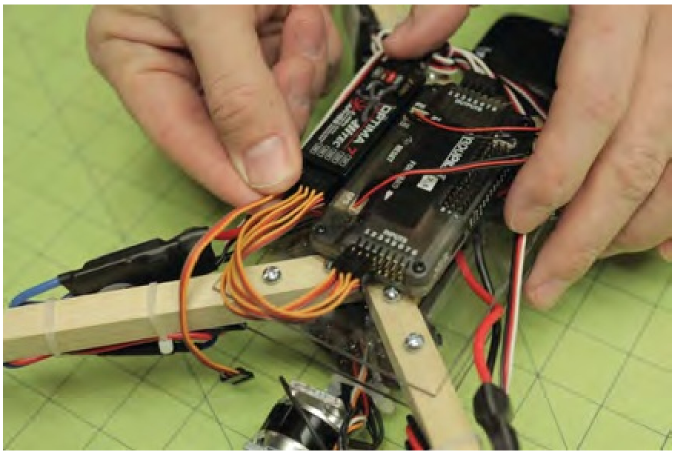
• Attach the flight controller. In this build
we use 3D Robotics’ ArduPilot Mega

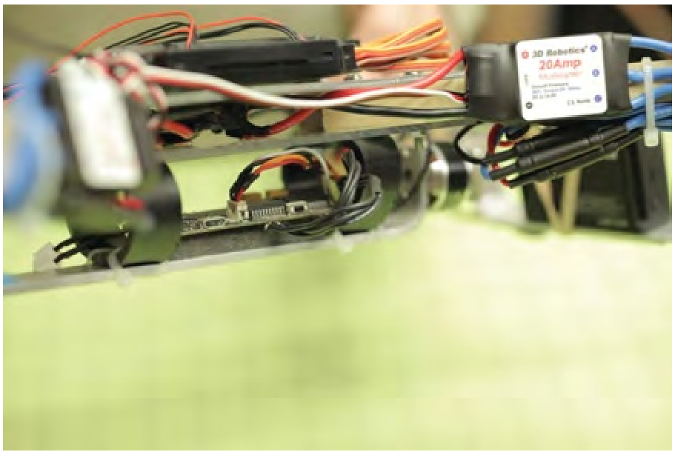
• Once you’ve got the CG right, fix the
(APM) 2.6, which contains an acceler—
shelf bracket to the shock mounts with
ometer and must be oriented correctly
two sets of crossed zip ties. Apply
with respect to the frame. Align the
hook-and-loop tape on top of the shelf
arrow on the APM case toward the
bracket and on the underside of the
front of the quad and fix it in place with
battery, and fix the battery in place.

double-sided tape.

Add a hook-and-loop strap around







Step #12: Install the Gimbal Controller

Step #12: Install the Gimbal

Controller

• Add the GPS/compass module, which

fits neatly on the rear extension of the

bottom frame plate, and also must be

aligned with the arrow forward. Tape

The gimbal controller consists of two boards:

the module in place and connect the

the larger controller board and the smaller IMU

cable to the APM's "GPS" port.

sensor unit. The controller board goes above

• Starting from the starboard-front posi—

the shelf bracket, in the space provided by the

tion and proceeding clockwise (viewed

shock mounts.

from above), connect the ESC signal

cables to APM outputs 1, 4, 2, and 3.

• Mount the receiver alongside the APM

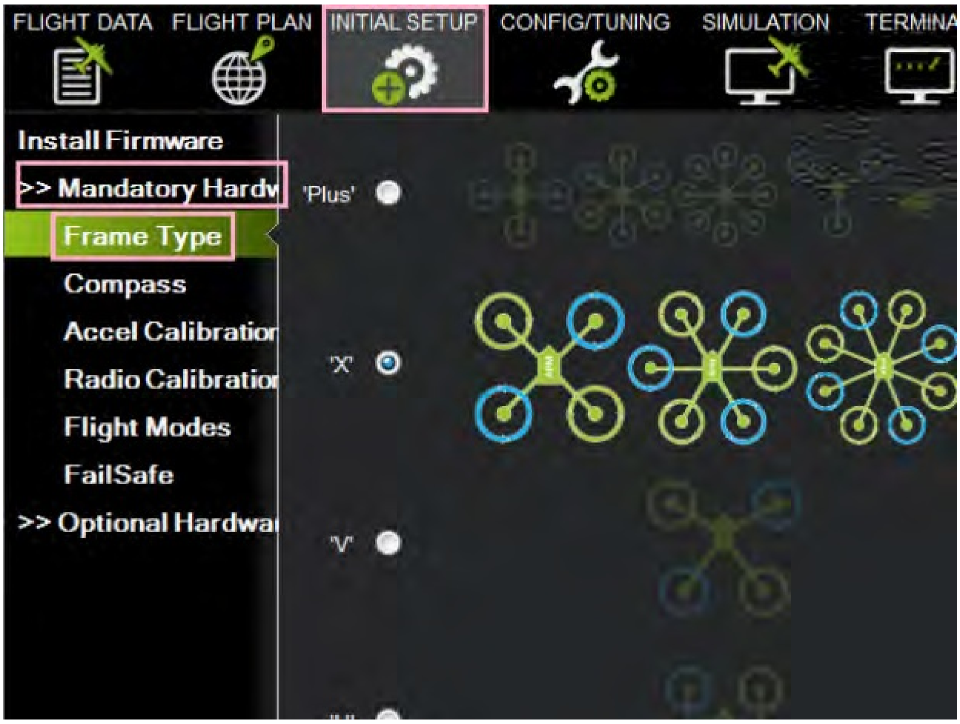
with double-sided tape, and connect

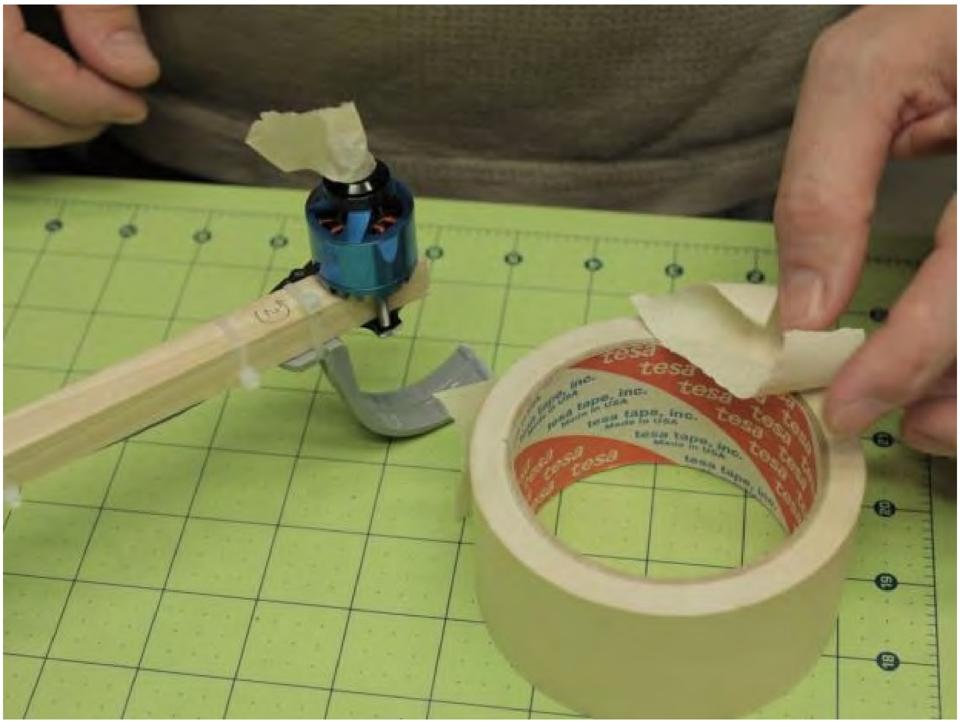
channels 1–5 to the corresponding

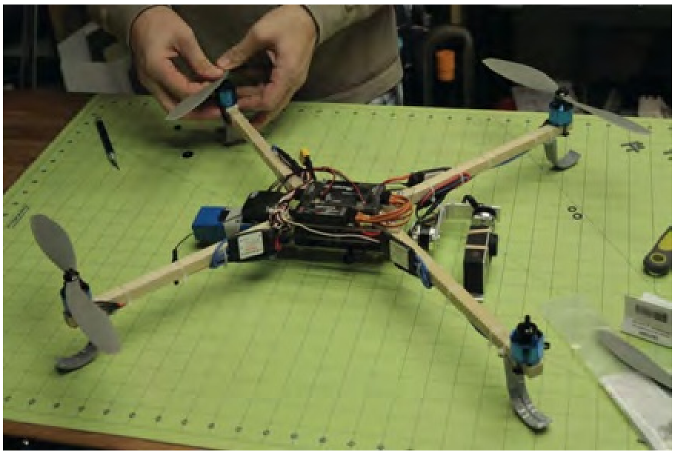
inputs on the APM.

Cover the top surface of the bracket with foam

weatherstripping to keep the solder points from shorting against the bare aluminum, then fix the controller board to it with zip ties. The IMU detects the orientation of the camera and needs to be mounted in the same plane; fix it to the underside of the pitch bracket with double-sided tape, and run the connector cable back to the control board. Connect the three wires from each gimbal motor to the ports on the control-


FLIGHT DATA
FLIGHT PLAN
INITIAL SETUP
CONFIG/TUNING
SIMULATION
TERMINA
Install Firmware
>> Mandatory Hardw
Frame Type
Compass
Accel Calibratior
Radio Calibratior
Flight Modes
FailSafe
>> Optional Hardwa
'Plus'
'X'
'V'


tesa
tesa tape, inc.
Made in USA



Step #13: Configure the Software

ler. Secure all wires with zip ties, leaving plenty

shafts to make it easy to see which way

of slack for the gimbal to rotate freely.

they are spinning. From above, motors

3 and 4 should spin clockwise, and

Step #13: Configure the Soft-

motors 1 and 2 counterclockwise (see

ware

Chapter 3). If a motor is reversed, simply swap any two of the three leads connecting it to the ESC.

• The most important factor for steady flight is balanced props! There are lots of tricks for doing this, but the simplest involves sanding the heavier side of each blade until the prop balances level on a horizontal shaft. (Sand only the flat, not the leading or trailing edges.)

• The flight controller, ESCs, and gimbal controller all need to be calibrated and configured before flight. Refer to the bundled or online instructions that came with your equipment. Specific tutorials are available through *http://makezine.com/the-handycopter-uav*.

Step #14: Add the Props

• Once the props are balanced, install them on the shafts and tighten the nuts. You'll use two conventional airplane "tractor" props and two reverse—pitched "pusher" props. Motors 1 and 2 take tractor props, and motors 3 and 4 take pusher props. (If you're not using the APM flight controller, your prop configuration may be different.) Once you've got it right, mark the number and direction of rotation for each motor on its boom for easy reference.

• Make sure the props are balanced, the parts are securely fastened, and none of the props, gyros, or controls are

• Before you install the propellers, put

reversed.

bits of masking tape on the motor

The Maiden Flight

Conclusion

Don’t expect your quad to fly perfectly the first time. You’ll likely need to make some tweaks and adjustments before it flies well. If you’ve never flown a quad before, remember to work the controls gently, as most beginners tend to oversteer. Your first goal should be to hover about 24” off the ground for 1-2 seconds and then immediately land. Once you can do that consistently, try to take off, rise above the “ground effect” zone (3'-4’), and then land gently. Work your way up gradually to longer and higher flights.

WARNING

It is likely that you will crash at some point, especially if this is your first multirotor. Keep a

If you need to reverse a motor, be

positive attitude, pay attention, and try to learn

sure to swap the motor control

something every time. Crashing, learning,

leads only, not the ESC power hub

repairing, and improving your skills and your

leads. Don’t ever reverse the power

machine is part of the fun and challenge of the

connections on an ESC!

hobby.

The Maiden Flight

Verify that all your radio trim settings are at zero (if you have to trim, do it through the APM, not the radio). Wait for wind-free conditions to actually make the first flight.

Chapter 11: The Handycopter UAV

77

WAVEcopter: A Waterproof

12

Quadcopter

WAVEcopter is a fully waterproof multicopter frame that I have constructed mostly from readily available and cheap electrical parts. My reasons for building it were to gain a new perspective on surfing photography, to do aerial surveying of event sites, and to satisfy my general fascination with robotics and aviation.

—From Make:44 by Alec Short

There are lots of different setups for copter

electronics, so I've skimmed over some of that

detail as I think there are better setups than

mine (like the ArduCopter). The most important

part of this project is being able to waterproof

the frame while housing an optimum balance

of battery power and weight.

The drone has made successful flights of over

10 minutes with no apparent overheating of

speed controllers or motors, which was a big

I rebuilt the copter after it suffered a serious

initial concern in a airtight/waterproof frame.

collision into a cliff on the south coast of Corn—

I'm new to multirotors and I've read a lot about

wall, England. (I believe it was a pilot error after

this, so it's either a myth or I've been lucky so

relying too much on a GPS fix and moving the

far. You can add heatsinks for the electronics on

copter from its initial takeoff point.) Although

the underneath of the main housing if you're

this was a serious collision—full throttle into a

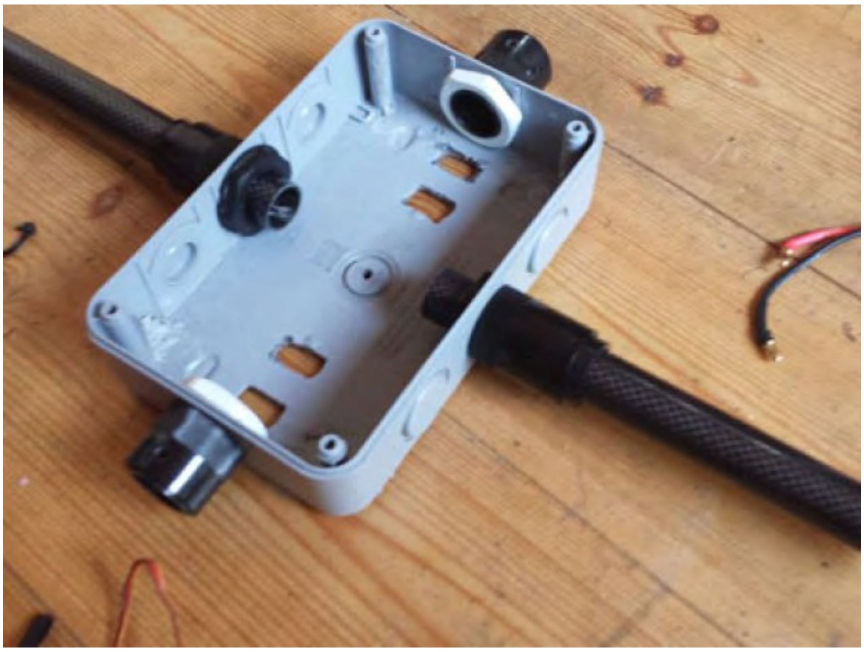
overly concerned.

granite cliff face at about 60 feet—all of the

I hope you enjoy the project!

electronics and camera equipment were

unscathed. This was testament to the rugged—ness of the airframe; damage was limited to broken props, a cracked hub, and severed motor wires, all easily replaced for minimal cost. The copter is now on build 2 as I’m planning on replacing the Naza M flight controller with an ArduCopter control board to enable mission planning with waypoints.



Step #1: Prepare the Hub

Step #1: Prepare the Hub

• You can see I cut out holes in the base

of the box to attach heatsinks, but I

• Place the 4-way PVC intersection face—

ended up not using them in the next

down inside the weatherproof electri—

build as they didn't seem to get hot.

cal socket box. You'll have to trim the

ends with a hacksaw to ensure a snug

Step #2: Prepare the Rotor

fit.

Arms

• Remove the hinged lid from the main

box to make things easily accessible.

• Cut the 1000mm tube into four equal

Pop out the center lugs and make sure

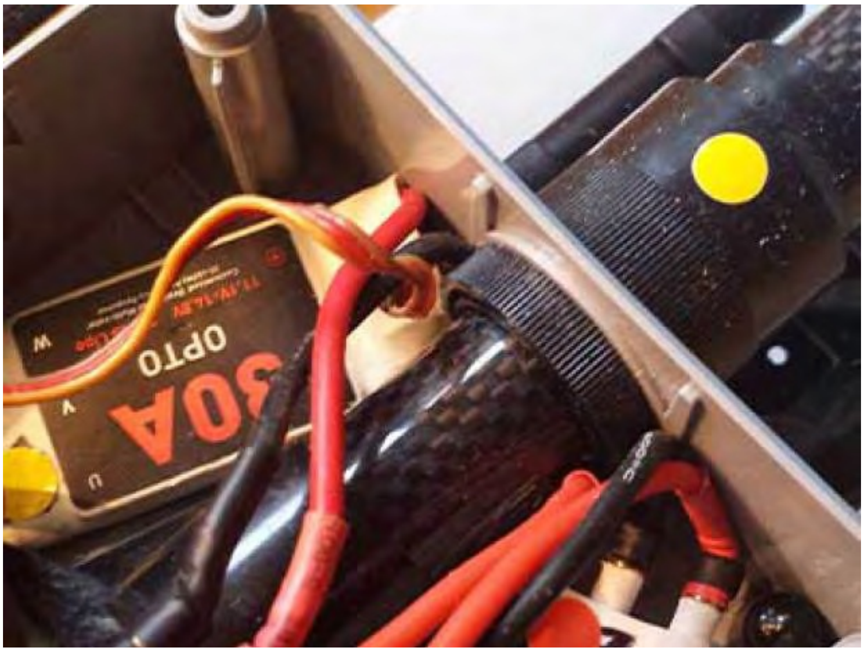
lengths of 250mm. I used a hacksaw.

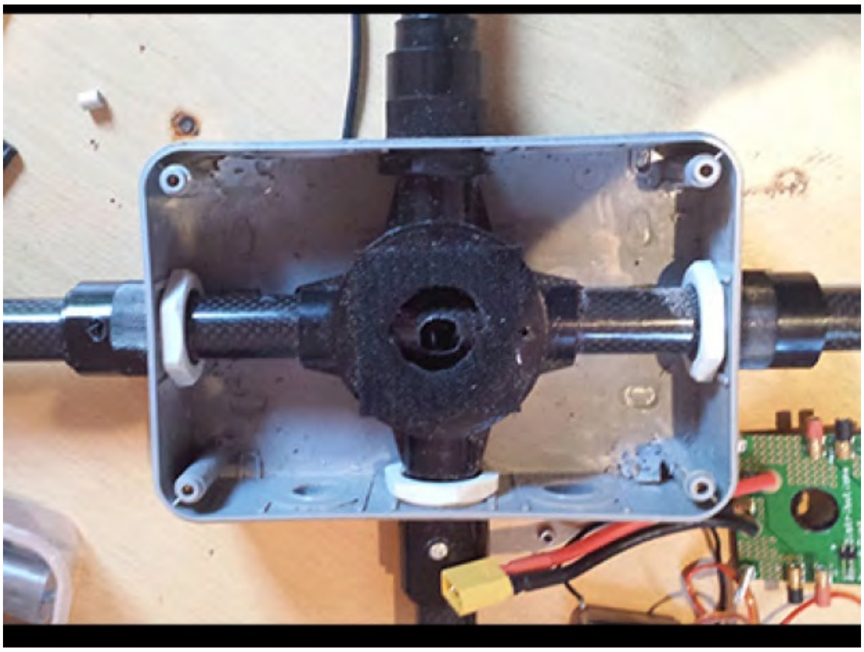
the 4-way intersection aligns with the

• Take all four conduit reducers and

holes. It should do perfectly.

grind away the little lip you can feel on the inside, so it’s flush with the internal diameter. I just held them in my hand and used a Dremel with a drum sander attachment. Make sure you can now slide the carbon tube through the reducer.





Step #3: Make the Motor Mounts

the 4-way hub as far as you can. Make

You might find you have sanded

sure each arm protrudes from the box

too much—if so, use another

an equal distance as the opposite arm

reducer. The tube needs to slide

(within 1mm–2mm).

through with a good push and no

less.

Step #3: Make the Motor Mounts

• Now lightly tap the reducer into the 25mm thread adapter until it stops.

• Cut both ends off the 3-way inspection
Unscrew the lock ring from the adapter
tees, as far back as you can. Make sure
and poke the threads through the main
the cuts are square. Depending on your
box, then screw the lock ring back on
motors you might have to glue a tap
to form a tight connection. Do this for
(faucet) washer on top of the inspec—
all four connections.
tion cover to give the motor screws
enough clearance. (I trashed a motor
here by screwing into the windings, so
be careful.) The washer also acts as a
vibration cushion for the motor.

• It's very important to upgrade the
screws that come with the inspection
cover as the motors will pull them free.
I used some M4 machine bolts and just
drove (forced!) them through the
threads. It's probably smarter to use
smaller bolts (M3) with nuts.

• Now take the carbon tubes and push
them/tap them with a rubber mallet
through the thread adapters and into

Step #4: Install the Power Electronics

wires through. You can seal this later

with Sugru.

• Now that everything is fitting together

and you're happy—take it all apart, as

you're about to install the electronics.

Step #4: Install the Power

Electronics

• Attach the rubber grommets to blank

off the cuts you made earlier. This is a

bit fiddly but they do fit; use a small

flat-blade screwdriver to pry them in.

They make an excellent seal once in.

• Attach the motor mounts to your rotor

arms by tapping slightly until they are

level and tight. You may have some

• As there are many different ESC/motor/

slight movement or twist on the

flight controller options out there, I will

mounts that may seem alarming but

assume the reader has a basic under—

we can fix this later with some PVC

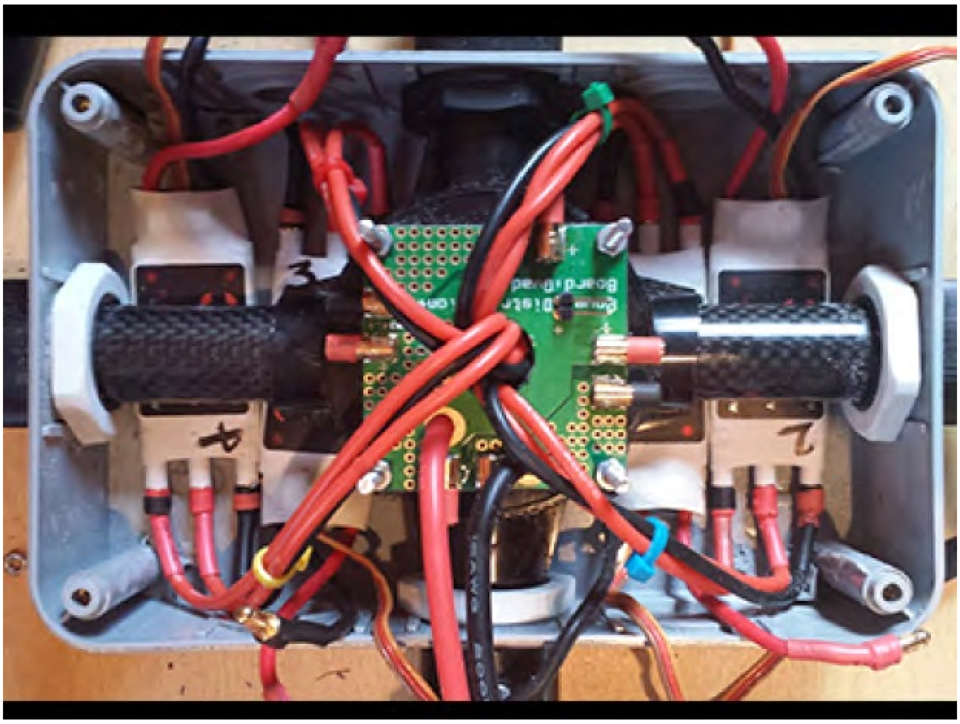
standing of how these are wired up. It's

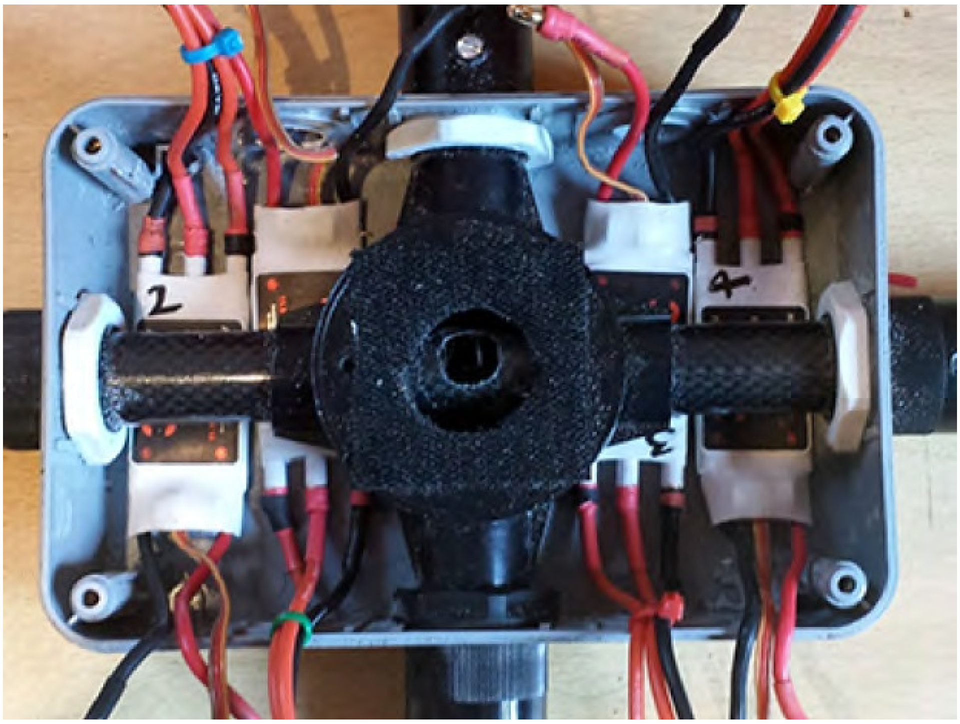
pipe welding cement.

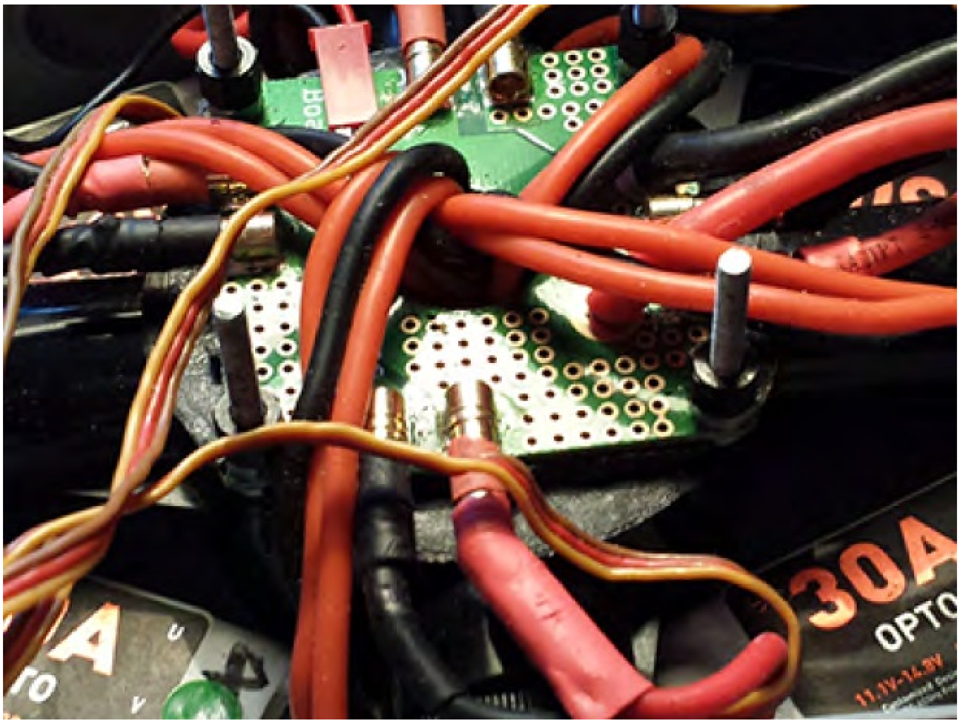
pretty simple.

• For the wiring harness of the 30A Naza ESC, measure the distance from the motor mounts to the center of the box and add 300mm. Cut your silicone wire and begin soldering the bullet connectors that you'll use to connect the power distribution board. (You don't have to use one of these boards, but I found it saved a lot of time.)

• Make a hole in the inspection cover just big enough to thread the motor







Step #5: Install the Flight Controller

flight controller.) Attach the PDB where you drilled the 25mm hole, with the battery connectors facing the hinge of the lid. I used sticky velcro tape because I knew I might need to take it off. As you are attaching the power board, pull through the wires three at a time and attach a small cable tie.

• You'll have great fun now squeezing all this in and making it look tidy and safe! It's worth adding some hot glue to the PDB connections as they are not very well insulated. Once you're confident

• It's a good idea to number or color—

it's all connected correctly, it's time to

code the ESCs at this stage because

install the flight controller.

you're going to be stuffing a lot of wires and you can easily get confused

Step #5: Install the Flight

when you're calibrating the flight con-

Controller

troller. I used little coloured stickers for a reference.

• Reattach your rotor arms and motor mounts and drill a 25mm hole on top of the 4-way hub. Thread the wires through the rotor arms—you'll want about 150mm of cable to play with at either end of the arms.

• Cut out a scrap of plastic that will fit inside your box and support your flight controller (FC). Drill four holes in the plastic that will align with the machine screw standoffs on your PDB.

• Insert four 50mm M3 machine screws through the underside of the PDB (power distribution board) and secure on the topside with lock nuts. (These will form part of your standoff for the


NAZA
TM and © 2012 DJI

Step #6: Prepare the Batteries

• Attach your ESC control wires to the FC.

• I just used gaffer’s tape to bind the two

Slide some 10mm round spacers on the

batteries together and then used a

machine screws on the PDB. Fix the FC

XT60 harness battery splitter to wire

to the plastic support (I used double—

them into the PDB.

sided tape as indicated by DJI) and

gently push it down onto the spacers,

Step #7: Install the GPS Puck

then attach lock nuts and screw them

tight.

Step #6: Prepare the Batter-

ies

• Drill a 50mm hole in the center of the

hinged lid. Then glue the 63.5mm plastic dished head on the top of the lid

with superglue or PVC pipe weld. Key

the surface lightly with sandpaper to

• It’s very important to get the specified

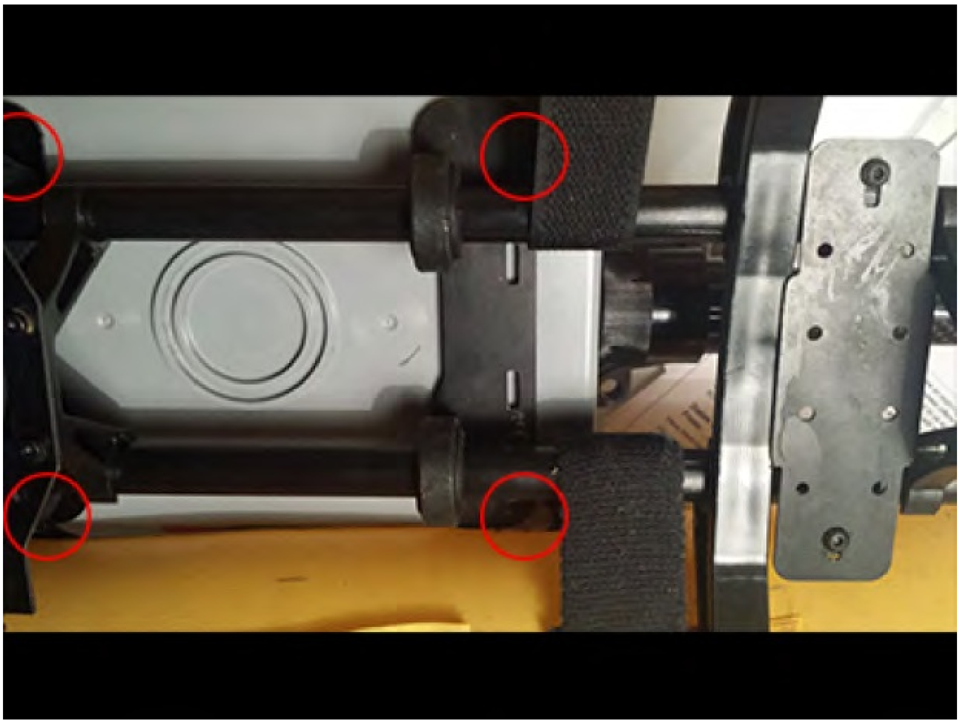
help the glue.

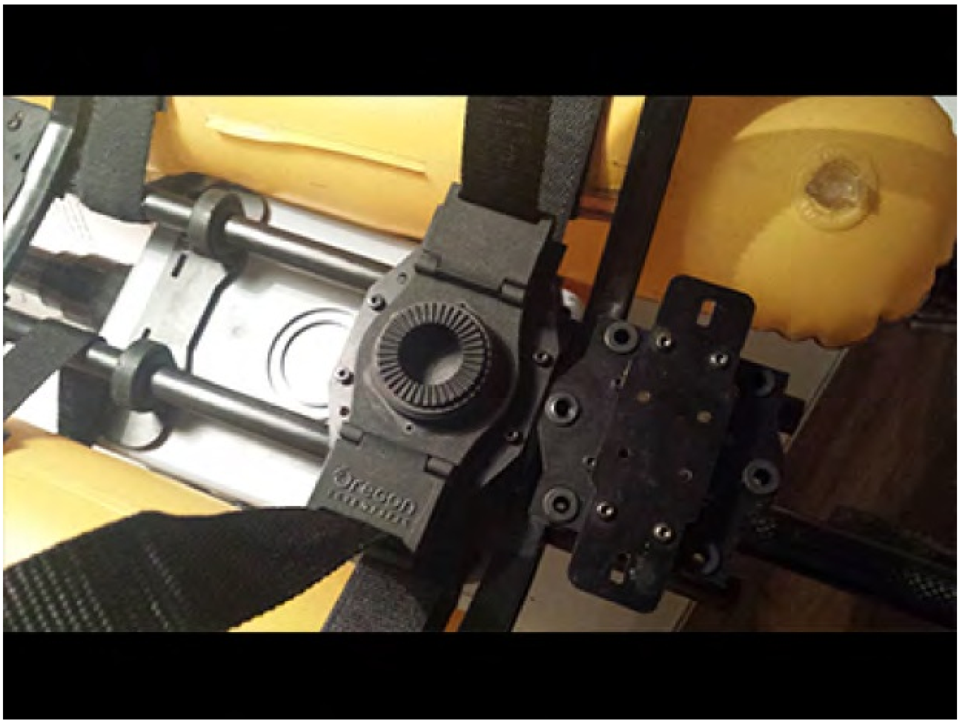
battery size that will fit under the lid of

the box. Each battery’s dimensions are:

102mm × 37mm × 24mm.


WAVEcopter





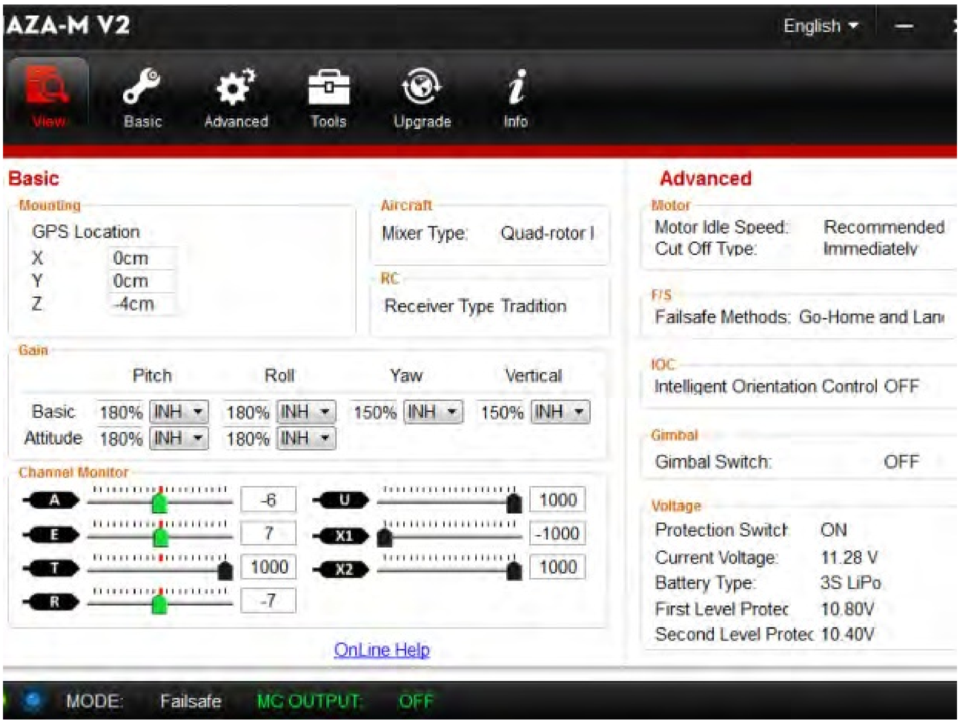
Step #8: Install Undercarriage and Floats

• Install the GPS puck in the hole in the lid and secure it with strips of velcro tape. These will do double duty to secure the battery pack as well.

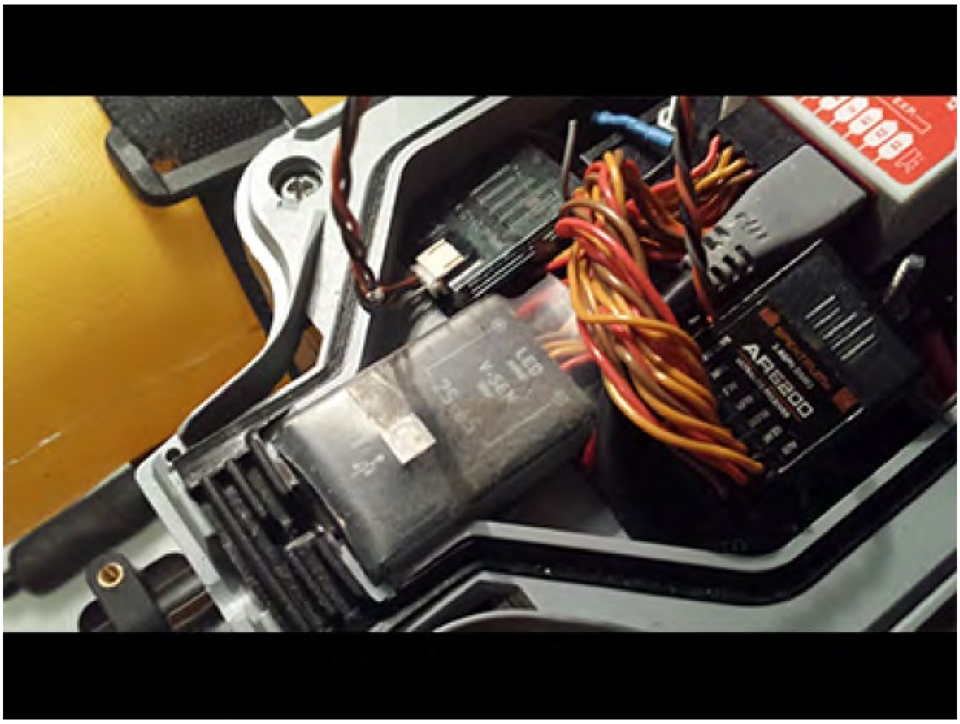
Step #8: Install Undercarriage and Floats

• Now attach the floats. I used velcro straps to attach them to the undercarriage. Your installation may vary.

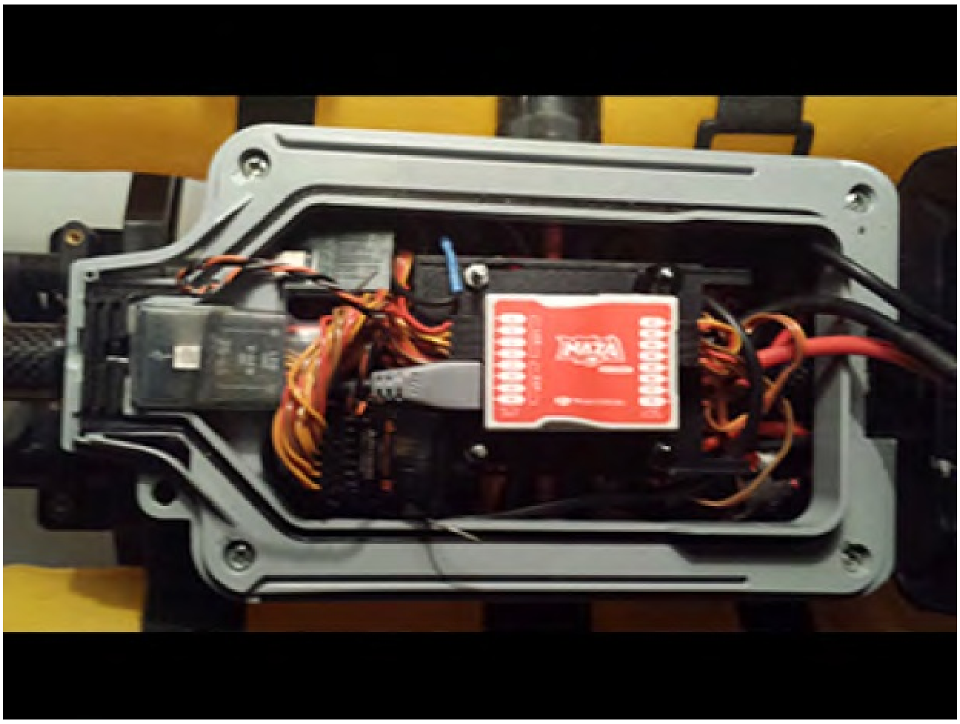
• Prepare your undercarriage. The landing gear kit I bought had two trays that attach to the frame, where you can easily attach camera accessories, FPV kit, *etc.*

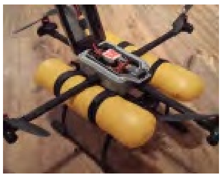


AZA-M V2
English
View
Basic
Advanced
Tools
Upgrade
Info
Basic
Mounting
GPS Location
X 0cm
Y 0cm
Z -4cm
Aircraft
Mixer Type: Quad-rotor I
RC
Receiver Type Tradition
Gain
Pitch Roll Yaw Vertical
Basic 180% INH 180% INH 150% INH 150% INH
Attitude 180% INH 180% INH
Channel Monitor
A -6
E 7
T 1000
R -7
U 1000
X1 -1000
X2 1000
OnLine Help
Advanced
Motor
Motor Idle Speed: Recommended
Cut Off Type: Immediately
F/S
Failsafe Methods: Go-Home and Lan
IOC
Intelligent Orientation Control OFF
Gimbal
Gimbal Switch: OFF
Voltage
Protection Switch ON
Current Voltage: 11.28 V
Battery Type: 3S LiPo
First Level Protec 10.80V
Second Level Protec 10.40V
MODE: Failsafe MC OUTPUT: OFF



AR6200





Step #9: Flight Check and Calibration

Step #9: Flight Check and

• One nice thing about the Naza is how

Calibration

perfectly snug the VU fits under the

clip of the main box.

• Install your motors, without props. As

long as they're brushless, which most

are, then no waterproofing is necessary. It's worthwhile spraying them

after water takeoffs and landings with

silicone spray to dry them out. (I've also

heard great things about Liquipel; if

you try it, let us know how it works for

you.

• I won't go into great detail here

because there are many different flight

controllers. Also, you'll notice I only

have a six-channel TX/RX system and

this isn't ideal when using GPS and RTH

functions on the Naza. I'll be upgrading the drone to an ArduCopter flight system in the near future and let you

know how I get on.

• If you're using the DJI Naza-M Lite

• Connect the batteries and test all your

setup, you'll find instructions online for

flight control systems on the drone

calibrating the controller with your

before attaching the props to the

computer via USB: *http://bit.ly/21KzqYT*.

motors.

Step #10: Final Checks and

Sealing

• It's now time to double-check that all

seals are good. If any of the motor

mounts or reducers are twisting in the

frame, detach them and add a small

amount of PVC weld to secure them.

Step #10: Final Checks and Sealing

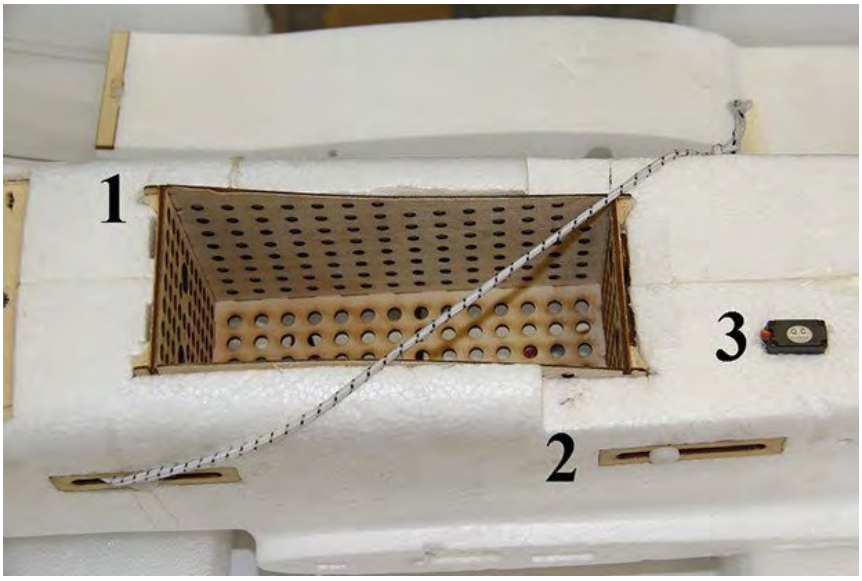
• Don't add any PVC weld to the round 4-way junction box. If (and when) an arm

breaks, you'll easily be able to remove

and replace that one arm rather than

remove the entire hub.

• Happy flying!



Payload Box and Drop Mechanism

for Drones and R/C Planes

13

When Uplift Aeronautics founder Mark Jacobsen envisioned using a fleet of drones to drop food and medical supplies on war-torn regions, he needed a device to make that happen. The answer was to modify fixed-wing foam UAVs, and the result was five different designs, including the Waliid, pictured here.

—By Michael Thomas Taylor

Figure 13-1 *Photo by Hep Svadja (all other photos cour-Figure 13-2 Bottom view of aircraft with payload box and tesy of Uplift Aeronautics) drop mechanism installed*

This project is a set of instructions for building

and installing a payload box and drop mecha-

Parts/Tools

nism for the X-UAV Talon R/C airplane. Design

credit goes to Brandon Fetroe of Uplift Aero-

• Wood, 1/8” sheets

nautics.

• Nylon bolts, four 1”, four 1.25”, 20

The files for the custom parts can be found on *threads per inch (8)*

Uplift's Github at https://github.com/upliftaero/

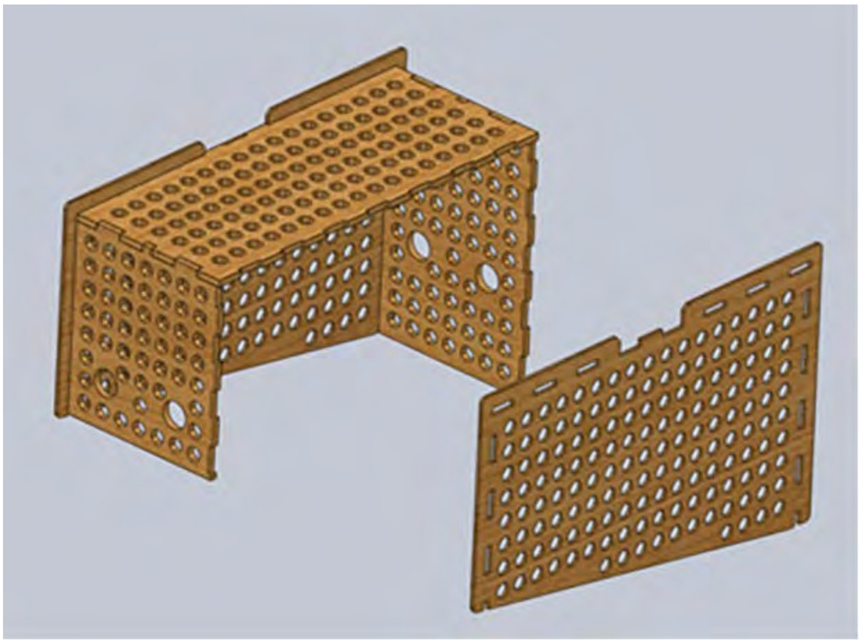
- *Nylon nuts, 20 threads per inch (8)*

waliid.

- *Metal washer*
- *Servo, 9g (micro size) analog metal*
- *Metal pin/control rod*
- *Metal tube, 1/2" long, 1/4" diameter*

guide hole for pin

89



Step #1: Construct Payload Box

- *Bungee cord*

Most of the custom parts were laser cut out of

- *X-UAV Talon kit*

1/8″ or 1/16″ plywood, with files provided in

the Git repository. In the absence of access to a

The system consists of three major compo—

laser cutter, most parts can be cut with hand

nents:

tools, omitting the grid of holes in the box

(done to save weight). SolidWorks part draw-

• The payload box provides a space to

ings are also available to work from in the

store and secure the payload in the

repository.

fuselage of the X-UAV Talon. It is

recessed into the body of the aircraft

Step #1: Construct Payload

through a hole cut in the bottom of the

fuselage.

Box

• The payload box is secured to four

1. The payload box provides a space to

mounting brackets glued into the sides

hold the payload inside the aircraft. It is

of the airframe. Four nylon bolts attach

designed to hold a single 3"×7.5"×6”

from the outside to hold it in place.

cardboard box.

• The drop mechanism is a servo that

2. Assemble the front, back, top and two

extends and retracts a metal pin pok—

side plates to make an open-sided box

ing through the side of the body. A

as shown. Secure the parts with wood

bungee cord wraps around the bottom

glue or superglue. The taller side will

of the payload and attaches to the pin

face towards the front of the aircraft,

to hold it in place.

and will be referred to as the “front” of

the box.

Figure 13-3 *The bungee secures to the pin of the drop*

mechanism; the servo retracts the pin to release the bun-

gee and drop the payload

3. Attach the bolt plate to the front and

The package is secured inside the airplane by a

rear of the box. The plate must be

bungee cord tied at one end to the wooden

aligned with the large holes in the front

plate in the nose of the aircraft. It is then

facing side. The plate serves as a

stretched across the payload box opening to a

mounting point for a pair of 1/4” 20

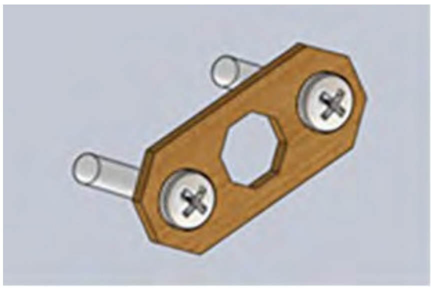
pin on the opposite side. When the servo

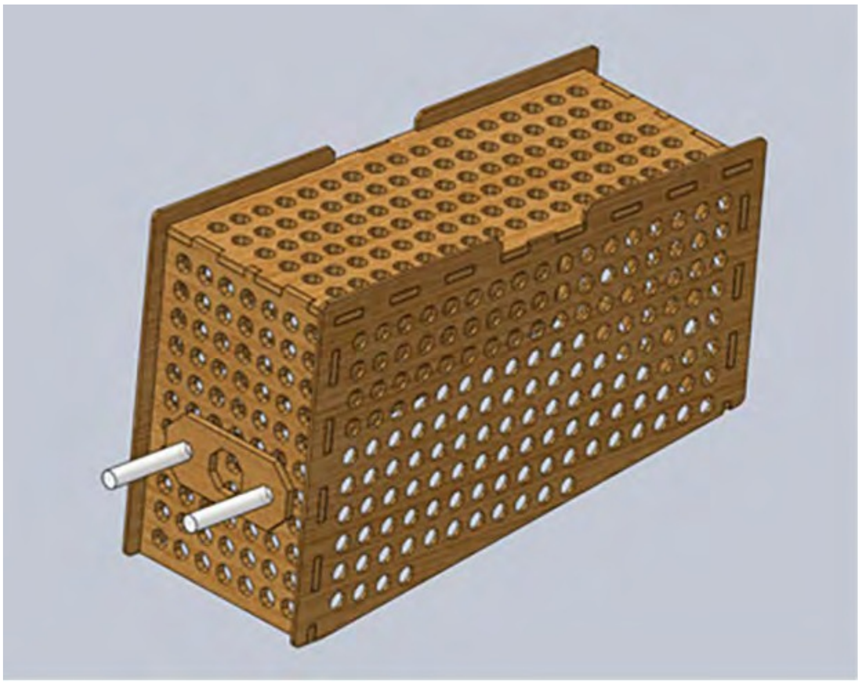
nylon bolts that will secure the payload

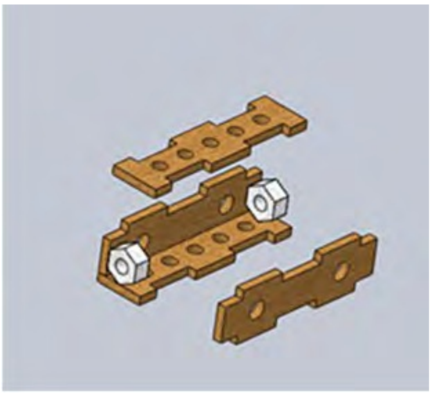
retracts the pin, the bungee will release and

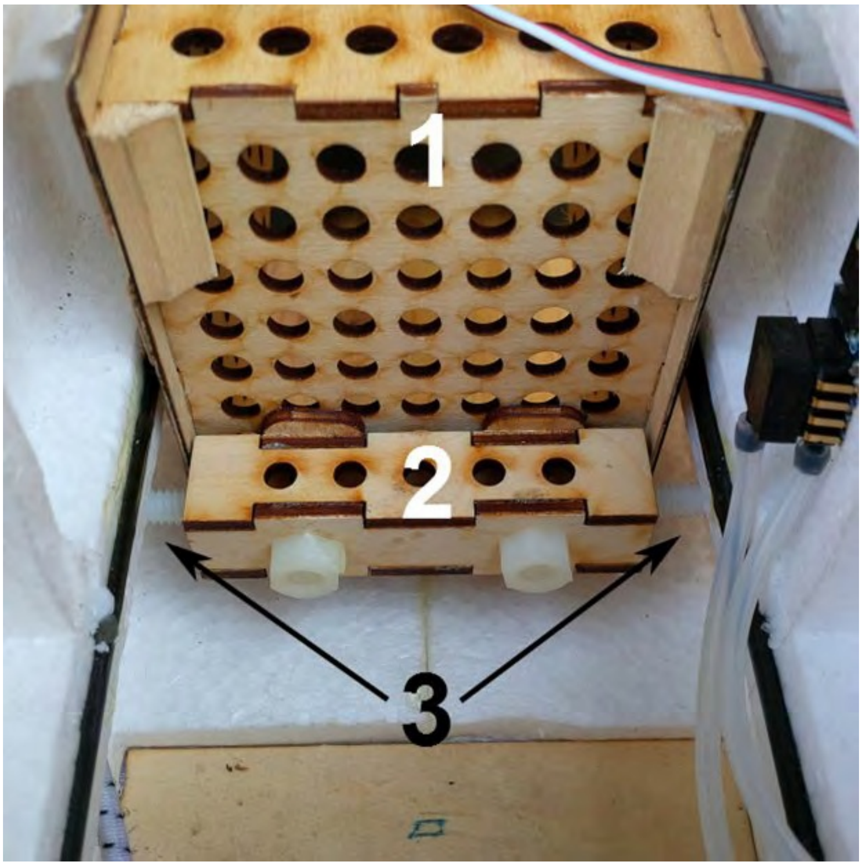
box to the mounting bracket.

drop the payload.









Step #2: Build Mounting Bolt Assembly

4. Align the plate so the bolts slot through perpendicular to the box as shown. DO NOT GLUE THE BOLTS TO THE PLATE—the bolts are meant to be

2. The payload box (1) is attached to the inserted after the box has been placed mounting assembly (2), which is in the airframe.

attached to the airframe by the bolts (3).

5. Attach the second bolt plate to the rear of the payload box.

6. (Optional) Strengthen the corners of the payload box with segments of *balsa wood.*

3. Each assembly has two nylon nuts that

will hold the external bolts, securing

Step #2: Build Mounting Bolt

the whole payload assembly to the air-

Assembly

frame. Use superglue to assemble three

sides of the wooden parts, then glue

the nylon nuts inside each end. Then

1. The payload box is held inside the air—

glue the last wooden piece to com—

craft by four nylon bolts that attach

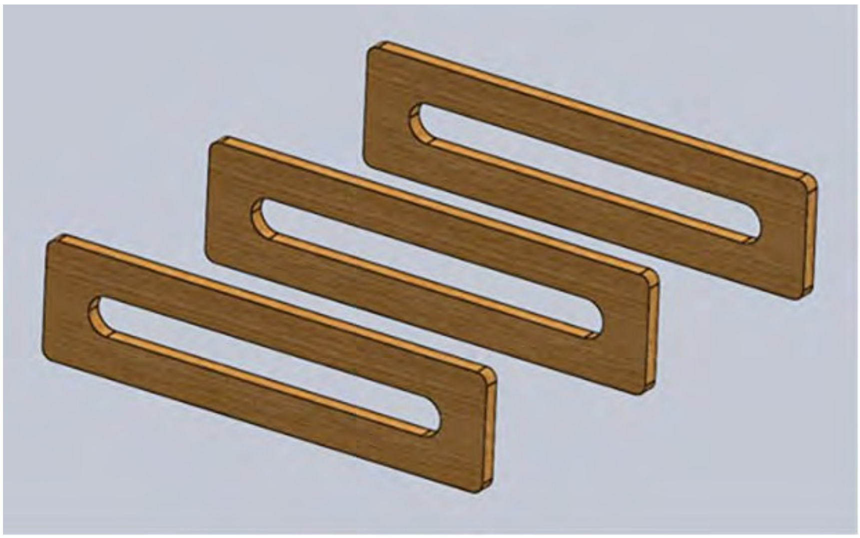
plete the assembly.

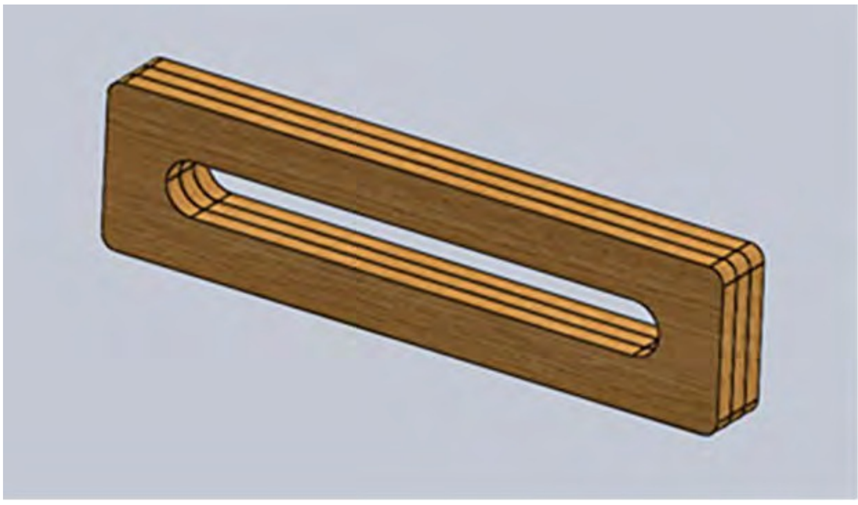
from the outside. To give these bolts

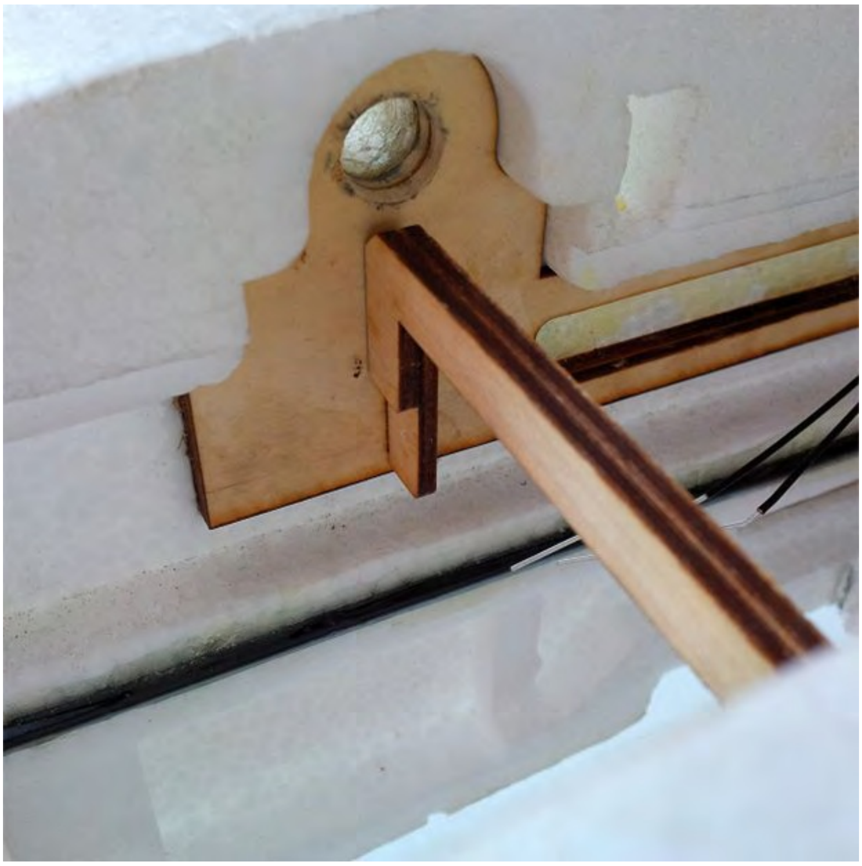
somewhere to attach to, a mounting

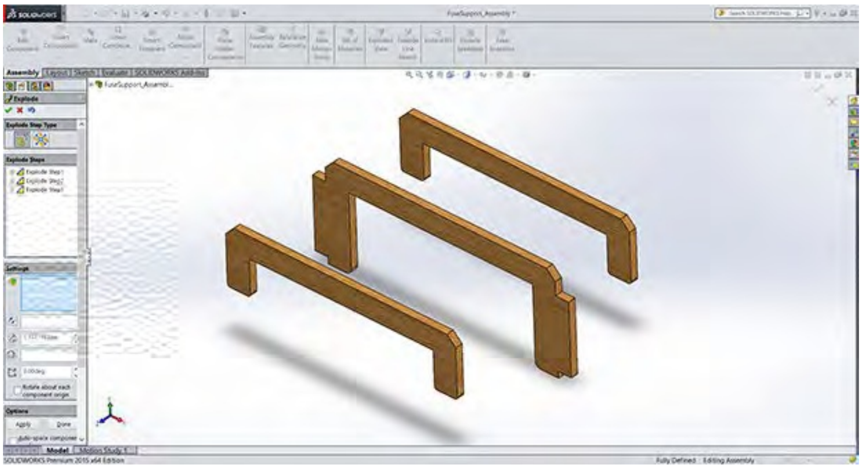
assembly attaches to the end of the

box.









Step #3: Construct Mounting Brackets

Step #3: Construct Mounting

Brackets

1. These brackets give the nylon bolts a

place to slot into the side of the airframe. They are long enough to allow

some flexibility in how far forward/aft

the payload box can be placed. Each

bracket is 3” long by 3/4” tall.

2. Glue the main piece (center) and two

of the supports (outsides) together.

Install in place of the original kit part.

The middle piece fits into the slots for

2. Assemble the mounting brackets by

the stock kit front brace.

stacking three of the laser cut pieces as

shown and gluing them together.

Step #5: Modify Airframe

Step #4: Assemble Front

1. Cut the payload box hole in the bottom

of the airframe. The hole should be

Brace

along the centerline. The 5.5″ from the

rear lip is approximate. The hole can be

1. The final custom part is a new front

moved more fore/aft to shift the center

brace for the wooden frame in the cen—

of gravity. It may be necessary to cut

ter of the fuselage. The new front brace

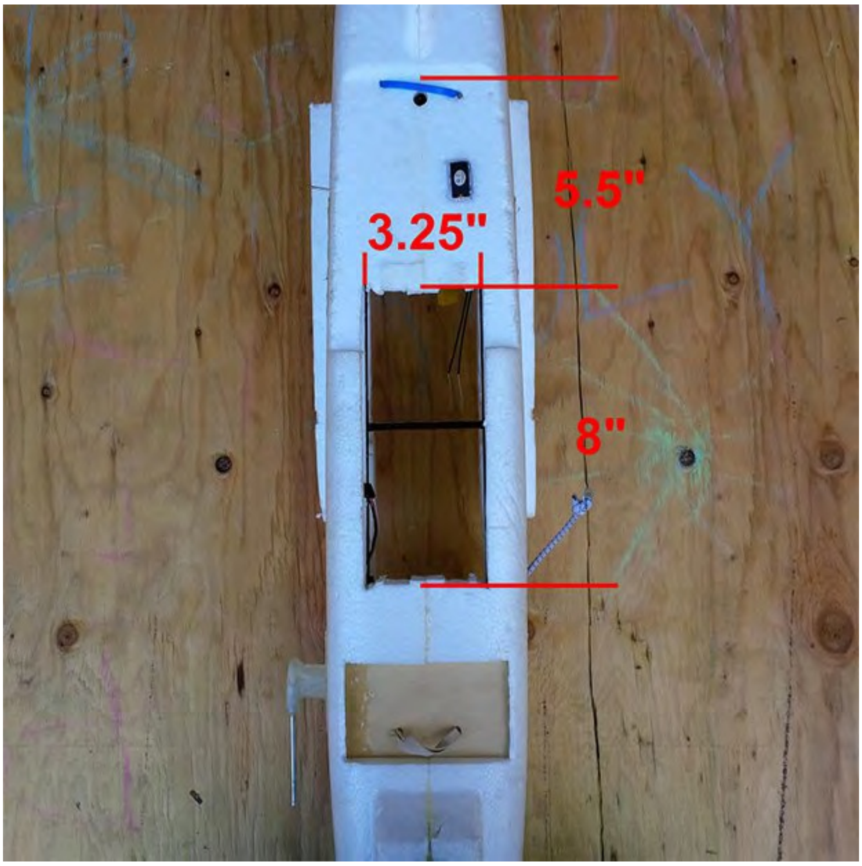
notches for the bolt plate and edges of

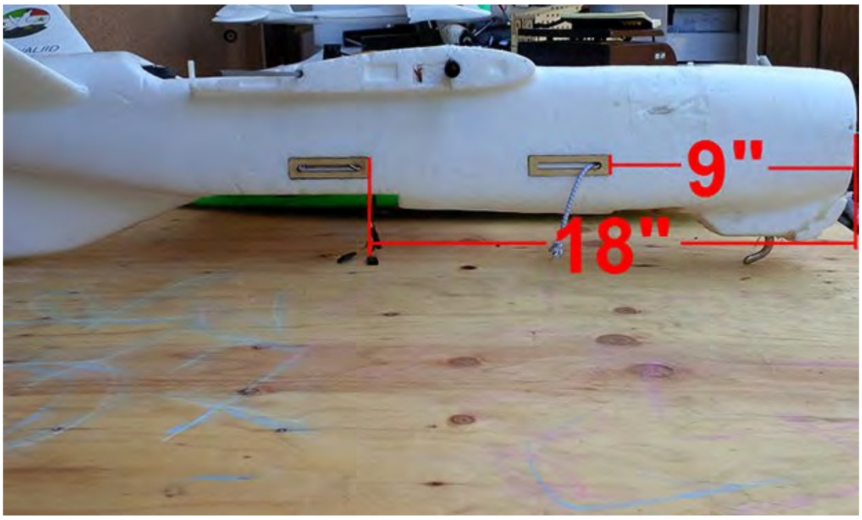
replaces the stock front brace in order

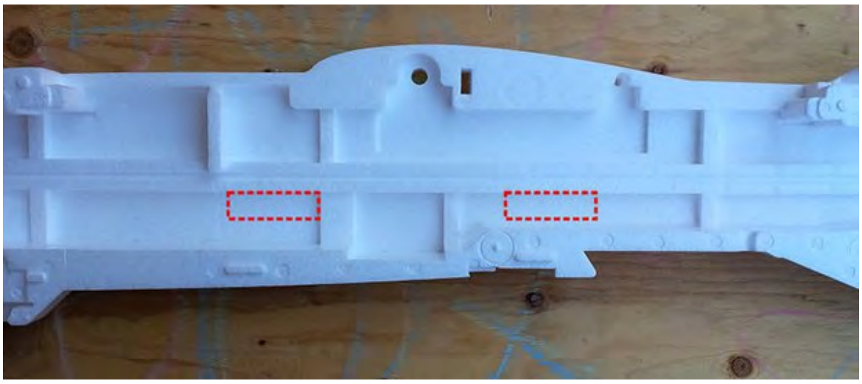
the box to fit.

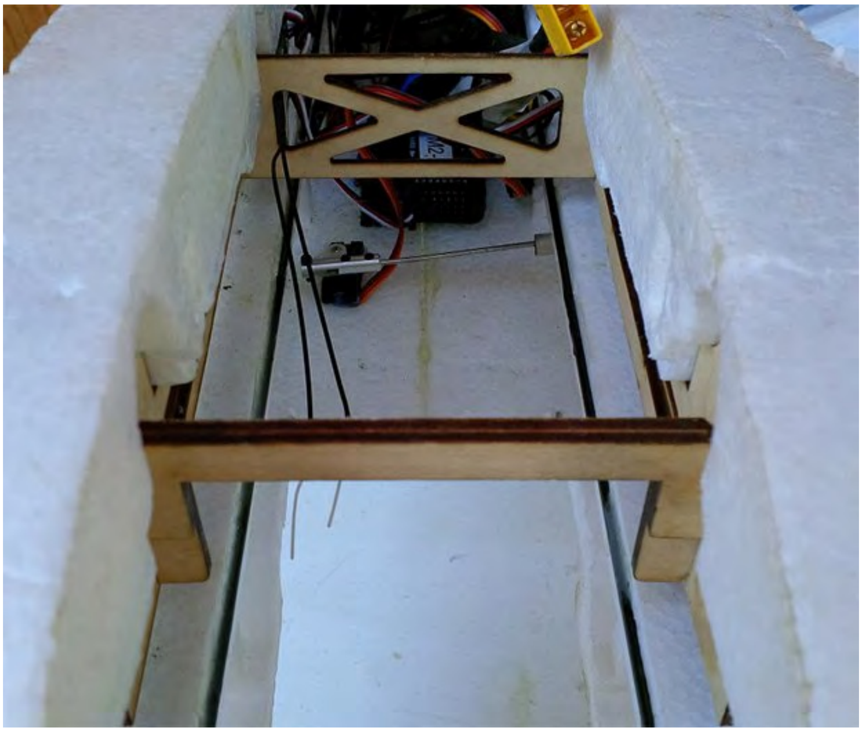
to provide enough room to fully insert

the payload box into the airplane.









Step #6: Install Front Brace

5. If you are modifying a new airframe, the top of the holes for the mounting braces align with the interior foam molding as shown.

Step #6: Install Front Brace

1. Install the new front brace for the *wooden frame. If the kit has not been*

2. Then cut the mounting bracket holes. It

assembled yet, simply replace the old

is important that the mounting brack—

front brace with the new part when

ets are in line with the mounting

building the wooden frame for the cen—

assembly when the payload box is

ter of the fuselage. If modifying an

installed.

already built kit, cut the old X brace

and glue on the outside pieces from

Step 4 to strengthen it.

3. It is a good idea to install the payload

box and take note of the mounting

assembly locations before cutting the

holes for the mounting brackets. (See

Steps 1 and 2.)

4. Cut two 3"× 3/4” rectangular holes in

the side of the fuselage to fit the

Step #7: Install Bungee and

mounting brackets. Adjust the location

Payload Box

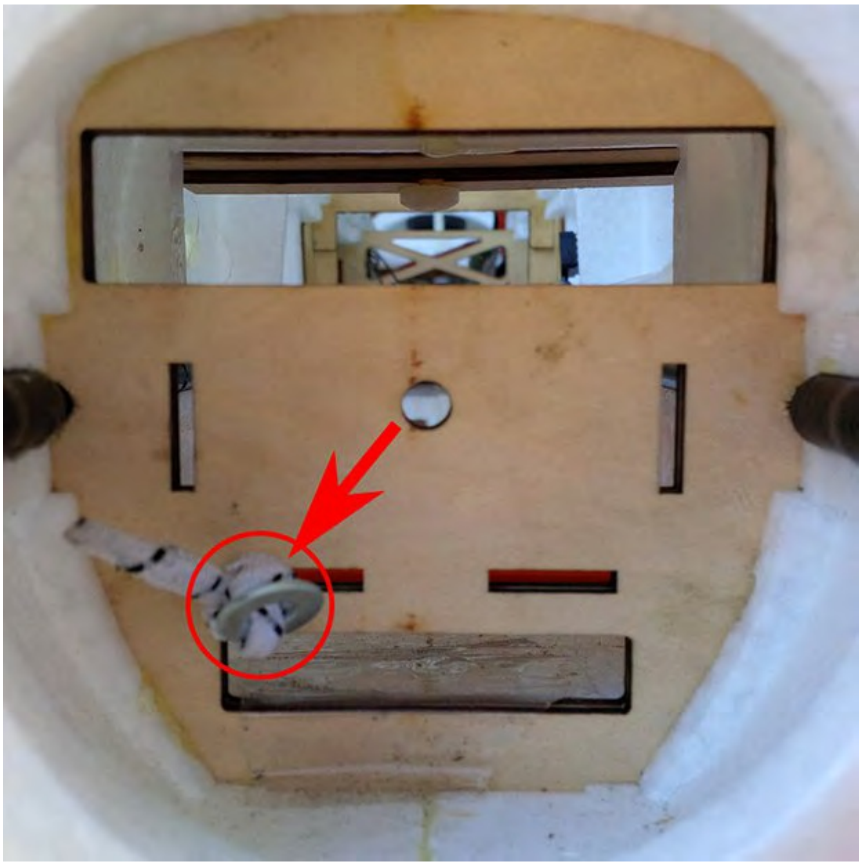
of the holes fore/aft depending on

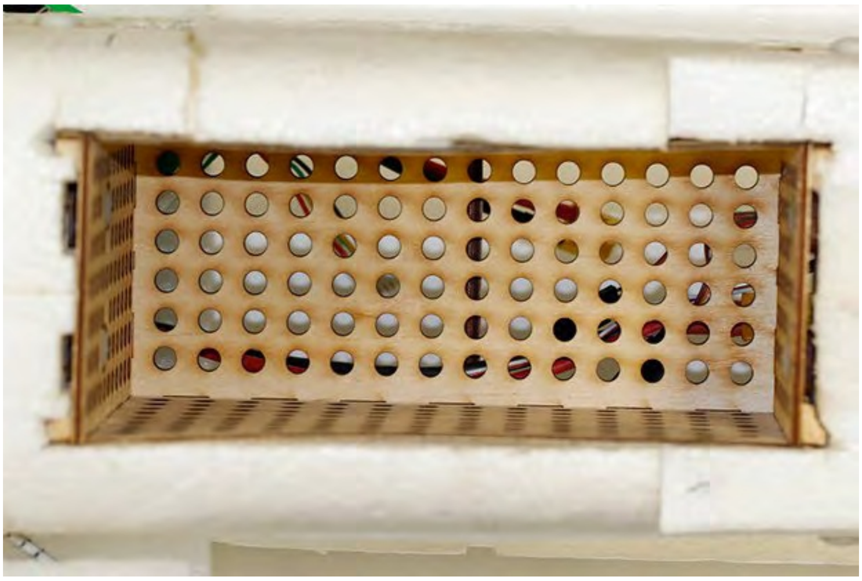
where the box will finally sit in the air—

1. Tie a length of bungee cord to the front

frame.

plate in the nose. It should be long





Step #8: Bolt It In

enough to reach out one front mount-

Step #8: Bolt It In

ing bracket and across the hole cut for

the payload to the other side rear

1. Place two 1" long 1/4" nylon bolts

mounting bracket (see photo in intro).

through the holes in the bolt plate on

Feed the other end through one of the

the front and back of the box once it is

front mounting brackets and tie a

in the airframe.

metal washer on the end.

2. Note: The bolt plates in the photo are

2. Insert the payload box into the hole cut

from an older design; see Step 1 for an

in the bottom of the fuselage. The tall

updated design.

end faces the front of the aircraft. It

should be nearly completely recessed

into the airframe.

Step #8: Bolt It In

3. Place the mounting assembly over the

brackets into the nuts (as seen in Step

bolts on the box. Secure with nuts.

2) in the mounting assembly. 4X: Front

Secure the payload box with 1.5" long

and back, and on both sides.

nylon bolts through the mounting

Build Your First Tricopter

14

They fly smoother and make better videos than quads. Build the Maker Hangar Tricopter and see for yourself!

—From Make:44 by Lucas Weakley

Quadcopters are a little easier to build, but tri—

craft. If you let go of the stick, a quad stops

copters have advantages that make them more

turning abruptly; for video work, this can be
exciting to fly—especially for shooting aerial
obvious and distracting. Let go of a tricopter's
video. I built my first one in 2010, inspired by
stick and the tilted tail motor takes a moment
David Windestal's beautiful aerial GoPro videos.
to return to a hovering position; this gives you a
I didn't get many flights out of that first build,
slow stop and even a little overshoot, as though
but I learned a lot. After building several more,
a person were moving the camera.
I've developed an affordable kit that anyone
Finally, tricopters are a lot of fun to fly, espe—
can build—the Maker Hangar Tricopter.
cially for stunts and acrobatics. The tilting
motor also gives you much higher yaw speeds

Why Fly Tri?

—that means they turn faster.
A tricopter's three motors are usually separated
by 120°, not 90° like a quadcopter's. This makes

A Tricopter for Makers

them great for video because you can place the
The Maker Hangar Tricopter is made of wood—
camera really close to the body and still have
hackable, easy to drill and cut, and a natural
no propellers in view. And where quads must
absorber of vibration, the enemy of aerial
rely on counter-rotating propellers to handle
video. The airframe is big, with plenty of room
torque and balance the aircraft, a tricopter can
for large controller boards, video transmitters,
use identical props because it has a special
drop mechanisms, or whatever you can imag—
servo in the back—a yaw servo—that twists
ine. And we widened the front arms to about
the tail motor to counter torque.
150° so our tricopter is more agile.
Tricopters fly differently, too. With their dedica—
The kit includes a 3D-printed tail assembly and
ted motor for yaw (turning), they fly with more
all the hardware you'll need, plus a wire rope
fluid, natural-looking movements—they can

vibration absorber that will pretty much erase

bank, pitch, and yaw like an airplane, but still

camera vibrations even if your propellers are

hover like a helicopter. A quadcopter's flight is

unbalanced. A carbon-fiber hinge provides a

more robotic, as the controller board calculates

strong, smooth connection between the tail

the precise rotation for all four motors to create

motor and airframe.

the proper torque and balance to yaw the air—

97

Parts

Finally, like most tricopters, the two front arms

• Motors, brushless outrunner, 900kV (3)

lock in place for flight, then fold back neatly for

Emax GT2215/12

transportation and storage.

• ESCs, 20A (3) Emax Simon

Parts

• Props, 10×4.7 (3)

• Batteries, LiPo, 3,300mAh (2)

• Maker Hangar Tricopter Kit—$85 from

http://bit.ly/1D9wNWU

• Servo, micro

• Servo extension, 6"

The kit includes:

• Wire, 16 gauge stranded

• Laser-cut plywood airframe parts

• Heat-shrink tubing

(download the files from Dropbox)

• Servo cable, male to male

• 3D-printed tail assembly (download

the files from Dropbox)

• JST connector (optional)

• Carbon-fiber hinge pieces

Tools

• Oak square dowels, 7/16"×7/16"×12"

(3) for the arms

• Drill and bits

• Bolts, stainless steel, M3: 25mm (8),

• Pliers, needlenose

6mm (4), 10mm (16), and 22mm (8)

• Pliers, side cutting

• Lock nuts, M3 (25)

• Wire cutters/strippers

• Washers, M3 (16) and M4 (2)

• Hot glue gun

• Bolts, nylon, 6-32×3/8” (4)

• Cyanoacrylate (CA) glue

• Nuts, nylon 6-32 (4)

• Screwdriver

• Standoffs, 6-32×1-1/2” (4)

• Hex driver set

• Cable ties (20)

• Adjustable wrench

• Push rods, 2-1/2"×0.047” (2)

• Sandpaper

• Push rod connectors (2)

• File

• Velcro straps (2)

• Hobby knife

• Wire rope, 3” lengths (4)

• Soldering iron and solder

Electronics (not included)—see the kit web

• Heat gun or hair dryer

page for complete recommendations:

• Helping hands (optional)

• Flight controller board (see Step 12

below)

It’s a great kit for anyone wanting to get into

multicopters or aerial photography. You can

• R/C receiver to match your R/C trans—

also build it totally from scratch: download the

mitter

PDF plans, laser cutter layouts, 3D files for print—

Specs

ing, flight controller settings, and watch the

how-to video series in this Dropbox folder.

Specs

- *Flight time: 12 minutes*
- *Frame weight: 325g*
- *Flight weight: 1kg*

• Compatible with 8″–10″ props

• Wire rope vibration absorber

Now put it together: slide an M4 washer on the

• 22mm motor mounts

hinge rod, then the tail piece, then another

washer. Finally, glue the 1/2" carbon tube to the

Step #1: Sand and Paint

end of the rod to capture the whole assembly.

Sand down any burrs or splinters on the

wooden parts. If you wish, paint with a couple

of light coats.

Hot-glue the servo into the tail piece and install

two "easy connectors" in 1/16" holes on the

servo arm. You can glue the hardwood tail arm

into the tail piece now as well.

Step #2: Assemble the

Hinged Tail

To build the hinge, glue the 2-1/2" carbon rod

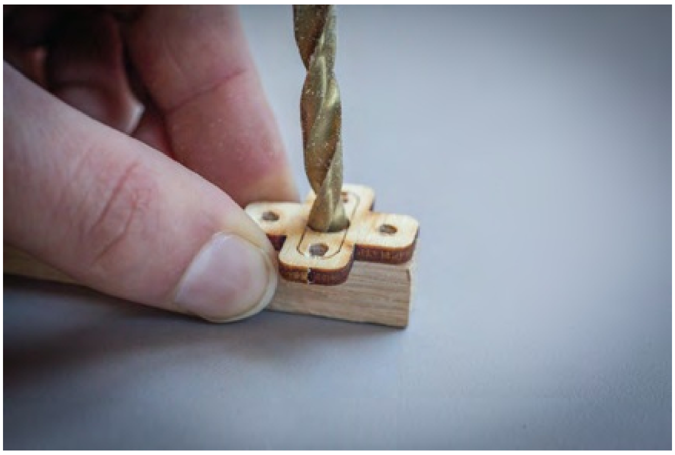
flush into the 3/4" carbon tube using CA glue.

Hot-glue this end into the 3D-printed motor

mount. Also hot-glue the 1" carbon tube into

the 3D-printed tail piece.


ROTATE
SPACING



Step #3: Assemble the Hinged Tail (Cont'd)

Step #3: Assemble the

Hinged Tail (Cont'd)

Bolt the tail motor into the motor mount with

M3 washers.

Finally, connect the servo linkages. Use pliers to

create a tiny "Z-bend" on the end of each push

rod. Hook the bent ends into the motor mount,

and slide the unbent ends into the easy connectors on the servo arm.

Note that the motor template has two different

spacing patterns; use each pattern on only one

arm, so your motors will end up being mounted

symmetrically.

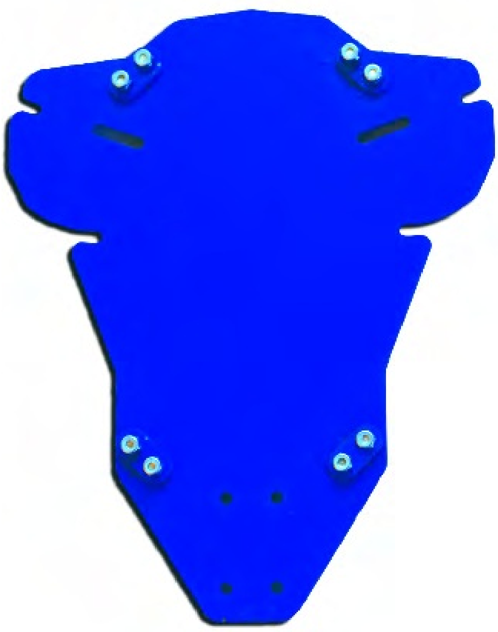
Step #4: Assemble the Front

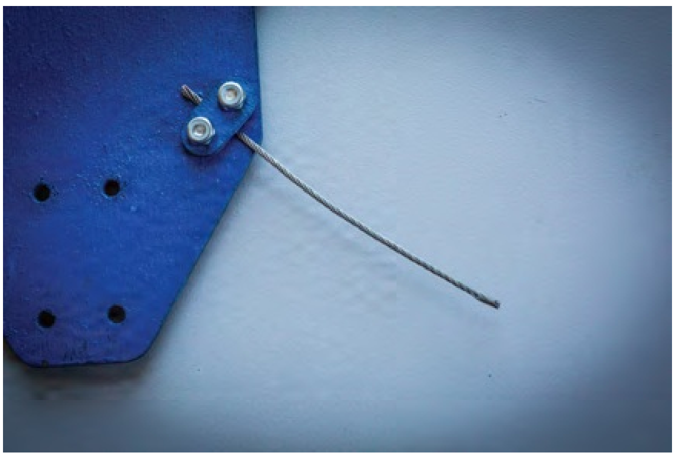
Arms

Drill each front arm using the two templates

provided: at one end for the motor mounts, and

at the other end for the rotation bolts for folding the copter arms.





Step #5: Assemble the Front Arms (Cont’d)

Step #5: Assemble the Front

Arms (Cont’d)

Then mount the remaining two motors using the four round plywood motor mount pieces—the ones with the larger center holes go up against the motors—and M3×22mm bolts with *washers.*

This tray is optional (you could just velcro the

battery to the bottom of the copter) but it's

highly recommended for video because it's isolated from vibrations by short wire ropes.

Clamp the four wire ropes into the brackets on

the bottom plate, but don't connect the camera

tray yet.

Step #6: Prepare the Body

Plates

Install the nylon standoffs on the upper body

plate, but don't mount the small top plate yet.

Step #7: Install the ESCs

Connect the three electronic speed controllers

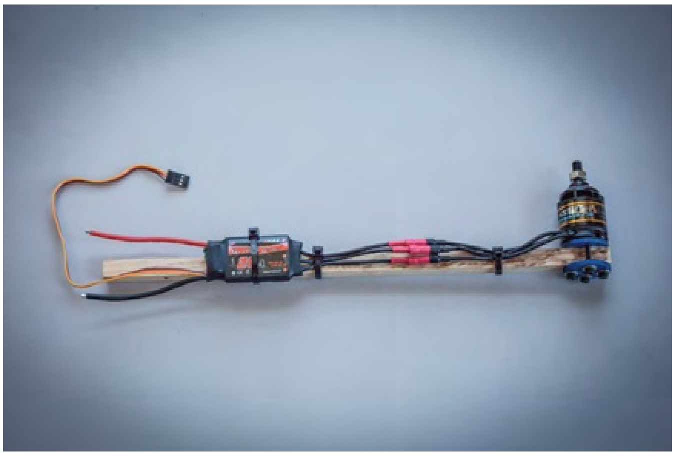
(ESCs) to the motors and zip-tie them to the

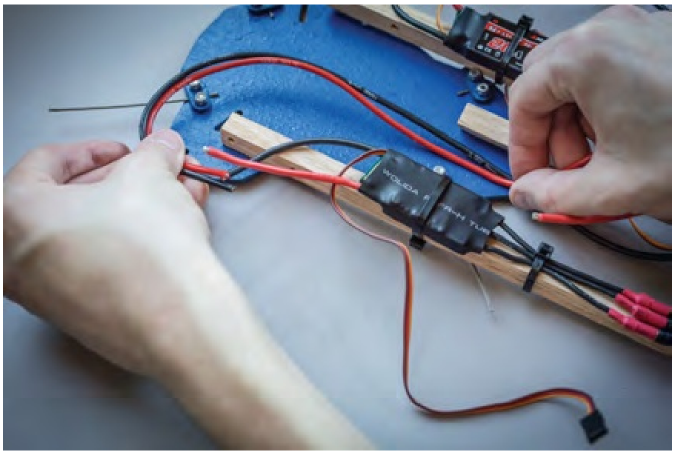
Bolt four of the small plywood brackets to the

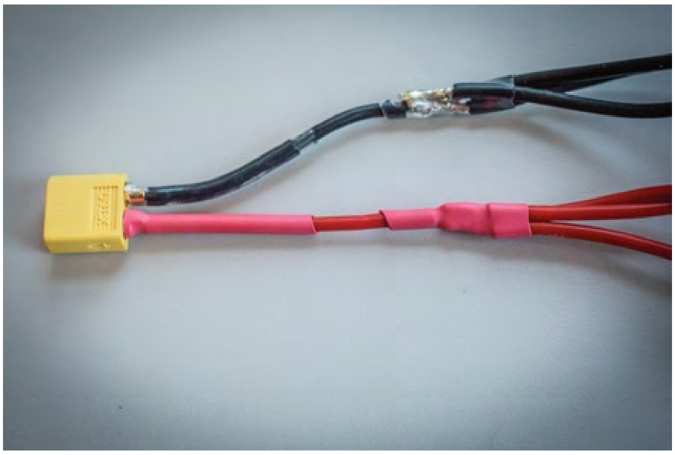
arms.

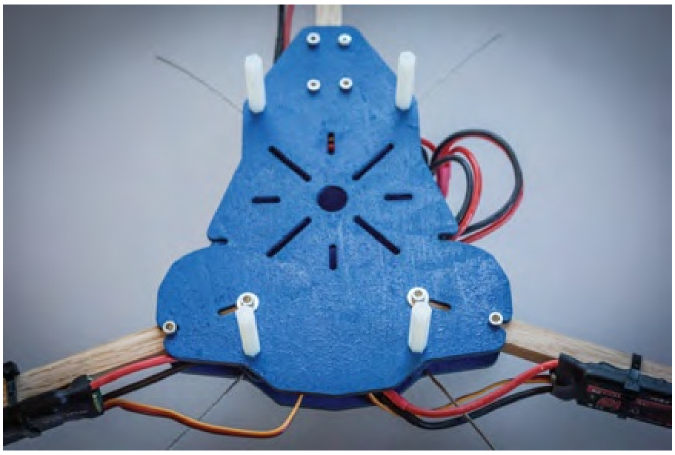
lower body plate, and four to the camera/

battery tray, using M3×10mm bolts and nuts.









Step #8: Attach the Arms

Arrange the three arms in their folded configuration, then measure out enough wire to

Step #8: Attach the Arms

extend all the power and ground wires to meet

Bolt the two front arms to the lower body plate

at the back of the body. Solder the extension

through the outer mounting holes, using

wires and insulate connections with heat-shrink

M3×25mm bolts and lock nuts. Place the upper

tubing. Strip the free ends and solder them into

body plate on top, then pass two more bolts

your battery connector.

through the locking slots and the inner arm

holes, and secure with washers and lock nuts.

Finally, clamp the tail arm between the body

plates using four bolts.

Now's also the time to splice in a

JST connector (optional) if you

want to power an onboard FPV

Test the folding action and loosen or tighten

(first-person video) system and

bolts until the arms fold smoothly and lock for-

watch live video from the tricop-

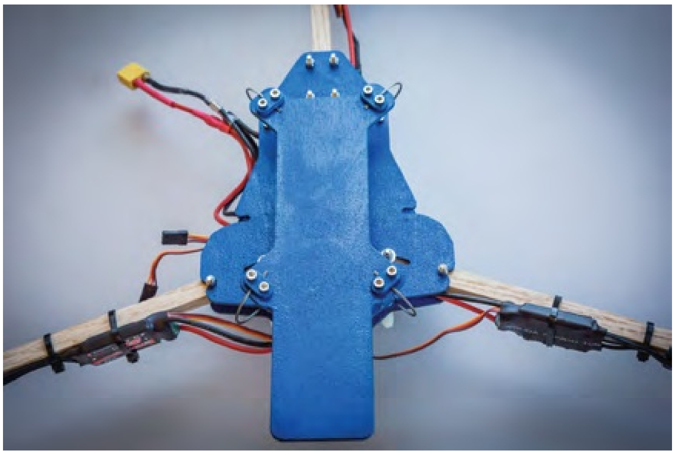
ward securely.

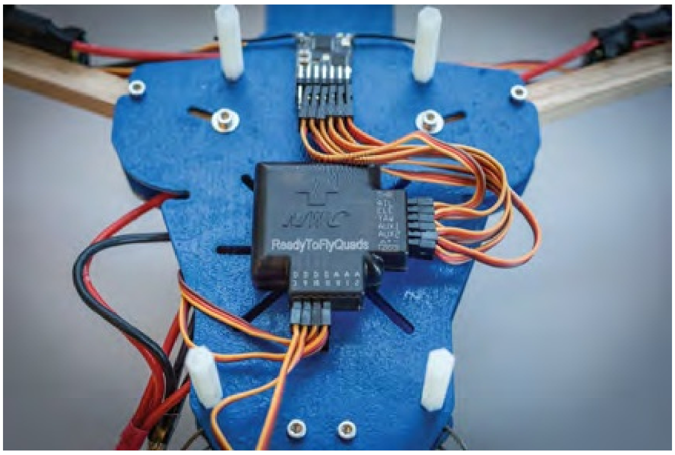
ter. Learn more about batteries,

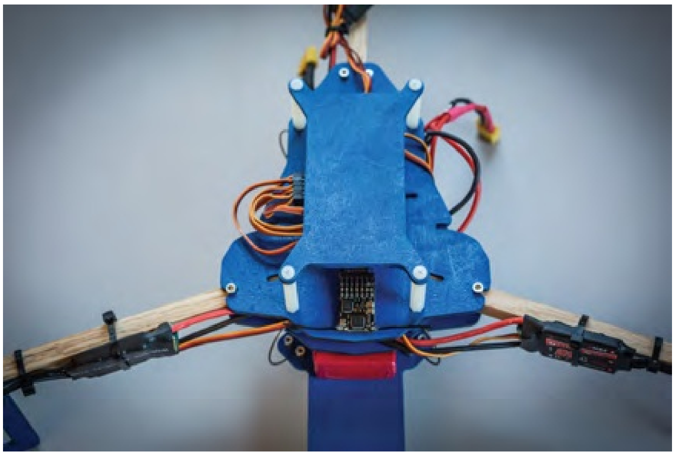
FPV, and other flight components

in the first season of Maker

Hangar videos.




ReadyToFlyQuads



Step #9: Mount the Landing Gear

Step #9: Mount the Landing

Step #11: Mount the Receiver

Gear

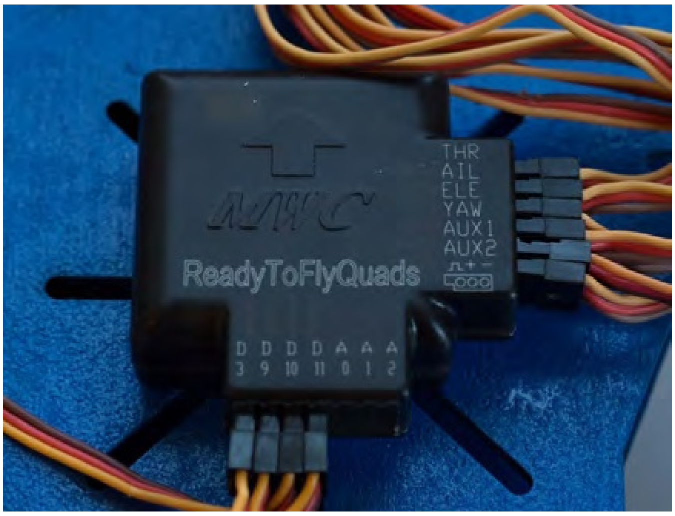
and Flight Controller

Zip-tie the two plywood landing struts to the
Attach your flight controller to the upper body
front arms.
plate using hot glue, double-sided tape, or
bolts through the mounting slots. (We used the
Flip 1.5 MWC controller. You can download the
settings at the Maker Hangar project page.)

Step #10: Suspend the Cam-

era Tray

Bind your R/C receiver to your transmitter (see
Maker Hangar Season One, Episode 12), and
Clamp the free ends of the wire ropes into the
then set the throttle ranges by plugging each
brackets on the camera tray. Make sure the
of your ESCs, in turn, into the receiver's Throttle
camera platform faces forward and the bolt
port (Season 2, Episode 4). Mount the receiver
heads face outward; you'll need access to them
and plug it into the flight controller. Center the
to adjust the tray later. Strap the battery to the
yaw servo and tighten the linkages.
tray with the velcro strap.
Finally, screw the top plate to the standoffs to
protect your electronics, and your Maker
Hangar Tricopter is complete!



Step #12: About Flight Controllers

These are the boards I recommend for the

Maker Hangar Tricopter:

OpenPilot CC3D

The best flight experience, easy setup, but

tuning takes time

HobbyKing KK2

OK flight experience, fast tuning with

onboard display, best for beginners

ArduPilot APM 2.6

Most powerful and expensive; program—

mable waypoint capabilities with GPS,

Step #12: About Flight Con-

compass, and barometer

trollers

Flip 1.5 Multi Wii Controller (MWC)

Small, simple, and affordable, but power—

The flight controller board converts the signals

ful and flies well; optional barometer and

from your transmitter into the motor speeds

compass

that move your tricopter. It also reads the aircraft's position and movements with its

onboard gyros and accelerometers, and makes

tiny changes to motor speeds to counter the

wind, torque, and other forces that are trying to

tip the copter over.

Index

Symbols

I

J

O

Colophon

The cover photo is by Mark Harrison. The cover and heading font is Benton Sans; the body font is Myriad Pro.

Document Outline