Enabling Technologies for Small UAVs

or:

How I Learnt to Stop Worrying and Love Drones

By Chris Clay

Introduction

In the past couple of decades, rapid technological advances have changed the way we see the world. Several of these new technologies has combined to form something completely new - consumer drones. These products put piloting aircraft firmly within the grasp of the public, and have found many new opportunities to do good in the world.
There are an amazing community of enthusiasts pushing the boundaries of Unmanned Aerial Vehicles (UAVs). They have worked together to develop drones from their origins in remote control model aircraft, and have shown outstanding collaboration and creativity.
Small unmanned aircraft are rapidly becoming big business, as a wide range of new applications are being developed beyond taking photos – or ‘dronies’! This essay will explore the enabling technologies behind the drone revolution, and the great public good these drones can do.

Enabling Technologies

Unmanned aerial vehicles today are unrecognisable from their ancestors. This is because a raft of new technologies have swept across the technological landscape. These technologies have made model aircraft safer, simpler and cheaper to build and fly.

New Structural Materials

Traditional UAVs were constructed from plywood and balsa wood in a rib-and-spar style as can be seen in Figure 1. This made them complex and fragile. These aircraft were only built by experienced hobbyists due to the high cost and long build time. New materials such as extruded and expanded polystyrene have made it possible to build cheap and durable aircraft for a fraction of the original cost. New foams simplify construction, by enabling complex 3D airframes to be created from simple 2D templates without needing reinforcement.

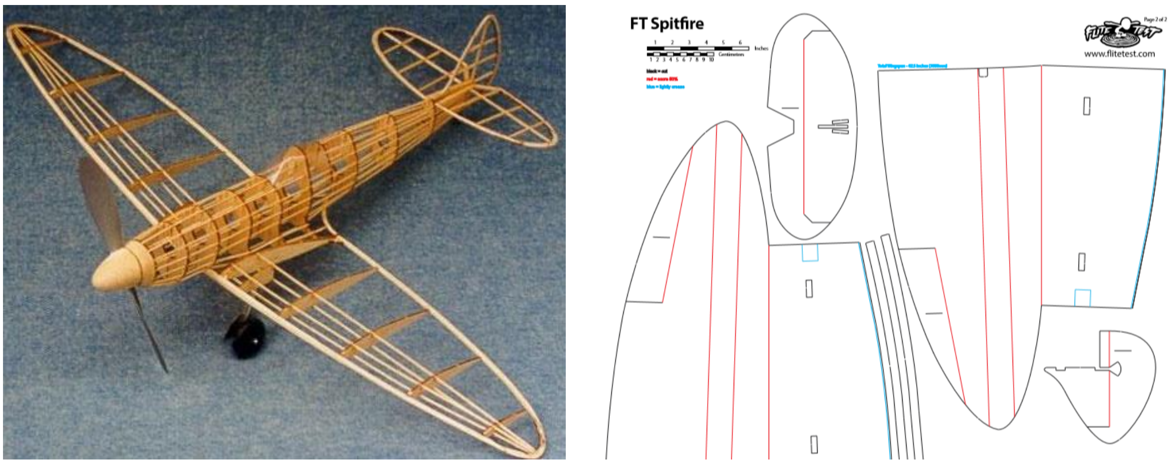

Figure 1: Old and New Methods for Making a Model Spitfire [1] [2]

The increased availability of 3D printers has enabled far more complex airframe geometries to be created. Whilst early 3D printed UAVs were heavy and fragile, improvements in the printing process and the use of strong but lightweight internal structures have made these drones capable flying machines. 3D printers have also allowed people to share and collaborate on UAV designs in ways not previously possible. This has enabled novices to simply download and print other people's drone designs, whilst also offering greater flexibility to advanced builders.

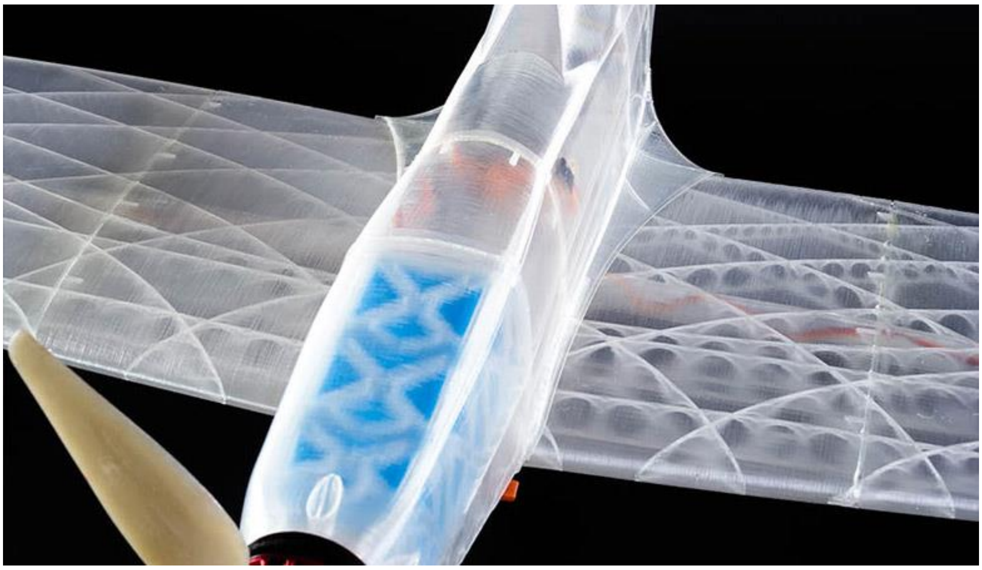

Figure 2: 3D Printed Small UAV with Internal Wing Structures [3]

Power Systems

Alongside changes to the airframe, UAV power systems have changed dramatically. When thinking about electric passenger aircraft of the future, it is important to realise that the electric aircraft revolution started small - in model aircraft. Previously, nitro or gas powered aircraft were noisy, heavy and expensive. Modern all-electric power systems have made it possible to achieve a higher power density for small models.

Using a combination of brushless motors and lithium batteries, these powertrains offer increased power density on small aircraft. This enables aircraft to carry greater payloads and widens the flight envelope, encouraging more unusual designs. The thrust to weight ratio of modern drones often exceeds that of all large aeroplanes, and even that of the Space Shuttle on takeoff! [4] Figure 3 provides a comparison between the different thrust to weight ratios of a variety of aircraft.

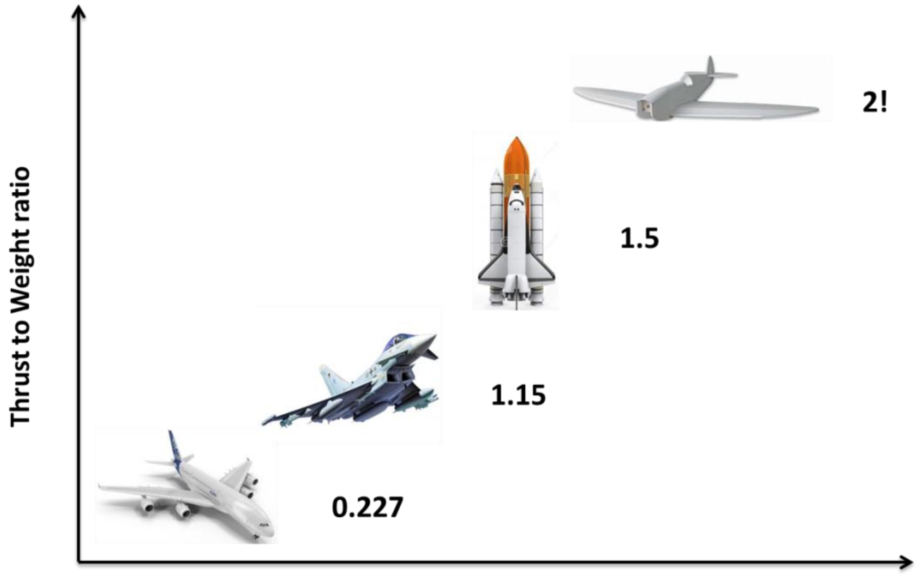

Figure 3: Thrust to Weight Comparison of Different Aircraft Types [4]

Flight Controllers

Remote control model aircraft have historically been fully manual systems, where the movement of the actuators was directly linked to the stick inputs of the operator. This meant that gusts of wind and other disturbances blew small UAV's around and made them challenging to fly. There was also no safety net to recover the aircraft if something did go amiss, except sheer pilot skill.

Miniature gyroscopes and accelerometers developed for mobile phones found their way into drones. These enabled drones to 'fly-by-wire', where external disturbances could be corrected for, reducing the need for the pilot to battle the elements. It also allowed beginner modes for UAVs – where the aircraft prevented the pilot from entering an undesirable attitude. This allowed budding pilots to learn more about flying and less about repairing their aircraft!

These fly-by-wire systems were a key enabling technology in the development of quadcopters. Such aircraft would be extremely difficult to fly without control systems to stabilise them against their own prop wash, and to keep them level.

Modern drones have continued to build on these core features, adding GPS and barometers to enable drones to hover in the same place on their own, and then developing waypoint following - where the drone follows a pre-planned route autonomously. Drones are now being equipped with even smarter sensor suites; such as stereoscopic cameras, laser rangefinders and ultrasonic sensors. This enables them to detect obstacles and even plan routes through congested environments.

One extremely sophisticated small UAV provides an indication of what the future might hold. RISER, a drone developed for inspecting highly radioactive environments, is able to fly fully autonomously in a GPS-denied environment that it has no information about. It achieves this through Simultaneous Localisation and Mapping, or SLAM. RISER uses a LIDAR to create a 3D map of its environment in real time, and then fly using that map. This capability enabled

Sellafield Ltd to survey the damage to the infamous and highly radioactive Windscale Pile that caught fire in 1957.

Figure 4: RISER at Sellafield [5]

Online Collaboration

Perhaps the greatest enabling technology has been the formation of online communities where people can share ideas and designs. The Internet has proven a very powerful tool for collaboration, and drones have been an excellent example. Free online resources have been created which enable novices to create their own drones with affordable materials and videos showing the whole build process. These communities have also developed new UAVs together and built a huge free knowledge base. They engage and challenge their members, through competitions and gatherings
They have also been used to indulge unusual tastes, and can be seen in Figure 5.

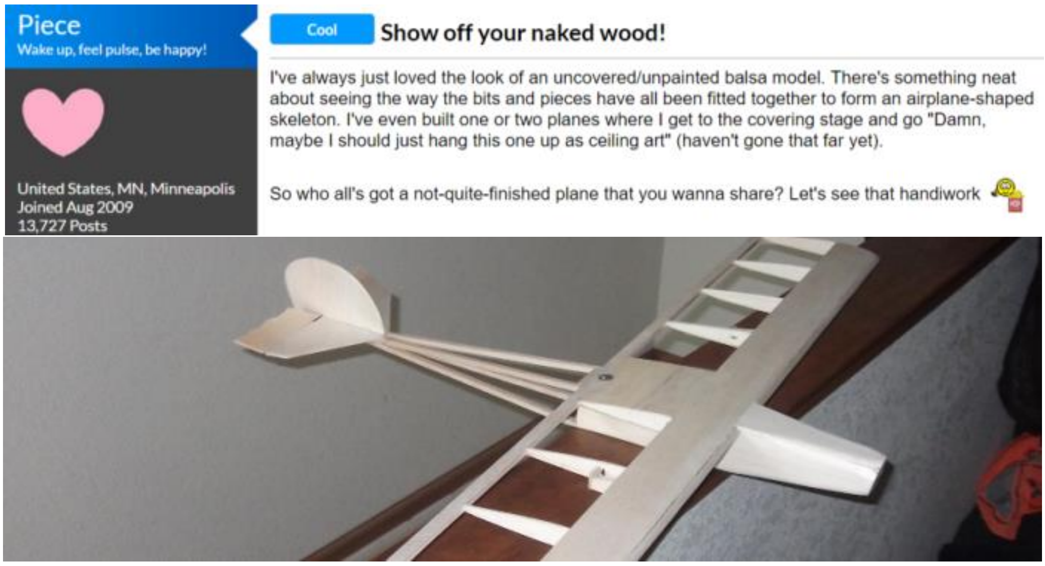

Figure 5: Online Communities for Every Taste [6]

Whilst the new commercial drone industry is now responsible for many of the cutting-edge products, some community projects remain the cutting edge in drone technology. Donation-funded flight controller developers have developed extremely fast, affordable, open source software and hardware. Example of these include the flight controllers used in racing quadcopters, almost all powered by the open source Betaflight, and also the open-source Pixhawk flight controllers which enable sophisticated autonomous flight on a budget.

How Drones Work

Initially control inputs are given to the transmitter by the operator. These signals are sent via radio frequency communications at 2.4Ghz, the same frequency as WiFi. This signal is received by the receiver on board the drone, which decodes it into individual command signals for each of the actuators. Each actuator receives a unique Pulse-Width-Modulated (PWM) signal which determines what it should do next. In systems with a flight controller, the flight computer also senses the aircraft's motion using the accelerometers and gyroscopes. It calculates what the actuators need to do to correct for any disturbances, then combines this with the requested movement from the operator.

Modern UAVs use brushless motors, which require speed controllers to drive them. The speed controller uses the PWM signal from the receiver to control the power supply to the motor. The brushless motor has 3 separate stator coils. By rapidly switching the 3 coils in the motor on and off, the speed controller induces a moving magnetic field in the motor. This moving magnetic field interacts with the permanent neodymium magnets in the rotor, causing it to rotate and generate torque.

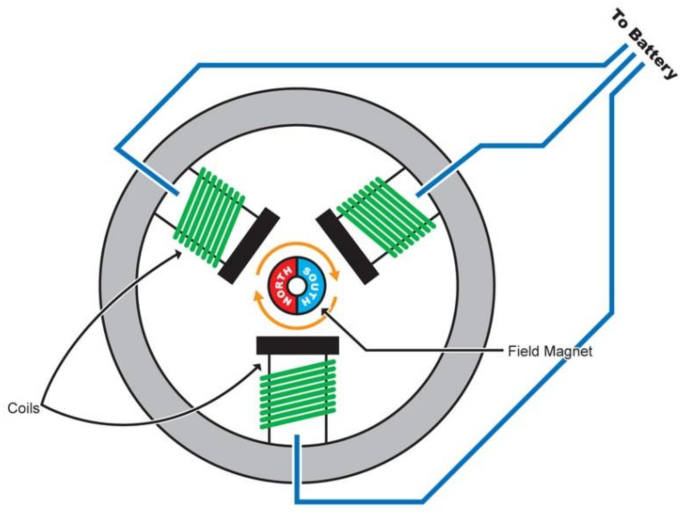

Figure 6: Simplified Diagram of Brushless Motor [7]

Power is typically provided by a lithium polymer battery. Whilst lithium ion batteries offer superior energy density to lithium polymer cells, they cannot tolerate high discharge rates. The discharge rating, or 'C' rating of a battery defines the minimum time a battery can be discharged in without damaging it. For example, a 2C battery can safely be discharged in half an hour. The longevity of today's lithium ion batteries suffers significantly if they are discharged at greater than 1C, or in less than one hour. This far exceeds the flight time of most small UAVs today, making modern drones too power hungry for such batteries. Some racing quadcopters require batteries with C ratings as high as 90C.

As in traditional aircraft, synergies between systems can multiply the effect of incremental performance improvements. For example, by selecting a more efficient propeller, the motor will require less current to meet its thrust requirement. Reducing the current demand on the power system enables the use of lighter speed controllers and power cables. It also enables the use of batteries with a lower C rating, which typically have a higher energy density. The weight savings in the power system will reduce the loading on the airframe during manouvers and landings, enabling further structural weight savings. All of these factors combine and multiply, enabling small design tweaks have potentially large improvements in aircraft performance.

The advances in drone technology have made today's drones lighter and more powerful than their predecessors. This has also had the effect of widening the flight envelope – increasing the scope for people to experiment with the weird and wonderful. Because of the scaling effects of size on materials and power systems, things that would never fly at larger scales suddenly become viable. This has encouraged members of the community to be creative – as can be seen in Figure 7.

Figure 7: Proof of the Very Wide Flight Envelope! [7]

Why Make Drones?

Drones are a hobby like no other. With the same core technologies, people have been able to do completely different things, creating highly original aircraft.

Figure 8: Solong Motorglider [7]

One example of this is this Solong motor glider, which was able to stay airborne for 48 hours on solar power. It's charged its batteries during the day using solar panels and used this energy to stay aloft at night. The reason they landed was because the pilot was too tired! This incredible feat of engineering was completed in 2005 by a team of enthusiasts – they developed a capability that giant organisations such as Google, NASA and Facebook are still working on today.

Figure 9: Homemade Slope Soarer [7]

Another fascinating part of the UAV hobby are slope soaring drones. These aircraft are the fastest small UAVs, yet they have no motors. They use thermal air currents over land in order to build up ferocious speeds. In order to handle the extreme g forces and to achieve the maximum possible speed these aircraft are designed are constructed almost entirely from carbon fibre. They are extremely aerodynamic and are also extremely strong. Figure 9 shows a glider that was able to achieve over 400 miles an hour. These aircraft take great piloting skill.

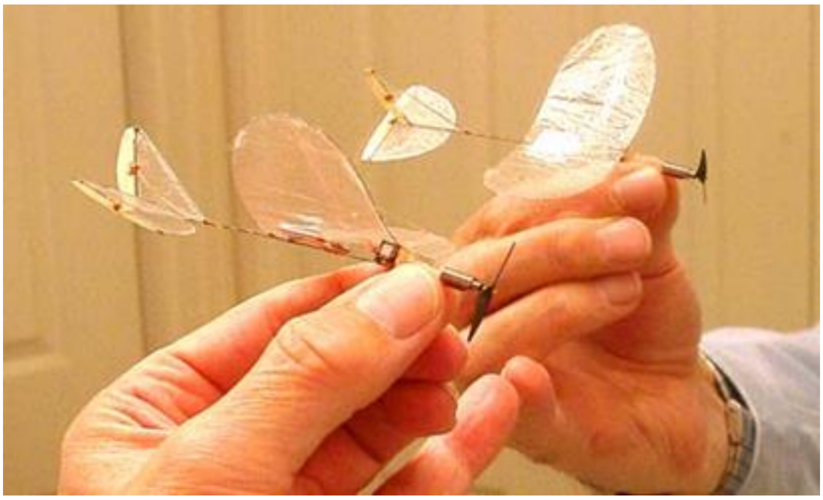

Figure 10: Micro RC Plane [11]

Incredibly, the aircraft in Figure 10 weighs less than a gram. It is constructed from tissue paper and yet still has a motor, rudder and elevator for control. There is a whole area of the Hobby dedicated to flying ultra-lightweight aircraft, including tiny 3D printed jets that are almost impossible to see in flight!

A Holistic Perspective on Design

When setting out to build a drone, you become the customer, the designer and the pilot. Combining these roles offers a new perspective on the design of more complex products. When taking on these roles in unison, it becomes clear that the solution to many challenging problems is not to develop novel and complex engineering solutions (as are often so tempting!). Instead, the problem can often be solved through other means. As the customer and the designer, you are in a unique position where you can tailor you solution to suit your requirements. You know which parts of the specification you may compromise on in order to meet those that matter most to you. Often in large projects, it is not possible to see the whole perspective and communication between parties is ineffective. This means that it is difficult to know where requirements have come from and if they are flexible. When you are the entire operation, it becomes easier to see different viewpoints, and these insights are of value in even the most complex engineering projects.

Drones for Good

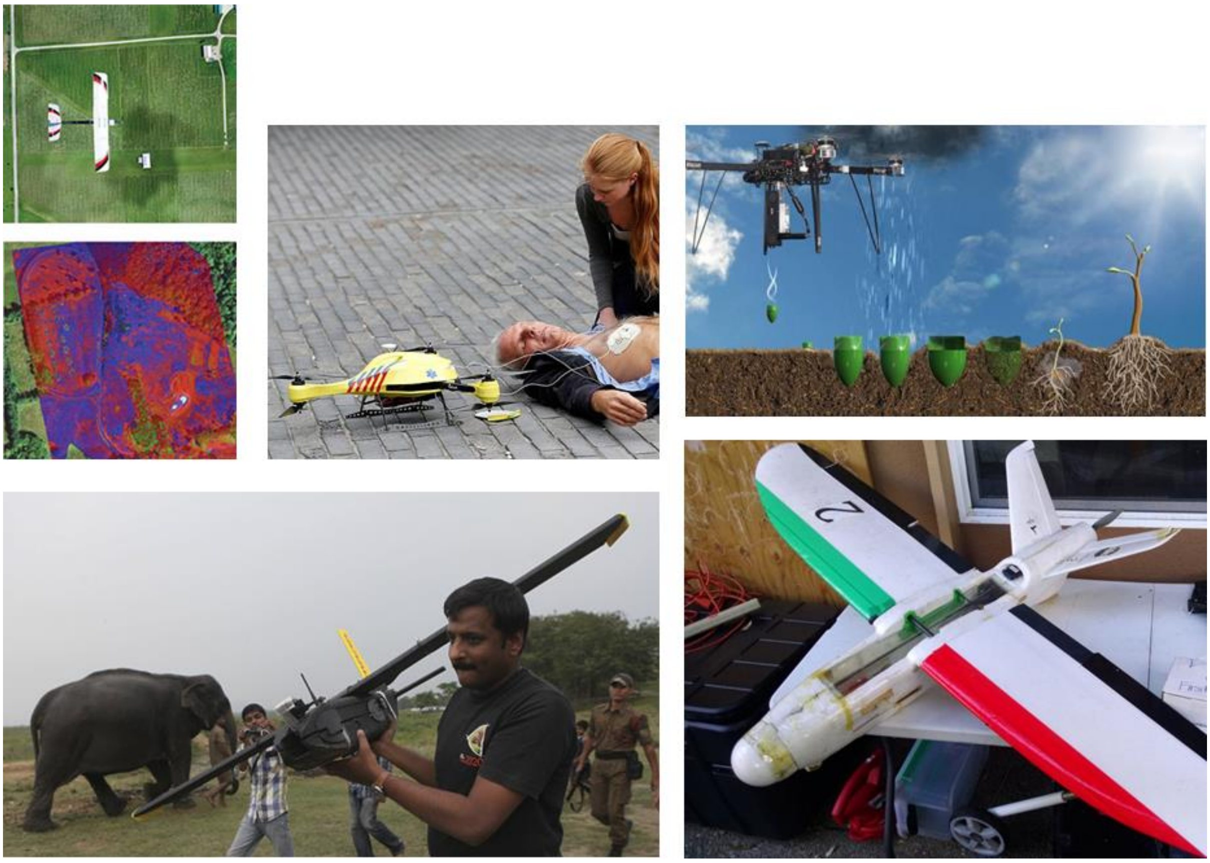

Figure 11: A Selection of Different Drone Projects Doing Good in the World [1] [13] [14]

With the same core technologies, people have been able to create drones that are able to do a wide range of things that help society. They offer a way to gather information from and deliver payloads to areas that are difficult or dangerous to go. Commercially, drones are now widely used in agriculture to help farmers boost their crop yield and in industrial inspection. Drones have even been deployed in the fight against poaching. Drones are able to track poachers, helping park rangers to protect wildlife.

One well-publicised project including involving drones is the Free Syria Airlift Project. [1] The goal of this project is to provide humanitarian aid to those trapped in areas of conflict in Syria. Using low cost off-the-shelf drones enables this project to deliver lifesaving medication to people who have nowhere else to turn.

Perhaps the most ambitious project involving drones is the 1 Billion Trees Project. [2] Their vision is to fight climate change and deforestation by planting a billion trees, using seed pods dropped from drones. Drones offer a highly autonomous and low maintenance platform which can multiply the effectiveness of their operators.

Summary

Drones are more capable than ever thanks to a wide range of new enabling technologies. They will continue to get smarter and safer, and become more commonplace as costs

continue to fall and new opportunities for their use arise. Drones are now more accessible than ever due to a huge community of enthusiasts that share ideas and collaborate to make fantastic new designs, and thanks to clever software that keeps drones in the air and off the repair bench.
Finally, building drones is an excellent way to develop a holistic view of the design of new products, and to become a better engineer. They are a fantastic way to challenge yourself. You are free to set your own goals and challenges - the only limit is your creativity!

References

[1] “Spitfire - Penn Valley Hobby Center,” 2001. [Online]. Available: www.pennvalleyhobbycenter.com/rubber/Easybuilt/LC01Spitfire.htm. [Accessed 7 2017].

[2] Flite Test, “FT Spitfire - Build,” 5 2013. [Online]. Available: https://www.flitetest.com/articles/ft-spitfire-build. [Accessed 7 2017].

[3] Pinshape, “3dLabPrint Spitfire,” 2016. [Online]. Available: https://pinshape.com/items/8135-3d-printed-3d-printed-rc-spitfire-mk-xvi-ver12. [Accessed 7 2017].

[4] Wikipedia, “Thrust-to-weight ratio,” 6 2017. [Online]. Available: https://en.wikipedia.org/wiki/Thrust-to-weight_ratio. [Accessed 7 2017].

[5] BBC, “How Sellafield's radiation-proof robots do our dirty work,” 8 2015. [Online]. Available: http://www.bbc.co.uk/news/business-33849026. [Accessed 7 2017].

[6] RCGroups, “Show off your naked wood!,” 1 2013. [Online]. Available: https://www.rcgroups.com/forums/showthread.php?1801564-Show-off-your-naked-wood%21. [Accessed 7 2017].

[7] “Difference Between Ac And Dc Motors,” DronEPIC, 2015. [Online]. Available: http://www.google.co.uk/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0ahUKEwiKgd2fg4HVAhVQLVAKHUiRBJkQjxwIAw&url=http%3A%2F%2Fdronepic.co.in%2Fblog%2Fdifference-between-brushed-vs-brushless-motor-pros-and-cons.html&psig=AFQjCNEvt9A5PH91xk. [Accessed 7 2017].

[8] RCGroups, “Flying Lawn Mower ARF aka Sky Cutter,” 12 2012. [Online]. Available: https://www.rcgroups.com/forums/showthread.php?1796429-Flying-Lawn-Mower-ARF-aka-Sky-Cutter. [Accessed 7 2017].

[9] RCGroups, “One for the record books--48 hours of flight!,” 6 2005. [Online]. Available: https://www.rcgroups.com/forums/showthread.php?378861-One-for-the-record-books-48-hours-of-flight!. [Accessed 7 2017].

[10] RCGroups, “Kinetic Transonic DP,” 1 2017. [Online]. Available: https://www.rcgroups.com/forums/showthread.php?2819794-Kinetic-Transonic-DP. [Accessed 7 2017].

[11] RCGroups, “Rabbit Recievers,” 10 2007. [Online]. Available: https://www.rcgroups.com/forums/showthread.php?754973-Rabbit™-Receivers#post8331197. [Accessed 7 2017].

[12] IEEE, “The Defibrillator Drone Is Another Good Drone Idea But Will It Work?,” 19 2014. [Online]. Available: http://spectrum.ieee.org/automaton/robotics/drones/defibrillator-drone-another-good-drone-idea. [Accessed 7 2017].

[13] BBC, “Getting aid to a war zone in a swarm of drones,” 5 2015. [Online]. Available: http://www.bbc.co.uk/news/magazine-32452678. [Accessed 7 2017].

[14] Wired, “Drones could help save the world's forests,” 5 2015. [Online]. Available: http://www.wired.co.uk/article/drones-for-good. [Accessed 7 2017].