Assignment 1 - Literature Review

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Drone Delivery - Parcel and Passengers

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Introduction

Over the past few years, there has been significant research and development into both delivery drones and passenger air vehicles (PAVs). With a rapidly growing demand for the once slow and tedious medical, postal and food delivery services, the need for delivery drones in society has also increased. Although a number of highly reputable companies such as Uber, Amazon and UPS are all currently prototyping, testing and modifying their drones, significant testing in dense rural areas must be undertaken to maximise safety, reliability and repeatability and minimise the chance of failure. Although the reality of delivery service drones is on the cusp of being released, human transportation drones are still years away. Despite a number of highly competitive Aerospace companies working on the development of safe, reliable, cost effective and environmentally friendly vehicles, a lot more safety and legal factors pose a risk to both the passengers and observers.

1 Parcel Delivery Drones

Parcel delivery drones have recently attracted significant interest from a number of major companies across the world. Despite the most common food and postal delivery services appearing to be the main reason for development, there are also a number of other highly valuable uses for these drones. These have been discussed in detail through their relevant fields of interest below.

1.1 Fields of Interest

1.1.1 Healthcare

Arguably the most common and sought after reason for the development of autonomous delivery drones is for the transportation of medication in life dependent situations. Currently there are only a small number of operational medical drones, with these being used to deliver blood and pharmaceutical products to health facilities in Rwanda and Ghana [1]. Although there are limited operational drones at the moment, there are many uses and plans for healthcare drones in the future. Being able to deliver automated external defibrillators would save far more lives, with testing proving that these drones can respond and arrive at a destination at least 4 times faster than a regular ambulance. After a cardiac arrest, the chances of surviving decreases by 10% for every minute that the patient goes without defibrillation [2]. Another use for these drones would be to distribute birth control, snake anti-venom and vaccines faster in rural areas. Therefore, it is clear why the use of drones in these situations would be of such great benefit to society.

Along with these drones being used for life dependent situations, they also pose great benefit to increasing the quality of life for sick or elderly patients. With the possibility for home based medical care, this would allow the sick and elderly to instead live at home far longer, with their medication being delivered to them via drone. This would vastly increase the quality of life for these people, allowing them to live more happily in their own homes, maintaining independence, saving time, and reducing the spread of germs and disease [3].

1.1.2 Food Delivery

Another important and beneficial use of these delivery drones is for a faster and more reliable click and collect food service. With Uber Eats and other services being such a success, companies began to realise that the demand for fast, easy and cheap food delivery is rapidly growing.

Although this delivery service is still yet to be released and commercially tested by some of the more major companies, testing in rural areas has provided insight into the benefits of this service. Uber has said that their drones can reduce delivery times to a mere 7 minutes, compared to the typical 21 minute delivery time from either a car or bicycle [4]. In addition to this, sustainability is another important factor. With the drones being small, compact and electric, this will significantly reduce

emissions and resources required by current delivery services.

Despite the benefits of releasing drone delivery services, this will inherently still produce a number of key challenges. These include safety, changing weather conditions (wind, rain, snow), air traffic management and noise pollution across more densely populated areas. Along with this, it is likely that these companies will face significant regulatory and technological restrictions until this service becomes a standard part of society. Simple issues such as overloading of the drones may also pose a concern unless measures are implemented to cease the drone from flying if it detects any weight issues [5].

1.1.3 Postal Delivery

The final reason for the development of these compact, sustainable and time saving delivery drones is for postal shipment. With the current shipping time of packages often being at least 1-3 business days, a more fast and reliable delivery method is required. The use of these drones is therefore predicted to reduce shipping time down to 30 minutes or less, with the capability of delivering packages up to 2.25kg [6]. Although this limits large packages from being shipped via drone, Amazon's CEO Jeff Wilke released statistics during his keynote talk that over over 70% of their current sales are from packages weighing 2.25kg (5lb) or less [7]. In addition to this, according to management consulting group McKinsey Company, 86% of abandoned shopping carts online are the result of expensive shipping costs [8]. With the price of drone delivery predicted to possibly be no more than a few dollars, this would further help to increase sales and customer satisfaction.

Despite the benefits of having a postal delivery service, this of course brings about disadvantages as well. According to Canada Post, it may be something that is "more of an emerging threat to the existing postal business" [8]. Although this does bring about certain negative effects, the advantages of an air based postal service would be of great benefit to society.

1.2 Drone Designs for Parcel Delivery and Companies Involved

Although there is a vast array of delivery drones currently being developed, prototyped and tested, only the most auspicious and promising of these drones will be discussed. The most common drone design for autonomous parcel delivery is a standard 4-8 rotor configuration, with the package being held beneath the base of the device. As shown in the figure below, Uber Elevate has opted for a conventional Hexacopter design, with the food delivery being encased in a small box below the flight controller and electronics. These boxes have been designed to keep the packages intact and hot until being delivered [9].

Figure 1: *Proposed Uber Eats Drone*

Similar to Uber Elevate, a number of companies such as UPS, DHL and Swiss Post have also opted for a multirotor design. This quadcopter design appears to be one of the most common delivery drones, with the parcel again being stored below the base of the device. These drones have a typical flight

range of 15 miles, with the ability of carrying packages up to 2.5kg or less. The figures below show a variety of these drones and emphasises their similarity.

Figure 2: *UPS Delivery Drone*

Figure 3: *DHL Delivery Drone*

Figure 4: *Swiss Post Medical Drone*

Although most companies have chosen to design multirotor helicopter drones, Amazon Air has instead designed a more unique Hybrid style drone (vertical take-off and landing with sustained forward flight). According to CEO Jeff Wilke, with the hybrid drone having 6 degrees of freedom, this allows more nimble and dynamic flight than a standard multirotor drone [10]. As this tilts during flight, packages cannot simply be placed under the base of the drone like some of the common designs. Instead, packages for delivery are stored in the fuselage in the centre of the drone.

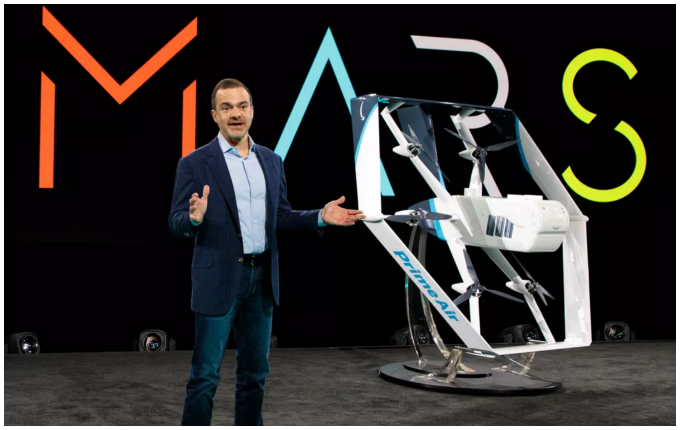

Figure 5: *Hybrid Drone Developed by Amazon Air*

Similarly, Google's parent company Alphabet has also designed a unique drone. Project Wing implements a hybrid style design allowing it to hover up and down, however also has the ability to sustain forward flight whilst travelling between destinations. What makes this even more unique is its delivery system. Instead of landing and potentially injuring someone, the drone lowers a rope connected to

the package, allowing it to remain in the air at all times. This drone is currently being tested in Canberra, Australia, with the Civil Aviation Safety Authority (CASA) approving the project for food and medical delivery [11]. Although still being trialled, the drone has successfully been delivering burritos, coffee and medication to a number of less densely populated suburbs. The figure below depicts the operation strategy of this drone.

Figure 6: *Fixed Wing Drone Developed by Google*

Another style of drone currently being utilised in society is a fixed wing aircraft by Zipline. This drone adopts conventional airplane features, however has an even more unique delivery and take-off method. After storing the package inside the plane, it is then ejected from the drone, with a parachute being used to deposit the medical supplies. As the plane also has no wheels for take-off, the drone is instead launched from a custom designed 'slingshot' [12]. Both the delivery and take-off mechanisms can be seen in the figure below.

Figure 7: *Delivery method*

Figure 8: *Take-off Mechanism*

1.3 Release/Estimated Arrival Time and Logistics

With such a large number of delivery drones currently being designed and tested, the commercial release date of these vehicles is largely governed by the Federal Aviation Administration (FAA). Although these drones are not being used in dense urban environments yet, a large number are being used in remote countries and locations.

As previously discussed, Zipline is a company that is currently using their drones to distribute vaccines, blood and life saving medication to remote parts of Ghana. This drone company has been operating since late 2016, and due to their great success and life saving support, is now worth more than $1.2 billion [13]. It is predicted that this company will continue to grow and expand as a result of its great success.

Another company currently responsible for administering medical and pharmaceutical products is Swiss Post. This company has been operational since 2017, with over 3000 successful flights between a pair of hospitals in Switzerland. However, a serious crash in May 2019 has suspended its operation until further notice [14]. With the drone weighing 10kg, this crash could have caused serious injury if it were to have crashed in a densely populated area.

In addition to the currently operational delivery drone services being used in rural areas, other major companies are also anticipating the release of their drones within the next few months. Amazon's Prime Air service recently received approval from the FAA to begin the testing of their drone, and as of August 8, filed a waiver that if approved will allow the company to begin their delivery service in the United States [15]. In this waiver, they outlined the logistics of their drone, providing a flow diagram of how their drone is planned to operate. This can be seen in the figure below.

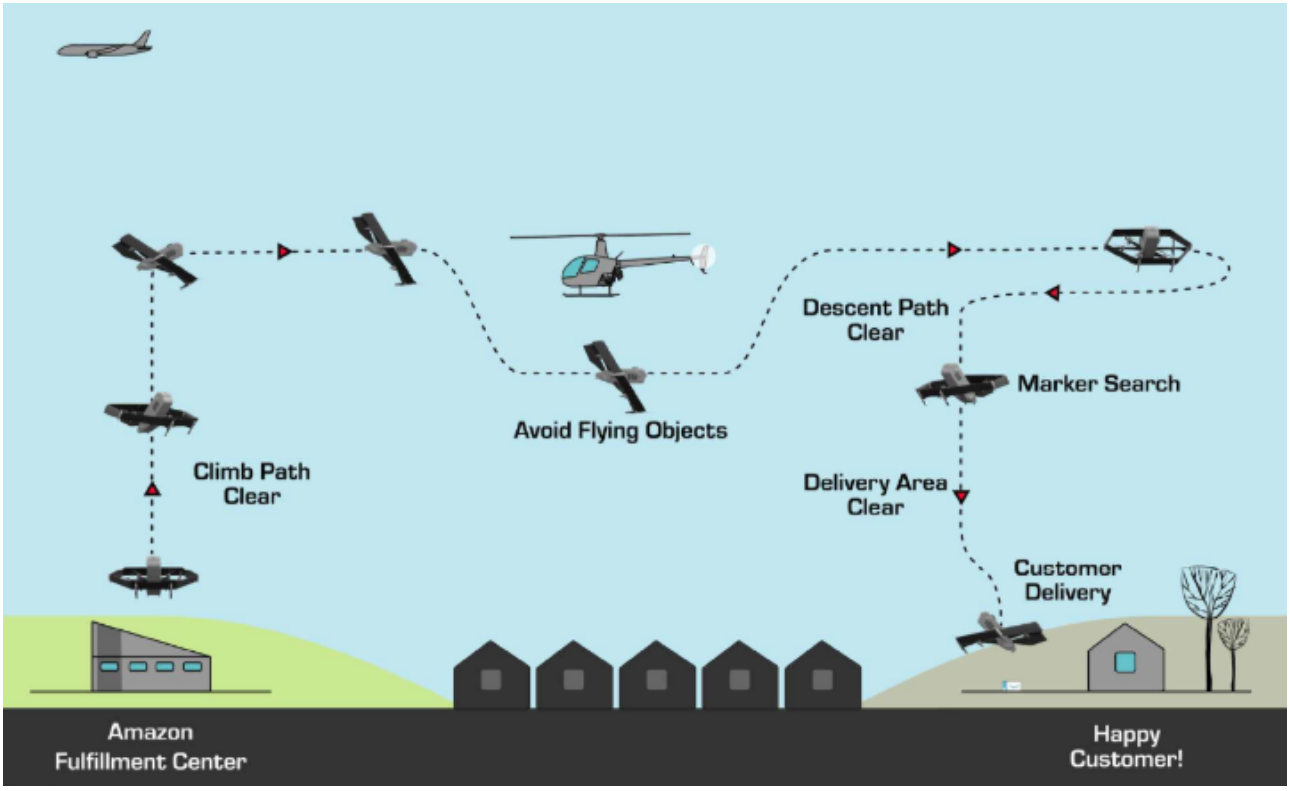

Figure 9: *Predicted flight path presented to the FAA*

Similar to Amazon Air, UPS is also seeking approval for the operation of their Horsefly drones for postal delivery. If approved, they will be legally allowed to fly over populated areas, at night and out of the operator's line of sight. Although the exact date release of this drone is unknown, it is likely they will receive approval at similar times to some of the other standard delivery drones.

DHL is one of the first postal delivery drones operating in the world. As of May 16 2019, and in partnership with the passenger drone company Ehang (discussed in detail further on), DHL launched the first fully automated and intelligent urban drone delivery service in China.

Possibly one of the most anticipated drones however, is the Uber Eats delivery drone. Uber has stated that this drone will be tested in San Diego during the Summer of 2019, with the aim being to test different methods of delivering their payload to customers in dense urban environments.

1.4 Parcel Delivery Drone Video Links

Below are a list of hyper linked videos to provide further information, clarity and insight into both the future and present state of delivery drones:

- Uber Elevate: https://www.youtube.com/watch?v=0yMv16p8FO8
- UPS: https://www.youtube.com/watch?v=JUOUt15DRbE
- DHL: https://www.youtube.com/watch?v=-gKHvUepybA
- Swiss Post: https://www.youtube.com/watch?v=gGsIgNASHUU
- Amazon Air: https://www.youtube.com/watch?v=3HJtmx5f1Fc
- Google: https://www.youtube.com/watch?v=vd8HmgkDhoU
- Zipline: https://www.youtube.com/watch?v=nnKnMgWy_tM

2 Passenger Air Vehicles (PAVs)

Unlike the delivery drones previously discussed, passenger drones are still in the midst of development and are years away from being reality. With transportation network companies seeing a large rise in popularity, it is clear why the development of PAVs is such an important field. Along with these drones being an extremely convenient and useful means of transport, a number of other reasons also set these apart from regular transport. As these drones will be electric, this will greatly reduce city emissions currently being produced by gas powered vehicles. In addition to this, other key reasons for their inclusion in society is to reduce traffic congestion, accidents and travel time and to provide a safer means of transportation. Another important use for these drones is to transport human organs for transplants in life saving situations. This is very similar to the parcel delivery drones, however there is the added option of transporting greater quantities between locations.

2.1 PAV Designs and Companies Involved

The most common PAVs currently being developed are electric vertical takeoff and landing (EVTOL) vehicles. These often resemble large scale quadcopter drones, with a cockpit for the passenger/s similar to a regular helicopter. Although a number of these drones consist of 4 regular arms, a common safety feature is to include 8 motors and propellers, with 2 on each arm. In addition to this, all of these drones have an interface screen, along with a control stick to alter the direction and speed of the vehicle [16]. The figures below depict the Ehang 184 (left), the newly released Ehang 216 (right) that has the added feature of seating 2 people, and the SureFly Workhorse (below). All of these designs exhibit similar features, however the stability and control of the Ehang 184 and 216 has proven to outperform the Workhorse (refer to video links).

Figure 10: *Version 1: Ehang 184*

Figure 11: *Version 2: Ehang 216*

Figure 12: *SureFly Workhorse*

Although the conventional drone design appears to be a popular choice for PAVs, Aurora Flight Sciences (a Boeing company) is working on the development of a more unique separate lift thrust (SLT) design. This design incorporate drone style rotors to vertically lift the aircraft, with an outfacing motor and wings taking over in forward flight for lift [17]. Similarly, Kitty Hawk has also been working on the development of an SLT drone, however have been testing their design for years under the guise Zephyr Airworks [18]. This drone operates in a similar manner, with 12 rotors being used to vertically lift the aircraft, and the 11m wings being used to produce lift during flight. Along with this, it has been proven to fly up to 110 mph and travel over 62 miles using the electric batteries. The figures below depict Boeing's partially complete PAV (left) and Kitty Hawk's successfully tested drone (right).

Figure 13: *Boeing's PAV*

Figure 14: *Kitty Hawk's autonomous flying taxi*

Another slightly less common PAV design is a multirotor helicopter drone. Fly Astro (left) have been working on the development of their VTOL drone, with this again consisting of a dual rotor design similar to Ehang and Surefly. This 2 person drone is designed to look like a small helicopter, with its full carbon fibre body attached to 16 individual rotors. In addition to this, the drone is outfitted with fiber optic internal communications, adaptive flight control, field oriented motor control and encrypted communication channels for increased safety [19]. Similar to Fly Astro, Volocopter (right) have also been working on a helicopter style drone. This drone utilises 18 rotors, and is capable of maintaining stable flight completely autonomously or through the use of a simple joystick [20]. Along with this, all communication networks are connected through the latest optical fibres.

Figure 15: *Fly Astro drone*

Figure 16: *Volocopter drone*

Although the main PAV designs can be seen above, there are a number of extremely unique concepts still in the midst of being trialled. Through a collaboration with Airbus, Audi and Italdesign, a detachable drone has been designed that not only operates as a flying aircraft, but also as a self driving vehicle. This style of design is the first of its kind, and has been proven to work on a scaled model 25% of the predicted size [21].

Figure 17: *Audi, Airbus, and Italdesign car/drone*

Another newly released design is a hydrogen powered air vehicle from Alaka'i. This design is a large style of drone, with the ability to seat 4 passengers and a pilot. CEO Stephan Hanvey announced that they were unable to "get to the point where we could have enough batteries to get to the payload that we knew we needed" [22]. With the drone being run from an alternative power source such as hydrogen, this extends the flight range to over 400 miles, with the ability to carry a payload of at least 454kg.

Figure 18: *Hydrogen powered air taxi*

The final design yet to be tested or even released is the Bell Nexus VTOL air taxi. Although it is still in the prototype phase, this vehicle is possibly one of the most promising designs. Due to its collaboration with Uber, along with its partnership with Safran, Thales, Garmin, Moog and Electric Power Systems (EPS), each subsystem of the air taxi will likely incorporate state of the art features [23]. In addition to the internals of the drone, the physical appearance and operation is closely modelled off the military tilt rotor aircraft previously designed by Bell. Although this passenger drone is much larger than the Ehang 184 and 216 for example, the ability to transport 4 people and a pilot significantly widens the market for this drone. Along with the ability to carry more passengers/cargo, and the added security of a pilot also makes this drone more of an electric helicopter than an autonomous drone.

Figure 19: *Bell Nexus VTOL Air Taxi*

2.2 Estimated Arrival Times

Although no passenger drones are currently being used in society, a large number of companies have predictions about when their drones will be operational. The most well known and possibly advanced PAV currently undergoing testing is Ehang's Autonomous Aerial Vehicle (AAV). This drone has been tested for a number of years in the city of Guangzhou, however has not yet been tested outside of China. Although it is unknown when this drone will be released to the public, on January 23 2019, the Airworthiness Department of Civil Aviation Administration of China (CAAC) issued the Guidance on UAV Airworthiness Certification based on Operational Risks [24].

In partnership with Uber's Elevate program, Bell has the goal of operating passenger drones in Dallas, Texas and Los Angeles by 2023 [25]. Despite being yet to test their drones, Uber is determined to be a leader in the growing field of air mobility, and is promising flight demonstrations by 2020.

Despite the Fly Astro drone containing significant advanced features, it is unlikely to be released within the next few years. After their successful flight in 2018, the company announced some of the improvements that they had planned for 2019. These include a new industrial patented design concept, a modular foldable design, improved payload and flight time capabilities, a triple redundant flight control system architecture, new motor controller and battery management systems, improved flight information displays, and larger customised propellers [26].

Another drone unlikely to be released anytime soon is the PAV from Alaka'i. As it was only announced in early May of 2019, the company has been yet to release any trials and demonstrations of the vehicle. Along with this, attorney Thaddeus Lightfoot who helps companies naviagte FAA rules, believes that it will be many years before the FAA allows autonomous flight of PAVs.

With the Kitty Hawk being an advanced and tested SLT drone, testing and approval is currently underway, with the hopes of this service being operational within the next few years. Kitty Hawk's Cora drone has an experimental airworthiness certificate from both the New Zealand Civil Aviation Authority (CAA) and the United States Federal Aviation Administration (FAA) [27]. Despite no official release data, they have stated that they are working with the CAA on further certification goals to hopefully bring an air taxi service to the commercial market.

The final highly anticipated drone is the PAV from Aurora Flight Sciences. With the company progressing from a design to a flying aircraft within the space of a year, it is likely that this drone will be one of the first on the market. With this company also being in partnership with Uber Air, their drone will also probably be operational as a flying taxi service by 2023.

2.3 Development Locations and Logistics

The first country responsible for the push to personalised aircraft transportation was in Guangzhou, China. After conducting thousands of test flights with and without passengers across the city, Ehang received approval from Guangzhou city government to establish a low altitude aerial transportation network for passengers and goods. Although they are yet to fly their drones in other countries, approval such as this is a large step towards commercialisation of PAVs.

Other PAVs are also being developed outside of China, with the US being a key country for this development. Although no drones are currently being tested in the US, the Department of Transportation advised that they would use the same process to consider approval of PAVs. This process is the same as any traditional approval used for commercial air carriers.

2.4 Safety of PAVs

One of the largest concerns for consumers is in regards to the safety of PAVs. Although they may seem like a dangerous means of transportation, key safety measures and precautions have been implemented by the companies responsible for their design.

The Ehang 184 and 216 have a number of key safety measures which have been designed in case of failure. The first of these is related to its unique propeller configuration. Although it has the layout of a standard quadcopter, the inclusion of a double motor and propeller system ensures that the drone can continue to fly if one set of the power system is acting abnormally, or in the case that one of the large 1.6m blades breaks. As the drone is therefore designed with full redundancy, it is unlikely that a motor or blade failure would ever result in a crash. In addition to the mechanical design aspects, the technology implemented in the drone also increases the safety of the flight. Each aircraft is embedded with a fail safe system, allowing the drone to immediately land if any of the software malfunctions or disconnects from the control center. Another safety feature is the encryption of all communication features, ensuring only Ehang can operate and control their drones.

With the Ehang 184 and 216 being one of the only PAVs to undergo testing, only a limited number of companies have released the safety information about their drones. The SureFly Workhorse also has similar safety features implemented, with the power drive system and propellers also being designed to allow the drone to continue flying if a motor or propeller fails. A safety feature that the Workhorse also includes is a ballistic parachute to allow a safe landing in the event of an emergency. Along with this, a backup battery power system further decreases the chance of a crash.

With only a few companies currently in the process of designing and testing their drones, it is likely that further safety features will also be included when they are released in the years to come. Although the companies involved in the design of these drones have ensured the safety features would allow for a safe journey for passengers, it is also important that they would pose no risk to the general public. For this reason, various legislative concerns are also a key factor in the progression and release of these drones.

2.5 PAV Video Links

Below are a list of hyper linked videos to provide further information, clarity and insight into the future of PAVs:

- Ehang 184: `https://www.youtube.com/watch?v=Mr1V-r2YxME`
- Ehang 216: `https://www.youtube.com/watch?v=yf3BGnzXSG4`
- SureFly: `https://www.youtube.com/watch?v=5yFZAPdYCck`
- Boeing: `https://www.youtube.com/watch?v=pv4A9IFm-7I`

- Kitty Hawk: https://www.youtube.com/watch?v=kJNACCPqFRQ
- Fly Astro: https://www.youtube.com/watch?v=IStmyk3R3Hc
- Volocopter: https://www.youtube.com/watch?v=ROJ76foyihs
- UBER AIR: https://www.youtube.com/watch?v=JuWOUEFB_IQ

Conclusion

After significant research surrounding the current employment and future ideation of delivery drones and PAVs, it is likely that within the next few years these methods of delivery and transportation will become a part of everyday life. With delivery drones already being used with great success in developing countries across the world, the commercial demand for drones will continue to increase. Along with the urgency for delivery drones in society, the public transport system will likely see a rise in air transportation. Although these PAV drones would pose as an extremely convenient, environmentally friendly and fast way of travelling between locations, this means of air transportation is likely to be years away due to fear from the public and new legislation and approval being required.

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