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INFORMATIONAL

Impact of Hydrogen Drones for Package Delivery

Fuel Cell Drones Gaining Altitude

CONTENTS

Introduction

Commercial UAVs (Unmanned Aerial Vehicles) or “drones” are proving to be both technically viable and cost effective in many industries as diverse as agriculture, mining, and search & rescue. As unmanned systems technologies mature, along with the data crunching and artificially intelligent “data sifting” capabilities needed to process the vast amounts of data collected and used in UAV operations, the uses of these flying robots are multiplying exponentially.

One application that requires massive investment in both technology and logistical capability is drone package delivery. Despite the daunting investment, many players have entered the space over the past several years, indicative of an opportunity that outweighs the costs. Why do we think this is?

Technological advancements and the ongoing migration of business operations to e-commerce platforms have dramatically improved consumer experiences and expectations. Consumers, particularly in densely populated urban areas, now expect a broad inventory of goods to be readily available to them both in-store and online. Consumers also expect that these products can be picked up or delivered to them at little-to-no additional cost in shorter and shorter delivery windows.

Online shopping is a modern retail channel which, in alignment with the global trend of urbanization, leads to increased commercial traffic, congestion, and pollution in areas with dense population. Therefore, the general public demands restrictions to the urban access of freight vehicles, resulting in a bottleneck for the further development of e-commerce. Freight logistics – and home delivery in particular - needs a sustainable solution that offers fast delivery, low cost, and pollution-free operation. Many of the largest package delivery firms on the planet have recognized that drone delivery has the potential to offer all of these, and are aggressively pursuing the capability.

This paper examines UAV delivery, and explores the advantages that hydrogen drones offer – both in operational costs and in lowering pollution in urban areas.

Drone Package Delivery Advancements

2019 has seen a plethora of advances in the use of drones for package delivery around the world. From one-hour convenience to life-saving medical applications, drone delivery is moving from the idea to the field trial stage. Some of these advances include:

Alphabet Wing & Walgreens: Medicine Delivery

On October 18, Wing, the drone delivery subsidiary of Alphabet (Google's parent), began commercial drone deliveries in Christiansburg Virginia. Partnered with Walgreen's and FedEx, Wing became the first delivery company in the United States to be granted FAA approval for a delivery service. To achieve this approval, the company's battery powered drones completed more than 70,000 test flights and 3,000 deliveries in Australia.

Figure 1- Wing Delivery Aircraft (source: Wing)

The delivery trials are part of a North Carolina drone Integration Pilot Program (IPP). There are nine IPP's in progress across the U.S. as part of a Federal Aviation Authority (FAA) program designed to help commercial, federal, state, local, and tribal stakeholders come together to explore and solve not only technical challenges, but also governmental and regulatory barriers as well. The North Carolina program, led by the North Carolina Department of Transportation (NCDOT), was selected by the FAA in May 2018 as one of the initial pilot programs, and has focused on drone delivery (other states' programs have other focus areas like agriculture and first responders).

UPS and CVS: Another Choice

Not to be outdone by Wing and Walgreen's, UPS and CVS announced plans to also begin drone deliveries with partner Matternet, also in North Carolina. Matternet and UPS also performed testing under the NCDOT IPP, but for deliveries between medical providers, rather than to consumers.

Figure 2- Matternet Quad (source: Matternet)

The UPS program utilizes the Matternet M2 quadcopter for deliveries. The drone is rated to carry a payload of 5 lbs (2.3 kgs) and fly about 12.5 miles (20kms). Typical commercial flight procedures require landing with at least 30% battery (to assure power is available for adverse conditions or events), so assuming a round trip, the delivery range is about 4 miles (6.4kms). Since the planned flights are within WakeMed campus in Raleigh, this range is sufficient.

Indro, London Drugs, and Canada Post

In a Canadian partnership that takes a potentially wetter approach, Indro, a drone operator in the Vancouver and Vancouver Island area, has partnered with London Drug and Canada Post to deliver medicine and medical supplies to the Gulf Islands, a dozen small islands between mainland British Columbia and Vancouver Island. Traditionally supplies to these islands are only available by ferry or seaplane, so the drone service has the potential to deliver emergency medical supplies in a fraction of the time. A significant aspect of this program is that the delivery drone flies beyond the visual line of sight of the remote pilot (BVLOS) – which means that the aircraft must automatically identify hazards and avoid them. Flying among islands, these hazards could range from low-flying manned aircraft to birds, power lines, or radio towers.

Figure 3- Indro Delivery Aircraft (Source: Richmond News)

Figure 4 - Amazon Prime Announces New Craft (source: Amazon)

Amazon Prime Air

Amazon has been a leader in the drone delivery space for years, pushing the envelope for package delivery with specialized aircraft – it is obvious that the company is investing for the future. Earlier in 2019 the company announced its latest delivery drone, a hybrid that converts

from a vertical take-off & landing (VTOL) craft to a winged aircraft once in flight – a transition critical for long-distance deliveries.

Amazon started experimental deliveries before pretty much anyone else – with those trials taking place primarily in England due to a regulatory environment that was easier to traverse. Prime Air has development centers in not only the U.S. and the U.K., but also in Austria, France, and Israel, and the company is clearly taking the future of package delivery seriously.

Uber

Uber has announced that it will begin delivering food in San Diego by 2020, under its Uber Eats service. The company has been trialing technology with initial partners including McDonalds, developing packaging that will keep food hot during the delivery trip. They've estimated that in the congested Southern California area, a 1.5 mile delivery will take just 7 minutes, compared to 21 minutes on a bicycle or car. The company announced a new delivery platform in October, a hybrid VTOL fixed wing craft reminiscent of the Amazon craft announced earlier this year. Uber Elevate has previously shown this type of a platform for its Air Taxi ambitions, but has a scaled down version it will use for fast and efficient food delivery. The aircraft has a total range of 12 miles with a payload, so a prospective customer can be about 6 miles from the food source.

Figure 5 - Uber Delivery Aircraft

Zipline

Zipline has probably delivered more packages by drone than anyone else (more than 21,000 at last count), having rolled out medical deliveries to rural areas in Rwanda and Ghana. The company has taken a very different approach


Figure 6 - Zipline Aircraft (source: Zipline)

from all others, using fixed-wing aircraft (small airplanes) for delivery, rather than multi-rotors. The use of these aircraft required far greater ground infrastructure for takeoff and landing (or capture), but has the advantage of far greater range. Since the Zipline aircraft drops supplies by parachute, it does not need to hover and land, making it far more efficient for flying long distances.

Drone Delivery Globally

Other drone delivery services and companies have been announced around the globe, including:

- Drone Delivery Canada has announced delivery services to remote areas in Canada's far northern reaches.
- DHL has started drone delivery services in China.
- Redwing, Zipline, Zomato, Swiggy, Tata, and Honeywell have all been approved in India for various drone delivery services, from medicine to fast food.
- Aha and Israeli logistics provider Flytrex are delivering food from restaurants to Iceland residents.

Why Hydrogen Drones?

Hydrogen offers a simple advantage over batteries: Range. The range of an aircraft (the distance it can fly on a single "tank of fuel" or battery charge) is limited by the amount of energy it can store. The lithium-ion and lithium-polymer batteries used in most drones can provide around 200-250 Wh/kg (the *energy density* of the battery). That is, a battery weighing 1 kg can power a 200 watt aircraft for an hour. Alternatively it can power a 2,000 watt aircraft for 1/10 of an hour, or 6 minutes. Realistically most delivery drones need from 2,000 to 5,000 watts of power, so a battery to power the drone for 20 minutes will weigh around 10-20kg.

For that same 10-20kg of weight, a hydrogen fuel cell (along with a hydrogen storage tank) can run the same drone for an hour, instead of 20 minutes on a battery. Three times the energy density means that a hydrogen drone can fly three times as far as a battery powered version, carrying the same cargo.

Flight Range Extension Example

If we look at one of the North Carolina IPP test sites as an example, the trials are based around the Wake Medical Center campus east of Raleigh. Assuming a 4 mile range with batteries, from this location the eastern half of Raleigh could be serviced.

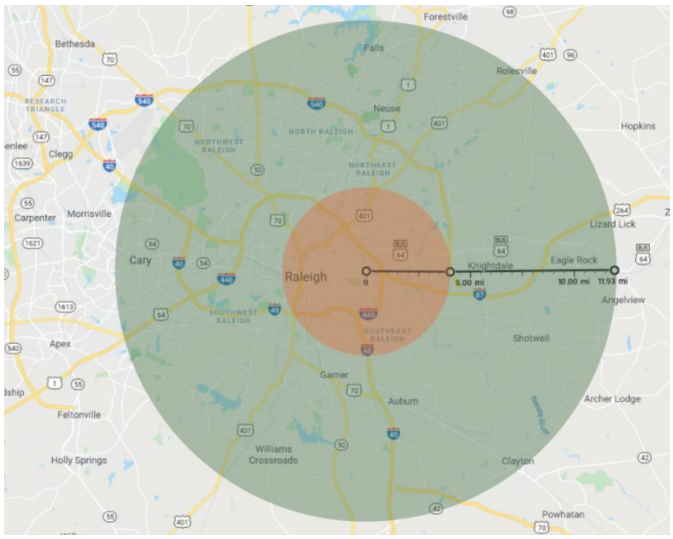

Figure 7 - Battery vs Hydrogen Delivery Range (map source: Google)

However, if we increase that 4 mile range to 12 miles – the 3x range increase drone operators typically see when converting from battery to hydrogen – the coverage area is increased by a factor of 9, resulting in coverage of not only the entire Raleigh area, but also surrounding communities. Figure 7 illustrates this: the red inner circle is the 4 mile coverage area (From Wake Medical Center), while the green outer circle is the 12 mile range.

Thus, if the goal was to be able to deliver medical supplies to the greater Raleigh area using battery powered delivery drones, 6-8 distribution centers, each having drone take-off & landing infrastructure, as well as the ability to recharge numerous drone batteries, would be required. Alternatively, a single distribution center with a single hydrogen refilling station would be needed to cover the same metro area – at a fraction of the cost.

Environmental Benefits

The hydrogen fuel cell power system is an electrochemical device that takes hydrogen from a tank and oxygen from the atmosphere, and combines the two to make electricity and water. Unlike lithium and cobalt, which must be mined (often at huge environmental cost), hydrogen can be a completely carbon-neutral and environmentally friendly fuel. While it has traditionally been produced from petroleum, “green hydrogen” is more and more being produced in a “reverse fuel cell” process, called electrolysis: Excess electricity from solar or wind farms is used to split water into hydrogen and oxygen. Green

hydrogen is completely clean across its lifecycle, and is a valuable way to put excess solar and wind production to use.

Because fuel cell powered drones produce no pollution and because they are extremely quiet, they are particularly suited to delivery in urban areas where both noise pollution and air pollution are a recurring problem.

Figure 8 BFD's Hydrogen Fuel Cell Hex-rotor. Water is the only emission.

Fixed-Wing Multiplier

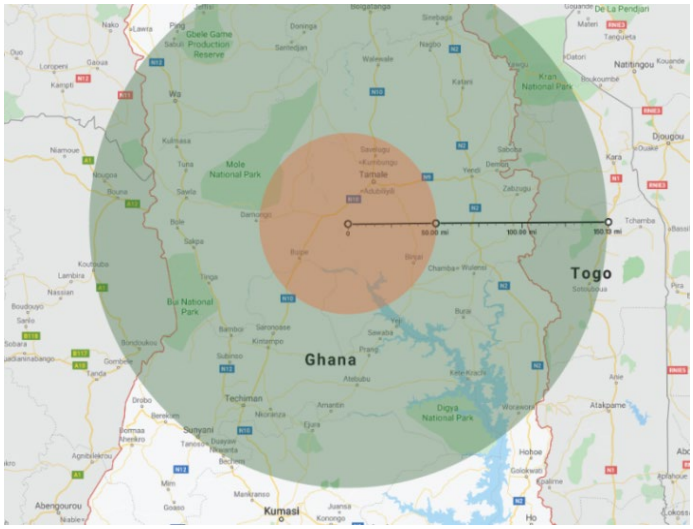

Figure 9 - Ghana Coverage: Battery vs Hydrogen (map source: Google)

The 3x range advantage of hydrogen can make an even bigger impact when fixed-wing drones are used. Zipline's aircraft is reported to have a delivery radius of 50 miles. By converting this battery powered fixed-wing craft to hydrogen and gaining the typical 3x range advantage, the delivery area explodes from 7,800 square miles to 70,000.

If we look at Ghana (one of Zipline's service areas), about 20 distribution centers would be required to cover the country, assuming a battery powered drone with a 50 mile radius. If we convert that to a hydrogen drone with a 150 mile radius, two distribution centers could cover not only Ghana, but also neighboring Togo, and parts of Benin, Burkina Faso, and Cote d'Ivoire.

Since these regional distribution centers rely on ground transport for resupply and have significant aircraft launch and recovery infrastructure, a 9x reduction in needed sites can potentially have a very significant impact on costs.

VTOL Fixed-Wing Hybrids

As discussed above, several package delivery leaders, including Amazon Prime Air and Uber, have announced aircraft that can take off and land vertically (VTOL), but which convert to fixed wing in flight. This type of aircraft is in fact the most ideal for hydrogen fuel cell use. The fuel cell is typically hybridized with a battery (the fuel cell charges the battery in-flight, and the battery powers the aircraft), and this permits the battery to be optimally sized for the aircraft's take-off and landing power needs – typically the time when power draw is at its highest. The fuel cell, on the other hand, can be sized for the aircraft's cruise power consumption, which is typically far lower. Since take-off and landing are typically very short duration, the battery can be small (and hence lightweight). Since the cruise power requirements are relatively low, the fuel cell can also be small (and hence lightweight).

The Ballard Hydrogen UAS Solution

Ballard Unmanned Systems fuel cell systems have been powering unmanned aircraft with hydrogen for over ten years, enabling longer, more robust flights than batteries or internal combustion (IC) engines. As waiver-free BVLOS operations near, Ballard is positioned as a market enabler, delivering cost competitive hydrogen power solutions that make possible the multi-hour flight durations required by commercial operators. Ballard is working with industry partners to deliver a complete hydrogen solution that incorporates not just the fuel cell system, but high pressure flight tanks and regulators, field recharging solutions and hydrogen on demand so that operators have easy access to hydrogen and all related system components, no matter how remote the mission.

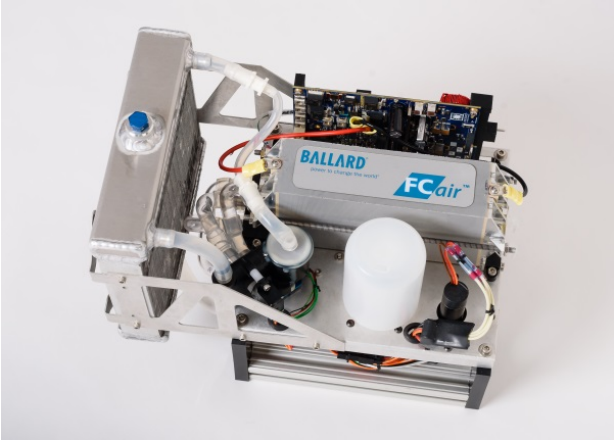

Figure 10 FCair™ 600W Hydrogen Fuel Cell

Lightweight Carbon Overwrapped Pressure Vessels (CPOVs) are another enabler for the hydrogen drone industry. Until recently, heavy steel tanks or cylinders were required to store hydrogen. The advent of COPVs, originally for aerospace applications but commercialized for fuel cell cars, trucks, and buses, means that meaningful volumes of hydrogen can now be stored in a container lightweight enough to be lifted by a UAV. Ballard offers several sizes of COPVs to aircraft designers to permit optimal range / weight tradeoffs.


Figure 11 - FCair™ COPV

Similarly, pressure regulators, which step down the high storage pressures within the COPV to the low pressure used by the fuel cell, were traditionally large and heavy devices. Ballard has partnered with regulator manufacturers to create miniaturized regulators that provide the performance needed for a UAV, but which are a fraction of the size and weight of traditional regulators.

Finally, hydrogen and compressed gas transport capability, operational familiarity, and safety best practice awareness are low within the UAS community. Ballard is committed to working with industry, government, and standards organizations to advance education and safe deployment of hydrogen power for not only UAVs, but also for automotive, truck, bus, rail, and marine applications. While industrial and lab-grade hydrogen are widely available throughout North America, the vast majority of sUAS operators have no exposure to no comfort with handling them. Ballard has engaged with suppliers to deliver multiple hydrogen sourcing and refueling options wherever commercial drones are deployed, with training organizations to assure safety best practices are known and followed, and with government agencies and regulators to assure applicable rules are clear, unambiguous, and easy to access. We also work with hydrogen refueling equipment producers to assure that refueling solutions minimize specialized gas handling knowledge, while maximizing safety. The Ballard FCair™ solution provides everything a platform maker or operator needs to launch emissions-free, quiet, long-range hydrogen drone operations. We provide the complete hydrogen solution, so the platform maker can concentrate on the aircraft, and the operator can concentrate on the mission.

Summary

A report published by the University of California, Berkeley Engineering department in 2015 projected that only 21.5% of Amazon packages were viable by drone (< 5 lbs and within 10 miles of distribution) while 64.5% met the weight limit but were out of delivery range. Utilizing hydrogen power eligible drone package deliveries for Amazon could increase drone coverage from 21.5% to more than 60% - a huge economic impact considering a Net product sales revenue of $141.9B in 2018. Combined with the fact that many Amazon distribution centers already have hydrogen supplies in place for forklift power, introducing hydrogen drones into distribution operations seems like a natural transition with a high return on investment.

Figure 12 –Amazon Fulfillment Centers Source: Business Insider

Through a decade of experience with both defense and commercial applications, we have observed that a 3x increase in hydrogen drone flight duration and range when compared to batteries is typical – some aircraft designed specifically for duration have achieved ratios far higher than this. In package delivery applications, the primary economic driver of hydrogen drone use is the 9x decrease in the number of distribution centers required to cover a given area. As leading retailers continue to ramp up drone package delivery operations, keeping hydrogen powered aircraft at the forefront of development can prove to be a critical decision to ensuring the future economic viability of broad scale drone-centric distribution. A study performed by The Boyd Company, and Princeton NJ that periodically studies "logistics-friendly" locations amenable to new distribution centers, estimated that a 500,000 square foot distribution center staffed by 150 employees could range from $11.5M to $15M per year to operate, depending upon its location.

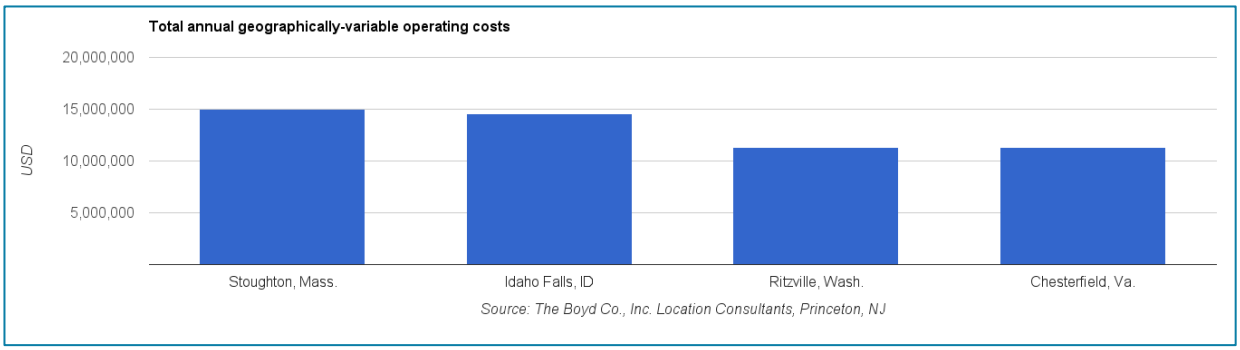

Figure 133 - Distribution Center Costs

The elimination of 89% of needed distribution centers would thus potentially have significant bottom line implications for any package distribution model that takes advantage of drones for the last mile.

Conclusion

Adoption of UAS for commercial applications is growing rapidly and is proving disruptive to many industries. Multiple package delivery players are poised to undergo dramatic changes from implementation and deployment of drones as delivery vehicles: speeding delivery response, reducing last-mile delivery costs, and eliminating last-mile air pollution. Hydrogen fuel cell technology has the potential to dramatically expand delivery reach, reduce distribution center costs, and eliminate last-mile delivery pollution. Because hydrogen drones can realistically achieve ranges three times those of battery powered drones, distribution center coverage areas can increase by a factor of nine, resulting in a dramatic reduction in distribution center density and hence costs. Multiple package delivery players are experimenting hydrogen drones, and those that are able to exploit the technology first will have a dramatic cost advantage over others that are tied to battery-only power solutions.