Decision-Support Tool for Designing Small Package Delivery Aerial Vehicles

Ashruf Ali
Nathan Ballou
Brad McDougall
Jorge-Luis Valle

George Mason University
System Engineering and Operations Research
Systems 490: Senior Capstone Design
Professor: Dr. Lance Sherry

Abstract— **The Unmanned Aircraft Systems market has been flooded with multi-rotor aerial vehicles with options that vary significantly in quality, capability and price. Users of Multi-Rotor UAS, particularly for small package delivery, are not experts on their design and do not understand the tradeoffs in utility. This projects serves to design a decision-support tool that considers an end user's set of requirements, and determines the most effective configuration of a multi-rotor aerial vehicle based on an objective function with weights established by the end user. The decision support tool leverages a power and dynamic simulation framework to specifically characterize a given multi-rotor configuration over a user's desired flight conditions. This dynamic simulation has yielded positive initial results and further testing and validation is ongoing.**

I. CONTEXT

A. Unmanned Aircraft Systems

For quite some time the Unmanned Aircraft Systems market has been dominated by Military applications. Up until the last five years it was uncommon for civilians to purchase and make use of these UAS in a functional capacity. Currently, the market for Commercial UAS, and more specifically Multi-rotor Aerial Vehicles, is niche and consists mostly of hobbyists. This is all largely due to a failure of the FAA to integrate UAS for commercial purposes into our National Airspace System (NAS). This integration has been mandated by congress and will likely happen by the close of 2015. Once the integration into NAS occurs, we see a major potential for growth in the Commercial UAS market.
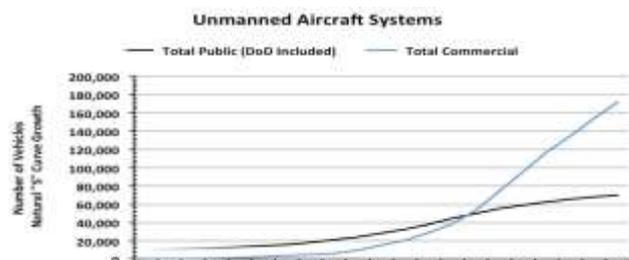

Figure 1: Public and Commercial UAV Expected Growth

What can be seen in the graph from Volpe's report to the National Transportation Systems Center is the progression of Public UAS vs Commercial UAS over the near future. Commercial applications of UAS are poised to exponentially grow and rapidly surpass the Public applications.

B. Potential for Growth

There are many areas that could thrive when Commercial UAS are integrated into the National Airspace System. Many of the areas that are highly anticipating immediate rapid growth are depicted in the picture below provided by the FAA.

Figure 2: Areas of Application of Commercial UAS

Although these are the areas commonly thought of being the most heavily affected by the Commercial UAS integration, we see the biggest potential for growth is in small package delivery.

C. Driving Factors behind Small Package Delivery

E-commerce, which relies heavily on delivery services to get goods from the seller to buyer, has been growing steadily over the years in the United States. What can be seen in the graph below, which is using data from the US Census Bureau's Annual Retail Trade Survey, is roughly a 10% increase year-to-year from 2006-2012.
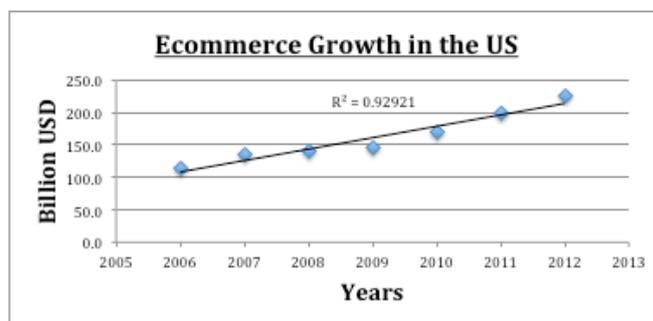

Figure 3: Ecommerce Growth 2006-2012

More importantly, E-commerce has not just been growing as an absolute, but is also slowly becoming a larger percentage of the overall Total Retail sales here in the United States. This means that each year more people are shopping by means of E-commerce as opposed to traditional brick and mortar leading to a higher demand for package delivery services. This trend of E-

commerce slowly becoming a larger percentage of Total Retail can be seen in the graph from the US Department of Commerce below. Starting at a mere 2.4% in 2005, it has now risen to just under 7% by the second quarter of 2014.
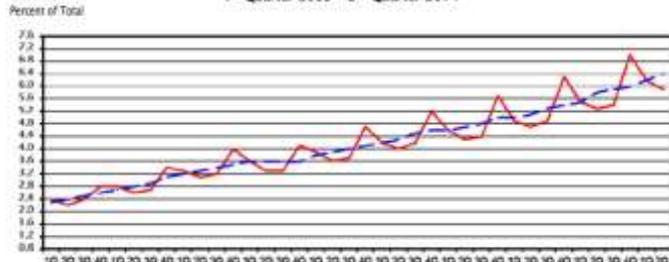

Figure 4: Ecommerce Sales as a Percentage of Total Retail Sales

These increases in the growth of Ecommerce and Ecommerce as a percentage of Total Retail can be seen affecting the proportion of retail sales that can be delivered which are delivered in the graph from Courier Express & Postal Observer below.
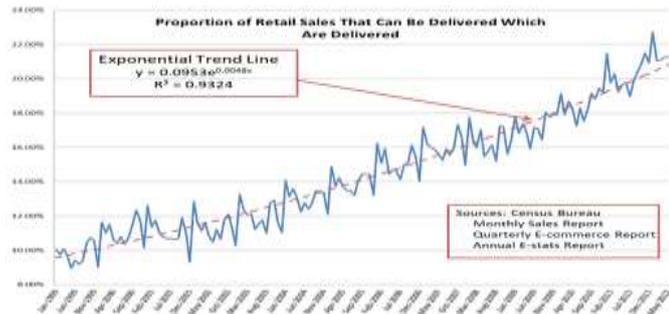

Figure 5: Percentage of Possibly Delivered Sales Actually Delivered

As of 1999, hardly 10% of retail sales that could be delivered were actually being delivered by the major shipping companies accounted for in the survey (USPS/UPS/FedEx). Fast-forward to 2012, and nearly ¼ of retail sales that could be delivered were actually being delivered by the major shipping companies. This growth of E-commerce driving the percentage of retail sales being delivered by major shipment/logistic companies has led to UPS and FedEx handling on average 25 million packages a day with an end of the year revenue of $90 billion in the year of 2012 alone.

Strictly due to the volume of packages being handled, this could be a huge market for Multi-Rotor Small Package Delivery Aerial Vehicles.

D. End Users of SPDAV

When we refer to small package delivery, the scope of the end users is not simply shipment/logistic companies. The potential end-users are broad and have very different missions but with similar requirements.

Market	Application
Shipment/Logistic	Transportation or delivery of mail and small packages.
Retail	Rapid delivery for non-brick & mortar purchases.
Food	Rapid food delivery.
Maintenance	Rapid parts delivery to inaccessible locations
Medical	Bring aid to remote location.

The one common theme to take away from all of these different markets and applications is that those who would be tasked with designing the multi-rotor platform are not Design Engineers.

II. GAP ANALYSIS

There is a market wide knowledge gap pertaining to performance and mission suitability of Multi-Rotor Aircraft.

Due to the newness of the technology, there are no resources/heuristics for making an informed decision.

There are many potential consumers of UAS that do not have the time, energy, or resources to understand the physics/mathematics/aerodynamics needed to properly select a Multi-Rotor SPDAV that best suits their needs. No single individual, or even organization, can be a subject matter expert on everything. We intend to bridge this gap caused by the general lack of knowledge around UAS and specifically their SPDAV applications

III. STAKEHOLDERS

Decision-Support Tool allows for all parties involved to be effected in a beneficial way ultimately creating a Win-Win scenario.
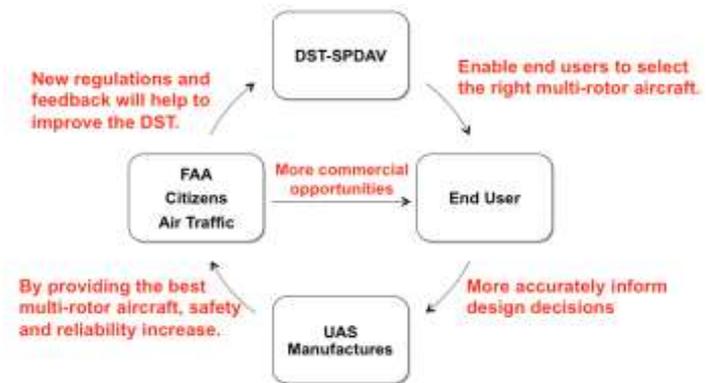

IV. PROBLEM – VISION

A. Problem

The market has recently been flooded with multi-rotor aerial vehicles with purposes spanning from a hobbyist toy to military direct action. All of these options vary significantly in quality, capability and price, leaving a lot of room to misinterpret needs and under or over compensate them. Users of Multi-Rotor UAS, in particularly, for small package delivery, are not experts on their design and do not understand the tradeoffs in utility.

B. Vision

We aim to design a decision-support tool that considers an end user's set of requirements, and determine the most effective configuration of a multi-rotor aerial vehicle based on an objective function with end-user established weights.

V. REQUIREMENTS

Below is a block diagram that outlines the functionality of our Decision-Support Tool. The input requirements coming in from the left side are processed through multiple models, which can be seen coming in from the bottom. Finally, you can see the output of the DST, a configuration of a SPDAV, coming out of the right side.
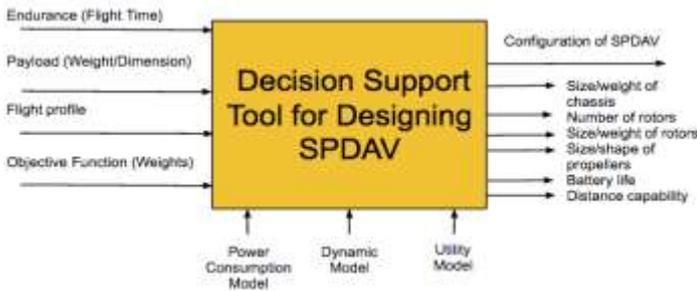
VI. SIMULATION

A. Simulation Methodology

The simulation is conducted in two stages – first a power model to identify promising candidates; then a full dynamic model to further characterize the specific performance of these configurations

For the power model, the user defines a maximum size, cost, minimum distance to travel with full payload, and maximum payload weight. These factors are then put through a simulation that quickly approximates the power draw, motor temperature, hover characteristics, and flight duration under normal loads. This portion of the simulation is fed either currently manufactured multirotor configurations or samples permutations of motor, battery, and propeller combinations. Unreasonable configurations (hovering requires greater than 80% throttle, exceeds maximum cost or size, motor temperature at maximum throttle exceeding 80 degrees Celsius.) The remaining configurations are then ranked based on user defined weights to prioritize models run through the full dynamic simulation.

The full dynamic model takes promising configurations and subjects them to a more detailed simulation. The user defines a typical flight profile and the model conducts a variety of simulation for each configuration to determine maximum package delivery distance for a variety of package weights and wind speed profiles. The program then outputs a three

dimensional graph showing results for each. This graph is curve fitted, and the integral taken to define a performance numerical value. The simulation then applies user defined weights to determine the value of an objective function for comparison amongst the other possibilities.

B. Expected Output

The below figure shows the output for an example small hexacopter configuration. The performance curve plots the maximum delivery distance over a given flight profile verses the frontal wind speed and payload weight.
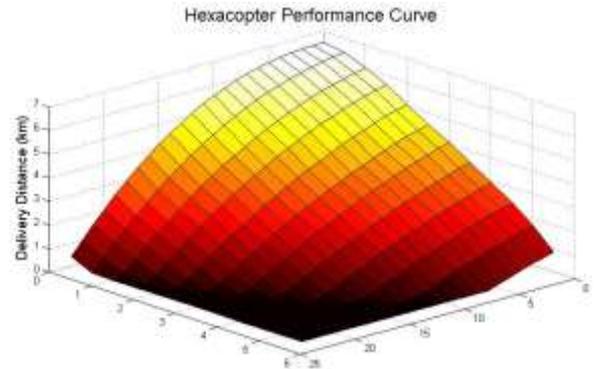
The hexacopter performance curve shows a maximum trip distance of approximately 6.7 km with no payload, with performance dropping dramatically as payload and wind speed increase. The no payload maximum wind speed is approximately 25 km/hr, while the maximum payload in no wind is approximately 6 kg. The curve further shows a greater decrease in delivery distance when increasing payload mass than when increasing wind speed conditions. This suggests that this configuration would be appropriate for small payloads in moderate wind environments.

VII. REFERENCES

1. Volpe, Unmanned Aircraft Systems (UAS) Service Demand 2015-2035, Published: September 2013, http://ntl.bts.gov/lib/48000/48200/48226/UAS_Service_Demand.pdf

2. FAA, Unmanned Aircraft Systems Section 333, http://pendletonuas.com/certification-process/

3. US Census Bureau, Monthly & Annual Retail Trade, Updated: Monthly, http://www.census.gov/retail/

4. US Department of Commerce, Quarterly Retail E-Commerce Sales, Published: November 2014, http://www.census.gov/retail/mrts/www/data/pdf/ec_current.pdf

5. Alan Robinson, Courier Express and Postal Observer, Published: July 2012 http://cepobserver.com/2012/07/is-the-growth-of-parcel-delivery-accelerating/