Decision-Support Tool for Designing Niche Small Package Delivery Aerial Vehicles

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Agenda

Context / Overview
Multi-Rotor Aerial Vehicles
Niche Package Delivery Applications
Problem & Vision Statement
Stakeholder Analysis

Method of Analysis
Mission / Functional / Input / Output Requirements
DST Overview: Power and Dynamic Models
DST Validation

Case Study: GMU Restaurant
Concept of Operations
Assumptions & Requirements
Utility Analysis
Business Case Analysis
Multi-Rotor Aerial Vehicles

- Quadcopter
- Hexacopter
- Octocopter
## Multi-rotor Configuration

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propellers</td>
<td><img src="image" alt="Propellers Image" /></td>
</tr>
<tr>
<td>Motors</td>
<td><img src="image" alt="Motors Image" /></td>
</tr>
<tr>
<td>Battery</td>
<td><img src="image" alt="Battery Image" /></td>
</tr>
<tr>
<td>Frame (Chassis)</td>
<td><img src="image" alt="Frame Image" /></td>
</tr>
<tr>
<td>Electronic Speed Controller (ESC)</td>
<td><img src="image" alt="ESC Image" /></td>
</tr>
<tr>
<td>Microcontroller</td>
<td><img src="image" alt="Microcontroller Image" /></td>
</tr>
</tbody>
</table>
Multi-Rotor Capabilities

- **Small** ➔ Max Size (tip-to-tip): 1-10 ft
- **Easy piloting** ➔ Programmable Flight Path
- **Attainable** ➔ COTS: Commercial Off-the-Shelf
- **Inexpensive** ➔ Price Range: $500-50,000
- **Agile** ➔ Responsive & Easy Directional Change
- **VTOL** ➔ Vertical Takeoff & Landing
- **Hover** ➔ Maneuverable Vertically & Horizontally
- **Maintainable** ➔ Fixed Pitch & Plug-n-Play Repairs
- **Safe** ➔ Less kinetic energy during flight
## Package Delivery Methods

<table>
<thead>
<tr>
<th></th>
<th>Traditional Method</th>
<th>Multi-rotor SPDAV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delivery Costs</strong></td>
<td>Initial: Vehicle</td>
<td>Initial: Multi-rotor</td>
</tr>
<tr>
<td></td>
<td>Recurring: Employee Wage &amp; Vehicle Maitenance</td>
<td>Recurring: Multirotor Maitenance</td>
</tr>
<tr>
<td><strong>Between Delivery Costs</strong></td>
<td>Fixed: None</td>
<td>Fixed: None</td>
</tr>
<tr>
<td></td>
<td>Recurring: Employee Wage</td>
<td>Recurring: None</td>
</tr>
<tr>
<td><strong>Area of Operation</strong></td>
<td>Limited to roads and sidewalks</td>
<td>Limited to 500ft of airspace</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>At the whim of human error</td>
<td>Known MTBFs for Multi-rotor parts</td>
</tr>
</tbody>
</table>

-Multi-rotor SPDAVs have **no costs while not delivering** payload and provide a **nearly unrestricted Area of Operation.**
Big Applications – Big R&D Resources

Amazon: Prime Air

DHL: Parcelcopter

Google: Project Wing

www.amazon.com/b?node=8037720011


http://www.wired.com/2014/08/google-reveals-project-wing-its-two-year-effort-to-build-delivery-drones/
## Niche Package Delivery Applications

<table>
<thead>
<tr>
<th>Market</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Just-in-time spare parts delivery</td>
</tr>
<tr>
<td>Medicine</td>
<td>Medical supply delivery</td>
</tr>
<tr>
<td>Warehouse</td>
<td>Real-time asset repositioning</td>
</tr>
<tr>
<td>Retail</td>
<td>Rapid delivery for non brick &amp; mortar purchases.</td>
</tr>
<tr>
<td>Food</td>
<td>Rapid takeout delivery</td>
</tr>
<tr>
<td>Remote Supplies</td>
<td>Delivery to areas with minimal traditional infrastructure.</td>
</tr>
</tbody>
</table>

*Niche Service Providers* do *not have the expertise to design multi-rotors.*
Niche Application Issues: **Complex Design Space**

-No single multi-rotor is optimal for every scenario.

-This is a complex design decision with non-linearities in the design-space.
Problem & Vision Statement

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

Design a decision-support tool that considers an end user’s requirements and determines the most effective Multi-Rotor Configuration for their particular application.
# Stakeholder Analysis

<table>
<thead>
<tr>
<th>Class</th>
<th>Stakeholder</th>
<th>Goals</th>
<th>Tensions</th>
</tr>
</thead>
</table>
| Primary     | 1. Service Provider                | 1. Receive a configuration recommendation based on their own requirements.  
2. Maximize profit through sale of product. | 1. Issues with rules/regulations implemented by the FAA that they must follow.  
2. Possible loss of profit by end users using the Decision-Support Tool. FAA rules/regulations restricting market growth.                                                                                                                                                                                                 |
|             | 2. Multi-rotor Manufacturers       |                                                                      |                                                                                                                                                                                                                                                                                                                                       |
2. Maintain a safe airspace to travel in and minimize all possible risks.  
1. To keep the NAS safe and well regulated.  
1. Have the ability to benefit from the service providers SPDAV | 1. Issues with rules/regulations for Commercial UAS may arise between them and the FAA.  
2. Safety concerns with the air traffic may be had with the FAA.  
3. Being held accountable for any issues that arise with the rules/regulations.  
4. Burden from the costs of new technology might be placed heavily on customers of service providers                                                                                                                                                                                                 |
|             | 2. Low-Altitude Air Traffic        |                                                                      |                                                                                                                                                                                                                                                                                                                                       |
|             | 3. Airspace Regulators (FAA)       |                                                                      |                                                                                                                                                                                                                                                                                                                                       |
|             | 4. Customer of Service Provider    |                                                                      |                                                                                                                                                                                                                                                                                                                                       |
Stakeholder Interactions: **Win-Win**

(1) DST-SPDAV

Enable service provider to select the right multi-rotor aircraft.

(2) Service Provider

Enhanced Service

(3) UAS Manufactures

More accurately inform design decisions

(4) Airspace Regulators
Citizens
Air Traffic

More commercial opportunities

(5) Customer of Service Provider

Increased Profit

New regulations and feedback will help to improve the DST.

By providing the best multi-rotor aircraft, safety and reliability increase.

By providing the best multi-rotor aircraft, safety and reliability increase.

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Method of Analysis
- Mission / Functional / Input / Output Requirements
- DST Overview: Power and Dynamic Models
- DST Validation

Case Study: GMU Restaurant
- Concept of Operations
- Assumptions & Requirements
- Utility Analysis
- Business Case Analysis
## Mission Requirements

<table>
<thead>
<tr>
<th>MR #</th>
<th>Requirement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR1</td>
<td>The DST-SPDAV shall recommend configurations of pre-existing multi rotor aircrafts that will be able to carry a user-defined payload for a certain distance over a default flight profile.</td>
</tr>
<tr>
<td>MR2</td>
<td>The DST-SPDAV shall recommend pre-existing configurations of multi-rotor aircrafts that are reliable and operate at a high performance.</td>
</tr>
</tbody>
</table>
## Functional Requirements

<table>
<thead>
<tr>
<th>FR #</th>
<th>Requirement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>The DST-SPDAV shall implement a power consumption model which evaluates the steady-state performance of battery, motor, and propeller combinations to determine systems that satisfy the users’ requirements.</td>
</tr>
<tr>
<td>FR2</td>
<td>The DST-SPDAV shall evaluate satisfactory pre-existing configurations in a full dynamic model to account for airframe aerodynamics and default flight profiles in order to recommend configurations.</td>
</tr>
<tr>
<td>FR3</td>
<td>The DST-SPDAV shall present multiple recommendations ranked by the user-defined weights to allow for cost vs utility analysis.</td>
</tr>
</tbody>
</table>
## Input Requirements

<table>
<thead>
<tr>
<th>IR #</th>
<th>Requirement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR1</td>
<td>The DST-SPDAV shall input minimum flight distance.</td>
</tr>
<tr>
<td>IR2</td>
<td>The DST-SPDAV shall input payload range.</td>
</tr>
<tr>
<td>IR3</td>
<td>The DST-SPDAV shall input the maximum size of the multi-rotor aircraft.</td>
</tr>
</tbody>
</table>
### Output Requirements:

<table>
<thead>
<tr>
<th>OR #</th>
<th>Requirement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR1</td>
<td>The DST-SPDAV shall output data showing the relationship between payload versus distance in order to be evaluated for utility analysis.</td>
</tr>
<tr>
<td>OR2</td>
<td>The DST-SPDAV shall output data showing the relationship between payload versus speed in order to be evaluated for utility analysis.</td>
</tr>
</tbody>
</table>
DST for Designing NSPDAV

DST Functionality Diagram

DST-NSPDAV

Minimum Distance to Travel

Payload Range

Maximum Width

Database

Power Model

Dynamic Model

Payload vs Distance Data

Payload vs Speed Data

Pre-existing Multi-rotor Configurations
Multi-rotor Free Body Diagram:

Source: Quad-Rotor Unmanned Aerial Vehicle Helicopter Modeling & Control
Power Model: Inputs

- Payload range from end-user

- Multi-rotor components from Database needed for Power Analysis

<table>
<thead>
<tr>
<th>Batteries</th>
<th>Motors</th>
<th>Propellers</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Capacity (mAh)</td>
<td>(1) Kv (rpm/v)</td>
<td>(1) Size</td>
</tr>
<tr>
<td>(2) Output Voltage</td>
<td>(2) Weight</td>
<td>(2) Prop Constant</td>
</tr>
<tr>
<td>(3) Max Discharge</td>
<td>(3) Max Current</td>
<td>(3) Power Factor</td>
</tr>
<tr>
<td>(4) Weight</td>
<td>(4) Size</td>
<td>(4) Weight</td>
</tr>
<tr>
<td>(5) Size</td>
<td>(5) Max Voltage</td>
<td></td>
</tr>
</tbody>
</table>
Power Model: Thrust and Power Relationship

\[ T = \frac{1}{3} p^2 D^2 r P^2 \]

\[ P = \text{PropConst} \times \text{rpm} \]

\[ \text{rpm} = K_v \times \text{Battery}_\text{volts} \]

\[ \text{Hover thrust} = mg \]

Max Thrust Produced by a Single Motor

\[ T = \frac{2}{3} D^2 P^2 \]

Source: Leishman, Principles of Helicopter Aerodynamics, 2002
Dynamic Model Inputs

- Pre-existing Configurations from Power Model
- Minimum Distance to travel

Default Flight Profile

Flight Profile

- Solid: Flight with payload
- Dashed: Return flight w/o payload
- Speed: 80% throttle
- Altitude: 350ft
Dynamic Model: Geometry and Moments of Inertia

Modeled as simple solids

Rotation Matrix

\[ I_L = T I_{LR} T^T \]

\[
T = \begin{bmatrix}
\cos \theta & \sin \theta & 0 \\
-\sin \theta & \cos \theta & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

For each component

<table>
<thead>
<tr>
<th>Cylinder</th>
<th>Cuboid</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{XX} = \frac{1}{12} m(3r^2 + h^2) )</td>
<td>( I_{XX} = \frac{1}{12} (h^2 + w^2) )</td>
</tr>
<tr>
<td>( I_{YY} = \frac{1}{12} m(3r^2 + h^2) )</td>
<td>( I_{YY} = \frac{1}{12} (h^2 + l^2) )</td>
</tr>
<tr>
<td>( I_{ZZ} = \frac{1}{2} m r^2 )</td>
<td>( I_{ZZ} = \frac{1}{12} (w^2 + l^2) )</td>
</tr>
</tbody>
</table>

Source: Mansson, Model-based Design Development and Control of a Wind Resistant Multirotor UAV, 2014
Dynamic Model: Battery and Velocity Relationship

Multi-rotor Battery VS Time

Hover velocity as a function of thrust using momentum theory

\[ V_h = \sqrt{\frac{T}{2\rho A}} \]

- \( T = \text{Thrust (N)} \)
- \( A = \text{Area swept out by rotor (m}^2\text{)} \)
- \( \rho = \text{density of air (} \frac{1.225\text{kg}}{m^3} \text{)} \)

Source: Leishman, Principles of Helicopter Aerodynamics, 2002

Figure 1. Discharge profile of output voltage.
DST Validation Approach

Check for basic functionality by comparing our thrust and power calculations for a configuration versus reliable experimental data.

- Configuration used: Hacker A30-10XL V3, 50A ESC, 4S2P 10000 mAh

- Propellers used: 13x6 APC, 11x6 APC, 11x6 Master Airscrew

Utilized static performance values of a single rotor from a study: *Propulsive System Optimization for a Unmanned Lightweight Multirotor*
## Thrust & Power: DST vs Experimental

<table>
<thead>
<tr>
<th>RPM</th>
<th>APC</th>
<th>Experimental Value</th>
<th>Calculated Value</th>
<th>% Error</th>
<th>Calculated Value</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>13x6</td>
<td>540</td>
<td>77</td>
<td>533.2</td>
<td>78.74797808</td>
<td>2%</td>
</tr>
<tr>
<td>5000</td>
<td>13x6</td>
<td>870</td>
<td>139</td>
<td>860.1</td>
<td>149.7541499</td>
<td>8%</td>
</tr>
<tr>
<td>6000</td>
<td>13x6</td>
<td>1300</td>
<td>240</td>
<td>1278.2</td>
<td>251.9577462</td>
<td>5%</td>
</tr>
<tr>
<td>7000</td>
<td>13x6</td>
<td>1780</td>
<td>345</td>
<td>1732.8</td>
<td>368.9757116</td>
<td>7%</td>
</tr>
<tr>
<td>8000</td>
<td>13x6</td>
<td>2300</td>
<td>500</td>
<td>2237.7</td>
<td>535.4084598</td>
<td>7%</td>
</tr>
<tr>
<td>4000</td>
<td>11x6</td>
<td>350</td>
<td>49.3</td>
<td>340.6</td>
<td>50.71154535</td>
<td>3%</td>
</tr>
<tr>
<td>5000</td>
<td>11x6</td>
<td>514</td>
<td>86.9</td>
<td>497.6</td>
<td>93.96503289</td>
<td>8%</td>
</tr>
<tr>
<td>6000</td>
<td>11x6</td>
<td>738</td>
<td>140.5</td>
<td>716.0</td>
<td>145.4464136</td>
<td>4%</td>
</tr>
<tr>
<td>7000</td>
<td>11x6</td>
<td>1000</td>
<td>197.9</td>
<td>950.1</td>
<td>214.8534171</td>
<td>9%</td>
</tr>
<tr>
<td>8000</td>
<td>11x6</td>
<td>1330</td>
<td>299.8</td>
<td>1305.5</td>
<td>311.6385688</td>
<td>4%</td>
</tr>
<tr>
<td>4000</td>
<td>11x6 Master Airscrew</td>
<td>328</td>
<td>45.152</td>
<td>318.4</td>
<td>47.02786077</td>
<td>4%</td>
</tr>
<tr>
<td>5000</td>
<td>11x6 Master Airscrew</td>
<td>486</td>
<td>74.0775</td>
<td>481.6</td>
<td>79.12783442</td>
<td>7%</td>
</tr>
<tr>
<td>6000</td>
<td>11x6 Master Airscrew</td>
<td>740</td>
<td>122.6159</td>
<td>732.7</td>
<td>134.2580536</td>
<td>9%</td>
</tr>
<tr>
<td>7000</td>
<td>11x6 Master Airscrew</td>
<td>950</td>
<td>176.375</td>
<td>930.3</td>
<td>182.4279857</td>
<td>3%</td>
</tr>
<tr>
<td>8000</td>
<td>11x6 Master Airscrew</td>
<td>1300</td>
<td>293.2058</td>
<td>1260.9</td>
<td>307.7366684</td>
<td>5%</td>
</tr>
</tbody>
</table>
11x6” Master Airscrew Thrust Comparison

Thrust (g) vs RPM

- Experimental Value
- Calculated Value

3% Thrust Error

11x6” APC Thrust Comparison

Thrust (g) vs RPM

- Experimental Value
- Calculated Value

5% Thrust Error

13x6” APC Thrust Comparison

Thrust (g) vs RPM

- Experimental Value
- Calculated Value

3% Thrust Error
10% Power Error

8% Power Error

DST for Designing NSPDAV

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Case Study: GMU Restaurant
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Case Study: Multi-rotor Delivery

Customer
- Order Food
  - Receive Order
    - Prepare Food
      - Package
      - Employee 1
      - Send to Multirotor Aircraft
    - Attach Package
      - Launch to determined location
      - Monitor
      - Travel to determined location
      - Drop Package
      - Go back
      - Employee 2
      - Receive Food
      - Wait for new order
  - Notify ETA
    - Multirotor Aircraft
      - Wait for new delivery
Case Study: Assumptions

Federal Aviation Administration

- Rules/Regulations for small commercial UAVs allow for this application.

Multi-Rotor

- Autonomous flight.
- Pre-determined flight paths for each delivery destination.
- Live video feedback.
- Modified for payload attachment.

Service Provider

- One multi-rotor will be adequate for the amount of demand.
- Have necessary equipment to support flight monitoring.
- Minimum wage worker capable of maintaining and interchanging batteries.
Case Study: Requirements

- **Payload** from 1-4 Kg. ➔ 2 foot-long subs & 2 bags of chips or 2 large pizzas

- **Minimum distance** of 2Km (4 Km round-trip). ➔ Diameter of GMU’s Fairfax campus: roughly 1 mile

- **Maximum Width** of 1700 mm (from tip to tip). ➔ Width of Multi-rotor access point inside business: 6 feet

- **Weights** for objective function. ➔ Comparison Survey evaluated with Swing Weights Method
Case Study: Multi-rotors Evaluated

<table>
<thead>
<tr>
<th>Model</th>
<th>Rotors</th>
<th>Total Weight (g)</th>
<th>Battery (mAh)</th>
<th>Propeller</th>
<th>Motor (Kv)</th>
<th>Width (mm)</th>
<th>MTBF (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJI-S800</td>
<td>6</td>
<td>4400</td>
<td>15000 (6S)</td>
<td>15x4” APC</td>
<td>415</td>
<td>1180</td>
<td>100</td>
</tr>
<tr>
<td>FAE-960H</td>
<td>6</td>
<td>9500</td>
<td>2x16000 (4S)</td>
<td>18x6” APC</td>
<td>480</td>
<td>1420</td>
<td>160</td>
</tr>
<tr>
<td>X8-HLM</td>
<td>8</td>
<td>3250</td>
<td>10000 (4S)</td>
<td>10x4.7” APC</td>
<td>440</td>
<td>1350</td>
<td>150</td>
</tr>
<tr>
<td>OFM-GQ8</td>
<td>8</td>
<td>6500</td>
<td>16000 (6S)</td>
<td>17x5.8” APC</td>
<td>420</td>
<td>1530</td>
<td>160</td>
</tr>
<tr>
<td>HL 48</td>
<td>8</td>
<td>7800</td>
<td>16000 (6S)</td>
<td>15x4” APC</td>
<td>520</td>
<td>1450</td>
<td>160</td>
</tr>
</tbody>
</table>
Payload vs Distance (Curve fitted)

\[ y = -0.0144x^3 + 0.1283x^2 - 0.9933x + 5.6768 \]
\[ R^2 = 0.9998 \]

\[ y = 0.005x^3 + 0.0608x^2 - 0.5114x + 3.4056 \]
\[ R^2 = 0.9977 \]

\[ y = -0.003x^3 + 0.0643x^2 - 0.7845x + 5.2075 \]
\[ R^2 = 0.9999 \]

\[ y = -0.0144x^3 + 0.1283x^2 - 0.9933x + 5.6768 \]
\[ R^2 = 0.9998 \]
Payload vs Distance (Curve fitted)

\[ y = -0.005x^3 + 0.0608x^2 - 0.5114x + 3.4056 \quad R^2 = 0.9977 \]

\[ y = -0.003x^3 + 0.0643x^2 - 0.7845x + 5.2075 \quad R^2 = 0.9999 \]

\[ y = -0.0144x^3 + 0.1283x^2 - 0.9933x + 5.6768 \quad R^2 = 0.9998 \]
\[
y = -0.1244x^3 + 1.0364x^2 - 3.5239x + 42.367
\]
\[R^2 = 0.9831\]

\[
y = -0.0319x^3 + 0.2116x^2 - 1.292x + 45.25
\]
\[R^2 = 0.9981\]

\[
y = -0.1533x^3 + 0.7787x^2 - 2.4989x + 34.776
\]
\[R^2 = 0.9976\]
Case Study: Multi-rotors Evaluated

- For a payload range between 1 Kg and 4 Kg.

<table>
<thead>
<tr>
<th>Model</th>
<th>Average Distance (Km)</th>
<th>Average Velocity (Km/h)</th>
<th>Rotors</th>
<th>Total Weight (g)</th>
<th>Battery (mAh)</th>
<th>Propeller</th>
<th>Motor (Kv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAE-960H</td>
<td>3.8</td>
<td>30.3</td>
<td>6</td>
<td>9500</td>
<td>2x16000 (4S)</td>
<td>18x6” APC</td>
<td>480</td>
</tr>
<tr>
<td>OFM-GQ8</td>
<td>3.7</td>
<td>42.8</td>
<td>8</td>
<td>6500</td>
<td>16000 (6S)</td>
<td>17x5.8” APC</td>
<td>420</td>
</tr>
<tr>
<td>HL 48</td>
<td>2.5</td>
<td>38.3</td>
<td>8</td>
<td>7800</td>
<td>16000 (6S)</td>
<td>15x4” APC</td>
<td>520</td>
</tr>
</tbody>
</table>
Utility Analysis

Distance (w1) 0.365
Speed (w2) 0.365
Size (w3) 0.090
Maintenance (w4) 0.180

<table>
<thead>
<tr>
<th>Model</th>
<th>Distance</th>
<th>Speed</th>
<th>Size</th>
<th>MTBF</th>
<th>Utility Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAE-960H</td>
<td>0.95</td>
<td>0.67</td>
<td>0.16</td>
<td>1.00</td>
<td>0.786</td>
</tr>
<tr>
<td>OFM-GQ8</td>
<td>0.93</td>
<td>0.95</td>
<td>0.10</td>
<td>1.00</td>
<td>0.875</td>
</tr>
<tr>
<td>HL 48</td>
<td>0.63</td>
<td>0.85</td>
<td>0.15</td>
<td>1.00</td>
<td>0.734</td>
</tr>
</tbody>
</table>
Utility vs. Cost Analysis

\begin{align*}
\text{UTILITY} &= w_1 \times \text{DISTANCE} + w_2 \times \text{SPEED} + w_3 \times \text{SIZE} + w_4 \times \text{MTBF} \\
\end{align*}

Department of Systems Engineering and Operations Research
Center for Air Transportation Systems Research
## Business Case Analysis

### Estimating Demand

<table>
<thead>
<tr>
<th>Description</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduate Population</td>
<td>22,000</td>
</tr>
<tr>
<td>Living on Campus (27%)</td>
<td>5,940</td>
</tr>
<tr>
<td>Ordering delivery or taking out food (24%)</td>
<td>1,426</td>
</tr>
<tr>
<td>Only delivery (46%)</td>
<td>656</td>
</tr>
<tr>
<td>2-3 Deliveries per week on average</td>
<td>1,639</td>
</tr>
<tr>
<td>Deliveries per day for the entire market</td>
<td>234</td>
</tr>
</tbody>
</table>


### Market Share – Number of deliveries per day

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Deliveries</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>23</td>
</tr>
<tr>
<td>11%</td>
<td>26</td>
</tr>
<tr>
<td>12%</td>
<td>28</td>
</tr>
</tbody>
</table>
## Business Case Analysis – Delivery Person

### Cost of Delivery Person

<table>
<thead>
<tr>
<th>Hours worked per day</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly rate</td>
<td>$8</td>
</tr>
<tr>
<td>Cost per day</td>
<td>$64</td>
</tr>
</tbody>
</table>

### Daily Revenue for delivery – Delivery fee $2

<table>
<thead>
<tr>
<th>10% - 23 deliveries</th>
<th>11% - 26 deliveries</th>
<th>12% - 28 deliveries</th>
</tr>
</thead>
<tbody>
<tr>
<td>$46</td>
<td>$52</td>
<td>$56</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Daily Profit or Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>($18)</td>
</tr>
</tbody>
</table>
DST for Designing NSPDAV

Profit Working with Delivery Person

- Delivery fee $2

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## Business Case Analysis – Multi rotor Aircraft

### Cost of Multi rotor Aircraft

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Aircraft + Batteries</td>
<td>$13,499</td>
</tr>
<tr>
<td>Cost of Motors + Battery</td>
<td>$1900</td>
</tr>
<tr>
<td>MTBF</td>
<td>160 hours</td>
</tr>
<tr>
<td>Hourly Cost of Use</td>
<td>$11.88</td>
</tr>
</tbody>
</table>

### Daily Cost

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Deliveries</th>
<th>Daily Cost per Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>23</td>
<td>$4.13</td>
</tr>
<tr>
<td>11%</td>
<td>26</td>
<td>$3.65</td>
</tr>
<tr>
<td>12%</td>
<td>28</td>
<td>$3.39</td>
</tr>
</tbody>
</table>

### Daily Revenue – Delivery fee $5

<table>
<thead>
<tr>
<th>Revenue</th>
<th>Daily Profit or Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>$115</td>
<td>$20</td>
</tr>
<tr>
<td>$130</td>
<td>$35</td>
</tr>
<tr>
<td>$140</td>
<td>$45</td>
</tr>
</tbody>
</table>

---

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DST for Designing NSPDAV

Profits Working with Multirotor Aircraft

- Profit - 10%
- Profit - 11%
- Profit - 12%

Graph showing the relationship between days and profit with different profit rates.
Conclusion and Recommendations

Case Study:
- The octocopter OFM-GQ8 is the best option due to its range and fast speed.
- If market share is lower than 10%, buying a multirotor aircraft for delivery would not be recommendable.
- If working with a multirotor aircraft, the delivery fee can be decreased if the market share increases.

In General:
- An expensive multi-rotor aircraft will not always offer the highest utility value. Any level of evaluation is not intuitive.
- Since end users present different requirements, a market evaluation is needed in order to assure viability and profitability of using a multi-rotor.
- If demand grows too large for one multi-rotor to handle, a queuing simulation would be needed to calculate the amount of necessary multi-rotors.
Questions?

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UAS America

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