Identification and Evaluation of Concepts of Operations for sUAS Package Delivery

Dr. Simon Briceno
Research Engineer
briceno@gatech.edu

Prof. Brian German
Langley Associate Professor
brian.german@aerospace.gatech.edu

Aerospace Systems Design Laboratory
School of Aerospace Engineering • Georgia Institute of Technology
Atlanta, Georgia
Industry Research

[Images of various drones and delivery services, including DHL, JD.com, Amazon, Google, Walmart, and Zookal.com.]

[Logos of Georgia Tech Aerospace Systems Design Laboratory and NASA.]
## Research Objectives

### 1. Identify potential concepts of operations (CONOPs), with focus on:

<table>
<thead>
<tr>
<th>Regulations</th>
<th>Economics</th>
<th>Safety</th>
<th>Vehicle</th>
<th>Mission</th>
<th>Package Security</th>
<th>Environment</th>
<th>Cyber Security</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of effects of regulations on feasibility</td>
<td>Development of economics model</td>
<td>Considered for CONOPs selection</td>
<td>Modeled via parametric performance</td>
<td>Considered for CONOPs selection</td>
<td>Considered for CONOPs selection</td>
<td>Considered for CONOPs selection</td>
<td>Important, but not considered in study</td>
</tr>
</tbody>
</table>

### 2. Evaluate CONOPs

- Modeling and simulation to perform vehicle routing and economic analysis
- Parametric vehicle architecture and performance

### 3. Examine tradeoffs

- Differing airspace restrictions
- Vehicle payload-range performance

---

Investigate sUAS package delivery **business cases** for plausible near-term implementation
Commercial sUAS fall between existing regulations - FAA regulates navigable airspace, AMA oversees hobby aircraft

- United States v. Causby 328 U.S. 256 (1946) relating to FAR 91
  - “The airspace, apart from the immediate reaches above the land, is part of the public domain.”
  - 500 ft. floor for civil aircraft in unpopulated areas, 1000 ft. from objects in 2000 ft. radius
- FAR 91.13 – aircraft may not be operated in a careless or reckless manner so as to endanger life or property of another
  - FAA v. Pirker (2011)
- Congressional research on privacy issues in 2013 determined that more testing was required
- Boggs v. Merideth (2016) may provide further clarification
  - Man shot down small drone flying over his property

Proposed FAA Requirements – Part 107 Summary

- Flight ceiling – 500 feet
- Class G uncontrolled, B through E allowable with ATC permission, A not allowed
- Some controlled airspace – around airports, military bases, national parks
- Visual line-of-sight is required (VLOS)
- Vehicle weight – less than 55 lbs
- Vehicle speed limited to 100 MPH
- Daylight operations

FAA regulations are evolving from year to year – many legal gray areas
Company Proposed Operations

Origin - Warehouse

Short-tail

Urban

Suburban

Rural

Long-tail

Tradeoffs

- Warehouse size
- Customer convenience
- Number of customers
- Operations near and over persons
- Airspace restrictions and flight corridors
- Takeoff and Landing requirements

- Customer convenience
- Logistical ease

To pickup location

To home
Initial CONOPs Investigated

Location – San Francisco and San Jose Area

- Impassable Terrain
- High Traffic Volume
- High Population Density
- Choke Points

Warehouse Placement

15 mile radius

Pickup Locations

- Store
- Half-mile Pickup Radius

Gas Stations

UPS Stores
Sample Mission

Sample Mission Profile

Flight ceiling - 500 ft. AGL

Multirotor
Cruise
Cruise climb
Takeoff

Minimum cruise height
Minimum flight height – TBD
Operation over private property - TBD

Descent
Landing

Gas Station Operation

Flat roof for easy takeoff and landing
Designed for high volume of customers and quick stops
No endangerment of humans

sUAS Vehicle Architectures

Multirotor
VTOL Fixed Wing
Conventional Fixed Wing

- Small area required for takeoff and landing
- Precise takeoff and landing
- Poor endurance

- Provides good takeoff and landing characteristics and better endurance, but increases technical complexity

- Large area required for takeoff and landing
- Imprecise takeoff and landing
- Good endurance

Multirotor
VTOL Fixed Wing
Conventional Fixed Wing
**Trade Study Environment**

**CONOPs**
- Regulations
- Safety
- Mission
- Vehicle

**Modeling and Simulation**
- Vehicle Routing Model
- Economic Analysis

**Parametric Study**
- UAS speed
- Number of packages
- Number of vehicles
- Number of warehouses
- Delivery radius

**Statistical Simulation**
- Delivery Coordinate
- Start and end time

**Explore CONOPs Tradeoffs and Suggest Business Case**

**Average total operating time and distance traveled**

**Parametric Study**
- Cost/distance
- Cost/vehicle
- Cost/time

**Economic Analysis**
- $/kWh
- $/gallon
- $/labor-hr
- Vehicle Acq. $
- Vehicle Maint. $

**Graph:** Deliveries in 120 minutes
Preliminary Greedy Routing Model

- Assigns closest vehicle to package
- All deliveries known at start of day
Preliminary Truck vs. UAS Study

- Parametric study varying number of packages and delivery radius
- As time window is decreased, feasibility point shifts in favor of UAS

120 min

- 60 packages
- 8.6 miles
- UAS outperform trucks

90 min

- 45 packages
- 8.6 miles

60 min

- 25 packages
- 8.6 miles

Average delivery time per package:

- Truck: 38 minutes
- UAV: 27 minutes

Cost per package:

- Truck: 1.72 $/package
- UAV: 1.27 $/package

38 minutes vs. 27 minutes
Utilizing an open-source toolset integrating Jsprit/Graphhopper and OpenStreetMaps to find global optimum and integrate road networks

Plan to explore the impacts of UAS routing, delivery radius, delivery density, number of warehouses, delivery windows, vehicle speeds...

Will then use the same framework to evaluate additional scenarios
Conclusions

• Goal is to explore plausible business cases

• First phase of work will end in May and will continue as a funded study

• Presenting work at AIAA Aviation 2016

• We encourage any interested parties to collaborate!