Delivering Potable Water to Wildland Firefighters

A presentation from the “Vulcan Drop” capstone team
May 5th, 2021
Project Overview

- Wildland firefighting is a physically demanding and inherently dangerous line of work
- Firefighters make hazardous and time consuming treks to supply themselves with potable water
- Use of manned aviation is limited due to low visibility, rugged terrain, and high costs

Mission Statement

The Vulcan Drop UAS will free firefighters from treacherous hikes along steep ridgelines by alleviating the weight each firefighter must carry to accomplish the mission. Vulcan Drop will excel in modular supply transport of payloads too small to justify the use of a helicopter and will deliver payloads to landing zones too steep, too small, or too dangerous for manned aviation. It will significantly reduce the physical burden and risk of injury that firefighters face daily and expand the current capabilities of aerial delivery in wildland firefighting.
Concept of Operations

**Vehicle Specifications**
- Single main rotor helicopter
- Empty weight: <70 lbs
- Truck bed transportable
- Gas propulsion system

**Performance**
- Vertical Range: 2,000 ft elevation gain
- Horizontal Range: 4 statute miles (round trip)
- 15 gallons of water per hour delivery rate

**Sensor Suite**
- Radio receiver/transmitter
- LIDAR sensor for altitude tracking

**Environment**
- 150 x 150 x 150 ft forest clearing
- Winds up to 20 knots
- 12,000 ft density altitude

**Primary Payload**
- 5 gallon cubitainer of water
- Modular design for adaptability

**Operation**
- Manual and autonomous waypoint tracking
- Ground based VTOL
- Round trip flight time: < 15 min
- Reload time: < 5 min

**Delivery Method**
- Single servo payload release
- Aerial drop at ~5 ft agl

**Launch/Recovery**
- Ground Station

**Forward Operating Base**

**Single Operator**

2 miles

1800 ft
200 ft
200 ft
Measures of Effectiveness

1: Delivers needed supplies to forward most firefighters in the field
2: Compatible with a variety of modular payloads
3: Capable of launch, delivery, and recovery within small forest clearings
4: Transported in a pick-up truck
5: Performs successive operations rapidly
6: Beyond line of sight and over the horizon capability
7: Operates in high winds and in high altitudes, such as those experienced in the Sierra Nevada Mountain Range
8: Mission system is affordable and drastically reduces cost, compared to manned aviation
The Design

Gas propulsion system
1. Allows for rapid refueling and scalability of mission
2. Much cheaper solution than LiPo for rapid re-deployment

Single main rotor
1. Integrates well with gas propulsion
2. More efficient than a quadcopter
3. Custom rotor blade for high DA

Cubic delivery system

Controlled via pixhawk and mission planner for autonomous capability

- GTOW ~ 112 lbs
  - FAA waiver required above 55 lbs
- 3.5 ft rotor radius
- Stands 3 feet tall
- 45 lb payload
Design Mockup

- Rotor blades (22 degree linear twist)
- Teetering Rotor Hub
- Swashplate
- Mission Systems
- Release Mechanism
- Fuel Tank
- Powertrain
- Hirth F-33
- Cargo Hold
- Direct Drive Tail Rotor
Verifying MOEs

Based on the design many of the MOEs were met
- Total cost ~ $9,000
- Fits in the bed of a truck
- Compatible with a modular payload
- Ability to navigate through small forest clearings

Through testing we hoped to prove the following MOEs
- Delivers needed supplies to the firefighters
- Capability in high winds and altitude
- Control system can safely conduct autonomous mission when comms are out of reach
- Rapid reload for successive operations
Aerodynamics – Airfoil Selection

**$C_L$ vs Angle of Attack**

- $v=12$
- NACA 0012

**$C_D$ vs Angle of Attack**

- $v=12$
- NACA 0012
Aerodynamics – Rotor sizing

● 3.5 ft radius - Constrained by truck bed
● 3 in chord - Determined by maximizing efficiency, limited by $C_T/\sigma$
  ○ Our design’s $C_T/\sigma=0.10$
● 22° twist - due to 12000 ft DA
● Tail size: 6 in radius and 1 in chord, determined to appropriately counteract torque of main rotor
Propulsion

- **Hirth F-33**
  - 0.063 gpm
  - 35 lbs
  - 28 HP

- **Transmission Efficiency**
  - Belt reduction ~ 95%
  - Bevel gear ~ 88%
  - **Overall ~ 83.6%**
Propulsion

- Max Range: ~ 80 kts
- Max Endurance ~ 55 kts
Flight Dynamics

Preliminary analysis on the original design:

- Stability derivatives
  - Inputs: Nb (Number of blades), c (chord length), \( \Omega R \) (Rotational Speed), W(weight), \( I_b \) (Blade Inertia), \( I_{yy} \) (Moment of inertia about the pitching axis), \( \alpha \) (lift curve slope), A (flat plate area), location of the center of gravity, offset, twist
  - Matlab then used to determine the inflow ratio, rotor solidity, flap frequency and stability derivatives
  - Assumptions made for: \( K_b \) and other stiffness parameters

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\lambda^2 - \left( X_u + g \frac{M_u}{M_q^2} \right) \lambda - g \frac{M_u}{M_q} = 0
\]

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\frac{M_u}{M_q (1 + \lambda/M_q)} \\
\end{array} \right| = 0
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-\frac{M_u}{M_q} & 0 & -\frac{M_q}{q}
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Flight Dynamics

Viability of mechanical actuation

- Bell and Hiller Rotor System
- Traditional Stabilizing Bar
- Tail sizing
Technology Demonstrator

- Scaled technology demonstrator was used to validate design choices
Cargo Hold and Release Mechanism
Cubitainer Drop Testing

Drop Height Test

Static Release Mechanism Test

Dynamic Release Mechanism Test

Mounted Release Mechanism Test
Fuselage Design and Fabrication
Technology Demonstrator Flight Dynamics

- **Swashplate Calibration**
  - Pitch Degree Calibration
  - -2 to 10 degrees collective

- **Telemetry unit and trim**
  - No working wireless unit available
  - Unable to trim for hover in flight
Single Rotor Flight Demonstration
Mission Systems

Hexsoon EDU450 Quadcopter + Futaba Controller
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Mission Systems Demonstration
Measures of Effectiveness Attainment

1: Delivers needed supplies to forward most firefighters in the field 🌻
2: Compatible with a variety of modular payloads ✅
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4: Transported in a pick-up truck ✅
5: Performs successive operations rapidly 🌻
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Thank you!
Propulsion

With payload (115.5 lbs)

Without payload (70.5 lbs)