Spring 2021
MMAT-B Team
Organization

Testing: MIDN 1/C
Cole Dittman

Mission Systems:
MIDN 1/C Max Gerber

Flight Dynamics:
MIDN 1/C Blake Jones

Propulsion: MIDN 1/C
Matthew Pinney

Structures: MIDN 1/C
Jared Cox

Project Manager:
MIDN 1/C Michael Porter

SEIT: MIDN 1/C
Brian McNamara
Project Overview

U.S. Navy Destroys Target With Drone Swarm — And Sends A Message To China

What we need:
- Expendable
- Easy to use
- Low cost
Mission

Sailors need a target that is **simple to use, easy to maintain**, and has a relatively **low cost per unit**. Fulfilling the training requirements of our sailors would equip the Navy with the technology they need to maintain mission readiness. Specifically, officers, non-commissioned officers, and enlisted personnel will be able to practice fighting their ships as they practice using their skills, techniques, and warfighting strategies to locate, engage, and destroy incoming drones without interacting with or relying on a third party. By simulating adversary drones in both appearance and performance, these targets will effectively test the ship’s short to medium range defenses. By replicating the chaos of battle, live fire practice will build sailors’ confidence in their abilities, resulting in increased **mission readiness** and an overall more effective fighting force able to bring its sailors back safely.
System Capability Definition

Beneficiary Input:

1. **Mr. Eggleston** (PMA-208 Test and Evaluation Lead)
   a. Lack of Low Speed Drone Training
   b. Heavy Reliance on USN Ships/Shore Drone Training
   c. Lack of cheap, expendable Low Speed Drone Targets

2. **Mr. Stepler** (Head Engineer Lead at Point Mugu)
   a. Competitors investing into Swarm and Kamikaze Drones
   b. Must be able to fly far enough to test all systems (CIWS, 50 cal., ext ext)

3. **Mr. Sanford** (Resource Requirements and Programs for Carrier Strike Group 4)
   a. Need of a camera
      i. Fly appropriate distances
      ii. Review for ship performance during live fire
   b. Target Price under $ 2,000.00 per unit
Measures of Effectiveness and Key Performance Parameters

1. **MOE 1 - Emulate an adversary drone**
   - KPP 1.1 Shall reach a dash speed of 90 knots
   - KPP 1.2 Shall operate in the air for 45 minutes
   - KPP 1.3 Shall make instantaneous 3G turns
   - KPP 1.4 Operate 5.5 Nautical Miles away from ground station

2. **MOE 2 - Allow a Naval Vessel to train independently**
   - KPP 2.1 Easily operable by a sailor with little training required
   - KPP 2.2 Shall launch within 30 feet

3. **MOE 3 - Be independent of the host ship**
   - KPP 3.1 Drone and Ground station are portable
   - KPP 3.2 Ground station is self contained and independent of ship systems
   - KPP 3.3 Launch Mechanism is self contained and easy to use
   - KPP 3.4 UAV entirely expendable

4. **MOE 4 - Provide crew feedback on the live fire exercise**
   - KPP 4.1 Shall stream data such as speed, location, and altitude to the ground station
   - KPP 4.2 Shall transmit live video to the ground station
**CONOPS**

**Specifications**
- Transmission Range: 10 km
- Endurance: 45 mins
- Max Pressure Altitude: 2,000 ft
- Cruise Velocity: 60 kts
- Dash Velocity: 90 kts
- Motor: Electric
- Weight: 17 lbs

45 mins of endurance allows the UAV to perform one of three mission profiles. If not disabled during flight, the UAV will crash land in the water.

The UAV will be launched via standard runway launch.

Mainly dependent on which weapon system is being used for targeting.

Maximum distance the UAV will travel from the ship is 10 km.

Come no closer than 500 ft of ship.

Packaged ground control system

UAV is actively operated by the user on the ship.

Real time flight performance data and video feed

Location tracking and communication to controller

UAV will be targeted by ship’s defense systems.

UAV will be launched from the flight deck of the ship.

Short-range engagements

Medium-range engagements

- 10 km
Design considerations/alternatives

- Performance
- Cost
- Risk
So Why This?

- V-Tail vs Standard
- Propeller vs Turbine
- Electric vs Gas
Structures

Specifications:

- 6 ft wingspan (made of fiberglass laid up around a foam core)
- Carbon fiber tail booms
- Aluminum landing gear and mounting plates.
- Bolts or Epoxy used to secure the UAS together.

Fabrication:
- Composites done by team
- CNC of connecting joints and water jet cuts of the frame and skin done by work order request.
Critical Calculations

Yield strength of bi directional Fiberglass-28,282 psi

Maximum Von Mises stress- 104.9 PSI
Aerodynamics

- **N-24 Airfoil**
  - Offers a balance of High Lift and limited Drag
  - Exceeds the required 1.4 CL at 1.5
  - CD of .03

- **Dimensions**
  - 1.15 Chord
  - 6 Foot Wingspan
  - 3 Degrees of twist
Propulsion

- Switched to Electric Propulsion
  - 16” x 10”, 3-bladed propeller
    - “Pusher prop” configuration
  - Rimfire 1.20 Electric Motor
    - Compatible with propeller
    - Similar performance to the DLE-20
      - Up to 3.2 hp
      - 450 RPM/V
  - Li-Po Battery
    - 6S
    - 22.2 V
    - 16,000 mAh

- Allows for:
  - 13.2 lbs of thrust
    - Determined through wind tunnel testing
  - 30+ min endurance
    - Determined through flight testing

Effect of Blade Geometry on Propulsive Parameters at $V = 15$ KTAS, Number Blades = 3, and Mean Blade Chord = 1.5”

<table>
<thead>
<tr>
<th>SIZE</th>
<th>THRUST (lbs)</th>
<th>TORQUE (ft-lbs)</th>
<th>RPM</th>
<th>BHP Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 x 12</td>
<td>16.7</td>
<td>1.65</td>
<td>7400</td>
<td>2.40</td>
</tr>
<tr>
<td>15 x 10</td>
<td>17.6</td>
<td>1.58</td>
<td>8100</td>
<td>2.45</td>
</tr>
<tr>
<td>15 x 11</td>
<td>17.45</td>
<td>1.66</td>
<td>7600</td>
<td>2.41</td>
</tr>
<tr>
<td>16 x 10</td>
<td>18.13</td>
<td>1.66</td>
<td>7700</td>
<td>2.43</td>
</tr>
<tr>
<td>16 x 12</td>
<td>18.07</td>
<td>1.84</td>
<td>6850</td>
<td>2.41</td>
</tr>
</tbody>
</table>
Mission Systems

- Basic mission system components essential for flying
  - Futaba 10J Transmitter (Controller)
  - Futaba R3008SB Receiver
  - Futaba S3004 Servos

Problems with implementing the original design
- PixHawk 2.4.8 damaged
- Did not order enough parts for the backup PixHawk Cube
- Insufficient testing; could not implement the PixHawk
Launch and Recovery

- High cost
- Complex
- Dangerous with propellers
- Not consistent
- Size may be a factor
- Calculated takeoff velocity: 22 knots
- Calculated minimum runway distance: 25 feet
- Runway launch
- No recovery needed (disposable aircraft)
Testing

- Testing was conducted on mission dependant subsystems such as the engine, tail booms, and electronics.
- Due to COVID-19 complications Testing was halted for a month.
- Tests conducted ranged from simply checking functionality to more complex gathering of data.

<table>
<thead>
<tr>
<th>Throttle Configuration</th>
<th>Idle</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>Full Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPM</td>
<td>0</td>
<td>2300</td>
<td>3800</td>
<td>5000</td>
<td>6200</td>
<td>7100</td>
</tr>
<tr>
<td>Thrust (lbf)</td>
<td>0</td>
<td>1.28</td>
<td>4.22</td>
<td>7.18</td>
<td>10.57</td>
<td>13.19</td>
</tr>
</tbody>
</table>
Flight Dynamics: Requirements

- Pusher propeller constrained design
  - Twin boom design
  - V-tail provides yaw and pitch stability and control while minimizing part count
- Imitate agile threat
  - Ability to pull 3-g’s and rapidly change direction
  - Still remain easy to control

<table>
<thead>
<tr>
<th>Component</th>
<th>Projected Area (ft²)</th>
<th>Moment Arm (ft)</th>
<th>Tail Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>6.90</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Horizontal Stabilizer</td>
<td>1.17</td>
<td>3.1</td>
<td>0.452</td>
</tr>
<tr>
<td>Vertical Stabilizer</td>
<td>1.15</td>
<td>3.1</td>
<td>0.591</td>
</tr>
</tbody>
</table>
Flight Dynamics: Predictions

- Stable in pitch and yaw
- Neutrally stable in roll
- Mil Spec Level 1 Handling

<table>
<thead>
<tr>
<th>Stability Derivative</th>
<th>Value (1/rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{m_0}$</td>
<td>-0.698</td>
</tr>
<tr>
<td>$C_{l_p}$</td>
<td>0.0189</td>
</tr>
<tr>
<td>$C_{n_b}$</td>
<td>0.1142</td>
</tr>
</tbody>
</table>

MATLAB

Upper Structural Limit

Lower Structural Limit

Load Factor (n)

Velocity (kts)
Flight Testing

- Four test flights conducted (35 mins total)
  - Aircraft was stable in roll, pitch, and yaw
  - Extremely agile (turns at greater than 70° AoB)
  - Straight and level flight does not require operator input
- Take Off Demonstration:
  - 25 ft roll
- Agility Demonstration:
  - Rapid roll rate
  - High-g pull up
  - Humpty-Bump - rapid change in direction
## Cost

<table>
<thead>
<tr>
<th>IPT</th>
<th>Items</th>
<th>Cost/Unit</th>
<th>Unit</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>16-10&quot;, 3 Blade</td>
<td>$20</td>
<td>1</td>
<td>$20</td>
</tr>
<tr>
<td></td>
<td>Rimfire 1.2 outrun</td>
<td>$140</td>
<td>1</td>
<td>$140</td>
</tr>
<tr>
<td></td>
<td>Battery</td>
<td>$325</td>
<td>1</td>
<td>$325</td>
</tr>
<tr>
<td>Systems</td>
<td>Pixhawk controller</td>
<td>$85</td>
<td>1</td>
<td>$85</td>
</tr>
<tr>
<td></td>
<td>Camera</td>
<td>$20</td>
<td>7</td>
<td>$140</td>
</tr>
<tr>
<td></td>
<td>GPS</td>
<td>$26</td>
<td>1</td>
<td>$26</td>
</tr>
<tr>
<td></td>
<td>Battery</td>
<td>$15</td>
<td>1</td>
<td>$15</td>
</tr>
<tr>
<td></td>
<td>Herelink</td>
<td>$699</td>
<td>1</td>
<td>$699</td>
</tr>
<tr>
<td>Structures</td>
<td>Foam</td>
<td>$30</td>
<td>1</td>
<td>$30</td>
</tr>
<tr>
<td></td>
<td>Carbon Fiber</td>
<td>$100</td>
<td>1</td>
<td>$100</td>
</tr>
<tr>
<td></td>
<td>Nuts and Bolts</td>
<td>$1</td>
<td>23</td>
<td>$23</td>
</tr>
<tr>
<td></td>
<td>Steel Components</td>
<td>$10</td>
<td>8</td>
<td>$80</td>
</tr>
<tr>
<td></td>
<td>Carbon Booms</td>
<td>$223</td>
<td>1</td>
<td>$223</td>
</tr>
<tr>
<td>Flight Dynamics</td>
<td>Standard Servos</td>
<td>$30</td>
<td>6</td>
<td>$180</td>
</tr>
<tr>
<td></td>
<td>Hinges</td>
<td>$0</td>
<td>4</td>
<td>$1</td>
</tr>
<tr>
<td></td>
<td>mounting gear</td>
<td>$20</td>
<td>1</td>
<td>$20</td>
</tr>
<tr>
<td></td>
<td>Takeoff Strip</td>
<td>$370.80</td>
<td>1</td>
<td>$370.80</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$2,478</strong></td>
</tr>
</tbody>
</table>

### 1 Drone
- **Expendable Materials**: $1,408
- **Reusable**: $1,069.80
- **Gross**: $2,478

### 10 Drones
- **Expendable Materials**: $14,080
- **Reusable**: $1,069.80
- **Total Cost**: $15,150
KPP Check

1. MOE 1 - Emulate an adversary drone
   - KPP 1.1 Shall reach a dash speed of 90 knots ✓
   - KPP 1.2 Shall operate in the air for 45 minutes ❌
   - KPP 1.3 Shall make instantaneous 3G turns ✓
   - KPP 1.4 Operate 5.5 Nautical Miles away from ground station ❌

2. MOE 2 - Allow a Naval Vessel to train independently
   - KPP 2.1 Easily operable by a sailor with little training required ✓
   - KPP 2.2 Shall launch within 30 feet ✓

3. MOE 3 - Be independent of the host ship
   - KPP 3.1 Drone and Ground station are portable ✓
   - KPP 3.2 Ground station is self contained and independent of ship systems ✓
   - KPP 3.3 Launch Mechanism is self contained and easy to use ✓
   - KPP 3.4 UAV entirely expendable ✓

4. MOE 4 - Provide crew feedback on the live fire exercise
   - KPP 4.1 Shall stream data such as speed, location, and altitude to the ground station ❌
   - KPP 4.2 Shall transmit live video to the ground station ❌
Questions?