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Agenda

- Introduction of Program and Project
- Analysis of Performance and Aerodynamics
  - Lift and Drag
  - Static Thrust
  - Thrust Required
  - Rate of Climb
  - Take-off Distance
  - Flight Endurance
  - Level Turn Performance
  - Airspeed Calibration
- Moments of Inertia
What is INSPIRE

- Interdisciplinary National Science Project Incorporating Research and Education Experience
  - Provide practical research experience
  - Provide professional career development information
  - Allow students to discover and utilize a network of resources
  - Established to motivate students to pursue STEM careers
The Project

- To Analyze the Aerodynamic and Performance Characteristics of the DROID 3
- Flight testing helped to validate our predictions and determine the capabilities of the DROID 3
The Steps

- Learning about Aerodynamics
- Measuring the Plane
- Calculating Aerodynamic and Performance Characteristics
- CDR (Critical Design Review)
- Creation of Flight Procedures
- Tech Brief
- Flight Testing
- Analysis of Data
- Final Presentation
The DROID 3

- Wingspan: 9 feet 8.5 inches
- Total Length: 8 feet
- Chord: 2 feet 1.5 inches
Vehicle Configuration

Full weight: 44.96 lbs

CG: 7” from leading edge of wing

- On-board Piccolo
- Pitot tube/Static port
- Tachometer
Lift and Drag
Lift and Drag were found by considering the glide ratio, forward motion over downward motion, considered equal to $L/D$ when thrust is absent.

- At 0 degree flaps $L/D = 7.78$
- At 15 degree flaps $L/D = 6.35$
- At 32 degree flaps $L/D = 5.34$
Static Thrust
Static Thrust

- Prediction: PropCalc
  - Determined an approximate RPM
  - Dimensions of propeller: 26x10
- Testing: Force gauge connected to tail of DROID
  - Different throttle settings
  - Recorded the RPM
Static Thrust

![Graph showing Static Thrust Available [v=0] with RPM on the x-axis and Thrust [lbf] on the y-axis, comparing Predicted Thrust and Actual Thrust.]
Thrust Required for Level Flight
Thrust Required

Initial Equation:

\[ T_{\text{required}} = \frac{W}{C_L / C_D} \]

Flight Testing:
- Used the RPM, airspeed, and propeller dimensions
- Inserted the propeller dimensions and RPM into PropCalc
- Several graphs with one point from each graph
- Final graph of thrust required
Thrust Required

Thrust Required vs. Velocity

- Actual Thrust
- Predicted Thrust $e=0.85$
- $T$ available $26\times10$
Thrust Required

- Challenges:
  - Finding areas where the velocity and altitude were consistent
  - Roll angle was close to zero
  - Finding level flight for a good amount of time
  - Amount of data per second
Rate of Climb
Rate of Climb

Thrust Required vs. Velocity

\[ ROC = \frac{VT_{ex}}{W} \]
Take-off Distance
Prediction

Distance (ft) vs. Angle of attack (degrees)
Test Data (Distance)

Latitude: \(0.00000389038 \times 365228 = 0.3000886159\) ft

Longitude: \(0.00019722353 \times 299656 = 25.365406128\) ft

\[A^2 + B^2 = C^2\]
Due to calibration of gyroscopic pitch sensor, \( \frac{3}{4} \) of a degree must be added to given pitch to receive actual pitch.
Take-off Distance

-0 deg. flap setting
-38.35 ft. take-off
-8.5 deg. angle of attack

Data
Data

Take-off Distance

Distance (ft)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Angle of attack (degrees)

-0 deg. flap setting
-38.35 ft. take-off
-8.5 deg. angle of attack
Take-off Distance

Distance (ft) vs. Angle of attack (degrees)

-0 deg. flap setting
-38.35 ft. take-off
-8.5 deg. angle of attack
Error Analysis

- Flight testing data was recorded at 1 Hz. Take–off was an estimated 1.5 seconds.
- Due to change in constants, analytical data was not applicable to take–off testing of 15 degree and 32 degree flaps settings.
Findings

15 degree flap setting had a take-off distance of 31.28 feet
32 degree flap setting had a take-off distance of 44.88946

For DROID 3 aircraft:
- Use 15 degree flap setting for optimized take-off
- Use 32 degree flap setting for optimized landing
Flight Endurance
Flight Endurance

- Flight Testing
  - Ground Test

- Data

<table>
<thead>
<tr>
<th>RPM</th>
<th>Weight Diff.</th>
<th>Time</th>
</tr>
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<tbody>
<tr>
<td>initial-3500</td>
<td>105g</td>
<td>10 min</td>
</tr>
<tr>
<td>3500-4500</td>
<td>130g</td>
<td>7 min</td>
</tr>
<tr>
<td>4500-5500</td>
<td>222g</td>
<td>6 min</td>
</tr>
<tr>
<td>5550-6500</td>
<td>270g</td>
<td>5 min</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>oz burned</th>
<th>oz per min</th>
<th>RPM</th>
<th>minutes on a full tank</th>
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<tbody>
<tr>
<td>3.70</td>
<td>0.37</td>
<td>3500</td>
<td>134.99</td>
</tr>
<tr>
<td>4.58</td>
<td>0.65</td>
<td>4500</td>
<td>76.32</td>
</tr>
<tr>
<td>7.83</td>
<td>1.30</td>
<td>5500</td>
<td>38.31</td>
</tr>
<tr>
<td>9.52</td>
<td>1.90</td>
<td>6500</td>
<td>26.24</td>
</tr>
</tbody>
</table>
Flight Endurance

![Graph showing flight endurance against velocity. The graph compares predicted and actual time.]
Level Turn Performance
Level Turn Performance

- **Initial Equation:**
  \[ R = \frac{V^2}{g \tan \phi} \]
  
  - \( R \): turn radius
  - \( V \): velocity
  - \( g \): acceleration due to gravity
  - \( \phi \): bank angle

- **Testing:**
  - Fly multiple level turns at constant bank and velocity
Level Turn Performance

20°–30°

Radius (ft)

0 10 20 30 40 50 60 70 80 90

Velocity (KTAS)

0 10 20 30 40 50 60 70

Actual Data

Φ=20°

Φ=30°
Level Turn Performance

30°– 40°

Radius (ft)

Velocity (KTAS)

Actual Data

$\Phi=30^\circ$

$\Phi=40^\circ$
Airspeed Calibration
Airspeed Calibration

<table>
<thead>
<tr>
<th>Trial</th>
<th>KTAS</th>
<th>Ground</th>
<th>Difference (Pitot-Ground)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>47.30318</td>
<td>47.79142</td>
<td>-0.48824</td>
</tr>
<tr>
<td>2</td>
<td>53.84654</td>
<td>54.51497</td>
<td>-0.66843</td>
</tr>
<tr>
<td>3</td>
<td>68.93083</td>
<td>72.25318</td>
<td>-3.32235</td>
</tr>
<tr>
<td>4</td>
<td>67.86904</td>
<td>68.37338</td>
<td>-0.50434</td>
</tr>
</tbody>
</table>

- Airspeed calibration factor calculated to be minute
- Calibration of −3.32KTAS was omitted as outlier
- Average calibration factor = −.55KTAS
Moments of Inertia
Moments of Inertia

• Find moment of inertia for $I_{xx}$, $I_{yy}$, and $I_{zz}$

Inertia tensor
Stress Testing–Simple Pendulum

- Ensure that channel and metal bar can hold weight of aircraft
- Placed 100 lbs on channel
- Allowed to sit for 10 minutes
- Successful!
Followed same procedure as before, only now testing strength of cables. At 90 lbs, the universal joints broke apart. Failed stress test. Retested with stronger universal joints, and was successful.
Roll Inertia Test

Time vs. Y accelerometers
Roll Inertia Test

Time vs. Y accelerometers (zoom)
Roll Inertia Test

- Poor data due to uncontrollable secondary oscillations
- Will use stopwatch data instead
- $T = 2.28$ seconds
Simple Pendulum

Roll Inertia Results

Rotational inertia about pivot point

\[ I'_{xx} = \frac{WT^2L}{4\pi^2} \]

Using parallel axis theorem...

\[ I_{xx} = I'_{xx} - \frac{WL^2}{g} - I_{rig} \]

Rotational inertia about aircraft’s axis

W = weight of aircraft and rig (lbs)
T = period (sec)
L = length of pendulum (ft)
Roll Inertia Results

\[ I'_{xx} = \frac{(51.115 \text{lbs})(2.28 \text{sec})^2(3 \text{ft})}{16\pi^2} = 20.207 \text{ slugs} \cdot \text{ft}^2 \]

Translational MOI = \( \frac{(51.115 \text{lbs})(3 \text{ft})}{32.2 \text{ft/sec}^2} \) = 14.298 slugs \cdot \text{ft}^2

\[ I_{rig} = 0.0393 \text{slugs} \cdot \text{ft}^2 \]

\[ I_{xx} = 20.207\text{slugs} \cdot \text{ft}^2 - 14.298\text{slugs} \cdot \text{ft}^2 - 0.0393\text{slugs} \cdot \text{ft}^2 \]
Roll Inertial Results

Measured

\[ I_{xx} = 5.8697 \text{ slugs} \cdot \text{ft}^2 \]

Estimated

\[ I_{xx} = 4.254 \text{ slugs} \cdot \text{ft}^2 \]

Percent Error

38%
Pitch Inertia Test

Time vs. X accelerometers

![Graph showing time vs. X accelerometers](image)
Pitch Inertia Test

Time vs. X accelerometers (1 oscillation)
Pitch Inertia Test

Time vs. X accelerometers (zoom)
Pitch Inertia Test

Time vs. X accelerometers (zoom)
Pitch Inertia Results

- \( T \) (period) is the time difference from peak to peak
- Took average of every period
- \( T = 2.2 \) seconds
Pitch Inertia Results

\[ I_{yy}' = \frac{WT^2L}{4\pi^2} \]

\[ I_{yy} = I_{yy}' - \frac{WL^2}{g} - I_{rig} \]

Use same method as \( I_{xx} \)
Pitch Inertia Results

Measured

$$I_{yy} = 4.478 \text{ slugs} \cdot \text{ft}^2$$

Estimated

$$I_{yy} = 3.862 \text{ slugs} \cdot \text{ft}^2$$

Percent Error

15.95%
Yaw Inertia Test

Time vs. Yaw gyros
Yaw Inertia Test

Time vs. Yaw gyros (1 oscillation)
Yaw Inertia Test

Time vs. Yaw gyros (zoom)

X: 1.211e+006
Y: 0.2557
Yaw Inertia Test

Time vs. Yaw gyros
(zoom)

X: 1.206e+006
Y: 0.2726
**Yaw Inertia Results**

- $T = 4.7$ seconds

\[
I_{zz} = \frac{gT^2d^2W}{16\pi^2l} - I_{rig}
\]

- $g =$ gravity constant (ft/sec$^2$)
- $T =$ period (sec)
- $d =$ distance between cables (ft)
- $W =$ weight of aircraft and rig (lbs)
- $L =$ length of cables (ft)

\[
I_{zz} = \left(\frac{32.2 \text{ft}}{\text{sec}^2}\right)(4.7 \text{sec})^2(2.104 \text{ft})^2(51.115 \text{lbs}) - 0.4692 \text{ slugs} \cdot \text{ft}^2
\]

\[
16\pi^2(5.25 \text{ft})
\]
Yaw Inertial Results

Measured

\[ I_{zz} = 2.4228 \text{ slugs} \cdot \text{ft}^2 \]

Estimated

\[ I_{zz} = 6.3976 \text{ slugs} \cdot \text{ft}^2 \]

Percent Error

62.13\%
In Conclusion

- Not all, but most predictions in our CDR were confirmed.
- We all learned a lot about math, physics, and aeronautics through this project.
- We are all really grateful for the time we have spent here, and those who have helped us at Dryden.
Questions?