# Ground Test:
# Bank Angle Safety Monitor

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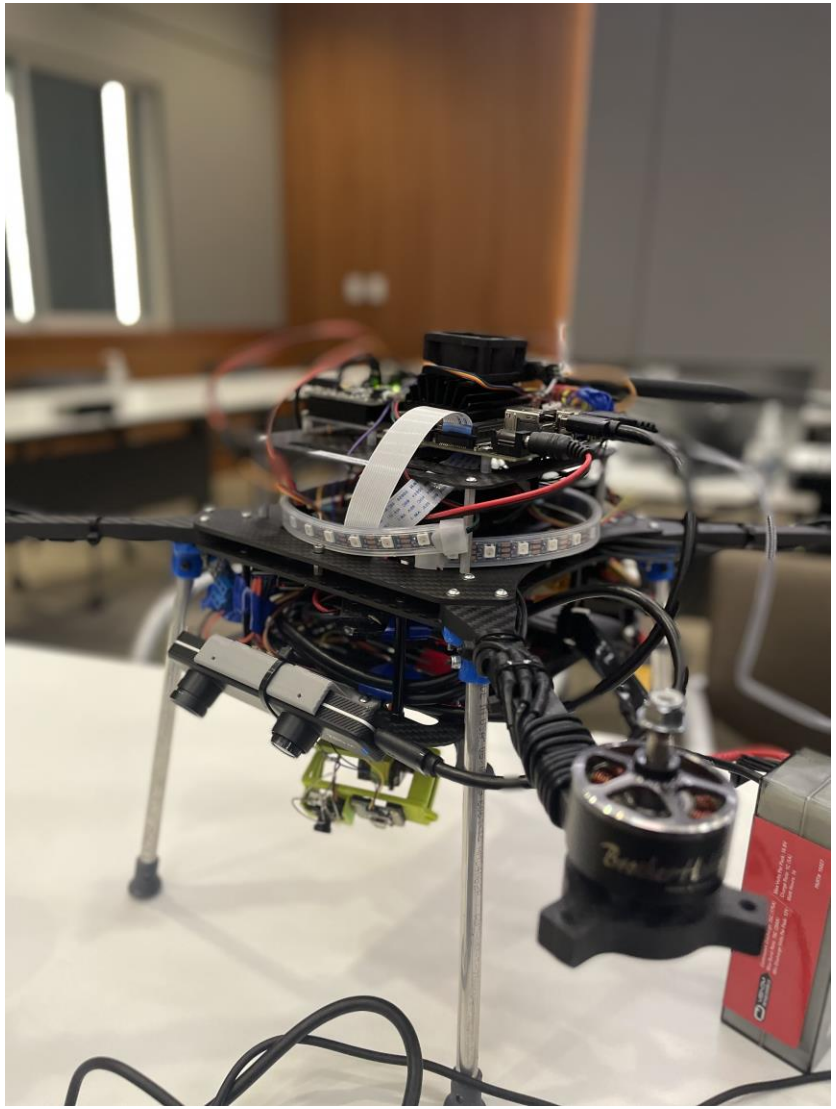
# Pictures :)



# Safety Monitor System

During flight of an AVR drone, avoiding overstress during maneuvering is key to the safety of the airframe and maintaining structural integrity.

- Goal: prevent forces from exceeding 90% of maximum limits
- The system will continuously determine a maximum limit for bank angle

# Meeting Customer Requirements

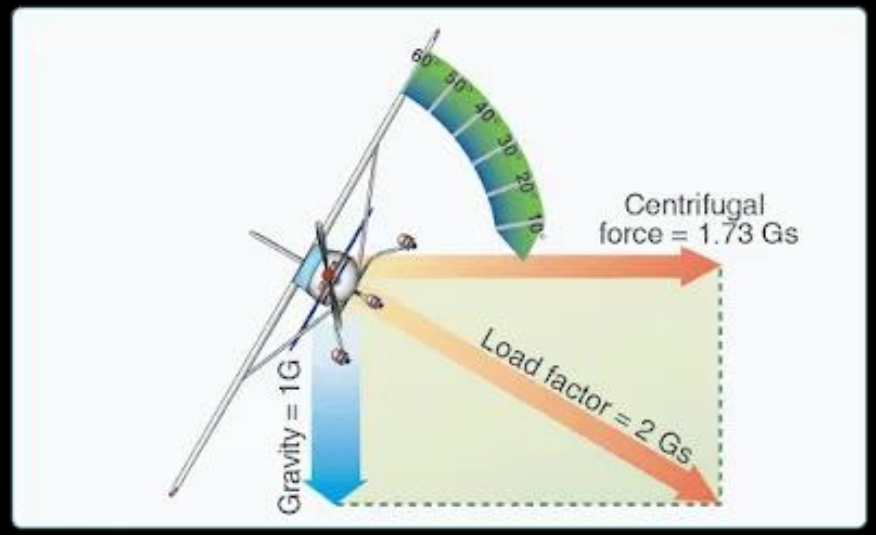
- Drone LED strip will change color to indicate the approach of the bank limit and when it is exceeded
- Green <=50% of maximum, Yellow text > 50%, orange > 75%, red > 90%, purple > 100%
- Warning indications revert/disappear as bank angle decreases

# Mathematical Approach

- The Safety Monitor System can determine the Drone's maximum allowable load factor with the equation:

$$n = 0.9\ (\frac{196\ N}{m})\ /\ 9.8\ \frac{m}{s^2}$$ (90% of drone's maximum load)

- The bank angle at which this limit is reached can be determined: $\theta = \arccos(\frac{1}{n})$




Centripetal force: $\mathrm{L}\ sin\theta = \frac{mv^2}{r}$

Lift force: $L = \frac{mg}{cos\theta}$

Plugging in L: $r = \frac{v^2}{gtan\theta}$

Image from Flight-Study

# Safety Measures and Test Preparation

- Ensure battery is charged sufficiently prior to ground test
- Secure battery to the drone to avoid any equipment failure
- Have set number of test cases for each procedure
- Check connection between drone and GUI

# Test #1 Procedure

- AVR Drone remains still on ground
- Mass is written into the Sandbox module
- Desired values (attitude) set in AVR GUI
- Test goal: Given any weight greater than zero, the system should be able to alert the operator as described in the preliminary review

# Part A: Mass = 4kg (no additional load)

- Using $n = 0.9\ (\frac{196\ N}{m})$ / $9.8\frac{m}{s^2}$ , and plugging in 4kg for the mass, n = 4.5G
- Yellow zone (50%$< x <$75%) reached at 2.3G, Orange zone (75%$< x <$ 90%) at 3.4G, Red zone (90%$< x <$ 100%) at 4.1G, and Purple zone (≥100%) at 4.5G
- Using the load factors determined above and $\theta = \arccos(\frac{1}{n})$, corresponding bank angles in degrees are 64.2, 72.9, 75.9, and 77.2 respectively
- System should give accurate bank angle alerts in yellow, orange, red, and purple zones
- System should be able to function with combined pitch/roll values

# Test #1 Part A (4kg): Prediction

| Pitch Angle (degrees) | Roll Angle (degrees) | Bank Angle (degrees) | Resulting Force (G) | 100% of Limit | Alert Color |
|---|---|---|---|---|---|
| 8.9 | 4.5 | 10.0 | 1.02 | 4.5 | None / Green |
| 35.3 | 55.8 | 66.0 | 2.5 | 4.5 | Yellow |
| 0.0 | 75.0 | 75.0 | 3.9 | 4.5 | Orange |
| 38.3 | 66.3 | 76.5 | 4.3 | 4.5 | Red |
| 0.0 | 78.0 | 78.0 | 4.8 | 4.5 | Purple |

# Part B: Mass = 8kg (additional load)

- Yellow zone reached at 1.1G, orange at 1.7G, red at 2.0G, and purple at 2.3G
- Corresponding bank angles in degrees are 24.6, 54.0, 60, and 64.0 respectively
- System should function appropriately given new bank angle and mass values, meeting all customer requirements

# Test #1 Part B (8kg): Prediction

| Pitch Angle (degrees) | Roll Angle (degrees) | Bank Angle (degrees) | Resulting Force (G) | 100% of Limit | Alert Color |
|---|---|---|---|---|---|
| 10.0 | 0.0 | 10.0 | 1.02 | 2.3 | None / Green |
| 0.0 | 33.0 | 33.0 | 1.2 | 2.3 | Yellow |
| 39.6 | 39.6 | 56.0 | 1.8 | 2.3 | Orange |
| 63.0 | 0.0 | 63 | 2.2 | 2.3 | Red |
| 23.3 | 61.7 | 66 | 4.8 | 2.3 | Purple |

# Test #2

- Mass is written into the Sandbox module
- Drone is picked up and tilted by hand to induce bank angles determined in Test #1
- The resulting angles and alert states are compared to those from Test #1
- The System should be able to change smoothly between alert states with both increasing and decreasing bank angles

# System Acknowledgments

- Model is based on the assumption that the drones maximum force load is 5Gs at 4kg.

  This parameter can be adjusted to fit the model to other aircraft

- For multi-directional bank, we assume total bank angle is a vector combination of pitch

  and roll values.

# Future Considerations

- A user interface on the GUI could be added to accept a mass input, rather than being hard-coded into sandbox
- GUI alerts could be added, specifying corrective behavior to the user and indicating the state of the exceedance for beyond visual range operation
- Modification to the flight controller could override pilot inputs to prevent bank angle exceedances

# Thank You