AERODYNAMIC DRAG AND STABILITY CHARACTERISATION OF A RIGID PARACHUTE

Background Information

Over time, parachutes have been used in various fields from skydiving to space travel, each with specific requirements for parachute characteristics. This project explores the aerodynamic characteristics of a rigid hemispherical parachute characterised by vent ratio and canopy size. Utilizing Computational Fluid Dynamics (CFD) simulations and physical drop tests, the project aims to enhance parachute performance through a comprehensive approach.

Methodology

CFD Simulations:

Ansys Student 2023 R2 was used to conduct CFD simulations. The turbulence model used was SST K Omega to replicate real-life conditions. Assumptions made in the simulation were that the parachute cannot deform, heat exchanged with the surroundings was negligible, the velocity of steady incoming airflow was 5 m/s and the density of air was 1.225 kg/m^3 .

Drop Tests:

Parachute canopy sizes, determined based on the estimated masses of parachute systems, aimed to maintain low terminal velocities. Canopies were crafted from non-porous polyester fabric, and payloads included an Arduino Nano 33 BLE with an LSM9DS1 inertial measurement unit for collecting acceleration and angular velocity data. Drop tests were conducted from a height of approximately 9.2 m. A Direction Cosine Matrix was utilised to convert data to the earth axes.

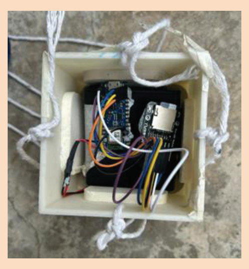


Fig 1. Payload Box

Fig 2. Parachute

Model Development

From F = ma,

$$F = mg - F_D = m\frac{dV_G}{dt} \quad (1)$$

Considering velocities in the body fixed frame,

$$a = \frac{dV_G}{dt} = \frac{dV}{dt}\Big| B + \underline{\omega} \times \underline{V} \quad (2)$$

Substituting (2) into (1),

$$F = m\frac{dV}{dt}\Big| B + \underline{\omega} \times \underline{V} \quad (3)$$

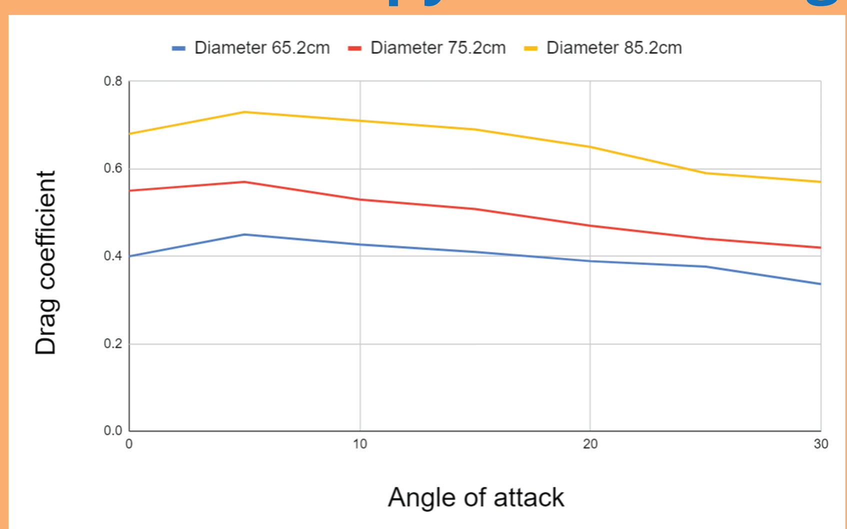
Considering key external forces, aerodynamic force and gravitational force in the earth-fixed inertial frame; gravitational force considered in body-fixed frame is hence,

$$F^b_{gravity} = F^e_{gravity}R_t = mg\begin{bmatrix} -\sin(\theta) \\ \sin(\phi)\cos(\theta) \\ \cos(\phi)\cos(\theta) \end{bmatrix} \quad (4)$$

Thus, our final force equation in the body-fixed frame is,

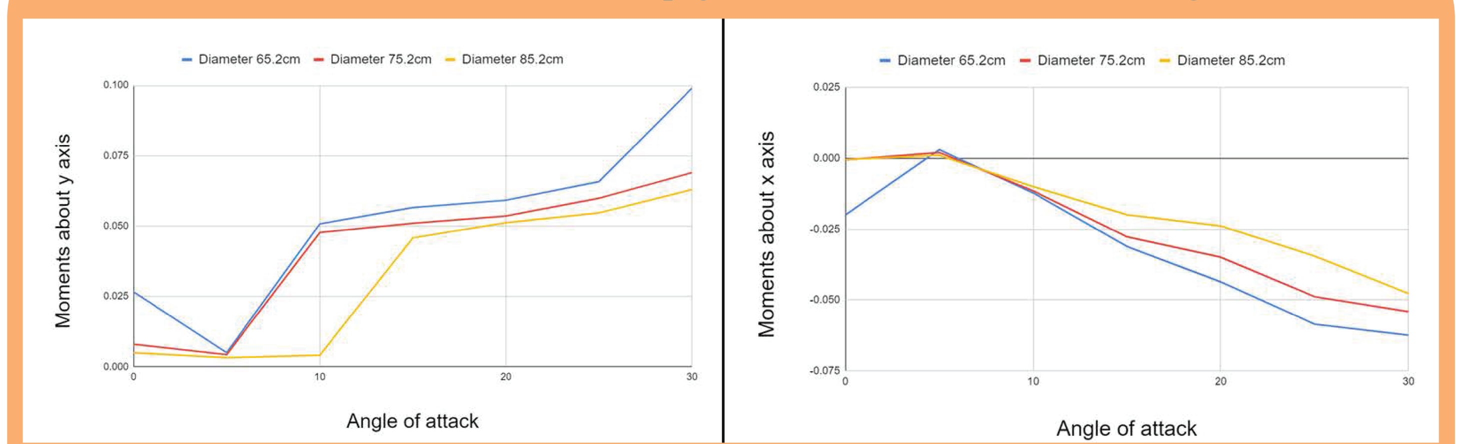
$$F^b_{gravity} + F_a = m \times \frac{dV}{dt} + m\underline{\omega} \times \underline{V} \quad (5)$$

Effect of Canopy Size on Drag



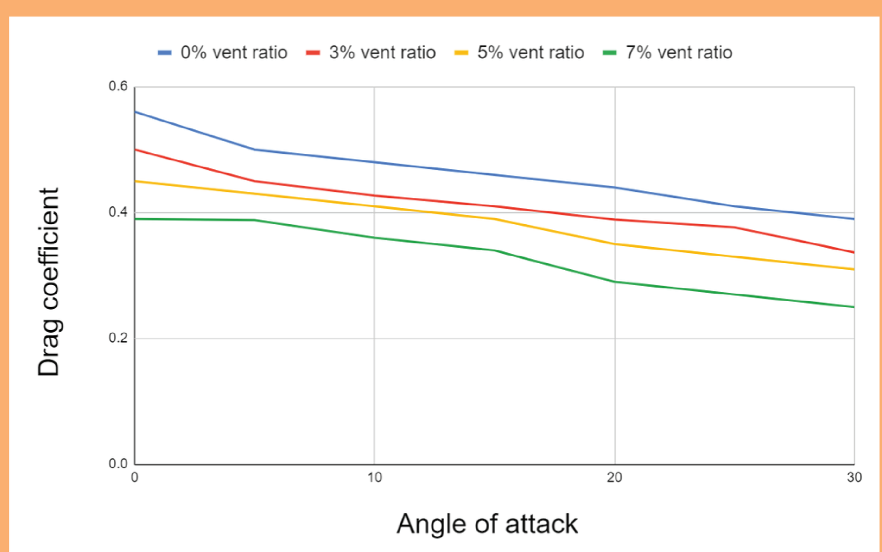
It was observed that as canopy size increased, the drag coefficients increased. This was likely due to increased pressure gradients.

Effect of Canopy Size on Stability



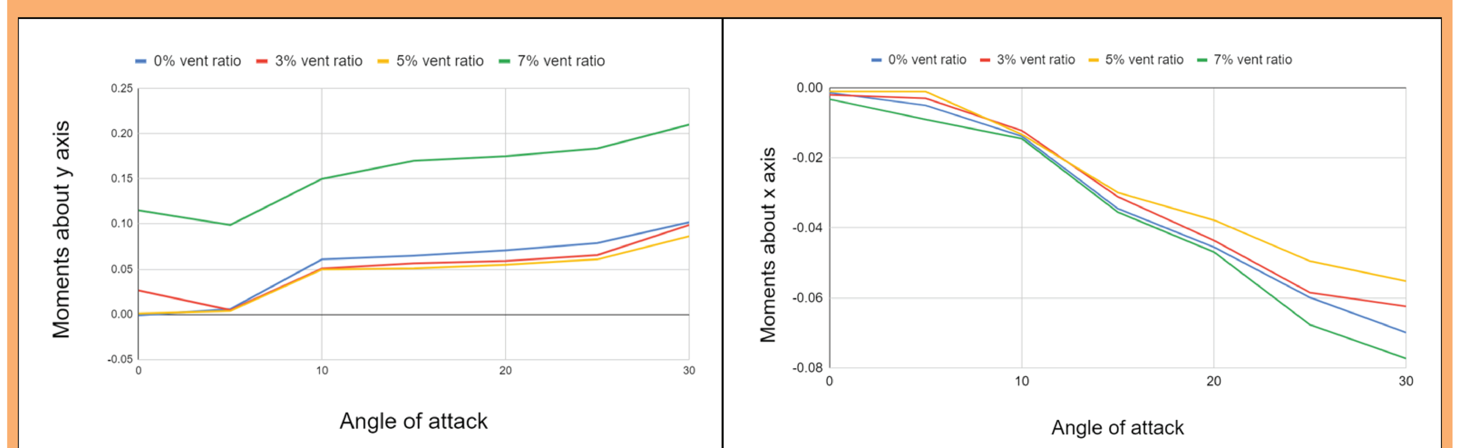
CFD simulation results showed smaller moments and increased stability of the parachute at increased canopy sizes, possibly due to slower rates of descent.

Effect of Vent Ratio on Drag



Larger vent ratio reduces overall drag coefficient, attributed to decreased pressure gradient and delayed flow separation at the vent. Though vent ratio's effect on drag is notable, its effect on parachute stability outweighs its drag implications.

Effect of Vent Ratio on Stability



CFD simulations highlighted a decreasing trend where an increase in vent ratio from 0% to 5% caused a decrease in the moments of the parachute while a further increase, beyond an optimum point, to 7% caused increased moments of the parachute, and introduced greater instability than that at 0% vent ratio.

Conclusion

- As vent ratio increased, drag coefficient decreased and stability increased until an optimal vent ratio before decreasing
- As canopy size increased, both drag coefficient and stability increased substantially

Future Research

- Use a controlled environment, more accurate and precise IMU and a fully rigid parachute
  - Minimise external factors that could affect data collected
- More precisely determine the optimal parameters of parachutes for various applications

References

- Dobrokhodov, V. N., Yakimenko, O. A., & Junge, C. J. (2012, May 22). Six-degree-offreedom model of a controlled circular parachute. Six-Degree-of-Freedom Model of a Controlled Circular Parachute. https://arc.aiaa.org/doi/10.2514/2.3143

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