Chapter 1
Redesign and Analysis of Cargo Containers for Delivery Drone Applications

Shivanshu Mishra, Vishal Kumar, Abdul Gani, and Faisal Shameem

Abstract Drone or octocopter drone is a new generation innovation that can perform operations like surveillance, media, etc. with ease setup and cost-efficient. The delivery drone is the upcoming evolution in the field of engineering. The design of cargo containers attached to drones affects the parameters like the speed, efficiency, dynamics, and controls. The present work proposes a modified elliptical-shaped design instead of a regular rectangular cargo container. For lightweight and durability, carbon fiber as a material is also proposed. The shape was analyzed through computational fluid dynamics technique by using Ansys. The results of the study showed that the new ellipse shape design of cargo container is more practical to use in high-speed operation and results in increased efficiency of the system like drone.

1.1 Introduction

The advancement in today's technology has extended the boundaries of drone technologies. The major application of drones is in military, civil, and agriculture services. Due to its wide applications, drones are now used for delivery purposes to solve efficient and reduced delivery time problems [1]. The major advantage of drone is they can cut short 80% of delivery time compared to ground vehicles based on their flexible routes and parallelized operations [2]. Due to their cheap, flexible, and fast delivery drones can bring revolution to delivery department.

The shape and size of the cargo container in delivery drone play a vital role in overall efficiency of the operation as most of the cargo containers are rectangular in shape which occupies a huge air resistance at its surface making overall delivery drone design less efficient. Some studies did airflow analysis on different structures of freight vehicles and it has been observed that the streamline shape is most efficient as air flows smoothly over the surfaces at high wind speed operation [3]. The main demerit of an ideal rectangular shape cargo container is that at high-speed operations

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the container becomes heavily unstable and limits the operational speed [4]. Therefore, we redesign the structure of cargo container into an ellipse shape, changed the material of construction to make it durable- lightweight, and carried out CFD analysis to know the results with respect to efficiency, control, and dynamics. The new design is separated into three different storing sections to utilize space and maintain equal weight distribution during operation.

1.2 Literature Review

The advancement in today's technology has pushed the boundaries of drone application; drones when attached to a cargo container can deliver various products in less time and more efficiently [5]. If we consider suburban areas and compare deliveries by a truck-only delivery and truck-drone delivery we see that the truck-only delivery is very advantageous economically [6]. Thus, it is important to study the drone characteristics and airflow analysis to be economical. Changing the design of light UAVS has resulted in more stability and performance [7]. These days drones can also perform their operations in automated modes with high velocity where their operation paths are predefined, Path generation is achieved by a unit quaternion curve and an associated parallel transport frame in the interactive process. [8]. But, it is important to select the specific type of drone for the delivery operations with respect to weight of cargo as more the number of motors and blades it has the more it consumes power, therefore, a study was conducted on octocopter drone and dodecacopter drone with, without periodic disturbance and it was observed that octocopter is more stable than dodecacopter without disturbance [9]. Hence, we can choose octocopter application for delivery drones.

The aerodynamic characteristic of the cargo container plays a major role in stability and performance parameters in delivery drones. A study on freight wagon was done where airflow analysis was done on the freight wagon the Reynolds number of the flow came out to be 10^5 [10]. Such shape containers with slung load are subject to massively separated unsteady flow and are limited by stability to operational airspeeds well below the power-limited speed of the configuration [4]. Thus, we believe there needs to be change in design of cargo containers for high-speed delivery applications. The shape can withstand the high-speed drag, giving more stability and dynamic controls. Cargo can be highly unstable while in motions and needed to be tied up for so but, locking and unlocking cargo can consume more time hence, we can use baffle at different intersections of container to reduce the instability of cargo similar to baffle used in liquid containers which reduces the amplitude of fluid slosh in partly filled tanks [11].

1.2.1 Proposed Design

The design is developed on Autodesk software, the conventional design of cargo section is rectangular shaped so we modified it to give the cargo section a shape of an ellipse (Fig. 1.1). This design is aimed to minimize resistance and drag caused by air thus making cargo section more aerodynamic and will eventually enhance the productivity of the drone to carry out the delivery operation in a less time and power.

The exterior of the design is developed like an ellipse shape as it has very less air resistance, the front and back edges have smooth (Fig. 1.2), which helps in creating aerodynamic path and increases controls due to less air resistance.

The interior of the cargo section is divided into three parts namely cargo1, cargo2, cargo3 separated by baffle (Fig. 1.3). We have divided it into three parts because by separating each compartment the weight distribution will be balanced and there will be less chances of instability while in motion.

Fig. 1.1 3D view of proposed cargo container

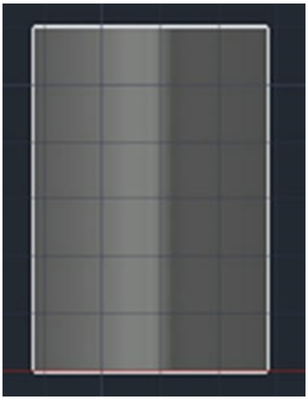


Fig. 1.2 Top view of proposed cargo container for drone application

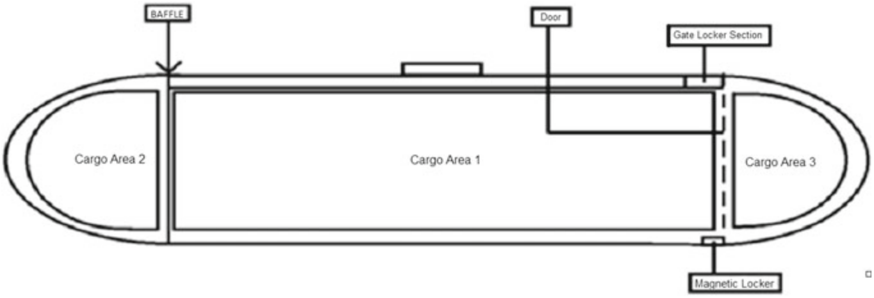
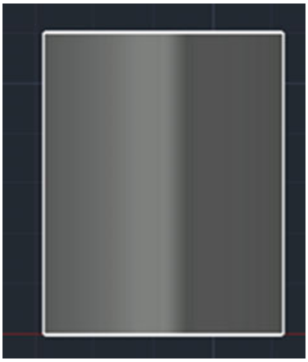


Fig. 1.3 Interior of proposed cargo container for drone application

Fig. 1.4 Bottom view of proposed cargo container for drone application



The cargo areas 2 and 3 are built to store small or lightweight goods whereas cargo area 1 has large storage area for large heavy goods. They both have separate doors for loading unloading cargo situated at top. The interior of the new design consists of single door situated between the cargo area 1 and 3 and also performs as baffle between the surfaces (Fig. 1.3). The door lock mechanism and stopper will be situated at top and bottom of cargo area 1. Additionally, user can construct an area on top of cargo area 1 to mount the container and drone. The top view of the design is replica of bottom view shown in Fig. 1.4 and the back view of the design is replica of front view of design shown in Fig. 1.5.

1.2.2 CFD Analysis

We carried out computation fluid dynamics (CFD) analysis on ANSYS 2021 software. Table 1.1 shows the analysis parameters. The design was exported to ANSYS for simulation results. The airflow analysis was performed with Air as inlet material, we first exported the design and various geometry were set which provided the

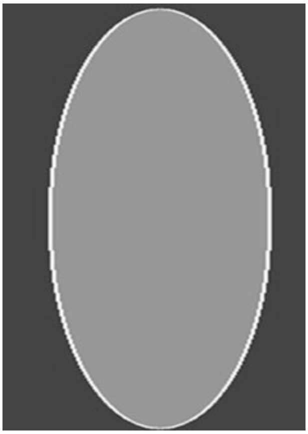


Fig. 1.5 Front view of proposed cargo container for drone application

Table 1.1 Analysis parameters

Velocity formulation	30 m/s
Viscous model	k-omega
Time	Steady
Flow	Fluent
Material	Air
Boundary conditions	Inlet velocity—30 m/s Pressure outlet—1 atm
Number of nodes	44,758
Number of elements	187,788
Enclosure dimensions	Length 12000 mm Breadth 4000 mm Height 2000 mm
Inflation	10 layers
Element size	Minimum 0.2 m Maximum 0.5 m
Converge	140 iterations

enclosure. Meshing was done and various input parameters were given mentioned below for simulation result.

In computational fluid dynamics, the k-omega (k–ω) turbulence model is a common two-equation turbulence model that is used as an approximation for the Reynolds-averaged Navier–Stokes equations (RANS equations). The model attempts to predict turbulence by two partial differential equations for two variables, k, and ω, with the first variable being the turbulence kinetic energy (k) while the second (ω) is the specific rate of dissipation (of the turbulence kinetic energy k into internal thermal energy). This design required SST k-omega turbulence model to calculate the value of lift force and drag force.

The two-equation model (written in conservation form) is given by the following:

$$\partial\left(\frac{\rho k}{\partial t}\right)+\frac{\partial(\rho ujk)}{\partial xj}=P-\beta^{*}\partial\omega k+\frac{\partial}{\partial xj}\left[\left(\mu+\sigma_{k}\frac{\rho k}{\omega}\right)\frac{\partial k}{\rho xj}\right]$$

where,

$$Sij=\frac{1}{2}\left(\frac{\partial uj}{\partial xi}+\frac{\partial uj}{\partial xi}\right)$$

1.3 Result and Discussion

Figures 1.6, 1.7, 1.8, 1.9, 1.10, 1.11, and 1.12 are derived from airflow simulation and we can see that the graph stables up after peak of air which shows the lower air resistance on surfaces.

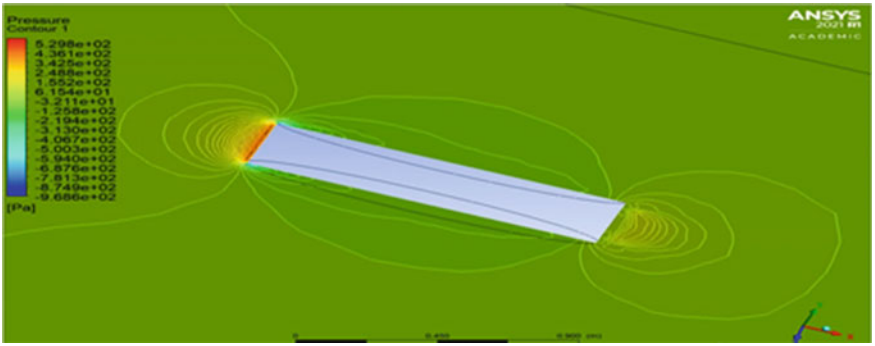


Fig. 1.6 Pressure contour line with respect to Pascal

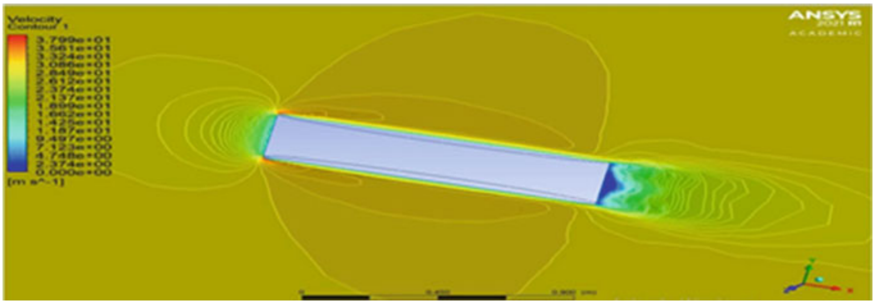


Fig. 1.7 Velocity contour lines with respect to kilohertz

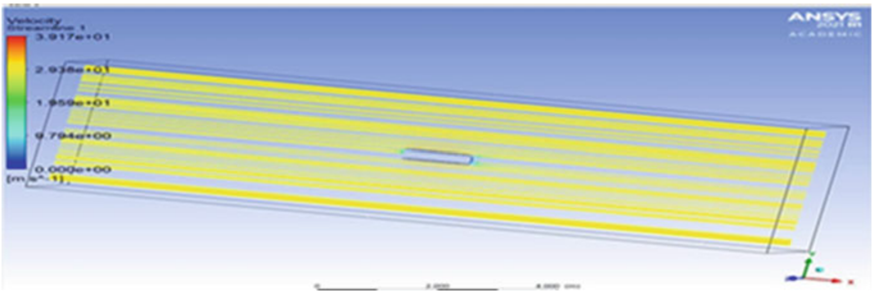


Fig. 1.8 Velocity streamlines with respect to kilohertz

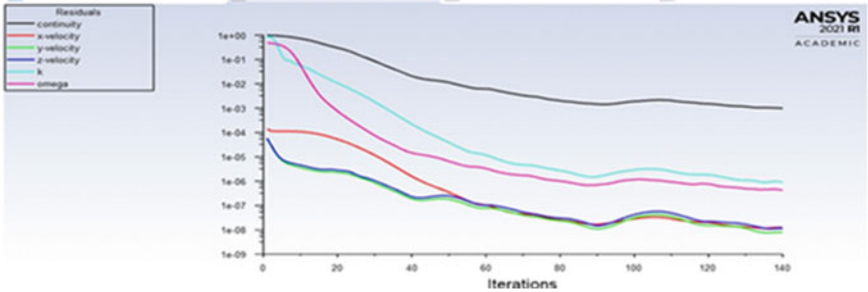


Fig. 1.9 Scaled residual plot, where x-axis is number of iterations and y-axis is equal to residuals

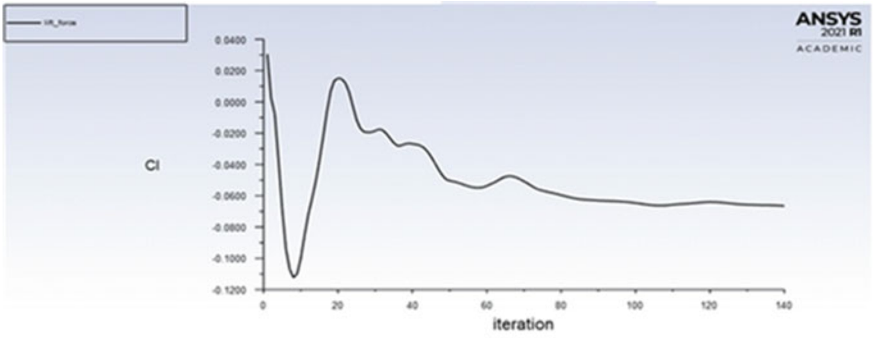


Fig. 1.10 Lift force plot, where x-axis is number of iteration and y-axis is equal to Coefficient of lift

Figure 1.6: In CFD-POST, the figure shows the pressure magnitude by the means of contour lines dawn on a physical body. The pressure values have been maintained at constant atmospheric pressure. The difference in contour lines and its color clearly shows the pressure difference at inlet and outlet.

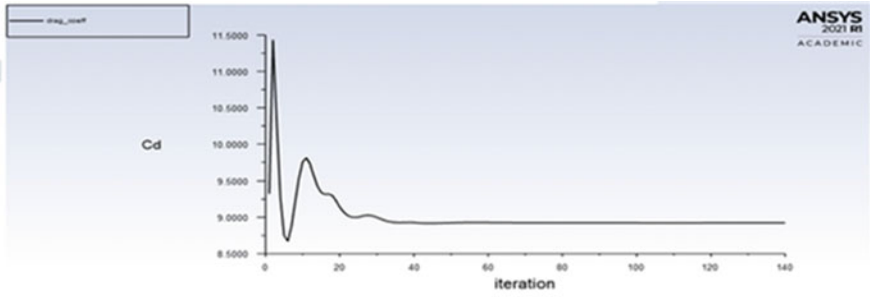


Fig. 1.11 Drag coefficient plot, where x-axis is number of iteration and y-axis is equal to coefficient of drag

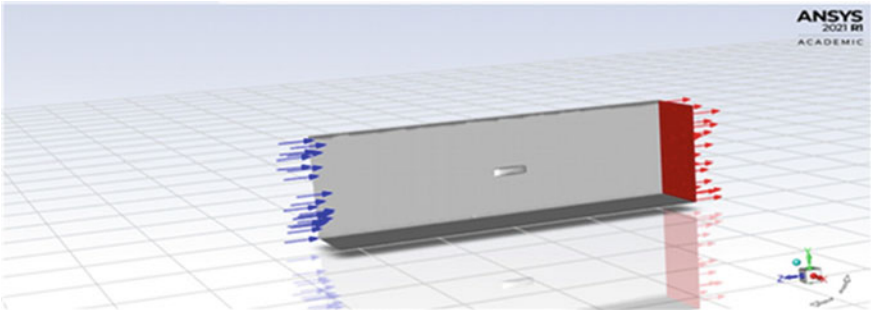


Fig. 1.12 Air inlet and outlet inside enclosure

Figure 1.7: In CFD-POST, we can see the velocity difference of air at inlet and outlet. The inlet velocity has been set to be 30 m/s while at outlet the velocity is set to default. The velocity of air at inlet will be much more than the velocity at outlet. The difference has been demonstrated with the help of contour lines.

Figure 1.8 shows the flow of massless particles through the entire domain to show the velocity difference at different points on the domain.

Figure 1.9 directly quantifies the error in the solution of the system of equations, as it measures the local imbalance of conserved variables in each control volume. The graph represents the residual value of every cell solved equation.

Figure 1.10 is the lift force graph, as the graph stables up after some readings it specifies the lift performance of the new design.

Figure 1.11 is the drag coefficient plot which specifies the air resistance on the surface; the graph gets constant after the initial force, i.e., air gets diverged through first phase of air, increasing the aerodynamic of design. Figure 1.12 is the plot of fluid flow from inlet to outlet, in the figure the blue arrow shows the direction of fluid through inlet section under the enclosure section and red arrow specifies the outlet of fluid.

1.4 Conclusion

From the CFD results, we can say that the newly designed shape of cargo container for drone application is more practical to use as the new design results in less drag due to its curved shape from front and backside which helps in resisting air to a great extent, the new material of construction which is carbon fiber make design durable and helps in decreasing weight.

When the design comes in contact with high wind it becomes aerodynamic and its controls increase, the easier it is for a drone carrying cargo to move, the less energy the system needs making it a valuable part for delivery drones operating at high speed.

References

1. Brar, S., Rabbat, R., Raithatha, V., Runcie, G., Yu, A.: Drones for Deliveries. Berkely university of California (2015)
2. Patchou, M., Sliwa, B., Wietfeld, C.: Unmanned aerial vehicles in logistics: efficiency gains and communication performance of hybrid combinations of ground and aerial vehicles. In: IEEE Vehicular Networking Conference (VNC) (2019)
3. Choi, K.-K., Cho, J.-U.: A convergent investigation on the air flow in driving according to a cargo container and the wind deflector. J. Korea Converg. Soc. (2020). 2713-6353 (eISSN)
4. Cicolani, L.S., Cone, A., Theron, J.N., Robinson, D., Lusardi, J., Tischler, M.B., Rosen, A., Raz, R.: Flight test and simulation of a cargo container slung load in forward flight. J. Am. Helicopter Soc. **54**(3), 32006–3200618 (2009)
5. Ackerman, E., Strickland, E.: Medical delivery drones take flight in east Africa. IEEE Spectr. **55**(1), 34–35 (2018)
6. Campbell, J.F., Sweeney II, D.C., Zhang, J.: Strategic design for delivery with trucks and drones. College of Business Administration, University of Missouri St. Louis, MO, USA (2017)
7. Kovanis, Skaperdas, Ekaterinaris: Design and analysis of a light cargo UAV prototype. AIAA 2010–4957 (2010)
8. Raffler, Wang, Holzapfel: Path Generation and Control for Unmanned Multicolor Vehicles Using Nonlinear Dynamic Inversion and Pseudo Control Hedging. Institute of Flight System Dynamics, Technische Universität München, Germany (2013)
9. Yıldırım, Çabuk, Bakırcıoglu: Design and trajectory control of universal drone system. Measurement **147**, 106834 (2019)
10. Östh, Krajnović: A study of the aerodynamics of a generic container freight wagon using large-eddy simulation. J. Fluids Struct. **44**, 31–51 (2014)
11. Yan, Rakheja, Siddiqui: Baffle Design Analysis for a Road Tanker: Transient Fluid Slosh Approach. Concordia University. 2008-01-2670 (2008)