

Design Innovations of Autonomous Aerial Rescue Vehicles for Urban Areas A Performance Optimization approach using Fundamentals of Computational Fluid Dynamic

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Abstract. It is very important to have an overall understanding of the aerodynamics, propagation efficiency and structural performance of an Autonomous Aerial Rescue Vehicles (AARVs) for Emergency Disaster & medical services. In the urban and remote application of AARVs in Emergency medical and disaster response, one of the most critical factors for optimizing the aerodynamic design of AARVs and therefore the maneuverability, stability and energy efficiency of the AARVs is Computational Fluid Dynamics (CFD). This paper explores and applies CFD methodologies in the aerodynamic design and analysis of AARVs, focusing on important aspects such as the aerodynamic force estimation, the propulsion system performance. The aerodynamic force is also evaluated, such as lift, drag coefficient and moment coefficient which are to enhance the stability and control of the vehicle at altitude 300 m at Mach number 0.05. The CFD simulations are also used to determine the efficiency of the propulsion system, the best thrust to weight ratio (T/W) and to save energy. By implementing CFD applied optimizations, the proposed design approach seeks to enhance the flight efficiency, decrease the emergency response times and it improves the overall effectiveness of AARVs in complex emergencies. The results show a way to the advancement of Autonomous Aerial Rescue Vehicle technology by offering a perspective into performance centric design strategies for next-generation of rescue operations. Finally, this study demonstrates the significance of CFD in the design and development of the AARVs which will be accepted as a reliable and effective vehicle in the emergency medical and disaster services.

Keywords: Autonomous Aerial Rescue Vehicles (AARVs), Computational Fluid Dynamics (CFD), Aerodynamics, Propulsion efficiency, Urban Air Mobility (UAM), Energy efficiency.

1. Introduction:

In densely populated urban centers like, Mumbai, Delhi, Chennai and Bengaluru traffic congestion and infrastructure constraints may cause significant delay in the emergency medical services [1,2]. These situation in urban areas must be noted with utmost importance because the prompt delivery of medical services, considerably affects critical patient's survival rates. As of the traditional ground-based Emergency Medical Services (EMS) often face difficulties in transiting through the congested city streets, especially during the peak hours, during the natural disasters and during a public event [3], [4]. The increasing population and vehicular density in urban cities, have further worsen these delays, pointing towards the need to find inventive and creative solutions that can easily and quickly avoid the ground-level obstacles and deliver rapid emergency care to the patient [5], [6], [7]. The novel idea of the Autonomous Aerial Rescue Vehicles (AARVs) offers a promising solution to the conventional EMS, as it utilizes the air

space at low altitudes to avoid delays caused by traffic and infrastructure issues, as mentioned in [8, 9]. The AARVs are rotor wing, battery powered, medium sized autonomous aerial vehicles which are equipped with advanced autonomous navigation systems that allows quick navigation, evacuation and transportation of injured individuals and medical supplies to remote healthcare facilities. The Autonomous Aerial Rescue Vehicles (AARVs), especially the ones that has electric vertical takeoff and landing (eVTOL) configurations, offers opportunities for a sustainable, efficient, and rapid emergency response [10], [11]. The AARV's ability to navigate the low altitude urban environment that greatly increases its speed to reach critical and injured patients also improves survival rates and the overall operational productivity of urban emergency systems. To make AARVs suitable for such operations, it is very important that its aerodynamic feature must be appropriate for such operations. Computational Fluid Dynamics (CFD) [12, 13, 14] is thus one of the key aspects to improve the performance and operational productivity of AARVs. CFD is very important not only for analyzing and improving the aerodynamic performance but also for the design to be energy efficient, and suitable of various urban environments [13], [15], [16].

The use of ANSYS application can be used to study the flow pattern, optimize drag and optimize propulsion systems to increase the efficiency of the flight [17, 18]. This research will focus on the use of CFD methods for designing and deploying AARVs in different urban environments. The study successfully shows how the eVTOL configurations for AARV design remain unchanged throughout the study, enabling sustainable operations and overcoming the specific challenges faced in an urban environment, making this study valuable for the next-generation Emergency Medical Response Systems (EMRSs).

2. Literature Review:

In recent decade, Unmanned Aerial Vehicle (UAV) has become an important component of the modern day-to-day life emergency framework due to its ability to save lives of injured people in critical situations during Search and Rescue (SAR) operations, and its ability to operate in complex environments and its quick deployment capabilities [19] [20]. The study on these framework highlights the importance of aerodynamic optimization to ensure their energy efficiency, stability and operational readiness.

Advanced computational analysis of the aerodynamic properties of air vehicles is a crucial tool in the aerospace industry and is termed as Computational Fluid Dynamics (CFD) [21]. Extensive applications of CFD study the lift enhancement, drag reduction and thermal regulation, providing a designer, engineer or researcher a vision for optimizing the air vehicle performance. Although the application of CFD in aerospace engineering seems widespread, studies based on the use of CFD in electric vertical takeoff and landing (eVTOL) configuration Autonomous Aerial Rescue Vehicles (AARVs) specifically designed for emergency medical operations is limited [22], [23], [24].

Aerodynamic optimization of UAVs for rescue is crucial to realize sustainable and stable flights, especially in difficult low altitude urban environments. An appropriate aerodynamic design reduces the drag (D), enhances lift to drag ratios (L/D) and also reduces overall energy consumption, which are very important for increasing the operational range and its endurance [18]. For emergency medical rescue operations, and the need for people to perform reliably and trustworthily in different environments, urban and remote, the above mentioned factors are of particular importance for AARVs [12], [25], [26], [27].

CFD study of UAVs offers a comprehensive visualization of fluid flow around the surface of a vehicle, giving the designer and engineer valuable information to consider when designing complex aerodynamics without 100% relying on physical prototypes or experimental testing in a controlled atmosphere. By simulating the airflow in applications like ANSYS, the pressure distribution aspect of CFD, allows the refinement of design aspects that improve the aerodynamic form, sustainability and the reliability of the vehicle [28], [29], [30]. CFD simulations are also being utilized to help answer some of the key questions for developing UAVs with electric vertical takeoff and landing (eVTOL) that involve determining and identifying the optimum rotor configuration, including blade length and angle, while also helping to improve blade aerodynamics and minimize turbulent flows that could destabilize the vehicle during takeoff and landing.

A typical example of the use of CFD in an unmanned aerial vehicle (UAV) based rescue system is the autonomous aerial vehicle "EHANG 216", as illustrated in Fig. 1A [31]. This is a passenger grade eVTOL that has been designed using advanced CFD modelling, resulting in an optimized aerodynamic shape, lower drag and higher stability. EHANG 216 can be designed for vertical takeoff and landing, and is suitable for rapid response scenarios [31]. Recent studies also states that CFD simulations are very necessary in refining propeller designs so as to decrease noise levels and enhance thrust efficiency. If these improvements are included in design they not only improve the vehicle performance but also ensure safer and more sustainable medical transport [32], [33], [34].

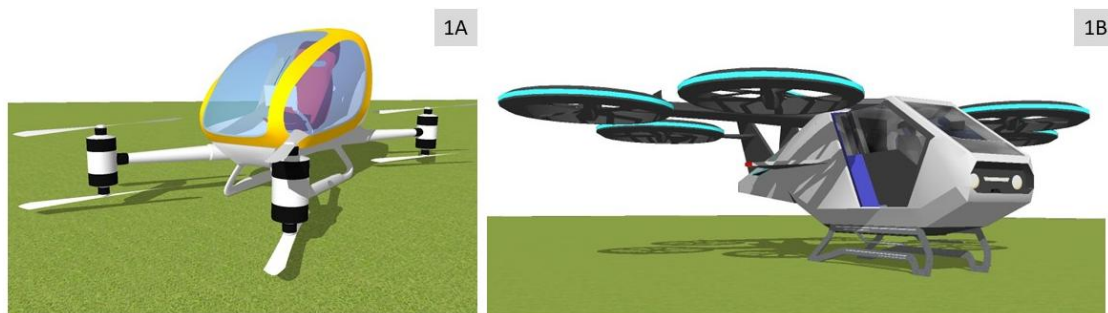


Fig. 1A. Conceptual 3D CAD model of EHang (Source: Created by Author¹).

Fig. 1B. Conceptual 3D CAD model of Volocopter (Source: Created by Author¹).

Another case study named the "Volocopter," which is a multirotor eVTOL, is developed for urban air mobility. The role of CFD simulations is important in designing and optimizing such vehicles with 18 rotors as shown in Fig. 1B [35]. CFD models have been used to study the interactions between airflow and designed and engineered, and energy efficiency (battery usage) and flight stability [16], [36], [37] have been improved. Further, CFD analysis can also be used to minimize rotor induced vibrations and to enhance the comfort of the passengers during transportation [38].

CFD is also very useful in the thermal management aspect of emergency medical rescue operations. Correcting the temperature inside the cabins of AARVs is vital to the correct operation of life-saving equipment. CFD simulation tools can simulate heat transfer and ventilation and help engineers design effective cooling and ventilation systems [28]. In the project "Airbus CityAirbus", for example, CFD analysis was used to optimize the ventilation and

cooling systems to ensure the operational integrity of medical equipment on board the aircraft in different environmental conditions. The above examples include characteristics that allow eVTOL based AARVs to maneuver around buildings and other structures in complex wind patterns even in congested urban areas [39, 40, 41].

CFD simulations also predicts and mitigates aerodynamic disturbances, thereby improving vehicle control and stability during takeoff, flight and while landing [42]. NASA has also done a study on the impact of urban canyons on UAV flight dynamics using the CFD modelling, and it is able to develop Advanced Control Algorithms (ACA) that improve the stability of UAVs in such challenging urban environment [25] [43] [44]. CFD is also a critical part of the certification and regulatory evaluation for eVTOL based UAVs, besides design optimization. Thorough analyses of vehicle performance under a variety of conditions are required for safety and regulatory compliance [18]. The results obtained from the CFD simulations fulfill all of these requirements by giving detailed information on the aerodynamics, structural strength and thermal performance. An example of this is the Federal Aviation Administration (FAA) requires detailed aerodynamics analysis for airworthiness certification, and CFD simulation is now required to meet these requirements. But the use of CFD in eVTOL based AARVs for medical rescue is yet to be sufficiently investigated.

The aerodynamic solutions for eVTOLs for EMS applications are still lacking, as the studies on UAVs done in recent years have been mostly concerned with conventional military and commercial eVTOLs. Future investigations should be done on incorporating patient specific design feature, such as ergonomic patient and unloading systems and strategies for vibration reduction. Aerospace engineers, medical personnel and regulatory authorities must collaborate in an interdisciplinary manner for solving different problems related to the emergency medical rescuing that arises in this context [4], [46], [47]. CFD has had a tremendous improvement over the years in the subject of aerodynamic analysis for aerospace applications, but for the application of medical rescue in eVTOL based AARVs, it is still in development. Such as the EHANG 216, Volocopter, and the Airbus CityAirbus case studies, which illustrate the significant role CFD can play in improving the aerodynamic performance, thermal management and flight stability of flying vehicles. Further research is essential to continue development of these systems to improve the design and operational capabilities of autonomous aerial rescue vehicles and enhance emergency medical service and save lives in critical situations.

3. Methodology and Tools:

3.1. CFD Modelling:

The conceptual drawings [48] and [49] are the first steps towards developing a 3D CAD model of an Autonomous Aerial Rescue Vehicle (AARV) in Sketchup application. It is customary to start with the first draft designs to consider the overall shape of the aircraft, the aerodynamics and key elements like placement of propellers or design of the landing gear. Next smoothing the design further with smoothen tool in Sketchup application to ensure smooth edges to be easily fluid around the vehicle. The 3D CAD model is then imported into FLUENT application and imported in ANSYS software to study various forces such as lift (L), drag (D), thrust (T) and lift to drag ratio (L/D).

Model Development: It is very important to have an understanding of the aerodynamic performance of an Autonomous Aerial Rescue Vehicle (AARV) and this can only be achieved

by building a model using computational fluid dynamics (CFD). The AARV was carefully modelled in 3D computer aided design (CAD) software using industry standard software packages Sketchup and ANSYS FLUENT, to enable this investigation to be carried out. These applications are selected because of their easy-to-generate 3D models, powerful solvers, excellent meshing capabilities and important aerospace certification. The 3D CAD model generated has the main body of the AARV and its propulsion system also. This simulation focuses specifically on fidelity at the geometric level, to capture the important aerodynamic characteristics and to enable accurate simulation results. AARV dimensions depend on the research goals and ergonomic needs.

Normal sitting height is estimated to be between 1.0 and 1.2 meters, and shoulder breadth is estimated to be 0.5-0.6 meters per person based on the average anthropometric parameters of the human body. Depending on the size of the boat, the required leg room is between 0.7 and 0.9 meters per person; an optimum cabin width is approximately 1.2 to 1.4 meters. Taking into account the seating positions of the pilot and co-pilot, the total length of the cabin is expected to be 1.5 to 2.0 m. (Refer Table 1).

Table 1. Anthropometric, Cabin, and Structural Design Dimensions of the Proposed Autonomous Aerial Rescue Vehicle (AARV)

Sr. No:	Category	Parameter	Value Range/ Dimensions (m)
1	Human Anthropometry	Seated Height	1.000 to 1.200
		Shoulder Width (per occupant)	0.500 to 0.600
		Legroom (per occupant)	0.700 to 0.900
2	Cabin Requirements	Minimum Cabin Width	1.200 to 1.400
		Total Cabin Length (Two Occupants)	1.500 to 2.000
3	eVTOL Design Considerations	Overall Length	3.500 to 5.000
		Overall Width (excluding rotors)	1.500 to 2.100
		Overall Height	1.500 to 2.500
4	Proposed AARV Dimensions	Fuselage Length	5.000
		Fuselage Width	1.850
		Fuselage Height	1.850

The airframe design for the Autonomous Airborne Rescue Vehicle (AARV) is designed to accommodate a variety of essential components, such as the cabin which contains the seating area and avionics systems, the power supply system (including the location of the Li-ion batteries), the propulsion mechanism (including rotors for a vertical takeoff and landing (VTOL) configuration), the landing gear, and the emergency egress. A conventional AARV with eVTOL type design configuration, typically exhibits an overall length (L) of approximately 3.5 to 5.0 meters, an overall width (W) (excluding rotors) that varies from 1.5 to 2.1 meters, and a height (H) that spans between 1.5 and 2.5 meters (Refer Fig. 2).

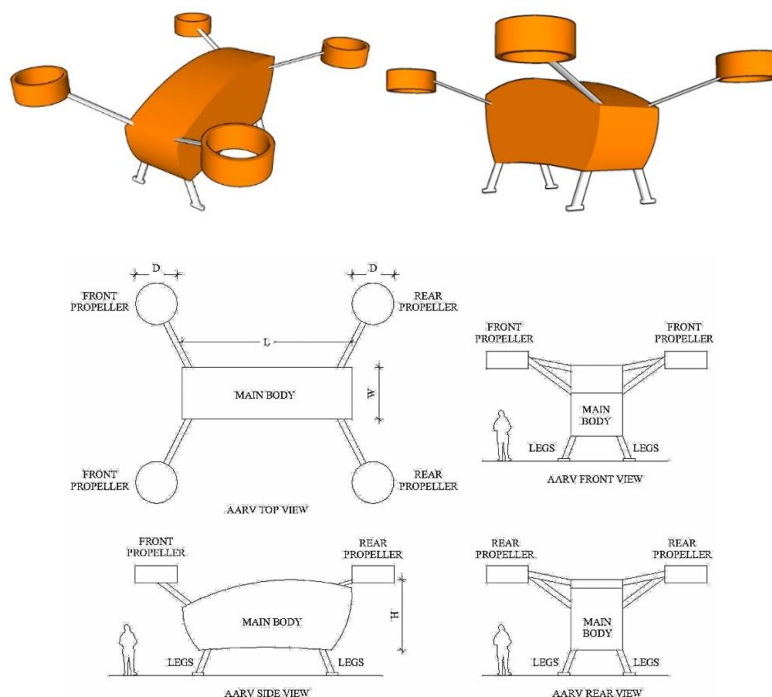


Fig. 2. Autonomous Aerial Rescue Vehicle (AARV) diagram and views (Source: Created by Author¹).

In consideration of these design parameters, the AARV's fuselage dimensions are 5.0 meters long, 1.85 meters wide, and 2.1 meters high.

Weight Calculation for AARV: The weight of AARV for carrying two patients for 15 km at speed of 60 km/hr was calculated assuming that:

Structure weight (airframe, landing gear, supports) (W):	≈ 300 kg
Battery weight (Li-ion, sufficient for 15 km flight):	~ 200 kg
Motors & Propellers weight:	~ 100 kg
Electronics & avionics weight:	~ 50 kg
Passengers (2 patients + minimal crew weight):	~ 150 kg (75 kg per patient)
Payload (medical equipment, first-aid, etc.):	~ 50 kg

$$W_{total} = 300 + 200 + 100 + 50 + 150 + 50 = 850 \text{ kg}$$

So, the total weight is approximately 850 kg.

This AARV 3D CAD model was subsequently loaded into the ANSYS Workbench program. The Fluid Flow (Fluent) tool was used to analyze the AARV model. This geometry was imported into Fluid Flow (Fluent), and DesignModeler Geometry was used to construct the AARV model. The Air Flow Domain (Enclosure) was constructed in DesignModeler geometry to surround the main body of the AARV.

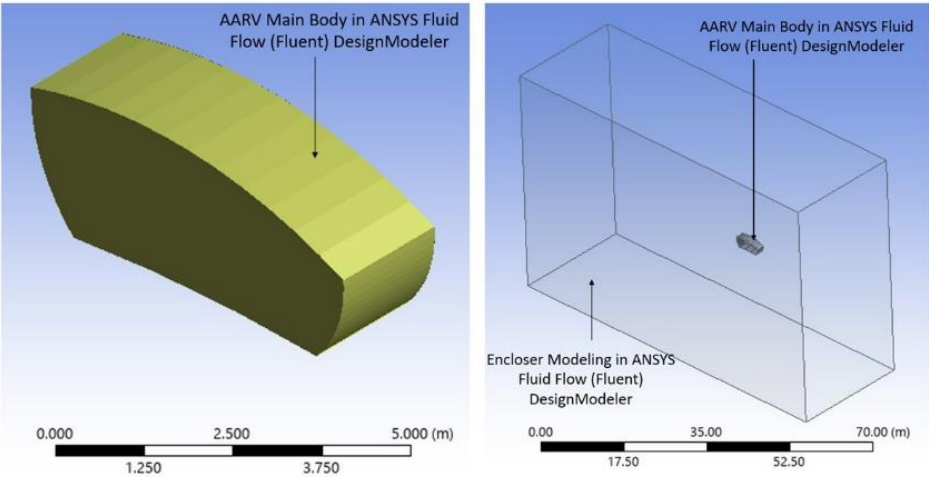


Fig. 3. Autonomous Aerial Rescue Vehicle (AARV) diagrams in ANSYS Fluid Flow (FLUENT) flow (Main body and Enclosure) (Source: Created by Author¹).

The computational domain of this simulation was built utilizing computational fluid dynamics (CFD) best practices to provide accurate and trustworthy results (Refer Fig. 3) [17]. Before proceeding with the geometry, the intake boundary was positioned three to five times the object's usual length to allow for proper flow expansion. To prevent artificial flow constraints and capture wake effects, the outflow border was positioned 10 to 15 times the average downstream length. The lateral limits were also placed at least three to five times the typical length from the item in order to prevent the flow's natural growth from being impeded [18]. To decrease numerical mistakes caused by boundary interactions, the vertical boundaries were all placed within this range, regardless of whether they represented a symmetry plane or a free-stream condition. The enclosure dimensions were chosen to eliminate boundary-induced errors and increase the precision of CFD simulations (Refer Fig. 4). Minor alterations were required, however, to meet the simulation's specific requirements, such as wind tunnel limits, external aerodynamics, and internal flow conditions.

Sketching Modeling	
Details View	
Cushion	Non-Uniform
☐ FD1, Cushion +X value (>0)	50 m
☐ FD2, Cushion +Y value (>0)	25 m
☐ FD3, Cushion +Z value (>0)	12.5 m
☐ FD4, Cushion -X value (>0)	25 m
☐ FD5, Cushion -Y value (>0)	25 m
☐ FD6, Cushion -Z value (>0)	12.5 m
Target Bodies	All Bodies

Fig. 4. ANSYS Simulation's computational domain dimensions (Source: Created by Author¹).

3.2. Mesh Generation:

High-fidelity mesh creation was used to investigate complex aerodynamic processes such as boundary layer development, flow dissociation, and wake production. To attain the best balance of precision and computational efficacy, a hybrid methodology was used, combining structured and unstructured mesh methods. The detailed mesh refinement was used in areas where high gradient flow was anticipated, such as at the leading and trailing edges, propeller blades, and areas where flow separation was expected. Viscous effects have been captured in the boundary layer meshes generated by using inflation layers which has yielded accurate estimates of drag and lift coefficient. Then, the mesh independence tests results were obtained for the simulation results, so as to ensure that the different mesh sizes do not impact the simulation results. The topologies of this mesh were then simulated as well as possible, and checked against known aerodynamic criteria for confidence in the simulation system. For the accurate study of AARV from the aerodynamic point of view, it is essential to carry out a methodical approach, which involves meshing. In two dimensions, quadrilaterals were chosen and in 3D, the elements were hexahedrals to increase accuracy and stability.

Using 10 to 15 inflation layers and a regulated growth ratio of less than 1.2 to provide a smooth transition, the starting cell height was set to maintain a y^+ value of less than 1 in order to determine an appropriate boundary layer resolution. To get precise resolution of the fuselage surface, a minimum cell dimension of 0.01 m is maintained [14].

The computational domain was set up to capture relevant flow physics in an efficient manner. While the lateral dimension is set at five times the fuselage length to guarantee adequate lateral resolution, it extends at least 10 chord lengths upstream to promote flow development and 20 chord lengths downstream to precisely resolve wake phenomena. While a coarser mesh is used in the far field to improve computing efficiency, the mesh refinement approach ensures a dense mesh close to the AARV for a complex boundary layer resolution (Refer Fig. 5). To prevent sudden changes that might negatively impact accuracy, a smooth transition in element size is maintained.

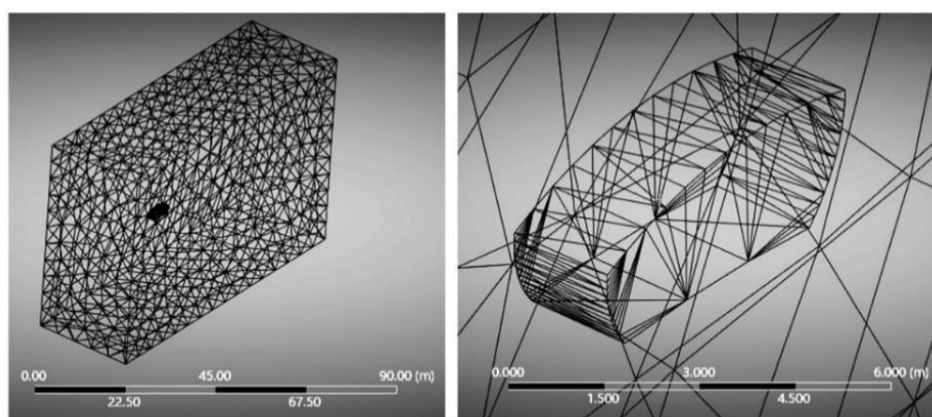


Fig. 5. High-fidelity mesh generation for Enclosure and Main Body
(Source: Created by Author¹).

The aspect ratio is limited to less than 5 in order to maintain the integrity of the element's shape, and skewness is controlled to stay below 0.85 in order to prevent numerical instabilities. The convergence and stability of the solution are further supported by enough orthogonality and

seamless transitions. This meshing approach is able to create a high fidelity computational grid while still keeping the cost of computing within reasonable bounds, ensuring the correct computational fluid dynamics (CFD) analysis. The methodology is reliable since it uses structured meshing, fine grained near wall resolution and logical size of domain to provide aerodynamic predictions of AARV.

3.3. CFD Setup for Simulation Framework:

The air flow in the simulation is kept low, incompressible and mostly laminar or transitional for an autonomous aerial rescue vehicle (AARV) operating at sea level altitude with a speed of Mach 0.05 (17.15 m/s). The following CFD setup was configured to ensure the correct aerodynamic performance of the AARV form is simulated.

A numerical simulation of incompressible flow is performed to ensure the stability and the accuracy of the numerical simulation. The SIMPLE method is used for the coupling of pressure and velocity. Depending on the aerodynamic study being conducted, a steady-state or transient approach might be used [16]. In the cruising condition, the flow parameter is in “steady state” which is easy for convergence to be effective, and a steady state simulation is performed. However, a transient simulation is necessary in order to capture the temporal variation of the flow in these situations where the aerodynamics is not stable, such as response to gusts or flow separation phenomena.

ANSYS Fluent was used for the analytical study as it is a pressure based incompressible flow solver. This solution is well suited for low speed aerodynamic situations and is well converged. The simulation uses the ANSYS Fluent software, which is a powerful simulation tool with robust meshing and solution features that are used to ensure consistent and high fidelity simulation results for aerodynamic performance evaluation.

3.3.1. Governing Equation:

The fundamental governing equations for fluid dynamics in Computational Fluid Dynamics (CFD) are written based on fundamentals of physics that describe the dynamics of the fluid motion. The governing equations are the Navier-Stokes equations and the continuity equation and energy equation.

- Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

- For steady, incompressible flow ($\nabla \cdot \mathbf{u} = 0$)

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

- Navier-Stokes Momentum Equations:

$$\rho \left(u \frac{du}{dx} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = - \frac{\partial P}{\partial x} + \mu \nabla^2 u$$

where:

u, v, w - these are velocity components.

μ it's a dynamic viscosity

P is a pressure.

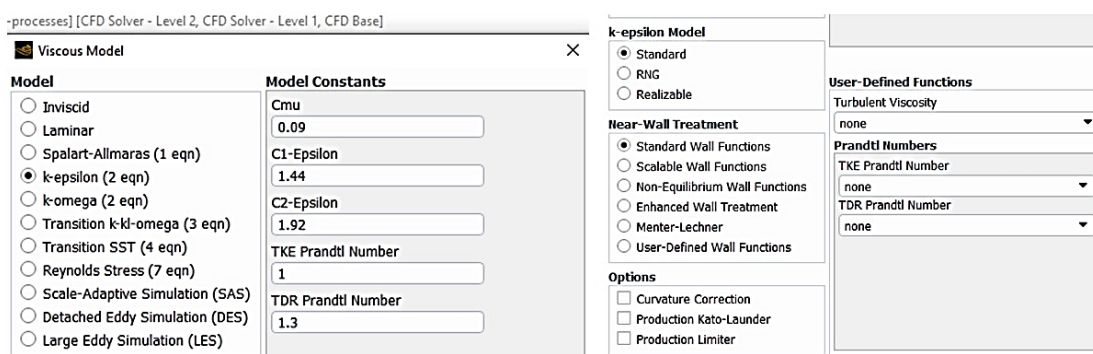
- Energy Equation (Negligible for Low-Speed Flow):

Since $M=0.05M$, thermal effects is a minimal or $T \approx T_0$, so that we can ignore this equation.

3.3.2. Boundary Conditions:

The computational fluid dynamics (CFD) simulation starts with a velocity inlet condition, where the velocity of the freestream is measured at 17.15 m/s and the turbulence intensity is 0.5%, which is a low turbulence environment condition. The fluid has a density of 1.225 kg/m³ and dynamic viscosity of 1.79×10^{-5} Pa·s. A pressure boundary condition is established at the outlet, with a predefined pressure of 98.95 kPa. The AARV's surface is depicted as a no-slip wall with an adiabatic condition to ignore heat transfer effects. If an external domain is included, the far-field boundary is defined using freestream pressure conditions of 1.225 kg/m³ and 98.95 kPa.

The Reynolds number determines the turbulence model used. For laminar flow ($Re < 5 \times 10^5$), the direct laminar model is used. In transitional flow regimes, the $k-\omega$ SST model is used to ensure accurate boundary layer forecasts. To provide reliable findings for totally turbulent flow, the Spalart-Allmaras or $k-\epsilon$ models are commonly used. The numerical discretization approach uses second-order methods for pressure, momentum, and turbulence. Convergence is achieved by maintaining residuals below 10^{-5} for continuity and momentum, and continuously monitoring lift and drag forces to keep variations under 1% over 100 iterations. Transient simulations use a time step of 0.001 seconds, with a total simulation period ranging from 5 to 10 second (Refer Fig. 6).



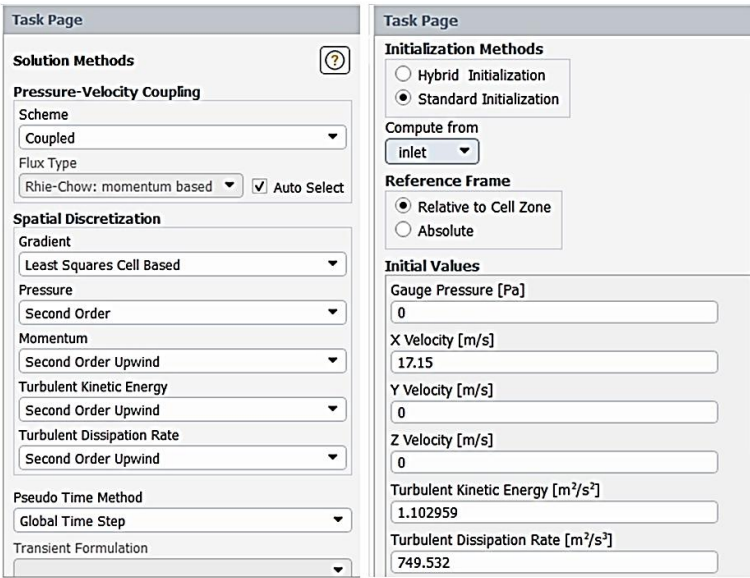


Fig. 6. ANSYS CFD SOLVER settings and Solution Methods settings (Source: Created by Author¹).

4. Result and Discussion:

The following table summarizes the aerodynamic analysis results received from the CFD simulation reports:

Table 2. Showing values of CFD simulation report of AARV using ANSYS FLUENT.

Parameter	Symbol	Value	Unit
Drag Force	Fd	748.43	N
Air Density	ρ	1.225	kg/m ³
Velocity	V	17.15	m/s
Reference Area	A	3.09	m ²
Drag Coefficient	Cd	1.3445	-
Lift Force	Fl	9.95	N
Lift Coefficient	Cl	0.01787	-
Lift to Drag Ratio	L/D	0.0133	-

The aerodynamic parameters summarized in Table. 2 show that drag reduction remains an important design priority. The rather high drag coefficient ($C_d = 1.3445$) suggests that fine-tuning the fuselage shapes and optimizing the overall geometry might greatly enhance aerodynamic performance and energy economy while flying. The velocity contours and streamline patterns produced from the CFD simulation (Refer Fig.7) show the aerodynamic behavior of the proposed AARV design. The results indicate that the lift to drag (L/D) ratio is rather low, implying inferior aerodynamic efficiency. Nonetheless, because the vehicle depends on propeller-generated power rather than conventional wings for lift, the lift coefficient (C_l) is not the most important predictor of flight stability.

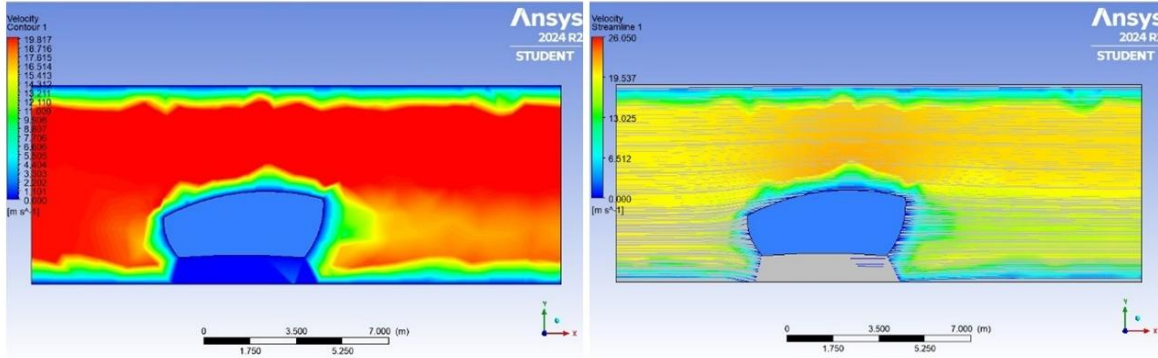


Fig. 7. Velocity Contours and Velocity Streamline (Source: Created by Author¹).

4.1. Propeller Analysis:

For propeller design, we calculated the thrust required to lift the AARV.

Total Thrust Requirement:

The required total thrust to lift the vehicle is given by:

$$T_{total} = m \times g$$

where

weight of AARV (m) = 850 kg

$g = 9.81 \text{ m/s}^2$,

Thus, the computed total thrust is: $T_{total} = 8338.5 \text{ N}$.

4.2. Thrust Per Rotor:

For an 8-rotor configuration:

$$T_{perrotor} = T_{total}/8 = 8338.5/8 = 1042.31 \text{ N}.$$

Each rotor must generate approximately 1.04 kN of thrust.

4.3. Power Requirements:

Using:

$$P = (T \times V) / \text{efficiency}$$

Assuming 70% efficiency, the computed values are:

Power Per Rotor = 29.78 kW

Total Power (8 Rotors) = 238.24 kW.

5. Efficiency Optimization:

Several optimizations may be used to increase energy efficiency and minimize power consumption. Increase the propeller diameter from 2.2-2.5 meters to 2.6-2.8 meters to improve thrust efficiency, while a little lower pitch-to-diameter ratio (8-9 inches) enhances hover performance. Using low-RPM, high-torque motors increases economy, while streamlining the vehicle minimizes its high drag coefficient ($C_d = 1.3445$). Other improvements include the redesign of propellers, which includes incorporating variable-pitch propeller mechanisms for best

hover and cruise performance, as well as varying the number of blades and aerofoil shape, and using high-strength and lightweight composite materials to reduce overall aircraft weight. Further, high energy density batteries, good motor control and power distribution and dynamic pitch adjustment will enhance performance. These enhancements can result in significant energy efficiency and overall performance improvements for the system.

6. Future Scope:

The research on Autonomous Aerial Rescue Vehicles (AARVs) to improve the Disaster Response System has raised a number of interesting research questions for the future. Hence, there is a need for more research in other industries to optimise and extend the use of AARVs in the context of emergency scenarios, with the advancement of technology. More advanced Computational Fluid Dynamics (CFD) models are further developed for use in future research projects: real-time turbulence simulation and multi-phase flow evaluation, which should further enhance the aerodynamic efficiency and stability in extreme climatic conditions. AI can greatly enhance the design and versatility of AARVs through optimization using CFD [50]. The autonomous navigation and decision making algorithms based on artificial intelligence could be further optimized for the use of a AARV in the highly dynamic and unexpected crisis scenario [51]. Additionally, models could significantly enhance the predictive maintenance and defect detection methods, guaranteeing the reliability of operation of AARV systems [52], [53].

Further research may be conducted on hybrid power or alternative energy power, such as fuel cells, power systems running on hydrogen or solar power, to further extend the life and sustainability of the operation. New battery technology such as solid-state batteries and wireless charging has the promise of greatly extending mission duration [54]. For a two-person crew, further research into seating arrangements, ingress/egress, and other structural efficiencies may lead to a more comfortable and safe seating layout and ingress/egress for rescuers and victims. Use of lightweight but high strength composite material can be explored for better payload efficiency [55, 56]. Research on the AAM system in the densely populated metropolitan areas is essential for real-world application. Working with the regulatory bodies will facilitate the establishment of uniform operational procedures, airspace integration regulation and security measures for AARV implementation in urban and border areas [36].

Future research could consider the use of numerous Autonomous Aerial Recovery Vehicles (AARVs) to help establish an organized disaster relief system. It could also significantly enhance the coverage efficiency, search and rescue, and coordinated response strategies in disaster situations [57], [58] using swarm intelligence. Future work could be dedicated to developing a more intuitive control interface for the operators that could include systems such as Augmented Reality (AR) pilot assistance, or Brain-Computer Interface (BCI) systems. The development of semi autonomous or remotely piloted operational modes may also contribute to improve mission flexibility. In the field, widespread testing of AARVs in earthquake, flood and conflict zones will be required to determine the operational effectiveness and viability of AARVs. Pilot projects are created together with emergency response institutions to speed up the transition from theory to practice. By looking at these potential research fields, the AARVs could be adapted as a part of the current disaster response systems, enhancing the speed, efficiency and effectiveness of life saving operations in both urban and remote areas.

7. Conclusion:

The study results have shown that the use of Computational Fluid Dynamics (CFD) in the design and performance of Autonomous Aerial Rescue Vehicle (AARV) is very useful for the application in urban Emergency Response scenarios. Through the use of CFD techniques, we thoroughly evaluated and enhanced the aerodynamic properties of AARVs, leading to greater stability, manoeuvrability and energy economy. We also found that the careful redesign of the aerodynamics and power plant of the AARVs makes them more effective in the actual practical and relevant applications of catastrophe and emergency.

In the light of the study, it is important to use the most up to date simulation tools and optimization techniques in the design process. The CFD analysis can then be performed to make very accurate changes to important parameters like drag reduction, lift augmentation, or energy use – leading to improved flight dynamics. In addition, the study offers valuable information on the influence of urban environmental factors on the performance of AARV, highlighting the need for flexible and strong airborne rescue systems.

Future study may look at improving AI-based computational fluid dynamics (CFD) modelling, instantaneous aerodynamic adjustments, and integrated propulsion systems to improve the dependability and responsiveness of autonomous aerial rescue vehicles (AARVs). Also, the need to develop prototypes to test in the real world will demand empirical evidence such evidence will be crucial when it comes to implementing the theory in real prototypes.

In summary, CFD plays an important role in advancing AARVs in the field of developing future autonomous aerial rescue systems. As AARVs develop and learn to utilize the newest in technological advancements, they can be better and safer at responding to emergencies and may revolutionize how cities respond in the future.

8. Abbreviations:

AARV:	Autonomous Aerial Rescue Vehicle
AI:	Artificial Intelligence
AR:	Augmented Reality
BCI:	Brain-Computer Interface
CFD:	Computational Fluid Dynamics

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