ISSN 2616-5767 Vol.7, Issue 4: 136-143, DOI: 10.25236/AJETS.2024.070420

Design and Simulation of Foldable Wing eVTOL UAV

Yixu Chu[1,a,#], Junying Lin[2,b,#], Kun Li[3,c,#]

[1]*Wuchang Univeisity of Technology, Wuhan, 430223, China*
[2]*Guangdong University of Technology, Guangzhou, 510006, China*
[3]*Beijing University of Financial Technology, Beijing, 101118, China*
[a]*1250370785@qq.com,* [b]*1076651785@qq.com,* [c]*1795711961@qq.com*
[#]*Co-first author*

Abstract: *Urban Air Mobility (UAM) has garnered significant global attention due to its potential to revolutionize transportation. The utilization of Electric Vertical Take-Off and Landing (eVTOL) vehicles in urban areas offers a promising solution for alleviating ground-level traffic congestion. This paper focuses on the design and study of a manned eVTOL with foldable wings, aiming to address the space limitation problem that arises in daily use scenarios. By integrating collapsible wings into the design, the eVTOL can significantly mitigate the constraints imposed by spatial and dimensional limitations, thereby enhancing its adaptability to existing transportation infrastructure. The mechanism design of these foldable wings is crucial for ensuring efficient operation and maneuverability. Through meticulous analysis and simulation, this paper examines various factors such as force distribution, center of mass positioning, and overall performance. Utilizing software like SolidWorks enables seamless integration of essential components like lifting mechanisms, retractable wings, and propellers into the vehicle's trunk based on a pickup truck model. To validate the feasibility and performance of this designed eVTOL with foldable wings, simulation analysis is conducted using ADAMS simulation software. This allows comprehensive testing under different scenarios while obtaining valuable data curves that provide insights into its capabilities. The findings from this research contribute towards advancing UAM technology by addressing practical challenges associated with space limitations in urban environments. The integration of foldable wing technology not only enhances operational efficiency but also opens up new possibilities for aerial transportation systems in densely populated areas. In conclusion, this paper presents an innovative approach towards developing a manned electric VTOL aircraft capable of efficiently navigating three-dimensional airspace while mitigating ground-level traffic congestion.*

Keywords: *autonomous eVTOL; electric aircraft; UAV; UAM; structure design; folding wing*

1. Introduction

EVTOLs, or electric Vertical Takeoff and Landing vehicles, are aircraft that are driven by electric propulsion systems and capable of vertical takeoffs and landings[1]. They have gained significant interest and attention in recent years as potential solutions for urban air mobility(UAM) and advanced transportation[2]. As a new type of UAV technology, electric vertical take-off and landing Unmanned Aerial Vehicle (eVTOL UAV) has the advantages of vertical take-off and landing, vertical flight and portability, which is widely used in military, civil and commercial fields[3]. However, the existing eVTOL Uavs still have some limitations in terms of flight efficiency and portability[4]. To solve this problem, a foldable wing design is proposed in this paper, which aims to improve the flight performance and portability of the eVTOL UAV.

Flying cars, which embody the concept of dual-mode transportation, are designed for both ground travel and flight[5]. They can operate as traditional automobiles on roads and, when necessary, take off, fly, and land as aircraft[6]. This emerging class of mobility solutions aims to provide a versatile and integrated approach to transportation by navigating urban landscapes and bypassing traffic congestion through switchable aerial-ground operation[7].A key focus in flying car research should be the development of hybrid systems that can seamlessly transition between ground and air travel[8].This involves prioritizing advancements in adaptive control systems, foldable wing/rotor technology, and modular designs[7]. Furthermore, investigations should extend to integrating advanced driver-assistance systems adapted for both road and aerial navigation to enhance safety and autonomy[9].

ISSN 2616-5767 Vol.7, Issue 4: 136-143, DOI: 10.25236/AJETS.2024.070420

This paper makes a design for the cooperation between the folding wing and the car, and uses simulation software to analyze the model.

There are three main technical challenges in designing a foldable wing evtol: the utilization of the internal space of the vehicle and its exterior design, the mechanical principle design and location selection of the lifting mechanism and the telescopic mechanism, and whether the vehicle centroid problem affects its normal operation[10].

The folding wing can reduce the lateral size of the aircraft to reduce the space occupied by the aircraft in transportation, storage, and utilization[11].

For the use of car interior space and appearance design. The car not only needs to meet the needs of normal travel in the city, but also needs to meet the needs of vertical take-off and landing[12],so not only the size of the body should be analyzed, but also the internal space for the storage of wings and other configurations has further requirements. Finally, a pickup truck with a large internal passenger space and a large space trunk was selected as the basis for transformation. Although the position of the lifting mechanism and the telescopic mechanism is chosen to be the rear of the center of gravity[13], due to the distribution of large weight parts such as the battery of the electric vehicle[14], it can still maintain the force balance and make the car run normally.

2. SolidWorks Flying Car

There is a schematic of the model flying car in action on land, as shown in Figure 1.

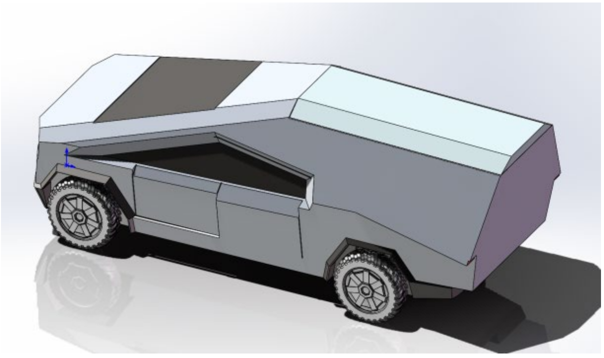

Figure 1: Folding wing folding configuration.

In the form folding wing folding configuration, the overall appearance of flying cars is similar to that of traditional cars, but with unique characteristics. The body lines are smooth to reduce air resistance. The wheel design is solid and has good grip to adapt to all road conditions. The body adoptshigh-strengthaluminum alloy material to ensure structural strength and reduce weight. The interior is equipped with comfortable seats, an advanced dashboard and operating system. The headlights on the front end of the vehicle are sharp, not only providing good lighting, but also adding a sense of technology. When driving on land, it relies on the rotation of the wheel to drive, driving smoothly, flexible control, and can freely shuttle through the city streets and highways.

There is a schematic of the model flying car model when the wings are deployed to run. As shown in Figure 2.

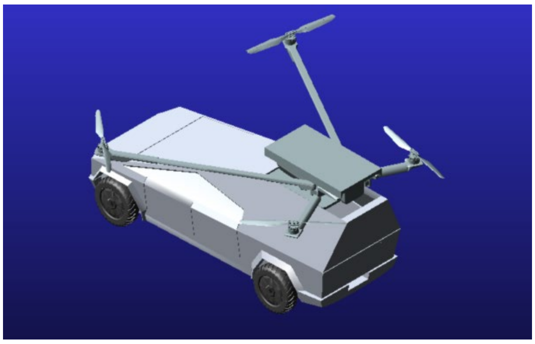

Figure 2: Flight pattern.

ISSN 2616-5767 Vol.7, Issue 4: 136-143, DOI: 10.25236/AJETS.2024.070420

When the flying car switches to flight mode, it shows amazing changes. The wheels fold up and the wings spread slowly from the sides of the car, like a giant bird ready to soar. The wings have a smooth, flat surface and an advanced aerodynamic design that provides enough lift during flight. The propeller at the back of the car kicks in, producing a powerful thrust. The tail fin on the top of the vehicle adjusts the Angle to help maintain flight stability and direction control. In the cockpit of the flying car, various flight instruments and navigation systems light up to provide the driver with accurate flight information. In flight, it is strong, through the clouds, quickly and smoothly toward the destination.

Shown below are the top view of the flying car, the front view and the side view (Figure 3).

Section 1: Top view

From the above observation of the flying car, the general outline of the car body is rectangular, the front of the car is mostly sloping lines, the rear of the car is straight lines, the propeller and lifting platform are distributed in the rear of the car, the top window can be opened to expand the operation of the flight mode.

Section 2: Front view

From the front of the flying car, the front of the car is a symmetrical pentagon, the overall line trend is straight, many twists and bends, the lights are pentagon, located on both sides of the front, the body length is 3.67 meters, the width of the car is 1.85 meters

The height of the car is 1.443 meters

Section 3: Side view

From the side view of the flying car, the body length is 3.67 meters, the ratio of the front, the body body and the rear is 1:3:2.5, and the door handle design is hidden, which not only looks more concise and beautiful, but also reduces the wind resistance and improves the aerodynamic performance of the vehicle. From the front to the rear, the height gradually increases and tends to flatten.

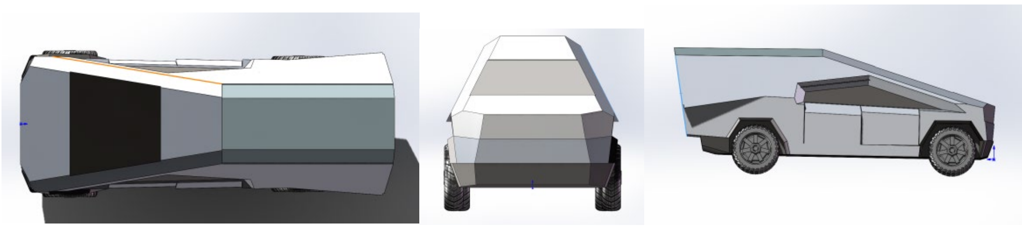

Figure 3: Three-view drawing.

1) Overall structure design

• The model shows the overall shape and dimensions of the flying car, including components such as the body, wings, propellers or lift platforms. As shown in Figure 4.

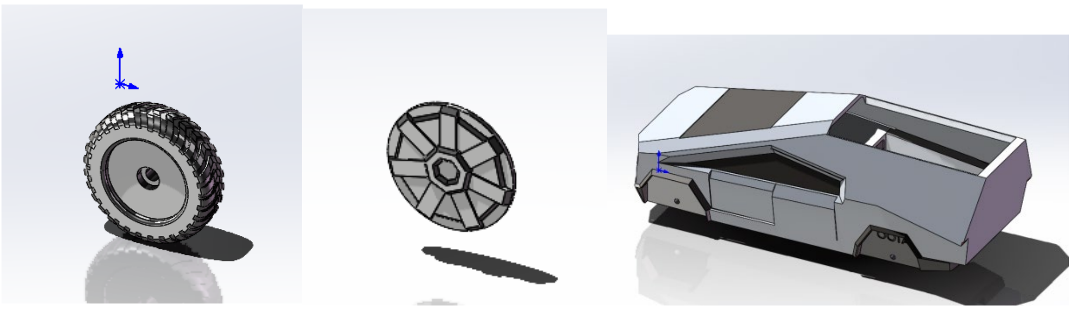

Figure 4: Schematic diagram of body structure and tire.

2) Power system design

• Detailed design of the mounting position and connection of the engine, motor or other power source. As shown in Figure 5.

ISSN 2616-5767 Vol.7, Issue 4: 136-143, DOI: 10.25236/AJETS.2024.070420

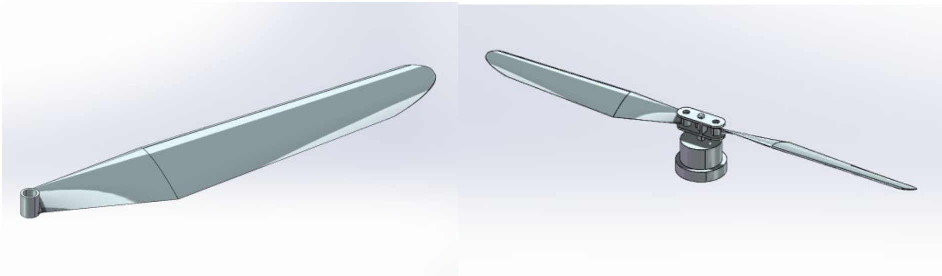

Figure 5: Schematic diagram of the propeller structure.

3) Flight mechanism design

• Draw the shape of the wing, the mechanism for adjusting the Angle, and the control surfaces (e.g., ailerons, elevators, rudder).

• Simulate the working principle and airflow effects of a propeller or jet engine. As shown in Figure 6.

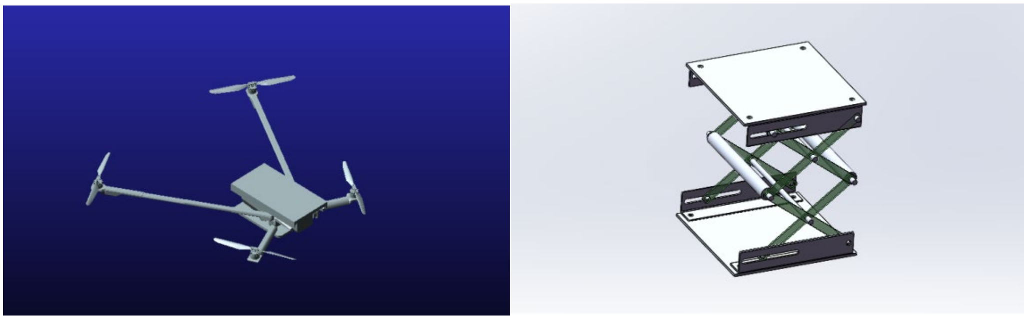

Figure 6: Schematic diagram of lifting mechanism and folding rotor structure.

4) Landing gear design

• Design retractable landing gear structures and demonstrate models in retractable and retractable states.

• Shock absorption and support mechanisms for landing gear.

5) Connection mode:

In the connection mode, because it involves a high-strength mechanical structure connection to ensure stability and safety in both flight and driving modes. Therefore, the bolted connection is easy to assemble and disassemble, and easy to maintain and replace parts. At the same time, riveting can provide better fatigue resistance in some cases. As shown in Figure 7.

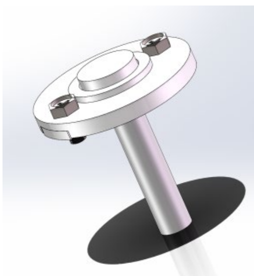

Figure 7: Schematic diagram of the bolt structure.

6) Material selection and characteristics

Aluminum body, rubber tires. Body aluminum alloy characteristics: Lightweight: The density of aluminum alloy is relatively small, which can significantly reduce the weight of the body, thereby improving fuel efficiency or increasing the driving range of electric vehicles.Rubber tire features:

Good elasticity: It can effectively absorb the vibration and impact of the road surface to provide a comfortable driving experience.

ISSN 2616-5767 Vol.7, Issue 4: 136-143, DOI: 10.25236/AJETS.2024.070420

3. Simulation of two forms of Foldable Wing eVTOL UAV based on ADAMS

3.1. Dynamic simulation preparation

Import the 3D model established in Solidworks into Adams View for dynamic simulation. To solve the dynamic analysis problem, only some key components are considered when establishing virtual prototype in Adams. This simplification helps to improve simulation efficiency, reduce computational complexity, and focus on the components that have the greatest impact on motion analysis. The simplified car shape model is shown in Figure 1. In order to prevent the graphics distortion and data failure that may be caused by Adams and SolidWorks in the process of model transfer, the 3D model established in SolidWorks is first saved as x_t format file, and then the x_t format file is imported into Adams. In order to simulate the most realistic situation, gravity and the ground are set in the adams simulation, and the contact between the tire and the ground is created, the static friction coefficient is set to 0.3, and the dynamic friction coefficient is set to 0.1 Before simulation, in order to avoid the penetration between the mutual motion contact members, it is necessary to define the moving part contact pair. As shown in Table 1.

Table 1: Motion constraint.

Part 1	Part 2	Kinematic pair
car body	wheel	revolute pair
rotor	car body	revolute pair
Lifting platform	car body	sliding pair
car body	ground	sliding pair

The simulation conditions are shown in Table 2.

Table 2: Simulation conditions.

Parameters	values
Step length	0.1
end time	10

3.2. Analysis of dynamic simulation results

3.2.1. Simulation and analysis of vehicle form kinematics

In the straight-line walking dynamics simulation, the tire angular velocity was set to 400, 800 and 1200 degrees per second, respectively, and the relationship between speed and time, displacement and time under the three angular velocities were obtained. Through the analysis of the simulation experiment data under different tire angular speeds, it can be observed that the displacement and speed of vehicle in unit time show different changes with the increase of tire angular speed. These data are of great significance for the study of vehicle motion characteristics and the optimization of driving stability.

The car's travel speed at three different tire angular speeds is approximately 550mm/s, 1100mm/s and 1650mm/s, and their displacements are 5000mm, 10000mm and 15000mm respectively. The data curves of the simulation results obtained under the three speeds. As shown in Figure 8 and 9.

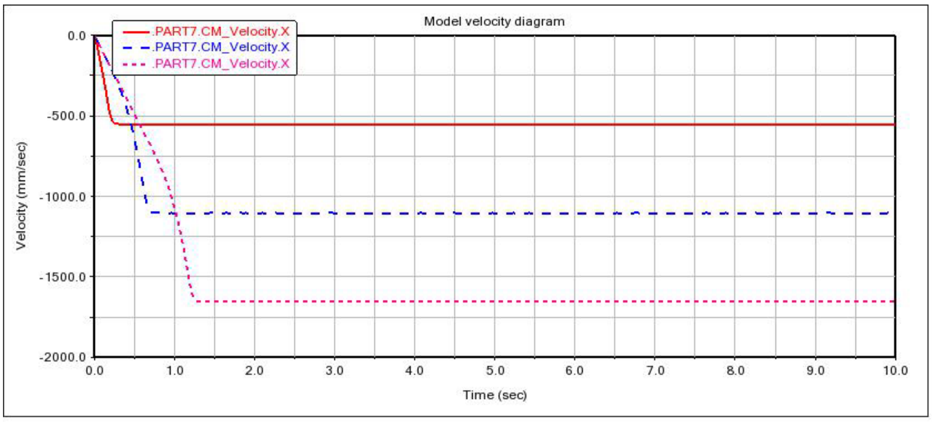

Figure 8: Relationship between linear motion speed and time in vehicle form.

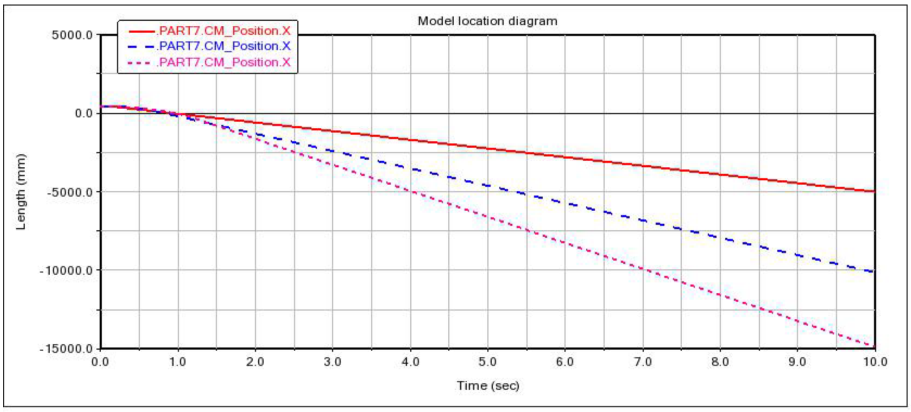

Figure 9: Relationship between linear motion displacement and time in vehicle form.

In the model vehicle shape curve kinematics simulation, the left turn and right turn are simulated. In the left turn simulation, the angular speed of the two left wheels of the car is set to 400 degrees per second, and the angular speed of the two right wheels is set to 800 degrees per second. In right-turn simulation, the angular speed of the two right wheels of the car is first set to 400 degrees per second, and the angular speed of the two left wheels is set to 800 degrees per second, and the position figure of the car is obtained after post-processing (the horizontal axis is the displacement in the Z direction, and the vertical axis is the displacement in the X direction. The red solid curve is the left turn, and the blue virtual curve is the right turn).Simulation curve of left-right turning position of the car. As shown in Figure 10.

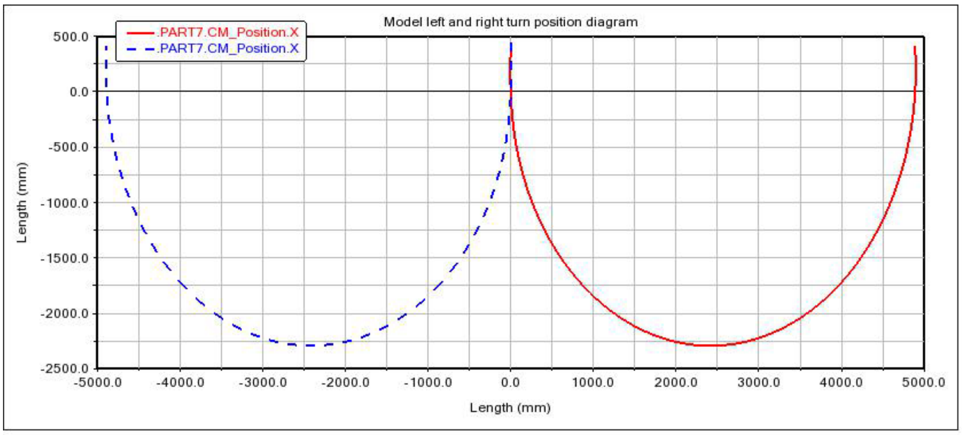

Figure 10: Model left and right turn position diagram.

3.2.2. Kinematics simulation and analysis of aircraft form

In the kinematic simulation of the aircraft form, in order to get closer to the flight condition in real life, three simulations are set up: ascending - hovering - landing in vertical direction, quadrilateral motion in vertical direction and quadrilateral motion in horizontal direction. These simulation models can help us better understand the motion characteristics of aircraft in different environments, and provide important references for the design of optimal control algorithms. By simulating the ascending, hovering and landing in the vertical direction, the stability and accuracy of the aircraft on the vertical axis can be deeply studied. For the vertical and horizontal quadrilateral motion, it is helpful to analyze the maneuvering performance of the aircraft in complex space and its corresponding control strategy.

To realize the ascending - hovering - landing of the aircraft model, it is necessary to first add a vertical upward motion pair in the body, so that the car rises 500mm in 2~3 seconds, and completes the air hovering in the following 3~5 seconds, and finally add a vertical downward motion pair to make the car land in the same place in 5~6 seconds. The relationship between the displacement and time of the aircraft in the Y-axis direction is shown in Figure 11.

ISSN 2616-5767 Vol.7, Issue 4: 136-143, DOI: 10.25236/AJETS.2024.070420

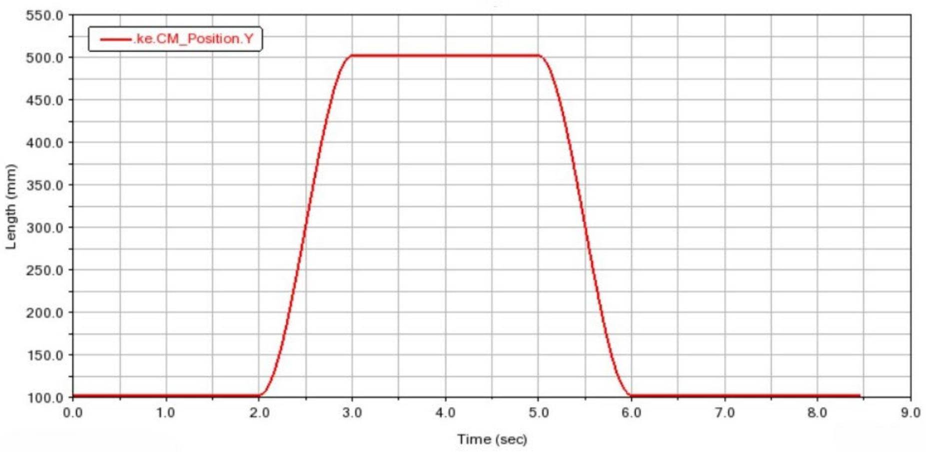

Figure 11: Model rise-hover-landing position diagram.

It is necessary to realize the quadrilateral movement of the model on the vertical plane, and to add motion pairs in the X and Y axes of the model, so that the model can realize forward - rise - backward - fall and finally return to the origin. The position diagram of the model in the Y-axis direction is shown in Figure 12.

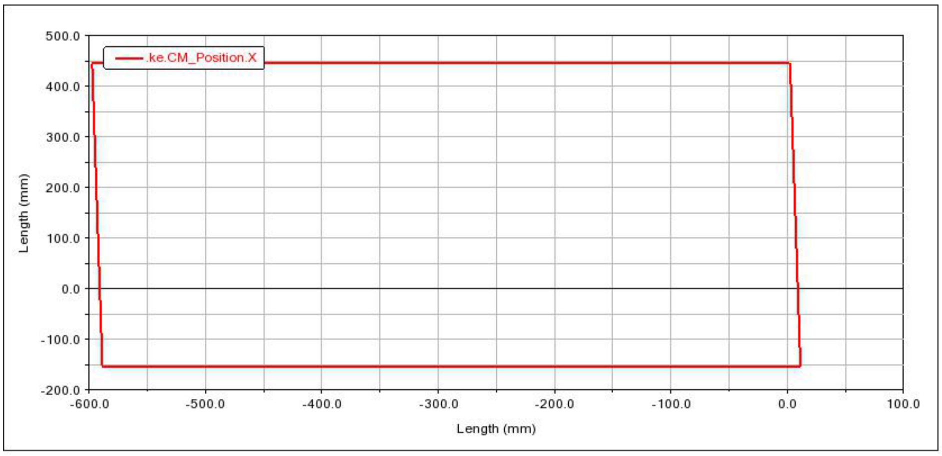

Figure 12: Quadrilateral motion of the model on the vertical plane.

It is necessary to realize the quadrilateral movement of the model on the horizontal plane, and to add motion pairs in the X and Z axes of the model, so that the model can realize forward - right translation - backward - left translation and finally return to the origin. The quadrilateral movement of the model on the X-axis plane is shown in Figure 13.

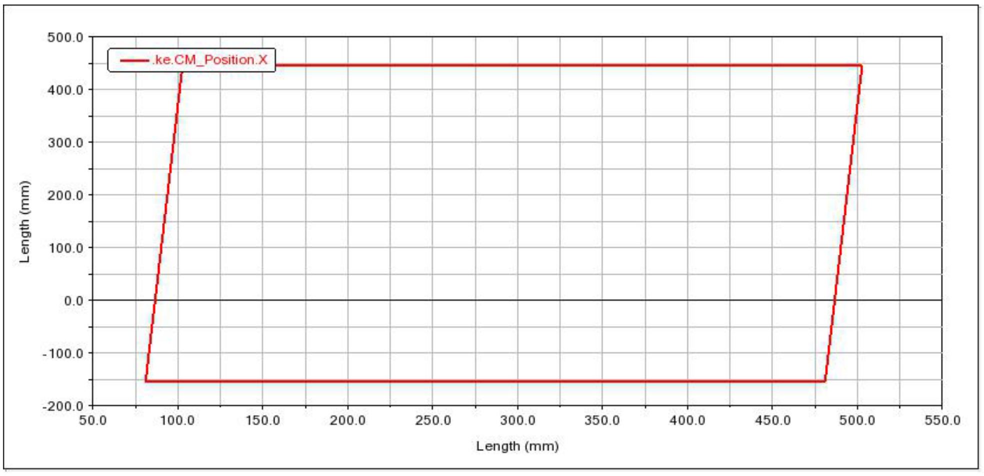

Figure 13: Quadrilateral movement of the model in the horizontal plane.

ISSN 2616-5767 Vol.7, Issue 4: 136-143, DOI: 10.25236/AJETS.2024.070420

4. Conclusions

Evtol will bring revolutionary and disruptive changes in several areas, including environmental protection, sustainable development, and artificial intelligence. These changes are intended to address the global challenge of traffic congestion. In this paper, considering the practical application of electric VTOL vehicle, a design scheme of electric VTOL vehicle with lifting folding mechanism and foldable wing is proposed. The objective is to weaken the impact in spatial constraints imposed on eVTOL vehicles by infrastructure tailored for traditional automobiles, such as parking spaces and garages. Therefore, in this paper, a VTOL EV model with a lifting and folding vertical mechanism is established, and the effectiveness of the foldable wing design is verified by simulation. Future work will focus on further optimizing the design of foldable wings to improve eVTOL flight performance and portability, thus advancing UAV technology.

References

[1] Raigoza K, Chadwick A, Kishore C. Electric Vertical Take-Off and Landing (eVTOL) Vehicle Reliability and Safety Analysis[C]//ASME International Mechanical Engineering Congress and Exposition. American Society of Mechanical Engineers, 2022, 86717: V009T14A036.

[2] Xu J, Yu J, Lu X, et al. Aerodynamic Performance and Numerical Analysis of the Coaxial Contra-Rotating Propeller Lift System in eVTOL Vehicles[J]. Mathematics, 2024, 12(7): 1056.

[3] Alsalem A, Zohdy M. A Review on Civil Applications of Vertical Take-Off and Landing Vehicles[C]//2023 IEEE Conference on Technologies for Sustainability (SusTech). IEEE, 2023: 130-137.

[4] Mohsan S A H, Othman N Q H, Li Y, et al. Unmanned aerial vehicles (UAVs): Practical aspects, applications, open challenges, security issues, and future trends[J]. Intelligent Service Robotics, 2023, 16(1): 109-137.

[5] Holmes B J, Durham M H, Tarry S E. Small aircraft transportation system concept and technologies [J]. Journal of Aircraft, 2004, 41(1): 26-35.

[6] Sochor J, Arby H, Karlsson I C M A, et al. A topological approach to Mobility as a Service: A proposed tool for understanding requirements and effects, and for aiding the integration of societal goals [J]. Research in Transportation Business & Management, 2018, 27: 3-14.

[7] Wei H, Lou B, Zhang Z, et al. Autonomous navigation for eVTOL: Review and future perspectives[J]. IEEE Transactions on Intelligent Vehicles, 2024.

[8] Ahmed S S, Hulme K F, Fountas G, et al. The flying car—challenges and strategies toward future adoption [J]. Frontiers in Built Environment, 2020, 6: 106.

[9] Piao J, McDonald M. Advanced driver assistance systems from autonomous to cooperative approach [J]. Transport reviews, 2008, 28(5): 659-684.

[10] Bravo Gutierrez B. Mechanical design and analysis of a portable crane unit[D]. Tampere University of technology, 2017.

[11] Kretov A, Tiniakov D. Evaluation of the mass and aerodynamic efficiency of a high aspect ratio wing for prospective passenger aircraft[J]. Aerospace, 2022, 9(9): 497.

[12] Wei L, Justin C Y, Briceno S I, et al. Door-to-door travel time comparative assessment for conventional transportation methods and short takeoff and landing on demand mobility concepts[C]//2018 Aviation Technology, Integration, and Operations Conference. 2018: 3055.

[13] De Simone M C, Veneziano S, Guida D. Design of a non-back-drivable screw jack mechanism for the hitch lifting arms of electric-powered tractors[C]//Actuators. MDPI, 2022, 11(12): 358.

[14] Manzetti S, Mariasiu F. Electric vehicle battery technologies: From present state to future systems [J]. Renewable and Sustainable Energy Reviews, 2015, 51: 1004-1012.