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Design and Simulation of a Tilt - Rotor Deformable Flying Car

Chengze Lyu[1,a,#], Minghao Li[1,b,#], Xinzhe Lyu[1,c,#], Tairui Wang[1,d,#], Zhixing Wang[1,e,#], Ziyan Zuo[1,f,#], Xiaoqing Zhu[2,*]

[1]*Beijing 21st Century School, Beijing, China*
[2] *School of Information Science and Technology, Beijing University of Technology, Beijing, China*
[a]*zacklcz@163.com*, [b]*18618366445@163.com*, [c]*18622320858@163.com*, [d]*16603528318@163.com*, [e]*ryanwangzhixing@163.com*, [f] *2197561194@qq.com*
**Corresponding author: alex.zhuxq@bjut.edu.cn*
[#]*Co-first author*

Abstract: *In order to solve variety traffic problems, a tilt rotor flying car is designed. For the prototypes, it adapted two tilt rotors, high-mounted folding wing, dual-vertical stabilizer. This helps the prototype possessed the ability of vertical take-off and landing, which means the car combined the advantages of a normal cars as well as a helicopter. The prototype has already been tested in variety of prospects, for example, the security and stability in the flying position; the long-duration of battery over pong distance and the high air and land mobility. The key or main advantage is that the prototype can drive faster than normal airplanes on the ground and fly at a speed surpassing the present cars. For the structure of our car, the most remarkable or significant point is that our blade, wings, stabilizers are all able to fold on or into the car in order to minimize the volume on the ground. With the help of energetic motors, the prototype is able to finish the transformation in just 125 seconds. What's more, the wheels of our prototypes each has its own steering mechanism which helps it to turn in a smaller radius. In order to give enough motion to take off or drive on the ground, we adapted two turbo prop with a spinning speed of 600 rotation per minutes as well as a engine with 800 horsepower. Then, with the help of Adams as well as Solidworks, the motion when it moves on the ground as well as in the air is simulated. Firstly, in the air our prototypes successfully finish the goal to fly a horizontal and vertical square. Secondly, the car went around a circle on the ground at a constant speed without any jolt, which shows its perfect stability in all time. In conclusion, the prototype of flying car successfully solved the problem in present days, but there are still lots of difficulties, like the charging time and the stability in bad weather.*

Keywords: *Tilt – Rotor, Flying Car, drone*

1. Introduction

1.1. Significance and Background of the Research

In recent years, the rapid pace of urbanization and worsening traffic congestion have made traditional land-based transportation increasingly inadequate for meeting the growing demand for efficient commuting. The emergence of flying cars has garnered considerable public attention as a novel transportation solution. By overcoming the constraints of ground transport, flying cars offer the dual capability of air and land travel, promising to greatly enhance travel efficiency and reduce urban traffic pressures.

In this context, the development of transformable flying cars that integrate tiltrotor and fixed-wing technologies is particularly noteworthy. These vehicles combine the vertical takeoff and landing (VTOL) capabilities of helicopters with the efficient cruising performance of fixed-wing aircraft, allowing for vertical takeoffs and landings within urban areas and switching to fixed-wing mode for long-distance travel. This integration improves both range and flight efficiency [1]. The significance of this innovative transportation mode extends across multiple dimensions. Socially, it not only enhances personal mobility but also profoundly influences urban planning, logistics, and emergency response. For example, in logistics, flying cars can expedite the delivery of urgent and high-demand goods, while in emergency situations, they can navigate through obstacles to save critical time. Technologically, the research and development of flying cars involve various cutting-edge technologies, fostering technological integration and innovation, and driving advancements in the tech industry [2].

Overall, the advent of flying cars represents a transformative shift in transportation, offering substantial benefits for both societal and technological progress.

1.2. Current Status around the World

In the field of deformable flying cars with tilt-rotor and fixed-wing fusion, there are many explorations at home and abroad, and some achievements have been made, but there are still many challenges.

The research on flying car in foreign countries started earlier and the technology is relatively mature. Bell of the United States is a leader in the application of tiltrotor technology. Its V-22 "Osprey" tilt-rotor aircraft has successfully applied tilt-rotor technology to large aircraft, demonstrated the advantages of tilting rotor in vertical take-off and landing and high-speed cruise. This technology provides an important reference for the design of deformable flying cars, and many flying car projects use the mechanical structure and control principle of its tilt-rotor to realize the switch between vertical take-off and landing and fixed-wing flight mode.

In addition, the German company Lilium is dedicated to the development of electric vertical take-off and landing (eVTOL) aircraft, the design of the Lilium Jet uses a distributed electric propulsion system and tilting ducted fan, to a certain extent, combined with the advantage of vertical take-off and landing and fixed wing flight. This design concept provides new ideas for the power system and wing layout of transformable flying cars, prompting researchers to explore more efficient and environmentally friendly flying car design schemes.

Although the domestic research in this field started a little later, it developed rapidly. Some universities and research institutions are actively engaged in relevant research. The research team of Beijing University of Aeronautics and Astronautics has carried out in-depth research on the dynamic characteristics and control methods of tilt-rotor aircraft[3] and in improving tilt rotor aircraft stability and handling has made certain achievements. Their research results provide theoretical support for the design of domestic deformable flying cars, and help to optimize the tilt-rotor system and flight control algorithm of flying cars.

However, research in this field at home and abroad still faces common challenges. At the technical level, the efficiency of the flying car's power system, the reliability and lightweight of the deformation mechanism, and the precision of the flight control need to be improved. In terms of regulations, the current lack of unified and perfect airworthiness standards and traffic management rules limits the commercial application of flying cars. These issues require the joint efforts of researchers, companies and governments around the world to move shape-shifting flying cars that combine tilt-rotor and fixed-wing vehicles from concept to reality.

In the field of deformable flying cars with tilt-rotor and fixed-wing fusion, there are many explorations at home and abroad, and some achievements have been made, but there are still many challenges.

1.3. The Research Objective

This study is dedicated to designing a deformable flying car that combines tilt-rotor and fixed-wing, and to analyzing and optimizing its performance with the help of simulation technology, in order to fill the gap in the current transportation field in terms of efficient land and air transportation tools, and to provide an innovative solution for the future development of three-dimensional transportation in the city. Specifically, the primary goal is to construct a set of practical and efficient overall design scheme for the flying car to ensure its stable and reliable operation in both land driving and air flight modes. On land, it has the maneuverability and road adaptability similar to that of a traditional car; in the air, it realizes smooth switching between vertical takeoff and landing and high-speed cruising to meet the needs of different travel scenarios.

Secondly, a series of strict performance indexes have been achieved through the careful design of the body structure, power system, control system and other key components. For example, in terms of loading capacity, it can meet the needs of personnel and cargo transportation of a certain scale; in terms of flight speed, range and endurance, it can reach the standard of practical application; in terms of safety, it can ensure the safe operation of the flying car in various complex environments through multiple design guarantees. At the same time, simulation technology is used to comprehensively simulate the performance of the flying car under different working conditions, accurately locate the shortcomings in the design, and accordingly carry out targeted optimization to improve the overall performance and reliability, laying a solid foundation for the subsequent prototype manufacturing and practical application.

1.4. Research Methods

This study employs a comprehensive approach, integrating theoretical analysis, modeling, and simulation techniques to conduct an in-depth investigation of a deformable flying car that combines tilt-rotor and fixed-wing technologies.

Theoretical analysis, the use of aerodynamic principles[4], study the airflow characteristics and aerodynamic distribution of the flying car in different flight modes, provide theoretical support for the design of the wing and rotor shape, and ensure flight stability and efficiency. Based on structural mechanics, analyze the stress of the airframe during flight, ground travel and deformation, calculate the stress and strain of key components, and ensure that the structural strength and stiffness meet the requirements. With the help of mechanical principles, we design reasonable deformation mechanisms for tilt-rotor and fixed-wing, and plan the movement trajectories of the components to ensure smooth and reliable deformation process.

In the model construction and simulation process, the powerful 3D modeling function of SolidWorks is used to accurately construct the components and the overall model of the flying car. From the fuselage frame to the internal mechanical structure, and then to the external wings and rotor blades, etc., the parameters such as size, shape and material properties are set in detail. Through virtual assembly, the connection and coordination between components are simulated, so that potential assembly problems can be found in advance and a solid geometric foundation can be laid for subsequent simulation and analysis.

Adams software is used to carry out simulation tests. After importing the SolidWorks model into Adams, all kinds of constraints, driving and loading conditions are added according to the actual working conditions. The change of rotor lift during vertical takeoff and landing, the air resistance during horizontal flight, and the road friction during ground driving are simulated. Through the simulation, the kinematics and dynamics data of the flying car in different states, such as speed, acceleration, component force, etc., are obtained to evaluate the performance of the design scheme and provide a quantitative basis for the optimization of the design.

2. Design Principles and Schemes of Variable - Form Land - Air Dual - Use Unmanned Transporter

2.1. Overall Design Framework

This design adopts a pure electric distributed propulsion system, combining tilt-rotor technology with a fixed-wing layout, achieving both vertical takeoff and landing (VTOL) and efficient cruising while ensuring flight stability. The overall appearance is shown in Figure 1. The core of this design is the foldable wings, allowing it to travel on regular roads like modern cars and enabling vertical takeoff and landing in open areas. This design is adaptable to complex urban environments and uses a pure electric power system, achieving zero carbon emissions and low noise. The built-in system is primarily AI-controlled, with manual control as a backup, enhancing driving safety and responsiveness to hazardous situations.

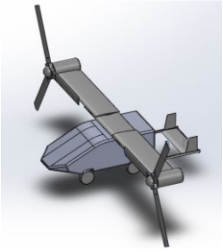

Figure 1. Integrity

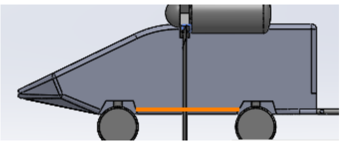

Figure 2. Vehicle

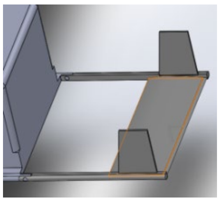

Figure 3. Empennage

2.2. Structure Design

2.2.1. Variable Structure Design

The airframe of this design is divided into three main parts: the vehicle body, the tail, and the tilt-rotor. The vehicle body features a streamlined design, as shown in Figure 2. Its aerodynamic contour has been optimized to effectively reduce the drag coefficient during high-speed travel, minimizing the impact of air resistance on vehicle performance and improving fuel efficiency and driving stability. Additionally, the axle section adopts a downward protruding structure, significantly reducing the likelihood of the chassis contacting the ground during landing or when traversing rough terrain. This design effectively reduces chassis wear, extends the lifespan of critical vehicle components, and enhances the vehicle's ability to navigate various road conditions safely. The interior seating is arranged in three rows, accommodating up to eight passengers. The specific configuration is three seats in the first row, two in the second row, and three in the third row, providing a reasonable distribution that meets the needs of family travel with multiple passengers. Furthermore, the third-row seats are designed to be removable, allowing users to expand the trunk storage capacity significantly based on actual needs, adapting to different usage scenarios. This modular design concept not only improves space utilization but also enhances the vehicle's versatility.

The tail section features a twin-tail boom design with foldable capabilities, as shown in Figure 3. When folded, it is positioned diagonally on the back of the trunk to reduce the vehicle's overall length, as shown in Figure 4. This allows the vehicle to fit into standard parking spaces and reduces the difficulty of making turns on the road.

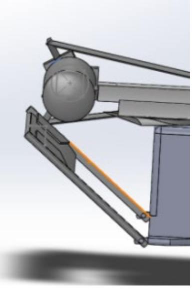

Figure 4 Folded tail wing

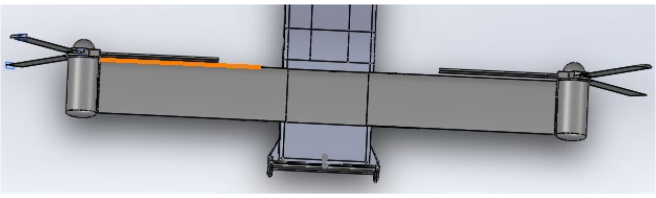

Figure 5 Wing

The tilt-rotor and fixed-wing are located on the vehicle's roof and also feature foldable storage, as depicted in Figure 5, with the stored state shown in Figure 6. The wing consists of a fixed-wing divided into three segments and two rotors. The fixed-wing can be horizontally rotated and stored on the roof, while in the deployed state, it spans up to 6 meters, providing sufficient lift during flight. The rotors use foldable three-blade propellers, which can be stored on either side of the roof. When deployed, the 2-meter-long blades and a brushless motor operating at 400 revolutions per minute deliver ample power for takeoff, landing, and flight.

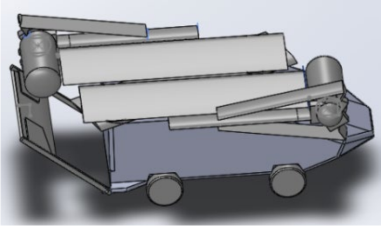

Figure 6. Folded tail wing

2.2.2. Material

The design uses materials such as aluminum-lithium alloy and carbon fiber, which reduces the weight of the vehicle body while ensuring structural strength. The application of aluminum-lithium alloys in flying cars has significant advantages. Its high specific strength and low density help reduce vehicle weight, thereby improving flight efficiency and range. At the same time, the excellent fatigue resistance and corrosion resistance of aluminum-lithium alloy enhance the durability and safety of flying cars in complex environments. In addition, good machinability makes the manufacturing process more efficient and helps to reduce production costs. These properties make aluminum-lithium alloys an ideal material choice for lightweight design and performance optimization in flying cars. The use of carbon fiber in flying cars also brings many benefits. The material is known for its superior strength-to-weight ratio, which rivals steel in strength but is much lighter, which means higher energy efficiency and longer flight range for flying cars. Carbon fiber is also extremely rigid, ensuring structural stability and precision in the flying car at high speeds. In addition, carbon fiber has excellent chemical and thermal resistance, allowing it to maintain its performance in harsh environmental conditions. Its sleek black textured exterior also adds a touch of futuristic technology to the flying car. As a result, carbon fiber is a key material for improving the performance, safety, and aesthetics of flying cars.

2.2.3. Power System

The propeller system of this vehicle utilizes two high-performance permanent magnet synchronous motors, with the following core performance parameters: the motor's rated operating voltage is 340 V, capable of outputting 120 Nm of torque under continuous operation, with a peak torque reaching 400 Nm to meet the instantaneous power demands during flight. The maximum speed of the motor is 17,000 rpm, ensuring stable operation of the propeller under high-speed conditions. The rated power is 100 kW, with a peak power of up to 200 kW, providing ample power support for the flying car. The motor is equipped with a 10:7:1 reducer, optimizing the matching of torque output and speed, while keeping the overall weight within 120 kg, balancing power density and lightweight design requirements. This motor features high efficiency, high power density, and excellent dynamic response characteristics, capable of meeting the multi-condition requirements for vertical takeoff and landing as well as cruising flight. Additionally, this vehicle employs solid-state batteries and monocrystalline silicon solar panels as power supply components for the propeller (Figure 7-8). The vehicle is equipped with a 300 kg solid-state battery pack, with an energy density of 370 Wh/kg, along with approximately 1.5 m² of monocrystalline silicon solar panels, enabling stable flight for 40 minutes in the air.

Figure7. Solid-state batteries

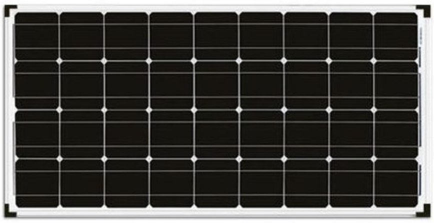

Figure 8. Solar panel

Image Source: https://www.nengyuanjie.net/article/67332.html

2.3. Control System Design

2.3.1. Sensors

To ensure the safe and normal operation of the vehicle, a variety of sensors are installed. The Inertial Measurement Unit (IMU)(Figure 9) is placed at the center of the vehicle body. The accuracy of these IMUs in measuring angular velocity can reach 0.01°/s, and the accuracy in measuring acceleration is 0.005 m/s², which can accurately detect the attitude changes of the vehicle.

Figure 9. Inertial Measurement Unit

For obstacle detection, 12 ultrasonic sensors (Figure 10) are evenly distributed around the vehicle, with a detection range of 3 - 9 meters. In addition, a high - resolution lidar sensor (Figure 11) is installed on the roof, and its detection range can reach 160 meters, which is used to create a detailed 3D map of the surrounding environment.

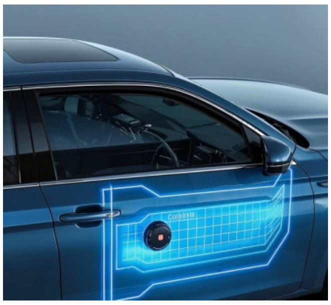

Figure 10. Ultrasonic sensors

Figure 11. Lidar sensor

2.3.2. Positioning System

The positioning system integrates the Global Positioning System (GPS) (Figure 12), the Beidou Satellite Navigation System (Figure 13), and the Inertial Navigation System (Figure 14). Under normal circumstances, GPS and the Beidou system can provide an absolute positioning accuracy of about 0.1 meters. The Inertial Navigation System consists of high - precision accelerometers and gyroscopes, which can continuously calculate the vehicle's position during the temporary loss of satellite signals. In addition, Wi - Fi positioning and Bluetooth beacons (Figure 15) are used for positioning in indoor and complex urban environments to ensure continuous and accurate positioning.[5]

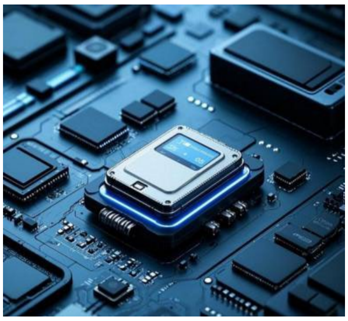

Figure 12. Global Positioning System

Figure 13. Beidou Satellite Navigation System

Figure 14. Inertial Navigation System

Figure 15. Wi - Fi positioning and Bluetooth beacons

2.3.3. Control System

The control system, working in coordination with the power system, is the core of the vehicle. A high - performance Microcontroller Unit (MCU) (Figure 16) with a processing speed of 1 gigahertz is used as the main control unit. It can process a large amount of data from sensors and the positioning system in real - time. The control algorithms include PID control for stable flight and driving, as well as fuzzy control for dealing with complex situations. The control system can adjust the tilt angle of the rotors, the motor speed, and the wheel steering according to the vehicle's state and the surrounding environment.[6]

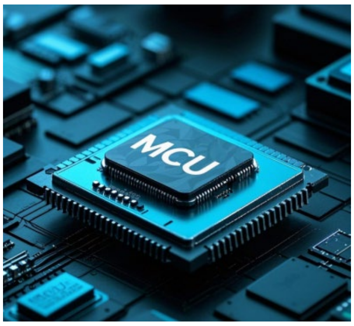

Figure 16. Microcontroller Unit

Figure17 .Display Screen

2.3.4. Display Screen

The display screen is a 15 - inch high - definition touch - screen located on the center console, with a resolution of 1920×1080, serving as the human - vehicle interaction interface. This screen can display real - time information such as vehicle speed, power status, flight altitude, and navigation maps. Users can also input commands through the touch - screen, such as setting the destination and switching between flight and driving modes. (Figure 17).[7]

3. Performance Examination and Simulation Analysis

3.1. Performance Examination

We tested the prototype's operations on the ground operations, maneuvering through the air and the transformation between the two configurations using Adams simulation software. We use the "motion" feature to set movements and measure the forces and torques of key parts involved.

3.2. Analysis of Simulation Results

3.2.1. Terrestrial Simulation

With the help of the Adams, the goal of making the car be driven on the ground is achieved. The car's prototype adapted 4 wheels which can each rotate independently. And hence it can obtain a smaller turning radius (Figure 18).

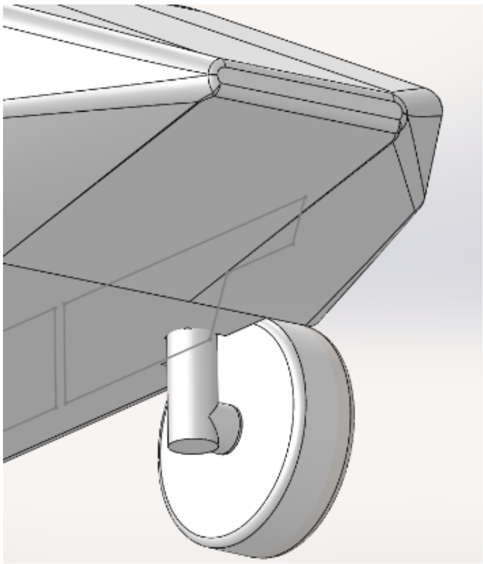

Figure 18: the wheel and the shaft

In order to make the car go around a circle, the prototype firstly adapted the Dim function which helps us to achieve the goal of "different movement in different stages". By contrast, subsequently it was changed into the Step functions because this function has the ability to move the car smoothly instead of stopping and starting abruptly (Figure 19).

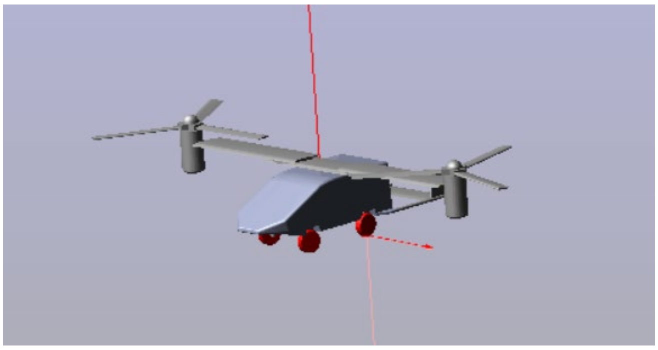

Figure 19: the turning of the prototypes

After the simulation, Adams is used for finding out the forces in those motions. Firstly, the forces between the wheel and the ground are about 16250.0 newtons, the biggest force is around 17500 newtons and the smallest force is around 7500 newtons, and through analyzing its components, we found out that nearly all of it is the normal force that the ground gave the wheels. The rest of it, for about 150 newtons, was the friction between the wheels and the ground, which provides the centripetal force for changing the direction. During our motion, our engine applied a torque about 3.897e5 newton times meters to the wheels (Figure 20).

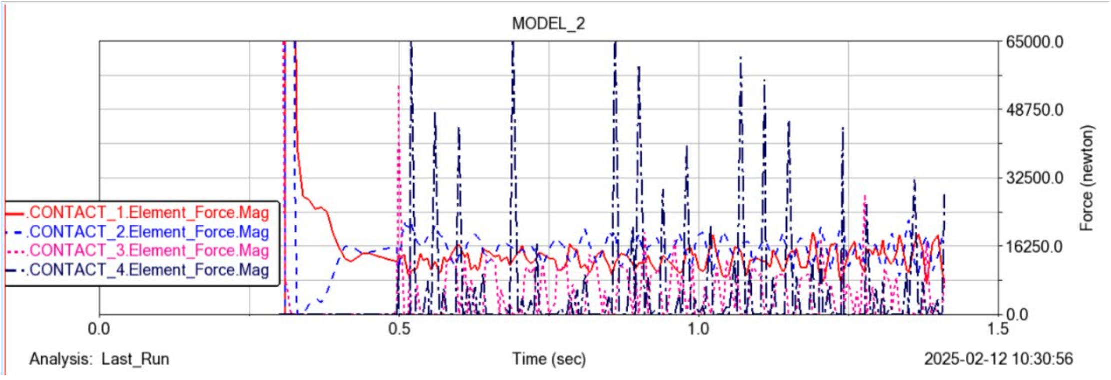

Figure 20. The forces of four wheels and the ground

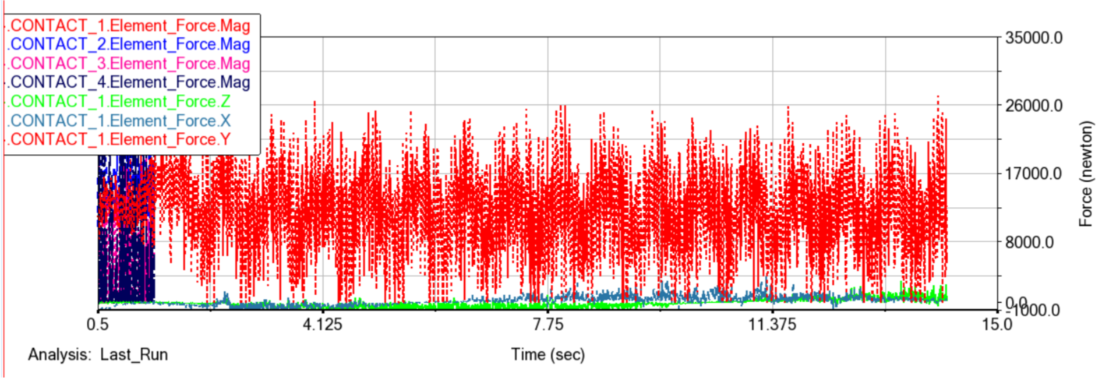

Figure 21: The composition of the forces

Secondly, the time for the prototypes to go around this circle is about 19 seconds, under this speed, the prototype car had excellent stability which means it would not roll over during driving. Thirdly, although the second picture displays the whole car at the flying position, actually it can folded until it is as small as a normal car (Figure 21). Hence, there is no necessary to worry about our prototypes will block the traffic.

3.2.2. Aeronautic Simulation

The special design of combining tiltrotor layout with the vehicle has enabled it to accomplish commuting tasks of an optimized flexibility and efficiency for the fact that helicopters are able to travel over intricate urban grids. Nevertheless, the setback on the power system is a potential breakthrough in the field of personal air transportation adapted for cities.

Several statistics has been brought out by the simulation test, by which has verified the validity of our design. The vehicle went through a motion which has a cubic track, containing motions direction towards $\pm x, \pm y$, and $\pm z$,for the flight test. During the process of vertical takeoff, the simulated maximum acceleration is $7.5 \mathrm{ms}^{-2}$, corresponding to a resultant force of 70,797.9N brought out by the engine. The maximum velocity during vertical takeoff is around $7.6 \mathrm{m/s}$. As a result, the total power of both engines should be $70{,}797.9\mathrm{N} \times 7.6\mathrm{ms}^{-1} = 538{,}064.04\mathrm{W}$(100% efficiency is assumed, the actual efficiency of the engine is around 60%). If this power supply is satisfied, transition to horizontal flight as airplanes has been made available

In a nutshell, the energy supply might become one of the main setbacks of the scheme. More advanced environmental-friendly energy source of higher density and efficiency must be adopted.

3.2.3. Structural Simulation

The converting process takes 125 seconds and 3 main steps, with propellers, wings, tail stabilizers and engines fold towards the body of the car, narrowing and shorten it for driving on normal roads as an ordinary car. Due to absence of mechanical structures and their friction in the simulation, the actual value for torques may be higher than the results of simulation .

Step 1: vertical stabilizers

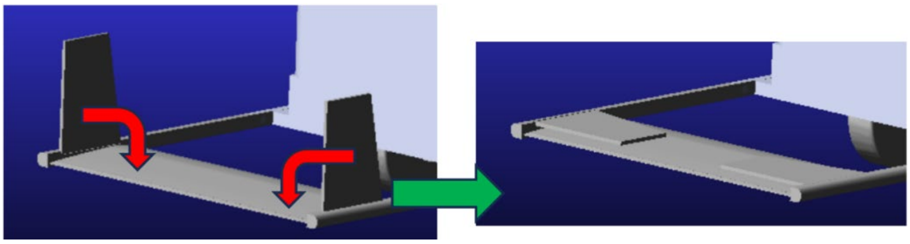

Figure 22. folding process of vertical stabilizers

The vertical stabilizers fold inwards for 90 degrees in 25 seconds to form a flat tail (Figure 22). During the process, actuators in beams propel the stabilizer to fold, the torque required for folding each vertical stabilizer is depicted below (Figure 23), with a maximum value of 5.1322 N*mm and a minimum of -8.9004N*mm. Due to the extended time and the relatively low weight of the vertical stabilizer (7.204kg), the torque required is low. Since the stabilizers are symmetrical, the torque on the two sides is identical.

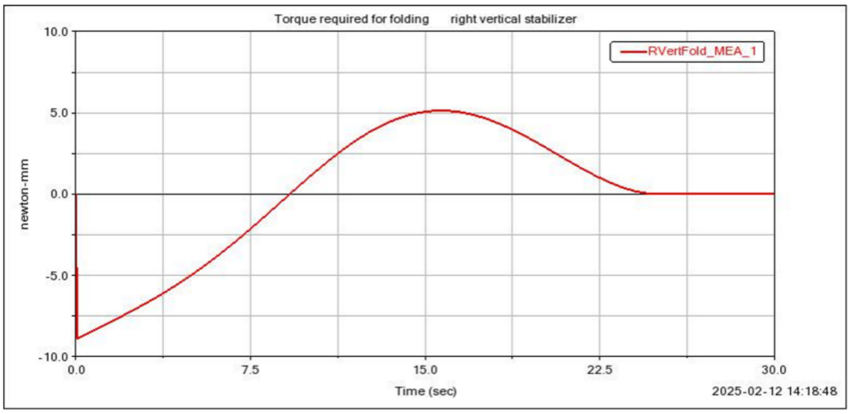

Figure 23. Torque required for folding the right vertical stabilizer

Step 2: propeller blades

The propellor blades on the left and the right side are folded in different manners, with combined movement of propeller pitch control, blade folding and turning the propeller as a whole. For clarity, the blades are color-coded and numbered as follows (Figure 24). Note that in actual operation the 3 blades on the same rotor shares the same design and are interchangeable during the folding operation, the color-codes and names used the description below do not represent a specific blade but the blade at that location instead.

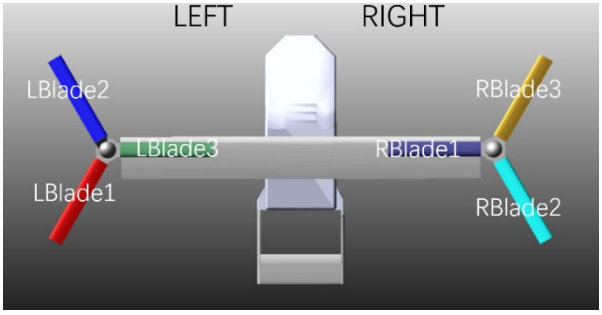

Figure 24. coloring and naming for propeller blades

This step starts simultaneously with step 1 (T+0 seconds). The step 2 begins with the adjustment of propeller pitch of LBlade1 and LBlade2. Meanwhile, the right propeller rotates 80 degrees counterclockwise from the position displayed above to give clearance for RBlade1 to fold below the wing. The RBlade1 and 3 also begins to fold 95 degrees inward.

At T+25s, the propeller pitch of the LBlade1 and 2 are completed that the blades are 90 degrees from horizontal, enabling them to fold toward LBlade3, which begins at this time point. The left engine rotates 90 degrees forwards while the right engine rotates 90 degrees backward. RBlade2 begins to fold downwards for 90 degrees as well (Figure 25).

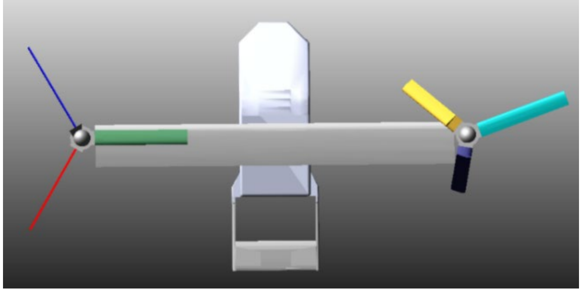

Figure 25. T+25s, note the position of right blades.

To adjust the angle so that the folding RBlade1 doesn't hit the ground, the right propeller begins to rotate clockwise for 20 degrees. The right propeller will eventually stay at 60 degrees counterclockwise away from the original position at T+57.5s

With the start of rotating the right propeller, all motions in step 2 starts (Table 1), the motion will stop at T+40s, T+50s and T+57.5s according to ch.1.

Table 1.Detailed procedure of step 2

T+_(s)	Start	End
0	LBlade1 propeller pitch LBlade2 propeller pitch Right propeller rotation RBlade1 fold RBlade3 fold	
25	LBlade1 fold LBlade2 fold Left engine rotate Right engine rotate RBlade2 fold	LBlade1 propeller pitch LBlade2 propeller pitch Right propeller rotation
27.5	Right propeller rotation backward	
40		RBlade1 fold RBlade3 fold
50		RBlade2 fold Left engine rotate Right engine rotate LBlade1 fold LBlade2 fold
57.5		Right propeller rotation backward

Figure 26 displays the magnitude of net torque on the propeller blades. By finding the difference of torque before and after the folding motion, the torque required for the actuators are found. Not that the change in the direction of gravity due to adjustment of propeller pitch results in the increment in torque of LBlade1 and 2 from T+0s to T+25s, which is not the driving torque for folding and therefore not considered. By isolating the time periods, it’s found that most of the net torque displayed are passive torques used to maintain the parts connected; by limiting the time periods, the torque exerted by actuators to fold the propeller are able to find out. (Figure 27).

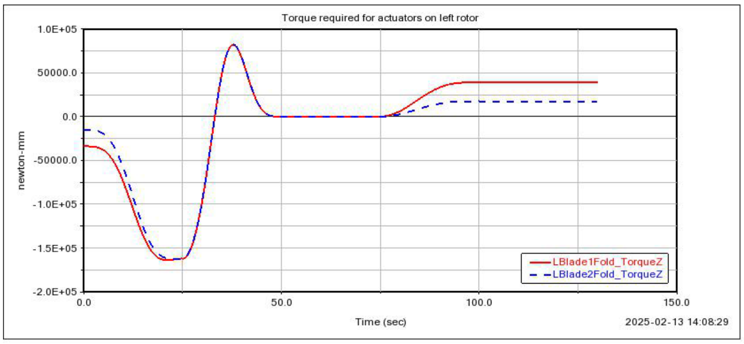

Figure 26. Torque required for actuators on left rotor

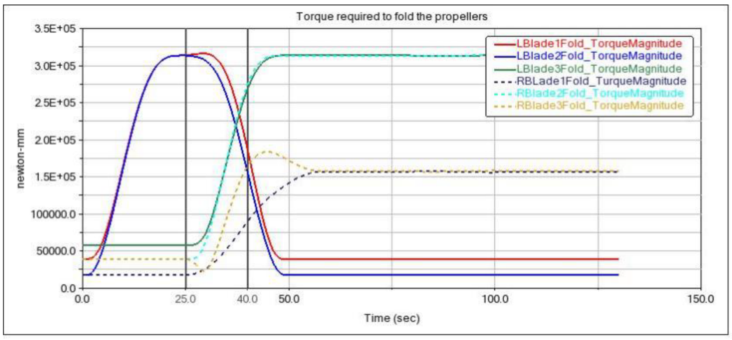

Figure 27. Torque required to fold propellers

For both LBlade1 and 2, the maximum torque found while folding is 82237.5231N*mm and the minimum value found is -1.6233e+5N*mm, resulting in the difference of 2.4457e+5N*mm of torque required for the actuators to exert.

On the right side, the torque required the for RBLade2 is 99984.7828N*mm, RBlade3 requires 67745.0769N*mm and 54625.075N*mm for RBlade1 (Figure 28). For easier maintenance and interchangeability, all actuators on both rotors should be capable of outputting the maximum level of torque.

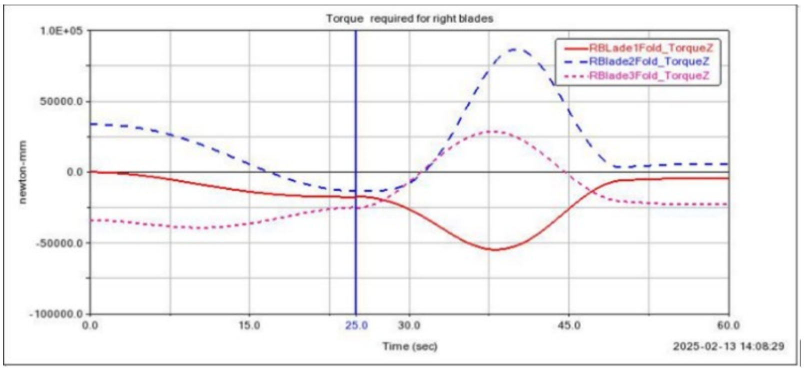

Figure 28. Torque required for right blades

The process of making precise adjustments to the angle of the right rotor, may be unable to achieve without the help of external ground supports through conventional turboshaft powered helicopters. However, with the help of highly responsive electric motors, this process can be achieved completely without external help-necessary for unmanned operations.

The two engines are rotating at different directions, while the left engine rotates forward to the direction of level flight, the right engine rotates to the opposite direction, which requires at least 180 degrees of freedom instead of 90 on conventional tilt-rotor aircrafts. Such problem should be considered when choosing the actuator for engine. For the right engine, 166100 N*mm (166.1 N*m) of torque is required for it to rotate, and 950170N*mm (950.17 N*m) is required for the left engine. Regarding that such motion is also used to convert from vertical take-off and horizontal fight, the torque required when converting midair should also be considered. In midair, the maximum torque (magnitude) required is 7.6124e+6 N*mm or 7612.4 N*m (Figure 29), comparing to the relatively low value during ground operations, this value should be taken into consideration for actuators.

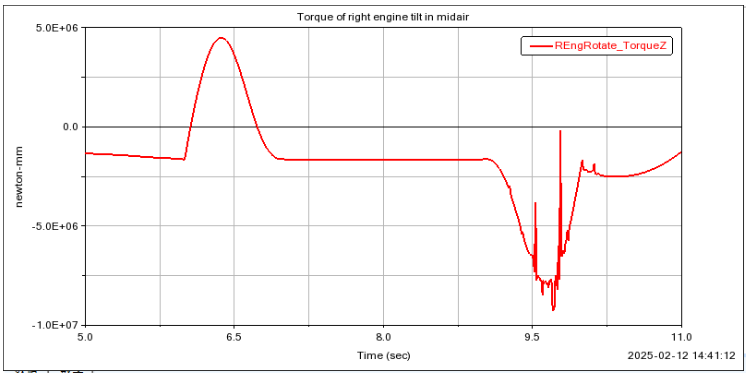

Figure 29. Torque of right engine in tilt in midair

Step 3: wings and tail

The main wing assembly starts to fold at T+75s and ends at T+100s in the process, the horizontal wing of shape ”---” folds inward to form a “N” shape. The left and right wings fold 155 degrees counterclockwise and the central part of the wing rotates 65 degrees clockwise (Figure 30).

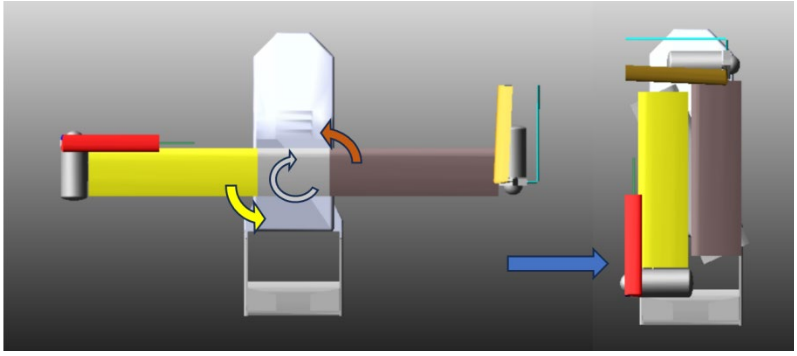

Figure 30. Folding process of main wing

Figure 31. Force required to rotate the tail assembly

During this process, according to Adams simulation, the torque required for left and right actuators to exert are 2.90122e-8 N*mm and 2.87828e-8 N*mm respectively. The value of this is exceptionally low due to absence of friction, the actual value will be higher in an actual run. After main wing is set, at

T+100s, the tail of the aircraft starts to fold. The tail assemble rotates 35 degrees upward to reduce length of the vehicle. In this process, each side only exerts extra 0.1671N to rotate the tail assembly (Figure 31). When friction between parts is included, the force will be greater.

4. Conclusions and Prospects

4.1. Result Summary

This study focuses on the design and simulation of a deformable flying car integrating tilt-rotor and fixed-wing, and a series of important results have been achieved through systematic research. In terms of design, a complete and reasonable overall scheme of the flying car was successfully constructed.

In terms of the body structure, suitable lightweight and high-strength materials are selected, combined with innovative structural design, which ensures the structural strength of the flying car under different working conditions, while effectively reducing the weight and improving the flight performance. In terms of the power system, after in-depth analysis and selection, the efficient matching of power between tilt-rotor and fixed-wing modes is realized, which meets the power requirements for vertical take-off and landing and high-speed cruising. The design of the control system realizes the precise control of the flight attitude and deformation process, which guarantees the stability and reliability of the operation of the flying car.

Through the simulation analysis, the performance of the flying car in various states, such as land driving, vertical takeoff and landing, and fixed-wing cruising, is comprehensively and deeply understood. The simulation results verify the feasibility of the design scheme and also provide a strong basis for further optimization of the design. In the land driving condition, the vehicle has good stability and maneuverability; in the vertical takeoff and landing stage, the lift generated by the tilt rotor is sufficient to support the flying car to take off and land smoothly, and the attitude control is accurate; in the fixed-wing cruise, the flying car shows excellent aerodynamic performance, and the flight speed and range reach the expected design indexes.

Overall, the deformable flying car integrating tilt-rotor and fixed-wing designed in this study has high feasibility and application potential at the theoretical level, which provides a useful reference for the development of new transportation modes in the future.

4.2. Innovations and Contributions

This study has achieved a series of innovations of significant value in the field of deformable flying car design integrating tilt-rotor and fixed-wing, and has generated positive contributions in various aspects.

From the innovation point of view, a major breakthrough was realized in the configuration design, which pioneered the combination of tilt-rotor and fixed-wing. This innovative design enables the flying car to combine the advantages of vertical takeoff and landing and high-speed cruising, breaking the shackles of the traditional flying car's single flight mode, and effectively expanding its scope of application in different scenarios. In terms of the deformation mechanism, through the selection of special materials and the adoption of a compact and reasonable layout, together with the subtle mechanical transmission and linkage devices, it successfully realizes the rapid and stable transformation of the flight mode, significantly reduces the deformation time and energy loss, and further improves the overall performance of the flying car. At the control system level, advanced intelligent algorithms are deeply integrated to accurately adjust the flight attitude with the help of adaptive control, diagnose and predict faults with the help of machine learning technology, and autonomously plan the optimal flight route with the help of path planning algorithms, thus enhancing the degree of intelligence and autonomous decision-making capability of the flying car in an all-round way.

In terms of research contributions, at the theoretical level, it opens up a new perspective for academic research in the field of flying cars, provides valuable design ideas and a solid theoretical foundation, vigorously promotes the improvement of the relevant theoretical system, and facilitates the in-depth cross-fertilization between multiple disciplines. In terms of technological development, it has led to a series of key technological breakthroughs, including the development and application of lightweight and high-strength materials, the exploration of engines and power conversion devices adapted to flying vehicles, and the wide application of intelligent control algorithms in the field of flying vehicles. In the field of practical application, the research results provide innovative solutions to alleviate the plight of urban traffic congestion and optimize the emergency rescue system. Flying cars can be widely used in urban logistics and distribution, emergency medical rescue, and inter-city fast commuting scenarios, which is of great significance to alleviate the pressure of ground transportation, improve the emergency response speed, and improve the people's travel experience [8].

4.3. Deficiencies and Future Prospects

Although this study has the advantages of vertical takeoff and landing, air hovering and other advantages of the traditional configuration of fixed-wing helicopters, as well as the high stability and better maneuverability of tilt-rotor vehicles, but the deformable flying car to truly commercialize and widely used still faces many challenges, and needs to be continued in-depth research in many aspects.

(1)Technology, key technologies still need to continue to break through. For example, improving the efficiency and reliability of the power system involves the research and development of high - efficiency flight engines. These engines aim to reduce energy consumption and enhance flight safety. Additionally, optimizing the structure of the deformation mechanism is crucial. This optimization should focus on achieving greater precision, lightweight design, and improved reliability, thereby reducing the risk of failure during deformation. Furthermore, strengthening the development of the control system is essential. This includes incorporating trap sensor technology and artificial intelligence algorithms to realize the flying car's road planning, autonomous obstacle avoidance, and intelligent decision - making functions.

(2)In terms of government policy, the existing regulations applicable to flying cars are still not perfect. In the future, it is necessary for the government, research institutions, and enterprises to work together to coordinate and establish a sound and unified flight standard, traffic management rules, and safety guarantee system. Through clear laws and regulations, the flight airspace, takeoff and landing requirements, flight speed, and pilot qualifications should be protected and restricted to shape the policy environment for the legal and compliant operation of flying cars.

(3)In addition, the penetration research of multi-domain integration is also crucial. The design of deformable flying cars has a wide range of fields, and in the future, aerospace, automobile manufacturing engineering, electronic information, material science, artificial intelligence algorithms, and many other fields need to further strengthen cross-field cooperation and exchanges, to promote the in-depth integration of science and technology, and to promote the continuous innovation and development of flying car technology.

References

[1] Wang Miaoxiang. (2024). Annual Review of Fixed-Wing General Aviation Aircraft in 2023. International Aviation (3), 59-62.
[2] Jing Jing. (2024). "Is the 'Flying Car' Making a Comeback?" Auto Observer 2, 22-23.
[3]Accumulating knowledge over four years through arduous research on coaxial tilt-rotor technology, and persistently pursuing the dream of aerospace with the spirit of Beihang University — A Record of the Growth Journey of the "New Concept Coaxial Tilt-Rotor Aircraft" R&D Team. (2017). Beihang University. http://www.ase.buaa.edu.cn/info/1009/6214.htm
[4] Ren Siqi. (2016). An Introduction to the Application of Aerodynamic Principles in Aircraft Manufacturing. Scientist, (16),2.
[5] Zafari, F., Gkelias, A., & Leung, K. K. (2019). A Survey of Indoor Localization Systems and Technologies. IEEE Communications Surveys Tutorials, 21(3), 2568 – 2599.
[6] Åström, K. J., & Hägglund, T. (2006). Advanced PID control. ISA-The Instrumentation, Systems and Automation Society.
[7] Sedehzadeh, S., Tavakkoli-Moghaddam, R., Baboli, A., & Mohammadi, M. (2015). Optimization of a multi-modal tree hub location network with transportation energy consumption: A fuzzy approach. Journal of Intelligent & Fuzzy Systems, 30(1), 43 – 60.
[8] Na Lin, Shaojun Zhou, Yi-Qin Yu, & Feng Deng. (2025). Construction of new low-altitude infrastructure from the perspective of low-altitude economic development. China Science and Technology Achievement, 26(1), 13-15.