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Research on Scientific Directions for Flying Cars at the Preliminary Design Stage

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Abstract: This article was written to investigate the research on the scientific directions for flying cars at the preliminary design stage to provide a rationale for the choice of scientific research in the area of flying cars. At present, the population of the Earth is gradually increasing, and traffic congestion will become a common phenomenon in cities in the future. This work used the methods of theoretical and statistical analysis to form an overall picture of this area of research. We researched the statistical data analysis conducted by scientists who dealt with flying cars and the associated issues. We gave a rationale for the choice of the object of scientific research, which is flying cars. People can read this information to have a starting point in their understanding of flying car design. This analysis of famous scientific works provides possible scientific directions that the research can take with respect to designing a flying car that combines the advantages of an airplane and a car and can take off and land on a normal highway for a short distance, as well as help people reach their destination quickly and easily.

Keywords: flying car; scientific direction; analysis

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1. Introduction

The current ground transportation system is suffering from various challenges, including the high cost of infrastructure development, limited land space, and a growing urban population. When driving in a city, especially in major cities, drivers who encounter traffic jams still cannot fly with their cars. A hundred years ago, this was a fantasy, but today, it is close to being a reality. Air mobility is a service that will improve existing transportation opportunities by bringing traffic into the air. Due to the increasing population, road traffic is growing at an alarming rate and many urban areas are experiencing traffic congestion. Flying cars will provide improved shortcuts for individuals to move between urban areas while reducing traffic congestion on land. The flying car is a vehicle that will become popular in future fast-paced urban life due to important characteristics such as short takeoff and landing capabilities, the ability to pass quickly regardless of terrain obstacles, and low emissions compared to large passenger aircraft.

Flying cars can solve traffic problems in the future, promote environmentally friendly urban ecosystems, and provide faster travel for people. Flying cars can be used for many different purposes, as they offer autonomous driving with vertical landing and take-off capabilities. The vehicle can be used in emergency operations, cargo transportation, air taxi operations, and security situations [1].

In recent years, the number of companies involved in the development of flying cars has increased rapidly, and some large companies have joined: Boeing has acquired the aviation technology company Aurora Flight Sciences and will join forces with Porsche to develop electric vertical takeoff and landing vehicles (eVTOL); Toyota has invested in Joby Aviation and SkyDrive; Geely Automobile has acquired the U.S. Terrafugia and invested in Germany's Volocopoter; and Chinese online technology giant Tencent has invested in Lilium several times. Mohamed-Slim Alouini et al. describe several potential innovations that make communication between eVTOLs and the ground feasible. These innovations include three-dimensional cellular networks on the ground, tethered balloons, high-altitude platforms, and satellites [1].

Therefore, to develop a preliminary design for a flying car, a deep analysis of research on the relevant scientific directions should be performed. The result will provide significant direction for investigations on flying cars, and it should facilitate the rapidly increasing development in the field of flying car design since it will allow this field to not repeat the path already taken by other scientists but to instead take into account the gained experience.

The purpose of the work is to research the scientific directions of flying cars at the preliminary design stage and to provide a rationale for the choice of scientific research in the area of flying cars.

2. Collection and Analysis of Information on the Direction of Scientific Investigation on Flying Cars

This section is devoted to information gathered about the names and countries of scientists investigating flying cars, along with their works, that are the most influential in the preliminary stage of flying car research. To conduct this analysis more effectively, a decision about a wide area of science was made.

To collect relevant information from scientific journals, scientific books, articles, authors (scientists), and publications from official websites of flying car companies, the Scopus database, the Research Gate social network, the Web of Science, Science Direct, etc., were used. In particular, their features for the study were taken into account.

The findings and the analyses of results were based on the highest impact factor, the number of possible combinations of inner limits, the research impact, the categories of research directions on flying cars, range of years, number of citations, number of times read, downloads, the place of publication, and indexing of web resources.

The three sections below correspond to three key points on which the current research was based:

- Scientists, publications, and flying cars companies;
- Scientists' claims;
- Flying cars' features.

2.1. Scientists, Publications, and Flying Car Companies

The list below represents *scientists* studying flying cars and *their publications*, which were selected based on the considerations described above.

- Haktan Yağmur (Turkey). "Conceptual Design of a Novel Roadable Flying Car" [1].
- Nasir Saeed (Saudi Arabia). "Wireless Communication for Flying Cars" [2].
- Larisa Ivascu (Romania). "The Flying Car–A Solution for Green Transportation" [3].
- Steven C. Crow Starcar Development Co. "A Practical Flying Car" [4].
- Mohammad Adhitya (Indonesia). "Center of gravity analysis of a flying car" [5]; "Folded wing mechanism for flying car" [6]; "Flying-cars body manufacturing using spraying elastic waterproof and water-absorbing frame fabric method" [7]; "Design and analysis of tubular space-frame chassis on flying car with impact absorbers material" [8]; "Drag polar analysis for a flying car model using wind tunnel test method [9]"; "Take off and landing performance analysis for a flying car model using wind tunnel test method" [10]; "Wheel retraction mechanism design of flying vehicle project" [11];
- James R. McBride (Ford Motor Company, MI, USA). "Role of flying cars in sustainable mobility" [12];
- Wolfgang Ott (San Jose State Univ, CA, USA). "HELIos, a VTOL flying car" [13];
- Gaofeng Pan (Beijing Institute of Technology, Beijing, China). "Flying Car Transportation System: Advances, Techniques, and Challenges" [14];

- Kaushik Rajashekara (University of Houston, TX, USA). "Flying Cars: Challenges and Propulsion Strategies" [15].

The following list shows the flying car *companies* selected for consideration.

- Personal Air and Land Vehicle (PAL-V) Europe;
- AeroMobil;
- Klein Vision.

2.2. Scientists' Claims

Each publication is reviewed below, while the intermediate results of the analysis are discussed in terms of possible modern scientific directions for each one.

- In [6], the authors discussed involving aerospace engineering in the automotive industry, which presents a major gap and has many limitations, but it does not rule out the possibility of making a flying car. They claim that wings are needed on this project to handle the air while the object is flying. The authors considered a few types of hinges, and linkage was found to be a good design to achieve a folding mechanism that fits into the structure of the wing, allowing a folded wing mechanism to be used when it fully expands for flying and that can fold when driving on regular streets [6]. **Scientific direction**: A folded wing mechanism for flying cars that can be used when driving on a normal street.
- In ref. [3], the authors briefly analyze the urban European context based on the available data from the 2019 report. Then, they present an inventory of existing flying car models as innovative solutions developed based on electric cars for green cities' transportation systems [3]. **Scientific direction**: Flying cars can offer new solutions for green urban mobility.
- The authors of [1] have represented current ground-based transportation systems, which are subjected to various challenges, including the high cost of infrastructure development, limited land space, and a growing urban population. Therefore, the automotive and aviation industries are collaborating to develop flying cars, also known as electric, vertical, takeoff, and landing aircraft (eVTOL). They believe that these eVTOLs will allow for rapid and reliable urban and suburban transportation. The safe operation of eVTOLs, which the authors discussed, will require well-developed wireless communication networks [1]. **Scientific direction:** Electric, vertical, takeoff, and landing aircraft (eVTOL) could be a rapid and reliable form of urban and suburban transportation.
- In ref. [5], the authors investigated one of the stages in designing a flying car, namely, determining the center of gravity. The center of gravity of the aircraft must be in the range of 15–25% of the mean aerodynamic wing chord so that the aircraft can fly stably. In a flying vehicle, the center of gravity is determined by arranging the components of the vehicle so that the center of gravity falls within that range [5]. **Scientific direction:** The results showed that the center of gravity when the fuel tank was in the middle of the vehicle was located at 444.7 mm in front of the forward center of gravity limits, and when the fuel tank was in the back of the vehicle, it was located at 366.05 mm in front of it. The second configuration tends to be more stable. Additionally, the canard is unable to balance the aircraft's lift force in a stalling condition.
- In ref. [13], the authors presented a single-seat, three-wheel, vertical takeoff and landing (VTOL) flying car concept of HELIos. It uses counter-rotating propellers enclosed in ducts. This technology eliminates the need for a tail rotor and makes the vehicle more compact. It needs no modification to switch between drive mode and flight mode [13]. **Scientific direction:** A vertical takeoff and landing flying car concept eliminates the need for a tail rotor and makes the vehicle more compact.
- Ref. [4] presents the theory of wings hanging on the sides, in which the driver plugs them into the fuselage when they want to fly, but not while the car is in use. The authors discuss most of the functions that this design serves in both road and sky

modes [4]. **Scientific direction:** A hanging-wing working mechanism which works in both road and sky modes.

- In ref. [12], the authors show that the interest and investment in electric vertical takeoff and landing aircraft (VTOL), commonly known as flying cars, have grown significantly. However, the authors note that the sustainability implications are unclear. They report a physics-based analysis of primary energy and greenhouse gas (GHG) emissions of VTOLs vs. ground-based cars that are efficient for tilt-rotor/duct/wing VTOLs when cruising but consume substantial energy for takeoff and climbing [12]; **Scientific direction:** For a vertical takeoff and landing aircraft, VTOL GHG emissions per passenger-kilometer are 52% lower than internal combustion engine vehicles (ICEVs) and 6% lower than battery electric vehicles (BEVs). VTOLs offer fast, predictable transportation and could have a role in sustainable mobility.
- In ref. [15], increasing interest in flying vehicles and the greater electrification of these vehicles with the advances in engines, electric motors, power converters, and communications is shown [15]. **Scientific direction:** The authors examine the challenges and requirements of developing a hybrid or a pure electric flying car, propulsion strategies for operations such as automobiles and airplanes, and vertical takeoff and landing (VTOL).
- The authors of [7] discuss the manufacturing method of flying cars' bodies. The focus of this research is on the technique of manufacturing flying cars' bodies by coating the body's frame with elastic fabric and spraying it. Two types of fabrics were used in this study, namely, water-absorbing fabric and waterproof fabric. A mold ring was used as the body frame, and the elastic fabric forming the surface was then sprayed with resin to make it harder. After the elastic fabric had hardened, fiberglass was added to strengthen the material. Then, a tensile test and a stress analysis were performed to determine the strength and suitability of the material [7]. **Scientific direction:** The method of manufacturing flying cars' bodies when using GFRP (waterproof fabric specimen) has better strength than when using GFRFP (water-absorbing fabric specimen).
- In ref. [8], the flying car is technically considered an airplane with the added feature of being able to move properly on a highway. To fulfill its function as an aircraft, the chassis construction of the vehicle must be strong enough to withstand the loads while flying or while functioning as a vehicle. The vehicle chassis is able to withstand collisions as much as possible as a passive safety system in the event of an accident [8]. **Scientific direction:** Compared with the chassis of a space-frame type without impact absorbers and filled with impact absorbers by filling rigid polyurethane foam, the stiffness of the chassis can increase by 2.9% and can reduce the displacement UY by 2.9% (displacement in the Y-direction of the selected reference coordinate system by SolidWorks Simulation).
- In ref. [9], a model is created at one-seventh the real size and is tested with a wind tunnel. The maximum value of this comparison is crucial for the determination of the overall design. The values are collected based on wind tunnel testing. This research is quantitative with a descriptive design [9]. **Scientific direction:** Drag analysis of a flying car model was carried out.
- The authors of [11] investigate how to maximize the limited space of a vehicle in terms of fuel storage so that it can travel a long distance. Without increasing the size and weight of the vehicle, efficiency can be achieved by reducing drag [11]. **Scientific direction:** A wheel retraction system is designed that can reduce parasite drag to 24%.
- The authors of [16] present the idea of this VTOL propulsion system, which is to combine the fan propulsion system with the car wheel system attached to the suspension system. Therefore, a special design was needed to allow the suspension system to change the takeoff or landing direction of the fan propulsion system and to perform its function (car wheel support system for driving and steering), specifically, when the flying car moves on the road. The selection of material and the wishbone shape are

important aspects of wishbone design to meet the design requirements. The wishbone shapes are made of steel tubes. After analysis through simulation, combined with material and variations on the wishbone shape, the combination design Upper Wishbone without Bracing and material AISI 1040 was found to be the best combination design. The shape design of an upper wishbone without bracing was chosen because it is lighter, easier to fabricate, and generated a smaller drag value than other designs. The material AISI 1040 was chosen because the price is cheaper than that of material AISI 4130, although it is a little more expensive than the material AISI 1020 [16]. **Scientific direction:** The takeoff or landing direction of the fan propulsion system can be changed, and it can perform its function (car wheel support system as driving and steering), specifically when the flying car moves on the road.
- The author of [17] presents the development of an aeroelastic analysis approach for the dynamic response of a Z-shaped folding wing. The structural model is established by the finite element method (FEM) and the component mode synthesis (CMS) method, accounting for the configuration-changing effects on inertial and stiffness characteristics. The aerodynamic model is directly built using the continuous-time state-space unsteady vortex lattice method (UVLM). The analysis results show that the folding and unfolding processes have opposite effects on both the aerodynamic load and the aeroelastic characteristics. Moreover, the effects become more significant with an increasing morphing rate [17]. **Scientific direction:** The folding and unfolding processes of the Z-shaped wing is presented in different configurations.
- In ref. [18], the authors provide information about the first documented manned all-electric VTOL flights, which occurred in 2011–2012. These flights were taken by a co-axial twin-rotor helicopter and a multi-copter. They were bare-bones aircraft with a solo pilot, enabled by lightweight permanent magnet synchronous motors and compact Li-ion batteries. They flew for only a few minutes (5–10 min) and lacked all attributes of a practical aircraft—payload, range, endurance, and safety—but proved the viability of electric trackless aircraft that, if realized on a practical scale, could open up new opportunities in aviation due to their many inherent strategic advantages [18]. **Scientific direction:** An all-electric VTOL structure and its influence on mass parameters and flight performance are presented.

2.3. Flying Cars' Features

The features of flying cars based on their inventors' scientific research interests are shown below.

The Curtiss Autoplane (Figure 1): in 1917, invented by Glenn Curtiss, who could be called the father of the flying car, unveiled the first attempt to build such a vehicle as roadable aircraft. It was shown at the Pan-American Aeronautic Exposition in New York City in February 1917. It made a few short hops before the entry of the United States into World War I in April 1917 ended the development of the Autoplane [16]. Although the vehicle was capable of lifting off the ground, it never achieved full flight. His aluminum Autoplane sported three wings that spanned 40 feet (12.2 m). The car's motor drove a four-bladed propeller at the rear of the car. The Autoplane never truly flew, but it did manage a few short hops [19].

Figure 1. Curtiss Autoplane [20].

Arrowbile (Figure 2): Developed by **Waldo Waterman** in 1937, the Arrowbile was a hybrid Studebaker aircraft. Like the Autoplane, it had a propeller attached to the rear of the vehicle. The three-wheeled car was powered by a typical 100-horsepower Studebaker engine. The wings detached for storage. A lack of funding killed the project [19].

Figure 2. Waterman Arrowbile [21].

Airphibian (Figure 3): **Robert Fulton**, who was a distant relative of the inventor of the steam engine, developed the Airphibian in 1946. Instead of adapting a car for flying, Fulton adapted a plane for the road. The wings and tail section of the plane could be removed to accommodate road travel, and the propeller could be stored inside the plane's fuselage. It took only five minutes to convert the plane into a car. The Airphibian was the first flying car to be certified by the Civil Aeronautics Administration, the predecessor of the Federal Aviation Administration (FAA). It had a 150-horsepower, six-cylinder engine and could fly 120 miles per hour and drive at 50 mph. Despite his success, Fulton could not find a reliable financial backer for the Airphibian [19].

Figure 3. Fulton Airphibian [22].

ConvAirCar (Figure 4): in the 1940s, **Consolidated-Vultee** developed a two-door sedan equipped with a detachable airplane unit. The ConvAirCar debuted in 1947 and offered one hour of flight and a gas mileage of 45 miles (72 km) per gallon. Plans to market the car ended when it crashed on its third flight [19].

Figure 4. Convair Model 118 ConvAirCar [23].

Avrocar (Figure 5): The first flying car designed for military use was the Avrocar, developed in a joint effort between the Canadian and British military. The flying-saucer-like vehicle was supposed to be a lightweight air carrier that would move troops to the battlefield [19].

Figure 5. Avro Canada VZ-9 Avrocar [24].

Aerocar (Figure 6): Inspired by the **Airphibian and Robert Fulton**, whom he had met years before, Moulton "Molt" Taylor created perhaps the most well-known and most successful flying car to date. The Aerocar was designed to drive, fly, and then drive again without interruption. Taylor covered his car with a fiberglass shell. A 10-foot (3-m) drive shaft connected the engine to a pusher propeller. It cruised at 120 mph (193 kph) in the air and was the second and last roadable aircraft to receive FAA approval. In 1970, Ford Motor Co. even considered marketing the vehicle, but the decade's oil crisis dashed those plans [19].

Figure 6. A 1949 Taylor Aerocar—N4994P [25].

3. Rationale for the Choice of the Object of Scientific Research

From the conception of the flying car until today, there has been little research progress, and the weight design requirements of cars and airplanes are so different that flying cars nowadays are gradually losing their car-driving function.

The design of flying cars can give full play to the advantages of both cars and airplanes, and the design of folding up the wings can be achieved to minimize the aerodynamic impact on the driving process, which will facilitate the pilot's driving and improve the comfort of the ride.

The internal frame of the fuselage can be made of a titanium alloy, which increases the cost to a certain extent, but due to the small size of the fuselage, the increase in cost is limited, whereas the strength of the key connection parts of the fuselage is greatly improved, as is the safety. The overall fuselage is streamlined, and due to the wide-body design, it will provide part of the lift to the whole flying car during the flight.

The engine can adopt a replaceable modular design, which currently uses gasoline power. Because the use of battery power cannot meet the speed and power needs, perhaps with current developments, the efficiency of the use of electrical energy can improve and the battery size can be greatly reduced, so the flying car can also use electrical energy to provide power.

Good airfoil and wing design are fundamental to ensuring flight and can be very useful from the point of view of additional equipment and design techniques. For example, flaps and slits are widely used on modern aircraft to increase lift at takeoff and increase drag upon landing. The torsional angle design applied to the wing also helps to improve wingtip stall speed. Wingtips are effective in reducing drag and fuel consumption during flight, but for some short ranges, the design requirements of a vehicle with added wingtips would increase the weight of the wing structure, and the additional weight would not compensate for the fuel savings from adding them.

The primary sources of loads on the wing are shear, bending moments, and torques caused by the lift generated by the wing. The load increases gradually from the wing tip to the root, supposing abrupt changes in the shear moment at the concentrated load and a linear relationship between the effect of the bending moment acting on the load at the wing root. The wing can be made of carbon fiber composite skin wrapped with an aluminum alloy beam, and the wing is divided into two parts, which can be folded in the lateral direction.

The fixing device between the engine and the fuselage frame and the connecting part of the wing, which are inevitably related to the structural strength and the flight life of the flying car, is also an important part of the flying car that should be investigated.

In addition, the car-driving process needs downforce to give the wheels and the ground better friction, in addition to an elevator to provide downforce, and the nose part of this flying car also needs to add a device to provide downforce.

4. Discussion

The last section discusses important scientific directions not fully covered or unexplored, along with possible future directions that were discovered in the research of the current article.

After analyzing scientific directions, well-known publications, and flying car concepts and catalogs, it can be observed that most of the research work is still at the stage of theoretical studies, and the cost and practicality of manufacturing flying cars have not yet been studied in depth.

Table 1 shows the comparison of scientific directions at the preliminary stage.

The difficulties faced by flying cars in terms of regulations, technology, and the market have also emerged. In terms of regulations, the current certification process of flying cars needs to pass the flight airworthiness certification and car driving certification, and temporarily borrowing from general aviation and ground car standards cannot fully represent the characteristics of flying cars; although low-altitude flight and ground driving have their own regulations, the effective linkage between them and the management of flying car operation mechanism has not been formed. In terms of technology, the current technology for flying cars in a low-altitude and intelligent driving environment perception, as well as decision-making and control technology, is not yet mature. On the market side, there is a lack of hardware and software facilities required for the operation of flying cars, and countries around the world have not yet achieved the normal operation of flying cars. In addition, research is only beginning on the topics of setting up a "route", avoiding and defining the responsibilities for accidents, air safety supervision, and methods of law enforcement. However, with the progress of technology and society, these problems will be solved.

Table 1. Comparison of scientific directions at the preliminary stage.

Scientific Directions	Results Have Been Achieved	Not Fully Covered Scientific Directions	Unexplored Scientific Directions
Folded wing mechanism for flying cars	yes	no	no
Determination of the position of the center of gravity of the flying car	no	yes	no
Vertical takeoff and landing flying car, eliminating the need for a tail rotor and making the vehicle more compact.	yes	no	no
Detachable wings	yes	no	no
Vertical takeoff and landing aircraft can reduce pollutant gas emissions and reduce the environmental impact of traffic	yes	no	no
Hybrid or electric power	no	yes	no
The manufacturing method of flying cars' bodies	no	yes	no
Wheel retraction system to reduce drag during flight	no	yes	no
Selection of materials for internal frame structure	yes	no	no
The need for the vehicle's undercarriage material selection and structural design to be robust enough to withstand the loads imposed during flight or when operating as a vehicle.	no	yes	no
Drag analysis of flying car models	yes	no	no
Airworthiness certification for flying cars	no	no	yes
Design of the body shape (to meet the aerodynamic requirements of both road travel and air flight)	no	no	yes
Traffic rules related to flying cars and flight routes	no	no	yes
Material selection for flying car glass	no	no	yes
Economic study of flying cars (e.g., economic comparison with cars and air travel, manufacturing costs)	no	no	yes
Comparison of the advantages and disadvantages of flying cars requiring runway takeoff and vertical takeoff and landing methods	no	yes	no

In fact, cars and airplanes belong to two different categories. The former need to undergo crash tests, need high-strength body rigidity, and, from the aerodynamic point of view, need to produce more downforce at high speed when the car is driving to improve the grip of the tires. Meanwhile, for airplanes, the lighter the weight, the better, the whole body is assembled with aluminum alloy and composite materials, and they do not need to undergo crash tests, whereas, from the aerodynamic point of view, the fuselage is designed to generate lift at high speed. However, one thing in common between cars and airplanes is that their fuselage must be streamlined to reduce drag.

In addition, the front windshield of a car must be made of glass, whereas the front windshield of a light aircraft is generally made of plastic to be less likely to break in a collision and to be lighter in weight.

The prospect of the development of flying cars is supported by the traction of objective demand and by technology. On the demand side, urban traffic congestion is the most common problem in major cities today, and traditional initiatives such as building viaducts and underground tunnels have not easily or effectively solved the problem of the traffic flow network effect of urban congestion, helicopters due to noise, safety limitations and limited application scenarios. In addition, urban traffic urgently needs to develop and use the three-dimensional low-altitude space of urban centers through flying cars in a way that is safe and environmentally friendly, so as to achieve three-dimensional intelligent transportation. In terms of technology, the great progress of electric vehicles and intelligent-networked vehicles has made good technical and industrial progress for the development of electric flying cars; the emergence of electric vertical take-off and landing (eVTOL), i.e., electric flying cars, makes high safety and low-noise urban air traffic possible.

5. Conclusions

After researching more than 20 scientific directions from results that have been achieved, scientific directions that are not fully covered, and unexplored scientific directions that are important for social life, a new scientific direction was formed, devoted to designing a flying car that combines the advantages of an airplane and a car, can take off and land on a normal highway for a short distance, and can help people reach their destination quickly and easily. Additionally, this will provide a significant direction for flying car investigations, and it should allow for rapidly increasing development in the field of flying car design since it will mean that scientists will not repeat the path already taken by others, but will take into account the gained experience. The flying car should be designed to provide people with a variety of faster and more convenient modes of transportation to choose from, and it can quickly change between car-driving mode and airplane-flying mode while looking over the ground during the flight to enjoy the scenery. When the road is not congested, it should be possible to use the car-driving mode, and when traffic congestion occurs or the route to the destination is more complicated due to the construction of the topography, then it should be possible to use the flight mode to quickly reach the destination, so that drivers can easily cross rivers and lakes and shorter mountain slopes, thus ultimately saving time and improving efficiency.

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