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Trends and Challenges in Realizing a Flying Car



Abstract: - Since the 20th century, researchers have worked to create a new concept that combines airplanes and automotive parts. This effort has led to many prototypes, conducted feasibility studies, and examined strategic approaches. Despite many debates, flying vehicles are viewed as a promising future transportation option. This study examines the history and future of flying cars, as well as their implementation challenges and technological advances. Flying cars with STOL and VTOL capabilities are reviewed. VTOL vehicle electrification and decarbonization are thought to be the future of flying cars. Lift and Cruise, Vectored Thrust, and Multicopters were the three main VTOL thrust types examined for performance. The study evaluated promising electric and hybrid VTOLs on the market. The flying car's aerodynamics, range, endurance, and cruising speed were considered in the feasibility analysis. The data show similarities amongst flying vehicles with similar propulsion technologies.

Keywords: flying cars, future technology, STOL, VTOL.

I. INTRODUCTION

With the innovation of advanced automobile and transportation technology, researchers are aiming to achieve safer mobility, subordinate traveling times, more access for transportation to larger population groups, in addition to a more sustainable system-wide traffic operations [1]–[4]. Moreover, researchers have been trying to develop new transportation technologies that enable mobility in two possible dimensions, on the ground and in the air [5]. The concept of flying cars is a smart advanced concept to minimize traffic congestion that is an issue for most cities worldwide. The most important advantage is that flying cars reduce the travel time for drivers to reach their destination [6], [7].

Throughout the past, vertical take-off and landing (VTOL) aircraft have been conveyed predominantly for military activities due to their lack of a requirement of runways, mostly in the navy and marines, e.g; BAE harrier, Bell-Boeing V22 Osprey, and Lockheed martin f-35b lighting II [8], [9]. On the other hand, little commitment has been made back then into developing the common aviation side of VTOL capabilities, because of its high fuel consumption, restricted payload capacity, and excessive noise. Nevertheless, this changed when researchers and big companies showed interest in VTOL capabilities for Intra and inter-city utilization, which is expected to have a big impact on the industry. Commercial flights or conventional aircraft require runways ranging up to 3500m and takes off and lands with speeds varying between 80 m/s to 120 m/s [8], [10], thus the benefits of civil flying vehicles are self-evident.

Manufacturing companies have been interested in designing and developing flying car prototypes, in addition, to try to commercialize them fast, and validate to people that the flying cars will be established and available in the market soon, possibly by 2025 [5]. Major aviation companies are researching hybrid and fully electrical functioning flying car technologies to build a sustainable innovation. NASA presented the puffin electric tail-sitter VTOL concept and showed the potential of eVTOL in terms of reliability and noise level [11]. Uber then managed to grab a lot of attention globally to flying cars with their big initiative Uber Elevate by setting a blueprint for urban air traffic [12]. Moreover, aviation giants such as Bell and Embraer, in addition to startups such as Kitty Hawk, Lilium, Joby Aviation, and E-Hang have shown interest to electrify VTOL technology and have designed and launched prototypes with the aims of reaching the goal of electrification [13]. The investments made into

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startups in the urban air mobility have reached up to 1 billion US dollars, and a market of 30 billion US dollars is expected [14].

This study aims to establish an understanding of the basic mechanics, ideas, and plans behind Vertical take-off and landing technologies, and to further explore the current technologies behind a flying car and carry out a feasibility study by performing a performance analysis on the major flying cars in the market. This paper is alienated primarily into two main parts, an intensive literature review, and a feasibility study on key future flying cars. The intensive review will investigate the advanced technologies surrounding a flying car, mainly VTOL technology, and will discuss the future of flying cars. The mechanics behind VTOL technology, along with the implementation and benefits of the technology, as well as the current advancement of VTOL technology will be researched.

II. HISTORY OF FLYING CARS

With the start of aviation and automobile, aircraft designers and manufacturers have always tried to illustrate a way for machines that could travel on the ground and as well as via air. Numerous inventors tried and struggled to combine the motorcar and the airplane, as Henry Ford mentioned in 1940: ‘Mark my word: a combination of airplane and motorcar is coming. You may smile, but it will come [15]. Many events were planned out just to determine practical and appropriate engineering applications; for instance, Glen Curtiss’ Airplane debuted in 1917 [16], the Waterman Aerobile in 1937 [17], the ConVairCar Model 118 in 1947 [18], the Aero-Car series from 1949 to 1977 [19], [20] and the AVE Mizar in 1973 [21]. The following flying cars prototypes shown in Fig. 1a-b are mainly constructed with fixed wings that are connected to the automobiles, enabling them to take off, land, and fly.



Figure 1: Curtiss Aeroplane [16]

With all the technological progress throughout the years, it only proves that the concept of having flying cars is not just a science-fiction script or research, but a realistic development of modern technologies that will soon come into existence. Many stakeholders over the past few years have been contributing to develop new automobile ideas, for example, the Urban Air Mobility (UAM), which aims to offer a universal and smart way of transportation for cargo and passengers in cities by broadly using the airspace [22], [23]. NASA also worked on finding the most suitable, technological, and law-abiding policies of flying cars to enable smooth addition of UAM with the open airspace and air transportation modes through the Urban Air Mobility Grand Challenge [24]. The flying cars concept implementation phase was initiated by Uber and with their project that is named ‘Uber Air’. The project aims to provide transportation services in compacted and populated regions and between cities and states commercially. This would not only deploy the flying fleet capacity to new heights but also increase the efficiency of existing highway networks [25].

Another concept was laid forward by NASA to integrate the air transportation framework for passengers in urban areas. This concept was visualized with the name ‘Urban Air Mobility’. There were some constraints to be resolved and rectified by them which included travel time considerations and acquisition cost. The cost analysis included maintenance, fuel consumption, and environmental protection. It was also inferred by some researchers that sharing the expenses of flying cars for transportation would reduce the average cost by many folds [26]. There were two concepts laid by researchers in previous works of literature regarding the public acceptance perspectives: the benefits of having air transportation to the public and the people’s adoption of flying cars. Because these

perspectives are interrelated, the research further continued with the fact that travel time, cost, environmental and operational considerations would serve as the motive for the successful execution of flying cars as an emerging technology. The perceptions of respondents are mentioned in Table 1 as shown below [27].

Table 1: Perceptions of flying cars [27]

Benefits	Overall unlikely	Overall likely
Lower Travel Time to destination	14.15%	85.85%
More reliable travel time to destination	20.90%	79.10%
Lower fuel expenses	70.58%	29.42%
Lower CO2 emissions	64.63%	35.37%

A. Short Take-off and Landing (STOL)

The flying car is a vehicle capable of either V/STOL or VTOL to fit the requirements and the niche of where it could be utilized [28]. The utilization varies from passenger- carrying flying vehicles or personal transportation to emergency rescue missions, and firefighting or military uses such as surveillance and monitoring of cargo and shipment deliveries. For improvements in STOL performance, it was observed that the flying car configuration and design should be considered. The placement of the exhaust, the weight and low wing loading are things to consider in the design stages. The STOL landing performance graph is shown in Figure 2 for a performance observation based on approach speed and landing distance [28].

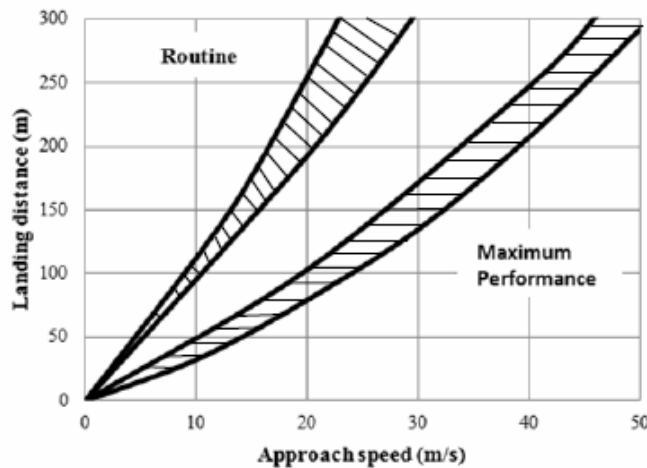


Figure 2: STOL Landing Performance [28].

As technology advances, aircraft manufacturers are focused on electrifying the flying car concept. Consequently, a technology called Distributed electric propulsion (DEP) evolved, allowing new configurations for flying cars by having numerous minor propulsion systems to be efficiently deployed across the aircraft. This technology will effectively enhance the performance of a fixed wing flying car with STOL capabilities. Some authors suggested that due to the easier certification procedure of a STOL flying car compared to a VTOL, this technology will have more benefits for a STOL and will allow for more weight reduction due to needing lesser propulsion systems [29]. The DEP approach tolerates more freedom during design stages making it more beneficial. The performance benefits of the DEP technology for short hub-to-hub transportation with small take off spaces are vast and a point of interest for many researchers [30], [31]. As a result, for Urban Air Mobility, a lot of VTOLs are manufactured to employ DEP for increased cruise performance, mechanical complexity reduction and noise reduction. Furthermore, it is believed that the appropriate technology for Urban Air mobility

is a VTOL capable flying car due to its ability to vertically take off from any ground space requiring low infrastructure requirements [12], [32].

B. Vertical Take-off and Landing (VTOL)

V/STOL is best achieved when the weight and the wing loading are low. There were many configurations observed when jet aircraft and non-jet aircraft were studied. It was concluded in this study that non jet V/STOLs have better range and consume less power in comparison to jet aircrafts. The results also supported the fact that the weight of an aircraft is not linearly related to the performance of the V/STOL [28]. An advantage of VTOL capabilities is that airports are not needed to get the car into flying mode; this is good for the environment, meaning less space used for building infrastructures. Previous studies noted that if the flying car was switched from flying mode to driving mode, the need for regulations and awareness is very important from the owners of flying cars as well as the owner of traditional cars [33]. So far, no VTOL flying car produced a fully capable system of safe take-off, cruising, noiseless, lesser emissions and could land safely in a heavily populated urban environment. However, it was predicted by most researchers in their literature that the 3rd decade of the 21st Century would be the start of commercialized flying cars, and considering the simulations, results, and efforts of Automotive companies, the fiction would soon be a reality.

Moreover, previous research showed benefits of an electric propulsion system VTOL with more rotors will result the flying car to travel at a low tip speed, however, when compared to an airplane with bigger but fewer rotors, a reduction in noise levels is observed [34]. It was also observed that using liquefied natural gas (LNG) as a fuel in a hybrid solid oxide fuel cell battery turbine system over pure battery-electric power solutions at the same power level provided some advantages in transportation modelling and determining energy-related constraints for system-level urban air mobility. Nevertheless, ensuring enough power and energy is available for vertical take-off and landing for a flying car is essential [35], [36].

III. ELECTRICAL VERTICAL TAKE-OFF AND LANDING (EVTOL)

Another evolution of technology came into existence when the concept of the flying car was transformed into an electrical system. Considering the engine characteristics, the operational features of flying cars were proposed to be hybrid systems by combining electric and gasoline engines. The fueling, maintenance, and other costs have not yet been disclosed officially but the literature suggested that the estimated selling price of flying cars would begin with around \$200,000. The major objective in developing the Electrical VTOL was to reduce gas emissions and make it environmentally friendly. Another aspect was the significance of research on flying car power batteries. A limitation found in Electrical VTOL flying cars was the battery. Depending on the capacity of the flying car, total weight, and the number of passengers that flying car would transport, on a 100 km hub-to-hub mission with one passenger on the vehicle, the gasoline engine VTOL found to have 28% increased greenhouse gas emissions as compared to Electrical VTOL. The evolution of electrical cars changed the view of research works and forced to implement the electrical system to flying cars as well to further increase the mission of decarbonization (emission of CO₂ gases) of the power grid [33].

The revolutionized invention of flying cars would be finally coming into existence in the form of personal aerial vehicles with amazing and interesting features. The technology involved focuses mainly on electrical VTOL and fully electric systems to keep the flying car concept as appealing as possible. Although prototypes were created, simulations and testing were conducted, some of the research areas are still pending which would be resolved by 2025 with the development directions for PAV.

Current flying car technologies are designed to be greener and more sustainable towards the environment; accordingly, the current flying car designs are all either electric or hybrid. The electric VTOL flying vehicles can be categorized into 5 classifications based on their thrust type as mentioned by the Vertical Flight Society [37]: Vectored thrust, Lift + Cruise, Multicopter, Hoverbikes/personal flying devices, and Electric rotorcraft/helicopter.

IV. PERFORMANCE ANALYSIS

To perform the performance analysis, the flying vehicles were categorized into three classifications based on the classification of their thrust configuration: Lift and Cruise, Vectored Thrust, and Multicopter. For a fully electric system, the electric range can be calculated using [38]:

$$R_{Electric} = E_{cruise} * \eta_{tot} * \frac{1}{g} * \frac{L}{D} * \frac{m_{Battery}}{m_{max}} \tag{1}$$

Where E_{cruise} is the required energy for the cruise, η is the efficiency of the drive terrain, g is gravity $g = 9.81 \text{ m/s}^2$, $\frac{L}{D}$ is the lift to drag ratio, $m_{Battery}$ is the mass of the battery, and m_{max} is the total mass of the vehicle.

It can be seen that the range clearly depends on the cruising energy, meaning it is the flight stage that consumes most energy. The lift to drag ratio and mass of the battery to the overall mass ratio is an important factor to determine the Range for an electric VTOL. V_{cruise} indicates the cruising speed of the flying vehicles and were obtained through the given specifications by the companies of each flying vehicle. The maximum take-off weight (MTOW), and payload capacity were also attained from the specifications given by the manufacturers of each flying car. Endurance or flight time was obtained through the following equation:

$$T = \frac{R}{V_{cruise}} * 60 \tag{2}$$

Since the flying vehicle is already VTOL capable, the thrust can be assumed to equal the weight, therefore:

$$Thrust = Weight = mg \tag{3}$$

Where m is the maximum take-off weight, and g is gravity $g = 9.81 \text{ m/s}^2$.

Equation (3) is assumed because all flying cars mentioned above are VTOL capable, which implies that the thrust to weight ratio should be above 1 ($T/W > 1$).

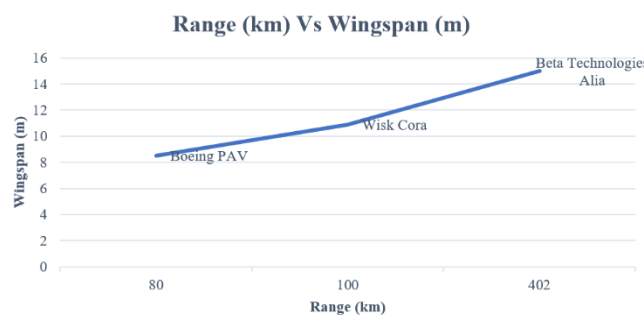


Figure 3: A relationship between Wingspan and Range of Boeing PAV, Wisk Cora and Beta’s Alia

Figure 3 shows the relationship between the wingspan and the range of the selected platforms with separate thrusters for lift and cruise. Observing the trendline from the graph above, it is evident that as the wings’ length increases, the range increases, which indicates that longer wings have better gliding, and are more efficient during cruising modes of the flight. This of course comes with a trade-off when discussing urban air mobility as space is considered an issue and lengthy wings can be considered a problem.

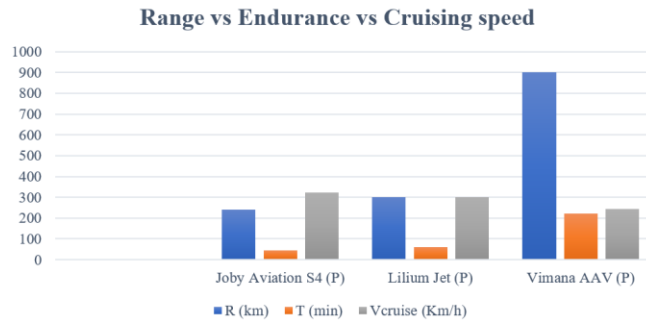


Figure 4: A comparison of Joby, Lilium, and Vimana's AAV

Figure 4 shows the range, endurance, and cruising speed of Joby’s S4, Lilium Jet, and the Vimana AAV. Observing the data provided in the graph, the Vimana has triple the range of the Lilium jet and almost four times the endurance, this is due to its hybrid propulsion system providing energy for longer ranges and flight times. The battery densities currently available cannot accommodate long ranges, and most of the electric VTOLs estimate their ranges with hopes of advancements in the battery industry soon. However, the ranges of the S4 and the Lilium jet match the needs of the utilization it is meant for; urban air mobility and hub-to-hub transportation. Observing the graph, there is a relationship between cruising speed vs endurance and range for a vectored thrust system, as cruising speed increases, the range and endurance decline. This is due to the high energy requirement of high cruising speeds; higher cruising speeds consume more energy.

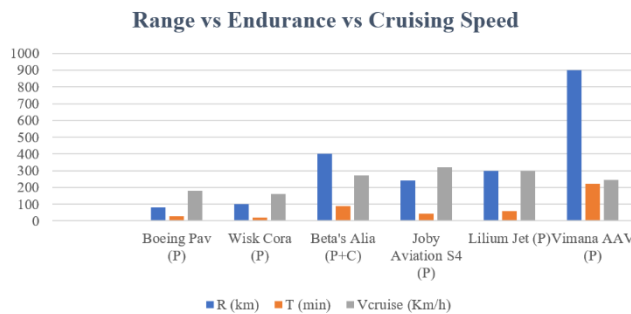


Figure 5: A comparison for all winged designs

Figure 5 shows the range, endurance, and cruising speed for all winged designs mentioned in Table (2). From the graph, vectored thrust systems have more range, more endurance, and higher cruising speeds comparing to systems that use two separate propulsion systems for lift and cruise; as for Beta’s Alia however, the company stated that the provided data is based on the advancements in the battery technology by 2025. For vectored thrust platforms, all propellers or ducted fans work together through vertical lift and forward movement of the flying car, hence the high cruising speeds. On the other hand, having two separate thrusters means that the propellers used for vertical lift do not participate in cruising, thus making the propellers extra weight during forwarding flight mode.

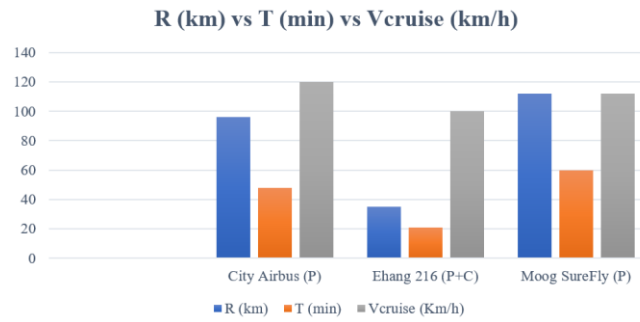


Figure 6: A comparison for City Airbus, Ehang 216, and Moog SureFly

From Figure 6, it is observed that for wingless VTOLs the cruising speeds are low compared to winged VTOLs. This is expected for a wingless setup since winged VTOLs have more efficient cruising capabilities allowing it to have better velocities during forward flight modes. The flight times on the other hand are similar between all VTOLs and endurance is an important factor when discussing performance and efficiency and the endurance of all three vehicles are within the range of winged platforms. According to the graph above, Moog Surefly has the highest range of 112 km, while City Airbus has a range of 96 km and Ehang 216 with the lowest range of 35 km with.

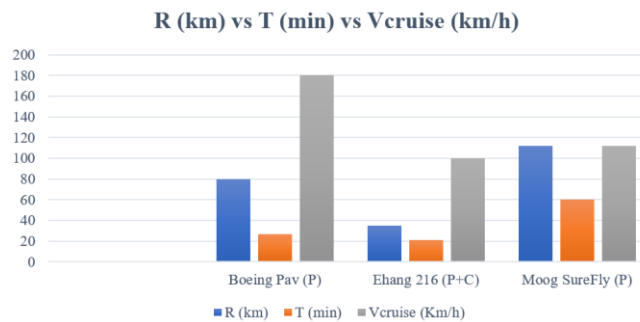


Figure 7: A comparison for Boeing PAV, Ehang 216, and Moog SureFly

The graph above shows values for a winged electric VTOL Boeing PAV along with the wingless electric VTOL Ehang 216 and a wingless hybrid VTOL Moog SureFly. All three vehicles are within the same weight range between 600 and 800 kgs. Observing Figure 7, Boeing PAV has the cruising speed advantage (180 km/h), this is due to its winged configuration and separate thrust system for forward flight. The rear propeller pusher and the winged set up empowering the flying vehicle to glide and cruise more efficiently during flight. The SureFly has high endurance abilities (60 mins), due to the distribution of energy consumption between a gasoline engine and a battery pack. Both multicopters have efficient hovering as their flight time and range are close. Moreover, The SureFly has the highest range of 112 km with a flight time of 60 mins, whereas the Boeing PAV with 80 km and Ehang 216 with 35 km and flight times of 26.6 mins and 21 mins respectively. From the analysis done above, it is concluded that a hybrid system is better for immediate adaptation of the flying car technology, because of its superior hovering and cruising performances, higher range, and acceptable cruising speed.

V. DISCUSSION

Based on the parameters analysed for each Flying car (Aerodynamics, Range, Endurance, and Cruising speed), Below are the findings' summary:

- For VTOLs that use separate thrusters for lift and cruise, it was observed that range is directly proportional to the wingspan. If the wingspan increases, range increases.

- For VTOLs that use vectored thrust for lift and cruise, it was observed that the range and endurance are inversely proportional to cruising speed, if the cruising speed increases, the range and endurance decrease.
- For VTOLs that have a multicopter configuration, no specific relationship was found on the discussed parameters.
- A hybrid powerplant has better performance specifications than a fully electric powerplant.
- Each classification (Lift and Cruise, Vectored thrust, and Multicopter) has their pros and cons, the utilization of each flying car is what determines which one is more feasible for a specific purpose.
- A fully electric powerplant for a VTOL fits the urban mission and the future of flying car more than a jet VTOL. However, further development regarding battery densities must happen in order to achieve higher and better performance.
- The performance data provided for a jet and an electric VTOL are similar to each other. The weight however is the deciding factor, while 82% of the Bell X-14's weight goes for its engine leaving less than 20% for other components and the payload, the S4 accommodates 25% of its total weight for the payload capacity.

Evaluating the performance mentioned above, the most realistically feasible flying cars out of each classification are as follows:

- Lift + Cruise: Boeing PAV and Wisk Cora have reasonable weights and a reasonable payload capacity, the battery technology could accommodate for the ranges of both VTOLs and the aerodynamics of a winged VTOL helps reach the ranges expected.
- Vectored Thrust: With the current battery technology, all three flying cars are overestimating their Range and cruising speeds. However, looking at other aspects, Joby S4 is the closest to achieving the UAM requirements, starting with its low noise levels that makes it one step closer to certification. The Vimana AAV being a Hybrid VTOL with weights less than the Joby S4 and Lilium Jet is something to take into consideration, if not for its overestimated range of 900 km that makes it less credible.
- Multicopters: Ehang 216 performance with the current technology could even exceed its estimated provided specifications. Its light weight, short range and low cruising speeds are deemed credible especially with its aerodynamic design, which makes it more feasible than other multicopters discussed in this paper. However, all multicopters mentioned in this paper have sensible performance specifications that are feasible and could be achieved.

VI. CONCLUSION

The study discussed an overview of the history and future of flying cars. The challenges in realizing the flying car as well as the technologies such as STOL, VTOL and eVTOL were thoroughly presented. A feasibility study was conducted on nine VTOLs that are in advanced development stages. The VTOLs were divided into three groups, the groups represented their classifications based on their thrust system and these are: Lift and Cruise, Vectored Thrust, And Multicopters. The analytical review was based on four parameters; the aerodynamics of the flying car, range, endurance, and cruising speed. The study set an overview of the logical parameters to analyze and determine whether the implementation of a specific flying car matches its characteristics. Performance analysis showed how different eVTOL designs affect flying vehicle performance and how their aerodynamics can improve performance. It will also establish the required flying car characteristics for different uses.

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