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Review Paper

A Comprehensive and Systematic Literature Review on Flying Cars in Contemporary Research

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Abstract. The integration of flying cars into urban transportation represents a significant advance in scientific and technological developments. This paper provides a comprehensive review of flying cars within the context of Urban Aerial Mobility (UAM), addressing the critical need for Vertical Take-Off and Landing (VTOL) vehicles in contemporary urban environments. The study is divided into two main parts: a historical review and a systematic literature review. The historical review, which covers developments up to 2013, traces the evolution of flying cars from their conceptual inception to early practical implementations. From 2013 onwards, the focus shifted to a systematic literature review, which meticulously analyzes research from the past decade to the present day. This bifurcated approach not only highlights the technological and infrastructural advancements but also underscores the social considerations and regulatory frameworks necessary for the successful deployment of flying cars. The paper commences with a categorization of flying vehicles, which serves to establish a contextual understanding. The methodology employed in this study, namely the systematic literature review, is then described. An in-depth bibliometric analysis of the selected references follows this. The findings are presented through a conceptual structure map, which delineates the boundaries of the research field. The paper discusses a number of key issues, including technological innovations, infrastructure requirements, societal impacts, and regulatory challenges. In addition, the paper highlights the practical implications and recommendations for the successful integration and adoption of flying cars. Additionally, the paper compares various flying car concepts with each other in terms of several aspects and presents a preliminary sizing study of the selected flying car concept via a demonstrative example. Finally, the paper identifies promising avenues for future research in the field of vertical take-off and landing vehicles, with the aim of enhancing the framework for urban air mobility. This comprehensive review synthesizes existing knowledge and provides an integrative view essential for future research and development in flying cars.

Keywords: Urban Air Mobility (UAM), Air Transportation, Flying Car, Vertical Take-Off and Landing (VTOL), Systematic Literature Review, Bibliometric Analysis, Aircraft Pre-dimensioning.

1. Introduction

1.1 General background and main motivations

Developing a new machine through computer-aided design and engineering tools involves several critical steps, including virtual prototyping and the dynamic modeling of the mechanical system of interest [1–3]. Before producing and utilizing a new automatic system, engineers focus on evaluating its performance in detail using sophisticated virtual models created with modern design and engineering tools [4–7]. This process is particularly critical in the aviation industry, where component failures pose a severe risk to the system integrity and, more crucially, the lives of users and operators interacting with the aircraft. In this context, a prominent role is played by advanced computer simulations grounded in Multibody System Dynamics (MBD) and Finite Element Analysis (FEA) [8–10], which allow for the Integration of Computer-Aided Design and Analysis (I-CAD-A) [11, 12].

Advances in materials science, computer-aided design, and propulsion technologies in the late 20th and early 21st centuries have reinvigorated interest in flying cars [4–6]. Modern aircraft systems are now being developed with electric propulsion systems, sophisticated flight control software, and advanced materials that offer enhanced performance and safety [13]. These technological innovations are crucial for overcoming the limitations that hindered earlier prototypes.

This paper aims to bridge the existing knowledge gap by providing a comprehensive overview of the historical context and a systematic analysis of recent research trends. To this end, the paper outlines the path forward for the development and implementation of flying cars within the framework of the urban air mobility.

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1.2 Problem statement and formulation of the research questions

Urban Air Mobility (UAM) systems represent a sophisticated integration of various technologies and components at the intersection of the automotive and aviation industries. Unlike simple mechanical systems, UAM encompasses a broad range of elements including advanced air navigation, communication, and control systems [14]. In general, UAM systems refer to vehicles that allow all modes of transportation intended for extremely short-distance flights, with a range of less than 50 kilometers, and low-altitude flights, with an altitude below 1.500 meters above the ground, both in urban and extra-urban areas [15]. UAM systems have many applications extending beyond basic passenger transportation, including public safety, emergency services support, blood and organ transportation, infrastructure control, traffic monitoring, and the transportation of commodities [16]. However, this concept also includes applying creative, intelligent mobility solutions incorporating safe, clean, and quiet technologies [17]. Therefore, flying cars seem to fit the need for implementing proper vehicles that perfectly concretize the futuristic concept of UAM [18].

The term ”Flying Car” encompasses a range of vehicle types that blend aviation and automotive technologies. To avoid confusion, it is essential to differentiate between two primary categories of flying cars: mixed-mode vehicles and Vertical Take-Off and Landing (VTOL) vehicles. Mixed-mode vehicles, also known as roadable aircraft or roadable flying cars, are designed to operate both on roadways and in the air. These vehicles feature automotive and aviation functionalities, allowing them to transition seamlessly between driving on roads and flying in the air. Typically, mixed-mode vehicles are equipped with retractable wings or rotor systems and capable of road navigation and vertical or horizontal flight. Their design aims to provide versatility and convenience by combining the functionalities of a car and an aircraft into a single vehicle [19]. In contrast, VTOL vehicles designed for UAM are specialized aircraft that do not possess automotive capabilities. These vehicles are intended solely for aerial operations and are equipped with technologies enabling vertical take-off and landing. VTOL vehicles are used primarily for short-distance air travel within urban environments. They are characterized by their ability to operate efficiently without needing conventional runways or road infrastructure. Unlike mixed-mode vehicles, VTOL vehicles are not designed to travel on roads but are optimized for air navigation, communication, and operational efficiency in urban airspace [20].

As mentioned before, UAM systems typically refer to vehicles designed for short-distance flights. Historically, the idea of flying cars has been embedded in popular culture and speculative fiction, symbolizing the ultimate convergence of personal freedom and technological advancement. The early 20th century saw the first attempts at developing flying cars, with Glenn Curtiss's Autoplane in 1917 representing a significant advance in this field [21]. Despite these initial forays, however, the technology of the era remained inadequate to achieve the desired results. Following the Second World War, there was a renewed interest in this field, with models such as the Aerocar by Moulton Taylor [20]. However, the practical implementation of these models remained elusive due to regulatory, safety, and technological challenges [22].

In this paper, a systematic literature review on the development of flying cars in contemporary research is carried out, thereby comprehensively identifying the trends, challenges, and prospects of this new field of study. The comprehensive literature review process proposed in this work aims to synthesize existing knowledge, provides an integrative view of flying cars in the context of UAM, and leads to identifying the critical areas for future research. The scientific aspects reviewed in the paper mainly focus on the fundamental issues typical of mechanical engineering. To the best of the authors' knowledge, this methodological approach has never been used before to analyze the research field of flying cars. Thus, the comprehensive exploration devised in this investigation aims to contribute to a holistic understanding of the feasibility and implications of integrating flying cars into 21st-century urban mobility.

The review is informed by a theoretical framework integrating technological innovation, urban planning, and transportation engineering concepts. This framework provides a structure for analyzing and synthesizing the literature on flying cars and urban aerial mobility. The initial component of the framework is technological innovation, which encompasses the design, architectural aspects, modeling, simulations, and energy and power systems of flying cars. This component permits the categorization of flying vehicles based on rotor configuration, power type, and control mode. Furthermore, it enables the evolutionary trajectory of flying cars to be traced regarding technological advancements. The second component of the framework pertains to urban planning. This component encompasses the operation and management of flying cars and the associated communications, air traffic management, and cybersecurity. This component allows for the analysis of the infrastructure requirements for integrating flying cars into urban environments. The third component of the framework pertains to transportation engineering. This includes examining the environmental and acoustic impact of flying cars, their social acceptance, and the regulatory challenges associated with integrating them into existing transportation systems. Additionally, it permits an investigation of the societal implications of flying cars and the regulatory frameworks necessary for their safe and efficient operation. Applying this theoretical framework to the literature review allows for a systematic analysis of existing literature, identifying gaps in current research, and suggesting future research directions. For example, the framework underscores the need for further research on safe and efficient aerial mobility in urban environments, rotor modeling and simulation, energy storage and power production, infrastructure development, and comprehensive strategies for managing air traffic.

1.3 Scope and contributions of this work

Since 2013, there has been a notable increase in academic and industrial research on flying cars, reflecting the rapid technological advancements and growing interest in the urban air mobility. This paper divides the literature review into two distinct phases in order to capture this evolution. The initial phase of the literature review encompasses a historical analysis up to 2013, while the subsequent phase is a systematic examination of the literature from 2013 to the present. The historical review traces the developmental milestones and early technological experiments that laid the groundwork for modern flying cars. In contrast, the systematic literature review examines recent advancements, exploring the integration of electric propulsion, autonomous flight systems, and regulatory frameworks necessary for their deployment in urban environments. The development of UAM systems, including flying cars, represents a paradigm shift in urban transportation. It is anticipated that these systems will alleviate congestion on the ground, reduce travel times, and provide new logistical solutions for emergency services, infrastructure monitoring, and public safety [18]. Nevertheless, the successful integration of flying cars into urban airspace necessitates addressing a number of challenges, including technological reliability, infrastructure development, social acceptance, and stringent regulatory compliance [23]. To this end, this study highlights some practical implications uncovered as a result of the literature review and provides recommendations on how this critical transition can be facilitated. In addition, in the presented study, fundamental flying car concepts are compared with each other from various perspectives, the most appropriate design configuration is selected, and a preliminary dimensioning approach that can be used for its design is introduced through a demonstration example.

Throughout history, urban mobility has undergone significant transformations [24]. From the invention of the automobile to the development of electric vehicles and the integration of autonomous technologies, innovative solutions have been continuously sought [25–27]. This has led to a futuristic vision that includes aerial mobility within cities. Flying cars are a vital component of UAM systems, a revolutionary concept redefining transportation in urban environments [28].

Aerial urban mobility has gained acceptance in the scientific community and has attracted interest since the beginning of the

21st century. Figure 1 illustrates the increasing number of scientific papers published on flying cars.

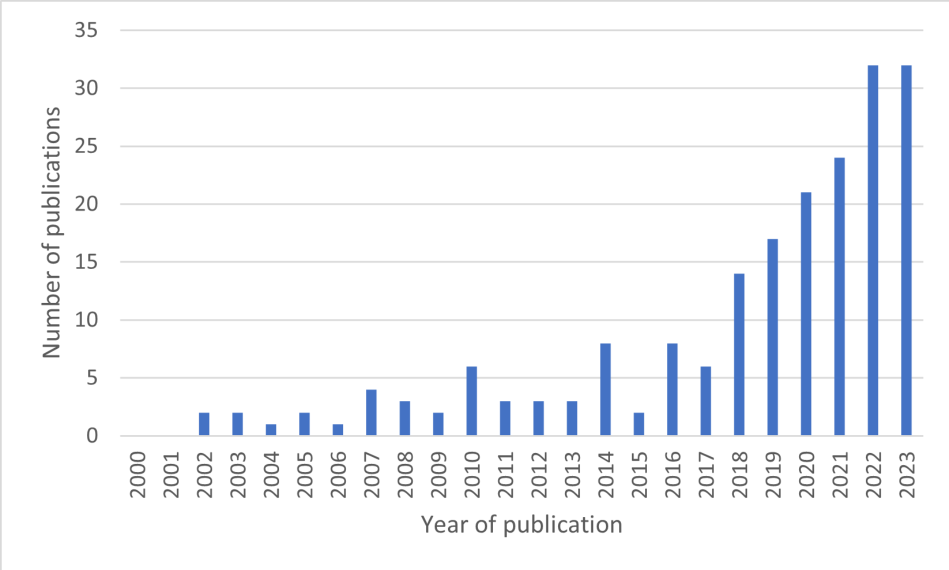

Fig. 1. Evolution of published papers on flying cars recorded in the Scopus database.

Due to the abundance of related literature, a review is necessary to synthesize the content by evaluating existing research [29]. To this end, identifying trends and patterns helps readers find the most relevant and valuable information on the topic [30], and this is the main objective of the present research work.

1.4 Organization of the manuscript

Apart from Section 1., which serves as an introduction to the present work, this paper is organized as follows. Section 2. classifies flying vehicles based on their rotor configuration, power type, and control mode. This classification was done before the literature review to provide context and understanding of the terminology used in the field of interest for the present investigation. Section 3. presents a historical summary of the evolution of flying cars. For this purpose, a narrative approach was employed to clarify the time evolution of the abstract concept and the practical implementation of a flying car. Section 4. outlines the methodology adopted for the systematic literature review process, the subsequent bibliometric analysis carried out in the paper, and the results obtained from the papers selected for the study. In particular, this review process was conducted between 2013 and the present. In Section 5., a categorized systematization of the set of papers analyzed in this investigation is provided. Section 6. discusses the practical implications and recommendations for the successful integration and adoption of flying cars. In Section 7., a comparative analysis of different flying car concepts is presented and a preliminary dimensioning approach for the selected design concept is explained. Finally, Section 8. summarizes all the work done, the conclusions of this investigation on flying cars, and the main lines of future research concerning urban mobility.

2. Vehicle design classification

2.1 Rotor configuration

This section examines critical aspects of flying car design, classifies them, and determines different configurations and design trends. By doing so, an analysis of the primary advantages and disadvantages of each design is presented herein.

Flying vehicles are typically classified based on rotor configuration and propulsion system architecture. In their study, Kiesewetter et al. evaluated NASA's list of UAM reference vehicles [31], the Vertical Flight Society's industry design directory classifications [32], and previous academic literature classifications [33] to identify five main types of rotor configurations [34]. These can be classified as rotary or fixed-wing, as shown in Figure 2.

The rotary-wing group includes "multirotor" and "rotorcraft" layouts. Multirotor designs (as shown in Figure 2a) generate lift through the action of each of their propellers, while rotorcraft configuration (as shown in Figure 2b) generates lift through a single propeller only [40]. An example of a multirotor flying car is the NEC Corp.´s quadcopter [35], while the PAL-V Liberty has the rotorcraft configuration [41]. On the other hand, fixed-wing aircraft are classified as lift+cruise, tiltrotor, and tilt-wing. The lift+cruise setup (refer to Figure 2c) features two distinct propulsion systems: one for lift and one for forward movement. As for the tiltrotor setup (refer to Figure 2d) and tilt-wing setup (refer to Figure 2e), both are categorized as vectored-thrust designs. This setup permits manipulating the propulsion system to direct thrust in multiple directions. Consequently, it enables the aircraft to utilize a single propulsion system for vertical take-off, landing, and forward flight [34]. The Boeing´s flying car is an example of lift+cruise [37], while the Moller M400 Skycar is an example of tiltrotor flying car [38] and the Terrafugia Transition is an example of tilt-wing configuration [39].

The multirotor configuration is known for its high stability and maneuverability and is a relatively simple mechanical system. However, it is less efficient during cruise flights, limiting its use to short-range operations, such as aerial photography, videography, infrastructure inspection, video surveillance, and airport shuttles [42]. The versatility of the rotorcraft configuration in take-off and landing, along with its good maneuverability, are its significant attributes. However, its stationary flight is characterized by a high power consumption [43]. Common uses for the rotorcraft include personal transport within urban environments and military and security applications [44]. Lift+cruise aircraft are renowned for their efficient cruise flight and vertical take-off, but this comes with added mechanical complexity. Their utilization covers short-haul, inter-urban, and regional flights [45]. Tiltrotors and tilt-wings also possess vertical take-off and landing ability, alongside cruise flight efficiency, resulting in increased horizontal flight speed. However, additional tilt systems and mechanisms are necessary, resulting in more complex mechanics and maintenance [46, 47]. This technology can be applied to long-range passenger and cargo transport and military operations [46].

(a) NEC Corp.'s quadcopter.

(b) PAL-V Liberty.

(c) Boeing´s flying car.

(d) Moller M400 Skycar.

(e) Terrafugia Transition.

Fig. 2. Primary flying cars rotor configurations [35–39].

2.2 Power type

Flying vehicles can be categorized into three types based on their propulsion system architecture: internal combustion, all-electric, and hybrid-electric systems. Most of these vehicles are powered by internal combustion systems [48]. Their chief benefit is the extensive knowledge in the domain that accompanies their use and the power they can generate, making them a suitable choice for long-distance travel. However, urban air mobility vehicles must utilize all-electric systems (refer to Figure 3) to comply with the low noise requirements in city environments [49].

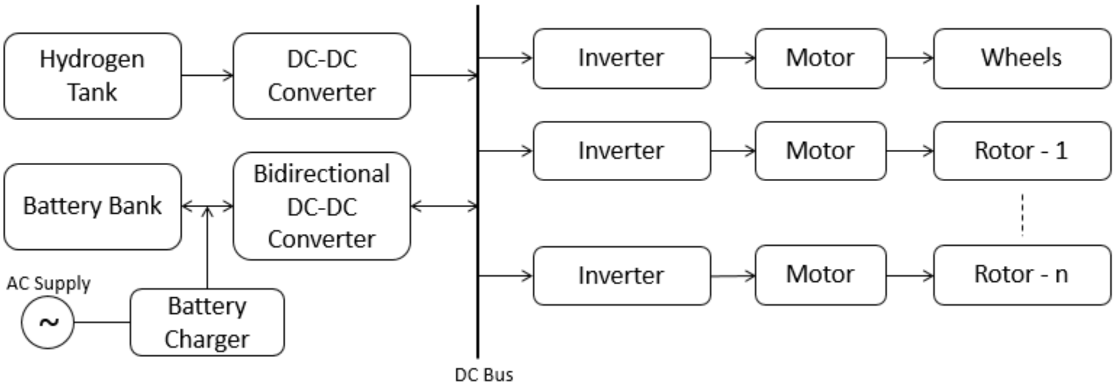

Fig. 3. Full-electric powertrain architecture with dual source-battery and fuel cell [13].

Hybrid systems (refer to Figure 4), which use an internal combustion system to produce electricity, may provide extended flight range with lesser noise than their internal combustion equivalents.

While fully electric flying cars have a flight range of 200 kilometers, hybrid-electric vehicles can travel up to 700 kilometers [50]. Nevertheless, noise impact remains a significant and restrictive factor in design [34].

Software is accessible to model noise contours and calculates travel routes that minimize noise impact, such as NASA's Aircraft Noise Prediction Program (ANOPP2) [51,52], and the NoiseMap suite [51]. Bian et al. found that full-electric vehicles have less impact on noise, whereas hybrid-electric cars are still in the development process [53].

2.3 Control mode

Based on the level of driving, cars and flying vehicles can be categorized into three types: autonomous driving, human-piloted, and hybrid driving. Autonomous driving vehicles pass without human intervention, typically controlled by artificial intelligence. These vehicles increase safety by minimizing human error and have the potential to optimize routes and efficiency [54,55]. However, decision-making challenges in dynamic environments and advanced perception technology requirements are significant weaknesses of autonomous driving vehicles [56–58]. Examples of such cars are the EHang 184 [59], and the Terrafugia TF-2 [60]. On the other end of the spectrum are human-piloted vehicles, which necessitate the direct involvement of a human pilot for flight and offer greater control in complex dynamic situations, as well as higher initial acceptance by users [56]. The primary drawbacks of

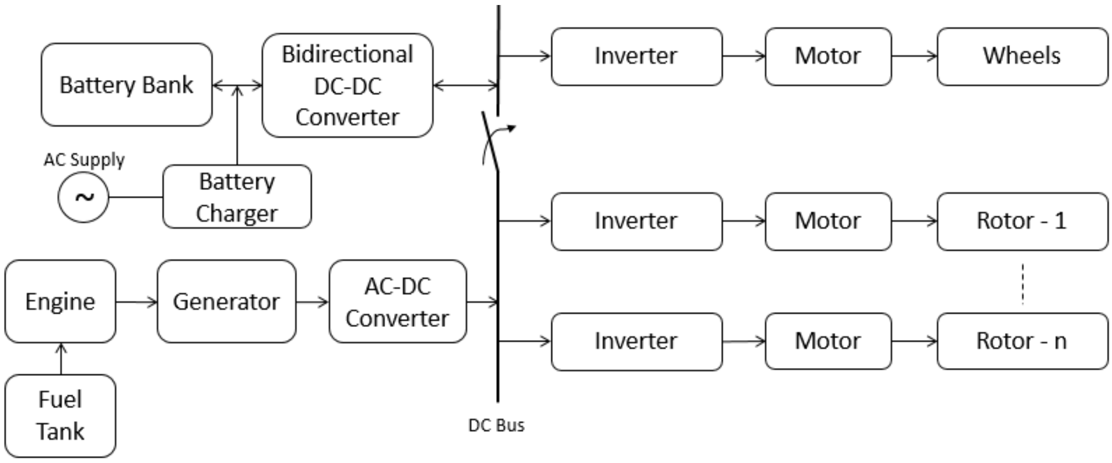

Fig. 4. Hybrid powertrain architecture with pure electric for drive and fuel engine for flight modes [13].

human-piloted flying cars include their reliance on the pilot's expertise and issues related to automation and efficiency [61]. PAL-V Liberty [36] and AeroMobil [62] serve as instances of human-piloted airborne vehicles. Hybrid driving vehicles, positioned between fully autonomous and human-controlled vehicles, offer flexibility to switch between driving modes according to conditions and preferences. They provide the advantage of adapting to different scenarios and optimizing resources based on the situation [63]. However, transitioning between modes requires safe systems and may entail complexities in the user-machine interface [63]. PAL-V VOLT (Drive & Fly Mode) [36] and Urban Aeronautics CityHawk [64] exemplify hybrid driving flying vehicles.

3. Historical Perspective

3.1 Overview

The idea of flying cars has a long history, with visionary geniuses like Leonardo da Vinci among the forerunners. Da Vinci sketched designs for aerial machines in his notebooks, drawing inspiration from bird-watching and mechanical principles [65]. Although these ideas did not materialize in his time, they laid the foundations for exploring the possibility of controlled flight. This section explains the development of the concept of flying cars until 2013 using a narrative literature review approach. By doing so, it is assumed that, by witnessing the time evolution of the idea of flying cars, the reader can better understand the objective foundations that made flying cars a reality.

3.2 Early 20th century

The 19th century was a significant period for the development of aerodynamics, mainly because of the critical contributions of George Cayley. Cayley is widely regarded as the father of aerodynamics, having formulated the fundamental principles of flight. He recognized the importance of fixed wings, control surfaces, and the need for a propulsion system [66]. His work established the essential concepts of lift and drag, laying the theoretical foundation for aviation [67]. Early theoretical concepts in this context focused on understanding the mechanical and aerodynamic principles of flight [68]. These concepts paved the way for future developments in aviation and formed the basis on which engineers and scientists built the first aircraft and flying cars.

The early 20th century saw significant progress in aerodynamics, which led to the development of flying cars. The Wright brothers' controlled flight in 1903 was a breakthrough [69]. Following this milestone, researchers began to study and improve airfoils. In the first two decades of the 20th century, the aviation industry made significant strides in engines and propulsion systems, paving the way for flying cars [70]. During this period, piston engines were the primary choice for air propulsion [71]. Experimental flying vehicles of the time used piston engines and adapted emerging aviation technologies [71]. The search for greater specific power and reliability to meet the unique challenges of flight was driven by conventional aircraft engines. Early attempts also investigated adapting piston engines for flying car designs, establishing the first links between the automotive and emerging aeronautical industries [72]. While limited in scope and capability, these experiments laid the foundation for future developments in propulsion systems for aerial mobility.

During the 1920s and 1930s, research was focused on improving the aerodynamic efficiency and stability of aircraft [73]. Pioneers such as Ludwig Prandtl and Theodore von Kármán made significant contributions to understanding wing theory and the lift/drag relationship [74]. Developing efficient airfoils became crucial in optimizing aircraft performance [75]. These aerodynamic advances influenced conventional aviation and the nascent exploration of flying cars [76]. A better comprehension of aerodynamic principles has allowed for the creation and construction of more efficient and stable aircraft, thus paving the way for future advancements in air transportation [77].

During the 1930s and 1940s, advancements in control technologies were instrumental in enhancing the stability and maneuverability of experimental flying cars [78]. The primary objective was to overcome control challenges in the dynamic aerial environment. Notably, the Cierva C.8L Autogyro [79] was a gyroplane symbolizing this era. These vehicles utilized improved control systems, capitalizing on rotary wing designs and emerging technologies [80]. Ailerons and rudders were commonly added to improve directional stability and maneuverability [81]. These developments set the foundation for more advanced systems, allowing for the incorporation of more sophisticated control technologies in flying cars [78]. Research during this era addressed critical challenges in navigation and control, paving the way for future advances in automated flight systems [82]. During this period, significant progress was made in experimenting with materials and structures for flying cars [83]. The focus was on reducing weight without compromising strength, which is essential for the efficiency and viability of these aircraft [83]. The introduction of aluminum alloys in airframe construction was a milestone [84], providing an optimal combination of strength and lightweight, improving the overall efficiency of flying cars [68]. Furthermore, composite materials were initially investigated, anticipating the requirement for more advanced structural solutions [85].

From the 1940s to the 1950s, research on flying cars focused on integrating autonomous systems and exploring technologies to pave the way for flight automation [86]. Significant advances were made during this period in pursuing more independent and safer operations [87]. Pioneering studies used gyroscopes to achieve automatic stability during flight [88,89]. The capacity to autonomously maintain balance was a significant advancement for the safety and efficiency of flying cars. Additionally, autopilot systems were introduced [90], which partially automated flight operations, freeing human pilots from routine tasks and enhancing overall safety.

3.3 Late 20th century

In the 1950s, there was a significant shift in the idea of flying cars due to advances in propulsion and theoretical concepts [91]. This period has marked the transition from piston engines to new forms of propulsion, such as jet engines [92]. This change affected not only conventional aviation but also the desire for ground vehicles that could fly. During this decade, aerospace technology and aerodynamics research significantly contributed to the theoretical foundations of personal air mobility [93]. The design of gravity-defying vehicles was better understood, with fundamental concepts such as lift and drag becoming crucial in the planning and constructing of flying car prototypes [20]. During this period, theoretical advances in aviation were significant, but practical application in functional prototypes was limited. Efforts focused on understanding how to translate theoretical principles into safe and efficient flying ground vehicles [76].

During the 1960s, practical applications of jet propulsion and flying cars advanced significantly [94]. The transition to jet engines enabled greater efficiency and speed, revolutionizing conventional aviation and opening up new possibilities for personal air mobility [95]. Practical experiments with model flying cars powered by jet engines have marked an important milestone. Prototypes incorporating these emerging technologies began to be developed, bringing with them the hope of a new era in mobility. These early attempts focused on the feasibility of jet propulsion and the stability and maneuverability of these hybrid vehicles [96]. Despite the advances, technological and engineering challenges remain. During this decade, there was a need for more advanced control systems and a better understanding of the interaction between propulsion and aerodynamics [97,98]. This led to a period of active experimentation that established the foundation for future improvements in flying car conception and design.

During the 1970s, the development of flying cars continued with a renewed focus on prototype creation and the consolidation of aerodynamic concepts. This period saw a significant increase in the construction and testing of experimental vehicles that incorporated the theoretical and practical advances of the previous decades [99,100]. The influence of aerospace research became more evident in more practical and efficient designs [101]. Researchers and designers in the past decade explored more advanced wing and rotor configurations to improve stability and flight performance for personal air mobility [102,103]. Efforts were concentrated on applying aerodynamics more effectively. Consolidation of aerodynamic concepts was fundamental in this decade, refining understanding the relationship between wing shape, lift and drag [104]. These advances improved existing prototypes and planned for more efficient and safer future designs. The vision of flying cars was still far from full-scale implementation, but this decade laid the groundwork for the next development phase [105]. This phase is characterized by integrating more advanced computer technologies and control systems.

The 1980s were a crucial time for the development of flying cars, as computer technologies and control systems advanced significantly [106]. With increased processing power and smaller electronic components, prototypes could incorporate more sophisticated control systems, resulting in improved stability and maneuverability [107]. Computer systems enabled better control of vehicles, enhancing safety and responsiveness during flight [108]. Additionally, flight autonomy was a key focus area, with computer systems enabling autonomous decision-making to maintain stability and safety [109]. The advancements in control technology during this decade paved the way for a new generation of flying cars that are more capable and safer. Furthermore, the merging of computer science and aerodynamics has created opportunities for automated flight research, leading to potential enhancements in the efficiency and operational safety of these vehicles [28].

In the last decade of the 20th century, there was a significant push towards exploring innovative materials and developing autonomous prototypes for flying cars [110]. This led to an increased focus on finding lighter and stronger materials, such as aluminum alloys, which offered an optimal combination of strength and light weight [111]. Research during this period was not limited to the structure of flying cars but also included the development of autonomous flight systems [112]. The ability to maintain balance autonomously was a significant advance in improving safety and efficiency [113]. Experiments with gyroscopes were conducted to achieve automatic stability during flight, and autopilot systems were incorporated to automate flight operations partially [114]. This decade has laid the foundations for autonomous personal air mobility, freeing pilots from routine tasks and improving operational safety. Advances in the last decade of the 20th century provided significant momentum toward the vision of personal vehicles that could take to the skies autonomously. However, flying cars were not yet an everyday reality.

3.4 From 2000 to 2013

During this period, there was a significant effort to find more efficient and sustainable propulsion systems. Electric motors emerged as a prominent alternative due to advances in battery technology [115]. This transition offered environmental benefits and the possibility of a more significant flight range [116]. Theoretical research focused on effectively applying these new forms of propulsion to flying cars, optimizing performance and energy efficiency [117].

The practical application of theoretical advances was translated into experimentation with prototypes, providing valuable data on flight performance and integrating new technologies. Extensive tests were conducted to assess the efficiency and feasibility of electrically powered flying cars with VTOL(Vertical Take-Off and Landing)-capable designs [118]. Experiments with different wing, rotor, and control surface configurations led to the definition of aerodynamic standards for the next generation of vehicles [119,120]. This iterative development process helped refine the shape and design of flying cars for optimal performance and represents a practical solution to logistical challenges, particularly in urban environments [121].

From 2000 to 2013, technology integration saw computers and control systems play a vital role. Miniaturization of sensors allowed for more accurate data collection, while improved control algorithms facilitated safer and more precise flight [122]. The sophistication of control systems enabled autonomous operations in certain flight phases, paving the way for automation and efficient fleet management [33].

The last stage of this development concentrated on finding lighter and stronger materials to enhance the efficiency of flying cars [123]. Advanced alloys and composite materials were experimented with in anticipation of the need for lighter structures that do not compromise strength [124]. Autonomy was a key area of research, with prototypes investigating the ability to make independent decisions to ensure stability and safety during flight [125].

4. Systematic literature review method

4.1 Generality

Literature reviews are crucial in providing a comprehensive and up-to-date view of knowledge in a specific field, particularly in continuous advancements in scientific and technological research. Researchers have relied on expert opinions from historical reviews to update their understanding of a particular topic of study or fundamental issue [126]. As discussed above, this paper first adopts the narrative literature review approach to provide a historical review of the topics of interest for this investigation. Subsequently, a systematic literature review approach is followed to determine an objective, comprehensive analysis of the previous and recent developments of flying cars.

As explained in [127, 128], a significant difference exists between the systematic literature review approach and the narrative method. Systematic reviews differ from traditional narrative reviews by adopting a replicable, scientific, and transparent process [129]. This process involves a detailed technology that minimizes bias through exhaustive literature searches of published and unpublished studies. Additionally, it provides an audit trail of the reviewer's decisions, procedures, and conclusions [130]. This section describes the methodology used to conduct a systematic review of the literature from 2013 to the present and its corresponding bibliometric analysis.

The historical literature review approach can be influenced by the reviewer's experience, prior beliefs, and subjectivity [131]. This is evident in the inclusion-exclusion criteria for papers, which are often not explained in the context of review papers. As a result, an arbitrary selection of evidence may not accurately represent the current state of knowledge [127]. Additionally, choosing certain studies over others can result in sample selection bias. Moreover, the data extraction process lacks standardization and systematization, and the synthesis of this information is often a narrative that places evidence side by side [131]. On the other hand, systematic approaches to the literature review, such as the techniques considered in this research, can overcome the limitations mentioned above [127]. This approach incorporates reliable methods for extracting factual and quantitative information from the literature, distinguishing it from traditional narrative reviews by adopting a replicable, scientific, and transparent process [126, 127].

This section describes the standard approach used to collect, refine, process, and analyze publications related to flying cars. In addition, a methodological bibliometric analysis is used to quantitatively study the collected literature material and identify relevant authors, publications, hot topics, and research groups.

4.2 Implementation of the proposed methodology

The systematic literature review method described above was successfully implemented, and the results of the present analysis are described in detail herein. The review was conducted in accordance with rigorous methodological standards to ensure both the comprehensiveness and the credibility of the findings.

Figure 5 shows the data obtained using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standard procedure [132].

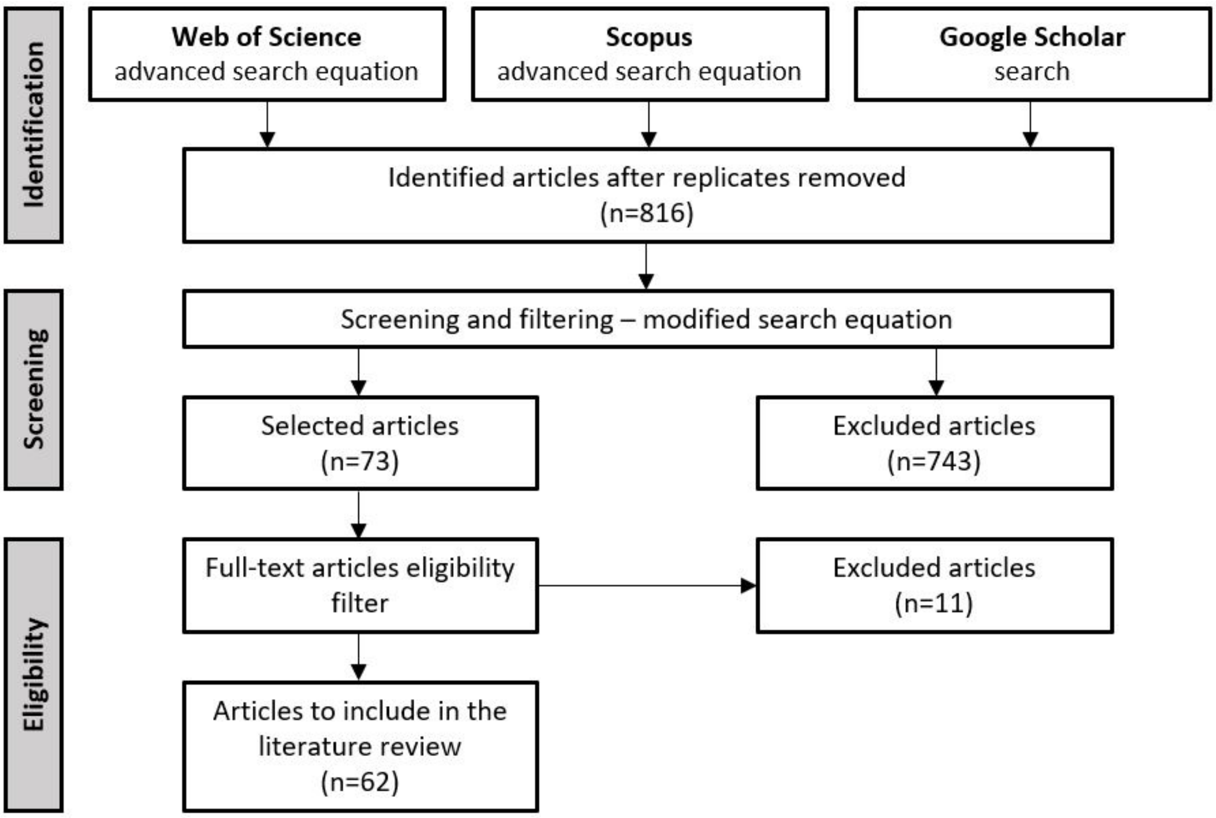

Fig. 5. Systematic literature review methodology - PRISMA flow diagram.

Figure 5 shows the systematic process used to identify relevant publications from 2013 to the present. This process guides the reporting of systematic reviews. A specific set of criteria was employed for the purpose of study selection. The review encompassed studies that concentrated on the technological advancements, infrastructure development, social considerations, and regulatory frameworks pertaining to flying cars and UAM. Studies that did not address the aforementioned areas or offer substantial insights into the field of flying cars and urban aerial mobility were excluded from the review. For each selected study, data were extracted on the study's purpose, methodology, findings, and implications. The input for the Web of Science and Scopus databases was an advanced search string with boolean operators as follows:

(”Flying Car” AND (”Aerial Vehicle” OR ”Vertical Takeoff and Landing” OR ”Urban Air Mobility” OR ”Personal Air Vehicle” OR VTOL))

A supplementary Google search was conducted using the same keywords. The combined results were filtered, and any documents that were not relevant to the objective of this review were excluded.

4.3 Bibliographic analysis

The bibliographic analysis of all documents indexed in Web of Science and Scopus was conducted using the Bibliometrix tool in R software [133]. Tables 1, 2, and 3 provide preliminary information on the literature collected, including the number of journals, average publication year, average citations per document, and total number of authors, among other details.

Table 1. Main information about the recollected documents.

Main information about data	Results
Timespan	2013 : present
Sources (Journals, Books, etc.)	48
Documents	62
Average years from publication	3.49
Average citations per documents	10.09
References	1901

Table 2. General information on document types and content.

Document types	Results
article	32
book chapter	3
conference paper	24
conference review	3
Document contents	**Results**
Keywords Plus (ID)	395
Authors Keywords (DE)	155

Table 3. General information on authors and author collaboration.

Author	Results
Total authors	172
Authors of single-authored documents	11
Authors collaboration	**Results**
Single-authored documents	12
Co-Authors per document	3.14

Table 4 lists the most relevant articles selected systematically, while Table 5 lists the most influential references for the documents in the systematic review.

Table 4. The top 10 most cited document in the review collection.

Most cited document	Total Citations	Total Citations per Year
KASLIWAL A, 2019, NAT COMMUN [134]	108	18.00
COHEN AP, 2021, IEEE TRANS INTELL TRANSP SYST [20]	100	25.00
RAJASHEKARA K, 2016, IEEE ELECTRIF MAG [135]	43	4.78
POSTORINO MN, 2020, SUSTAINABILITY [136]	35	7.00
AHMED SS, 2021, J AIR TRANSP MANAGE [137]	31	7.75
PAN G, 2021, IEEE ACCESS [28]	26	6.50
AHMED SS, 2020, FRONT BUILT ENVIRON [25]	26	5.20
LUO Y, 2021, ETRANSP [138]	21	5.25
SHI X, 2018, PROC IEEE CONF DECIS CONTROL [139]	19	2.71
COKORILO O, 2020, TRANSP RES PROCEDIA [24]	15	3.00

Figure 6 displays the scientific production of the top 10 authors during the period considered in this study.

In particular, the factorial analysis was carried out by using the Multiple Correspondence Analysis (MCA) technique with the authors' keywords of the collection of selected articles. Figure 6 shows the number of documents published, with bubble size indicating the quantity. In Figure 6, small bubbles represent one publication, while large bubbles represent two. The intensity of the

Table 5. The 10 most cited references in the review collection.

Most cited references	Total citations
GRAYDON, ET AL., SUPRA NOTE, 120 [140]	6
BACCHINI A, 2019, AEROSPACE [141]	3
EKER U, 2020, TRAVEL BEHAVIOUR AND SOCIETY [142]	3
TRANCOSSI M, 2015, SAE TECHNICAL PAPER [143]	3
UBER ELEVATE [144]	3
ABIDIN A.Z, 2004, 9TH ASIAN PACIFIC INTEGRATED MODEL (AIM) WORKSHOP [145]	2
FED. AVIATION ADMIN., 2009, NEW YORK CLASS B AIRSPACE HUDSON RIVER [146]	2
MORGAN STANLEY, 2019, ARE FLYING CARS PREPARING FOR TAKEOFF? [147]	2
ARIFFIN R.N.R, 2013, PROCEDIA ENVIRONMENTAL SCIENCES [148]	2
BANSAL P, 2016, TRANSPORT. RES. C EMERG. TECHNOL. [149]	2

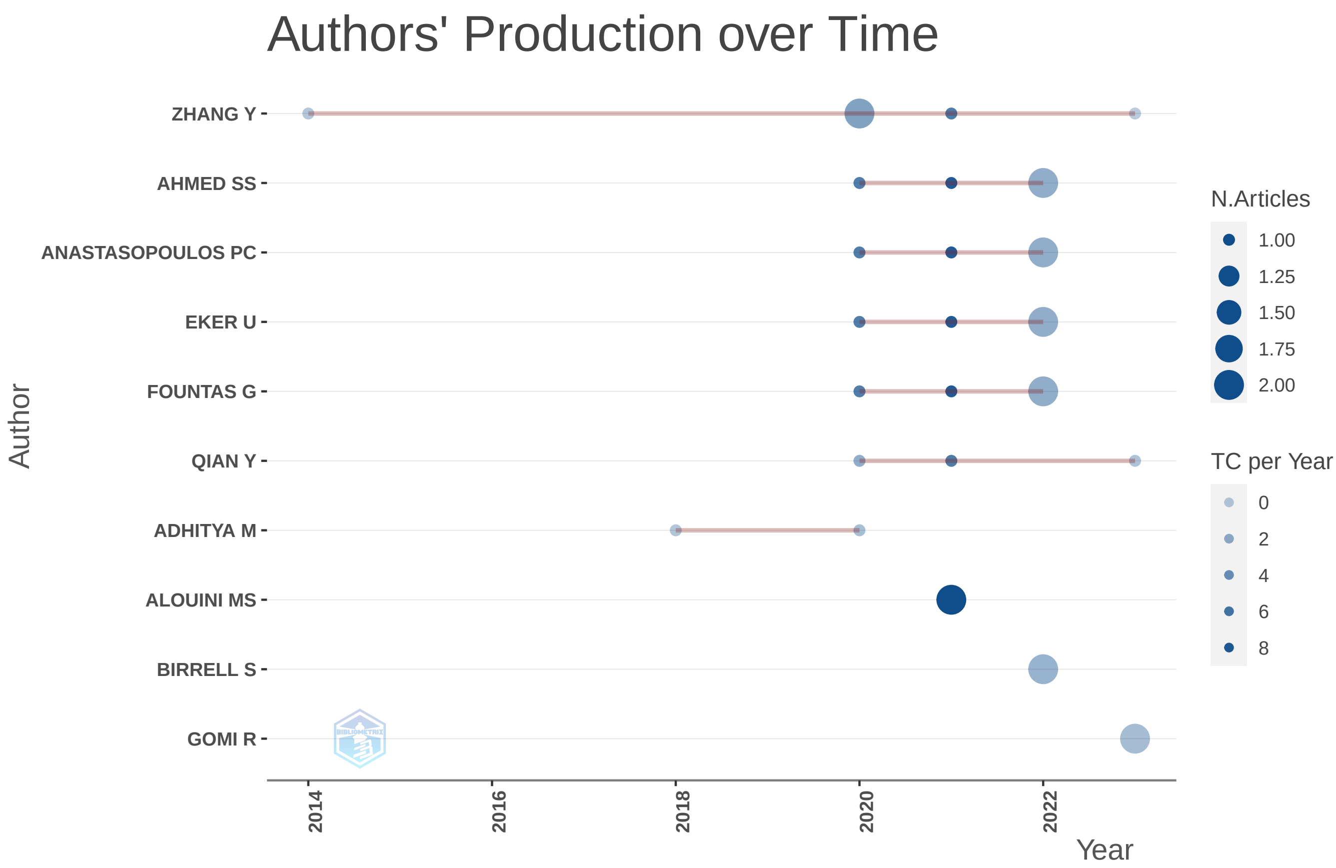

Fig. 6. The top 10 authors production over time. Bubble size indicates the number of documents published. Small ones represent one publication and the large ones two. The colour intensity is proportional to the total citations per year.

color indicates the total citations per year. The authors are listed in descending order of relevance. The relevance of the analysis is evaluated based on the number of publications within the established time interval.

Figure 7 shows the conceptual structure map of the research topics reviewed in this work.

Figure 7 shows the relationship between words based on the proportion of documents containing them as keywords. This indicates their similarity [150]. Figure 7 shows the center of the research field as the origin of the axis, which represents the average position of all column profiles [133,150]. The percentages reported in the Dim 1 (63.88%) and Dim 2 (25.75%) axes represent the data variation resulting from dimensionality reduction. The K-means algorithm identified 4 clusters, each represented by a different color. Purple means advanced aviation technologies, blue refers to propulsion, green encompasses aircraft operations and design, and red includes aspects related to urban air mobility.

Figure 8 displays the social structure of the researched field through a co-authorship network, illustrating the association between the authors of the systematically collected documents in this review paper [150].

The format used to mention each author is "surname + first initial letters of their names". The Kamada-Kawai network layout and normalization using the Salton index and clustering with the Louvain algorithm were employed. The size of the edges is proportional to the number of shared works between the connecting authors. The colors represent the identified clusters of common co-authorship.

Figure 8 helps to identify influential research groups and authors. In this case, Sheikh Shahriar Ahmed, Ugur Eker, Grigorios

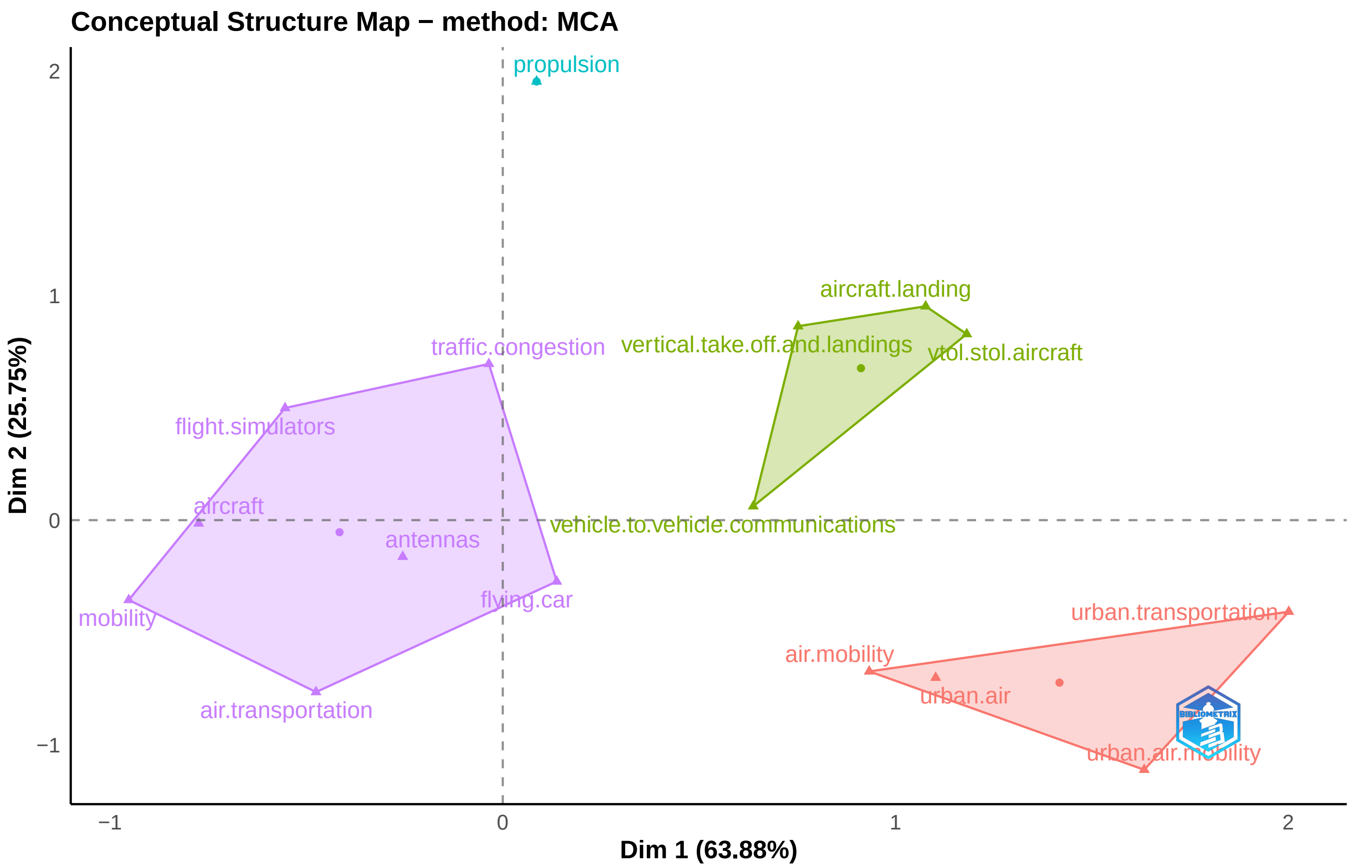

Fig. 7. The conceptual structure map created with the MCA algorithm and the K-Means clustering algorithm.

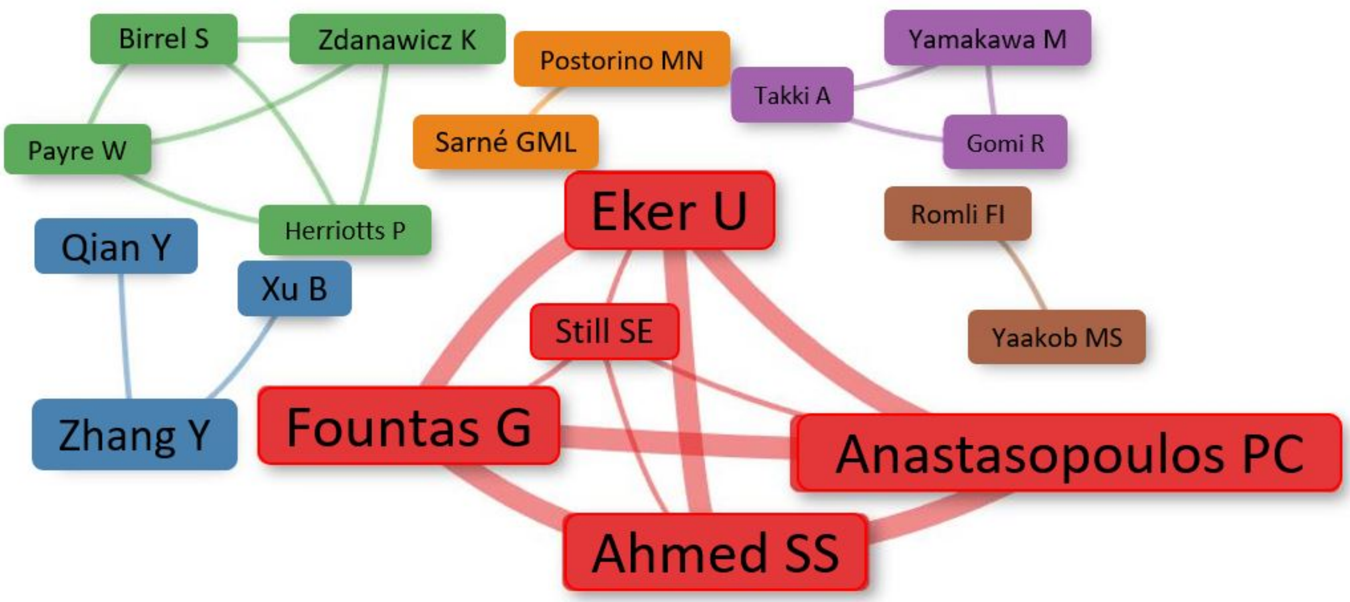

Fig. 8. Authors collaboration network.

Fountas, and Panagiotis Anastasopoulos are the most influential authors in the time window analyzed in this study.

In summary, the systematic methodology used in this work enabled the identification of the leading research papers available in the literature. This identification allowed for recognizing the fundamental problems related to flying cars. The following section discusses these fundamental issues in detail.

5. Fundamental issues

5.1 Summary

This section analyzes the main issues related to flying cars identified in the systematic literature review process performed before. A more exhaustive reading of the collected papers has been done to achieve this goal. The following research branches have been identified based on this reading and the conceptual map created with the MCA algorithm and the K-Means clustering algorithm. The fundamental issues identified by the systematic review analysis and discussed herein deal with the technology of flying vehicles, their infrastructures, the social consideration of this new means of transportation, and the novel set of regulations to be introduced for the proper fruition of flying cars.

5.2 Technology

Technological advancements in aerial vehicles have accelerated significantly since 2013, transforming the once futuristic concept of flying cars into a tangible reality with the potential to revolutionize transportation. The key technological challenges related to flying cars include vehicle design, vehicle architecture, modeling and simulation tools, and energy and power systems. In this section, we synthesize these key aspects, highlighting their interconnections and common themes.

5.2.1 Vehicle design

The design of flying cars represents a groundbreaking advancement in transportation by integrating aerospace and automotive technologies. This hybridization addresses the limitations of traditional terrestrial mobility, as discussed in [151,152]. The design process prioritizes both function and form, focusing on aerodynamics, vertical propulsion, safety, and efficiency for three-dimensional travel. The result is not only a futuristic aesthetic but also a vehicle optimized for practical use.

Within the realm of propulsion systems, there are two main categories of propellers that have been extensively researched: cycloidal blade propellers and fan wing propellers. The cycloidal blades mode offers features like vertical take-off and landing (VTOL), instantly alterable vector thrusting, and low noise levels, making it highly versatile [153]. In contrast, the fan wing mode excels in providing high efficiency, energy savings, and stable low-speed cruising without stalling [154]. Thus, there exists a trade-off between optimizing cruising efficiency and enhancing vehicle stability.

A noteworthy contribution to this field is Li's innovative propulsion system design, which ingeniously combines cycloidal blades and fan wing propellers to address the balance between cruise efficiency and stability [155]. Furthermore, Shao et al. conducted simulations using MATLAB Simulink to demonstrate that ducted fans outperform isolated fans in terms of lift and noise control [156]. Trancossi et al. introduced a novel propeller wing design based on the Coanda effect, which is the tendency of a fluid jet to adhere to a convex surface [157, 158]. This design incorporates a morphing ducted-fan concept to maximize lift at low speeds, specifically between 5 to 30 meters per second.

In addition to propellers, the fuselage plays a critical role in the aerodynamics of flying cars. Mihara et al. optimized the fuselage design for multi-rotor, vectored-thrust (tilt-rotor), and lift + cruise types of flying cars [159]. They identified four objective functions crucial for the sustainability of flying cars: the energy required for a round trip, rotor noise, rotor downwash speed, and landing area size. Their analysis revealed that current lithium-ion battery capacities are insufficient for these designs, necessitating advancements to at least 293 watt-hours per kilogram. While flying cars demonstrate lower noise levels compared to conventional helicopters, the development of rotors that further minimize environmental noise is essential. Moreover, flying cars have an advantage in landing capabilities, as their downwash speeds and required landing areas are smaller, allowing them to land in more confined spaces.

The control system is an essential component of flying cars, particularly in the context of automation. Shi et al. proposed a novel controller framework for VTOL vehicles with wings, which serves two primary functions: determining the vehicle's position and velocity based on input forces and moments, and calculating the necessary forces and moments for achieving desired trajectories [160]. Prototype testing has demonstrated the system's stability and robustness against external factors like strong winds. Despite these advancements, a universal control model adaptable to various propulsion systems, such as multirotor and tilt-wing, is still needed. During the transition from ground to flight in VTOL aircraft, stabilizing the pitching oscillation is crucial. Xu et al. developed a control module that quickly mitigates these oscillations, achieving stabilization within six seconds [161]. Research continues on strategies to further reduce oscillation amplitude and time, thereby enhancing flying car stability.

5.2.2 Vehicle architecture

The architectural design of flying vehicles presents a unique challenge, as it requires the seamless integration of aeronautical and automotive engineering principles to redefine mobility. Designers must incorporate vertical and horizontal propulsion systems, along with advanced navigation and control technologies, to facilitate the transition from terrestrial to aerial operation. The primary goals of vehicle architecture are to enhance user safety and comfort while addressing the complexities of three-dimensional travel.

Rajashekara et al. explored the architectural considerations of different propulsion systems, including internal combustion, electric, and hybrid engines [135]. Each mode of transportation, whether on the ground, during lift, or in flight, may necessitate distinct propulsion solutions. For example, VTOL operations might require a dedicated engine separate from the one used for cruising, depending on performance and range requirements. A study by Rajashekara et al. concluded that the optimal strategy involves using identical components or subsystems for ground propulsion, flight, and lift. This approach minimizes deadweight, as it eliminates unused functionality that might be needed in one operation but not in another [135].

5.2.3 Modeling and simulations

Simulations are a cornerstone in the development of flying cars, offering a virtual platform to assess various flight conditions and operational scenarios. These simulations range from aerodynamic assessments to comprehensive flight simulations, providing critical insights for optimizing the design and performance of flying vehicles. They also play a vital role in safety evaluations, enabling engineers to foresee and mitigate potential challenges before physical testing.

Traditional simulation methods can be computationally intensive due to the complex movements of aircraft. However, innovative techniques like Moving-Grid Finite Volume (MGFV) and Moving Computational Domain (MCD) have emerged, allowing for accurate simulations of aircraft behavior during critical phases like take-off and landing [162]. Gomi et al. employed these techniques to simulate the take-off and yawing phases of an eVTOL aircraft with coaxial propellers, revealing that altitude differences did not significantly impact aircraft behavior, though they did affect ground-level wind strength [163]. Future research will focus on how atmospheric conditions influence eVTOL performance at varying altitudes.

Takii et al. used similar modeling techniques to simulate turning flights of an eVTOL flying car, considering interactions between fluids and rigid bodies [164]. They discovered that the numerical simulations produced a turning radius 22% larger than theoretical predictions [164]. This demonstrates the value of these techniques for large-scale simulations without excessive computational costs. Additionally, Proper Orthogonal Decomposition (POD)-based Reduced-Order Models (ROM) offer a mathematical approach for analyzing complex systems with high-dimensional data. This method is particularly useful in fluid dynamics and structural mechanics, as it enables efficient real-time simulations and optimization by reducing the system to its dominant modes [165]. Peters et al. successfully applied POD ROM to predict rotor distributed loads with remarkable accuracy and efficiency, reducing simulation time from 20 hours to less than a second while maintaining an error margin of under 1% [166]. However, further studies are necessary to fully understand the application challenges of POD ROM in rotor modeling.

CFD simulations under complex conditions, such as turbulent inflows, are recommended to enhance the accuracy of POD-based ROMs. Including these variables will test the model's capability to extract meaningful data in intricate domains [166].

In a separate study, Pardede and Adhitya used a scaled model and wind tunnel to evaluate the aerodynamic stresses on a fixed-wing flying car during flight [167]. They applied a dynamic model to calculate take-off and landing distances, finding that the flying car required 415.10 meters for take-off and 325.63 meters for landing [167]. While these distances are shorter than those needed by commercial aircraft, they are longer than the few meters VTOL aircraft require, highlighting VTOL's clear advantage in confined spaces.

5.2.4 Energy and power

Efficient propulsion systems are essential for flying cars, as they must operate effectively in three-dimensional environments. This transition from ground to aerial mobility necessitates the development of compact, lightweight energy and power technologies capable of supporting take-off, flight, and landing. Managing energy efficiently is crucial to maximizing range and reducing fossil fuel dependency, which can be achieved through sustainable solutions like electrification and renewable energies. Therefore, optimizing energy and power systems is critical for flying cars' viability and performance.

Luo et al. proposed a model using flight mission profiles to simulate the power battery's operating characteristics, such as current, power, and state of charge (SOC) [138]. Their findings showed that take-off and landing phases demand more energy than cruising, making them the limiting factors in mission planning. The power characteristics are mainly influenced by speed and acceleration parameters, with each 100-meter increase in flight altitude reducing the cruising range by nearly 20 kilometers. Consequently, enhancing battery energy density is essential for flying cars, as they require higher capacities than traditional electric vehicles [138].

Liu's work focused on the sensitivity of total cost of ownership estimates to changes in VTOL technical and cost parameters, using a Monte Carlo simulation to analyze various factors [168]. These factors include cruising speed, altitude, energy reserves, battery energy density, and costs associated with VTOL body manufacturing, maintenance, and energy prices. The analysis of 50,000 cases indicated that battery-electric VTOLs are already the most cost-effective option for trips below 200 kilometers, such as intra-city and short-range inter-city travel [168]. Improving battery energy density to 600 watt-hours per kilogram would provide a significant cost advantage for battery-electric VTOLs across all ranges, offering high returns on investment [168]. While fuel cells and internal combustion engines might be cost-effective for long-range applications under certain conditions, they face strong competition from ground transport options like high-speed rail. The study concludes that prioritizing battery-electric VTOL development and creating high-energy-density batteries tailored for VTOL applications is crucial [168].

5.3 Infrastructure

Infrastructure is crucial for successfully implementing flying cars, as it shapes the environment for take-off, flight, and landing. Introducing these innovative aerial vehicles requires careful infrastructure planning, including installing vertical take-off and landing ports and implementing dedicated air traffic management systems. Additionally, it is essential to consider aspects such as energy recharge, vehicle maintenance, and the creation of safe and efficient air routes. The construction of adequate infrastructure ensures the operability and safety of flying cars and lays the foundation for their successful integration [169, 170]. As discussed in detail below, the principal issues related to the infrastructure of flying cars are the operation and management, the communications and air traffic management, and cybersecurity in general.

5.3.1 Operation and management

The operation and management of flying cars present unique challenges beyond technical aspects. Introducing aerial vehicles necessitates a comprehensive approach to air traffic planning and management, efficient route coordination, and advanced control and communication systems. Safety is also crucial, including implementing emergency protocols and continuous monitoring systems. Fleet management, preventive maintenance, and integration with urban infrastructures are also essential elements. In addition, the efficient and safe operation of flying cars requires close collaboration between governmental entities, regulators, and private companies. This will lead the way toward aerial mobility that is not only technologically advanced but also organized and safe in its day-to-day operation.

Romli and Yaakob analyzed the time and cost of using a Personal Air Vehicle (PAVE) for domestic use [171]. The case study examines a standard route for UPM students from the University Putra Malaysia (UPM) in Serdang, Selangor, to Pekan Rabu in Alor Setar, Kedah. The study found that using a PAVE is more time-efficient, while people are willing to pay an average extra cost of 1.31 dollars per hour less on the road [171].

Postorino et al. discussed three types of scenarios for urban air mobility: point-to-point services, long/medium-distance trips, and short/medium-distance trips [136]. After describing each scenario, they analyzed the mobility for short/medium-distance trips and concluded that it would be the scenario that most closely resembles urban air mobility. After studying this scenario with different levels of demand, it was observed that as demand increases, network congestion also increases, resulting in increased costs and travel times. However, increasing the number of connections can help to decongest traffic [136]. The goal is to find the equilibrium point that optimizes the flow of vehicles, minimizes time and costs, and avoids or minimizes traffic congestion.

In contrast, Kish et al. compared the standard flight path of 10 nautical miles at 2000 feet to the typical route from Chicago airport to the city center [172]. The study utilized three established aircraft models: the R44, the C172, and the Velis. The research aimed to measure the ability of these three certified aircraft to execute a reference mission trajectory that is appropriate for most metropolitan areas. According to [172], the C172 offers a precise cost and time advantage, with a fee of 75 dollars per passenger and a travel time of 11 minutes. However, it is essential to note that the price is relatively high compared to existing ground transport options.

Optimizing fuel efficiency is crucial in efficiently using energy resources during vehicle operation, especially given the growing environmental awareness and the need to reduce greenhouse gas emissions [173]. In [174], Yang et al. proposed an intelligent energy management strategy based on deep reinforcement learning to optimize fuel and electricity use in a flying car. The study describes two scenarios, namely Search and Rescue (SAR) and Urban Air Mobility between two points (UAM point-to-point). It compares two algorithms. For this purpose, the paper uses DP-based (Dynamic Programming) and DDQN-based (Double Deep Q Network) algorithms for UAM point-to-point transportation. Compared to the DP algorithm benchmark, the DDQN algorithm results in an 11.20% higher total cost but a 63.01% shorter computation time for SAR. Therefore, the power distribution strategy based on the DDQN algorithm produces a total cost similar to that of the DP algorithm but with a shorter computation time [174]. The total cost based on DDQN is 1.81% higher than the benchmark, but the computation time is 69.66% shorter. The power distribution strategy based on the DDQN algorithm generates a total cost similar to the DP algorithm but with a faster computation time [174]. Although the time taken to calculate optimal energy resources has been significantly reduced, a solution to simultaneously reduce fuel costs has yet to be found.

5.3.2 Communications and air traffic management

Flying vehicles are identified by a unique number that enables them to communicate their position [175]. However, the introduction of flying cars has led to identifier saturation [176]. To address this issue, Ghayouraneh et al. [177] proposed a dynamic system for assigning identifiers, which avoids the traditional static system's saturation problem. After simulating various demands, the researchers observed satisfactory results with this new methodology. However, further simulations are necessary during peak times and dates to estimate its performance in crucial situations. They concluded that despite having a dynamic allocation for the identifier of flying vehicles, a central control system would be necessary to store all flight information in different regions [177].

Flying cars can use the ground communication system during take-off and landing but require a wireless communication system for the cruising phase. In their paper [178], Saeed et al. suggested four options for wireless communication, that is, Connectivity Using Cellular Networks, Connectivity Using Tethered Balloons, Connectivity Using High-Altitude Platforms, and Connectivity Using Satellite Networks. They also proposed a design methodology for each option. However, it should be noted that using Cellular Networks may not provide adequate coverage. To adapt these optimizations for eVTOL and improve communication, it is proposed to add extra antennas pointing towards the sky. However, this would require a financial investment and a careful selection of antenna locations. Tethered balloons, a known technology with an operating range of 200-400 meters [179], have been used in the past. Flying cars operate at a height of 300 meters [178]. Therefore, their position must be well-controlled to avoid collisions. High-altitude platforms are a better option as they operate at greater altitudes, avoiding collision risks and providing a more comprehensive communication range. Satellites, however, can provide real-time information on eVTOLs' position, speed, altitude, and direction and send it to the ground, enabling continuous tracking [178]. Furthermore, due to their increased range, they can cover greater communication distances, reaching areas other systems may not be able to. Of the four systems mentioned, the satellites are the most advantageous.

5.3.3 Cybersecurity

Although this innovation can potentially revolutionize travel, it presents significant security challenges, particularly in the cyber realm. The interconnectivity of these vehicles creates new vulnerabilities that cybercriminals could exploit, with potentially devastating consequences. The most common types of cyber-attacks include jamming, spoofing, man-in-the-middle attacks, and denial-of-service attacks.

Jamming attacks involve malicious interference in wireless communication systems, such as Wi-Fi, Bluetooth, mobile phone networks, and GPS (Global Positioning System) systems [139]. A jamming attack aims to disrupt essential services, prevent devices from communicating, or even take down a network entirely in a denial-of-service attack [180]. Jamming attacks use physical devices to overload a network with strong signals, disrupting normal operations [181]. Telecommunications fraudsters can take advantage of service disruption and confusion for callers by committing fraud attacks, such as call spoofing.

Spoofing is assuming someone else's electronic identity to conceal one's identity and commit crimes on the internet. In the context of UAM, this may involve receiving false GPS information about a vehicle's position. Spoofing can cause the car to deviate from its route and, in the worst case, cause an accident. This can happen to the GPS and the vehicle's control and stabilization systems [182, 183].

A Man-In-The-Middle (MITM) attack is a type of cyberattack in which the attacker secretly intercepts and may even modify the communication between two parties who believe they are communicating directly with each other [184]. The attacker positions themselves between the two parties and must be able to observe and intercept messages without either party being aware that their communication has been compromised. An example of an MITM attack is active eavesdropping. This occurs when an attacker establishes separate connections with two victims and relays messages between them, tricking them into believing they communicate directly over a private connection. However, the attacker controls the entire conversation [185]. This type of attack can cause severe consequences in the UAV environment, mainly if the pilot contains the vehicle from a first-person point of view. In this scenario, an MITM attack can cause the aircraft to crash.

A Denial-Of-Service (DOS) attack is an attempt to make a computer system or network unavailable to legitimate users [186]. This is typically achieved by consuming the victim's network bandwidth or overloading the computational resources of the attacked system [187]. DOS attacks overload server ports with multiple information streams, rendering the server unable to provide its service. A DOS attack can undermine a UAV's controls or video transmission, depending on the type of communication link that uses the wireless connection [188].

In [189], Tang analyzed the cybersecurity vulnerabilities of UAM and proposed a system to resist and minimize the risk of cyber-attacks. The proposed system includes fully autonomous flight supported by physical loading of flight map plans, multiple inter-validating navigation systems, symmetric encryption for combined video transmission, secondary control, and navigation data link, asymmetrically encrypted ADS-B (Automatic Dependent Surveillance-Broadcast) and RFID (Radio Frequency Identification) tags for air traffic controllers and law enforcement, and blockchain-based PKI (Public Key Infrastructure) for management of keys [189]. This may improve social acceptance by reducing the risk of cyber-attacks on a flying car.

5.4 Social consideration

The integration of flying cars into modern transportation systems extends beyond mere technological advancement; it ushers in a new era that demands careful consideration of societal impacts. This innovation's potential to reshape urban dynamics, influence space distribution, and affect quality of life necessitates a broader perspective on its implications. As we delve into the critical issues associated with flying cars, we explore equitable access to this new mode of transport, the potential to alleviate traffic congestion, and the reduction of environmental pollution. Furthermore, attention must be given to the societal concerns of noise, privacy, and public acceptance, which are intrinsic to the successful deployment of flying cars. This section aims to synthesize the available literature and highlight the relationships between the environmental and acoustic impacts and the social acceptance of flying cars, underscoring the need for a harmonious balance between technological innovation and social welfare.

5.4.1 Environmental and acoustic impact

The environmental implications of flying cars are a focal point in assessing their feasibility and societal acceptance. Greenhouse gases (GHGs), particularly carbon dioxide, methane, water vapor, and nitrous oxides, play a significant role in climate change by trapping heat within the Earth's atmosphere [190, 191]. Kasliwal et al. [134] provide an insightful analysis of the energy consumption and GHG emissions associated with Vertical Take-Off and Landing (VTOL) vehicles compared to traditional ground-based cars. In scenarios where VTOLs operate over a distance of 100 kilometers with a single pilot, GHG emissions are observed to be 35% lower than those of Internal Combustion Engine Vehicles (ICEVs) but 28% higher than Battery Electric Vehicles (BEVs) [134]. Notably, when VTOLs are fully loaded with three passengers, their emissions per passenger-kilometer are 52% lower than ICEVs and 6% lower than BEVs, presenting a promising case for their environmental viability [134].

Expanding upon this, studies by Alfonso et al. [192] and Mundumba et al. [193] draw comparisons of Urban Air Mobility (UAM) emissions across different regions, such as Chicago, Dallas, Sweden, and the European Union. These studies reinforce Kasliwal et al.'s findings by demonstrating that regions utilizing higher percentages of renewable energy sources for electricity production incur lower environmental impacts. This relationship underscores the potential synergy between renewable energy adoption and UAM technologies, as increased renewable energy usage can substantially mitigate the environmental footprint of flying cars [134].

The material composition and manufacturing processes involved in flying car production also contribute significantly to their environmental impact. André [194] emphasizes that the materials used for non-recurring components account for 5% to 10% of a vehicle's total life cycle carbon footprint. Of the materials examined—aluminum, steel, titanium, copper, carbon fiber, and polymers—carbon fiber emerges as a favorable option due to its relatively low production-related emissions, second only to titanium. Given that carbon fiber constitutes up to 60% of an eVTOL's material composition, optimizing its use can play a crucial role in enhancing environmental sustainability. André further suggests that maximizing passenger capacity is critical to improving the ecological efficiency of flying cars [194], a notion supported by Prakasha et al. [195], who propose that autonomous piloting could enhance passenger loads and reduce environmental impact.

In addition to environmental considerations, the acoustic impact of flying cars remains a significant societal concern. The noise generated by different vehicle configurations, particularly rotary-wing versus fixed-wing configurations like lift + cruise, can influence public acceptance. Research by Zhang [196] indicates that rotary-wing designs generally produce lower noise levels, whereas fixed-wing configurations disperse noise in both horizontal and vertical directions, potentially increasing acoustic disturbances. Little et al.'s work highlights that the Mach number of the blades, rather than the number of rotors, primarily dictates sound intensity [197].

Understanding how individuals perceive noise is also critical. In a novel study by Hara et al. [198], the authors employed electroencephalography (EEG) to evaluate stress responses to industrial drone noise, a proxy for future flying car sounds. Despite reducing the noise volume from high levels (86-92 decibels), stress indicators remained elevated, suggesting a heightened sensitivity to aerial noise [198]. The study proposes that perceived noise levels must remain below 73 decibels to facilitate societal acceptance of this transportation mode.

To further illustrate the potential noise impact, Glaab et al. [199] simulated two scenarios in New York City, considering different vertiport locations. Their findings indicate that locating a vertiport within the city significantly exceeds the 50-decibel noise threshold established by the Federal Aviation Administration (FAA). In contrast, situating vertiports on the city's outskirts maintains noise levels within acceptable limits.

In conclusion, it is imperative to analyze each flying vehicle configuration on a case-by-case basis, incorporating detailed flight path assessments and empirical flight tests. By validating noise emission data, stakeholders can develop strategies to mitigate acoustic impact, fostering a more harmonious coexistence between flying cars and urban populations.

5.4.2 Social acceptance

The societal embrace of flying cars hinges upon understanding and addressing public perceptions and acceptance, a vital determinant of the successful deployment and integration of aerial mobility solutions. The research by Ahmed et al. [25] offers valuable insights into the socio-demographic factors influencing public willingness to adopt flying taxis. Analyzing responses from 692 individuals across 27 countries, the study reveals that gender, age, ethnicity, education level, income, and household composition significantly impact individuals' willingness to engage with flying taxi services. Moreover, personal factors, such as driving experience, accident history, and vehicle maintenance costs, alongside perceived benefits and concerns, play crucial roles in shaping public attitudes toward this new transport modality. The research indicates distinct variances among ethnic groups, with Asians displaying a greater propensity to hire autonomously operated flying taxis compared to non-Asians [25]. Additionally, urban residents exhibit a willingness to pay a premium of 20 dollars per mile over their rural counterparts, reflecting the urban population's higher demand for innovative mobility solutions in congested environments [25].

Ahmed et al.'s subsequent study further delves into the potential impact of flying cars on residential relocation preferences [200]. Through a survey of 584 U.S. residents, the study examines how socio-demographic, behavioral characteristics, and perceptions of flying cars influence individuals' willingness to relocate. Findings suggest that suburban and rural residents demonstrate less inclination to move to urban centers, preferring the amenities and lifestyle offered by less densely populated areas. Conversely, the desire to use flying cars for airport access significantly affects urban relocation preferences, as U.S. airports are often located further from city centers than in other regions like Europe. Interestingly, the study highlights that respondents' willingness to relocate is not directly linked to their perceptions of flying cars' mobility benefits, such as reduced travel times and congestion, warranting further investigation [200].

Innovative research by Birrell et al. [201] utilizes virtual reality (VR) to explore user experiences within future urban air mobility infrastructures, termed metropolitan airports. By immersing 20 participants in six distinct scenarios, the study observes individuals' reactions to potential urban airports where flying cars and drones can land and take off. Participants reported an intuitive environment, with signage facilitating navigation and enhancing site accessibility [201]. The design featuring glass barriers offering visibility of incoming and outgoing aircraft was perceived as safe by participants. A notable suggestion from thirteen participants was the separation of inbound and outbound passengers, which could potentially improve passenger flow and overall experience. Future research could implement and evaluate this design modification to enhance user satisfaction.

Yavas and Tez contribute to the discourse on social acceptance by introducing the Technology Acceptance Model (TAM) for Urban Air Mobility (UAM) [202]. This theoretical model identifies factors that influence user acceptance of UAM, with Perceived Usefulness (PU) emerging as a crucial determinant of user behavior and a mediator for UAM acceptance. The model also underscores the direct impact of variables such as Intention to Fly (IF), UAM Conceptual Intention (UCI), Environmental Consciousness (EC), UAM Affordability (UA), and General Reliability (GR) on Behavioral Intention to Use (BIU) [202]. Notably, PU partially mediates the relationships between IF, UCI, EC, UA, and BIU, while fully mediating the connection between GR and BIU [202]. These findings highlight the necessity of aligning technological development with cultural norms and traditions, emphasizing that technological advancement alone is insufficient. Instead, the integration of new technologies must resonate with cultural contexts to secure a sustainable foothold in an ever-evolving society.

5.5 Regulations

The Federal Aviation Administration (FAA) uses airspace classes in the United States to manage air traffic efficiently and safely. These classes are defined by criteria such as altitude and purpose of operation and facilitate coordination between aircraft and air traffic controllers.

According to the FAA regulations, Class A airspace is reserved for high-altitude en-route flight and commercial operations, fully controlled by the FAA, with an altitude range of 18000 feet (5486.4 meters) to 60000 feet (18288 meters) above sea level. On the other hand, Class B airspace is tailored to local needs and has an altitude range from the surface to a specific upper limit. It is designed to manage air traffic in congested metropolitan areas and requires constant coordination with the control tower. This airspace generally extends from the surface to approximately 10000 feet (3048 meters). Class C airspace is defined as the airspace from the surface up to 4000 feet (1219.2 meters) Above Ground Level (AGL). It is intended for areas with moderate air traffic and has established communication requirements with the control tower for entry. Class D airspace follows a similar structure. The surface area is limited to 2500 feet (762 meters) above ground level (AGL). This classification is intended for airports with control towers and operational traffic but with less activity than Classes B and C. Class E airspace varies in altitude according to location and airspace requirements. It is primarily used for transition space and traffic control in areas where other classes do not apply. Class G airspace extends from the surface to varying altitudes depending on location. The airspace classes are shown in Figure 9 for better compression.

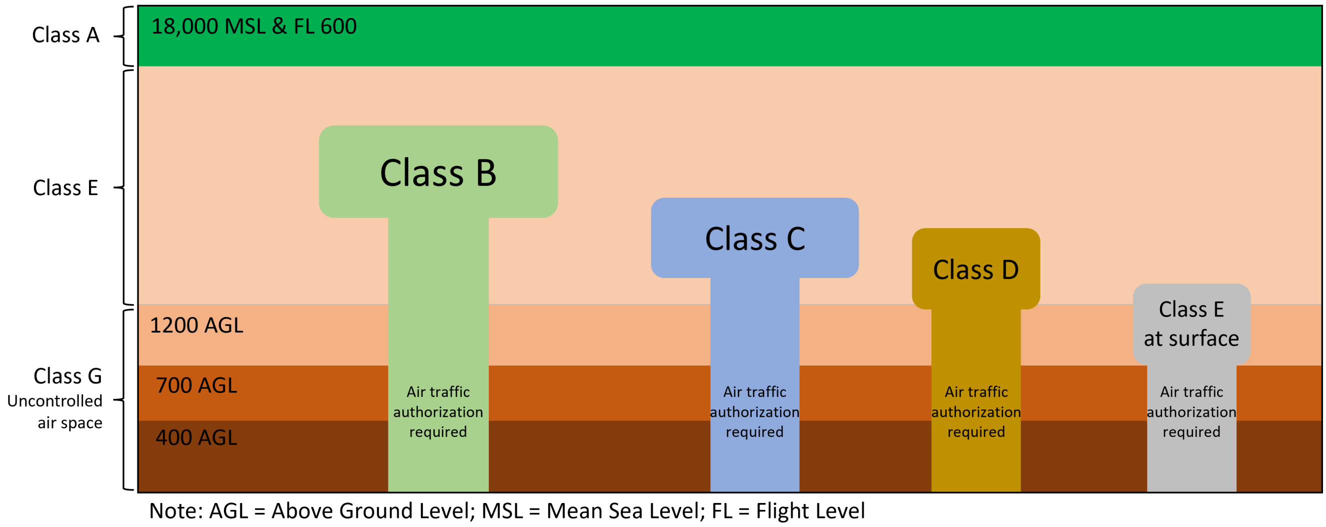

Fig. 9. Airspace classes [203].

Although specific classes govern traditional air operations, technological advancements have sparked interest in integrating uncrewed aerial vehicles and even conceptualizing ”flying cars”. Lascara et al. [204] suggested that flying vehicles could use class G for air mobility. This offers fewer restrictions than controlled airspace and greater autonomy as clearance from air traffic controllers is not required. However, the absence of centralized control may increase the risk of collisions or conflicts between these vehicles. Additionally, G-class designated airspace often lacks the necessary infrastructure to support urban operations, such as advanced navigation systems, aerial signaling, and aerial emergency services. Therefore, advanced traffic management systems are required to avoid conflicts and ensure safety.

However, the regulation for these vehicles is still under development, and their placement in airspace classes will depend on factors such as operating altitude and ability to integrate safely with conventional air traffic.

6. Implications and recommendations

Implementing flying cars in urban environments presents complex challenges and transformative opportunities that necessitate strategic considerations derived from the literature review. This section discusses practical implications and provides recommendations for policy changes, regulatory frameworks, industry practices, and guidelines to facilitate the successful integration and adoption of flying cars.

6.1 Infrastructure implications

The deployment of flying cars requires a robust infrastructure capable of supporting their unique operational needs. Key recommendations include the establishment of dedicated vertiports equipped with advanced safety and operational systems. Vertiports serve as crucial hubs for vertical take-off and landing operations, ensuring efficient passenger transfer and vehicle maintenance. Moreover, integrating sophisticated air traffic management systems is essential to regulate airspace effectively and mitigate potential collisions. These systems should incorporate real-time monitoring and collision avoidance technologies to guarantee safe and seamless flight operations in congested urban areas. Additionally, developing energy recharge stations and maintenance facilities strategically across urban landscapes is vital to optimize operational efficiency and minimize downtime for flying cars.

6.2 Social considerations and public acceptance

Addressing societal concerns and fostering public acceptance are pivotal for the widespread adoption of flying cars. Recommendations emphasize mitigating environmental impacts by promoting the use of renewable energy sources and sustainable materials in vehicle production. This approach aims to reduce greenhouse gas emissions associated with flying cars, aligning with global efforts towards environmental sustainability. Furthermore, implementing effective noise reduction strategies and stringent regulations is essential to minimize the acoustic impact on urban residents. Public engagement initiatives and community consultations play a crucial role in fostering understanding and acceptance of aerial mobility technologies. These efforts are instrumental in building trust and garnering support from local communities, ensuring a smooth transition towards integrating flying cars into urban transport systems.

6.3 Regulatory and policy recommendations

Adapting existing regulatory frameworks is critical to accommodate the operational complexities of flying cars and ensure their safe integration into urban airspace. Recommendations advocate for developing specific airspace classifications tailored to the unique characteristics of flying cars. These classifications should balance autonomy with stringent safety measures to facilitate safe and efficient flight operations. Moreover, establishing rigorous licensing and certification standards for operators and manufacturers is essential to uphold safety and operational integrity. These standards should encompass comprehensive assessments of vehicle design, performance capabilities, and adherence to operational protocols. International collaboration is crucial for harmonizing regulatory frameworks across borders, facilitating seamless cross-border operations and promoting global interoperability of flying car technologies.

6.4 Technological and industry best practices

Promoting technological innovation and industry best practices is fundamental to advancing the capabilities and reliability of aerial mobility technologies. Recommendations focus on developing advanced communication systems to enhance connectivity and data exchange between flying vehicles and ground infrastructure. Robust communication networks play a pivotal role in facilitating real-time flight coordination and operational management, ensuring safe and efficient urban air traffic. Additionally, implementing stringent cybersecurity measures is essential to safeguard against potential cyber threats and protect the integrity of aerial operations. Continuous research and development efforts are essential to enhance vehicle efficiency, safety features, and environmental sustainability. Investing in research initiatives promotes technological advancements that optimize energy consumption, reduce emissions, and improve overall vehicle performance.

The successful integration and adoption of flying cars in urban environments require a comprehensive approach that addresses infrastructure development, societal considerations, regulatory adaptations, and technological advancements. By implementing the recommended strategies derived from the literature review, policymakers, industry stakeholders, and urban planners can pave the way for a sustainable and transformative future of aerial mobility. These recommendations provide a framework for navigating the complexities and seizing the opportunities presented by flying cars, ensuring they contribute positively to urban mobility while safeguarding public safety and environmental stewardship.

7. Demonstrative example

7.1 Overview of the methods for the pre-dimensioning

The pre-dimensioning of aerial vehicles, particularly those intended for use in urban air mobility applications, represents a critical step in the design process. This involves the determination of the primary geometric and performance characteristics of the vehicle at an early stage of the design process. This process serves as a foundational phase that guides subsequent detailed design and optimization efforts. The methodologies employed in pre-dimensioning vary significantly depending on the type of vehicle, its intended mission, and the design philosophy adopted by the engineering team. This section provides an overview of the most commonly used methods for the pre-dimensioning of aerial vehicles, with a particular focus on their applicability to next-generation UAM vehicles, including flying cars and quadcopters.

One of the most traditional approaches to pre-dimensioning is based on statistical methods derived from historical data. This approach entails collecting a comprehensive data set comprising existing aerial vehicles with analogous mission profiles. Subsequently, regression analysis is employed to ascertain empirical relationships between pivotal design parameters, including weight, wing area, power requirements, and payload capacity. For example, Raymer's method is a commonly utilized approach within the aviation industry, offering empirical formulas that correlate these parameters with the gross takeoff weight (GTOW) of the aircraft. The book 'Aircraft Design' describes this method in detail [205]. For instance, Raymer et al. employed this methodology for the conceptual design and analysis of a manned Mars airplane configured for a range of purposes, including exploration, research, cargo transport, photography, and the linking of multiple settlements [206]. While this method is well-suited for conventional fixed-wing aircraft, its applicability to UAM vehicles necessitates careful consideration of the distinctive characteristics of vertical takeoff and landing vehicles, including their reliance on rotorcraft technology and the necessity for compactness in urban environments. An alternative method is Roskam's method, defined in the multivolume series 'Airplane Design' [207] and is widely used in aircraft design. This method provides guidelines for estimating the weight of different components based on the overall weight of the vehicle. It can be adapted for UAM vehicles by considering specific factors, such as Vertical Take-Off and Landing (VTOL) capabilities and the use of electric propulsion systems. By following this methodology, Giraldo et al. proposed a conceptual design of a turboprop aircraft capable of carrying ninety passengers on regional flights [208].

Another approach that is widely recognized is the use of first-principles physics-based models. These methods entail the application of fundamental principles of aerodynamics, propulsion, and structural mechanics to estimate the requisite dimensions and performance characteristics of the vehicle. The Blade Element Theory (BET) is a well-established methodology in rotorcraft pre-dimensioning. It entails computing the thrust generated by each blade section based on local flow conditions and blade geometry. This method is particularly pertinent to pre-dimensioning VTOL and multicopter designs, as it facilitates a more comprehensive comprehension of rotor performance under diverse operational circumstances [209]. Furthermore, momentum theory, another physics-based approach, is frequently employed in conjunction with BET to estimate the induced velocity and power requirements of rotors. To optimize the exploration and utilization of wind energy, Mahmuddin proposed a computational approach based on Blade Element Momentum (BEM) theory to analyze and optimize wind turbine propeller blades [210]. Moreover, Benini and Toffolo proposed a methodology for the optimal design of horizontal-axis wind turbines, integrating Blade Element Theory and Evolutionary Computation [211]. While more complex than statistical methods, these models offer greater accuracy and can be adapted to various configurations typical of UAM vehicles [212]. Another significant approach in the pre-dimensioning process is the utilization of analytical models. These models entail the resolution of the governing equations of motion, aerodynamics, and structural mechanics, thereby enabling prediction of the vehicle's behavior. Analytical methods are especially beneficial for elucidating the trade-offs between disparate design parameters and identifying critical constraints. For example, the Breguet range equation [213] is a well-known analytical model used to estimate the range of an aircraft based on its aerodynamic efficiency and energy storage capacity. In the context of UAM, the Breguet equation can be modified to account for the distinctive flight profiles of urban air vehicles, which frequently entail short-range flights with frequent vertical maneuvers. Another significant approach is the use of scaling laws, which are derived from similarity theory. Scaling laws provide a means of estimating the performance of a scaled-down or scaled-up version of an existing design, maintaining geometric, kinematic, and dynamic similarity throughout. This method is especially beneficial during the conceptual design phase of UAM vehicles, where designers frequently utilize small-scale prototypes or simulations to validate design concepts. The Buckingham Pi theorem is often employed in this context to derive non-dimensional parameters that govern the behavior of the system. For instance, scaling laws can be utilized to predict the lift and drag characteristics of a scaled model based on the Reynolds number, which is a function of the vehicle's velocity, characteristic length, and kinematic viscosity of the air [214].

In recent years, the development of Multidisciplinary Design Optimization (MDO) frameworks has emerged as a prominent approach in the pre-dimensioning of aerial vehicles. MDO integrates various disciplinary models into a unified optimization process, including aerodynamics, propulsion, structures, and controls. This approach enables the concurrent evaluation of diverse design objectives, including weight reduction, while simultaneously optimizing performance and efficiency [215]. One illustrative example of MDO implementation in UAM can be found in the work of Martins and Lambe [216], who developed an MDO framework tailored to the distinctive challenges posed by electric VTOL aircraft. These frameworks frequently utilize surrogate models or machine learning techniques to minimize computational complexity, facilitating their use in initial design stages where rapid iteration is paramount. Furthermore, contemporary computational tools, including Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA), have assumed a pivotal role in the pre-dimensioning of aerial vehicles. CFD enables designers to predict and optimize the aerodynamic behavior of the vehicle, thereby facilitating the refinement of aspects such as fuselage and wing shape with the objective of minimizing drag and improving energy efficiency. This is demonstrated by Comis Da Ronco et al. [217], who present a fast and effective CFD-based automatic loop for optimizing rotorcraft components. In contrast, FEA is employed to assess the structural robustness of the vehicle under diverse load circumstances, guaranteeing that the design fulfills safety and performance criteria. These instruments, heretofore utilized exclusively in the detailed design phase, are now being incorporated into the initial design stages due to advancements in computational capabilities and high-fidelity simulation software. This enables the comprehensive examination of intricate phenomena such as flow separation, structural deformation, and thermal effects that are challenging to capture with empirical or analytical techniques [218].

In addition to these traditional methods, recent advances in Artificial Intelligence (AI) and Machine Learning (ML) have facilitated the exploration of novel avenues for pre-dimensioning UAM vehicles. Artificial intelligence and machine learning algorithms can be trained on extensive datasets of existing aircraft designs to predict the performance of new concepts. Furthermore, these algorithms can investigate a vast array of design alternatives and discern promising configurations that may need to be discernible through conventional methodologies. To illustrate, a neural network-based model could be trained to predict the aerodynamic efficiency of a UAM vehicle based on its shape and size, thereby enabling the rapid evaluation of multiple design options [219]. While the application of AI and ML in pre-dimensioning is still in its infancy, it offers considerable promise for accelerating the design process and enhancing the quality of the final product. Furthermore, it is essential to consider the role of regulations and standards in the pre-dimensioning process. UAM vehicles must comply with the rigorous safety and performance standards established by aviation regulatory bodies, including the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA). These standards impose constraints on the design of UAM vehicles, such as minimum requirements for structural strength, energy efficiency, and noise levels [220]. Therefore, the pre-dimensioning process must consider these regulatory requirements to ensure that the final design is certifiable and can be operated safely in urban environments [221]. Finally, it is crucial to underscore the significance of design heuristics and expert judgment in the pre-dimensioning phase. While quantitative methods provide a robust basis for design decisions, the experience and intuition of seasoned engineers frequently inform the final configuration of the vehicle. Design heuristics, which are rules of thumb derived from practical experience, facilitate the reconciliation of theoretical predictions with real-world performance. For instance, heuristic techniques may be employed to determine the ratio of rotor diameter to vehicle size or mass distribution across the airframe concerning successful designs from previous projects [222].

7.2 Concept choice

In the previous sections, it was discussed how next-generation aerial vehicles represent a significant technological advancement in mobility. These vehicles excel in multiple areas such as safety, performance, user-friendliness, energy efficiency, and environmental impact. In this section, potential flying car configurations shown in Figure 2 will be analyzed based on these attributes. Safety is of utmost importance, and each model offers innovative solutions to ensure passenger protection. The quadcopter by NEC Corp. boasts a dual propulsion system and advanced collision avoidance sensors for high safety levels during flight [35]. The PAL-V Liberty utilizes standard safety systems complemented by collision sensors for reliable protection [41]. The flying car by Boeing incorporates a reinforced structure, multiple redundancy systems, and advanced obstacle detection for increased safety [37]. Additionally, the Moller M400 Skycar features a parachute recovery system and emergency landing capabilities [38], while the Terrafugia Transition provides advanced crash protection and a dual-engine backup system for emergency landings [39]. From the performance point of view, these vehicles have several features. The quadcopter by NEC Corp. stands out for its high range, speed, and ability to cover significant distances [35]. The PAL-V Liberty offers good range and speed, although not equal to those of the quadcopter [41]. The flying car by Boeing has moderate range and speed, making it efficient for urban travel [37]. The Moller M400 Skycar features high speed and vertical takeoff and landing capability [38], while the Terrafugia Transition combines moderate speed and range, being designed for both road and air travel [39]. In terms of energy efficiency, the models vary widely. The quadcopter by NEC Corp. uses advanced batteries and an energy recovery system [35]. The PAL-V Liberty has energy efficiency comparable to that of a helicopter [41]. The flying car by Boeing has a hybrid power system, optimized for urban commutes [37]. The Moller M400 Skycar features efficient fuel consumption and hybrid power options [38]. The Terrafugia Transition is efficient in both travel modes, using automotive fuel [39]. The environmental impact of these vehicles is an important consideration. The quadcopter by NEC Corp. produces low emissions and has a low noise impact due to its advanced propeller design [35]. The PAL-V Liberty reduces emissions but may have a greater noise impact [41]. The flying car by Boeing is designed to minimize urban noise pollution and produce low emissions [37]. The Moller M400 Skycar has moderate emissions and the potential for noise pollution reduction [38]. The Terrafugia Transition has emissions like those of a small plane and moderate noise levels [39].

A review of existing concepts offers an understanding of the current state of solutions and technologies in use, as well as an insight into the most effective practices within the field. This facilitates comprehension of the methodologies that have been previously investigated and the technological solutions that have been developed. It is of the utmost importance to conduct thorough research on existing concepts and to prioritize functional requirements, as this provides a robust foundation for the subsequent design and sizing processes. In the absence of these preliminary steps, the resulting sizing may prove suboptimal or fail to align with the actual needs of the project. These steps guarantee that the design is innovative, feasible, and in accordance with industry expectations and standards [223].

The aforementioned requirements informed the selection of the vehicle for the preliminary design phase. This section outlines the design process undertaken to apply an initial sizing method to a specific vehicle, selected based on functional requirements [224]. The selected vehicle exhibits characteristics analogous to those observed in unmanned aerial vehicles (UAVs), and thus existing theories and methods for UAVs were applied for sizing. The initial stage of the process is the preliminary sizing of the motors. In the field of drone design, the initial stage often entails an approximate estimation of the weight and the selection of motors for a multitude of reasons pertaining to the intricacy and particular requirements of these vehicles. The total weight of a drone has a direct impact on its flight performance, including range, maneuverability, and battery life. It is essential that the selected motors are capable of lifting the expected weight and providing the necessary thrust. Consequently, the estimation of the total weight and the selection of appropriate motors are pivotal stages in guaranteeing that the drone is capable of flight in an efficient and secure manner. In order to obtain an optimized UAV with minimal unwanted side effects, it is necessary to apply an integrated and life-cycle oriented approach to the system. Sadraey introduces the conceptual, preliminary, and detailed design of a UAV based on a systems engineering approach [223]. In each phase, the application of this approach is described through a design flowchart and practical steps. In contrast, Desai et al. present an optimized method for the design and development of a drone, or UAV, with the objective of carrying thirty simulated passengers and a model rocket as the propulsion system, while maintaining a range of five minutes [225]. The UAV must be designed to include a mounting mechanism for the passengers and the rocket, as well as the capacity to undertake aerial missions following a series of pre-programmed waypoints.

In conclusion, next-generation aerial vehicles offer a variety of advanced solutions ranging from safety and performance to ease of use, energy efficiency, and environmental impact. Each model has unique features that make it suitable for different needs and contexts of use. To choose a single concept for a system analysis, all these features are evaluated. From this analysis, a weight can be assigned to each feature, and using the scoring method, a concept can be chosen on which to perform an initial prototyping study. The purpose of this initial design is to evaluate the loads involved in enabling the aircraft to move and to determine the necessary motor speed for optimal performance.

Table 6. Comparison of next-generation aerial vehicles (Decision-making method: Score method).

Vehicle	Safety	Performance	User-friendliness	Energy efficiency	Environmental Impact	Total
NEC Corp.'s Quadcopter	9	10	10	9	9	47
PAL-V Liberty	8	8	7	8	8	39
Boeing's Flying Car	8	8	7	8	8	39
Moller M400 Skycar	7	8	6	7	7	35
Terrafugia Transition	7	8	6	7	7	35

As can be seen from Table 6 that the Quadcopter of NEC Corp. stands out as the best model in terms of safety, performance, ease of use, energy efficiency, and environmental impact. This makes it the top choice among the five flying cars analyzed.

7.3 Preliminary sizing of the flying vehicle motors

After completing the evaluation of the functional requirements of a flying vehicle and selecting the most suitable concept, the next step is the preliminary sizing of the motors. This process is essential to evaluate the motors required for the various flight maneuvers. The first step is to assess the necessary forces to ensure the balance of the system in flight. For the sake of simplicity, a simplified aerial vehicle is considered here as shown in Figure 10. As can be seen from Figure 10 the mechanical system, which can move in two-dimensional Euclidean space, consists of a beam that represents one-half of the aerial vehicle sectioned along the longitudinal axis and carries motors at both ends. It is assumed that the beam rotates about its center of gravity by a certain pitch angle θ. Due to the rotation of propellers, the two thrust forces, F_F and F_R, exert to the system. F_F corresponds the thrust force applied to the front arm, F_R refers to the thrust force applied to rear arm.

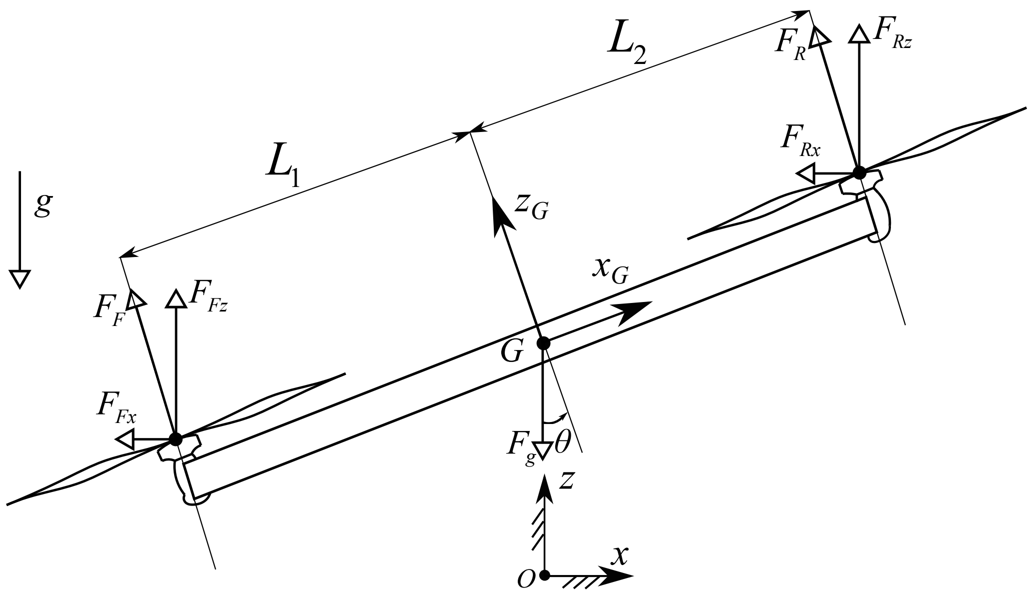

Fig. 10. Simplified aerial vehicle.

By considering force components in x and z directions shown in Figure 10, the following equilibrium conditions must be met in z direction and around y-axis (which is perpendicular to the plane of the paper):

$$\begin{cases} F_{Fz} + F_{Rz} = F_g \\ F_F L_1 = F_R L_2 \end{cases} \tag{1}$$

where F_{Fz} and F_{Rz} respectively refer to components of F_F and F_R in z direction. To illustrate the preliminary sizing procedure, let assume the distances of the two motors from the center of mass are $L_1 = L_2 = 1700$ (mm), and the weight force F_g, which corresponds to half of the weight of the aerial vehicle, is 3000 (N). From the relationships given in Equation (1), it is possible to compute thrust forces acting on the front and rear parts of the aerial vehicle for different values of the angle θ. The values of lift forces for different values of the angle θ are shown in Table 7.

Table 7. Values of the thrust forces and corresponding RPM values for different values of θ.

θ	F_F	F_R	N
0	1500.00	1500.00	4945.74
5	760.13	2251.33	6059.05
10	790.97	2255.31	6064.41
15	828.38	2277.45	6094.10
20	873.49	2319.05	6149.50
25	927.67	2382.46	6233.02
30	993.10	2471.00	6347.78
35	1072.22	2590.10	6498.96
40	1169.05	2747.17	6693.12
45	1289.06	2953.59	6940.01
50	1440.84	3226.33	7253.37

Once thrust forces generated by the motors are computed, it is possible to determine the motor velocity required to ensure this force. Specifically, the motor velocity in revolutions per minute (RPM) is calculated using an empirical formula proposed by Quan Quan [226]. By knowing the diameter D_p which is expressed in (m), the thrust force F_R which is expressed in (N), and the air density ρ which is expressed in (kg/m^3), one can estimate the revolutions of the propeller expressed in (RPM). The revolutions per minute can be calculated from the following formula:

$$N = 60\sqrt{\frac{F_R}{\rho C_T D_p^4}} \tag{2}$$

where N stands for the revolutions per minute and C_T is the dimensionless thrust coefficient. For the sake of simplicity, only revolutions per minute of the rear motor, which is exposed to greater thrust force due to the maneuver, is evaluated here. Therefore, the motor selection will be based on the maximum force value. Additionally, the coefficient C_T is a function of propeller data and can be determined by using the following formula:

$$C_T = 0.25\pi^3\lambda\zeta^2 B_P K_0 \frac{\varepsilon \arctan\left(\frac{H_P}{\pi D_P}\right) - \alpha_0}{\pi A + K_0} \tag{3}$$

where H_P is the pitch expressed in (m), and B_P refers to the number of blades [226]. For the design of this concept system developed in this study, the following values are chosen: $A = 5\ (-)$, $\varepsilon = 0.85\ (-)$, $\lambda = 0.75\ (-)$, $\zeta = 0.5\ (-)$, $\alpha_0 = 0\ \text{(rad)}$, $B_P = 2\ (-)$, and $K_0 = 6.11\ (-)$. The coefficient $A = D_P/c_P$ is the aspect ratio, where $D_P = 1.6\ \text{(m)}$ is the propeller diameter and c_P is the blade average chord length. The parameter λ is a correction coefficient, while the parameter ε is another correction factor that arises due to downwash. The parameter α_0 is the zero-lift angle of attack. Also, H_P is taken as $0.2\ \text{(m)}$. The evaluation of these parameters is based on the values reported by Quan Quan [226], who provided a set of average parameters. The only parameters that may vary are the number of blades and blade pitch. Using these constants, it is possible to compute the RPM as shown in the Table 7. Therefore, to ensure the proper functioning of the system based on this preliminary sizing, it is necessary to use a motor that can achieve this RPM.

A preliminary step in selecting motors for a quadcopter is evaluating the RPM, which is a key but not the only aspect of motor characterization. Generally, a numerical value followed by "KV" is used to specify a brushless motor. The term KV indicates the rotational speed of the motor per unit of supplied voltage. For example, a motor with a rating of 1000 KV will rotate at 1000 RPM for every volt applied. Therefore, if 10V is applied, the motor will reach 10.000 RPM. Consequently, the choice of the motor depends not only on the RPM but also on the supply voltage. Assuming the use of 12S batteries, with a voltage of 4.2V per cell, the total voltage would be 50.4V (12S means 12 cells in series, so the total voltage is the sum of the voltages of each cell). As can be seen from Table 7, the maximum rotational speed is approximately 8000 RPM. Therefore, the KV characterizing the motor type will be determined as follows:

$$KV = \frac{8000}{50.4} = 158.73 \simeq 160 \tag{4}$$

At this preliminary stage, the choice of motor depends on both rotational speed and the type of power supply. Obviously, other factors may also influence the motor selection, such as geometric constraints. This section aims to provide the reader with an initial approach to selecting and defining the motor for the concept realization. It is evident that choosing the most appropriate motor involves a trade-off among various design constraints, which cannot all be addressed here due to the need for a detailed and thorough analysis.

8. Summary, conclusions, and research perspective

The general research framework of the authors is grounded in three principal pillars, which are mutually interconnected areas concerning mechanical systems and deal with multibody system dynamics, nonlinear optimal control, and applied system identification [227–229]. In this vein, this paper presented a literature review on flying cars, specifically in urban aerial mobility.

This investigation led to a review paper on flying cars as a viable solution for enhancing Urban Air Mobility (UAM). The review carried out in this work was divided into two parts. The first part aimed to provide context by unifying documents, articles, and research works up to 2013 through a historical literature review. In the second part of this work, a systematic literature review was conducted from 2013 to the present to obtain a more detailed overview of the present research field. For this purpose, bibliometric methods were used to statistically analyze this research field systematically and statistically, thereby identifying relevant documents, references, and authors involved in this challenging endeavor. A detailed and exhaustive analysis of the papers found in the literature survey was performed to categorize and identify the current state of the art in the development of flying cars for urban transportation. Next, practical implications and recommendations that can be useful for facilitating this futuristic transition were discussed. Finally, different flying car concepts were compared in terms of several aspects, such as safety, performance, user-friendliness, energy efficiency, and environmental impact, and a preliminary dimensioning approach for the selected design concept was presented via a demonstrative example.

To summarize the fundamental outcome of the present study, this review identified four critical issues for implementing flying cars as a means of urban mobility. The fundamental problems found in this investigation are the following.

- Researching the economic viability of using flying cars to determine accessibility and market niche.
- Studies focused on improving battery performance and capacity.
- Research on different types of fuel that are not detrimental to the environment.
- Flight simulations in challenging conditions, such as turbulent flows or adverse atmospheric conditions.
- Establishing regulations including flying cars for airspace management.

Some possible directions for future research are discussed below, together with an assessment of the open main problems.

Future research in the following developments concerning flying cars for the UAM aims to establish safe and efficient aerial mobility in urban environments. Additionally, future research will cover rotor modeling and simulation, including Proper Modal Order Reduction (POD) and Reduced Order Modeling (ROM) to overcome challenges associated with this innovative form of transport. Although proven effective in predicting distributed loads accurately and efficiently [165, 166, 230], further research is needed to understand the challenges of using this technique in rotor modeling, especially under complex conditions such as turbulent flows. Energy storage and power production are also fundamental topics, emphasizing the need for efficient and powerful propulsion systems for three-dimensional flying vehicle operations. Research on energy management, including the use of batteries and sustainable solutions, is essential to increase autonomy and reduce dependence on fossil fuels. Infrastructure is crucial for the safe and efficient operation of flying vehicles. This includes planning take-off and landing ports, implementing air traffic management systems, ensuring energy recharging, maintaining vehicles, and creating safe and efficient air routes.

To address the technological challenges identified in this study, researchers could pose questions such as: how can advanced propulsion technologies like hydrogen fuel cells or next-generation batteries be optimized for use in flying cars to improve energy efficiency? What are the environmental implications of different materials used in the construction of flying cars, and how can sustainable materials contribute to reducing the overall carbon footprint of these vehicles? Additionally, what are the technological and regulatory challenges in implementing fully autonomous flying cars, and how can these challenges be mitigated through the development of advanced navigation systems and artificial intelligence? Hypotheses derived from these questions may involve testing specific materials for reducing vehicle weight while maintaining structural integrity or assessing the effectiveness of autonomous flight capabilities in improving traffic management and safety.

The operations and management of aircraft pose multifaceted challenges that extend beyond technical aspects. Integrating aircraft into urban airspace requires a holistic approach to air traffic planning and management, efficient route coordination, and advanced control and communication systems. Communication and air traffic management are important research areas to ensure unique vehicle identification and effective communication during different phases of flight. For example, Ghayouraneh et al. proposed dynamic identifier allocation systems to optimize in-flight connectivity and ensure system security [177]. Cybersecurity is also vital, given the interconnectedness of flying vehicles and associated vulnerabilities. The solution proposed in [189] suggests a system that incorporates autonomous flight, symmetric and asymmetric encryption, and blockchain technologies to ensure the integrity and security of the system against cyber threats. Understanding societal attitudes, behavioral patterns, and the acceptance of flying cars among diverse populations is essential for their successful adoption. Future research should focus on longitudinal studies tracking public perception and acceptance of aerial mobility technologies over time. Additionally, analyzing the socioeconomic factors influencing individuals' willingness to use flying cars and potentially relocate to urban centers would provide valuable insights. Furthermore, exploring the psychological impacts of noise pollution generated by flying cars on urban residents and developing effective mitigation strategies is crucial.

To further explore these societal dynamics, researchers could investigate questions such as: how do demographic factors such as age, income level, and geographic location influence public acceptance and willingness to adopt flying cars as a mode of transport? What are the long-term effects of noise pollution from flying cars on urban residents' health and well-being, and what strategies can be implemented to mitigate these impacts? How can target public engagement strategies and community involvement initiatives enhance public acceptance and integration of flying cars into urban transport systems? Methodologically, researchers may utilize surveys, focus groups, and experimental studies to gather empirical data on public attitudes and behavioral responses to aerial mobility.

Developing adaptive regulatory frameworks and policy guidelines tailored to the unique challenges of flying cars is essential for their safe and efficient integration into urban airspace. Future research efforts should focus on several critical aspects: research could assess the effectiveness of existing airspace classifications in accommodating the operational requirements of flying cars and propose modifications or new classifications where necessary. Additionally, analyzing international regulatory differences and identifying opportunities for harmonization to facilitate global interoperability of flying car technologies would be beneficial. Furthermore, evaluating the economic implications of regulatory decisions on industry stakeholders, urban infrastructure, and environmental sustainability is essential.

To guide regulatory and policy development, researchers could explore questions such as: how can airspace regulations be adapted to ensure the safe integration of flying cars into urban airspace while minimizing congestion and ensuring efficient traffic management? What are the economic benefits and challenges of integrating flying cars into existing transportation networks, and how can policy frameworks optimize these outcomes? How can international collaboration and standardization efforts contribute to establishing global norms for the safe and sustainable operation of flying cars across different regions and jurisdictions? Methodologically, comparative policy analysis, economic modeling, and stakeholder consultations could inform evidence-based policy recommendations.

Conducting comprehensive Environmental Impact Assessments (EIAs) is critical to understanding the ecological footprint of flying cars and identifying effective mitigation strategies. Future research should focus on several crucial areas of environmental assessment: research could quantify greenhouse gas emissions and air quality impacts associated with different propulsion technologies and operational scenarios for flying cars. Additionally, assessing the lifecycle environmental impacts of materials used in manufacturing and maintaining flying cars, focusing on resource efficiency and waste management, is essential. Furthermore, developing predictive models to forecast the long-term environmental consequences of the widespread adoption of flying cars in urban ecosystems and natural habitats would provide valuable insights.

To advance environmental impact assessment, researchers could pose questions such as: what are the comparative environmental impacts of electric versus hybrid propulsion systems for flying cars, considering factors such as energy consumption and emissions? How can sustainable sourcing and recycling practices for materials used in flying car production contribute to minimizing environmental degradation and promoting circular economy principles? What are the potential indirect ecological impacts of increased urban mobility facilitated by flying cars, such as changes in land use patterns and biodiversity loss? Hypotheses derived from these questions may involve testing alternative materials and propulsion technologies to reduce carbon footprints and enhance environmental sustainability.

In conclusion, all the research perspectives discussed herein highlight the importance of taking an interdisciplinary and holistic approach to addressing the challenges of integrating flying vehicles into urban environments. Therefore, it turns out to be fundamentally important to collaborate across engineering, social sciences, and other disciplines to create sustainable and practical solutions that benefit both technology and society.

Author Contributions

This review paper was principally devised and developed by the first author (Carlos Pérez Carrera). Great support in the development of the paper was provided by the second author (Ömer Ekim Genel), by the third author (Rosario La Regina), and by the fourth author (Carmine Maria Pappalardo). The detailed review carried out by the fifth author (Domenico Guida) considerably improved the quality of the work. The manuscript was written with the contribution of all authors. All authors discussed the results, reviewed the methodology, and approved the final version of the manuscript.

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Conflict of Interest

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The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

[1] Haug, E.J., Computer aided kinematics and dynamics of mechanical systems, volume 1, Allyn and Bacon Boston, 1989.
[2] Kaiser, I., Strano, S., Terzo, M., Tordela, C., Anti-yaw damping monitoring of railway secondary suspension through a nonlinear constrained approach integrated with a randomly variable wheel-rail interaction, Mechanical Systems and Signal Processing, 146, 2021, 107040.
[3] Marano, D., Cammarata, A., Fichera, G., Sinatra, R., Prati, D., Modeling of a three-axes mems gyroscope with feedforward pi quadrature compensation, in Advances on Mechanics, Design Engineering and Manufacturing: Proceedings of the International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2016), 14-16 September, 2016, Catania, Italy, Springer, 2017, 71–80.
[4] Shabana, A.A., Dynamics of multibody systems, Cambridge university press, 2020.
[5] Kaiser, I., Strano, S., Terzo, M., Tordela, C., Estimation of the railway equivalent conicity under different contact adhesion levels and with no wheelset sensorization, Vehicle System Dynamics, 61, 2023, 19–37.
[6] Razmjooei, H., Palli, G., Abdi, E., Terzo, M., Strano, S., Design and experimental validation of an adaptive fast-finite-time observer on uncertain electro-hydraulic systems, Control Engineering Practice, 131, 2023, 105391.
[7] Cammarata, A., Sinatra, R., Rigato, R., Maddio, P.D., Tie-system calibration for the experimental setup of large deployable reflectors, Machines, 7, 2019, 23.
[8] Nikravesh, P.E., Computer-aided analysis of mechanical systems, Prentice-Hall, Inc., 1988.
[9] Calabrese, A., Spizzuoco, M., Galano, S., Tran, N., Strano, S., Terzo, M., A parametric study on the stability of fiber reinforced rubber bearings under combined axial and shear loads, Engineering Structures, 227, 2021, 111441.
[10] Cammarata, A., Sinatra, R., Rigano, A., Lombardo, M., Maddio, P.D., Design of a large deployable reflector opening system, Machines, 8, 2020, 7.
[11] Shabana, A.A., Computational continuum mechanics, John Wiley & Sons, 2018.
[12] Calabrese, A., Quaglini, V., Strano, S., Terzo, M., Online estimation of the friction coefficient in sliding isolators, Structural Control and Health Monitoring, 27, 2020, e2459.
[13] Swaminathan, N., Reddy, S.R.P., RajaShekara, K., Haran, K.S., Flying cars and evtols—technology advancements, powertrain architectures, and design, IEEE Transactions on Transportation Electrification, 8, 2022, 4105–4117.
[14] Rahman, N.A.A., Urban air transport and the future of tourism, in Contemporary Marketing and Consumer Behaviour in Sustainable Tourism, Routledge, 28–37, 2024.
[15] Straubinger, A., Rothfeld, R., Shamiyeh, M., Büchter, K.D., Kaiser, J., Plötner, K.O., An overview of current research and developments in urban air mobility–setting the scene for uam introduction, Journal of Air Transport Management, 87, 2020, 101852.
[16] Wang, L., Deng, X., Gui, J., Jiang, P., Zeng, F., Wan, S., A review of urban air mobility-enabled intelligent transportation systems: Mechanisms, applications and challenges, Journal of Systems Architecture, 102902.
[17] Coppola, P., De Fabiis, F., Silvestri, F., Urban air mobility (uam): Airport shuttles or city-taxis?, Transport Policy.
[18] Garrow, L.A., German, B.J., Leonard, C.E., Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research, Transportation Research Part C: Emerging Technologies, 132, 2021, 103377.
[19] Radic, A., Quan, W., Ariza-Montes, A., Koo, B., Kim, J.J., Chua, B.L., Gil-Marín, M., Han, H., Do tourists dream of urban air mobility? psychology and the unified theory of acceptance and use of technology, Journal of China Tourism Research, 1–35.
[20] Cohen, A.P., Shaheen, S.A., Farrar, E.M., Urban air mobility: History, ecosystem, market potential, and challenges, IEEE Transactions on Intelligent Transportation Systems, 22, 2021, 6074–6087.
[21] Cummings, C., Mahmassani, H., Comparing urban air mobility network airspaces: Experiments and insights, Transportation Research Record, 2678, 2024, 440–454.
[22] Jin, Z., Ng, K.K., Zhang, C., Robust optimisation for vertiport location problem considering travel mode choice behaviour in urban air mobility systems, Journal of the Air Transport Research Society, 2, 2024, 100006.
[23] Takacs, A., Haidegger, T., Infrastructural requirements and regulatory challenges of a sustainable urban air mobility ecosystem, Buildings, 12, all Open Access, Gold Open Access, Green Open Access.

[24] Cokorilo, O., Urban air mobility: Safety challenges, volume 45, 2020, 21 – 29.
[25] Ahmed, S.S., Hulme, K.F., Fountas, G., Eker, U., Benedyk, I.V., Still, S.E., Anastasopoulos, P.C., The flying car—challenges and strategies toward future adoption, Frontiers in Built Environment, 6.
[26] Li, J., Cheng, H., Guo, H., Qiu, S., Survey on artificial intelligence for vehicles, Automotive Innovation, 1, 2018, 2–14.
[27] He, X., Lv, C., Towards safe autonomous driving: Decision making with observation-robust reinforcement learning, Automotive Innovation, 1–12.
[28] Pan, G., Alouini, M.S., Flying car transportation system: Advances, techniques, and challenges, IEEE Access, 9, 2021, 24586–24603.
[29] Straubinger, A., Rothfeld, R., Shamiyeh, M., Büchter, K.D., Kaiser, J., Plötner, K.O., An overview of current research and developments in urban air mobility – setting the scene for uam introduction, Journal of Air Transport Management, 87.
[30] Rother, E.T., Systematic literature review x narrative review, Acta paulista de enfermagem, 20, 2007, 5–6.
[31] NASA, Uam reference vehicles – sacd, 2023.
[32] Society, T.V.F., evtol aircraft directory, 2023.
[33] Garrow, L.A., German, B.J., Leonard, C.E., Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research, Transportation Research Part C: Emerging Technologies, 132, 2021, 103377.
[34] Kiesewetter, L., Shakib, K.H., Singh, P., Rahman, M., Khandelwal, B., Kumar, S., Shah, K., A holistic review of the current state of research on aircraft design concepts and consideration for advanced air mobility applications, Progress in Aerospace Sciences, 142, 2023, 100949.
[35] A japanese “flying car” has successfully made its first test flight.
[36] B.V, P.V.I., Pal-v, 2018.
[37] Creedy, S., Boeing ’flying car’ completes first test flight, 2019.
[38] Courtney, W.S., You can buy the moller skycar flying car on ebay today...for 5 million dollars, 2017.
[39] Contributors, W., Terrafugia transition, 2019.
[40] Johnson, W., Rotorcraft Aeromechanics, Cambridge Aerospace Series, Cambridge University Press, 2013.
[41] Heathman, A., The pal-v liberty flying car is unveiled at the geneva motor show, 2018.
[42] Pradeep, P., Wei, P., Energy-efficient arrival with rta constraint for multirotor evtol in urban air mobility, Journal of Aerospace Information Systems, 16, 2019, 263–277.
[43] Donateo, T., Ficarella, A., A modeling approach for the effect of battery aging on the performance of a hybrid electric rotorcraft for urban air-mobility, Aerospace, 7.
[44] Saberi, H., Hasbun, M., Hong, J., Yeo, H., Ormiston, R., Overview of rcas capabilities, validations, and rotorcraft applications, Annual Forum Proceedings - AHS International, 2, 2015, 1315–1344.
[45] Shamiyeh, M., Rothfeld, R., Hornung, M., A performance benchmark of recent personal air vehicle concepts, 2018.
[46] Chauhan, S., Martins, J., Tilt-wing evtol takeoff trajectory optimization, Journal of Aircraft, 57, 2019, 93–112.
[47] Radotich, M.T., Conceptual Design of Two Tiltrotor Aircraft for Urban Air Mobility, Aeromechanics for Advanced Vertical Flight Technical Meeting 2022, 2022.
[48] Hall, E.J., Internal-combustion engine, 1919.
[49] Elmore, E., Scata, D., 2020 redac -uam/uas acoustics research status | federal aviation administration, 2020.
[50] Terrafugia reveals new details on transition flying car due in 2019, 2019.
[51] Rizzi, S.A., Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations, NASA, 2020.
[52] Rizzi, S., Rafaelof, M., Community noise assessment of urban air mobility vehicle operations using the faa aviation environmental design tool, INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 263, 2021, 450–461.
[53] Bian, H., Tan, Q., Zhong, S., Zhang, X., Assessment of uam and drone noise impact on the environment based on virtual flights, Aerospace Science and Technology, 118, 2021, 106996.
[54] Mathur, A., Panesar, K., Kim, J., Atkins, E., Sarter, N., Ballin, M., Goodrich, K., Paths to autonomous vehicle operations for urban air mobility, 2019.
[55] Palli, G., Strano, S., Terzo, M., A novel adaptive-gain technique for high-order sliding-mode observers with application to electro-hydraulic systems, Mechanical Systems and Signal Processing, 144, 2020, 106875.
[56] Yang, X., Wei, P., Autonomous free flight operations in urban air mobility with computational guidance and collision avoidance, IEEE Transactions on Intelligent Transportation Systems, PP, 2021, 1–14.
[57] Gandelli, E., Lomiento, G., Quaglini, V., Strano, S., Terzo, M., Tordela, C., Estimation of the instantaneous friction coefficients of sliding isolators subjected to bi-directional orbits through a nonlinear state observer, Engineering Structures, 249, 2021, 113374.
[58] Galano, S., Calabrese, A., Losanno, D., Serino, G., Strano, S., Tuning the lateral response of unbonded fiber reinforced elastomeric isolators (u-freis) through horizontal holes: Experimental and numerical findings, Composite Structures, 289, 2022, 115454.
[59] Hang, E., Ehang | uam - passenger autonomous aerial vehicle (aav).
[60] Aerofugia, Aerofugia aerofugia.
[61] Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., Antoniou, C., Factors affecting the adoption and use of urban air mobility, Transportation Research Part A: Policy and Practice, 132, 2020, 696–712.
[62] Aeromobil, 2019.
[63] Rendón, M.A., Sánchez R., C.D., Gallo M., J., Anzai, A.H., Aircraft hybrid-electric propulsion: Development trends, challenges and opportunities, Journal of Control, Automation and Electrical Systems, 32, 2021, 1244–1268.
[64] Aeronautics, U., Urban aeronautics | evtol | real flying cars | fancraft technology.
[65] Sawday, J., Engines of the imagination: Renaissance culture and the rise of the machine, Engines of the Imagination: Renaissance Culture and the Rise of the Machine, 1–402.
[66] Ackroyd, J., Sir george cayley, the father of aeronautics. part 1. the invention of the aeroplane, Notes and Records of The Royal Society - NOTES REC ROY SOC, 56, 2002, 167–181.
[67] Ackroyd, J., Sir george cayley, the father of aeronautics part 2. cayley’s aeroplanes, Notes and Records of The Royal Society - NOTES REC ROY SOC, 56, 2002, 333–348.
[68] Anderson, J.D., Fundamentals of aerodynamics, Mcgraw Hill Education, 2017.
[69] Editors, H., Wright brothers, 2009.
[70] Allen, J.E., Armstrong, F.W., Denning, R.M., Evolution of aviation and propulsion systems: The next fifty years, Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 209, 1995, 15–33.
[71] Sinigaglia, T., Martins, M., Siluk, J., Technological evolution of internal combustion engine vehicle: A patent data analysis, Applied Energy, 306, 2022, 118003.
[72] Upham, P., Maughan, J., Raper, D., Al, E., Towards sustainable aviation, Earthscan Publications, 2003.
[73] Rogers, E.W.E., Aerodynamics — retrospect and prospect, The Aeronautical Journal, 86, 1982, 43–67.
[74] von Karman, T., The Wind and Beyond: Theodore Von Karman, Pioneer in Aviation and Pathfinder in Space, Plunkett Lake Press, 1967.
[75] Prandtl, L., Theory of Lifting Surfaces, 1920.
[76] Anderson, J., A history of aerodynamics: And its impact on flying machines.
[77] Goldstein, S., Fluid mechanics in the first half of this century, Annual Review of Fluid Mechanics, 1, 2003, 1–29.
[78] Bissell, C., A History of Automatic Control, Springer Berlin Heidelberg, Berlin, Heidelberg, 53–69, 2009.
[79] Cierva c.8, 2023.
[80] Elliot, D., Rotary wing aircraft, 1938.
[81] Stalker, E., Rotary wing aircraft, 1949.
[82] Howard, R.W., Automatic flight controls in fixed wing aircraft–the first 100 years, The Aeronautical Journal, 77, 1973, 533–562.
[83] Grum, J., Book review: Fundamentals of composites manufacturing, materials, methods and applications, International Journal of Microstructure and Materials Properties, 2.
[84] Ashkenazi, D., How aluminum changed the world: A metallurgical revolution through technological and cultural perspectives, Technological Forecasting and Social Change, 143, 2019, 101–113.
[85] Soutis, C., Fibre reinforced composites in aircraft construction, Progress in Aerospace Sciences, 41, 2005, 143–151.
[86] Marshall, D.M., Barnhart, R.K., Shappee, E., Most, M., Introduction to unmanned aircraft systems, Crc Press, 3rd edition edition, 2016.

[87] Pavek, K., Albus, J., Messina, E., Autonomy levels for unmanned systems (alfus) framework: An update, Proceedings of SPIE - The International Society for Optical Engineering.
[88] Melvin, S., Gyroscopic apparatus, 1943.
[89] Carlson, B., Automatic pilot, 1940.
[90] Eduard, F., Johannes, T., Control apparatus for vehicles, 1940.
[91] Choueiri, E.Y., A critical history of electric propulsion: The first 50 years (1906-1956), Journal of propulsion and power, 20, 2004, 193–203.
[92] Sanghi, V., Lakshmanan, B., Sundararajan, V., Survey of advancements in jet-engine thermodynamic simulation, Journal of Propulsion and Power, 16, 2000, 797–807.
[93] Moran, T.H., Mowery, D.C., Aerospace, Daedalus, 120, 1991, 135–154.
[94] Aspinwall, R.H., Baker, C.R., Jet propulsion, uS Patent 4,137,708, 1979.
[95] Lancaster, O.E., Jet propulsion engines, volume 2247, Princeton University Press, 2015.
[96] Ballal, D.R., Zelina, J., Progress in aeroengine technology (1939–2003), Journal of aircraft, 41, 2004, 43–50.
[97] Al-Lami, H., Aslam, A., Quigley, T., Lewis, J., Mercer, R., Shukla, P., The evolution of flight control systems, Technology Development, System Architecture and Operation.
[98] Cousins, W.T., History, philosophy, physics, and future directions of aircraft propulsion system/inlet integration, in Turbo Expo: Power for Land, Sea, and Air, volume 41677, 2004, 305–320.
[99] Engineering:ave mizar - handwiki.
[100] Lebouder autoplane, 2022.
[101] Greene, D.L., Energy-efficiency improvement potential of commercial aircraft, Annual review of energy and the environment, 17, 1992, 537–573.
[102] Chambers, J.R., Innovation in flight: research of the NASA Langley Research Center on revolutionary advanced concepts for aeronautics, volume 4539, National Aeronautics and Space Administration, 2005.
[103] Lee, J., Mo, J., Analysis of technological innovation and environmental performance improvement in aviation sector, International journal of environmental research and public health, 8, 2011, 3777–3795.
[104] Kroo, I., Drag due to lift: concepts for prediction and reduction, Annual review of fluid mechanics, 33, 2001, 587–617.
[105] Cone, J.C.D., Minimum induced drag airfoil body, uS Patent 3,270,988, 1966.
[106] Prencipe, A., Breadth and depth of technological capabilities in cops: the case of the aircraft engine control system, Research policy, 29, 2000, 895–911.
[107] Scott, A.J., The aerospace-electronics industrial complex of southern california: The formative years, 1940–1960, Research Policy, 20, 1991, 439–456.
[108] Steinberg, R., Aircraft operating efficiency on the north atlantic, a challenge for the 1980's, NASA. Langley Research Center The 1980 Aircraft Safety and Operating Probl., Pt. 2.
[109] Valavanis, K.P., Advances in unmanned aerial vehicles: state of the art and the road to autonomy.
[110] Asundi, A., Choi, A.Y., Fiber metal laminates: an advanced material for future aircraft, Journal of Materials processing technology, 63, 1997, 384–394.
[111] Vogelesang, L.B., Development of a new hybrid material (arall) for aircraft structures, Industrial & Engineering Chemistry Product Research and Development, 22, 1983, 492–496.
[112] Cooper, M.G., Elliott, E.M., Hartzell, D.A., Autopilot flight director system, uS Patent 4,644,538, 1987.
[113] Ruffier, F., Franceschini, N., Optic flow regulation: the key to aircraft automatic guidance, Robotics and Autonomous Systems, 50, 2005, 177–194.
[114] Rauschelbach, P., Aircraft automatic flight control system, uS Patent 3,848,833, 1974.
[115] M. Sabri, M., Danapalasingam, K., Rahmat, M., A review on hybrid electric vehicles architecture and energy management strategies, Renewable and Sustainable Energy Reviews, 53, 2016, 1433 – 1442.
[116] Friedrich, C., Robertson, P.A., Hybrid-electric propulsion for aircraft, Journal of Aircraft, 52, 2015, 176–189.
[117] Wheeler, P., Sirimanna, T.S., Bozhko, S., Haran, K.S., Electric/hybrid-electric aircraft propulsion systems, Proceedings of the IEEE, 109, 2021, 1115–1127.
[118] Fredericks, W.J., Moore, M.D., Busan, R.C., Benefits of hybrid-electric propulsion to achieve 4x cruise efficiency for a vtol uav, in 2013 International Powered Lift Conference, 2013, 4324.
[119] Oosedo, A., Abiko, S., Konno, A., Koizumi, T., Furui, T., Uchiyama, M., Development of a quad rotor tail-sitter vtol uav without control surfaces and experimental verification, 2013, 317 – 322.
[120] Ahmad, S., Chipperfield, A., Tokhi, M., Dynamic modelling and optimal control of a twin rotor mimo system, volume 1, 2000, 391 – 398.
[121] Kraenzler, M., Schmitt, M., Stumpf, E., Conceptual design study on electrical vertical takeoff and landing aircraft for urban air mobility applications, 2019, 1–12.
[122] Fumian, F., Di Giovanni, D., Martellucci, L., Rossi, R., Gaudio, P., Application of miniaturized sensors to unmanned aerial systems, a new pathway for the survey of polluted areas: Preliminary results, Atmosphere, 11, 2020, 471.
[123] Silva, C., Johnson, W.R., Solis, E., Patterson, M.D., Antcliff, K.R., Vtol urban air mobility concept vehicles for technology development, in 2018 Aviation Technology, Integration, and Operations Conference, 2018, 3847.
[124] Parveez, B., Kittur, M., Badruddin, I.A., Kamangar, S., Hussien, M., Umarfarooq, M., Scientific advancements in composite materials for aircraft applications: a review, Polymers, 14, 2022, 5007.
[125] Valavanis, K.P., Unmanned aircraft systems challenges in design for autonomy, in 2017 11th International Workshop on Robot Motion and Control (RoMoCo), IEEE, 2017, 73–86.
[126] Nakagawa, S., Samarasinghe, G., Haddaway, N.R., Westgate, M.J., O'Dea, R.E., Noble, D.W., Lagisz, M., Research weaving: Visualizing the future of research synthesis, Trends in Ecology & Evolution, 34, 2019, 224–238.
[127] Linnenluecke, M., Marrone, M., Singh, A., Conducting systematic literature reviews and bibliometric analyses, Australian Journal of Management, 45, 2019, 175–194.
[128] Cook, D., Mulrow, C., Haynes, b., Systematic reviews: Synthesis of best evidence for clinical decisions, Annals of internal medicine, 126, 1997, 376–80.
[129] Orlova, A., Titova, T., Analysis of the 'dynamics of railway vehicles' research field development using scientometric approach, Vehicle System Dynamics, 59, 2021, 1148–1169.
[130] D, T., Denyer, D., Smart, P., Towards a methodology for developing evidence-informed management knowledge means of systematic review.
[131] Xiao, Y., Watson, M., Guidance on conducting a systematic literature review, Journal of Planning Education and Research, 39, 2019, 93–112.
[132] Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Preferred reporting items for systematic reviews and meta-analyses: The prisma statement, International Journal of Surgery, 8, 2010, 336–341.
[133] Aria, M., Cuccurullo, C., bibliometrix: An r-tool for comprehensive science mapping analysis, Journal of Informetrics, 11, 2017, 959–975.
[134] Kasliwal, A., Furbush, N.J., Gawron, J.H., McBride, J.R., Wallington, T.J., De Kleine, R.D., Kim, H.C., Keoleian, G.A., Role of flying cars in sustainable mobility, Nature Communications, 10.
[135] Rajashekara, K., Wang, Q., Matsuse, K., Challenges and propulsion strategies, IEEE Electrification Magazine, 4, 2016, 46 – 57.
[136] Postorino, M.N., Sarné, G.M., Reinventing mobility paradigms: Flying car scenarios and challenges for urban mobility, Sustainability (Switzerland), 12.
[137] Ahmed, S.S., Fountas, G., Eker, U., Still, S.E., Anastasopoulos, P.C., An exploratory empirical analysis of willingness to hire and pay for flying taxis and shared flying car services, Journal of Air Transport Management, 90.
[138] Luo, Y., Qian, Y., Zeng, Z., Zhang, Y., Simulation and analysis of operating characteristics of power battery for flying car utilization, eTransportation, 8.
[139] Shi, X., Yang, C., Jiayang, X., Liang, C., Chen, J., Anti-drone system with multiple surveillance technologies: Architecture, implementation, and challenges, IEEE Communications Magazine, 56, 2018, 68–74.
[140] Graydon et al supra note 120.
[141] Bacchini, A., Cestino, E., Electric vtol configurations comparison, Aerospace, 6, 2019, 26.
[142] Eker, U., Fountas, G., Anastasopoulos, P.C., Still, S.E., An exploratory investigation of public perceptions towards key benefits and concerns from the future use of flying cars, Travel Behaviour and Society, 19, 2020, 54–66.

[143] Trancossi, M., Dumas, A., Madonia, M., Subhash, M., Pascoa, J., Das, S., Grimaccia, F., Bingham, C., Smith, T., Vucinic, D., et al., Preliminary implementation study of acheon thrust and vector electrical propulsion on a stol light utility aircraft, Technical report, SAE Technical Paper, 2015.
[144] Uber elevate.
[145] Abidin, A., Mansor, H., Ahmad, R., Abdullah, R., Chung, I., The estimation of carbon dioxide emissions from the transport sector in malaysia (2000–2020) for national institute for environmental studies, in 9th Asian Pacific Integrated Model (AIM) Workshop, Kuala Lumpur, Malaysia, 2004.
[146] Collareno, K., The flight path to transportation equity: How legislators can ensure that urban air mobility delivers inclusive transportation services, U. Ill. L. Rev., 639.
[147] Stanley, M., Are flying cars preparing for takeoff?
[148] Ariffin, R.N.R., Zahari, R.K., The challenges of implementing urban transport policy in the klang valley, malaysia, Procedia Environmental Sciences, 17, 2013, 469–477.
[149] Bansal, P., Kockelman, K.M., Singh, A., Assessing public opinions of and interest in new vehicle technologies: An austin perspective, Transportation Research Part C: Emerging Technologies, 67, 2016, 1–14.
[150] Manrique, C., Pappalardo, C., Guida, D., On the analytical and computational methodologies for modelling two-wheeled vehicles within the multibody dynamics framework: A systematic literature review, Journal of Applied and Computational Mechanics, 8, 2022, 153-181.
[151] Romano, L., Sakhnevych, A., Strano, S., Timpone, F., A hybrid tyre model for in-plane dynamics, Vehicle System Dynamics.
[152] Genovese, A., Strano, S., Terzo, M., Design and multi-physics optimization of an energy harvesting system integrated in a pneumatic suspension, Mechatronics, 69, 2020, 102395.
[153] Siegel, S., Seidel, J., Cohen, K., McLaughlin, T., A cycloidal propeller using dynamic lift, in 37th AIAA Fluid Dynamics Conference and Exhibit, 2007, 4232.
[154] Hanson, D.B., Compressible helicoidal surface theory for propeller aerodynamics and noise, AIAA Journal, 21, 1983, 881–889.
[155] Li, D., Design of a new vtol uav by combining cycloidal blades and fanwing propellers, 2013.
[156] Shao, Y., Liu, L., Xu, Z., Design of four ducted fan-type electric vertical take-off and landing flying car, 2022.
[157] Trancossi, M., Hussain, M., Shivesh, S., Pascoa, J., A new vtol propelled wing for flying cars: Critical bibliographic analysis, SAE Technical Papers, Part F129883.
[158] Reba, I., Applications of the coanda effect, Scientific American, 214, 1966, 84–93.
[159] Mihara, Y., Nakamura, T., Nakamoto, A., Nakano, M., Airframe design optimization and simulation of a flying car for medical emergencies, International Journal of Automation Technology, 16, 2022, 183 – 196, all Open Access, Gold Open Access.
[160] Shi, X., Kim, K., Rahili, S., Chung, S.J., Nonlinear control of autonomous flying cars with wings and distributed electric propulsion, volume 2018-December, 2018, 5326–5333.
[161] Ai, T., Xu, B., Xiang, C., Fan, W., Zhang, Y., Modeling and multimode analysis of electrically driven flying car, 2020, 1565–1571.
[162] Demirdžic, I., Peric, M., Finite volume method for prediction of fluid flow in arbitrarily shaped domains with moving boundaries, International journal for numerical methods in fluids, 10, 1990, 771–790.
[163] Gomi, R., Takii, A., Yamakawa, M., Asao, S., Takeuchi, S., Nishimura, M., Flight simulation from takeoff to yawing of evtol airplane with coaxial propellers by fluid-rigid body interaction, Advances in Aerodynamics, 5.
[164] Takii, A., Gomi, R., Yamakawa, M., Tsubokura, M., Turning flight simulation with fluid-rigid body interaction for flying car with contra-rotating propellers, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 14073 LNCS, 2023, 566 – 577.
[165] Fresca, S., Manzoni, A., Pod-dl-rom: Enhancing deep learning-based reduced order models for nonlinear parametrized pdes by proper orthogonal decomposition, Computer Methods in Applied Mechanics and Engineering, 388, 2022, 114181.
[166] Peters, N., Silva, C., Ekaterinaris, J., A data-driven reduced-order model for rotor optimization, Wind Energy Science, 8, 2023, 1201 – 1223.
[167] Pardede, W.M., Adhitya, M., Take off and landing performance analysis for a flying car model using wind tunnel test method, volume 2227, 2020.
[168] Liu, M., Hao, H., Lin, Z., He, X., Qian, Y., Sun, X., Geng, J., Liu, Z., Zhao, F., Flying cars economically favor battery electric over fuel cell and internal combustion engine, PNAS Nexus, 2.
[169] Calabrese, A., Losanno, D., Barjani, A., Spizzuoco, M., Strano, S., Effects of the long-term aging of glass-fiber reinforced bearings (frbs) on the seismic response of a base-isolated residential building, Engineering Structures, 221, 2020, 110735.
[170] Calabrese, A., Gandelli, E., Quaglini, V., Strano, S., Terzo, M., Tordela, C., Monitoring of hysteretic friction degradation of curved surface sliders through a nonlinear constrained estimator, Engineering Structures, 226, 2021, 111371.
[171] Romli, F.I., Yaakob, M.S., Personal air vehicle (pave) application in malaysia, 2014, 59 – 64.
[172] Kish, B.A., Wilde, M., Silver, I., Wheeler, B., Cleveland, A., Reppen, K., Flight test comparison of three air vehicles flying urban air mobility mission trajectories, volume 2022-March, 2022.
[173] Secanell, M., Wishart, J., Dobson, P., Computational design and optimization of fuel cells and fuel cell systems: A review, Journal of Power Sources, 196, 2011, 3690–3704.
[174] Yang, C., Lu, Z., Wang, W., Wang, M., Zhao, J., An efficient intelligent energy management strategy based on deep reinforcement learning for hybrid electric flying car, Energy, 280.
[175] Prandini, M., Piroddi, L., Puechmorel, S., Brazdilova, S.L., Toward air traffic complexity assessment in new generation air traffic management systems, IEEE transactions on intelligent transportation systems, 12, 2011, 809–818.
[176] Mondoloni, S., Rozen, N., Aircraft trajectory prediction and synchronization for air traffic management applications, Progress in Aerospace Sciences, 119, 2020, 100640.
[177] Ghayouraneh, S., El-Ghazaly, S.M., Rankin, J.M., Dynamic addressing for on-demand mobility, 2018.
[178] Saeed, N., Al-Naffouri, T.Y., Alouini, M.S., Wireless communication for flying cars, Frontiers in Communications and Networks, 2, all Open Access, Gold Open Access, Green Open Access.
[179] Alsamhi, S.H., Ansari, M.S., Ma, O., Almalki, F., Gupta, S.K., Tethered balloon technology in design solutions for rescue and relief team emergency communication services, Disaster medicine and public health preparedness, 13, 2019, 203–210.
[180] Pu, C., Jamming-resilient multipath routing protocol for flying ad hoc networks, IEEE Access, PP, 2018, 1–1.
[181] Guvenc, I., Koohifar, F., Singh, S., Sichitiu, M., Matolak, D., Detection, tracking, and interdiction for amateur drones, IEEE Communications Magazine, 56, 2018, 75–81.
[182] Shane, S., Sanger, D.E., Drone crash in iran reveals secret us surveillance effort, The New York Times, 7.
[183] Humphreys, T., Statement on the vulnerability of civil unmanned aerial vehicles and other systems to civil gps spoofing, Technical report, University of Texas at Austin, 2012.
[184] Elakrat, M.A., Jung, J.C., Development of field programmable gate array–based encryption module to mitigate man-in-the-middle attack for nuclear power plant data communication network, Nuclear Engineering and Technology, 50, 2018, 780–787.
[185] Wang, L., Wyglinski, A.M., Detection of man-in-the-middle attacks using physical layer wireless security techniques, Wireless Communications and Mobile Computing, 16, 2016, 408–426.
[186] Europol, How can dos attacks paralyse the internet, 2018.
[187] Kamkar, S., Skyjack, 2013.
[188] Tewes, J., Cybersecurity as airworthiness, available at SSRN 3033898.
[189] Tang, A.C., A review on cybersecurity vulnerabilities for urban air mobility, volume 1 PartF, 2021, 1 – 17.
[190] Ritchie, H., Roser, M., Rosado, P., Co2 and greenhouse gas emissions, Our world in data.
[191] Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., Erasmi, S., Greenhouse gas emissions from soils—a review, Geochemistry, 76, 2016, 327–352.
[192] Afonso, F., Ferreira, A., Ribeiro, I., Lau, F., Suleman, A., On the design of environmentally sustainable aircraft for urban air mobility, Transportation Research Part D: Transport and Environment, 91, 2021, 102688.
[193] Mudumba, S., Chao, H., Maheshwari, A., DeLaurentis, D., Crossley, W., Modeling co2 emissions from trips using urban air mobility and emerging automobile technologies, Transportation Research Record: Journal of the Transportation Research Board, 2675, 2021, 036119812110064.
[194] André, N., Sustainable design of electric vertical take-off and landing aircraft for urban air mobility, 2022.

[195] Prakasha, P.S., et al., Urban air mobility vehicle and fleet-level life-cycle assessment using a system-of-systems approach, in AIAA Aviation 2021 Forum, 2021, 2457.
[196] Zhang, T., Barakos, G.N., Furqan, Foster, M., High-fidelity aerodynamic and acoustic design and analysis of a heavy-lift evtol, Aerospace Science and Technology, 137, 2023, 108307.
[197] Little, D.S., Majdalani, J., Hartfield, R.J., Ahuja, V., On the prediction of noise generated by urban air mobility (uam) vehicles. i. integration of fundamental acoustic metrics, Phys. Fluids, 34.
[198] Hara, S., Takahara, K., Mitsukura, Y., Stress evaluation using eeg for novel air mobilities, 2022, 72–73.
[199] Glaab, P., Wieland, F., Santos, M., Sharma, R., Tamburro, R., Lee, P.U., Simulating fleet noise for notional uam vehicles and operations in new york, in 2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC), 2019, 1–10.
[200] Ahmed, S.S., Fountas, G., Eker, U., Anastasopoulos, P.C., Are we willing to relocate with the future introduction of flying cars? an exploratory empirical analysis of public perceptions in the united states, Transportmetrica A: Transport Science, 18, 2022, 1025 – 1052.
[201] Birrell, S., Payre, W., Zdanowicz, K., Herriotts, P., Urban air mobility infrastructure design: Using virtual reality to capture user experience within the world's first urban airport, Applied Ergonomics, 105, all Open Access, Green Open Access, Hybrid Gold Open Access.
[202] Yavas, V., Tez, Ö.Y., Consumer intention over upcoming utopia: Urban air mobility, Journal of Air Transport Management, 107.
[203] Administration, F.A., Aeronautical information publication - aip, faa, accessed 10 January 2024, 2023.
[204] Lascara, B., Lacher, A., DeGarmo, M., Maroney, D., Niles, R., Vempati, L., Urban air mobility airspace integration concepts, The Mitre Corportation.
[205] Raymer, D.P., Aircraft Design: A Conceptual Approach, AIAA Education Series, AIAA, Reston, VA, 5th edition, 2012.
[206] Raymer, D.P., French, J., Finger, D.F., Gomez, A., Singh, J., Pillai, R.G., Monjon, M.M., Marcos de Souza, J., Levy, A., The raymer manned mars airplane: A conceptual design and feasibility study, in AIAA Scitech 2021 Forum, 2021, 1187.
[207] Roskam, J., Airplane Design: Part V, Component Weight Estimation, Roskam Aviation and Engineering Corporation, Ottawa, KS, 1989.
[208] Fuentes, G., Ceron-Munoz, H., Parra, J., Design of an advanced turboprop aircraft for regional operations with ninety passengers, in 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, 2013, 24.
[209] Benini, E., Significance of blade element theory in performance prediction of marine propellers, Ocean engineering, 31, 2004, 957–974.
[210] Mahmuddin, F., Rotor blade performance analysis with blade element momentum theory, Energy Procedia, 105, 2017, 1123–1129, 8th International Conference on Applied Energy, ICAE2016, 8-11 October 2016, Beijing, China.
[211] Benini, E., Toffolo, A., Optimal design of horizontal-axis wind turbines using blade-element theory and evolutionary computation, J. Sol. Energy Eng., 124, 2002, 357–363.
[212] Ledoux, J., Riffo, S., Salomon, J., Analysis of the blade element momentum theory, SIAM Journal on Applied Mathematics, 81, 2021, 2596–2621.
[213] Cavcar, M., Breguet range equation?, Journal of Aircraft - J AIRCRAFT, 43, 2006, 1542–1544.
[214] Hu, P., kan Chang, C., Research on optimize application of buckingham pi theorem to wind tunnel test and its aerodynamic simulation verification, Journal of Physics: Conference Series, 1507, 2020, 082047.
[215] Wang, Z., Huang, W., Yan, L., Multidisciplinary design optimization approach and its application to aerospace engineering, Chinese science bulletin, 59, 2014, 5338–5353.
[216] Martins, J.R., Lambe, A.B., Multidisciplinary design optimization: a survey of architectures, AIAA journal, 51, 2013, 2049–2075.
[217] Comis Da Ronco, C., Ponza, R., Benini, E., Aerodynamic shape optimization of aircraft components using an advanced multi-objective evolutionary approach, Computer Methods in Applied Mechanics and Engineering, 285, 2015, 255–290.
[218] Spalart, P.R., Venkatakrishnan, V., On the role and challenges of cfd in the aerospace industry, The Aeronautical Journal, 120, 2016, 209–232.
[219] Dong, Y., Tao, J., Zhang, Y., Lin, W., Ai, J., Deep learning in aircraft design, dynamics, and control: Review and prospects, IEEE Transactions on Aerospace and Electronic Systems, 57, 2021, 2346–2368.
[220] Federal Aviation Administration, Federal aviation administration, https://www.faa.gov/, 2024.
[221] European Union Aviation Safety Agency, Regulations, https://www.easa.europa.eu/en/regulations, 2024.
[222] Allen, J.G., Coates, G., Trevelyan, J., A hyper-heuristic approach to aircraft structural design optimization, Structural and Multidisciplinary Optimization, 48, 2013, 807–819.
[223] Sadraey, M., A systems engineering approach to unmanned aerial vehicle design, in 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, AIAA, 2010, 9302.
[224] Sadraey, M., Unmanned Aircraft Design: A Review of Fundamentals, 2017.
[225] Desai, Y., Ali, J., Rhoades, C., Ayers, A., Madani, M., De Backer, W., Design and prototype of an autonomous uav, in 2024 Regional Student Conferences, 2024, 85574.
[226] Quan, Q., Introduction to multicopter design and control, Springer, 2017.
[227] Cammarata, A., Pappalardo, C.M., On the use of component mode synthesis methods for the model reduction of flexible multibody systems within the floating frame of reference formulation, Mechanical Systems and Signal Processing, 142, 2020, 106745.
[228] Pappalardo, C.M., La Regina, R., Guida, D., Multibody modeling and nonlinear control of a pantograph scissor lift mechanism, Journal of Applied and Computational Mechanics, 9, 2023, 129-167.
[229] Pappalardo, C.M., Lök, S.I., Malgaca, L., Guida, D., Experimental modal analysis of a single-link flexible robotic manipulator with curved geometry using applied system identification methods, Mechanical Systems and Signal Processing, 200, 2023, 110629.
[230] Ravindran, S.S., A reduced-order approach for optimal control of fluids using proper orthogonal decomposition, International journal for numerical methods in fluids, 34, 2000, 425–448.

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