NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

DEPARTMENT OF APPLIED
SOCIAL SCIENCES

TECHNOLOGY ASSESSMENT OF eVTOL PERSONAL AIR TRANSPORTATION SYSTEM

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Master of Science in Science and Technology Policy
Studies in The Graduate School of Social of Middle East
Technical University of Ankara

DOCTORATE PROGRAM ON TECHNOLOGY ASSESSMENT
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Abstract

This thesis intended to provide a holistic vision on the potential consequences of the introduction of emerging electrical Vertical Takeoff and Landing (e VTOL) Personal Air Transportation System (PATS) to contribute to the forming of public and policy opinion, and to assess the impacts and the feasibility of that. Instead of looking from a detailed vehicle design viewpoint, we tried to understand the need, the impacts, and the perceptions and the concerns of stakeholders. Thus, it was set a framework and methodology starting with a technology assessment point of view in the light of transportation system analysis. Limitations of the current ground and airline transportation systems, increasing congestion, poor block speed, combined with expanding population and demand for affordable on-demand mobility are driving the development of future transportation technology and policy. The third wave of aeronautics might be the answer and could bring about great new capabilities for society that would bring aviation into a new age of being relevant in daily lives since eVTOL PATS is envisioned as the next logical step in the natural progression in the history of disruptive transportation system innovations. However, there are a lot of questions. Although there was difficulty since the system was an emerging air transportation mode, an interdisciplinary study has been conducted to assess the impacts of developing such a capability. The research questions were determined to address the research objectives. What is the current state of mobility and eVTOL air transportation mode? What are the potential benefits of eVTOL air transportation mode for user and society? What are the perceptions of service providers, regulator, and user? What are the main challenges including technology, regulation, operation, social and environment aspects to enable the system? What are the enabling technologies? Nevertheless, with the results obtained lately from the research activities, revolutionary technologies and regulations are bringing us closer to eVTOL PATS reality every day. It can be argued that a new socio-technical transition will come about like the transition from horse drawn carriers to cars. Even if it is still a long way to go, it seems rather likely that the time has been arriving in the next decade. Their existence and operation would therefore need to be taken into consideration for today's planning considerations and construction projects to be able to have this emerging air transportation mode available in the future. As the technology underlying eVTOL PATS evolves, wider eVTOL adoption across various markets is likely to be supported further if a set of key challenges such as safety and security, ease of use and autonomy, noise, infrastructure, and air traffic management are overcome. Achieving drastic improvements in ease of use, safety and community acceptable noise are the most critical steps towards the future feasibility of this market. Multi-use demos and demonstrating successful operation with early vehicles, namely eVTOL PATS prototype field operations, will create public acceptance and understanding of potentials in emerging air transportation mode for public good, use and learn in multiple applications. The overall perception of the user, service provider and regulator are positive, and the support is high. Shortly, a successful implementation and sustainable transition will depend on overcoming technological hurdles, regulatory frameworks, operational safety, cost competitiveness, and sensibilities of the affected communities. There is a need to enable people and goods to have the convenience of on-demand, point-to-point safe travel, further, anywhere in less travel time, through a network of pocket airports/vertiports, and there is a significant potential benefit so that policy makers, regulators and metropoles' transportation planning departments should consider an inclusion of eVTOL air transportation mode into the scenarios and policies of the future.

Keywords: Technology Assessment, Electric Vertical Takeoff and Landing Personal Air Transportation System (eVTOL PATS), Key Enabling Technologies, Door-to-Door Block Speed, Travel Time Saving, Daily Radius of Reach, Urban Air Mobility, Technology Impacts, Perception of Stakeholders.

Resumo

Esta tese pretende fornecer uma visão holística sobre as potenciais consequências da introdução do Sistema de Transporte Aéreo Pessoal (PATS) de Decolagem e Pouso Vertical elétrico emergente (e VTOL) para contribuir para a formação de opinião pública e política, e para avaliar os impactos e a viabilidade disso. Em vez de olhar de um ponto de vista detalhado o projeto do veículo, tentamos entender a necessidade, os impactos, as percepções e as preocupações das partes interessadas. Assim, foi definido um quadro e uma metodologia partindo de um ponto de vista de avaliação de tecnologia à luz da análise do sistema de transporte. As limitações dos atuais sistemas de transporte terrestre e aéreo, o aumento do congestionamento, a baixa velocidade do tráfego, combinados com a expansão da população e a mobilidade com procura acessível estão impulsionando o desenvolvimento de futuras tecnologias e políticas de transporte. A terceira onda da aeronáutica pode ser a resposta e pode trazer grandes novas capacidades para a sociedade que trariam a aviação para uma nova era de ser relevante na vida cotidiana, uma vez que o VTOL PATS é visto como o próximo passo lógico na progressão natural na história das inovações disruptivas do sistema de transporte. No entanto, há muitas perguntas. Embora tenha havido dificuldade por se tratar de um modo de transporte aéreo emergente, um estudo interdisciplinar foi realizado para avaliar os impactos do desenvolvimento de tal capacidade. As questões de investigação foram determinadas para atender aos objetivos do projeto. Qual é o estado atual da mobilidade e do modo de transporte aéreo eVTOL? Quais são os benefícios potenciais do modo de transporte aéreo eVTOL para o utilizador e a sociedade? Quais são as percepções dos provedores de serviços, regulador e utilizador? Quais são os principais desafios, incluindo tecnologia, regulamentação, operação, aspectos sociais e ambientais para habilitar o sistema? Quais são as tecnologias facilitadoras? No entanto, com os resultados obtidos ultimamente nas atividades de pesquisa, tecnologias e regulamentações revolucionárias estão nos aproximando cada dia mais da realidade do VTOL PATS. Pode-se argumentar que uma nova transição sócio-técnica ocorrerá como a transição de carruagens puxadas por cavalos para automóveis. Mesmo que ainda seja um longo caminho a percorrer, parece bastante provável que a hora esteja chegando na próxima década. A sua existência e operação, portanto, precisam ser levadas em consideração para as questões de planeamento e projetos de construção de hoje para poder ter esse modo de transporte aéreo emergente disponível no futuro. À medida que a tecnologia subjacente ao eVTOL PATS evolui, é provável que a adoção mais ampla do eVTOL em vários mercados seja ainda mais apoiada se um conjunto de desafios importantes, como segurança e proteção, facilidade de uso e autonomia, ruído, infraestrutura e gestão de tráfego aéreo forem superados. Alcançar melhorias drásticas na facilidade de uso, segurança e ruído aceitável pela comunidade são os passos mais críticos para a viabilidade futura deste mercado. Demonstrações multi-uso e demonstração de operação bem-sucedida com veículos iniciais, ou seja, operações de campo do protótipo eVTOL PATS, criarão aceitação pública e compreensão dos potenciais no modo de transporte aéreo emergente para o bem público, uso e aprendizado em várias aplicações. A percepção geral do utilizador, prestador de serviço e regulador é positiva, e o suporte é alto. Uma implementação bem-sucedida e uma transição sustentável dependerá da superação de obstáculos tecnológicos, estruturas regulatórias, segurança operacional, competitividade de custos e sensibilidade das comunidades afetadas. Há uma necessidade de permitir que pessoas e mercadorias tenham a conveniência de viagens seguras de que necessitam, ponto a ponto, e além disso, em qualquer lugar em menos tempo de viagem. Isso pode ser feito por meio de uma rede de aeroportos/vertiports, e há um benefício potencial significativo para que os formuladores de políticas, reguladores e departamentos de planeamento de transporte das grandes metrópoles considerem a inclusão do modo de transporte aéreo eVTOL nos cenários e políticas do futuro.

Palavras-chave: Avaliação de Tecnologia, Descolagem e Pouso Vertical (VTOL), Sistema de Transporte Aéreo Pessoal VTOL Elétrico, Economia de Tempo de Viagem, Raio Diário de Alcance, Mobilidade Urbana, Impactos tecnológicos, Percepção dos Stakeholders.

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List of Acronyms

ABM – Agent Based Modelling

AGATE – Advanced General Aviation Transportation Experiment

AHS – American Helicopter Society

AIAA – American Institute of Aeronautics and Astronautics

ARMD – Aeronautics Research Mission Directorate

ASTM – American Society for Testing and Materials

ATC – Air Traffic Control

ATM – Air Traffic Management

ATS – American Travel Survey

BRS – Ballistic Recovery System

CTA – Constructive Technology Assessment

DARPA – Defense Advanced Research and Project Agency

DEP – Distributed Electric Propulsion

DLR – German Aerospace Agency

DNL – Day Night Level

EAA – Experimental Aircraft Association

EASA – European Aviation Safety Agency

ECA – Entity Centric Abstraction

ELOS – Equivalent Level of Safety

EPATS – European Personalized Air Transportation System

EU – European Union

Eurostat – Statistical Office of the European Commission

eVTOL – Electric Vertical Take Off and Landing

FAA – Federal Aviation Administration

FAR – Federal Aviation Regulations

FATO – Final Approach and Take Off

GA – General Aviation

GAMA – General Aviation Manufacturer Association

GAP – General Aviation Propulsion

GDP – Gross Domestic Product

GNSS – Global Navigation Satellite System

ICT – Information and Communications Technology

CBA – Cost Benefit Analysis

IFR – Instrument Flight Rule

IMC – Instrument Meteorological Condition

KIT – Karlsruhe Institute of Technology

NASA – National Aeronautics and Space Agency

OCDE – Organization for Economic Co-operation and Development

ODM – On-Demand Mobility

OEM – Original equipment manufacturer

OTA – Office of Technology Assessment

PATS – Personal Air Transportation System

PAV – Personal Air Vehicle

PAVE – Personal Air Vehicle Exploration Program

PSA – Public Safety Area

R&D – Research and Development

R&D&I – Research and Development and Innovation

S&T – Science and Technology

SAFAR – Small Aircraft Future Avionics Architecture Research

SATS – Small Aircraft Transportation System

SES – Single European Sky

SESAR – Single European Sky ATM Research

TA – Technology Assessment

TAF – Transportation Architecture Field

TVF – Transformative Vertical Flight

UAS – Unmanned Aerial System

USA – United States of America

UTM – Unmanned Aircraft System Traffic Management

VOCT – Value of Commuting Time

VTOL – Vertical Take Off and Landing

VTT – Value of Travel Time

VTTS – Value of Travel Time Saving

1. Introduction

For most people, transportation alternatives are personal cars, commercial air transportation, trains, or buses, but these options have a downside. Additional use of cars yields more road congestion and air pollution, which is already a serious concern. While trains or buses are very convenient in some cities, they are basically for scheduled trips and are not an efficient method to cover door-to-door trips. Other alternatives that can be considered are high-end transportation methods such as rotorcraft, business jets, etc. However, these options exist only for licensed pilots or the wealthy, most of the public simply cannot afford to use these high-speed, on-demand modes. New products and services responding to the evolving wants and needs of travelers must be created. Potential solutions to this could lie in many areas such as intelligent ground transportation systems, high-speed rail transportation or small aircraft transportation system. In short, if the current transportation system is under pressure to improve and evolutionary improvements to existing system are not enough to achieve the desired level, a new transportation mode must be introduced into the existing system.

A literature review sheds light on the complexity of urban mobility from technical, socio-technical, and user experience perspectives. In one of the workshops of the International Transport Forum entitled “designing cities for people” (OECD, 2014), it was pointed out that the world's population is increasingly concentrated in cities causing problems of inequality and accessibility. The proportion of people living in the world’s urban areas is expected to rise in the coming decades. This growth generates increasingly challenging situations for urban travelers, such as traffic chaos, insecurity, poorer quality of life, limited parking space, air pollution, and noise. This poses a risk for the quality of life. To avoid such a future, urban planning will need to adopt approaches that focus on the diversity of citizens and their needs, thus encouraging the development of new approaches to ensure their quality of life. The comprehension of users’ needs and wants is a matter that concerns every stakeholder of urban mobility and a powerful way to bring together their views in designing integrated mobility systems.

The electric Vertical Take Off and Landing (eVTOL) Personal Air Transportation System (PATS), conceivably revolutionizing our daily life in the future, is such an example. It must be recognized that eVTOL PATS will differ from current air transportation modes in that they eventually should appeal to a significant percentage of the general-public. This leads to considering the impacts of eVTOL PATS. Vehicle-oriented or technology-driven design processes often ignore this aspect. They lack consideration of whole aspects of the consequences of an emerging eVTOL PATS implementation.

A new socio technical transition at transportation will come about like the transition from horse drawn carriers to autos. Governing transport and traffic are a very complex issue that includes many different socio-technological aspects. Such transition requires assessment and impact analysis. Transport planning must mediate between various influences such as economic interest, environmental protection, land-use planning issues, human health, safety, or social equality. It must take into consideration technical innovation, quality standards, habits, standards of living, ideological visions, and other factors. As a result, introducing a new mode into the transport system is not possible without a certain extent of acceptance by its users and citizens. Like any innovations, eVTOL PATS must be adapted by the users and accepted by the public. Against this background, it is of utmost importance to understand the perspectives and expectations of potential users and/or citizens when carrying out a technology assessment for eVTOL PATS. Therefore, the present doctoral thesis aimed to explore the socio-technological environment of eVTOL PATS and to assess different aspects related to the emerging eVTOL air transportation mode.

In this context, this research intended to provide a holistic vision on the potential consequences of the introduction of emerging eVTOL PATS into the transport system to contribute to the forming of public and policy opinion while assessing the positive and negative impacts of that. Instead of looking from a detailed vehicle design viewpoint, the research aimed to understand the need and the perceptions of the stakeholders, to identify the key entities in the system, and to assess the positive and negative impacts. The research set the framework and methodology starting with a technology assessment (TA) point of view. Because the rapid growth of ever complex technologies and the increased visibility of technology’s role in shaping society and its capacity as a useful and interdisciplinary tool for systematic study of whole aspects placed TA as an approach of several fields in social science and humanities, management, and strategy.

Despite the proliferation of companies developing electric and hybrid/electric eVTOL air vehicles, the literature about their real impacts on user, environment, air traffic and infrastructure received less attention. Currently, the perception and preferences of society and the impacts in relation to eVTOL PATS are unclear. The existing literature offers several relevant insights, but also has shortcomings. An approach from technology assessment point of view does not exist. This study intended to contribute to the research gap in the literature and to increase the awareness of ongoing developments by performing a technology assessment of emerging eVTOL air transportation mode at an early stage of technology development. This study will be a reflexive pioneering work in individual transportation of the future.

The contribution of this study can be important for two main reasons. First, TA considers its task as interdisciplinary approach to preventing or reducing the potential negative consequences of new and emerging technologies caused by the uncritical application and commercialization of new technologies. In other terms, TA is the systematic study of the impacts on society and the environment that occur when a technology is introduced, extended, or modified. Second, the fundamental rationale of TA is that various social groups other than the actual initiators and proponents of a technology are claiming the right to have their say in decisions concerning the future application and diffusion of a technology. Additionally, the content of this research can help decision makers identify their roadmaps.

Investments and operations in the transportation sector are often evaluated by positive and negative impact analysis. Just as consumers need accurate and comprehensive information when making personal travel decisions, decision makers and communities need accurate and comprehensive information on all significant impacts when making transport policy and planning decisions since newer approaches will have a profound influence upon the pattern of life. This eventually reshapes the pattern of life for many individuals. This is another important starting point in this study.

Although there was difficulty since the system was an emerging eVTOL air transportation mode, an interdisciplinary study has been conducted to assess the impacts of developing such a capability. The research questions were determined to address the research objectives. What is the current state of mobility and eVTOL air transportation mode? What are the potential benefits of eVTOL PATS for user and society? What are the perceptions of service providers, regulator, and user? What are the main challenges including technology, regulation, operation, social and environment aspects to enable the system? What are the enabling technologies? The detailed research design will be discussed in the next chapter. Nevertheless, the first step will be understanding the current mobility issues and the need for a new transportation mode which is being covered in the coming section.

1.1 Problem Background: Is There a Need For a New Transportation Mode?

This subsection provides a foundation for the rest of the study by discussing the mobility issues, the current means of transportation and the need for a newer approach.

Mobility is one of the basic human needs in all time periods and was as central to the functioning of society in the past as in the present. Besides, the Transportation System (TS) that is providing mobility, composed of transportation vehicles, their supporting infrastructure and the people who use, operate, and build the system itself is one of the largest and most complicated system of systems of modern civilization. Our existing transportation systems are the cumulative result of countless separate decisions and investments made by public, private organizations and individuals and has continuously expanded its capability through technology revolutions. Nobody knows how the future will look like exactly, but there is a hint pointing at changes in the transport system. There are new technological options. Technically spoken, for example flying is not a challenge anymore. Since the 1950s civil aviation has experienced an extreme increase in numbers of passengers. In the second half of the 20th century the old dream of flying became a real option for a large part of the world population. It surely is safe to assume that such a development was hardly imaginable at the beginning of the 20th century. Since then, the transport system has not experienced the successful introduction and diffusion of a completely new technology for mass transport again.

However, an understanding of the brief transportation transformation and facts is required prior to outlining and discussing the problem. The developed nations entered the 1900s with a transportation system for people centered upon the horse, the railroad, and the steamship, with associated travel times the order of hours to days and weeks, depending on distance. In the closing years of the same century, the auto has long supplanted the horse and the fix wing aircraft has nearly driven the railroad and steamship companies from the long-range passenger business. Travel times have shrunk to minutes to hours while average amount of time travelled per day has remained relatively constant. If the statistical travel data continues the same trend, it appears that once high speed, on demand travel service is offered to the market, consumers will utilize these vehicles for increased mobility reach instead of saving travel time (SAT-RDMP, 2015). Because mobility studies have shown that over the last 100 years, while travel speeds have increased tenfold, average amount of time travelled per day has remained relatively constant at about 1.25 hours per day (Schaefer, 1998). This statistic also holds true for other countries at different effective technology levels (Gakenheimer, 1999). For instance, over the last 30 years, average ground speed has increased slightly to the current value of 35 miles/ hour with 1995 and 2000 data showing the first decreases for ground mobility (Rhino Corps., 2005). The daily radius of action has improved from about 3 miles per day in 1900, to about 25 miles per day in 2000 for intra urban travel (American Travel Survey, 2011).

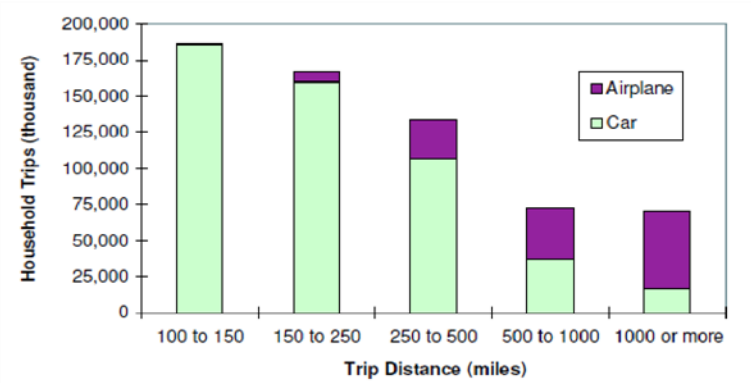


Fig. 1.1 Current Mode Choice Based on Distance, source: (OECD Travel and Mobility Survey, 2011).

In case of current means of transportation, according to OECD Travel and Mobility Survey (2011), car access and car usage is still by far the determinant aspect in overall mobility. The current dominant transportation mode for short to moderate range is the car, which possibly more than any other single technical achievement, has enabled the current lifestyle enjoyed by the developed nations (Trends Magazine, 2012). Households are getting smaller but have more vehicles, and many households own several vehicles. Although the modal share of cars may be increasing, buses, still, remain a basic means of transportation in cities. More time spent in transportation and longer distances despite fewer trips. A large percentage of transport is for leisure purposes because of an increase in living standards (Violland, 2011). However, the status of auto has created massive safety problems and has been responsible for so many environmental impacts on the other side. The most advocated alternatives involve some form of mass transit, which have, along with enormous capital costs, several other drawbacks such as passenger wait time, weather exposure and lack of privacy, security, pride of ownership and personal stowage. Additional drawbacks are the fact that they are not portal to portal and there is no guarantee or having a seat, as well as an inherent assumption regarding increased population density.

What can be understood from the discussions above is that our transport system is reaching its limits under several aspects. Over the last 50 years we were able to observe a strong increase in passenger transport in the Western world and beyond, but this increase was based on the existing modes road-bound transport, rail, waterways, and civil aviation. Congestion and the waste of space for new roads are serious challenges to the economic growth and the quality of life in European countries. Daily commuting is reaching their limits during peak travel times, which results in environmental issues due to wasted fuel and loss of time and money. The average trip time is increasing due to suburban expansion and increased congestion, causing non-trivial changes in family life as travelers attempt to utilize nontraditional time slots, or suffer long nonproductive commutes. For example, urban transport which accounts for a significant part of total mobility and for even greater proportion of its negative consequences is related to a wide range of unsolved problems and challenges that need to be tackled to guarantee a high quality of life in cities. City population faces increasing emissions of pollutants and noise, as well as congestion and reduced accessibility as shown briefly in the Figure 1.2 below. According to Texas A&M Transportation Institute (2014), the cost of congestion as time is 6.9 billion hours additional travel time and 42 hours per person annually. In the USA, 5.7 billion gallons of fuel wasted in traffic yearly, of a seven-fold increase in traffic delays over the past 30 years (Hodges, 2010). In Europe, approximately 100 billion Euros are lost every year because of congestion (PPlane Project, 2014). In Istanbul, almost 2 billion Euros are lost every year because of congestion (cnnturk.com, 11.10.2017).

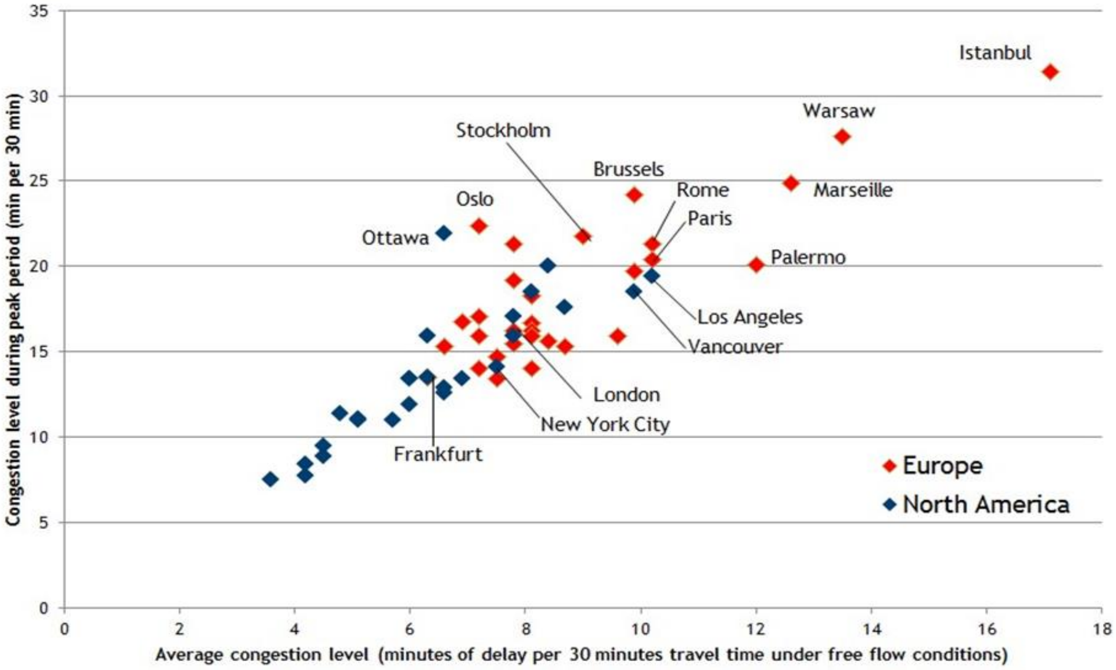


Fig. 1.2 Comparison of average and peak hour congestion levels in major European and North American cities, source: (analysis based on floating car data for Q2/2012).

On the other hand, air travelers are predominantly served by large airlines using the traditional hub-and-spoke system. Airlines account for about 2% of all trip miles, and a much lower percentage of all trips (American Travel Survey, 2011). While this system is an efficient method in many ways and has increased its capability in recent years, air travelers are increasingly dissatisfied with the current air transportation system as it gradually becomes plagued by delays, long waits, and built-in inefficiencies both in the air and on the terminal areas (DeLaurentis, 2002). In terms of door-to-door passenger time, comfort, convenience and satisfaction, the hub and spoke system is extremely ineffective for especially short to mid-range trips where the bulk of trips are taken (De Laurentis, 2002). A current study being conducted by Volpe in cooperation with NASA shows that 29% of the total door to door trip time is the actual gate to gate time of the airliner for trips under 500 miles. The rest are terminal time 33%, access egress time 18%, and wait time 20% (Driving many miles in congestion to reach a hub, arriving early for ticketing, security, baggage checks, connection through other hubs, driving again to reach destination, etc.) (Moore, 2003). Even more, aviation is going through one such catastrophic event due to the terrorist attacks, which rises an important issue. If ground to air missiles attacks on airliners were to occur, there is little that could be done to keep large aircraft secure in the skies. No matter what attempts are made at securing the safety of large transports, they will continue to make highly visible and tempting targets. Currently with a weather delay at just one of the major hubs, the entire system experiences significant setbacks. While centralized systems are efficient, they do not provide a robust system solution. The hub and spoke aviation system can only continue to grow if it is a robust system. In nature, natural selection shows that for systems to survive and promote the maximum market size, highly distributed systems result. This robustness is essential to prevent a catastrophic loss in mobility that would yield disastrous effects on the economy.

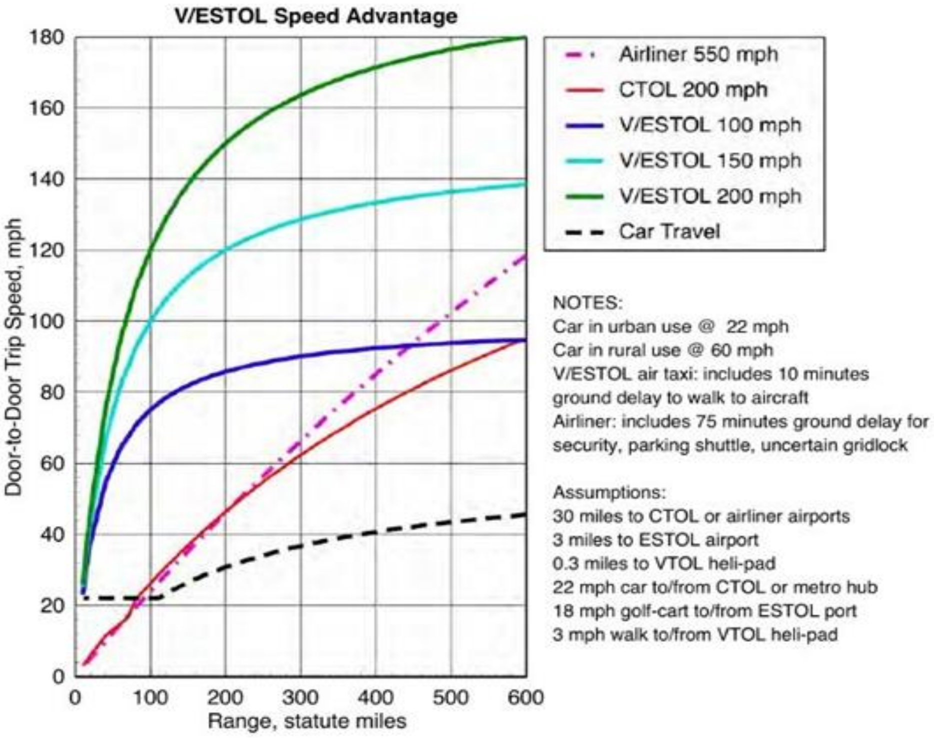
Besides, it is clear that per capita income rises as per capita annual travel rises. Since personal daily travel time budgets remain constant at 1.25 hours per day (Schafer, 1998), the growing demand for societal mobility is already driving a continually increasing demand for high-speed transport, air travel. The challenge facing aviation is to meet the predicted growth in demand for air travel (increasing 4-5% per year over the next 20 years), but to do so in a way that ensures that environment is protected (Schaffer and Victor, 1997).

As a result, the TS is under pressure to improve, as ground highway and air hub and spoke travel congestion result in increasing delays, the infrastructure investment required to attempt break even through these two highly constrained systems will be insufficient and artificially limit economic growth through loss of time and opportunity. Society cannot easily or otherwise, continue to bear costs imposed by almost sole reliance upon the automobile for short to immediate range passenger transport, alternatives are necessary for the future. In other terms, limitations of the current ground and airline transportation systems, increasing congestion and poor block speed, combined with expanding population and demand for affordable mobility are driving the development of future transportation technology and policy.

A new and radically different way of seeing the problem of individual mobility, and of the roles of various stakeholders in finding solutions is also necessary. Therefore, a new mobility system, a new product resulting from innovative ideas and revolutionary technologies must be developed and introduced. Against this background, it could be argued that it is time to think about new options for the transport system. From the perspective of science and policy making, it is important to get prepared for future transport options. Transport infrastructures are long-lasting systems; it is crucial to early anticipate future transport innovations to be able to govern them in a most responsible and sustainable way. These are also the kinds of observations and reflections which motivated this research.

One radical solution to the existing problems might be in the air. The third wave of aeronautics could bring about great new capabilities for society that would bring aviation into a new age of being relevant in most people's daily lives. The ability to personalize air travel using on demand, highly distributed air transportation system may provide the degree of freedom and control. eVTOL Personal Air Transportation System is envisioned as the next logical step in the natural progression in the history of disruptive transportation system innovations and would provide, percentage wise, the same increase in speed as the auto provided over the horse. What is driving eVTOL Personal Air Transportation System? The convergence of several factors such as emerging technologies, societal demands, business opportunities and possible relaxation to some operational constraints are driving the emerging air transportation mode (Dudley, 2018). It can be observed in Figure 1.3 that the block speed advantage of VTOL air vehicle against car and airline travel is so clear up to 600 miles.

What is driving eVTOL Personal Air Transportation System? The convergence of several factors such as emerging technologies, societal demands, business opportunities and possible relaxation to some operational constraints are driving the emerging air transportation mode (Dudley, 2018).



NOTES:
Car in urban use @ 22 mph
Car in rural use @ 60 mph
V/ESTOL air taxi: includes 10 minutes ground delay to walk to aircraft
Airliner: includes 75 minutes ground delay for security, parking shuttle, uncertain gridlock

Assumptions:
30 miles to CTOL or airliner airports
3 miles to ESTOL airport
0.3 miles to VTOL heli-pad
22 mph car to/from CTOL or metro hub
18 mph golf-cart to/from ESTOL port
3 mph walk to/from VTOL heli-pad

Fig. 1.3 Door-to-Door Block Speed Advantage of VTOL Air Vehicles, source: (Seeley, 2010).

The first important point to understand whether new transportation mode is the one we need is to discuss expectations from the transportation system investment. For this reason, an understanding of the most prominent goals of transportation investments is required prior to outlining and discussing the impacts of emerging air transportation mode. Two of the most prominent goals of transportation investments are time savings and improvements in the reliability (i.e., Predictability) of travel time (Hensher, 2001). Thus, the value of travel time is a critical factor in evaluating the benefits of transportation investment. Travel time is one of the largest categories of transport costs, and time savings are often claimed to be the greatest benefit of transport projects such as roadway and public transit improvements[1].

Overall, it is argued that all systems evolve, based on a combination of slow growth and catastrophic events. Understanding the driving evolutionary forces permits an understanding of the pressures and where they may lead. Within this context, it can be argued that a new socio technical transition will come about like the transition from horse drawn carriers to autos.

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[1] The Value of Travel Time (VTT) or The Value of Commuting Time (VOCT) refers to the cost of time spent on transport, including waiting as well as actual travel. In modern society with specialized occupations, travel time to work (commuting) takes up a large part of the individual’s daily schedule. The VTT includes costs to consumers of personal (unpaid) time spent on travel, and costs to businesses of paid employee time spent in travel. The Value of Travel Time Savings (VTTS) refers to the benefits from reduced travel time costs. Another topic in the value of time research is the value of reliability. Especially in urban areas where congestion is common, many travelers consider it more important to decrease the uncertainty of the travel time than to reduce the travel time itself.

Really, aviation has been a key catalyst for economic growth and has had a profound influence on our quality of life, and undoubtedly its influence on daily life will continue increasingly over the coming decades. In this century, aviation has the potential to enable expanded air accessibility for more in our society. The future needs of commerce, mobility, safety, and security in air transportation will not be met unless strategies, coupled to new technologies, transform the airspace infrastructure and business models with a system of systems perspective, to interface aviation with the entire transportation system and mobility user needs.

Nevertheless, there is both a need and an opportunity to include in the transportation mix eVTOL PATS which would provide, percentage wise, the same increase in speed as the auto provided over the horse which means travel time saving and reliability. If a new air transportation mode is to be developed, what goals would be established for this system? It appears that it would be a quite different set of functions than what the airlines used to shape the second wave of aeronautics.

1.2 The Scope and Organization of The Thesis

This subsection outlines and defines the scope of the study and provides the structure of the thesis. In this research, however, the possible alternatives will remain within the third dimension, aerospace field. The scope of this study is to provide a holistic vision to contribute to the public and policy opinion forming on the potential consequences of the introduction of emerging eVTOL air transportation mode as an answer to the existing issues or as the next logical step in the natural progression. The study also intends to enlarge understanding of emerging on-demand eVTOL air transportation mode which is to provide a dramatic time savings and increased reach in personal mobility and to supplement commuter services in urban or regional transportation system.

The main objectives of this research are to analyze the potential benefits of eVTOL PATS, to assess the impacts and the major challenges, to discuss key enabling technologies, and to understand the perceptions of the stakeholders. Provided more are researchable questions and design approaches to assess opportunities and challenges that may result from the implementation of emerging eVTOL air transportation mode through with a sample technology assessment framework for emerging technologies. The main contribution of this research will be synthesizing the policy advice to address challenges related to the implementation of eVTOL air transportation mode.

The present work contains five more chapters. The following chapter discusses the research approach, the research questions, the technology assessment framework, and the methods used to answer the research questions. It first illustrates the main ingredients of the research describing the approaches and questions. Then, it describes the technology assessment framework which is a multi criteria analysis framework to examine potential positive and negative impacts of an emerging eVTOL air transportation mode. It also concentrates on presenting the various research methods used: surveys (with self-administered questionnaires and standardized interviews); annual forum and summit papers and presentations; eVTOL news; and relevant companies' web sites. This chapter also presents the technology assessment framework as a sample framework for evaluating economic, technological, social, and environmental aspects of a long-term emerging socio-technological system.

The third chapter sets the main theoretical foundation that will help us understand and visualize the key entities in the system and the impact dimension. The third chapter describes the theoretical framework underpinning this research in three different subchapters to assist in facilitating the course of the thesis. The first subsection discusses the technology assessment point of view. It first examines its task as interdisciplinary approach to solving already existing problems and preventing or reducing the potential negative consequences of new and emerging technologies caused by the uncritical application and the commercialization of new technologies by emphasizing the fundamental rationale of TA afterwards. Because the rapid growth of ever complex technologies and the increased visibility of technology's role in shaping society place TA as an approach of several fields in social science and humanities, management, and strategy. The second subsection analysis transportation system to understand basic terminology, the whole picture, the current mobility issues, and the need for a new transportation mode. It also introduces main stakeholders, resource network, driving and disrupting factors to facilitate the abstraction of the key entities in the whole system since the system is one of the largest and most complicated system of modern civilization. Furthermore, the third subsection starts by introducing concepts related to eVTOL PATS and then, discusses the attractiveness of eVTOL air transportation mode and the state of the work.

The fourth chapter presents the main results and findings in the seven blocks. The first subsection discusses the results of projects in Europe and U.S. The second subsection reviews the results of myCopter Project that can be leveraged for eVTOL air transportation applications. The third subsection presents results of NASA and AHS International conferences, workshops, and annual forums. The fourth subsection presents results of Uber elevate summit and white paper to explain. The fifth subsection presents the findings of companies developing electric and hybrid electric VTOL air vehicles. The sixth subsection presents the results of the questionnaire and interviews in Istanbul, Ankara, and Izmir. The last subsection presents the results from the case study in Istanbul to visualize potential benefit in terms of monetary.

The fifth chapter presents the assessment of eVTOL PATS in four blocks that address the research questions. The first subsection examines the perceptions of the user, regulator and service provider based on primary and secondary survey results. The second subsection discusses the potential benefits based on secondary data assessment. The third subsection presents technology aspect, the necessary technologies to enable eVTOL PATS. The fourth subsection presents the major challenges and the main impacts on user, society, air traffic, environment, and legal aspect. This chapter combines and analysis the primary and secondary results and findings from the previous chapters within the context of the research objectives.

In the last chapter, the main conclusions of the thesis are described. The last chapter summarizes the main findings and synthesis in the study addressing the research questions and emphasizes the main contributions. Practical policy advice is herein put in scope with the research. Afterwards, it discusses an overview of the limitations of this thesis and possibilities for future work.

2. Research Questions and Methodology

2.1 Introduction

This chapter discusses the researchable questions, the methodology and the research framework and describes the methodological procedures employed to answer the research questions. This section offers the rationale for the chosen research philosophy, approach, strategy, purpose, and time-horizon. In addition, consideration of ethical issues and limitations of the research methodology are also provided in this section. Overall, the chapter facilitates replication of the research methods employed, supporting the study's reliability (Fink, 2003). Methods refer to the range of techniques available to collect evidence about the social world. They are tools or lenses to be applied to different kinds of research questions researchers seek to address. The selection of methods to collect data depends on the nature of the inquiry and the type of information required. In this study, a combination of methods was used to answer the research questions. Mainly qualitative but both approaches were employed. The main research instruments that were used are: interviews, questionnaires, case study to collect primary data and documentation research, analyzing existing similar project results, relevant forum and workshop reports and presentations, and company web sites to collect secondary data. The researcher has also attended relevant activities, exhibitions, and conferences until the end of the research.

A literature review sheds light on the complexity of urban mobility from technical, socio-technical, and user experience perspectives. In one of the workshops of the International Transport Forum entitled "designing cities for people" (OECD, 2014), it was pointed out that the world's population is increasingly concentrated in cities causing problems of inequality and accessibility. The proportion of people living in the world's urban areas is expected to rise in the coming decades, to reach 66% by 2050 (UNDESA, 2014). This growth generates increasingly challenging situations for urban travellers, such as traffic chaos, insecurity, poorer quality of life, limited parking space, air pollution, and noise. This poses a risk for the quality of life. To avoid such a future, urban planning will need to adopt approaches that focus on the diversity of citizens and their needs, thus encouraging the development of innovative approaches to observe travellers and ensure their quality of life.

The comprehension of users' needs and wants is a matter that concerns every stakeholder of urban mobility and a powerful way to bring together their views in designing integrated mobility systems. Urban mobility actors, therefore, are given opportunities to innovate and create new products and services responding to the evolving wants and needs of travellers. In sum, if the transportation system is under pressure to improve and evolutionary improvements to existing system are not enough to achieve the desired level, a new transportation mode must be introduced into the existing system. eVTOL Personal Air Transportation System, revolutionizing our daily life in the future, is such an example. It must be recognized that eVTOL Personal Air Transportation Systems will differ from current air transportation modes in that they eventually should appeal to a significant percentage of the general-public. This leads to considering their impacts. Vehicle-oriented or technology-driven design processes often ignore this aspect. They lack consideration of whole aspects of the consequences of an emerging eVTOL Personal Air Transportation System implementation.

Instead of looking from a detailed vehicle design/analysis viewpoint, understanding the leverage effect of a vehicle's top-level design requirements, its impacts, the perceptions of stakeholders and the challenges in implementing might be right approach to assess the emerging air transportation mode. According to Auvinen & Tuominen (2014), technological, social, economic, political, legal, and environmental dimensions need to be considered to understand the complexity of mobility. There is difficulty since the system is an emerging air transportation mode and a complex system (GAO, 2021). The rapid growth of ever complex technologies and the increased visibility of technology's role in shaping society place Technology Assessment (TA) as an approach of several fields in social science and humanities, management, and strategy. TAs are significant given the growing effects of S&T on society, economy, and other areas. Within this context, TA considers its task as interdisciplinary approach to solving already existing problems and preventing potential damage caused by the uncritical application and the commercialization of new technologies. In other terms, TA is the systematic study of the impacts on society and the environment that occur when a technology is introduced, extended, or modified. Therefore, this PhD thesis focuses on emerging eVTOL air transportation mode in a framework and methodological approach starting with TA point of view in the light of transportation system analysis.

Innovative technologies can have a range of effects, potentially both positive and disruptive, that TA can explore. GAO has broadly defined TA as the thorough and balanced analysis of significant primary, secondary, indirect, and delayed interactions of a technological innovation with society, the environment, and the economy and the present and foreseen consequences and effects of those interactions (GAO, 2021). Technologies present opportunities and challenges that may vary, depending on the policy context in which they are assessed. Therefore, part of a TA is considering the policy context surrounding a given technology. Policy can be used to articulate a range of actions a policymaker could consider that may enhance benefits or mitigate the challenges of a technology, making it critical to understand and evaluate the effects of technology by (GAO, 2021):

- highlighting potential effects of a technology,
- elaborating on the challenges and benefits associated with a technology,
- highlighting the status, viability, relative maturity, and public and private uses of a technology,
- describing the regulatory environment of a technology,
- exploring ethical, legal, and social questions that may arise from the application of a technology.

TAs include a robust initiation and design process that considers factors such as stakeholder input, the current state of knowledge, and relevant and appropriate methodological considerations in defining and investigating appropriate researchable questions (GAO, 2021). Focusing the TA on answering specific researchable questions can assist researchers to define and select the appropriate scope and approach, ensuring that collection and analysis of the data are relevant, sufficient, and appropriate to answer the research questions. As part of the TA process, developing TA design and scope helps guide and coordinate the research activities to enhance quality and ensure effective use of resources. TA do not have a uniform design approach.

Interdisciplinary nature of TA can also present challenges to shared understanding (GAO, 2021). A wide range of methodologies has been utilized in TA works ranging from analytic techniques to integrated impact analysis approaches. Policy formulation TA works typically employed more holistic and multifaceted research methodologies. However, there are no universal tools or methods that can be applied in all TA studies. It requires the invention of new methodologies and approaches to meet the new demands of the field. This research started with problem-oriented assessment which addressed the need and the means of solution for the current mobility problems and took the form of technology-oriented assessment which examined emerging eVTOL air transportation mode and analyzed its impacts The chapter also proposes an assessment framework to describe and analyse different facets of a new or emerging technology implementation. As we were discussing future-oriented knowledge generation, this methodological approach was of outmost relevant.

During the first phase, the scoping decisions were made, the analysing dimensions were determined, and the researcher continued to build on the situation analysis work and gather more background information. Scoping decisions may affect the conclusions a TA can draw, as well as the research questions. Therefore, this stage should emphasize the areas that have been scoped out, along with any other key decisions, limitations, and considerations that provide context to the research. The dimensions along which to analyse will be highly context-specific, vary from TA to TA, and depend on the scope and research questions of the TA. An initial situation analysis may entail a preliminary literature search, early interviews with experts, and review of relevant projects reports, among other methods. In the initial research analysis, transportation system, eVTOL air transportation mode and TA literature with a broad variety of government, academic, and private sources were reviewed to get a sense of what have been done. Key entities with their attributes in the emerging eVTOL air transportation mode have been identified. The ecosystem of eVTOL Personal Air Transportation System has been modeled and visualized by using Agent Based Modeling approach and structural modeling in terms of virtual emerging air transportation mode architecture consisting of stakeholder network, resource network, drivers, and disrupters. Shortly, the initial situation analysis was used to:

- develop an initial understanding of the emerging technology, eVTOL air transportation mode, in the complex transportation system context,
- Inform the aims of the research and possible researchable questions to be assessed,
- Identify other preliminary activities (such as initial interviews and identifying potential data sources),
- Identify the key entities in emerging eVTOL air transportation mode such as resource and stakeholder networks, drivers, and disrupters, and modelling the ecosystem as a virtual eVTOL air transportation system architecture.

Stakeholders include a wide range of internal and external stakeholders who advise, review, contribute to, and may be affected by the technology. Resource networks include technical and operational aspects such as air vehicles, infrastructure, and airways. The research questions serve to guide the development of policy by stating their overall aims and helping to identify the landscape and scope. In sum, the researcher confirmed the scope, highlighted limitations, assumptions, and other factors, refined the research questions, and identified and selected appropriate design, methodologies, data sources and analysis tools. The research plan was detailed in the next sections.

2.2 Research Objectives and Questions

For general people, using eVTOL air transportation mode still needs time for a while. Several significant technology advances across key enabling technologies are required prior to the ability of eVTOL air transportation mode to provide a benefit to a more significant portion of the public than current general aviation aircraft. There are still a lot of questions. However, after a literature review that sheds light on the revolutionary developments of key enabling technologies and regulations, this study has assumed that eVTOL Personal Air Transportation System was technically possible and the time has been arriving and the early implementation was feasible in the next decade. With the results obtained lately from the research activities, significant progress was made across many of the critical required capabilities. In other terms, revolutionary technologies and regulations has been bringing us closer to eVTOL air transportation mode reality every day. Although this assumption could be a topic to discuss, it was nonsense from technology assessment point of view for an emerging eVTOL air transportation mode. It was evaluated that assessing the potential impacts and understanding the perceptions of stakeholders would be more contributive to develop policy to prevent or diminish the potential negative impacts caused by the uncritical application of emerging eVTOL air transportation mode.

This dissertation intended to provide a holistic future vision to contribute to the public and policy opinion forming on the potential consequences of emerging eVTOL air transportation mode since it might be an answer to the issue of current means of transportation which results in environmental impacts and loss of time and money or the next logical step in the natural progression and a profound influencer upon the pattern of life of people. Instead of looking from a detailed vehicle design viewpoint, the need, the impacts, the key entities, the potential benefits and the perceptions of user, service provider and regulator were investigated in this dissertation using documentary research, interview, survey, and case study methods. The central trigger question to begin this research was whether more attention should be paid to the ongoing developments in emerging eVTOL air transportation mode and an inclusion of this air transportation mode into the scenarios and policies of the future should be considered. We found that TAs used a variety of design approaches and methodologies to answer various categories of researchable questions. TAs include one or more of the following categories of research objectives, which are not mutually exclusive (GAO, 2021):

- describe status of and challenges to development of a technology,
- assess opportunities and challenges arising from the use of technology and,

- assess policy implications or policy options related to a technology.

Provided below are the research objectives of this thesis helping to identify the landscape, scope, and research questions for above categories of objectives:

- To discuss the potential benefits of eVTOL Personal Air Transportation System,
- To understand the perceptions of the service provider, regulator, and user,
- To discuss the major challenges in case of implementing eVTOL Personal Air Transportation System,
- To visualize the ecosystem of eVTOL Personal Air Transportation System in terms of virtual transportation system architecture consisting of stakeholder network, resource network, drivers, and disrupters,
- To provide a holistic vision on the potential consequences of emerging eVTOL air transportation mode to contribute to the public and policy opinion,
- To offer a technology assessment framework for an emerging technology.

Provided below are researchable questions and design approaches for these research objectives to assess opportunities and challenges that may result from the implementation of emerging eVTOL air transportation mode and understanding the perceptions of stakeholders. One of the questions can be defined as following: It is necessary a policy advice to address challenges related to the implementation of eVTOL air transportation mode? A second question is about the current state of eVTOL air transportation mode: is it in a prototyping stage? Or is in a commercial stage following the proof-of-concept?

It will be necessary to identify and describe the current picture, the status of eVTOL air transportation mode. To answer these questions, one needs to identify and describe the key entities in the innovation process. It is also necessary to visualize the ecosystem of eVTOL Personal Air Transportation System in terms of virtual transportation system architecture consisting of stakeholder network, resource network, drivers, and disrupters. Finally, is necessary to discuss the eVTOL Personal Air Vehicle design and mission considerations, requirements, and feasibility and time arrival.

Another key question is what are the potential benefits of the eVTOL air transportation mode for user and society? To answer this, we need to proceed the following:

- Gather and assess existing reports or other evidence on benefits associated with the implementation of eVTOL air transportation mode.
- Use quantitative and qualitative approaches to analyse and display relevant information.

- Discuss the analyzing dimensions such as current means of mobility and problems to understand the need, the cost of delays in transportation, the value of travel time saving, time attribute of door-to-door block speed, daily radius of reach and other public benefits.
- Illustrates the potential benefits in terms of the value of travel time saving and reducing travel cost in Istanbul case study.

The fourth research question is what are the perceptions of service providers, regulator, and user? To answer it one needs to gather and analyse the perceptions of service providers, regulator, and user to identify and synthesize policy. As well, is necessary to research the impacts, perceptions, concerns and expectations of service provider, regulator and user based on questionnaire, interviews, existing project results, forum reports and literature review.

The fifth question is what are the main challenges including technology, regulation, operation, social and environment aspects to enable the system? It is important that the features of eVTOL Personal Air Transportation System enable the widespread commercialization. It is also needed to know what unintended consequences may arise from using the eVTOL air transportation mode. We must gather and assess existing reports, the perceptions or other evidence on negative impacts associated with the implementation of eVTOL air transportation mode. We have as well to research the impacts, concerns and expectations based on interviews, existing relevant project results, annual forum reports, workshop presentations and literature review.

Finally, the sixth question is what are technical challenges to the development of the eVTOL air transportation mode? For this we need to review and observe developments of key enabling technologies, and to gather and analyse reports or other evidence of technical challenges to development of eVTOL air transportation mode.

The research questions were explored based on the primary and secondary data such as annual forum and workshop reports, presentations, relevant companies` web sites, survey, relevant projects` reports and literature review. This chapter also seeks to explain and justify the methodological approach through which they will be answered in the next sections.

2.3 Methodological Considerations

Hussey and Hussay (1997) define methodology as the overall approach of the research process starting from the theoretical underpinning to the collection and analysis of the data (Gill and Johnson, 1997). Like theories, methodologies cannot be true or false, only more or less useful. The methodology in any research is supposed to specify how the research will be conducted and controlled. Ellis and Levy (2009) cite that the research onion is a tool helpful for academic students to conduct the research process in a proper format by following each stage of techniques helpful in deriving results of the research process. The research onion is categorised in six divisions namely philosophies, approaches, strategies, choices, time horizons, techniques, and procedures. Each layer of Saunders's (2009) research 'onion' was discussed to explain why each element was selected, and how this assisted in answering the research question. To answer the research questions, a clear rational for the most appropriate methodology was sought.

2.3.1 Research Approach

The outer layer of Saunders (2007) research 'onion' refers to determine an appropriate research philosophy. The research philosophy promotes consideration on how knowledge should be developed to answer the research question. Having decided on a suitable research philosophy, other methodological elements were subsequently considered. A pragmatic approach was selected which is not committed to any one system of philosophy or reality, allowing the researcher the freedom to select procedures that best meet their needs and TA methodological approach. This approach looks at the 'what' and 'how' to research based on its intended consequences.

According to Saunders (2009), the second layer of research onion model is related to the research approach. There are two basic research approaches in the field of academic research which are Inductive and deductive approaches. According to the same author, the inductive approach advocates “a more flexible structure to permit changes of research emphasis as the progresses by gaining an understanding of the meanings humans attach to events.” The inductive approach is based on human perception therefore the generalization is less important since the data is mainly qualitative (Saunders, 2007). On the other hand, the deductive approach focuses on scientific principles and transformation of theories into adequate data size in order to generalize the conclusions (Saunders, 2007).

This research started with a deductive approach to discuss the current mobility problems and then to examine emerging eVTOL air transportation mode as a solution alternative. However, in this research, the inductive approach was used to investigate, explore, predict, and assess the potential benefits, the perception of the stakeholders and the major challenges in case of implementing emerging eVTOL air transportation mode.

The research aims future oriented knowledge generation while finding the answers to the research questions using technology assessment point of view approach. Overall, a complementary approach was taken into consideration for this study. While inductive and deductive approaches to research seem quite different, they can be complementary. A researcher might begin a study with the plan to only conduct either inductive or deductive research, but then he or she discovers along the way that the other approach is needed to help illuminate findings.

2.3.2 Research Strategy

The third layer is related to the selection of appropriate research style that could be helpful in identifying the data collection and analysing sources, and most importantly how the researcher is going to use gathered data within the research (Sanders, 2009). He states as well that the "Research strategy is general plan of how the researcher will go about answering the research questions. It will contain clear objectives, specify the sources from which you intend to collect data and consider the constraints you will inevitably have." There are distinctive styles available to the researcher, and these include experiment, survey, case study, action research, grounded theory, ethnography, and archival research. While drafting this dissertation, diverse sources were used when collecting data to increase the validity of the collected data. The strategies chosen to conduct this research were based on desk research, survey, and case study strategy.

Basically, there are two forms of data: primary and secondary data. Primary data is any form of evidence that you collect yourself through your own research in the form of surveys, interviews, questionnaires, focus groups, observations, experiments. Primary data collection methods do not involve the collection of data from other researchers' work and their studies. The methods used for primary data in this study were semi-structured interviews, structured questionnaire, and Istanbul case study. Questionnaires were analysed using a graph form and commented upon with reference to interviews with experts and existing literature. The methods used for primary research depicted at greater length in the following paragraphs.

Secondary data is the data that has been previously collected and published. Collecting secondary data is the collection of evidence from previous researchers' work and using their findings as a basis for your dissertation in relation to the questions posed. The secondary data originated from various sources were used in this study. In the preparatory period, the researcher started with reviewing literature related to current means of transportation problems and emerging eVTOL Personal Air Transportation System to get deeper insight into and understand the key entities of the emerging eVTOL air transportation mode. The other sources used for collection of secondary data to answer research questions were magazine articles, relevant projects` reports (myCopter, NASA PAV&SATS, EPATS, PPlane), AHS annual meeting reports, workshop presentations, on-line sources (internet databases, eVTOL News, Urban Mobility News), companies' materials (internal and external), and UBER white paper summit.

Another option is through a mixed methods approach which would be the collection of both primary and secondary data. In a dissertation where one is assessing the impacts of emerging eVTOL air transportation mode, it is likely that all the research techniques mentioned above would be used. Accordingly, both primary and secondary research techniques were used in this study. Once you have decided what type of data you will be collecting, you will then need to determine whether the data being collected is qualitative or quantitative as this will have an impact on the analysis of your research. The choice of whether to use a qualitative or quantitative methodology is based on the nature of the questions being asked, the state of the field, and the feasibility of the approach.

2.3.3 Research Choice

The fourth layer of the 'research onion' model is related to the nature of the study and is strongly associated with the type of research (Saunders, 2009). It is to acknowledge that the nature of study could be categorised into three major elements. These elements are qualitative, quantitative or a combination of both.

Qualitative research methodology is a scientific method used by researchers whenever there is phenomenon about which little is known or one wishes to obtain more, or new in-depth insight to the problems in question. Field research is especially appropriate for the study of those behaviours and attitudes that need to be explore in a social context, within their natural setting, "as opposed to the somewhat artificial settings of experiments and surveys" (Babbie, 2001). Qualitative research covers opinion, perception, thought process and emotions. There is a multiplicity of qualitative methods that allow the researcher to collect all the data as possible. The qualitative methodology can be exploratory, predictive, or descriptive and it also considers the complexity and dynamic qualities of the socio-technical system of systems. The research involves the use of multiple sources of data. This might include interviews, field notes, documents, journals, and quantitative elements (more information on quantitative research follows). A case study focuses on a particular problem or situation faced by a population and studies it from specific angles. A case study involves systematically gathering enough information about a particular person, social setting, event, or group to permit the researcher to effectively understand how it operates or functions (Gerring 2007). This methodology is the most suitable approach to accomplish the research objectives of the qualitative phase. It permits the use of different techniques to get the correct data to explore these complex issues. Qualitative interviews differ from the survey questions in that there is not a particular set of questions that must follow a set of predetermined words to be asked in a definite order. The interviews allow the researchers to dig out information as the interview prospers (Babbie, 2001). During the interviewing process it is necessary to create an appropriate climate for informational exchanges and individuals' predisposition to reach the highest possible level of disclosure.

The quantitative method is usually and efficiently dealing with numbers and measurable data, and special consideration is given to the implementation of statistical tools. Thereof, data collected can be presented in table, graph, or statistical form. For this research, table and graph form were utilized as it was better at presenting the data for analysis and extracting useful information from the data.

Another option is through a mixed methods approach which would be the collection of both qualitative and quantitative mechanisms. A combination of both, 'mixed-method' research was chosen for this study as it incorporated the use of both quantitative and qualitative data collection techniques. According to Saunders (2007), an advantage of using mixed-methods over mono-methods, is that triangulation can take place.

From the beginning of the study, mainly exploratory and predictive qualitative research with confirmatory quantitative research have been conducted. The criteria to select the documents was set and key actors were identified for exploratory interview. We have reviewed the literature and similar projects` reports which have been previously attempted to address or been relevant the subject. The initial research helped the development of further research strategy, framing the subject and setting the context and the questions for investigation. The literature review assisted in understanding and deepening of current means of transportation, the statement of problem, status of emerging eVTOL air transportation mode. The first stage of the study provided the necessary background and the landscape.

2.3.4 Time Horizon

The fifth layer has an association with the period that has been taken to complete the research. It includes two kinds of time horizon; one is cross-sectional, and another one is longitudinal. Cross-sectional is used for the shorter period, and longitudinal is used for the longer period (Saunders, 2007). Given the time constraints for this dissertation, a cross-sectional research design was chosen to provide a ‘snapshot’ of the impacts of emerging eVTOL air transportation mode in case of implementing.

2.3.5 Data Collection and Analysis

For any research, the identification of an appropriate means of data collection is obligatory to reach its objective (Sarantakos, 1994). The final layer of Sunders ‘research onion’ model (2009) deals with the data collection and data analysis tools. Here, the researcher takes the decisions regarding the selection of most appropriate collection and analysis tools. After considering the most suitable research methods and strategies using Saunders (2009) research ‘onion’ model and the technology assessment point of view, this research employed documentary research, interview, survey, and case study as a tool for collecting data. Therefore, qualitative primary data collected through semi-structured interviews with Civil Aviation Agency, State Airports Operation Agency, Izmir and Istanbul Municipality transportation departments managers, and qualitative secondary data collected through survey and focus group studies of relevant projects and companies. Quantitative primary data collected through structured questionnaire (Annex 1) with Izmir Municipality transportation planning department staff and calculation of the value of travel time saving in Istanbul case study. Quantitative secondary data were collected through documentary desk research in table and graph format and analysed and interpreted to find the answers to the research questions and to meet the research objectives. The following section introduces the research methods and offers a justification for their use in this dissertation.

Documentary research method refers to the analysis of documents that contains information about the phenomenon we wish to study (Bailey 1994). Documentary methods differ from primary research data where the researcher is responsible for the entire research process from the design of the project, to collecting, analysing, and discussing the research data (Stewart, 1984). Documentary research involves the use of texts and documents as source materials such as publications, newspapers, videos, and innumerable other written, visual, and pictorial sources in paper, electronic, or other `hard copy’ form (Payne and Payne, 2004). This study employed various documentary sources. These include surveys, industry reports, simulation findings, focus group studies and interviews conducted by the consultancy firms and similar projects namely myCopter, PPlane, EPATS in Europe and NASA PAV&SATS in US, eVTOL resources such as eVTOL News, Urban Mobility News, NASA and AHS International Annual Forum workshop presentations and reports, Uber Elevate white paper and summits, the companies’ web sites, Istanbul Municipality transportation master plan and the literature about transportation systems. These secondary data collected through documentary research were used to address the research questions, in other terms to assess the potential benefit, the negative impacts and the major challenges, to understand the perception of user, and to identify the key enabling technologies. Since the subject was an emerging eVTOL air transportation mode and limited papers from academia, NASA and AHS International annual forum presentations, reports, and videos, eVTOL News, Urban Mobility News, Transformative Vertical Flight workshops, Uber Elevate summit white paper were valuable resources to collect data addressing the research questions and generating future knowledge. Each one was discussed, examined in detail, and assessed in the fourth and fifth chapters. However, this research focused on the efforts and events relevant eVTOL air transportation mode to keep the scope of the study.

Surveys were designed to collect data to answer the research questions. Surveys are a method of gathering similar information from many people at the same time with either a descriptive and/or exploratory nature (Henn, 2009). A “descriptive” survey was used to describe a sample in terms of proportions and percentages of people (Punch, 2006). The preparation of the surveys included three exploratory interviews to formulate and calibrate the questions. These exploratory interviews were qualitative with significant latitude to discuss the topic of eVTOL Personal Air Transportation System. Qualitative interviews differ from the survey questions in that there is not a particular set of questions that must follow a set of predetermined words to be asked in a definite order. The interviews allow the researchers to dig out information as the interview prospers (Babbie, 2001). These interviews were prepared based on literature review and analysis of eVTOL air transportation mode news. Interviewees were composed of experts identified as having sound knowledge of and experience about transportation and air transportation system. The interviews occurred in Turkey, Germany, and Portugal, were developed between September 2014 and May 2015, and lasted around half an hour.

After, the surveys were prepared for launch through self-administered questionnaires and standardized interviews. The questionnaires and interviews employed fixed formats for questions and answers to ensure consistency of data collection (Leeuw 2008). The difference between the two techniques is the presence of the interviewer and the ability to see the questions. The survey included one face-to-face questionnaire, and four interviews. The questionnaires addressed staff of the two municipalities’ 24 transportation planning experts, collecting 21 answers.

The survey was preceded by a clear explanation that the objective of the work was to determine the perception, the concern and the expectation of the transportation planning staff. The questionnaires were anonymous 24 of 30 professional planning staff to discourage any feeling of pressure to answer affirmatively. The interviews were confidential, which discouraged fabricating or strengthening of responses per an anticipation of desired answers. Therefore, there is little or no ground to think that there was bias towards answering affirmatively towards the use of indicators.

The samples for the survey were only composed of individuals who were involved in two municipalities' transportation planning departments (Istanbul and Izmir) and Civil Aviation Agency and State Airports Operation Agency in Turkey. The samples were created using nonprobability sampling methods (Saumure, 2008) in the following way: the samples of civil aviation agency, state airport operation agency and two municipalities' transportation planning department leaders and two municipalities' transportation planning department staff were selected using purposive criterion sampling (Palys, 2008), and two municipalities were selected based on the congestion level. In these contexts, there were totally four managers of agency and departments, and 24 transportation planning department staff in the survey, and 21 responses were received corresponding to a response rate of more than 80%. The response rates obtained were considered significant by normal standards in social research, where they are traditionally lower (Baruch, 1999). The answers were not compulsory by law, there were no economic incentives to answer, and the questionnaires were not part of the national statistical system. Thus, only volunteers could reply to the survey. Finally, the questions of the questionnaire were short (it took an average of fifteen minutes to answer all of them).

The questions were introduced to identify the perception, the opinion, and the level of knowledge of service providers about the emerging air transportation mode, namely: (i) "Please rate your highest priority expectations from highest 1 to 7 in case of implementing eVTOL Personal Air Transportation System for urban and regional transportation."; (ii) "Please rate your highest priority concerns from highest 1 to 9 in case of implementing eVTOL Personal Air Transportation System for urban and regional."; and (iii) "Please rate main challenges to enable eVTOL Personal Air Transportation System for urban and regional transportation, from highest 1 to 6.". Nevertheless, all questionnaires (and standardized interviews) shared the same structure composed by 7 questions (see Annex 1 – Questionnaires):

1) The questionnaire inquired about the aviation experience and the level of knowledge about the emerging air transportation mode. In this closed compulsory question, it was possible to answer yes or no.

2) The questionnaire inquired about the opinion of transportation planning staff and tried to understand the perception based on rating the following seven activities: (a) I would be comfortable with flying in a self-piloting personal air vehicle; (b) I would be comfortable with flying in an aircraft flown by a fully autonomous pilot; (c) I would prefer on demand air transportation rather than a scheduled airline; (d) I would be comfortable with flying in air taxi; (e) I would be comfortable with flying in a single pilot monitored mass air vehicle; (f) Using personal air vehicle for transportation is likely to help relief urban congestion; and last, (g) eVTOL Personal Air Transportation System for urban and regional transportation can contribute business profit, traffic congestion relief, and daily life quality.

3) The questionnaire inquired about highest priority expectations rating from highest 1 to 7 in case of implementing eVTOL Personal Air Transportation System for urban and regional transportation.

4) The questionnaire asked to rate concerns from highest 1 to 9 in case of implementing eVTOL Personal Air Transportation System for urban and regional transportation.

5) The questionnaire asked to rate main challenges to enable eVTOL Personal Air Transportation System for urban and regional transportation, from highest 1 to 6.

The survey also included standardized interviews, as mentioned previously. They are a data collection technique carried out in the presence of an interviewer to collect the same standardized data gathered in the self-administered questionnaires, and to allow room to develop other issues that could be relevant for the research (Leeuw, 2008). In fact, the four face-to-face interviews were conducted not only to collect standardized data, but also to gather other information expressed in the interviews. The interviews targeted Civil Aviation Agency general manager, State Airport Operation Agency deputy manager, Izmir Municipality transportation department manager and one expert from Istanbul Municipality transportation department from May 2015 to May 2016. The interviews lasted on average half an hour. The interviews were important not only to collect the same information as the questionnaires, but also to give space for new issues to arise during the conversation and to reach saturation of information.

A case study involves systematically gathering enough information about a particular person, social setting, event, or group to permit the researcher to effectively understand how it operates or functions (Gerring 2007). It permits the use of different techniques to get the correct data to explore complex issues and contributes to the understanding of subject in natural settings. The first stage of the research provided the necessary background and information to develop a case study to quantitatively evaluate out the potential benefit in terms of monetary value of travel time saving and reducing travel cost based on the assumption of shifting drivers to eVTOL air transportation mode enough to minimize congestion delay in Istanbul case study.

Data were analysed using effective methods to assess the nature of the relationships between and among variables. After setting resource and stakeholder entities with their arbitrations, the impact analysis with considering the perceptions of stakeholders and relevant project reports was the useful brainstorming technique that provided a structured approach and helped the researcher think through the potential consequences of the introduction of emerging eVTOL air transportation mode before it was widely implemented at early stages, so that you could identify as many of the negative impacts or consequences of eVTOL air transportation mode as possible.

2.3.6 Validity and Criticisms of Documentary Method and Ethical Considerations

The data analysed in this dissertation were documentary sources freely available on the internet, books, and other public domains, as such permission for further use and analysis within this dissertation is implied. It can therefore be concluded that there are no ethical implications to this research.

Limitation are the boundaries that restrict the research scope and may cause difficulty in completing the research (Cooper and Schindler, 2002). A documentary analysis is limited by the availability of material, missing or incomplete data, inaccuracies in material and inherent biases. Bailey (1982) cites ‘many documents provide an incomplete account to the researcher who has had no prior experience with or knowledge of the events. Conversely, the collection and analysis of data can be time-consuming while at the same time unable to warrant validity and reliability (Saunders, 2012). The documentary research method is sometimes marginalised or when used, it only acts as a supplement to the other general research methods. The secondary data collected through documentary research were used to address the research questions. Since the subject was an emerging technology and limited papers from academia, NASA, AHS International Annual Forum presentations, reports, and videos, eVTOL News, Urban Mobility News, VFS (Vertical Flight Society), Aviation Week, Transformative Vertical Flight workshops, Uber Elevate summit white paper were limited valuable resources to collect data for generating future-oriented knowledge.

Despite this criticism, this method is just as good as and sometimes even more cost effective than the social surveys, in-depth interview, or participant observation. The main advantage of conducting documentary research for this dissertation was the ability to gain access to information that would otherwise be difficult to obtain in any other way (Bailey, 1982). A further strength of using documentary source is the fact the research can obtain reliable data without being present in the field and generate future oriented knowledge about an emerging technology which is particularly useful given the time constraints for this dissertation. Secondary data analysis may save time for researchers as participant recruitment and data collection are avoided. However, when utilizing this approach, researchers must build their research questions based on the available data.

2.3.7 Summary

This dissertation intended to provide a holistic future vision to contribute to the public and policy opinion forming on the potential consequences of emerging eVTOL air transportation mode since it might be an answer to the issue of current means of transportation which results in environmental impacts and loss of time and money or the next logical step in the natural progression and a profound influencer upon the pattern of life of people. Emerging eVTOL air transportation mode can have a range of effects, potentially both positive and disruptive, that TA can explore. Instead of looking from a detailed vehicle design viewpoint, the need, the impacts, the key entities, the potential benefits and the perceptions of user, service provider and regulator were investigated in this dissertation using documentary research, interview, survey, and case study methods. Thus, in this research, it was set a framework and methodological approach starting with TA point of view in the light of transportation system analysis. TA is the systematic study of the impacts on society and the environment that occur when a technology is introduced, extended, or modified. That is why this PhD thesis focuses on the TA of emerging eVTOL air transportation mode.

The selected research methods and analytical techniques employed were to address the research questions and gain their in-depth understanding. A mix, both qualitative and quantitative research methodology, was utilized. Qualitative research was utilized because there was a phenomenal where the researcher was assessing the consequences of an emerging eVTOL air transportation mode and wished to find out more about and generate future knowledge from the technology assessment point of view by using impact analysis. Quantitative method was utilized as it was better suited for data which is measurable and able to present it in graphical or table form specially to discuss potential benefit, the perception of user and the key challenges. A questionnaires survey and interviews were conducted to gather data about the perceptions of the service provider and the regulator to answer the research questions. Questionnaire survey method was used for employees of Izmir and Istanbul Municipalities` Transportation Planning Departments while interviews were conducted with managerial personnel of transportation departments, Civil Aviation and State Airports Operation Agencies. A sample of twenty-four correspondents were obtained for the questionnaires survey while four managerial personnel were selected appropriately for the interview. Questionnaires surveys were conducted and hosted at the organization’s office face to face. This is because the questionnaires were able to be presented easily to correspondent and allow data collection to be done with ease. On the other hand, interviews were conducted face to face and data collected were written down immediately and analysed as well.

Data were analysed using effective methods to assess the nature of the relationships between and among resource and stakeholder entities. After setting resource and stakeholder entities, impact analysis with considering the perceptions of stakeholders was the useful brainstorming technique that provided a structured approach and helped the researcher think through the potential consequences of the introduction of emerging eVTOL air transportation mode. Overall, this chapter has addressed in detail the research strategy approaches employed in this study to collect and analyse the data and pointed out the potential limitations.

2.4 Research Framework

This section discusses a framework in which how the study assesses an emerging eVTOL air transportation mode. It will be a central argument in this research that a holistic perspective is needed to understand and assess the impacts of the technological innovations. In doing so, an approach that considered whole aspects and different components of the emerging eVTOL air transportation mode, as well as the relationships among them, was used and an interdisciplinary study was conducted to assess the potentials and the impacts of developing such a capability.

As we stated above, the research design is the master plan specifying the methods and procedures for outlining, collecting, and analysing the data in a research study. For this reason, the first step was to define the factors affecting research design. The main factors affecting this research design were figured out as following; technology assessment point of view, future oriented knowledge generation, a long-term vision, an emerging air transportation mode, a socio-technological system of systems, stakeholders network (society, regulator, local municipalities, users, industry, research institutions, service providers, interest groups), resource network (air vehicles, infrastructure, air ways), purpose of the research (explorative and predictive), approach (both qualitative and quantitative) and data (primary and secondary data).

Within this context, the study tried to offer a practical TA framework, shown in Figure 2.1 below, starting with TA point of view in the light of system analysis which could be applicable for any technology after tailoring it. In this research, the virtual key entities with their arbitrations in the ecosystem of emerging eVTOL air transportation mode was identified by using Entity Centric Abstraction and modeled by inspiring and using both top down and bottom-up approaches such as System Hierarchy and Agent Based Modeling approach. The Entity Centric Abstraction guided the construction of a virtual eVTOL air transportation mode in the form of an Agent Based Modeling. This approach also facilitated the abstraction of the key entities with their arbitrations and helped understand and assess the impacts in social and environmental aspects of a long-term emerging eVTOL air transportation mode.

After setting the resource and stakeholder entities, impact analysis with considering the perceptions of stakeholders was the useful brainstorming technique that provided a structured approach and helped the researcher think through the potential consequences of the introduction of emerging eVTOL air transportation mode before it was widely implemented at early stages, so that you could identify as many of the negative impacts or consequences of eVTOL air transportation mode as possible. Impact analysis method provided a structured brainstorming approach to analyze the cross-effect analysis between stakeholders and resource networks, and relationships among stakeholders. Finally, implementation of new policy or technology was only likely to be realized if substantial benefits could be expected. This required careful comparison of anticipated benefits against projected negative impacts. Final step was suggesting policy advice preventing or minimizing potential negative impacts of new technologies.

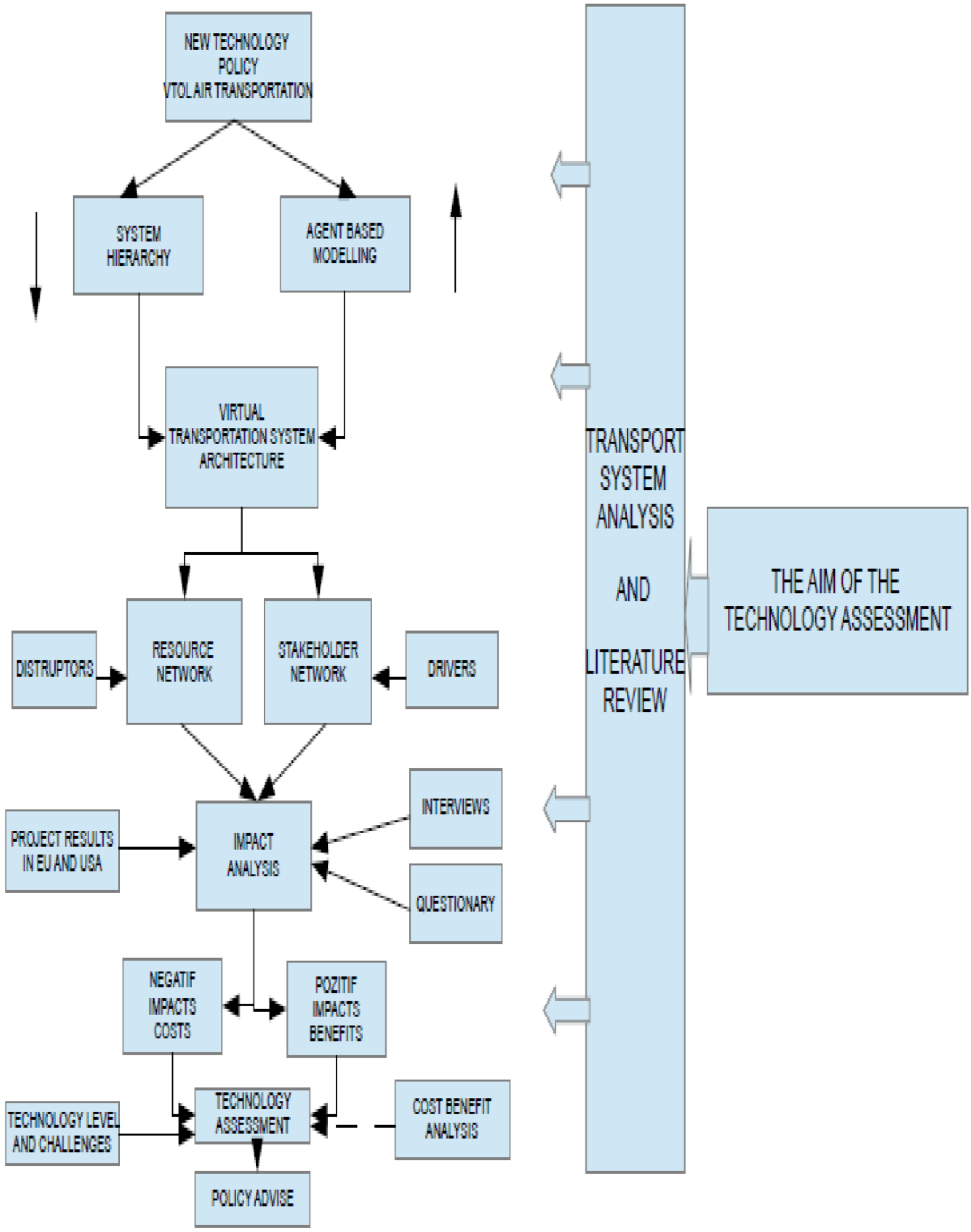

Fig. 2.1 The Framework for TA of eVTOL air transportation mode

3. Setting a Theoretical Framework

This chapter introduces the theoretical framework to study emerging eVTOL air transportation mode addressing technology assessment, transportation system and eVTOL Personal Air Transportation System. The first subsection discusses technology assessment approach since the rapid growth of ever complex technologies and the increased visibility of technology's role in shaping society place TA as an approach of several fields in social science and humanities, management, and strategy. The TA approach also frames the work. The second subsection discusses Transportation System (TS). As we have covered briefly in the first chapter, TS that is providing mobility, composed of ground, air and water transportation vehicles, their supporting infrastructure and the people who use, operate, and build the system itself is one of the largest and most complicated system of systems of modern civilization. Thus, it is very important to think of an emerging eVTOL air transportation mode in the context of its containing systems from the system-of-systems perspective. At this point, the investigation of the emerging eVTOL air transportation mode should start by placing an eVTOL PATS within the evolving TS. As Charles Darwin indicates, it is not the strongest, fastest nor smartest, but the fittest that survives in an environment. The objective of this section is to understand the big picture, getting familiar with the socio-technological system, the aspects and basic terminology and creating a virtual eVTOL Personal Air Transportation System architecture in the light of the transportation system analysis. Entity Centric Abstraction (ECA) guides the construction of a virtual VTOL Personal Air Transportation System coached in the form of an Agent Based Modelling (ABM) to create the virtual emerging eVTOL air transportation system structure and propose a holistic, hypothetical representation of the key entities in the transportation system. The third and last subsection summarizes the research subject, eVTOL Personal Air Transportation System, addressing key entities in the system, basic design parameters, attractiveness of eVTOL air transportation mode and the current picture of that.

3.1 Technology Assessment

This subsection argues why we need technology assessment approach while framing the research and gives a brief information what the technology assessment is. Technical change derives from the inherent endeavor to modify the outside world to smooth out the risks of existence. By challenging nature with his crafts, man has progressively created a functional link between science, technology, and economy. This has led to rapid growth of ever complex technologies and societal systems where technology is geared to maximizing economic growth and the average expectancy of material well-being. In short, the increased visibility of technology's role in shaping society place TA as an approach of several fields in social science and humanities, management, and strategy.

In this context, TA considers its task as interdisciplinary approach to solving already existing problems or preventing potential damage caused by the uncritical application and the commercialization of new technologies. In other terms, TA is the systematic study of the impacts on society and the environment that occur when a technology is introduced, extended, or modified. The fundamental rationale of TA is that from now on various social groups other than the actual initiators and proponents of a technology are claiming the right to have their say in decisions concerning the future application and diffusion of a technology. If someone wants to have a common definition at all, TA is a scientific, interactive and communicative process which aims to contribute to the formation of public and political opinion on societal aspects of science and technology (TAMI, 2004). Because of the ever-increasing recognition on the importance of technological innovation on the economy and on society, TA is becoming more mainstream, more formalized and more embedded in institutions such as parliaments and firms (Smits, 1991).

The purpose of TA is to provide competent, unbiased information concerning the physical, biological, economic, social, political, and environmental impacts of technology. More specifically, the goal of TA is to anticipate these impacts, to identify the various stakeholders who may be affected by implementation of technology, and to analyze the effects of alternative policies. Common to all TA strands, it is the wish to reduce the potential negative consequences of new and emerging technologies and to optimize the uptake and socioeconomic impacts of new technologies (Rip, 2001).

The future of any leading-edge sector depends on decisions made decades earlier. In key technology areas such as energy, materials, design, transportation systems, infrastructure, and environmental protection, making correct and timely decisions is crucial. Most funding organizations, decision support and policy making require information on the potential consequences of the introduction of new technologies before they are widely implemented at early stages of their development when the direction of the innovation process already can be influenced but its implications can hardly be foreseen. The principle of considering the knowledge, presumed or probable technology impacts in decisions already at an early stage is part of the basic concept of TA. It was introduced as an early warning of technological risks and unintended consequences, later also a tool for an early diagnosis of the chances and potentials of the technology (Fleischer, 2004). As we defined above, TA is a scientific, interactive, and communicative process with the aim to contribute to the public and political opinion forming on science and technology related societal aspects like exploitation of potential dealing with secondary effects, and technological risks, overcoming problems of legitimacy and technology conflicts. It produces knowledge, orientation, and procedures to deal with societal challenges in coping with technology (Fleischer, 2004).

An important problem concerning technology assessment is the so-called Collingridge dilemma: on the one hand, impacts of new technologies cannot be easily predicted until the technology is extensively developed and widely used; on the other hand, control or change of a technology is difficult as soon as it is widely used. And more in reality, there is little adaptation because the social consequences are difficult to clarify and impossible to attest objectivity and because practical and political involvements make it generally difficult to modify the course of action. This makes decision makers hesitant and ready to justify ongoing technological trends, rather than to challenge them. Consequently, most conventional assessments are neither objective nor value-neutral exercises but instead are greatly influenced and biased by the values of the most powerful stakeholders, which are in many cases the developers and proponents (i.e., corporations and governments) of new technologies under consideration.

Although the core effort of TA is analysis of impacts, especially high order or unforeseen ones, the scope of TA varies. Some studies are very broad, while others are quite specific. Generally, TA may take any one of the following forms.

a) project assessment which focuses on the impacts of a project,

b) problem-oriented assessment which addresses means of solving some specific societal problem,

c) technology-oriented assessment which examines some new technology and analysis its impacts on society and the environment.

TAMI project final report (2004) tries to systematize different kinds of issues TA projects are addressing in three dimensions: Technology oriented like the questions to new developments in biotechnologies and in information and communication technologies etc.; domain oriented like health, work, mobility etc.; and consequence oriented which will put the emphasis on societal trends or changes that are technology related like privacy, sustainable development, gender division etc. This typology is helpful to identify where the project starts from and what its initial perspective is. This influences the goal setting of the TA project and the project design.

TA does have a history and one can describe it in terms of generations of TA. The first generation of TA strands was policy-oriented emerging in the 1960's in the U.S. with the advent of the Office of Technology Assessment (OTA) at the time U.S. Congress saw the need to have advanced warnings on the potential societal, economic, ethical, and political effects of new technologies in the U.S. and elsewhere. Thus, TA has its origins in providing useful intelligence for public policy. Around that period, TA was defined as the name for a class of policy studies which attempt to look at the widest possible scope of impacts in society of the introduction of a new technology. Its goal was to inform the policy process (Coates, 1976). However, at the end of the 1970s, American industry picked up the term of TA quite independently of the OTA definition, more in line with notions of technology readiness assessment. This industry used TA as a means of anticipating what was going on outside of their firm to see how it affected their own activities (as opposed to anticipating the effect of their technology developments on markets and society). Moreover, whilst in the U.S. the Congress dissolved OTA in 1995, policy-oriented TA was heterogeneously spreading across several public agencies in European countries with participatory traditions such as in Germany, Denmark, Switzerland, and the Netherlands (Rip, 2001). A branch of such activities can be defined as parliamentary TA. TAMI report (2004) and most recently PACITA project (2011-2015) have been important European projects focusing efforts on sharing best practices and harmonizing parliamentary technology assessment, despite the vast heterogeneity.

The second generation of TA strands, emerging in the mid-1980s and early 1990's, shows an uptake of TA by non-governmental institutions. In this wave, firms begun applying TA along the same lines as the original OTA thrust, as opposed to TA as technology readiness assessment. Here, TA acts as a tool in supporting strategies up to and including agenda building (Rip, 2001). During this time, TA became process oriented developing tools and methodologies targeted at shaping new technology developments in line with emerging demands. The variety of methods applied ranged from trend exploration and Delphi, through to interventions in innovation networks and consensus meetings (Van den Ende, 1998). It is no coincidence that this 2nd generation of TA coincided with the emergence of biotechnology, which began to raise societal concerns in the mid-80s well into the 90s and 2000s, especially with regards to genetically modified organisms. A pressure to anticipate on societal impacts became a pressing issue, which shaped motivations and approaches to TA. Shedding light on the blurry borders between the different TA strands, Rip (2001) offers a typology of TA including: "Public Service TA", "TA for public arena", "TA to specific sectors", "TA in firms and technological institutes" and "Constructive Technology Assessment".

Böhle and Moniz (2015), building on such a typology, characterize TA in terms of the different spheres in which those strands might fall: the “Policy sphere”, dealing with the “political system”; the “Public sphere” referring to “civil society” and the “Science & Technology sphere” dealing with the research and innovation system. Rip, Böhle and Moniz suggest that the applicable sphere to the cases or problems under analysis depends to whom TA addresses. It can be either decision-makers part of the policy system, civil society from the public sphere or firms and non-governmental bodies from the innovation system (Böhle, 2015). Constructive TA (CTA) was developed in the Netherlands early 1980s, particularly through a dedicated program organized by the national nanotechnology initiative NanoNed (Rip, 2013), but also applied and discussed elsewhere, and attempts to broaden the design of new technology through feedback of TA activities into the actual construction of technology. Contrary to other forms of TA, CTA is not directed toward influencing regulatory practices by assessing the impacts of technology. Instead, CTA wants to address social issues around technology by influencing design practices. CTA focuses on the wider interaction of the broad range of actors (including society) that have a “stake” in the development, deployment, and use of new technology fields (Robinson, 2010). CTA has often focused on technology fields in their early stage of emergence, where uncertainty reigns and there is a need to both characterize potential future developments and to construct assessment approaches collectively to assess these new developments (Robinson, 2010).

Another important point is the question of how TA is done. Numerous authors and agencies have provided steps to be undertaken by an interdisciplinary assessment team. The overall similarity of their strategies is striking, and they typically define TA in terms of ten components. The first step involves defining the scope and depth of the assessment and identifying the actors at interest to the technology, those likely to gain or lose because of impacts. The second step is a through description of the technology being evaluated. At the third step, the assessors attempt to anticipate the character and timing of changes in the technology and others related to it. The purpose is to reveal factors such as likely future cost savings, new applications of the technology, and possible future scientific breakthrough. At the fourth step, the assessment team attempts to describe those aspects of society likely to interact with the technology under consideration. Various social indicators and surveys are useful at this stage. Based on the social description, assessors next seek to represent the most plausible future configurations of society and to project possible changes in it. At the sixth step, with these projections in mind, the assessment team can accomplish identifying both direct and higher-order impacts of the proposed project or technology. At the seventh step, the interdisciplinary team studies the likelihood and magnitude of various impacts identified during work on the previous assessment steps. Here expertise essential to disciplines plays a greater role. At the eighth step, the team use these analyses both to evaluate the impacts and to determine their significance relative to the technology and to societal goals. At the ninth step, the impacts are suitably evaluated, and the assessors compare options for implementing technological developments and for dealing with their consequences. Based on this analysis, explicit policy recommendations may or may not be made. Finally, the team determines ways in which the results of its study can be communicated to persons or groups most likely to benefit from it.

As a result, after these discussions, this thesis aimed to enlarge understanding of an emerging air transportation mode, eVTOL PATS, through with technology assessment point of view. TA approach provides opportunity to design the entire transportation system up-front, instead of having vehicles show-up ad-hoc with mismatched requirements, instead of forcing vehicles into existing infrastructure, instead of developers needing to believe “if we build it, they will come”.

3.2 Transportation System

This subsection introduces basic terminology, key entities; stakeholders, networks, drivers, disrupters, and concepts needed in understanding the emerging transportation mode, eVTOL PATS. Afterwards, it presents a virtual eVTOL air transportation system architecture. This section also deals with the potential benefit, the most prominent goals of transportation investments, namely time savings and improvements in the reliability of travel time.

Before the Industrial Revolution, people depended on bio-mechanic systems and nature for transportation. In 1796, the locomotive engine was invented as a precursor of revolutionary change. For the first time in human history, a small crew could carry almost a limitless number of passengers and cargo on the railroad. From the 1910s onward, it has been mass production of automobiles that has allowed the public to travel freely. Cars are inexpensive, easy-to-use, on-demand vehicles completely suitable for the diverse needs of diverse individuals. The last evolution since the 1950s has occurred through the expansion of commercial air transportation. The nation's travelers have been able to enjoy long-range, safe travel with considerably improved mobility, at an affordable cost after airline deregulation.

In case of current means of transportation, according to OECD Travel and Mobility Survey (2011), car access and car usage is still by far the determinant aspect in overall mobility. The current dominant transportation mode for short to moderate range is the car, which possibly more than any other single technical achievement, has enabled the current lifestyle enjoyed by the developed nations (Trends Magazine, 2012). Households are getting smaller but have more vehicles, and many households own several vehicles. A shift from public to private transport could be observed over this period. Approximately 50% of all travel trip miles involve distances less than 25 miles (accounting for over 90% of all trips), and clearly these trips will belong to the auto mode of travel for many years to come. Another 40% of the trip miles are at distances from 25 to 100 miles, with auto currently capturing almost 100% of that. The remaining 10% of trip miles are at distances greater than 100 miles, with auto capturing 76% of that market and airlines only 19% (American Travel Survey, 2011).

In the process of supplanting older transportation systems, newer approaches have also had a profound influence upon the structure of modern societies. This eventually reshaped the pattern of life for many individuals. For example, in the U.S., cities have expanded out of 18th century seaports, and 19th century rail heads, where much of the developed region was by necessity within walking distance of the transportation terminals, into tremendous suburbs with attendant reductions in crowding, and increased opportunity for individual home ownership.

Mobility studies have shown that over the last 100 years, while travel speeds have increased tenfold, average amount of time travelled per day has remained relatively constant at about 1.25 hours per day (Schafer, 1998). This statistic also holds true for other countries at different effective technology levels (Gakenheimer, 1999). It would seem plausible each person travels about one and half hour per day and this would be consistent with the allocation of a daily time budget which “competes” with other activities such as sleep, work, eating, personal care and recreation. With only twenty-four hours in the day there is only a limited proportion of the time that can be utilized on travel. This is consistent with the concept of a travel time budget. If the statistical travel data continues the same trend, it appears that once high speed, on demand travel service is offered to the market, consumers will utilize these vehicles for increased mobility reach instead of saving travel time. For instance, over the last 30 years, average ground speed has increased slightly to the current value of 35 miles/ hour, with 1995 and 2000 data showing the first decreases for ground mobility (American travel survey, 2011). The daily radius of action has improved from about 3 miles per day in 1900, to about 25 miles per day in 2000 for intra urban travel (American travel survey, 2011).

As we have covered briefly in the first chapter and above, transportation system that is providing mobility, composed of ground, air and water transportation vehicles, their supporting infrastructure and the people who use, operate, and build the system itself is one of the largest and most complicated system of systems of modern civilization. Thus, it is very important to think of an emerging eVTOL air transportation mode in the context of its containing systems from the system-of-systems perspective. The existing transportation systems are the cumulative result of countless separate decisions and investments made by public and private organizations and individuals. They have continuously expanded its capability through technology revolutions, and any transportation system that offers the lowest door to door travel time has always driven out lower speed competing modes unless the economics of the higher speed system were grossly unfavorable.

The big picture of the TS is presented in Figure 3.1 to this end. The TS on top is divided mainly into a ground transportation system and an air transportation system according to the primary mission space. The air transportation system in turn has multiple, lower-level, constituent systems. Commercial transports and general aviation (including business aircraft) are treated as separate systems for they utilize different vehicles and infrastructure. Similarly, the ground transportation system can be split into several constituent systems as indicated.

The user will interact with the TS, and they are adaptive with respect to any changes in the TS. If airline ticket prices go down, some users who planned to visit a place by car may change their decision. In other words, even a change in eVTOL PATS design requirements at the very bottom level will propagate all the way up to the top level. The public will interact with a different, new TS. This mechanism surely endows the TS with a system-of-systems (SoS) character and involves complicated dynamic processes that cannot be completely understood or easily modelled.

As we know that transportation system that enables mobility is indeed a complex system where all transportation related events occur and composed of many heterogeneous elements. Complexity in the TS stems primarily from three properties; the heterogeneity of constituent systems, the distributed nature of these systems (Carson, 2002), and the presence of deep uncertainty (Lempert, 2003) in exploring its future state. Complex systems often lie beyond our scope of understanding easily. They usually have large numbers of defining elements and exhibit non-linear dynamics in their behaviors. Moreover, complex systems also contain interactions between elements that are too complicated to completely analyze and comprehend, making them extremely difficult to deal with analytically or empirically. This complexity presents challenges to understanding, modeling, and assessment.

The aim of this section is to help understand the transportation system by placing emerging eVTOL air transportation mode within the transportation system hierarchy and creating the virtual transportation system structure and proposing a holistic representation. Anyone who wishes to understand and to shape the transportation system, he/she would realize that not only physical factors such as vehicles and infrastructure, but also organizational elements should be taken into consideration. Otherwise, a wide variety of elements in the TS cannot be examined together, which loses the vantage point of the holistic perspective. Emerging eVTOL air transportation concept with massive numbers of small air vehicle operations, could entail adverse societal consequences including safety concerns, noise, and inefficient energy consumption per unit per capita. This case also points to the need other than resource entities are present that desire to exert forces on the architecture for their own interest. At this point, it is clear, the investigation should start by placing emerging eVTOL air transportation mode within the transportation system hierarchy which is presented in Figure 3.1 to this end. In the center of the figure, a hypothetical eVTOL PATS is envisioned and fitted that has a set of design requirements. It is not the strongest, fastest nor smartest, but the fittest that survives in an environment.

The decomposition of the TS follows the hierarchy-centric approach. In fact, any Personal Air Vehicle (PAV) concept can be abstracted through this breakdown. But this traditional modeling which is based on the top-down approach is not always an ideal and enough way to treat complex systems. Using Agent Based Modeling (ABM) approach with Entity Centric Abstraction (ECA) takes the other position. These are bottom-up modeling techniques that focus on constructing a virtual world. In this research, an ABM simulation was not developed instead ABM approach was used as a guide in modelling emerging eVTOL air transportation mode while abstracting the key entities.

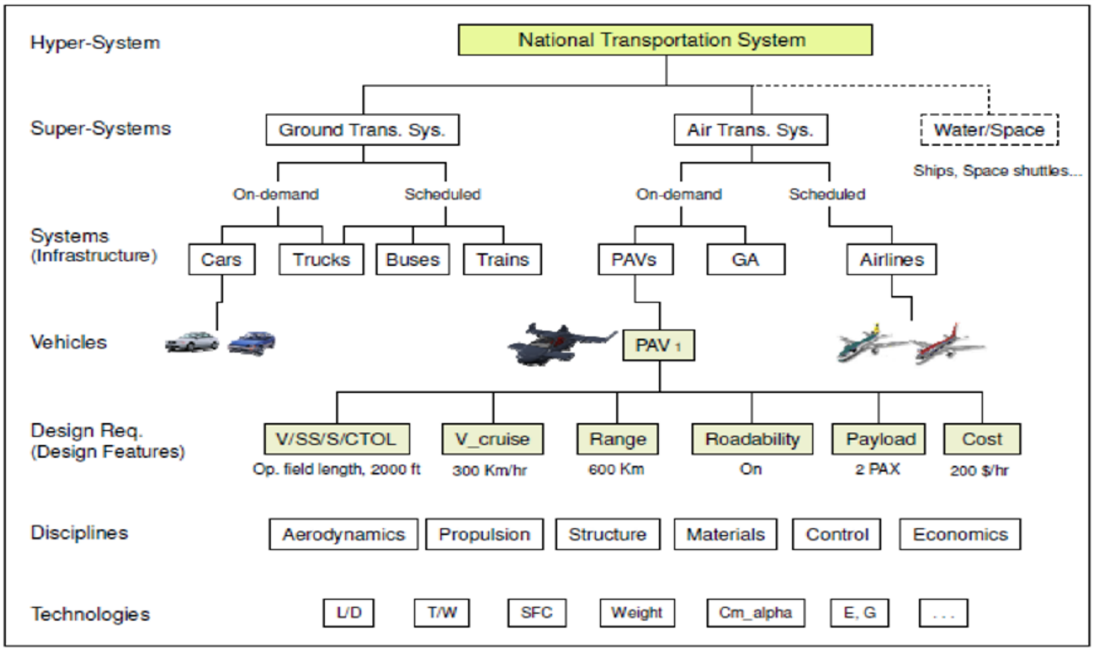

Fig. 3.1 eVTOL PAV in the Hierarchy Structure of the Transportation System, source: Lewe, 2005.

The idea behind is that the behavior of a complex system derives from the low-level interactions among its constituent elements. It encodes attributes and behaviors at the individual component or microscopic level of the system. The system's macroscopic properties emerge because of these attributes, behaviors, and the interactions between them. It is thus a powerful complement to top-down modeling approach. The fundamental building block of models of complex systems are the so-called entities.

The abstraction process produced the concept of entity which is composed of attributes (being), functions (doing), sentience (thinking), and linking to externalities (interface). Given the foundation, the abstraction process begins by identifying and hypothesizing key entities in the TS. Two pairs of entity descriptors emerge: explicit-implicit and endogenous-exogenous. Based on these descriptors, four entity categories are generated: resources, stakeholders, drivers, and disruptors. All these entities are inter-webbed by networks that define the linkages among themselves (Lewe, 2002, 2005) and are described in further details. The power of abstraction enables this hypothetical generalization. Inside of transportation resources there is a connectedness in the sense that a perturbation at any lower level will result in an impact on many stakeholders and thus permeate into the entire system. This is so partly because all resources are bonded together via a topographical network that defines the physical connection between resources in which material can ow. Additionally, trains, busses, automobiles and airplanes and their respective infrastructure are connected in an economic sense, facilitating the intermodal and multi-modal nature of transportation (Lewe, 2005). Thus, proper abstraction should embrace the concept of the network perspective, then, the flexibility and degree of interoperability between resources becomes extremely important. Different types of infrastructure will offer varying degrees of flexibility. Thus, the degree to which infrastructure resources are reconfigurable is an important design consideration. The combined considerations of resources and their network is vital to achieve significant improvement in future transportation architecture.

In short, ABM and ECA represent a family of bottom-up approaches to model complex systems. The building block of ABM system is the adaptive and autonomous agent that interacts with the environments and other agents to achieve certain objectives (Lewe, 2005), (Wooldridge, 1995), (Holland, 1995).[3,4] Now, we will discuss a little bit those four entity categories: resources, stakeholders, drivers, and disruptors in Figure 3.2.

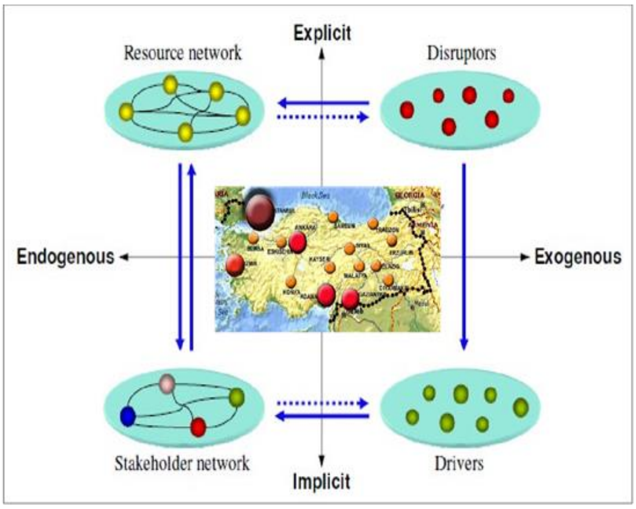

Figure 3.2 Key Entities in the Transportation System

The resource network is a complicated web of vehicles and infrastructure that consumers physically experience and providing the means to transport people from origin to destination, thus having explicit nature when traveling. The function of the resource network is supported by the operation of the vehicles, the portals and enroute space that connects spatially separated points. The most essential entities of the resource network are visualized together in Figure 3.3.

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[3] ABM is especially suited to model complex system such as TS and possess unique advantages in modeling complex systems. The impact introduced by new policies can be modeled by modifying agent characteristics, objectives, ruins to interact with others or environment parameters. The major strength of ABM comes from the fact that it is a simple, versatile, and flexible method that is well suited for studies of complex non-linear system. The shortcoming of ABM is that it needs highly simplified agents well-defined rules.

[4] Georgia Institute of Technology is developing a multiple agent-based simulation prototype named Transportation Architecture Field (TAF). It constitutes of four basic entity groups: resources, stakeholders, drivers, and disruptors. The resource entities represent physical components such as vehicle and infrastructure. The stakeholders reside in both private and public sectors including consumers, service providers, insurers, regulatory agencies, infrastructure providers, etc. The driver entities influence the stakeholders implicitly in terms of economic, societal, and psychological situations. On the other hand, the disruptor entities affect the performance of the resource network explicitly by reducing the efficiency or connectivity of the network. Each entity embraces a set of attributes, functions, interfaces, and sentience with a flexible boundary. To formulate TAF, an abstractive geographic unit ‘locale’ is introduced as a basic building block where agents reside. Each locale consists of four entity groups that are treated as global modules. The locale is further interconnected and interacts with other locales. As the simulation progress, the collective behavior of the network can be fed back to the global modules, which in turn changes the locales. This retrospective procedure builds the basic agent-based model. The model is calibrated against 1995 American Travel Survey (ATS) and the result is satisfactory (Lewe, 2005). Two case studies are conducted. The first study evaluates the Personal Air Vehicle (PAV) and the Small Aircraft Transportation System (SATS) concepts proposed by NASA. The second case study concentrates on the roadability and vertical take-off capability of PAV system. It is not clearly stated in the literature whether the outputs have been verified.

Traditionally, resources within a general category have been treated in their own realm. Further improvement in mobility will nevertheless demand an integration of these distinct dimensions. Exploring a new mobility resource in this larger context can reveal its competitive advantage relative the existing resources and uncover the extent to which it is in harmony with a future transportation architecture. Consequently, a view that encompasses all resources in the TS together is useful.

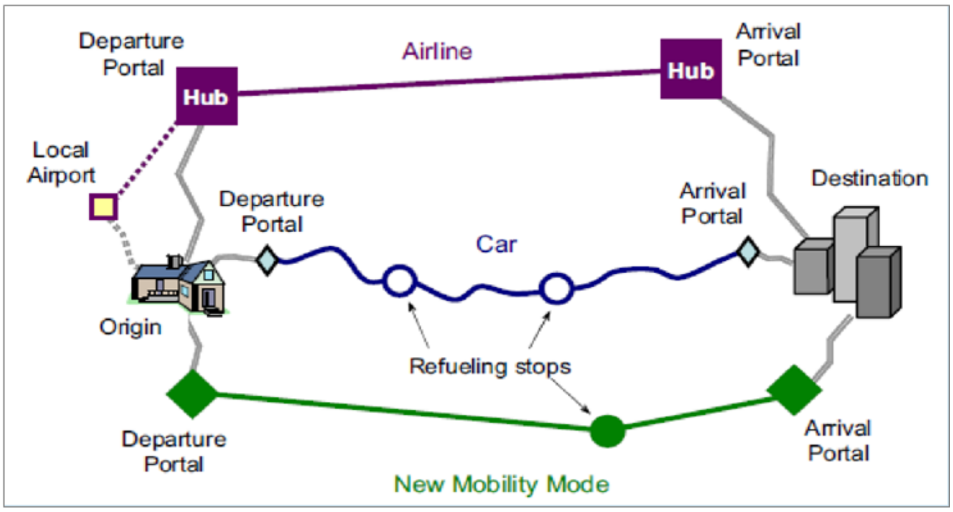

Fig. 3.3 Simplified Resource Network

Two existing modes (airline and car) are most important in terms of traffic volumes as the emphasis is on long-distance passenger trips. A new mobility mode is infused into this unit network as the focal point to explore future transportation architectures. Thus, the capability of entity representations should also aim a hypothetical new mobility mode, eVTOL Personal Air Transportation Systems shown in Figure 3.3. Vehicle is a primary entity of the resource network to user. Portals and enroute space, often called infrastructure together, provide the settings in which a vehicle operates. A ground vehicle is on-demand, cost-effective and suitable for daily, short-haul trips while a business jet aircraft offers the most time efficient method to travel from coast to coast. Despite their distinct characteristic, each vehicle can be regarded as an object that encapsulates its own functions and attributes including technological/economic characteristics. A brief synopsis of vehicle`s attributes is listed in Table 3.1. This is a template for representation of any type of vehicle. Other soft factors including vehicle comfort, perceived prestige and safety, emission, coolness factor, security concerns, or practically anything else can be qualitatively modeled and added. The interfaces should also prepare connections to account for the influence on vehicle`s attributes and functions from various factors in the transportation environment.

Table 3.1 Vehicle Attributes, Adapted from (Lewe, 2005).

Technical Performance	Economic Characteristics	Infrastructure Capability
Cruise speed	Acquisition cost	Types of portals
Maximum range	Direct operating cost	Types of enroute space
License requirement	Insurance/maintenance cost	Need of secondary mode
Payload capacity	Price/fee schedule	
Weather resistance		

Portals refer to the transition points between modes of transportation. They can be airports, bus and train stations, highway on-ramps or whatever portal types are required by new forms of travel. In our case, vertiports/vertistops and pocket airports are the portal types that are required by eVTOL PATS in Figure 3.4. A portal can be characterized by the type of vehicle it accommodates, location, maximum throughput per given period, construction time/cost and required resources for operation. The operational scheme of portals varies. All these features constitute a portal entity defined by its own attributes, interfaces, and functions. Among the various attributes, the most important ones include time-related characteristics regarding transportation activities such as processing time for boarding a travel method, waiting time and portal delay in Table 3.2.

Table 3.2 Portal Time Attributes, Adapted from (Lewe, 2005).

Time-Breakdown	Descriptions
Mode connection	Required time to transfer from/to secondary mode
Wait-ahead	Required time for most scheduled services
Wait-in-line	Required time for processing ticketing, baggage claims, security check
Portal delay	Undesirable waiting time due to capacity limit, weather, etc.

These characteristics combine to take up most of the non-moving portions of travel. The combined time at the destination portals is less than these at the origin portals since the wait-ahead portion becomes negligible.

Fig. 3.4 Possible eVTOL Personal Air Vehicle Vertiport in the city, source: (Lilium, 2018)

The enroute space of the infrastructure is made up of air routes, highways, rail roads, etc. and support points for rest and refueling/recharging that have their own effects on block speed and the ratio of trip distance to combined travel time. The enroute space can be conceptualized through an entity representation as well. Among the various attributes, each enroute space has a degree of construction cost, required autonomy level, disruptor susceptibility and so forth in Table 3.3.

Table 3.3 Enroute Space Entity, Adapted from (Lewe, 2005).

Attributes	Interfaces
Types of portals and vehicles	Refueling/recharging/rest points/boarding/parking
Path-length parameter	Enroute delay effect (inter- and intra-city)
Construction cost	Influence from weather effect
Operation cost and rule	The number of vehicles that accommodates

The portals and enroute space share common characteristics; they are stationary, expensive to build and many stakeholders in multiple levels must draw consensus to construct them. They also have their own secondary properties, for example a non-towered, rural airport is more susceptible to adverse weather than a hub airport at a large metropolitan area. Similarly, unexpected catastrophic events may have different effects at different locations and for different types of portals and enroute space.

In our case, eVTOL PATS is free from large infrastructure requirements to enable the vehicle to be used in a distributed way for optimal door to door travel. Smaller vehicles that could achieve a low enough acoustic signature and require limited or no runways would utilize new high capacity vertiports or ‘pocket airport’ infrastructure, to enable much closer proximity aviation operations to neighborhoods and businesses.

In short, it has been discussed that each element in the resource network can be described by the entity representation. Such generic abstract approach offers the capability of synthesizing the emerging eVTOL air transportation mode. In formulating the emerging eVTOL air transportation mode, one should keep in mind that a harmony of the three basic entities (vehicle, portal and enroute) is much more important than their capabilities alone to achieve overall transportation goals.

These explicit entities, however, is not enough to completely formulate the problem. eVTOL PATS concept with massive numbers of small eVTOL air vehicle operations, could entail adverse societal impacts. This care points to the need for consideration of other than physical factors. Certain entities are present that desire to exert forces on the architecture for their own interests. If we wish to understand the transportation architecture and to assess an emerging eVTOL air transportation mode, we should take into consideration not only resource network, but also the stakeholders that desire to exert forces on the architecture for their own interest. Stakeholders employ resources organized in networks to achieve an objective under the various exogenous entities (Lewe, 2005). The organizational entities, the stakeholders, need a different treatment since representation of their sentience as well as their interconnections are the key challenge. This connectedness comes in two forms. Firstly, one stakeholder may interact with another directly. Secondly, if a stakeholder influences a resource, the state of the transportation architecture will be modified. The consequences of the new state are a perturbation back to the originator and other stakeholders (Lewe, 2005).

Various approaches can be exploited for the stakeholder network. The use of ABM is a well-suited approach for manifesting the complicated behaviors of a collection of sentient entities. The stakeholders in the TS are agents. By any sense and can be modeled as such through the analysis of goals and behaviors i.e., manifesting sentience and functions. This stakeholder network can be hypothesized as a complicated web linking distinct organizations as nodes, as exemplified in Figure 3.5 below.

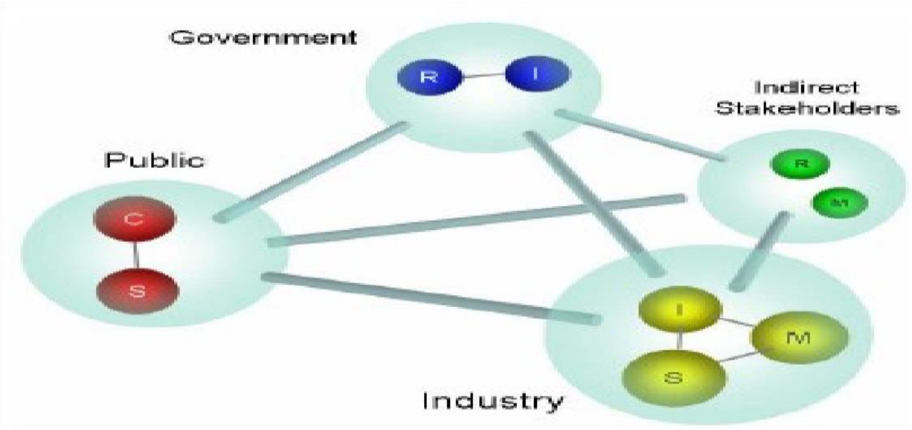

Fig. 3.5 Stakeholders Network

There are four types of stakeholders considered in this research: public (consumers, society), government (regulator, infrastructure), industry (service providers, manufacturer, insurance), and indirect stakeholders. Consumers are the source that generates all transportation activities and transportation related issues. It is an understatement to say that the transportation consumers are the most important sentient entity among the stakeholder types. Other types of stakeholders, to say the least, are passively responding to the consumers' individual or aggregate behaviors and to the regulator. Like how generic consumers are not visible until they participate in the market, the transportation consumers become recognizable as they purchase tickets or make travel arrangements. The transportation service providers interact with the consumers while coordinating their own resources. The basic function of the service providers in the model is to look at a trip and to offer price and time information to the consumers. Implementation of this task requires a set of logic to discern trip and consumer attributes to which a service provider suitably responds. Three business models of the providers are identified: SELF, RENT or HIRE, and FARE. Proper combination of the model and the resource constructs a distinctive service provider. The importance of the regulator cannot also be overemphasized. The regulator is an important tool of policy decision that shapes the transportation architecture, the rules of transportation activities and related issues. In case of emerging eVTOL air transportation mode, its importance is more critical since it is the authority that gives flight license and certification. Safety and security are also critical aspects that regulator is responsible for.

Another important point is that different stakeholders have different objectives. This dictates that the objectives of different stakeholders may conflict with each other. That is why the concern of all the stakeholders and the sensitivities between them must be tracked. While there has been no shortage of innovative air vehicle concepts proposed in the past, very few come to fruition partly due to the disregard of the broader group of stakeholders. The relevant stakeholders are identified in Table 3.4 where a broad abstraction has resulted in a collection of stakeholders in both private and public sectors, ranging from the actual consumers of transportation services to those involved in R&D. Each stakeholder has different objectives representing their interests that dictate the way they influence the transportation architecture. Indirect stakeholders influence the TS by their outputs or goals being accepted or altered by other direct stakeholders. Individual user wants to spend less time and money and maximize mobility and daily radius of reach with acceptable safety and reliability. The importance of the consumers cannot be overemphasized. A unit consumer can be generated from households and enterprises. For society, the noise, emissions, energy cost and security are paramount. For service providers, the ability to make a profit while satisfying both user and society is the challenge.

Table 3.4 Transportation System Stakeholders and Their Objectives, Adapted from (Lewe, 2005).

Category	Stakeholder	Objectives
Public	Consumer	Min: travel time, expense Max: safety, mobility reach, comfort
	Society	Min: noise, emission Max: quality of life
Central Government Local	Regulator	Max: safety, security
	Infrastructure Provider	Min: budget, delay Max: capacity
	Service Provider	Max: travel time saving, sustainability, consumer satisfaction
Industry	Manufacturer	Max: profit, market share, service provider satisfaction
	Service Provider	Max: profit, market share, service provider satisfaction
	Insurance	Max: profit, market share, customer satisfaction
Indirect	Research Agencies	
	Media	

Traditionally, the scope of a resource design problem included only a subset of the stakeholders (e.g., regulator, consumer, manufacturer, researcher link). However, an evolving SoS, the concern of all the stakeholders and the sensitivities between them must be trucked. For concrete improvements to be made, each stakeholder must realize value. Future innovations in transportation are unlikely to lie solely in radical resource designs, but also in understanding the complicated interactions stemming from the implicit entities and their networks. Therefore, the following paragraphs are devoted to the description of the agents and the transportation environment.

Actual transportation activities occur when two entity groups, resource, and stakeholder networks, have meaningful ties with the transportation environment where all transportation related events occur. In that environment, however, there exist even other exogenous entities within its boundary. For the transportation architects and from a design perspective, there is no control variable within exogenous entities such as weather since they have unidirectional influence. These exogenous entities have also wide-reaching effects. These exogenous entities can be categorized into two groups according to how they affect the transportation environment, drivers, and disruptors in Table 3.5.

Table 3.5 Exogenous Entities, source : Lewe, 2005.

Category	Drivers	Disruptors
Effect	Determining overall demand profile for transportation activities	Causing delay and/or cancelation of transportation activities
Examples	• Economic factors: GDP, household income, fuel price • Societal factors: demographic characteristics, urbanization trend • Psychological factors: culture, perception of safe/secure system	• Artificial disruptors: accident, terrorism, pollution • Natural disruptors: weather related events that affect operational condition of resources

Driver entities are largely concerned with economic, societal, and psychological circumstances that influence the stakeholder network. In market-driven world, a great measure of transportation phenomena governed by many economic factors. These include household income and gasoline price, demographic-related issues concerning growth and migration. Further, much more than quantifiable factors go into the transportation stakeholders. A large portion of transportation activities are motivated by cultural and psychological reasons. Some trips are made because of lifestyle choice and are influenced by specific cultural events, summer vacation etc. Psychological factors are also important. The surge in air travel after Lindbergh`s successful transatlantic crossing is a prime example. With perturbation in any of the driver entities, each stakeholder seeks to adapt to change circumstances, which brings reconfiguration of the transportation architecture.

Disruptor entities affect the resource network and/or a portion of the driver entity group. They reduce the efficiency of the resources network, disable nodes and links of the network, or even bring the entire system down. Prime example weather influences the resource network as a real-time basis; visibility problems, severe turbulence, icing, and thunderstorms are primary issues that degrade punctually, safety and operations. Natural disasters also influence the transportation environment. These natural events affect the local environment, and the influence may cascade into the remainder of the national system. There also exist artificial disruptors under two categories. The first group influences the resource network directly (e.g., traffic accident, mishap operation). The second category of events affects psychological concerns, an element of the driver group. The drop-in air travel after the 9/11 attacks is a primary example. In summation, these two groups together determine circumstances and constraints for all transportation activities. While difficult to describe and often too transient to predict, drivers and disruptors are significant parts of the TS.

The previous discussion was devoted to abstracting the elements of a transportation architecture. The subsequent task in completing the entity-centric abstraction framework is to properly establish the connection between the four entities to enable synthesis of the final form. A transportation architecture results through the union of a resource network, stakeholder network and set of exogenous entities. The description between these entity groups and the time-variant transportation environment can be concisely, portrayed in the Transportation Architecture Field (TAF), as illustrated in Figure 3.6. This depiction summarizes the entity-centric abstraction for synthesizing a transportation architecture.

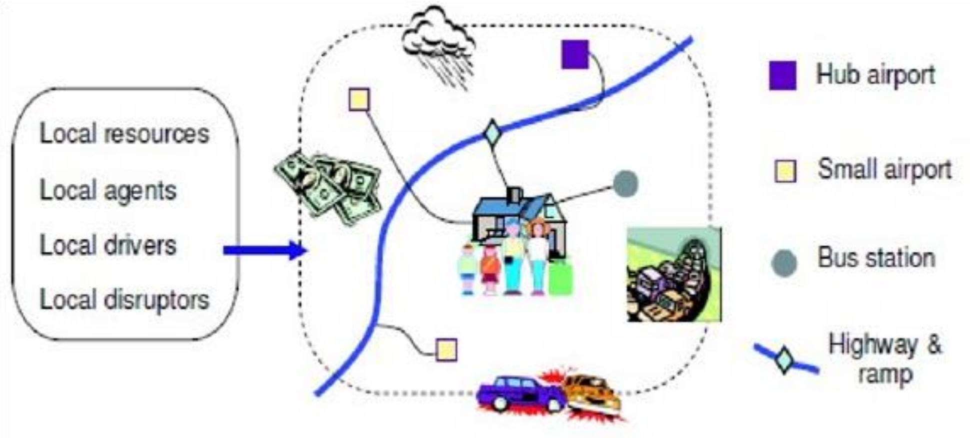

Fig. 3.6 Transportation Architecture Field (TAF)

The TAF is constructed through abstracting and organizing the entities as networks. The networks for resources and stakeholders give the TAF a system-of-systems character. The transportation stakeholder network embodies the decisions concerning the status of the TS, while the resource network determines how the TS is configured when accessed by consumers. The dual network effects are co-mingled and evolve over time with the evolving TAF. Then, the type, structure and attribute of the networks can be treated as the architecture design parameters (Lewe, 2005). Overall, the centrality of constructing the TAF stems again from the recognition that the organization of things can be just as important as the nature of things to be organized.

After modeling transportation architecture and setting resource and stakeholder entities, it is better to discuss the evaluation process, impact, and cost-benefit analysis (CBA) in the transportation system a little bit. Impact analysis is a useful brainstorming technique that provides a structured approach for looking at a proposed change and helps us think through the full impacts, so that you can identify as many of the negative impacts or consequences of the change as possible. As such, it is an essential part of the evaluation process for major decisions. More than this, it gives you the ability to spot problems before they arise, so that you can develop contingency plans to handle issues smoothly. The main intent is to determine potential impacts of technology applications. This information is essential for decision makers and the public when evaluating projects.

Another important point regarding implementation of new technology is only likely to be realized if substantial benefits can be expected. Meanwhile, there will also be costs that inevitably accrue during implementation and after. This requires careful comparison of positive and negative impacts. Therefore, a life-cycle cost benefit model which evaluates costs and benefits quantitatively is essential to evaluate such developments. Thus, investments and operations in the transportation sector are often evaluated by CBA. For example, the Federal Aviation Administration (FAA) recommends CBA in all aviation investment proposals. In many of these analyses, the travel time saved is the outstanding benefit. Two of the most prominent goals of transportation investments are time savings and, to a lesser extent, improvements in the reliability of travel time. It is not surprising, then, that most investments seek to save travel time by reducing congestion, raising free-flow travel speed, and/or reducing circuitry of travel. In other terms, reduction of delay in passenger or freight transportation is a major purpose of investments.

It is difficult to name a concept more widely used in transportation analysis than the value of travel time. For most infrastructure improvement projects, travel time savings constitute the most significant perceived benefits and the most widely accepted user benefits (Mackie, 2001). They are used as the primary justification of such development needs. Travel time savings refer to the value of time saved by reducing the total length of travel time. Travel time can be broken down into several categories: actual travel time, waiting time, vehicle accessing time and time spent for parking. They constitute more than half of the project benefits (Hobeika, 2003) and are quantified using the concept of the ‘Value of Time (VOT)’. The value of time differs depending on several factors: trip purpose, income level, vehicle type, in-vehicle versus out-of-vehicle and magnitude of savings.

The Value of Travel Time (VTT) or The Value of Commuting Time (VOCT) refers to the cost of time spent on transport, including waiting as well as actual travel (Mackie, 2001). In modern society with specialized occupations, travel time to work i.e., commuting, takes up a large part of the individual’s daily schedule. The VTT includes costs to consumers of personal (unpaid) time spent on travel, and costs to businesses of paid employee time spent in travel. The Value of Travel Time Savings (VTTS) refers to the benefits from reduced travel time costs (Mackie, 2001). Travel time is one of the largest categories of transport costs, and time savings are often claimed to be the greatest benefit of transport projects such as roadway and public transit improvements. Without commuting, this time could have been used in other activities. Therefore, individuals are often willing to pay for reducing commuting time or, analogously, require compensation for longer commuting time.

Another topic in the value of time research that has attracted increased attention lately, is the value of reliability (Hensher, 2001). Especially in urban areas where congestion is common, many travelers consider it more important to decrease the uncertainty of the travel time than to reduce the travel time itself. Closely associated with VTTS, reliability has long been viewed as a source of utility distinct from reduction of the expected trip time. If travelers are uncertain about travel time, they typically include a “buffer” in their schedules, leaving early and sacrificing a known amount of time at the origin to insure against a costlier delay in arriving at the destination. This insurance will be frequently unnecessary or excessive and occasionally inadequate. Alternatively, insuring against delay may mean choosing a more reliable route or mode with a slower expected speed or a higher monetary cost.

In short, generally, there are three types of benefit due to the expansion of construction of transportation facilities:

- Transportation System User Benefits: Quantitatively, transportation system user benefits are defined as ‘the savings in vehicle operating costs, travel time value, accident costs, and fares that the users will enjoy. Qualitatively, users are benefited from improvement of accessibility, comfort, and convenience, etc. In general, the qualitative terms are hard to model and convert to monetary terms explicitly but will be considered in the justification of the project.

- Social Benefits: Social benefits describe the benefit not only enjoyed by the actual user of the facility but also beneficial to other non-users. The social benefits include reduced air pollution and noise level, and the economics growth of the adjacent region.
- Transportation Agency Benefits: For transportation agencies, new facilities will improve ridership and revenue will increase if there are any charges associated with the new facility. In addition to travel time and travel cost, infrastructure investments may anticipate improvements in safety, comfort level, macroscopic economics, dispatch reliability, and schedule predictability. These benefits are usually referred as hard-to quantify benefits in the literature.

On the other hand, user costs are primarily evaluated considering three aspects: transport costs, travel time and other social costs. External cost refers to a negative side-effect of a project. During a transportation project, one of the most common external costs is the environmental impact including noise and emission. Aviation external costs including noise and emission have been a major concern when airport infrastructure project is proposed.

3.3 eVTOL Personal Air Transportation System

This subsection gives a brief definition of eVTOL PATS, the attractiveness of that, the state of the work, and discusses eVTOL PATS resource network, within the context of the previous subsection.

Aviation has experienced one hundred years of dynamic growth and change, resulting in the current air transportation system dominated by commercial airlines in a hub and spoke system. The first fifty years of aviation was a very chaotic, rapid evolutionary process involving disruptive technologies that required frequent adaptation. The second fifty years produced a stable evolutionary optimization of services based on achieving an objective function of decreased costs. In the third wave of the aeronautics over the next fifty years, there is the potential for aviation to transform itself into a more robust, scalable, adaptive, secure, safe, affordable, convenient, efficient, and environmentally fare and friendly system (Moore, 2006).

The vision has been to enable people to have the convenience of on-demand, point-to-point air travel, anywhere, anytime, further in less travel time, through a network of pocket airports and vertiports/vertistops. It is the distant vision of aviation being designed around the needs of the traveling public (Moore, 2006). Obviously, there is a key difference between airlines, which operate in a centralized hub and spoke infrastructure, and eVTOL PATS which will operate in a highly distributed infrastructure and offer closer proximity to destinations and a significantly less burden than centralized services (Driving many miles in congestion to reach a hub, arriving early for ticketing, security, baggage checks, connection through other hubs, driving again to reach destination, etc.).

eVTOL PATS is envisioned as the next logical step in the natural progression in the history of disruptive transportation system innovations. As the automobile improved quality of life and standards of living in the 20th century, eVTOL PATS is envisioned to do likewise in the 21st century. For example, considering door to door block travel time, on demand eVTOL PATS has the potential to achieve a daily mobility reach of 125 to 250 miles, providing another five to ten-fold increase over the auto today. The goal of eVTOL PATS is to provide a breakthrough in personal air mobility, through dramatic time savings, increased daily radius of reach and therefore a greatly improved quality of life. In most projects regarding personal air transportation, eVTOL PATS is described as an emerging eVTOL air transportation option that allows individual or personal mobility. The personal aspect is reflected by a low number of seats in the vehicle which allows more specific and individual flight paths (Meyer, 2011). Personal ownership and maintenance are not seen necessary, in contrast, fractional ownership is suggested as a scheme to reduce costs and to improve utilization (Moore, 2006).

Based on the aspects which are frequently mentioned in the literature, eVTOL PATS is defined shortly as a network of self-operated or fully automatic, 1-9 seats small eVTOL air vehicles that take off and land vertically, capable of use and affordable by a large portion of the public and provides immediate and flexible air transportation. Users can dictate trip origin, destination, and timing. eVTOL PAVs will also be 2-3x faster than cars and hub-and-spoke up to 500-600-mile range. They are envisioned as safe, near all weather, easy to use, vertical takeoff and landing ability vehicles of the future (15 years) for general population. eVTOL PAVs can be categorized based on the ability of vehicle to operate in one or two modes: air and street. Dual mode air vehicles can operate on the ground as well, while single mode air vehicles are not able to do so (Meyer, 2011). Therefore, another mode of transport is necessary to transport the user to and from the takeoff/landing area if the portal is not close enough to walk.

Fig. 3.7 Various Personal Air Vehicle Concepts in History, source: (Moore, 2006).

The future of eVTOL Personal Air Transportation System will probably evolve from the current General Aviation market as technologies and capabilities are developed to affect a larger market share. As the market evolves, it is likely to first exist as professionally piloted air taxi operations from smaller airports and portals as an intermediate step towards personal on demand service. As costs decreases, through such factors as lower acquisition costs and single pilot operations, more pervasive air taxi operations will establish the initial market. The self-operated market will follow with the addition of ease-of-use technologies that permit low-cost licensing and modern certification practices to achieve both safer and lower cost high quantity air vehicles. A range of missions, aircraft types and operations will enable trips that were not time/cost effective with current transport (e.g., conventional takeoff and landing commuter), alternative to car travel to avoid/alleviate city congestion (e.g., vertical takeoff and landing air taxi, “urban air mobility”), and new, more rapid methods of cargo distribution (e.g., UAS package delivery).

The eVTOL air transportation resource network is a complicated web of eVTOL air vehicles and infrastructure that consumers physically experience and providing the means to transport people from origin to destination. The function of the resource network is supported by the operation of the eVTOL air vehicles, the portals and enroute space that connects spatially separated points. The most essential entities of the resource network are visualized together in Figure 3.8 below.

Fig. 3.8 eVTOL Resource Network; Air Vehicles, Vertiports/Vertistops and Enroutes

eVTOL air vehicles will be designed by the constraints not by the performance (Vascik, 2018). They should feature, at least, safety, simplicity and convenience for user acceptance, and low noise level for community acceptance. They will be capable of automatically avoiding either air traffic, bad weather, and restricted and tower-controlled airspace. They will fly in either automatic or manual modes between approved landing zones (vertiports and airports).

eVTOL air vehicles have many advantages over helicopters and airplanes. eVTOL air vehicles have higher cruise speed, lower noise, lower vibration, and superior economics than helicopters. They have more convenient downtown service, access to small cities and remote rural communities, increased operational flexibility, increased mission flexibility, more competitive economics than airplanes. They also do not need runways. Such a vehicle would generally fill a transportation niche between commercial airline and auto because it would have greater speed and range than an auto and would have better on demand utility and block speed up to 500-600 miles than airlines (Moore, 2003). eVTOL Personal Air Transportation System has the potential to impact up to 45% of trip miles traveled (Moore, 2003). The attractiveness of eVTOL PATS are desired travel time (on-demand travel), travel time savings (efficient block speed), extending daily radius of the action (five to ten times further), increasing trips per day, less distances from doorstep to portals (enable much closer proximity air transportation to neighborhoods and businesses), operable from anywhere (point to point travel), expanding transportation choice, comfort and relieving road traffic congestion.

Fig. 3.9 Flying Demonstrators of eVTOL Personal Air Vehicles; Volocopter, Lilium Jet, EHang 184, source: http://evtol.news, retrieved in October 2018.

However, there are challenges to overcome. The technology challenges that must be surmounted include ease of use, automated airspace control, affordable propulsion, economically viable concepts, low noise, modern certification procedures, and near all-weather capability while achieving a factor of ten improvement in small aircraft safety. Intra urban mission technologies that are required include improved propulsion system thrust to weight, increased efficiency, simple yet effective high lift systems with low-speed control, powered lift innovations, lightweight structures, design tools capable of the modeling and analysis of unconventional concepts, and the ability to convert alternative energy sources to thrust. At 5th Transformative Vertical Flight Workshop in January 2018, the Working Group #1 addressed technology requirements as VTOL capability, high density airspace operations, energy efficiency and storage, navigation (sense avoid), affordability, safety, noise, and emission. Achieving drastic improvements in ease of use, safety, and community low noise are the most critical steps towards the future feasibility of this market, as agreed upon by industry members in the PAV workshops that defined the sector goals (Moore, 2006).

The overall goal implies integrating technology areas with practical everyday transportation requirements to design a class of air vehicle which will achieve the following goals:

- Vertical and extremely short takeoff and landing,
- Operation at block speeds markedly faster than current combinations of land and air transportation,
- Increasing daily radius of action,
- Unit cost comparable to current luxury cars and small general aviation aircraft,
- Excellent reliability,
- Ability to integrate with existing land and air transportation system,
- Minimum environmental cost,
- Excellent safety comparable with airlines.

For eVTOL PATS to be a viable transportation alternative, it will have to integrate seamlessly in the existing transportation environment. eVTOL PAVs must be safe, cost-effective, and socially acceptable. According to the transportation statistic, in 90% of the cases, commuting trips are shorter than 25 km and rarely exceed 30 minutes. Peak hour delays on such trips are generally about 15 to 20 minutes. These figures provide a clear framework in which eVTOL PATS will operate if they are to provide a solution to congestion problems. Furthermore, to be accepted by society, eVTOL PATS will have to deal with various safety concerns, legal issues, ecological aspects, and noise.

As we figured out from the discussions in previous subsection, saving travel time is a key aspect of the eVTOL PATS value proposition. In the Uber's ridesharing use case, they measure and minimize the comprehensive time elapsed between request and drop-off. This is affected by both vehicle performance, particularly cruise speed and take-off and landing time, and system reliability, which can be measured as time from request until pick-up. In this context, key problems to solve are air vehicle designs for 150-200 mph cruise speeds and maximum one-minute take-offs and landings[5], as well as issues like robustness in varied weather conditions, which can otherwise ground a large percentage of a fleet in an area at arbitrary times (Uber, 2016).

On the other side, it is critical to understand how that design decisions impact the utility and economics of operating the air vehicles and whether that limits any desirable use cases. The purpose of the research of Aerospace Systems Design Laboratory School of Aerospace Engineering at Georgia Institute of Technology was to expand the boundaries of the knowledge of the personal air vehicle design space in this context. Any eVTOL PATS system should be understood in the context of the transportation system, and correct decision-making is critical in generating design requirements, which will guide the next development efforts as alternatives concept vehicles are being formulated. A new method was proposed to account for system-of-systems aspects and to aid a decision-making process in synthesizing design requirements for a personal air vehicle system. A traveling party was treated as an agent, and the infrastructure environment in the national transportation system was easily represented in the model. A few simulations were performed to demonstrate the capability of this new approach (Lewe, 2002). The method not only measures the effect of design requirements of a personal air vehicle system through sensitivity analyses, but also evaluates the effect of system technologies quantitatively, while maintaining the system-of-systems perspective. With this powerful method, designers can extract essential technical requirements that allow polishing of concept vehicles; policy makers can investigate the infrastructure and technology impact of new systems; and business planners can perform an analysis based on their own market assumptions.

The method made it possible to measure the leverage effect on the transportation system due to changes in top-level eVTOL PAV design requirements. Therefore, this method is logically

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[5] Uber's economic modeling shows that these performance numbers are necessary for feasible long distance commute VTOL service. Shorter trip distances could utilize slower vehicles, with a penalty of having lower vehicle productivity.

extended to a capability enabling comparison among different vehicle concepts quantitatively, which has never been done before (Lewe, 2002).

Table 3.6 eVTOL PAV Basic Design Requirements, source: (Lewe, 2002).

Requirements	Settings		
Nominal cruise speed (km/hr.)	300	350	400
Number of passenger seats	2	4	6
Refueling range (km)	600	900	1200
Easy-to-fly technology	ON-OFF		
Road ability (Dual mode)	YES-NO		

In the simulation study of Aerospace Systems Design Laboratory School of Aerospace Engineering at Georgia Institute of Technology, through Scenarios Velocity$_L$ and Velocity$_H$, the sensitivity analysis of the PAV market share to nominal cruise speed was carried out. Obviously, increasing airspeed gave a benefit as verified in Figure 3.10. The beauty of this figure is to convey the benefit quantitatively (Lewe, 2002).

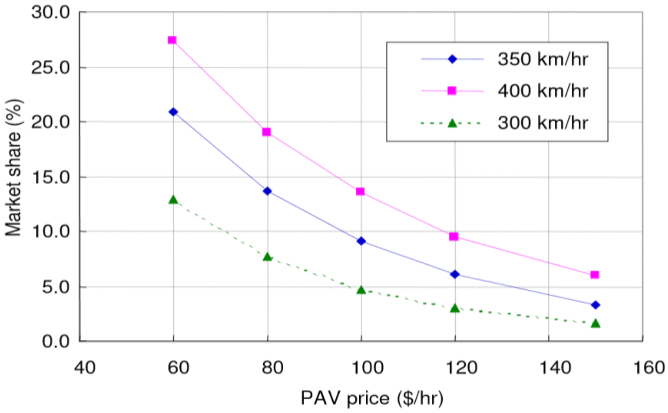

Fig. 3.10 Result of Scenario Velocity$_L$ and Velocity$_H$, source: (Lewe, 2002).

Although urban commute distances are typically 8.5 miles each way according to the U.S. Census, this is unlikely to be a good early use case due to the dense support infrastructure that would be required. Mega Commuters (within the same metropolitan area) have average daily commutes of 93 miles each way. While these longer trips need much less infrastructure, they would require vehicles that are cruise efficient, or that employ some sort of hydrocarbon-based range extender (to compensate for relatively low battery specific energy), to be able to do more than a single trip on current battery energy storage solutions. When we consider the effect of range generally, in the simulation, Scenarios Range$_L$ and Range$_H$ were intended to gauge the sensitivity to the changes in refueling range. In Figure 3.11, increasing refueling range by 300 km does not have much benefit, while decreasing range by 300 km results in missing a salient number of travelers (Lewe, 2002).

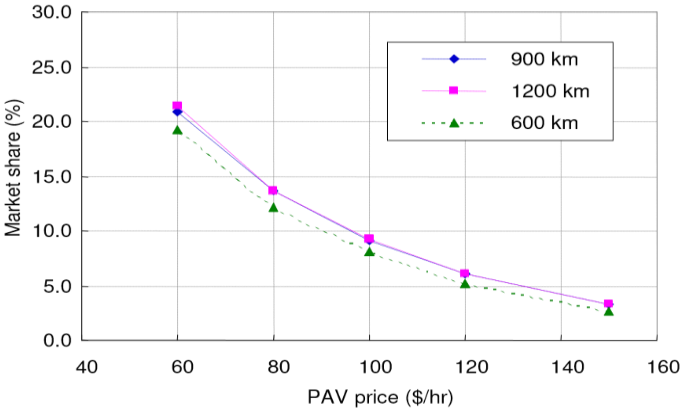

Fig. 3.11 Result of Scenario Range$_L$ and Range$_H$, source: (Lewe, 2002).

Current commuting practices suggest that a minimal effective eVTOL PAV range in the near-term is to conduct two 50-mile trips at maximum speed, with enough energy for two takeoffs and landings, while meeting the FAA Instrument Flight Rules (IFR) 30-minute reserves (plus flight to an alternate location). It’s likely that by working collaboratively with the FAA and GAMA, vehicle manufacturers could establish the basis for shorter range electric aircraft to have decreased reserve energy requirements, since they have many alternative landing locations and low uncertainty over the short flight time for a change in the weather conditions. Implicit in this range requirement is the need to maintain a minimum of 20% charge in the battery to ensure a high cycle life. This type of mission has a similar energy requirement as performing a single 200-mile trip at the best range flight speed (Uber, 2016).

Payload weight, and therefore number of passengers, determines the overall size of the air vehicle. Useful payload is reduced by the pilot weight. Over time it’s highly likely that eVTOL PAVs will become autonomous, though we expect that initial operations will require pilots. Utilizing pilots in the initial period permits a strategy of building up statistical proof for FAA certification while slowly increasing the level of automation. Therefore a 2-seater eVTOL PAV would be a minimum, which would allow for just a single passenger. Larger payloads will require greater power for takeoff and landing, which means more noise. Larger aircraft are more structurally efficient and can carry a higher ratio of passengers per pilot, resulting in improved operating costs. Based on prior helicopter noise sensitivity with vehicle size, the greatest probability of meeting the severe community noise limitations exists with smaller eVTOL PAVs that are carrying fewer passengers.

The American Travel Survey[6], which tracks statistics relating to automobile transportation usage, provides reasonable guidance concerning typical car-like on-demand passenger trip size. This data shows that for trips less than 100 miles, over 70% of all trips contain a single person with an average load factor of 1.3 people. For trips greater than 100 miles, over 59% of all trips contain a single person with an average load factor of 1.6 people. Prior conventional air-taxis achieved remarkably similar statistics. Because of all these factors, the payload capacity that likely best serves urban air-taxi flights would be a 2 to 4 passenger-size aircraft (including the pilot if there is one). Such a size permits true on-demand operations with a near-term piloted solution, with the larger size enabling pooling to provide the lowest possible trip cost. While increasing to 5 or 6 passenger aircraft will provide improved economics and efficiency, it's doubtful that such a large size aircraft could meet the severe community noise restrictions.

In the same simulation, the next scenarios, Pax_2 and Pax_6, examined the effect of varying eVTOL PAV passenger capacity. If other conditions are kept the same, big aircraft incur expensive acquisition cost. This is not always a bad situation because travel cost per capita can be reduced if a vehicle operates at a full load. The simulation showed that a decrease in passenger capacity from the baseline of four to two resulted in a significant decrease in market share. However, an increase in passenger capacity to six did not yield as great a change, shown in Figure 3.12. This is in line with the initial assumption that specified relatively small travel parties (Lewe, 2002).

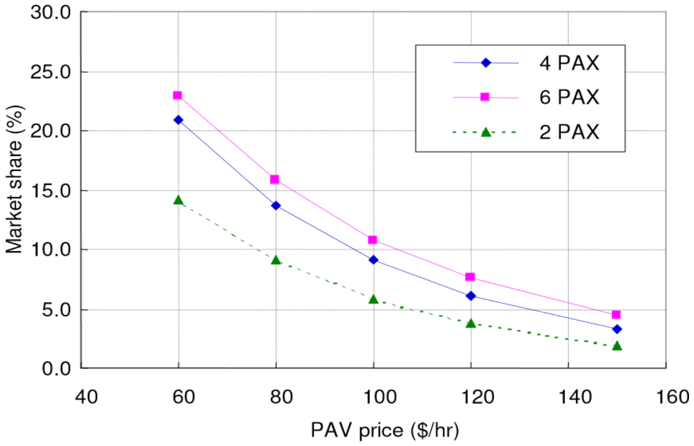

Fig. 3.12 Result of Scenario Pax_2 and Pax_6, source: (Lewe, 2002).

The amount of lift generated must exceed the total vehicle weight, with occupants, by enough margin to allow for climb and maneuvering. The front-to-back and side-to-side balance

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[6] https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/subject_areas/national_household_travel_survey/index.html

is important to keep the center of gravity aligned with the center of lift, again with enough margin to allow safe control in all regimes of flight. Pilots are required to evaluate loading for every flight to assure that these parameters remain within limits. For small aircraft, these concerns become more critical because each passenger represents a significant percentage of the total weight. eVTOL PAVs will have a maximum payload capacity, which may also vary depending on the trip altitude and the temperature. This raises questions about how the eVTOL PAV operator will deal with passenger weights. Initially, the pilot might need to assess the weight of the passenger that is about to come aboard and distribute riders accordingly (commercial airlines do this today on small planes). As vehicles mature, sensors in the vehicle may be able to do this automatically, especially when paired with ridesharing mobile applications which will maintain user information. Distributed Electric Propulsion (DEP) represents a partial solution from the outset, in that the center of gravity range will likely be wider than for a similar aircraft with conventional propulsion.

In the same simulation, the scenario easy-to-fly technology and the scenario dual mode were also studied. In the scenario easy-to-fly technology, the easy-to-fly technology was removed from the baseline eVTOL PAV, which would result in the same percentage of pilots as presently. As expected, the easy-to-fly technology had the largest effect on the market share, which can be evidenced by huge gap in Figure 3.13. While the advantages of enabling easy-to-fly technologies are intuitive, the simulation illustrated the effect quantitatively. Now a decision maker can measure the importance of the technology (Lewe, 2002).

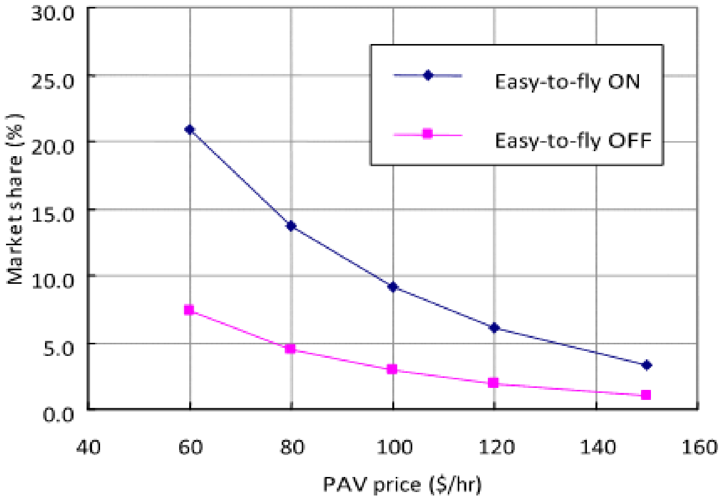

Fig. 3.13 Result of Scenario Easy-to-Fly ON-OFF PAV, source: (Lewe, 2002).

In the scenario dual mode, the scenario dual mode explored the effect of incorporating a road ability function to the baseline PAV, making it a dual mode PAV. The primary concern for manufacturers would be the extent of increase in market share that can be achieved through dual-mode vehicles. The benefit in market share can be compared through a quick feasibility study against the cost increase to achieve the road ability function. The first impression on this study is that the gap between two curves is smaller than that of Scenario Velocity_H. This means, if other conditions were kept the same, increasing cruise velocity by 50 km/hr. would be a better engineering decision than making a vehicle roadable (Lewe, 2002).

Mostly eVTOL PAV operations will involve the ability to take off with a rapid climb at a steep glide path angle to reach a cruising altitude up to a few thousand feet, then decelerate to land vertically at the end of the trip. There will likely be a limited need to hover for durations not exceeding one minute, with most vertical takeoff and landing transitions taking place in approximately 30 seconds. eVTOL PAVs will spend far more time in cruise which raises the question of how to optimize such a vehicle across short-term hover power versus long-term cruise energy. The design tradeoffs determining whether to use a wing or rotor depend primarily on speed, range, and hover requirements, as well as design constraints at the landing zone. As eVTOL PAV designs mature, there is likely to be a continuum of approaches from fixed multirotor designs, through tiltrotor to variants of blown-flap airplanes (Uber, 2016).

Adding wings to enable high aerodynamic cruise efficiency combined with being able to tilt rotors or turn on/off different prop-rotors to provide lift or cruise power is a likely solution when biasing designs for cruise more than hover. These solutions, however, add weight, which increases power requirements for takeoff and landing due to the increased disc loading[7]. This can also increase the noise and downwash in undesirable ways. The overall energy savings favorably impacts the economics of the flight and supports a rebalancing of design priorities from hover to cruise efficiency. Future versions of eVTOL PAVs may re-bias their designs for different infrastructures as well as primary use cases.

eVTOL PATS ridesharing networks will eventually need to have a variety of eVTOL air vehicle types, just as automobile ridesharing services offer customers today. eVTOL PAVs will likely be developed across several different speed and range capabilities. eVTOL PAV optimized for shorter trips (less than 50 miles) won’t require as much speed as eVTOL PAV capable of meeting the needs of longer distance commuters and regional air transportation. As operators consider the parameters impacting the future service, it’s obvious that speed will certainly be bounded on the low end by typical ground speeds to be competitive with other modes of transportation through a door-to-door trip speed advantage. This suggests that we

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[7] https://en.wikipedia.org/wiki/Disk_loading

need to seek an effective speed—one that accounts for any ground transportation time to get the customer to and from the vertiports— that will provide at least a two times door-to-door trip speed advantage. Based on NASA and MIT Urban VTOL studies[8],[9] a three to four-time trip speed multiplier could be achieved in highly congested metropolitan areas during peak travel times. Since there’s a great deal of dependence on the local travel conditions, a specific speed requirement is difficult to lock down. Studies suggest that 150-200 mph is where eVTOL PAV becomes most efficient[10]. An upper limit (in the US) is the FAA speed limit of 287 mph for flight operations at lower than 10,000 feet. In certain sensitive geographic locations, the FAA has decreased this maximum speed to 230 mph (i.e., Washington D.C). Balancing the higher efficiency of lower speed with the desire to achieve high vehicle productivity to amortize costs across more miles of travel will likely yield a compromise of a desirable eVTOL air vehicle speed between 150 and 230 mph.

Lastly, the research will cover the current stages of development on eVTOL PAV concepts by mid-July of 2021 to evaluate whether the time has been arriving. The Vertical Flight Society (VFS) has been working to advance eVTOL PATS air vehicles since 2013, providing technical, professional, and business resources to this burgeoning sector. As a leading advocate of the “Electric VTOL Revolution,” VFS has been holding its Electric VTOL Symposiums since 2014, started its Electric VTOL Newsletter in 2016, and launched its Electric VTOL website in 2017. In mid-July, VFS added the 300th eVTOL aircraft to its World eVTOL Aircraft Directory. The Society’s Electric VTOL News website (www.evtol.news), the first and more expansive eVTOL information website, catalogues all known eVTOL aircraft concepts. This comprehensive directory now includes more than 300 eVTOL air vehicle concepts — a leap of 50 air vehicle since January 2021, representing some 215 different companies/developers. These 300 entries include everything from conceptual studies and defunct projects to air vehicles that are currently being flown for certification testing. For the past 30 months, the VFS World eVTOL Aircraft Directory has grown at a steady pace of 100 entries per year — an average of two new eVTOL air vehicle concepts are added each week.

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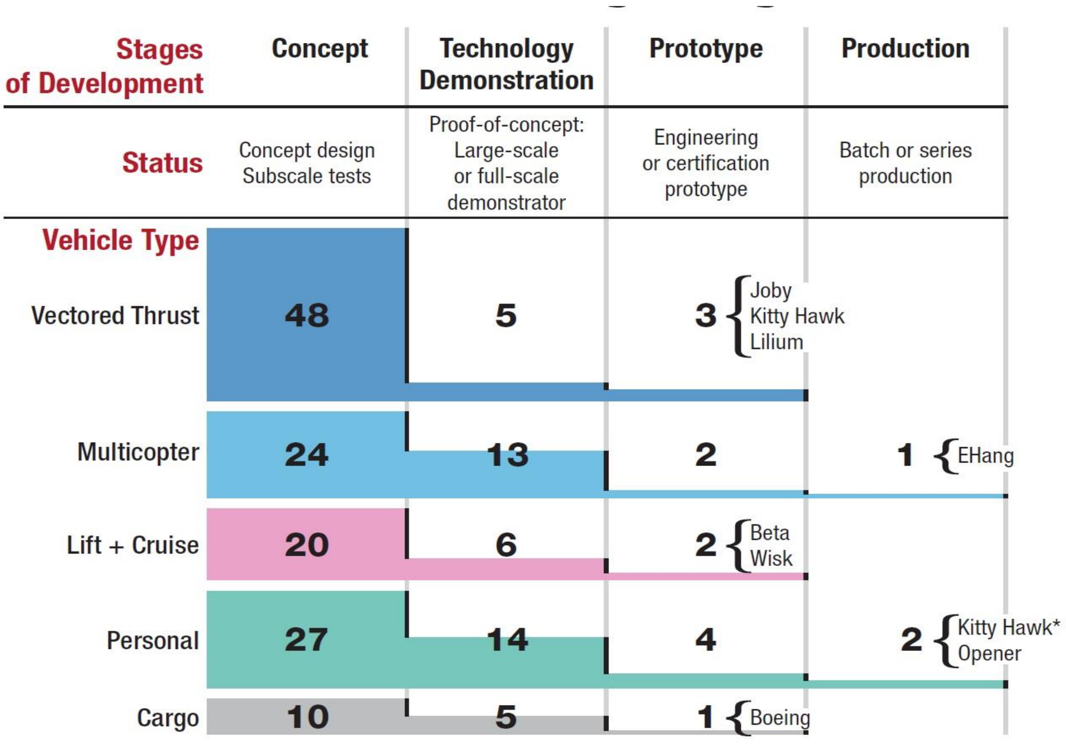
[8] Silicon Valley as an Early Adopter for On-Demand Civil VTOL Operations, Kevin Antcliff et al, AIAA Paper 2016-3466, June 2016.

[9] Los Angeles Urban VTOL Air-Taxi Study, Parker Vascik, http://vtol.org/what-we-do/transformative-vtolinitiative/transformative-proceedings/transformative-workshop-briefings

[10] https://aero.larc.nasa.gov/files/2012/11/Distributed-Electric-Propulsion aircraft



*Canceled

Fig. 3.14 Stages of Development on more than 300 concepts in the eVTOL Aircraft Directory, source: (Aviation Week Network, 2021).

As shown in the resulting graph in Figure 3.14, VFS and Aviation Week estimate that 43 companies were at the large-scale demonstrator phase. A dozen had flown engineering or certification prototypes (in the order shown in the graphic): Joby Aviation, Kitty Hawk (Heaviside), Lilium, Volocopter, EHang, LIFT Aircraft, Beta, Wisk, Hoversurf, Kitty Hawk (Flyer), Opener BlackFly and the Boeing Cargo Air Vehicle. Of these, three aircraft had gone into batch or series production, namely the EHang 216, the Kitty Hawk Flyer (since discontinued) and the Opener BlackFly, each with around 100 units.

VFS estimates that more than $4B has gone into exploring the transformative potential of eVTOL air vehicle. Much of the approximately $1B in annual funding for eVTOL air vehicle for passenger and cargo urban air mobility (UAM) and other advanced air mobility (AAM) missions is coming from outside of the traditional aerospace industry. For example, Toyota Motor Corporation has invested some $394M in US-based Joby Aviation (bringing total outside investment to $720M) and Hyundai Motor has pledged to invest $1.5B in its UAM efforts. In Germany, Lilium has now raised $376M from investors like Baillie Gifford, Tencent and Atomico, while Volocopter has received $140M, largely from transportation companies like Daimler, Geely and DB Schenker.

4. eVTOL Resources: Results and Findings

This chapter covers main eVTOL PATS resources and presents their relevant results and findings addressing the research questions. The first subsection provides results of the projects and activities related to Personal Air Transportation System in Europe and U.S. especially focusing on myCopter Project. The next provides results of NASA and AHS International annual forums and workshops. The third subsection provides the findings of Uber Elevate summits and white paper. The fourth subsection analysis briefly the companies developing eVTOL air vehicles and their web sites. The fifth subsection provides the results of the questionnaire and the interviews. The last subsection tries to visualize the potential benefit in terms of travel time saving in Istanbul.

4.1 Projects and Activities In Europe and U.S.

This subsection briefly covers the results of the relevant projects and activities: Small Aircraft Transportation System (SATS) project; NASA Personal Air Vehicle (PAV) effort; European Personalized Air Transportation System (EPATS) project; SESAR Project; and myCopter project. However, the results presented here focused on relevant projects within the context of the research questions.

4.1.1 Previous Efforts and Related Research

This section summarizes some related research activities in the US and EU regarding personal air transportation in a broader sense. In general, there are two big players who have done extensive research on personal air transportation systems and personal air vehicles. These are the NASA in the US and the European Union in the form of their Framework Programs for Research and Technological Development.

NASA has already made investments in small aircraft through Advanced General Aviation Transportation Experiments (AGATE), General Aviation Propulsion (GAP), and Small Aircraft Transportation System (SATS). These programs have established advanced cockpit systems, crashworthiness and lightning strike standards, an advanced small turbofan engine, automatic takeoff and landing vehicle control, prototype efforts for a Highway in the Sky airspace control system, and many other elements of the total required system. Whatever the future will be in civilian aviation, the governments will play a significant role by stimulating research in high payoff technologies and by imposing societal constraints. Government research shifts industry focus from near-term profit to a longer-term vision. At the same time constraints are imposed on industry to provide limits on an otherwise profit driven focus to ensure safety and environmental friendliness.

NASA’s research in the field of personalized air travel was conducted through the Small Aircraft Transportation System (SATS) program. The research regarding the Personal Air Vehicles (PAV) was done separately in the Personal Air Vehicle Exploration Program called PAVE.

In pursuit of the safe, reliable, and affordable personalized air transportation option, in 2000 NASA established SATS project. As the name suggests personalized air transportation would be built on smaller aircraft than those used by the airlines. The Small Aircraft Transportation System was a revolutionary program utilizing aircraft seating 14 or less to offer an affordable and convenient means of travel (Jaroszewicz, 2009). Of course, smaller aircraft can operate from smaller airports and 96% of the American population is within thirty miles of a high-quality, underutilized community airport as are most of their customers, family members, and favorite vacation destinations (Yue, 2005). In many cases, these satellite airports are in closer proximity to the city or area of interest for passengers (Horne, 2008). Tarry and Bowen (2001) note that SATS is an emerging solution to the overburdened hub and spoke air transport system and relative isolation of communities that do not have access to air travel. Further development in the usage of those airports provides a means of economic enhancement for rural areas of the country.

The SATS technology roadmap encompasses on-demand, widely distributed, point-to-point air mobility, through hired-pilot modes in the nearer-term, and through self-operated user modes in the farther-term. The nearer-term concept is based on aircraft and airspace technologies being developed to make the use of smaller, more widely distributed community reliever and general aviation airports and their runways more useful in more weather conditions, in commercial hired-pilot service modes. The farther-term vision is based on technical concepts that could be developed to simplify or automate many of the operational functions in the aircraft and the airspace for meeting future public transportation needs, in personally operated modes. The authors interpreted the success of SATS to be a cooperative effort between government, industry, and academia. Implementation of a small aircraft transportation system also alleviates pressure on capacity-constrained airports, thereby allowing growth for air carriers. Interestingly, the government has been subsidizing air transport service in communities that cannot support an air carrier.

Though there are many obstacles to the vision of a time when nearly every trip of more than one hundred and fifty miles is taken by air, the focus of the SATS Project was on providing reliable access to the nation’s 3400 public-use airports that have paved runways at least 3000 feet long (Yue, 2005). If people can’t assume that they will be able to access their community airport reliably, they won’t plan future trips around those airports. Since most of those airports don’t have ground-based navigation aids and are difficult, if not impossible to find in poor visibility, one objective of the SATS Project was to lower the landing minima at those airports to conditions in which there is a 200-foot ceiling, and the visibility is ½ mile. It is assumed that adding expensive ground-based infrastructure to thousands of airports would be unacceptable to small communities and to the Federal Aviation Administration (FAA), so the new capabilities would need to be aircraft-based. During poor visibility operations at these non-towered airports, most of which do not have radar coverage to the surface, current air traffic control procedures restrict operations to one operation at a time. Consequently, a second objective of the SATS Project was to enable greater operational efficiency at those airports in poor visibility conditions, once again, without requiring expensive ground-based infrastructure. The goal was to enable simultaneous operations at those airports in instrument meteorological conditions (IMC). The SATS Project also wanted to provide pilots new tools that make it easier to fly safely. The objective was to develop tools that would make a median-proficiency instrument-rated pilot confident that they could navigate safely to that fogged-in community airport and land in that high-traffic environment. Finally, the SATS Project wanted to assure that SATS traffic would be able to integrate with the existing enroute traffic in the NAS. Solutions to these four challenges are referred to as the four SATS operating capabilities. The project was responsible for developing technologies and demonstrating that those capabilities are feasible. The project was also responsible for assessing the impact on mobility, the environment, and the NAS that would result from implementing those capabilities.

The SATS concept represents a departure from the direct extension of air transportation business and service models of the past in three significant ways. First, the SATS concept is based on an on-demand, point-to-point, and widely distributed network topology. Second, the operating capabilities are conceived to use airspace and runways in instrument meteorological conditions that cannot be used in the current NAS architecture. Third, the concept is based on developing and applying new aviation technologies to make the use of smaller aircraft and more widely distributed community airports practical for public transportation. The results of early assessments of market adoption appear to support the viability of economically attractive business models for on-demand air service in business travel markets that are not well served by the scheduled hub-and-spoke system. The early technical assessments appear to support the viability of the high-volume operating capability in non-radar airspace as a means of making access more reliable to more airspace and more runways possible in near all-weather conditions. In summary, the Small Aircraft Transportation System concept has potential to respond to certain externalities affecting the needs for mobility in the 21st century. In the near term, the SATS Project is developing technologies that would enable reliable, safe, scalable, affordable, on-demand air access to small communities that cannot attract scheduled air service today. In the longer-term, the SATS vision provokes advances in mobility in the form of greatly increased radius of action of daily life (Holmes, 2004).

Another important project, the NASA/Langley Personal Air Vehicle Exploration (PAVE) project was established to investigate the feasibility of creating vehicles which could replace personal ground and air transportation schemes. The mission was door to door personal travel (a system solution involving air and ground) where you want, when you want, and improvements in lifestyle and benefits for entire U.S. population.

PAVE was different from prior efforts. The vision of providing on-demand personal air mobility was tightly aligned with NASA’s Aeronautical Research Theme of enhancing mobility, and providing faster, further travel, anywhere, at any time. PAVE addressed many Aerospace Technology Enterprise objectives such as:

- Increased Mobility “enable people to travel faster and farther, anywhere, anytime”,
- Increased Capacity -both at hub and spoke, and on highways,
- Increase Safety, Reduce Emissions, Reduced Noise,
- Pioneer Technology Innovation,
- Commercialize Technology.

Personal Air Vehicles offer the potential for a breakthrough in mobility, capacity, congestion, and quality of life through the development of an on-demand aerial transportation system. However, there are good reasons why Personal Air Vehicles are currently limited to General Aviation hobbyists and are not part of a viable transportation system embraced by the public. Significant technology challenges prevent the free market from capitalizing on large market demand and public interest. In a combined effort NASA and industry have identified the missions most applicable to these vehicles and the technology challenges that exist to lay the foundation for viable products and a vibrant market. A 3-year system study has investigated these missions and technologies and developed concepts as a framework for understanding the benefits and technology impact. The missions include an evolution from the current small airport operations to a requirement set that encompass extremely short and vertical takeoff operations. The technology challenges that must be surmounted to support rural and regional missions include ease of use, automated airspace control, affordable propulsion, economically viable concepts, low community noise, modern certification procedures, and near all-weather capability while achieving a factor of ten improvement in small aircraft safety. Key demonstrations were identified that would establish a clear future vision of vehicle capabilities for a change in perception that encourages investment from the aerospace and auto industries.

The objective of the PAVE research was to enable safe, affordable, easy-to-use, and acceptable personal air vehicle technologies that expand access to more communities. In addition, much greater reach, flexibility, robustness, freedom, individual control, and speed would be achieved than the current hub and spoke or highway systems for a broad segment of the American public. Many of the key hurdle will need not only technology development, but also public demonstration of less quantitative characteristics such as ease of use and community noise acceptability.

The required technologies have been grouped into three categories. A near-term set of technologies is required to create a transition growth market that extrapolates from the existing General Aviation market, overcomes a first set of common hurdles across all mission types. These prioritized technologies include ease of use with automatic airspace operations, economically viable concepts with affordable power, advanced certification processes, low community and interior noise, and near all-weather capability. The mid-term set of technologies expands upon the accessibility and utility of small aircraft to meet an increased level of everyday use through increased efficiencies and short field performance. These technologies are grouped into propulsion efficiency improvement, increased payload fraction through decreased propulsion system weight, and improved high-lift performance while maintaining simple and robust aerodynamic systems. The far-term set of technologies further increases the short field performance to approach the goal of point-to-point travel through vertical takeoff and landing operations. These technologies are grouped into environmentally acceptable powered lift capability, lightweight structures, ability to model and analyze unconventional concepts, and the ability to convert alternative energy sources into thrust. Ease of use involves everything from time and cost for proficient training, to interaction with the national airspace system, to operation of the aircraft.

The bottom line for PAV technologies is that there is the opportunity to make small aircraft much better than they are today, and to develop an on-demand transportation system that would be much faster and provide more throughput than what we have today. This capability to travel faster, further, anytime, anywhere is a dream that is achievable, and one that could lead us into a new age of mobility. Main findings are:

- Design constraints are defining the problem, not performance.
- Utilization is a primary concern (addition of air-taxi and air-rental).
- Poor performance of baselines, and availability of new synergistic technologies make this mission appear fertile for major improvements with advanced designs.
- Circulation control and distributed engine technologies are highly synergistic.
- Follow on work will provide detailed designs, technologies, and costing as well as greater depth in top level systems benefits.

Another major undertaking which will have a significant impact on the national air transportation system of the United States is the NextGen program. This long-term program aims at transforming the national air transportation system of the United States, mainly the aging ground-based air traffic control system, into a satellite-based system to tackle the future demands of the American air traffic. The system changes shall reduce congestions and improve the passenger satisfaction. The program consists of five main elements:

- The full implementation of ADS-B across the national airspace to assist air traffic controllers and pilots with accurate information for separation in the air and on the ground.
- The System Wide Information Management (SWIM) is a standardized single infrastructure and information management system that provides high quality and in time data to all users and applications. The aim is to reduce the number of different interface types and systems, to avoid data redundancy, and to assist the sharing of multi-user information.
- Next Generation Data Communications means the conversion from the old voice communication system used by air traffic controllers and pilots to a data communication system where pieces of information are exchanged via data link.
- The Next Generation Network Enabled Weather is a new national weather information system based on global weather observations and sensors which is updated in real time. The goal is to allow for better decision making for the air transportation sector and to reduce weather attributed weather delays.
- The NAS voice switch is the replacement for many different currently used voice switching systems by one single air / ground to ground / ground voice communication system.

In Europe, the Small Aircraft Transport System (SATS) aims at the segment of the transport market that is not served by scheduled air transport or high-speed trains, which today results in a substantial need for road travel for short to medium distances, to answer the specific needs of business and other users. The SATS will use small 4 to 19 seater aircraft, single pilot crew and automated control & guidance, flying IFR operations, with propulsion systems that are tailored to the missions, using the network of regional airports, supported by appropriate ATM-ATC systems and an ICT infrastructure (Information and Communication Technology) to provide an easy reservation system and per-seat on-demand air travel and enable more effective operational and administrative procedures (SAT-RDMP, 2015). The small aircraft transport mode can fill a gap, which exists between surface transport and regular mass air transport. The challenge is to create a new mode of transport by wider use of small aircraft using local and regional airports, enabling access to more communities in less time. The main idea is to shift a part of medium/long distance passenger car trips to small aircraft to improve the efficiency of passenger transport, relieve the congestion on roads and thus reduce the environmental impact. Considering the travel cost and the value of time saved by air travel, SATS will offer an attractive alternative to travel by car for distances greater than 200 kilometers (SAT-RDMP, 2015). The Small Aircraft Transport responds to trends in society that are serious challenges for transport system i.e., spending less time in travel and creating better conditions for traveling, while meeting the following conditions:

- Use less energy,
- Increase safety and security,
- Reduce pollution,
- Reduce costs,
- Exploit more efficiently the existing infrastructure,
- Deploy intelligent transport system to achieve efficiency and easy way of reservation service.

The European Personal Air Transportation System (EPATS) was a project funded by the European Commission under the Sixth Framework Program which focused on a new air transport system with small, smart aircrafts able to operate under all-weather condition. It was mainly intended to serve destinations with an underdeveloped transport network where other fast modes of transportation are not viable due to a low flow of passengers. The system shall fill a niche between today’s surface and the hub and spoke air transportation system shown in Figure 4.1 and offer a new, fast transportation mode for long distance trips at affordable costs (Baron, 2010). The project was looking at technologies required for this kind of system, at its market potential up to the year 2020, and at the potential impacts on ATM and airport infrastructure in Europe, as well as on environmental, safety and security issues (Laplace, 2008).

EPATS addresses only long-distance passenger trips with travel distances starting from 100 km up to 1,000 km and can be described as an air taxi service for small communities which are otherwise poorly connected. The project wants to use smaller airports which still have free capacities at present. The aircrafts under consideration have no VTOL capability, are operated by one pilot, and have a seating capacity from 3 to 19 passengers (Baron, 2010). Nevertheless, the project also aims for all weather operability which raises similar questions in terms of sensor technology and air traffic management.

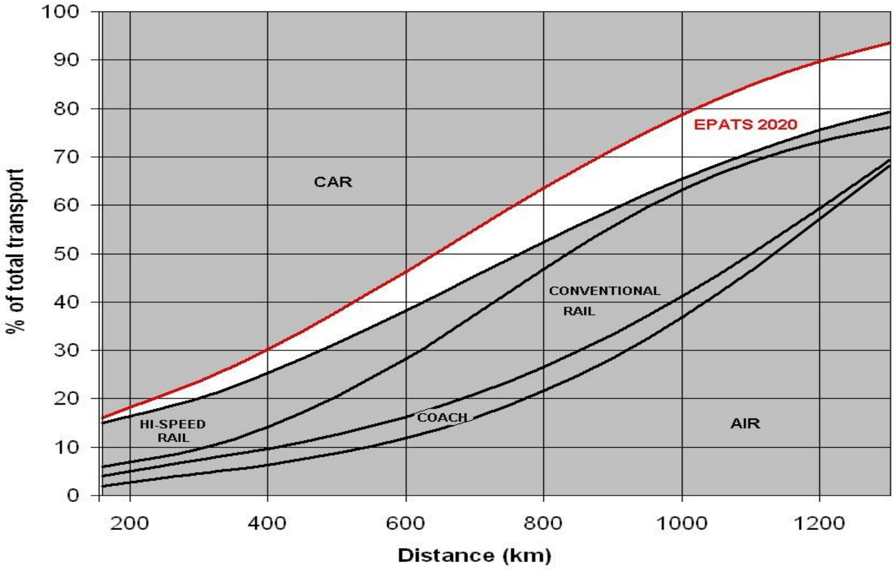


Fig. 4.1 EPATS vision for the modal split of interregional trips in Europe for 2020, source: (Baron and Piwek, 2008).

The project EPATS showed that the currently available airport infrastructure (2570 airports and airfields in Europe) is enough to provide easy access to all European communities. About 60% of the European population is living within 20 kilometers from the nearest regional airport, whilst for 95% of the European population the nearest regional airport is within less than 40 kilometers. The existing airport infrastructure will be enough (SATS will use satellite CNS and satellite-based landing aids). Calculations show that small aircraft transportation is cost effective compared to road traffic over distances greater than 200 kilometers. Using modern mass-produced small aircraft based on advanced technology and an intelligent transport business model, SATS will be affordable, and once full maturity is reached, costs will be similar or less than car travel (EPATS, 2010). The environment remains the main policy area where further improvements are necessary. The impact of different modes of transport on environment is usually assessed by costs externalities measurements. Many research were made to compare road and air transport. In all cases, the impact of air transport on the environment is much friendlier than in the case of road transport; it concerns noise pollution, local air pollution, traffic congestion, crash, and others (EPATS, 2010). EPATS study showed that small aircraft transportation is beneficial for business travel in Europe, especially in southern France, Spain, Portugal, and Italy, as well as in Eastern Europe, adding a new relevant market towards the current business aviation market which is currently more mature between London and Milano. The EPATS project showed that 7% (96 billon pas.km) of the future car travel (by means of affordable operating costs) in 2020 could be shifted to SATS. This would require a fleet of 89 000 small aircraft (4 to 19 seats) and generate up to 43 million flights per year. Using professional pilots for small transport aircraft operating both under Parts 91 and 135 of the FAR or EU PART OPS, SATS will have a far lower accident rate than road transport. The challenge to SATS is to reach safety levels like those of current commercial air transport (Part 121 or EU OPS air carriers).

Improved small aircraft will be based on new technologies that facilitates pilot situation awareness and flying in poor weather which will help reach the projected safety levels. Additionally, the small aircraft will be supported by new training systems. Using small aircraft means that the pilot costs will have to be shared by a lower number of passengers so, it is crucial to reduce the crew to one pilot, replacing the second by automatic system. SATS will be characterized by efficient pilot management, maximizing the pilot availability and skills, complying with the rules addressing flight time limitations and required rest periods. Technology challenges which will receive extra attention are the aircraft and propulsion efficiency, all weather operations, single pilot operations, noise and emission reduction, safety and security, cabin comfort as well as net-centric IT systems to support different business models (Piwek, 2001).

Another European Project, Single European Sky (SES), is a response of the European Commission to coping with the ongoing and expected growth in air travel (Eurocontrol, 2010). The finding that the airspace could not be organized following national borders, but traffic flows instead led to a call for common rules and procedures at the European level and the “Single European Sky” (SES) initiative was created to meet this need in 1999 (Eurocontrol, 2010). While the SES is mainly acting in legislation, the supporting Single European Sky ATM Research (SESAR) program is responsible for the technologies and procedures needed to modernize and optimize the future European ATM (Eurocontrol, 2010). SESAR is an initiative by the European Commission that started in 2004 and that has the aim to restructure the air traffic management system in Europe (SESAR, 2010). It should be noted that SESAR is not a single project but consists of more than 300 projects involving all the players such as the airliner and the aviation industry. The undertaking consists of three main phases (SESAR, 2010):

- A Definition Phase (2004-2008) led by Eurocontrol that has delivered a master plan for the development and deployment of the next generation ATM system.
- A subsequent Development Phase (2008-2013) responsible for the future technological systems, components, and operational procedures.
- And, lately, a Deployment Phase (2014-2020) in which the new air traffic management infrastructure shall be produced and implemented at large scale.

At the core of SESAR is the new concept of operations, the so called four-dimensional (4D) trajectory also known as “business trajectory” (SESAR, 2010). It works on the principle that the airspace user, the air navigation service provider, and the airport operator agree on a common trajectory for the flight which is defined according to its three spatial dimensions and time. By this, trajectory constraints of the airspace and of the airport capacities are included. Once the trajectory is accepted, it becomes the reference for the airspace user who must follow it; and the service provider who shall facilitate the user in doing so. Real time information sharing between all stakeholders is foreseen for all phases of the flight including ground operations (SESAR, 2010). An individual project called 4D Contract Guidance and Control Project is dedicated to clarifying questions around the 4D business trajectory and to path the way for its implementation.

Although SESAR will have a major influence on the European airspace architecture, the operational procedures, and technical components in the air and on the ground focus clearly on the commercial aviation sector and on flights in controlled airspace. It remains to be seen how many of the new procedures and technologies will be adopted by the general aviation sector for flights in unmanaged airspace.

Some smaller projects addressing more specific areas of research such as all-weather operations, cockpit design, automation, legislation, etc., at the European level will now be presented.

The project sFly (2009-2011) was an FP7 project and was looking at very small and light helicopters (<500 g) which could operate autonomously in city-like environments (inside and outside). These helicopters can be used for search and rescue tasks, environmental monitoring, security surveillance tasks, inspections, etc. As GPS has problems in very dense environments and is shadowed by buildings, etc., it is not a viable solution for the helicopters in sFly. The project is therefore looking into complete vision-based and fully autonomous navigation and includes work on coordinated swarm flying of these vehicles in dense environments. Although, the sFly helicopters are much smaller and unmanned, the environment in which they operate (close to buildings or even in buildings) and the high level of automation aimed for are comparable. sFly is led by the Autonomous Systems Lab of the Swiss Federal Institute of Technology Zurich which was also involved in myCopter and there responsible for the work package about control and navigation of a single PAV (myCopter, 2014).

The Small Aircraft Future Avionics Architecture (SAFAR) is a FP7 three-year project that has started in 2008. SAFAR is looking at the whole avionics architecture for small aircrafts that shall provide point-to-point on demand traffic (European commission, 2011). The goals are to improve the handling qualities and the safety of the aircrafts and, at the same time, to make the aircrafts less cost intensive. The project aims at reducing the pilot workload significantly by providing continuous flight envelope protection and by improving the handling characteristics of the aircraft. The project aims at different modes of automation (manual control, control via flight guidance and control via flight management). In the long term, automatic 4-D flight vectoring via on-board ATM/FM is aimed for, and, as a pre-step, 4-D flight vectoring provided by ATC via ADS-B is foreseen (Meyer, 2011).

The PPlane project is another FP7 project addressing directly the Out of the Box idea of a personal air transportation system. The project started in October 2009 and had a duration of 36 months. A systematic and innovative approach has been developed and implemented within the PPlane project to identify and analyze future customers’ needs and to propose novel ideas for PATS. This system satisfies the end users while respecting all environmental and social constraints. PPlane is looking at aircrafts from 4 of up to 8 passengers and investigates several potential PATS concepts with different levels of automation and of required pilot training (Le Tallec, 2012). As the project website states, a selection process shall follow to find out about the most promising air transportation systems and to elaborate them further by also including technological and societal aspects. The focus points of the project seem to be safety and security aspects, automation and control, human factors, and environment, but they also state to be looking into economic and social factors as well as into regulation issues (Le Tallec, 2012). As part of this selection process, a Delphi Survey was conducted which collected the views of more than 150 experts (mainly from the field of aeronautics) regarding customer preferences in the field of future personal air transportation (Roudstein, 2010). In summary, the PPlane project is an important milestone in the long road towards a revolutionary personal air transport system.

Although, all projects envisioned are very different, either much smaller or much bigger project, the issues of different level of automation, the visualization of these different modes, safety and the goal of a reduced pilot workload are similar tasks to be studied.

4.1.2 The Project myCopter

This section provides information about the myCopter Project based on User Perspectives and Expectations report written by Meyer and reviewed by Decker in 2011 and 2014.

The myCopter project proposed an integrated approach to enable the first viable PATS based on Personal Aerial Vehicles (PAVs) envisioned for travelling between homes and working places, and for flying at low altitude in urban environments. Such PAVs should be fully or partially autonomous without requiring ground-based air traffic control. Furthermore, they should operate outside controlled airspace while current air traffic remains unchanged and should later be integrated into the next generation of controlled airspace. The myCopter project aimed to pave the way for PAVs to be used by the public within the context of such a transport system. The project consortium consisted of expert partners that would address the development of advanced technologies necessary for a viable PATS, as well as performed socio-technological evaluations to assess the impact of a PATS on society. To this end, dynamic models for potential PAVs were designed and implemented on motion simulators and a manned helicopter. An investigation into the required flight competencies of PAV users was conducted, which guided a user-centric design of suitable human-machine interfaces. Furthermore, the project introduced new automation technologies for obstacle avoidance, path planning and formation flying. This project was a unique integration of social investigations and technological advancements that are necessary to move personal transportation into the third dimension.

The project myCopter was also responsible for exploring the socio-technological environment of PAVs. In contrast to other projects dealing with the design and actual construction of PAVs, the project myCopter took a different starting point and focused on the key issues surrounding a future implementation of a personal air transportation system, and it studied the topics of safety, legal aspects, technical & operational challenges, environmental and socio-economic issues, the aspect of system integration, and positive effects on journey time and the road traffic. Its aim was to investigate the infrastructural environment for PAVs and to study the potential impact on society and the social expectations towards PAVs.

PAVs are expected to shift the role of users from traditional flight control to flight management. PAVs will likely be autonomous for safety-critical phases of the flight, such as obstacle avoidance and landing spot selection for safe arrival and departure. Research addressed collision avoidance with other traffic and swarming of vehicles along established routes such as highways to minimize the impact on urban areas. PAVs will have a large impact on society, raising numerous questions concerning user expectations and interactions with new aerial transportation systems. It was important to engage in dialogue with experts, like regulators and stakeholders, and potential users of a PATS.

Within the project, state-of-the-art research facilities were used. Unmanned aerial vehicles served as testbeds for the development of automation algorithms. Two ground-based simulators, the CyberMotion Simulator and the HELIFLIGHT-R Flight Simulator, were used in experimental evaluations with humans in the loop. In addition, they aimed to implement aspects of their automation technologies and human-machine interface designs into the Flying Helicopter Simulator, a fly-by-wire / fly-by-light research helicopter operated by DLR.

The project has been broken down into distinct phases. In the first year, they identified key socio-technological issues, experimental paradigms, and automation requirements, thus laying a coherent foundation for subsequent research. In the second year, initial tests were performed with automation algorithms and evaluations with humans in the loop were conducted on the experimental paradigms. The third year entailed experiments on the human-machine interface and training issues and included simulations and tests that would be performed with automation in flight. In the final year, results from exploration of the socio-technological environment were summarized for public dissemination. In addition, part of the technological advancements was implemented on the Flying Helicopter Simulator.

After the challenges and problems discussed in the project it must be said that a bunch of requirements exists regarding a PATS and the PAVs inside which is not easily to be met. Although some technical issues are on a good way (energy density of storage technology) and single components for sure seem to be feasible (e.g., noise reduction technologies) it must be said that today’s existing demonstrators are still far away from the described “myCopter” in the full autonomy scenario. Next to the issues regarding the pure vehicle and user competences it must be said that the surrounding infrastructure for PAVs is as important. Their existence and operation would therefore need to be taken into consideration for today’s planning considerations and construction projects to be able to have this transport option available in the future.

These examples illustrate well that the barrier will probably not be the PAV technology itself. Prototypes exist and even if it is still a long way to go, it seems rather likely that in the next decades a highly autonomous or even a full autonomous PAV will be available. The crucial point is the embedment of the new transport mode in the existing transport system and to make it compatible with the habits and preferences of the users (Meyer, 2011). It took less than half a century to make the regime of automobility a dominating element of the transport sector. This included a reconstruction of urban areas to enable automobility. The pace of change is generally much higher nowadays than it was about hundred years ago. PAVs come along with benefits. The analysis conducted in the myCopter project revealed that, amongst others, the issue of automatization is a highly crucial enabler for a broader market penetration of PAVs. From that perspective, it is imaginable that the ongoing automatization of other transport modes (including the upcoming automatization of private cars) will pave the way for PAVs. Here, one can assume that full autonomous driving might even be easier to reach in the air since the overall number of unexpected participants in the systems (such as bicycle riders and pedestrians, playing children, dogs, etc.) is much lower.

To explore the empirical findings of user perceptions and expectations related to the introduction of PAVs, three focus groups were prepared in three different countries (Germany, Switzerland, and the United Kingdom) and conducted in November 2013 and January 2014. Key aspects of the discussion were the participants' feelings and impressions related to the existence and availability of PAVs in their local environment and the issues and challenges associated with this emerging air transportation mode. The focus group discussions were divided into two main parts. The first part was about the current local traffic situation and how people experience their way of traveling in the cities, especially their daily commute. After this collection of more general problems in current urban transport systems and options for improvement, the second part of the discussion started with a small narrative imagining the existence of small personal air vehicles available for personal commuting. The discussions brought out very lively and critical perceptions; potential challenges and solutions were voiced by the participants.

Whenever the idea of personal air vehicles or flying cars is presented and discussed, many questions regarding not only the technical feasibility of such vehicles but especially concerns about safety (collision avoidance, controlled flight into terrain, terrorist threats, etc.) are expressed. Further questions arise on how a design of Air Traffic Management for them could look like and on where the aircrafts would be allowed to fly and at what times. Other major challenges seem to be the topics of certification and regulation and the question of how to integrate the PAVs into the existing ground transportation but also into the existing air transportation system (Muller, 2010). In the field of environmental issues the uncertainty about energy consumption and emissions is noticeable; especially the issue of noise disturbance seems to be a key one that comes up whenever people are confronted with the idea of PAVs flying around in higher counts in a city environment. All of them will not be described in detail here. A focus was set on weather, safety and on noise.

The safety issue was interestingly coming up in all focus groups straight away at the beginning. Safety issues mentioned by participants included both safety of users of PAVs (“on board”) and people on the ground. Regarding on-board safety, misuse by terrorists, laser attacks, computer hacking into the system and danger through PAV parts dropping of one PAV down to another one was envisioned. Also, the problem of induced fire due to a PAV crashing into buildings was raised. The problem of overhead lines (power, trams) that could prevent a secure landing in emergency cases and would be a handicap for PAV operations in cities generally was mentioned too. Also, problems with aerodynamics during landing at places where buildings around could embrace the air flow were considered.

In terms of emergency cases, a distinction was made between an emergency for the person inside because of medical reasons and a system failure (loss of power, computer malfunction, etc.). An additional major challenge is surely the weather situation and how the PAV would be able to cope with strong winds, snow, icing, and heavy rain. These problems were briefly mentioned by the participants but not further discussed because not much input could be given by the moderator because of the missing detailed design and further specifications of the PAV itself.

In the category of environmental issues, the energy consumption, power sources and energy storage for powering the PAV, noise and visual disturbances caused by swarms of PAVs were topics as well as the appearance of electric smog and maybe new health risks due to dispersed dust during take-off and landing. A major issue was seen in the fact that PAVs would cause their negative effects like noise and visual disturbance everywhere and people would have no chance to escape. In contrast to adverse effects by cars which are bound to visible infrastructure on the ground which could be avoided by living far away from major streets and so on this was difficult to achieve with PAVs assuming that they could use most of the airspace. To have an open, not obstructed view was seen as a valuable property in Tübingen and Zurich. The idea to have PAV “streets” or routes above the lake of Zurich for example was seen as not acceptable and people there were very aware of and concerned about their surrounding landscape and the potential impact PAV/PATS might have on them. Especially the expected swarm traffic during rush hour was a major source of concern:

PAV traffic was seen by many participants as more suitable for big cities like New York or Frankfurt where already a lot of background noise exists and the general setting fits better in terms of atmosphere and architecture. As one potential solution to the visual disturbance problem created through hundreds of small vehicles flying around everywhere, the option to bundle and concentrate PAV traffic to certain “streets in the air” possibly connected to already existing major main traffic routes (highways) on the ground was very reasonable and helpful for acceptance. At these routes already, a lot of noise would exist, and the recreation value would be minimal. Therefore, additional traffic would not do as much harm.

A frequently discussed question was if the PAV option would really improve the traffic situation on the ground or if every newly created mobility option and added capacity would not just lead to new traffic up to a point where everything – including the air space – would be overcrowded.

Every transport option relies on its own specific infrastructure. Regarding PAVs it was thought about where these would be able to land (“even on the own balcony”) and stored and if this would be partly possible together with cars or not (shared car parks). Also, effects and implications on future architecture were discussed as this quote illustrates. Not only buildings but also pylons, telegraph wires and other objects not easy to detect for the PAV system and its sensors could need to be adapted to provide a safe operational environment for them. Another aspect belonging to the infrastructure complex is the issue of maintenance. The prechecks from the commercial airliners are present in people’s heads and the fact that legally even before a car journey the driver is forced to do some checks. The need for prechecks was not questioned but it was doubted whether the average user would be competent to do them. The service issue for PAVs was seen with a high amount of trained people needed to provide it associated with the question of costs and practicability (availability of PAV for operation).

A lot of the discussion related to the question whether people would use the PAV in a kind of sharing scheme (even within a fixed schedule potentially) or if they would own it by themselves. This differentiation has a lot of consequences regarding infrastructure needs (parking space), maintenance & service issues, costs, and availability. All these mentioned issues are strongly connected to the level of autonomy of the PAVs and their degree of autonomy. The full-autonomy option would be a basic requirement for the sharing scenario because in a 1-2-seater PAV a “taxi driver” who is piloting is not really an option. The possibility to have the PAVs operating in a full autonomous mode was seen as a good option to be able to provide door to door transportation and to ease the parking issue. In general people said that they would like and accept the full autonomy PAV version for the daily commute and flying in the city environment especially in dense traffic situations. The option to fly by oneself was seen as attractive for situations with less or no other traffic around, outside the city and/or in leisure time. Regarding difficult flight tasks or emergency situations many participants were claiming that in these circumstances it must be possible to take over control. This would mean that a manual interface for piloting would be needed on the PAVs. This requirement of manual taking over if the system fails would also have consequences for either the design of a potential superior maybe central system which would be responsible then or would add to the user skills required to be allowed to use a PAV (training, license, etc.).

Regarding a perceived loss of control, the positions of participants were quite mixed. Many weighed the upsides and downsides of autonomous flying and piloting in various contexts and with different rationales. One question coming up in every focus group was the one after the responsibility in case of an accident in the autonomous mode. Another challenge which relates to authorities and the legal framework was about standards regarding the communication system of the PAVs (between each other but also with other flying vehicles) and the batteries. For the batteries an exchange system to minimize waiting times and allow for greater distances or broader timeframes of availability in a sharing model were called for and a problem was seen in the fact that different companies would bring different standards onto the market.

In summary it can be said that all three focus group discussions were very lively and insightful. The participants brought in a lot of personal opinions, comments and valuable criticism regarding the PAV concepts and future PATS. They also made several suggestions regarding future design options and operational models for both personal air vehicles and transportation systems accommodating them. As a general observation from all three focus groups one could state that the major issues regarding PAVs that were raised are safety problems (on the ground and in the air for the PAV itself), environmental issues (visual impacts, noise), challenges with respect to infrastructure (city architecture, integration into existing ground traffic, maintenance & service), organizational and business models, level of autonomy, system design and operational aspects, privacy and legal issues, as well as thoughts about user groups and areas of application.

It was interesting to see how people switched between two perspectives – that of the potential user who sees attractive new transportation options and that more outside perspective of residents or people on the street who might be affected by the potential impacts of PAVs. They tried to picture how PAV traffic would look like in their city and everyday life, in their garden, from their flat, etc., but the personal perspective from “inside the PAV” was imagined in detail as well.

It is impossible to draw a single, generalized conclusion from observations. The picture is rather mixed in various ways. First, it should be noted that the focus groups were exploratory and thematically rather broad. They were designed to provide first insights into a broad set of perceptions and concerns rather that a detailed discussion of pros and cons linked to single issue. Second, a few ambivalences and ambiguities were identified that should be subject of further research. So, for instance, most participants did not express clear preferences regarding fully automated PAV or those that allowed for self-piloting. Another example regards ownership models. While some participants preferred their own PAV (for various practical reasons), others very much liked the idea of the "PAV on demand". A third example is linked to the broader "loss of control" debate – some participants argued that handing over control to the PAV is perceived as a loss, other participants said that they perceive it as an actual gain since they trust the control technology mid-air much more than individual persons with unknown piloting abilities. Thirdly, future focus groups could – and perhaps should – be linked to more realistic simulations of a PATS including real-life traffic situations. What can be said is that more effort would be needed to be put into the simulations to make them complex (other PAV traffic present in the sky for example) and realistic enough to be convincing for the participants.

4.2 NASA and AHS Annual Forums and Workshops

This subsection presents information about AHS International's and NASA's annual forums and workshops that gather a community of aerospace profession ranging from technologist to business entrepreneurs who recognized that emerging technologies could transform air transportation by enabling new air transportation systems. The reports and presentations at these forums and workshops provide cutting edge vertical flight technologies in the world and valuable resources for eVTOL PATS assessment. Here, in this section, we will give a general picture and summary and we will use the necessary findings and observations in the relevant sections of assessment chapter.

Over the past years NASA, in collaboration with the National Institute of Aerospace, has conducted a series of government/industry workshops to identify the key technologies and capabilities required to enable transformational On-Demand Mobility (ODM) systems to be developed and deployed. The agendas, presentations and results of these workshops are all archived at the web site.[11]

The initial workshop was an "On-Demand Mobility Forum" conducted in Oshkosh, Wisconsin, July 21-22, 2015. The primary purpose was to acquaint the attendees of the

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[11] http://www.nianet.org/ODM/roadmap.htm, https://nari.arc.nasa.gov/wghome

Experimental Aircraft Association (EAA) Oshkosh Air Venture Show with studies that illustrate how potential new technologies and approaches could enable a transformational ODM capability. There was significant enthusiasm expressed by over 50 attendees, and excellent industry suggestions were received, New industry members were added to the ODM community.

The second workshop was an "On-Demand Mobility Roadmapping Workshop" conducted in Kansas City, Missouri, October 21-22, 2015. The Kansas City venue allowed significant participation by the FAA Small Airplane Directorate to discuss regulatory, flight operations and airspace issues. A wide variety of small and large companies and universities presented ODM relevant technologies under development. The group decided to begin the development of three different categories of roadmaps: Simplified Vehicle Operations and Airspace; Electric Propulsion; and Manufacturing, Integrated Structures and Community Impact. Break-out sessions were then held for each of these groups to identify relevant technologies. A series of weighted Figures of Merit for ODM systems were also developed, and relevant technologies were mapped to them. There were close to 100 attendees, as the ODM community of practice continued to grow.

An additional "ODM and Emerging Technology Workshop" was conducted in Arlington, VA March 8-9, 2016. The Washington, DC venue allowed significant participation by FAA and NASA ARMD senior leadership. In additional to presentations by key ODM vehicle and technology developers (as well as NASA and FAA), results of promising market studies were presented for VTOL and CTOL systems. Potential ODM system operators, such as Cape Air and Imagine Air also gave presentations that showed the possible benefits of ODM research to their business plans. NASA presented its ODM technology planning and project results, and FAA presented thoughts on regulatory, certification and airspace challenges and potential solutions. Technology roadmapping discussions were held and plans finalized for working groups to develop roadmaps. There were over 150 attendees, with even more organizations and companies being added to the community.

The fourth workshop was an "On-Demand Mobility Report Out" conducted in Hartford, Connecticut, on September 29-30 2016 in conjunction with the SAE 2016 Aerospace Systems and Technology Conference. The primary purpose of the workshop was to present the final draft of the ODM technology roadmaps and updated mission studies. The three technology roadmapping working groups were dissolved, and two new mission working groups—Thin-Haul Commuters and Urban VTOL Air Taxis—were created. These roadmaps provide technology projects, studies, and capability developments that are time-phased to feed into several ODM flight demonstration projects. Proposed flight demonstration projects, to be closely coordinated with the FAA and performed in partnership with industry, are in support of two major mission classes: thin-haul commuter vehicles and urban VTOL vehicles.

In general, the roadmap development process, including the several workshops, was well thought out and executed. Specifically, NASA should be commended for including so many outside organizations, companies, and other government organizations in this highly collaborative process. The integrated ground and flight development projects appear to be feasible and appropriate in content and timing. This process also led to the creation of a very large and diverse community of practice that includes technology developers, vehicle developers, vehicle operators and government regulators. The organizations vary from small start-ups to the world’s largest aerospace companies, foreign and domestic, as well as several government agencies. This community of practice has now reached a critical mass and is attracting national and international attention as well as private capital.

The AHS International has also conducted a series of forums and workshops to identify the key technologies and capabilities required to enable transformational eVTOL air transportation systems to be developed and deployed. The agendas, presentations and results of these workshops are all archived at the web site[12]. The AHS Annual Forum is the longest running and most established VTOL event in the industry. Unlike trade shows, the AHS forums provide access to an elite technical community responsible for directing and executing the engineering and manufacturing process of the global vertical flight industry.

The Technology Display, running concurrent with the forum, is the most extensive exposition of cutting-edge vertical flight technologies in the world, and includes other technologies more broadly applicable to aerospace in general. Leading manufacturers, service providers, defense agencies, universities and research and development organizations showcase the very latest in vertical flight technology.

The global Vertical Flight Technical Society was founded in 1943 as the American Helicopter Society (AHS), now AHS International, and provided a platform for everything from VTOL MAVs/UAS to rotorcraft and eVTOL to STOVL. AHS International expands knowledge about vertical flight technology and promotes its application around the world. It helps advance safety and acceptability and advocates for vertical flight R&D funding. AHS have a proud history of advocacy and support. AHS worked with NASA, Army, and Air Force to save the NFAC wind tunnel. AHS provided major foundational support to transformative

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[12] http://www.vtol.org/transformative

initiatives, Joint Strike Fighter/F-35B STOVL and V-22 Osprey tiltrotor. AHS is also providing major foundational support to new transformative initiatives – Future Vertical Lift (FVL)/Joint Multi-Role (JMR) – Electric and hybrid-electric VTOL (eVTOL) concepts. AHS International is developing an “Ecosystem” – Partnerships with cities, real estate companies, aircraft OEMs, electric vehicle charger manufacturers & cities – and connecting innovators, investors, regulators, technical experts, standards organizations.

AHS has also provided foundational support and has led a series of Transformative Vertical Flight Workshops annual series with NASA, AIAA and SAE to explore the potential, and track the development of, many emerging electric and hybrid-electric propulsion technologies that might enable and drive new forms of air transportation in the future, and to build community and develop industry roadmap since August 2014. The primary emphasis was on the potential for on-demand air-taxi operations with vertiport-capable configurations and design. However, the initiative also includes, with equal emphasis, the capability for commercial package delivery, and the delivery of strategic military assets. This is not an initiative on small drones (Unmanned Air Systems), but on manned and optionally manned aircraft, with practical payloads of at least 100-500 lb. and gross take off weights of 1000-5000 lb. and beyond (Datta, 2018).

The five TVF workshops were largely unstructured and organic affairs where expert opinions were sought and solicited through invited talks and seminars, with follow-up discussions held by participants in break-out sessions. The membership/constitution, tasks, and deliverables of the working groups were left undefined. The results of the previous workshops (mainly 2-4) were assembled in form of two excel sheets: TVF Mission Subtopic Matrix 1.2 and TVF Roadmap 5.2, and these were distributed by NARI to the working group leads as guiding documents. The first document, the Subtopic Matrix, stated the four mission categories and listed four broad challenges related to: a) community/market acceptance, b) technology, c) certification / regulations and d) Infrastructure (Datta, 2018). The workshop materials are documented at the AHS website.[13]

The first workshop (Aug 2014, Arlington, VA, by AHS and AIAA) identified the existence of a multi-discipline community interested in transformative vertical flight and established a consensus that further collaborations were warranted. It was resolved to conduct a series of workshops.

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[13] https://vtol.org/what-we-do/transformative-vtol-initiative

The second workshop (Aug 2015, NASA Ames, Moffett Field, CA, by AHS, AIAA and NASA) assembled a community of interest to advocate for transformative vertical flight development. It identified high level requirements and initiated transformative vertical flight roadmap developments.

The third workshop (Sep 2016, Hartford, CT, by SAE, AHS, AIAA, NASA) informed participants about developments in transformative vertical flight design configurations, operational concepts, technology, market opportunities, and regulatory environment. It collected participants' preliminary suggested activities to serve as a starting point for the roadmap development. During workshop 3, the idea of smaller, more focused Roadmap Working Groups was floated, to bring some structure to the forums and a web portal for volunteers to contribute ideas was created.

The fourth workshop (Jun 2017, Denver, CO, by AHS, AIAA, SAE, NASA (co-located AIAA's AVIATION 2017 conference)) formed four mission-oriented roadmap development working groups. Four Working Groups were established: Private Intra-city (Short range ~ 5 – 50 miles); Commercial Intra-city (Short range ~ 5 – 50 miles); Commercial Inter-city (Longer range ~ 50 – 150 miles); and Public Services (Medical, fire, disaster, enforcement. The relevant presentations, videos and links are all archived at the web site[14].

The fifth workshop was held in Jan 2018, San Francisco, California. Other concurrent activities on the same theme were: The Transformative Vertical Flight Special Session at the AHS Forum 72, May 2016, and the Transformative Urban Air Mobility Special Session at the AHS Forum 73, May 2017 – both of which are also well documented.

4.3 UBER Elevate Summits and White Paper

This subsection provides a brief information about Uber, the San Francisco based transportation and technology company, which has expanded to 450 cities in 73 countries and serves 60 million monthly users, and their efforts regarding urban mobility and eVTOLs; Uber Elevate White paper published in 2016 and Elevate Summits in 2017 and 2018.

Uber now added a third dimension to its business model in late September 2016. It introduced the overall framework of a future on-demand air transportation system. Uber envisions that a network of small, electric aircraft that take-off and land vertically will enable fast, reliable transportation between suburbs and cities, and within cities.

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[14] http://www.vtol.org/transformative

Uber’s Elevate team is developing an urban aviation ridesharing product called Uber Air. A network of small, electric aircraft that take off and land vertically, will enable rapid, reliable transportation between suburbs and cities and, ultimately, within cities. Starting in 2023, Uber customers will be able to push a button and get a flight on-demand with Uber Air. For their vision, Uber published a white paper called “Elevate” for ODM operations, including the major technical, regulatory, and economic challenges.[15] This comprehensive report has also provided significant contribution to this study. Uber has established and funded a group to perform additional ODM studies and analyses.

The Uber Elevate Summit in Dallas, April 2017, became a watershed industry event that brought together 500 stakeholders and significantly raised global profile of the emerging e VTOL industry (Swartz, 2017). The summit was a very public launch pad for an array of transformative eVTOL air vehicle. Uber Elevate leadership has also welcomed 700+ of the world's foremost aviation leaders in industry, government, and academia to discuss the vision for how urban aviation will help cities become smarter, better, and more efficient at the second Uber Elevate Summit, May 2018, in Los Angeles.[16]

The summits have showcased major advancements unfolding across the urban aviation industry, exploring themes of urban mobility, technological progress across aircraft and battery systems, airspace management, operations, and product at scale. Uber elevate role is closing vehicle capability gaps through requirement standards, user surveys, tools, and technologies that accelerate partners and developing a highly efficient airspace-operations-network that provides seamless multi-modal to users (Moore, 2018). Five aircraft companies have signed on as partner, and while many other companies have also begun developing eVTOL aircraft for similar or related applications. They are exploring ways to overcome barriers to make the vision a reality. Reviewing Uber’s white paper and summit presentations contributed a lot in the assessment section, chapter five, to learn more about eVTOL PATS for the future.

Over the next few years, Uber will be continuing to work closely with city and country stakeholders to ensure that Uber create an urban aviation rideshare network that is safe, quiet, environmentally conscious and supports multi-modal transportation options.[17] To bring Uber Air to market, Uber have assembled a network of partners that include vehicle manufacturers, real estate developers, technology developers and three ‘launch cities. At the first Uber Elevate Summit in 2017, the team announced that the first trial city would be Dallas, a city with a rich

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[15] (https://www.uber.com/elevate.pdf).

[16] www.uber.com/elevate or www.vtol.org/uber

[17] https://www.uber.com/info/elevate/

history of aviation. At the Web Summit later that year, they announced that Los Angeles would become second launch city — one of Uber's top markets and the most congested city in the world. In response to growing interest from across the globe, Uber announced open criteria for a third launch city outside of the United States. Importantly, Uber is not looking for cities to provide tax breaks or local incentives. Rather, they are looking for cities with aspirational vision who are investing in their transportation systems and wish to bring Uber Air to market for their residents as quickly as possible. These cities will be the first to offer Uber Air flights with the goal to begin demonstrator flights in 2020 and commercial operations in 2023.

On-demand aviation has the potential to radically improve urban mobility, giving people back time lost in their daily commutes. Uber is close to the commute pain that citizens in cities around the world feel. Just as skyscrapers allowed cities to use limited land more efficiently, urban air transportation will use three-dimensional airspace to alleviate transportation congestion on the ground. A network of small, electric aircraft that take off and land vertically will enable rapid, reliable transportation between suburbs and cities and, ultimately, within cities.

The development of infrastructure to support an urban eVTOL network will likely have significant cost advantages over heavy-infrastructure approaches such as roads, rail, bridges, and tunnels. It has been proposed that the repurposed tops of parking garages, existing helipads, and even unused land surrounding highway interchanges could form the basis of an extensive, distributed network of "vertiports" (eVTOL hubs with multiple takeoff and landing pads, as well as charging infrastructure) or single aircraft "vertistops" (a single eVTOL pad with minimal infrastructure). Furthermore, eVTOLs do not need to follow fixed routes. Trains, buses, and cars all funnel people from A to B along a limited number of dedicated routes, exposing travelers to serious delays in the event of a single interruption. eVTOLs, by contrast, can travel toward their destination independently of any specific path, making route-based congestion less prevalent.

Recently, technology advances have made it practical to build this new class of eVTOL air vehicle. Over hundred companies, with as many different design approaches, are passionately working to make eVTOLs a reality. eVTOL aircraft will make use of electric propulsion so they have zero operational emissions and will likely be quiet enough to operate in cities without disturbing the neighbors. These eVTOL designs will also be markedly safer than today's helicopters because eVTOLs will not need to be dependent on any single part to stay airborne and will ultimately use autonomy technology to significantly reduce operator error.

Uber’s experts expect that daily long-distance commutes in heavily congested urban and suburban areas and routes under-served by existing infrastructure will be the first use cases for urban eVTOL air transportation mode. This is due to two factors. First, the amount of time and money saved increases with the trip length, so eVTOLs will have greatest appeal for those traveling longer distances and durations. Second, even though building a high density of landing site infrastructure in urban cores (e.g., on rooftops and parking structures) will take some time, a small number of vertiports could absorb a large share of demand from long-distance commuters since the “last mile” ground transportation component will be small relative to the much longer commute distance.

They also believe that in the long-term, eVTOL air transportation mode will be an affordable form of daily transportation for the masses, even less expensive than owning a car. Ultimately, if eVTOL air transportation mode can serve the on-demand urban transit case well—quiet, fast, clean, efficient, and safe—there is a path to high production volume manufacturing (at least thousands of a specific model type built per year) which will enable eVTOLs to achieve a dramatically lower per-vehicle cost. Initially, of course, eVTOL air vehicles are likely to be very expensive, but because the ridesharing model amortizes the vehicle cost efficiently over paid trips, the high cost should not end up being prohibitive to getting started. And once the ridesharing service commences, a positive feedback loop should ensure that ultimately reduces costs and thus prices for all users, i.e., as the total number of users increases, the utilization of the aircraft increases. Logically, this continues with the pooling of trips to achieve higher load factors, and the lower price feeds back to drive more demand. This increases the volume of aircraft required, which in turn drives manufacturing costs down. This is very much the pattern exhibited during Uber’s growth in ground transportation, fueled by the transition from the higher-cost UberBLACK product to the lower-cost and therefore more utilized UberX and UberPOOL products.

Mark Moore, Uber`s engineering director of aviation (and previously at NASA where he worked on Greased Lightning, among other electric aviation projects), believes that the integration of autonomy and robotics into new e VTOL designs will improve piloting and safety, reduce acquisition and operating cost, and ultimately re-invigorate the general aviation industry by inspiring a new generation of aviators and passengers to fly. He expects companies will spend the next two to three years developing prototype two to four seats eVTOL designs with experimental certifications proceeding under 14CFR Part21.195 as the FAA works out electric propulsion certification rules.

4.4 Companies Developing eVTOL Air Vehicles

This subsection presents the eVTOL concepts as a general picture and the companies developing eVTOL air vehicles to understand whether the time has been arriving. AHS International has compiled a comprehensive list of all these eVTOL air vehicle concepts. Very limited data is available, nevertheless a short version of the list is in Appendix 2 for completeness of documentation.

A community of aerospace profession ranging from technologist to business entrepreneurs recognized that emerging technologies especially electric propulsion and safe autonomy can transform air transportation by enabling new aviation transportation systems that provide greater operational flexibility, improve user convenience, does not degrade the environment, and enhance air transportation services (Dudley, 2018).

In this context, the first documented manned all-electric VTOL flights occurred during 2011-12 (Schneider, 2012). They were a co-axial twin-rotor helicopter (Chretien, 2012) and a multi-copter (Schneider, 2012). They were bare-bones aircraft, with a solo pilot, enabled by light-weight permanent magnet synchronous motors and compact Li-ion batteries. They flew for only a few minutes (5-10) and lacked all attributes of a practical aircraft – payload, range, endurance, and safety – but even so, demonstrated the feasibility of eVTOL, which, if brought to fruition in practical scale, could open new opportunities in aviation due to its many inherent strategic advantages.

Very soon there was an explosion of interest in personal drones and a frenzy of design and development of small eVTOL air vehicle (Whittle, 2017). On 3 March 2016, DARPA awarded Aurora Flight Sciences (now a Boeing Company) U.S. $89.4 million to develop a eVTOL distributed hybrid-electric experimental plane (designated XV-24A) further solidifying interest in this area. Today, merely ten years from the first manned eVTOL demonstrator, a total of at least 300 documented designs / commercial ventures can be found in public domain (Aviation Week Network, 2021). As a result, many companies are investing and doing engineering work, and actively recruiting to hire staff. Working groups are working to identify needs, coordinate standards and policy definition. Military and commercial eVTOL industries are developing and flying demonstrators at an incredible pace as seen in the Figure 4.2 below.

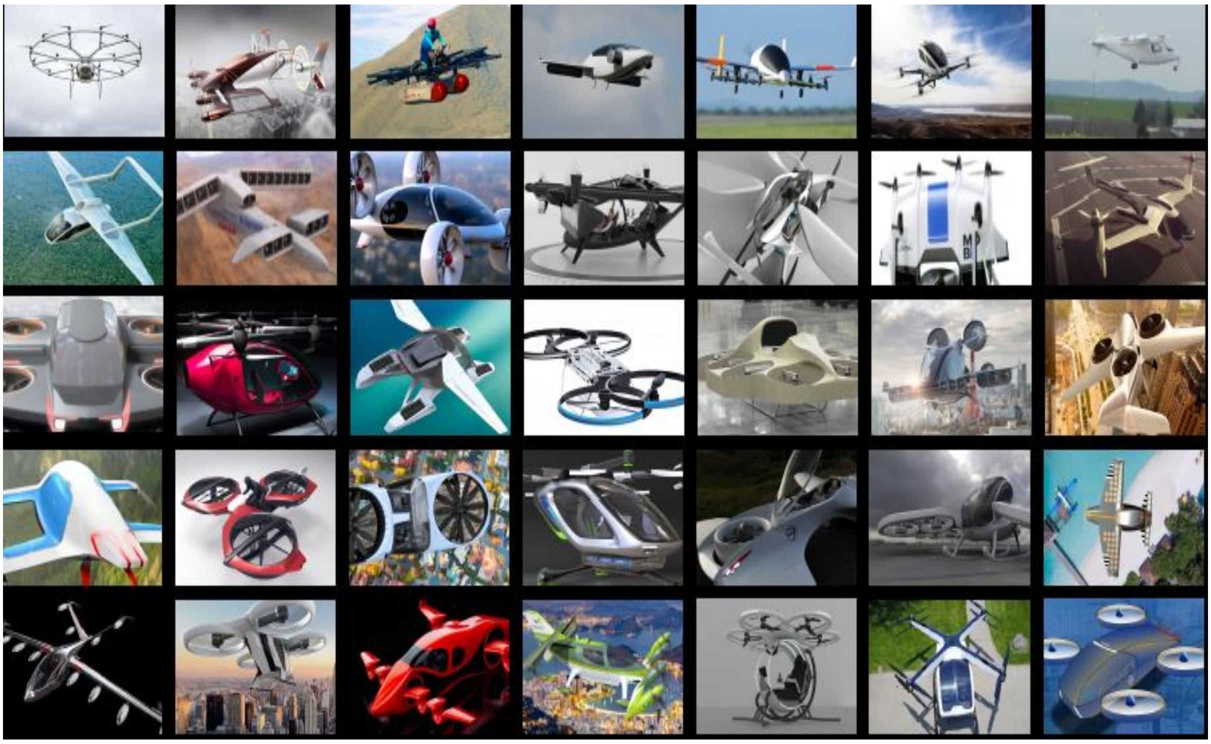

Fig. 4.2 eVTOL Flying and Developing Demonstrators, source: (eVTOL News).

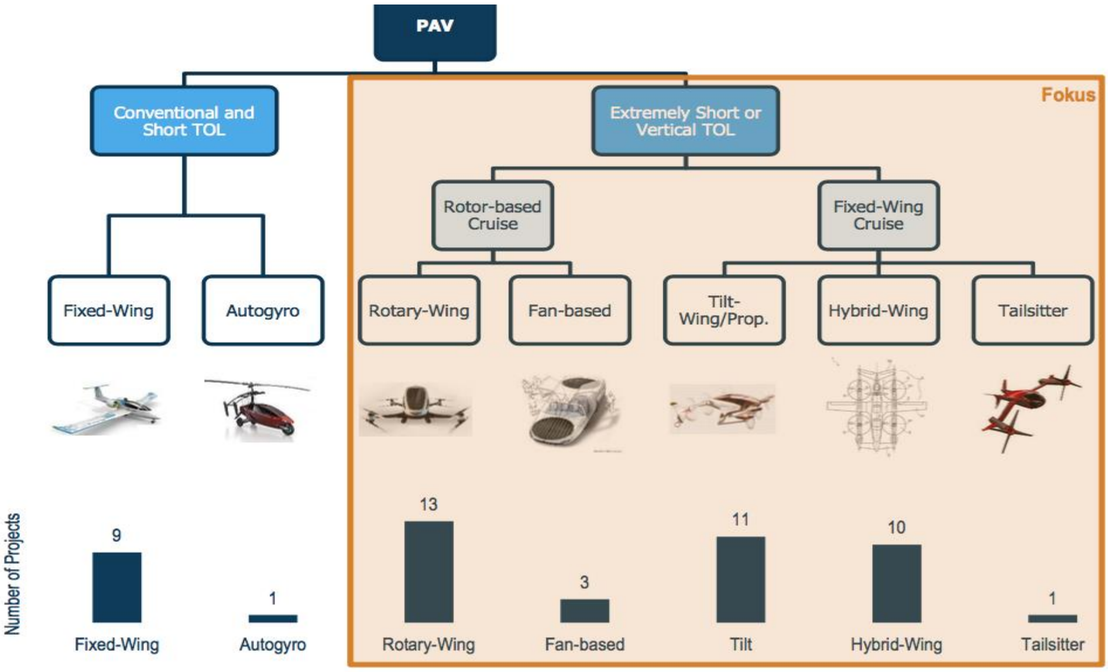

Fig. 4.3 Current Efforts About eVTOL Personal Air Transportation System, source: (eVTOL News).

The number of the companies currently developing eVTOL is increasing significantly, and the number of the eVTOL PAV concepts is more than 300. The complete list of eVTOL air vehicles is provided in Appendix 4. The companies were listed in four subgroups[18]; Tilt Thrust; Lift + Cruise; Wingless; and Hover Bikes/Hover Seats. As we can observe, there is a burgeoning eVTOL aircraft ecosystem, and several companies that are already developing and flying early vehicle prototypes mentioned in Chapter 3.3.

Jaiwon Shin, NASA Associate Administrator for the Aeronautics Research Mission Directorate, recently discussed NASA's optimism around these VTOLs at a White House workshop on Drones and the Future of Aviation[19]. "Air-taxi will combine electric propulsion, autonomy, vertical lift and many other communication and navigation capabilities. Fully autonomous air-taxi...operations, especially in very populated and heavy traffic...areas, I think it's an exciting possibility. So, when we converge all these capabilities… a lot of new chapters in aviation are possible... it's a dawn of a new era in aviation."

The eVTOLs envisioned as serving within a ridesharing network will need to address four primary barriers to commercial feasibility: safety, noise, emissions, and vehicle performance. The two most important technologies to overcome these challenges are Distributed Electric Propulsion (DEP) and autonomous operation technologies (Uber, 2016). Several manufacturers have demonstrated concepts which showcase ways to use DEP technology to achieve different advantages (and penalties), depending on whether the designer favors cruise efficiency, hover power required, vehicle control, design simplicity, payload, or vehicle cost.

Zee.Aero is the largest of these companies with a focus on advancing the required component technologies (i.e., advanced electric motors, motor controllers, batteries, quiet propulsors, etc.). So far, the vehicle concepts publicly disclosed by Zee[20] utilize a lift plus cruise configuration, where the vertical lift and forward thrust are provided by separate, non-articulating propulsors. This type of concept approach results in extra motor weight and aircraft drag since the vertical lift propulsors are ineffective in forward flight. However, the design complexity is low.

Joby Aviation[21] has a different concept approach with their S2 and S4 concepts using a distributed set of tilting prop-rotors (six to twelve depending on the size/capacity of the vehicle) which rotate with the direction of flight so that the propulsors provide both vertical lift and thrust throughout the flight. Since less thrust is required in forward flight than in hover, the

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[18] www.vtol.org, www.eVTOL.news

[19] Jaiwon Shin, NASA Associate Administrator, Aeronautics Research Mission Directorate. https://www.whitehouse.gov/blog/2016/08/02/harnessing-potential-unmanned-aircraft-systems-technology

[20] http://www.bloomberg.com/news/articles/2016-06-09/welcome-to-larry-page-s-secret-flying-car-factories

[21] http://www.jobyaviation.com/

inboard prop-rotor blades fold against the nacelle to ensure the highest propulsive and motor efficiency during cruise. This approach has lower motor weight and aircraft drag but has much higher complexity due to the articulating motor and propulsors.

A^3/Airbus has shown its Vahana[22] concept which, instead of articulating the prop-rotors, rotates a forward and aft wing with four prop-rotors on each of the wings. This is a tiltwing/tilt-tail approach, like the recent NASA GL-10 DEP flight demonstrator[23]. This approach reduces the complexity by only requiring two actuators for the wing rotation and avoids prop-rotor download thrust impingement on the wing during hover and transition, while achieving both vectored thrust and lift.

Many additional companies have other approaches, such as the highly redundant 18 proprotor eVolo Volocopter[24], or the compact eHang 184 quad/octocopter[25]. These multi-copter approaches will be significantly slower (~60 mph) with shorter range capability, as well as lower efficiency since they aren't using wing-borne flight. Other concepts such as the Lilium push to extremely high levels of distribution while coupling the vertical lift in closely with the wing high-lift system.

These are only a few of the key eVTOL manufacturers within the space, but there is no established set of standards around eVTOL. The next challenge beyond the vehicle design is the way in which any designer or the wider ecosystem can push toward satisfying the certification and regulatory procedures required to enable scaled manufacturing.

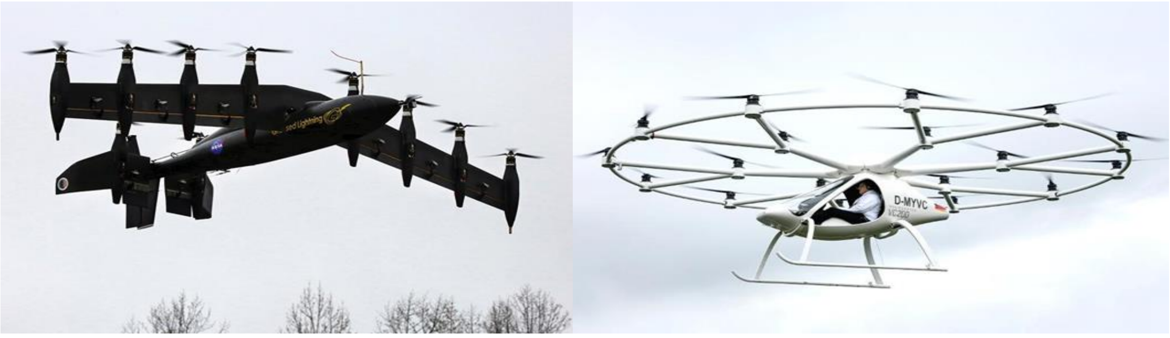

Fig. 4.4 NASA GL-10 Greased Lightning (2014 tethered, 2015 transition) and e-volo Volocopter VC200 (2013 tethered, 2016 manned)

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[22] https://vahana.aero/

[23] http://www.nasa.gov/langley/ten-engine-electric-plane-completes-successful-flight-test

[24] http://www.e-volo.com/index.php/en/

[25] http://www.ehang.com/ehang184

Fig. 4.5 Aurora eVTOL (left) and Aurora XV-24A Lightening Strike (Right), first flight 2018

Fig. 4.6 Lilium Jet (left) first flight 2017 and Airbus Vahana (right)

Many eVTOL start-ups are releasing the video showing the first flight of their full-scale prototype aircrafts in 2017-2018. 2018 has also been the year that legacy car companies have decided to get in on the eVTOL trend. That year has seen Aston Martin, Rolls-Royce and Toyota also announced eVTOL/Flying-car concepts. Porsche is also eyeing the market closely and has hinted that it might be revealing a flying-car/eVTOL of its own soon. The lately developments and the details available at VTOL investor website[26].

Kitty Hawk and Zephyr Airworks have signed an agreement with Air New Zealand to fly the Kitty Hawk Cora on air taxi services across the country. The announcement did not specify when they expect the service to launch. According to the announcement, Kitty Hawk has conducted seven hundred flight tests globally.

German eVTOL manufacturer Volocopter will be performing test flights of its air taxi prototype in Singapore. The tests will be supported by the Singapore Ministry of Transport, the Civil Aviation Authority of Singapore (CAAS) and the Economic Development Board (EDB). The flight tests will culminate in public demo flights. Alongside these flight tests, Volocopter is also setting up a product design and engineering team in Singapore to support further air taxi

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[26] https://www.vtol-investor.com/news/

service expansion in the region. The Volocopter prototypes have preliminary flight permits in Germany and are currently working with EASA to receive commercial flight certification. Things have been quiet on the testing front with Volocopter since its initial public demo tests in Dubai in September 2017. Volocopter partnered with the Roads and Transport Authority of Dubai to work to launch a full-scale version of its air taxi service in the city.

Terrafugia was acquired by Chinese auto group Zhejiang Geely in November 2017. The Transition is fully certified both for road use and flight in the United States. The aptly named aircraft will be able to transition between flight and driving modes within a minute. Early specs of the Transition show flight speeds of 100mph with an in-built boost mode. The aircraft's expected range is around 400 miles. Other similar VTOL/STOL projects are seeking the experimental-aircraft certification which requires a lengthy testing process. Terrafugia managed to bypass this by designing the aircraft in accordance with the FAA's 'light sport aircraft' certification. The TF-2 is targeting the urban air-transport market – with a four-seat configuration and a detachable pod system in which an electric truck will drive the passenger pod to the aircraft and attach it in under two minutes. Like the Transition, the TF-2 will be a piloted hybrid electric aircraft and will be able to utilise all-electric propulsion and autonomous systems when the technology matures.

Toyota expressed interest in the VTOL space when it acquired Cartivator in 2017. Cartivator was a pet-project of 30 engineers designing a combined car/VTOL concept. Toyota fully acquired the company and rebranded the project SkyDrive – the name under which the patent was filed. The Toyota concept is most reminiscent of Audi's and Airbus's joint VTOL project - the Pop. Up. Next. Their two-seater, fully electric car features a separate drone-like aircraft that attaches to the roof of the car to transition the vehicle to flight mode.

Astro entered the VTOL field in May this year when it purchased VTOL manufacturer Passenger Drone for an undisclosed sum. The project was well underway at the time of purchase, but Astro has remained quiet since it bought its way into the VTOL space. Since buying the company, Astro also acquired Kasaero GmbH – an independent German R&D company specializing in lightweight composite aircraft. Texas-headquartered Astro Aerospace has been granted a special flight operations certificate (SFOC) by Transport Canada to conduct test-flights of its autonomous eVTOL in Canadian aerospace. The passenger drone codenamed 'Elroy', is a two-seater multicopter capable of fully autonomous flight. The aircraft is targeting the urban air-transport market, with a top speed of 70km/h and a flight time of 25 minutes. Following this certification, the aircraft has started test flights at Toronto Markham Airport. So far it has performed multiple flight maneuvers, take-offs and landings and avionics testing.

The Texas company Workhorse has begun the formal process to sell its VTOL brand Surefly. The SureFly was the first aircraft project that Workhorse developed. The two-seater hybrid-electric VTOL will retail for $200,000 and is designed to accommodate a pilot and passenger or a pilot and cargo. The aircraft weighs in at 550 pounds and has a top speed of around 70mph. The aircraft entered the type-certification process and is the first VTOL multicopter to start the process. Since Workhorse announced it was undergoing FAA experimental certification in June, it has become clear that it would be one of, if not the first of, the new wave of VTOLs to hit the market.

UK eVTOL start up Vertical Aerospace has released a video showing the first flight of its full-scale prototype aircraft. The company has taken a further 12 test flights. Whilst the exact specs of the aircraft were not disclosed, the company’s website claims the aircraft weighs around 750kg and uses full-electric propulsion to drive its four rotors at a top speed of almost 200mph. Vertical Aerospace hopes to submit the vehicle for full certification with EASA and bring the aircraft to the market by 2022. Whilst many VTOL start-ups are researching and developing new technologies to make their aircraft possible, Vertical Aerospace is taking a grounded approach to air-taxi development, using existing technology to launch the aircraft, and improving it down the line. Unlike many air-taxi projects, Vertical Aerospace is not utilizing autonomous flight for the VTOL, instead opting for a piloted flight system that could be transformed into being autonomous later. The aircraft is targeted at the short-haul flight market – which is one of the biggest contributors to air pollution in the UK – and is offering a carbon-free alternative for city-to-city transport.

Washington based start-up Jetoptera[27] announced that it was starting its VTOL testing campaign – which will see each individual component of the aircraft tested in the lead up to the development of a full-scale production VTOL model. Jetoptera completed its first round of fluidic propulsion tests to judge the viability of the system in July 2018. Jetoptera announced that it was starting the full test campaign of the fluidic propulsion system on a test aircraft of more than 50kg.

In sum, the agendas, presentations and detailed results of these concepts and flights are all archived at the companies’ web sites. This momentum and common interest provide an incredible opportunity for advancement. Regarding some of the demonstrator in figures above have been flying, this time is not another revisiting. The time has been arriving to fruit in the next decade.

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[27] http://www.jetoptera.com/

4.5 Questionnaire and Interviews

This subsection presents results concerning the perception, expectation, and challenges relevant to eVTOL PATS based on the questionnaires and supplemented with results from the interviews.

The survey was preceded by a clear explanation that the objective of the work was to determine the perception, the concern and the expectation of the transportation planning staff. The questionnaires were anonymous 24 professional planning staffs to discourage any feeling of pressure to answer affirmatively. The interviews were confidential, which discouraged fabricating or strengthening of responses per an anticipation of desired answers. Therefore, there is little or no ground to think that there was bias towards answering affirmatively towards the use of indicators. The samples for the survey were only composed of individuals who were involved in two municipalities' transportation planning (Istanbul and Izmir) and Civil Aviation and State Airports Operation Agency in Turkey.

The answers were not compulsory by law, there were no economic incentives to answer, and the questionnaires were not part of the national statistical system. Thus, only volunteers could reply to the survey. Finally, the questions of the questionnaire were short (it took an average of fifteen minutes to answer all of them). The work involved self-administered questionnaires and standardized interviews, as mentioned previously. In this work, the survey included face-to-face questionnaire, and four interviews. The questionnaires addressed staff of the two municipalities' 24 transportation planning experts, collecting 21 answers.

In the first section, the questions were introduced to identify the perception, the opinion, and the level of knowledge of service providers about the emerging air transportation mode. Second, questions were added to understand the air vehicle design parameters in terms of expectations, concerns, main challenges and operation model, namely: (i) "Please rate your highest priority expectations from highest 1 to 7 in case of implementing eVTOL Personal Air Transportation System for urban and regional transportation."; (ii) "Please rate your highest priority concerns from highest 1 to 9 in case of implementing eVTOL Personal Air Transportation System for urban and regional."; and (iii) "Please rate main challenges to enable eVTOL Personal Air Transportation System for urban and regional transportation, from highest 1 to 6.". Nevertheless, all questionnaires (and standardized interviews) shared the same structure composed by 7 questions (see Annex 1 – Questionnaire):

The questionnaire inquired about the opinion of transportation planning staff and tried to understand the perception based on rating (using the scale; 1 – Strongly Disagree, 2 – Somewhat disagree, 3 – Neither Agree nor Disagree, 4 – Somewhat Agree, 5 – Strongly Agree) the following seven activities: (1) I would be comfortable with flying in a self-piloting personal air vehicle; (2) I would be comfortable with flying in an aircraft flown by a fully autonomous pilot; (3) I would prefer on demand air transportation rather than a scheduled airline; (4) I would be comfortable with flying in air taxi; (5) I would be comfortable with flying in a single pilot monitored mass air vehicle; (6) Using personal air vehicle for transportation is likely to help relief urban congestion; and last, (7) eVTOL Personal Air Transportation System for urban and regional transportation can contribute business profit, traffic congestion relief, and daily life quality.

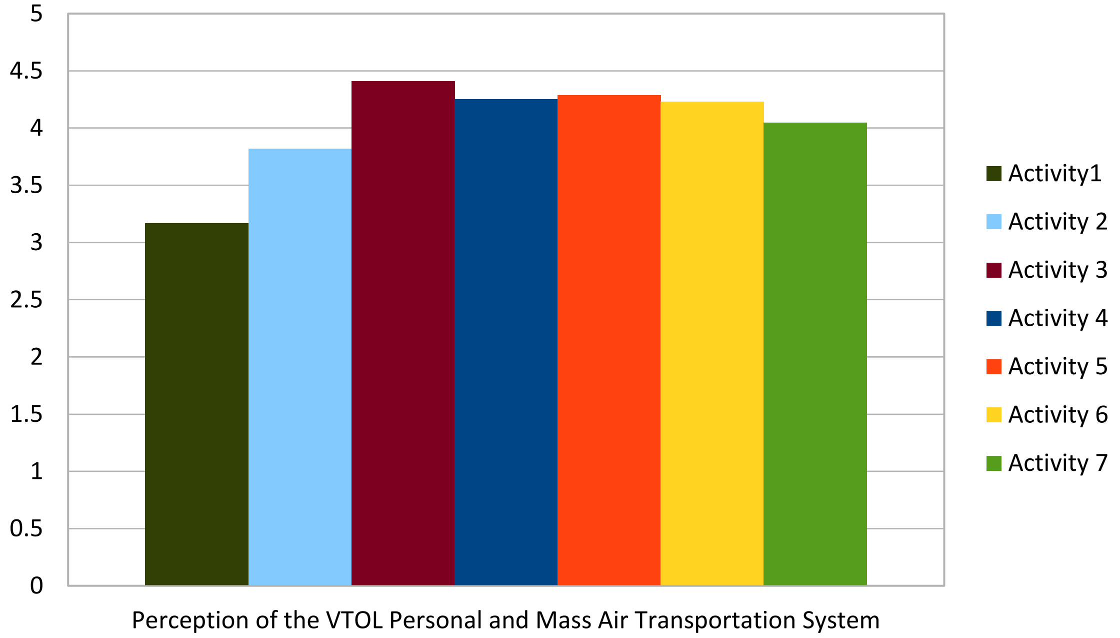


Fig. 4.7 Perception of eVTOL PATS

Fig. 4.7 reveals that the overall perception of the eVTOL PATS is significantly positive. Only, they are not clear about self-piloting. They prefer on-demand air taxi transportation mode. They also think that eVTOL PATS is likely to help congestion and to contribute business and daily life quality.

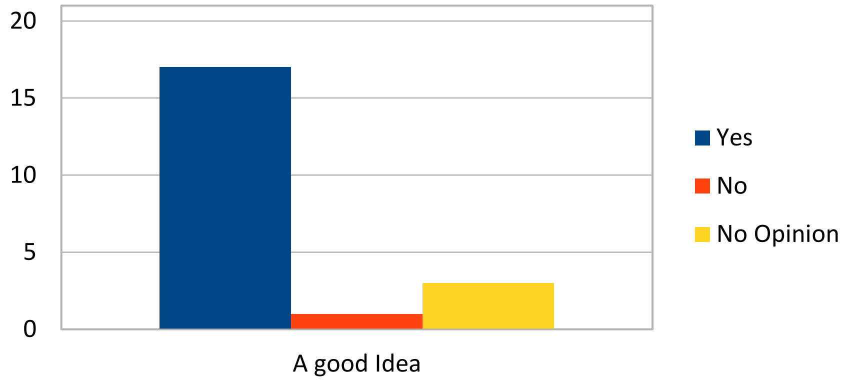


Fig. 4.8 The Support for eVTOL PATS

Fig. 4.8 reveals that the support for eVTOL PATS is significantly high.

The questionnaire inquired about highest priority expectations rating from highest 1 to 7 in case of implementing eVTOL Personal Air Transportation System for urban and regional transportation.

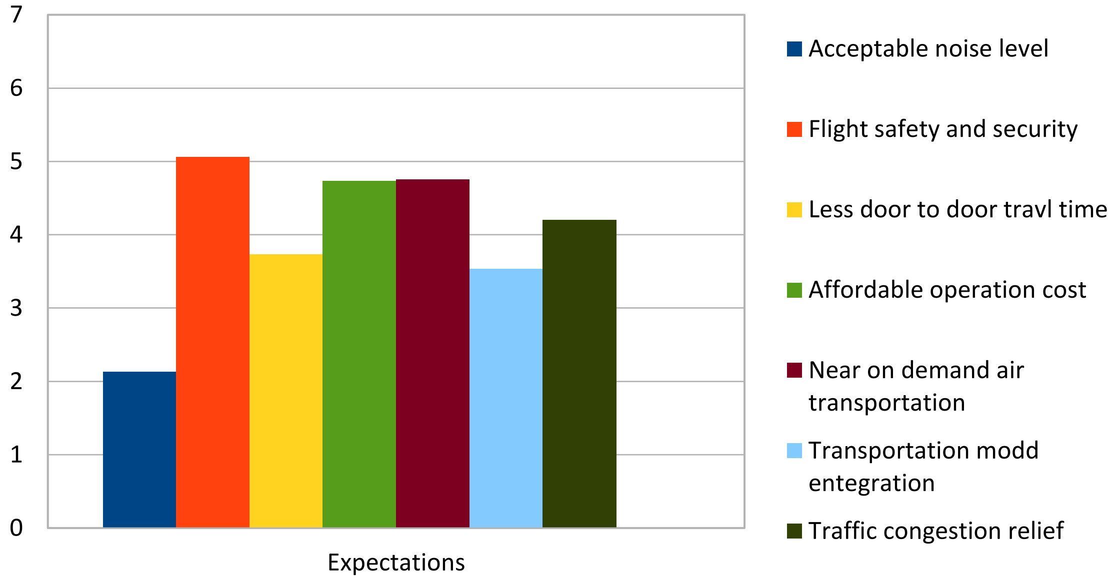


Fig. 4.9 Expectations from eVTOL PATS

Fig. 4.9 reveals that they expect a safe, on-demand and cost-effective affordable eVTOL PATS which should help to relief congestion and to lessen travel time while integrating existing modes. Surprisingly they put the noise in the last.

The questionnaire asked to rate concerns from highest 1 to 9 in case of implementing eVTOL Personal Air Transportation System for urban and regional transportation.

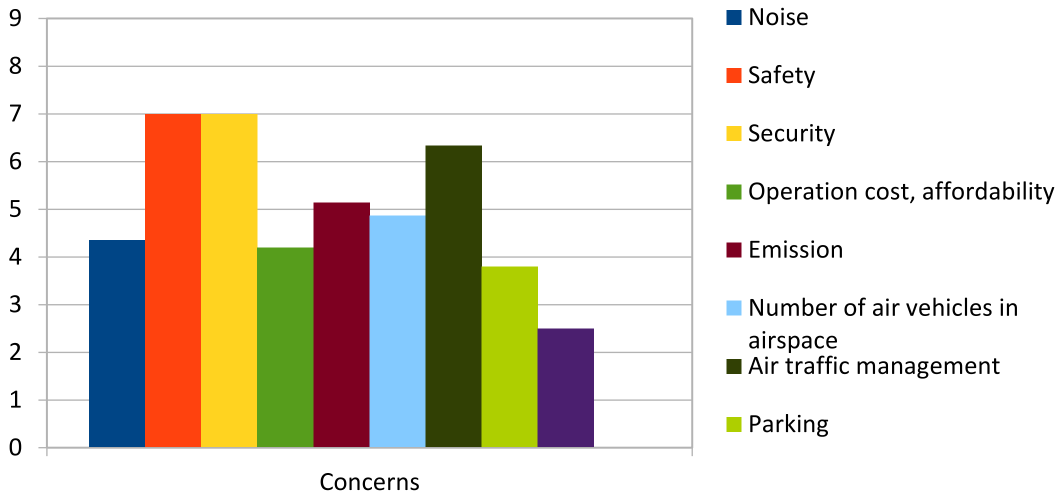


Fig. 4.10 Concerns About eVTOL PATS

Fig. 4.10 reveals that they concern safety and security the most, and air traffic and the number of air vehicles in airspace are also a matter of fact to handle. Results also show that environmental impacts, namely emission and noise, can influence the decision making. The questionnaire also asked to rate main challenges to enable eVTOL Personal Air Transportation System for urban and regional transportation. The flight safety and security was the most important challenge. The safety issue was interestingly coming up in all straight away. The air traffic management was the second. Overall, the perception of eVTOL PATS is strongly positive and the support for the concept was significantly high though they were not well informed.

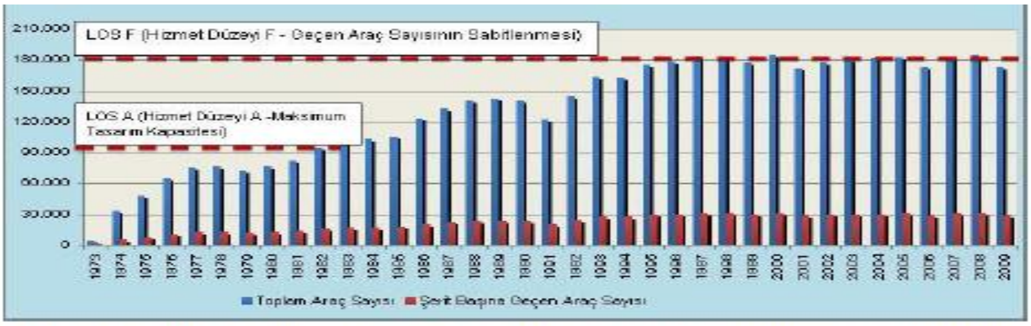
The survey also included standardized interviews, as mentioned previously. In fact, the four face-to-face interviews were conducted not only to collect standardized data, but also to gather other information expressed in the interviews. The interviews targeted Civil Aviation Agency general manager, State Airports Operation Agency deputy manager, Izmir Municipality transportation department manager and one expert from Istanbul Municipality transportation department from March 2014 to May 2016. The interviews lasted on average half an hour. The interviews were important not only to collect the same information as the questionnaires, but also to give space for new issues to arise during the conversation and to reach saturation of information. Interviews with regulators may also help explain the need to be well informed and trained about the emerging air transportation mode even though they are the members at the top decision making about air transportation. The security and safety issue were interestingly coming up straight away. As mentioned previously, the perception of eVTOL PATS is strongly positive.

4.6 Case Study

This subsection provides some data about Istanbul’s current transportation issues and tries to visualize the potential benefit of introducing eVTOL PATS in terms of travel time saving value as a rough estimation in monetary, not scientific, based on average transportation statistic data. Why did I select Istanbul as a case study? The demand would be expected to grow in the future with both population and income as well as in response to increasing congestion. Money and gas are lost every year because of congestion. As we can see in the Figure 1.2 in chapter one, Istanbul has the most congestion level during peak period and free conditions.

Another important point is that the number of drivers using bridges is almost double the daily design capacity of bridges in Istanbul and the main roads are being used overcapacity as we can see in the figures 4.12 and 4.13 below. Istanbul is a multicenter metropole and end-to-end city distance is more than 100 kms. According to Istanbul Municipality Master Plan, the number of travelers who use car and public transportation mode is:16.462.916 travelers (%47 of total); 10.371.637 travelers by public and 6.091.279 travelers by car (%32 public, %15 car). Average daily car travel time is 40 min (approximately 15 min delay due to congestion based on the Figure 1.2), and average public transportation travel time is 66 min (approximately 26 min delay due to congestion based on Figure 1.2). Daily car number in traffic is 3.879.796 cars (6.091.279 travelers / 1,57 travelers per car).

Fig. 4.11 The Usage of Road Capacity in Istanbul in 2009; Black Region is Overcapacity, source: (Istanbul Municipality Transportation Master Plan).



ekil 12.6.4 Boğaziçi Köprüsünden Geçen Günlük Araçların Mevcut Durumda ve Maksimum Tasarım Kapasitesindeki Hizmet Düzeyi Değerleri

kil 12.6.5 FSM Köprüsünden Geçen Günlük Araçların Mevcut Durumda ve Maksimum Tasarım Kapasitesindeki Hizmet Düzeyi Değerleri

Fig. 4.12 The Daily Number of Driver Using Bridges (Daily design capacity; for Boğaziçi Bridge-90000 and for Fatih Sultan Mehmet Bridge-120000), source: (Istanbul Municipality Transportation Master Plan).

Table 4.1 Transportation Projection in Istanbul, source: (Istanbul Municipality Transportation Master Plan).

	Year 2006	Year 2009	Year 2023
Population	12.009.000	13.393.665	17.217.056
Gross Domestic Production per citizen ($)	4.955	9.783	20.884
Travel Number (number of people in each travel including walking)	20.924.133	24.271.995	**35.027.482**
Number of cars (Registered in Istanbul)	1.351.782	1.841.446	4.335.882
Mobility (Travel number/population)	1.74	1.81	2.03

After emphasizing these relevant transportation data, we will try to visualize the potential benefit in terms of travel time saving value and reducing travel cost value in a rough monetary estimation assuming some average statistic.

It was assumed that average travel cost $1,9 per mile in 2023 based on average speed is 33 miles per hr. and average travel cost per hr. is $62,7 per hr. (average speed is 33 miles per hr. * average travel cost $1,9 per mile in 2023). The value of travel time is $10,04 (dividing gross domestic production per citizen $20.884 by annual working hours 2080 hrs.) Because time saved from travel could be dedicated to production, yielding a monetary benefit to both travelers and their employers. It is also argued that the result of reduction is not linear and a 5% reduction in traffic volumes leads to 10-30% increase in average vehicle speeds. We assumed that each 5% reduction in traffic volume leads to 20% increase in average vehicle speed and we reduced car traffic volume enough to relieve congestion by shifting travelers to eVTOL PATS. After these assumptions, we will try to estimate the value of travel time saving and the value of travel cost reduction:

- The value of travel time saving; total daily saved travel time is 361.031.747 min and 6.017.196 hrs. (269.662.562 min public (10.371.637 travelers*26 min delay) plus 91.369.185 min car (6.091.279 travelers*15 min delay), and the value of travel time saving is $ 60.412.648 (6.017.196 hr.*$10.04) daily and the value of travel time saving is $ 22.050.616.100 ($60.412.648*365 days) annually. Travelers who will use eVTOL PATS will also travel in less time, lower than average 25 min per car. If we assume that they travel average in 10 min, then this means15 min less travel per travelers and extra travel time saving.
- The value of reducing travel costs; if we do not expand transportation modes, the number of cars in the traffic is 3.879.796 cars, and total travel time on the traffic is 2.586.531 hrs. (3.879.796 cars * 40 min per car) and total travel cost is $59.194.055.100 (2.586.531 hrs.*$62,7 per hr.*365 days). If we reduce car traffic volume in the traffic by introducing on-demand eVTOL PATS (to relive the congestion we need to decrease 1.163.939 cars then, 2.715.857 cars will be in the traffic), total travel time on the traffic is 1.131.607 hrs. (2.715.857 cars*25min per car (15 min delay due to congestion eliminated from 40 min)) and total travel cost is $25.897.392.100 (1.131.607 hrs.*$62,7 per hr.*365 days). The difference is $33.296.663.000 ($59.194.055.100-$25.897.392.100) saving by reducing travel cost.

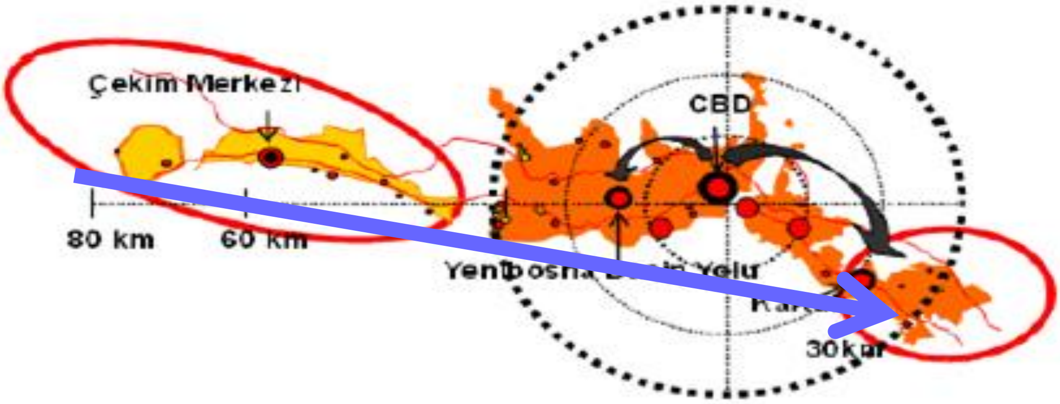


Fig. 4.13 Potential Benefit of eVTOL PATS in Istanbul in case of end-to-end City Urban Air Transportation (With Current Modes; min 2 hrs. by Car, with eVTOL Air Transportation mode; max 00:30 hr.)

In sum, big cities like Istanbul offer high-density eVTOL PATS market where travel time is money and suffering. The value of travel time saving, and travel cost reducing is noticeable and makes sense. With four-or-five passenger air vehicles that are 2-5 times faster than single-commuter cars crawling in the traffic, the vision might be productive and affordable.

5. Assessment of eVTOL Personal Air Transportation System

This chapter discusses the research questions concerning the resource network and the stakeholders based on previous eVTOL resources analysis and the survey results. The first subsection provides the perception of the stakeholders, namely potential users, service providers and regulator, concerning eVTOL PATS. The next subsection tries to assess the potential benefits of implementing eVTOL PATS. The third subsection tries to point the key enabling technologies in which considerable progress will have to take place regarding flying prototypes. The last and fourth subsection tries to assess the major challenges to enable eVTOL PATS.

5.1 The Perception of The Stakeholders

As we mentioned before in myCopter project review in subsection 4.1.2, introducing a new mode into the transport system is not possible without a certain extent of acceptance by its users and citizens. Governing transport and traffic are a very complex issue that includes many different socio-technological aspects. Transport planning must mediate between various influences such as economic interest, environmental protection, land-use planning issues, human health, safety, or social equality. It must take into consideration technical innovation, quality standards, habits, standards of living, ideological visions, and other factors. Therefore, like any innovations, eVTOL PATS must be adapted by the users and accepted by the public. Against this background, it is of utmost importance to understand the perspectives and expectations of potential users and/or citizens when carrying out a technology assessment for eVTOL PATS. However, executing a user survey for this purpose was beyond the scope and power of this study. Thus, this subsection tries to understand the perspectives and expectations of potential users based on myCopter project and Airbus focus group studies, and of service providers and regulator based on our questionnaire and interviews.

The myCopter project describes the empirical findings of user perceptions and expectations related to the introduction of eVTOL PAVs. To get a first feeling about the attitudes of potential users the KIT partners conducted a one-day “explorative workshop” in May 2012 with 11 students from the technical university on “new dimensions of urban traffic”. The focus group discussion was structured in a more general first part (mobility of the future) followed by a second part confronting the participants with the idea of using the third dimension for individual air travel. In a last third section the attendees were asked to develop their own PAV vision and to think about requirements for such a PATS. The output of this workshop was that the participants did not question the technical feasibility of eVTOL PAVs in general and confirmed the main issues found by the consortium such as noise, automation, parking, availability of this transportation (weather). Additional aspects were mentioned as well such as the idea to also have a usability of the vehicle “on the ground”, which would allow for flying just above street level and be able to “swim” with the car traffic. Generally, doubts about the benefits of PAVs, even after a lively debate about potential advantages, remained and a major part of the participants judged the idea as “Over-Engineering”. In their opinion the level of automation needed to have PAVs safely operating in a city environment would already solve the congestions problems on the ground if implemented in today’s cars.

Later, three focus groups were prepared in three different countries (Germany, Switzerland, and the United Kingdom) and conducted in November 2013 and January 2014 and had the aim to explore the perceptions and expectations which people have regarding this new technology. Key aspects of the discussion were the participants’ feelings and impressions related to the existence and availability of PAVs in their local environment and the issues and challenges associated with this travel option. The focus group discussions were divided into two main parts. The first part was about the current local traffic situation and how people experience their way of traveling in the cities, especially their daily commute. The second part of the discussion started with a small narrative imagining the existence of small personal air vehicles available for personal commuting. This narrative was used to familiarize people with eVTOL PAVs as an additional transportation option and make them think about the concept of flying vehicles. In a first step of this second part people got time to get acquainted with this idea and to get answers to their questions regarding the characteristics and capabilities of eVTOL PAVs and about the design and structure of the whole eVTOL PATS. In a second step people were then able to connect challenges and issues they found with different eVTOL PAV design options (business concepts, level of autonomies). The discussions brought out very lively and critical perceptions; potential challenges and solutions were voiced by the participants. A detailed review of the myCopter study was provided in previous chapter.

As a general observation from all three focus groups one could state that the major issues regarding eVTOL PAVs that were raised are safety problems (on the ground and in the air for the PAV itself), environmental issues (visual impacts, noise), challenges with respect to infrastructure (city architecture, integration into existing ground traffic, maintenance & service), organizational and business models, level of autonomy, system design & operational aspects, privacy & legal issues, as well as thoughts about user groups and areas of application. The participants brought in a lot of personal opinions, comments, and valuable criticism regarding the PAV concepts and future eVTOL PATS. They also made several suggestions regarding future design options and operational models for both personal air vehicles and transportation systems accommodating them. However, it is impossible to draw a single, generalized conclusion from observations. The picture is rather mixed in various ways. People switched between two perspectives – that of the potential user who sees attractive new transportation options and that more outside perspective of residents or people on the street who might be affected by the potential impacts of PAVs. Most participants did not express clear preferences regarding fully automated or self-piloting, ownership models and loss of control debate.

Based on those findings, data for European and North American cities were gathered and analyzed to assess the number of eVTOL PAVs (and the related infrastructure needs) required to substitute a share of car commuter traffic by eVTOL PAV that is enough to significantly reduce urban congestion and contribute to the project’s overall goal.

These data, supported by more detailed data from various German cities, allow for some (preliminary) conclusions on eVTOL PATS requirements regarding eVTOL PAV design (range, speed, …) as well as well as plausible mission scenarios and infrastructure requirements:

- To have measurable impact on traffic congestion in metro areas, eVTOL PATS would have to substitute a substantial share of car traffic during peak hour(s). Experts consulted by ITAS estimated that a net substitution of 10 % of recent car traffic could have this effect, if this reduction in travel times does not induce new traffic or shifts from other transportation modes (like public transportation or cycling)
- The clear majority (ca. 90 %) of commuting trips to work is shorter than 25 km and does not take longer than 30 minutes.
- Peak hour delays in most European cities are no longer than 15 min, in very rare case up to 30 min (based on the assumption of 30 min travel time to work under free flow conditions)
- Key factors for modal choice are availability, cost, reliability, and door-to-door travel times.
- Door-to-door travel times for eVTOL PATS will heavily depend both on the eVTOL PAV concept (pre- and post-trip routines, level of autonomy, speed) and eVTOL PATS infrastructures, especially within cities.
- Weather data indicate that availability / reliability may be further limiting factors.

The next contributive study is based on Airbus Research by the Boston Consulting Group. The Airbus research describes the empirical findings of potential user perceptions and expectations related to urban air mobility. Three focus groups were prepared in three different countries (Germany, US, and China) and had the aim to explore the perceptions and expectations which people have regarding this new technology and to discover motivational needs and levers for urban air mobility as shown in Figure 5.1.

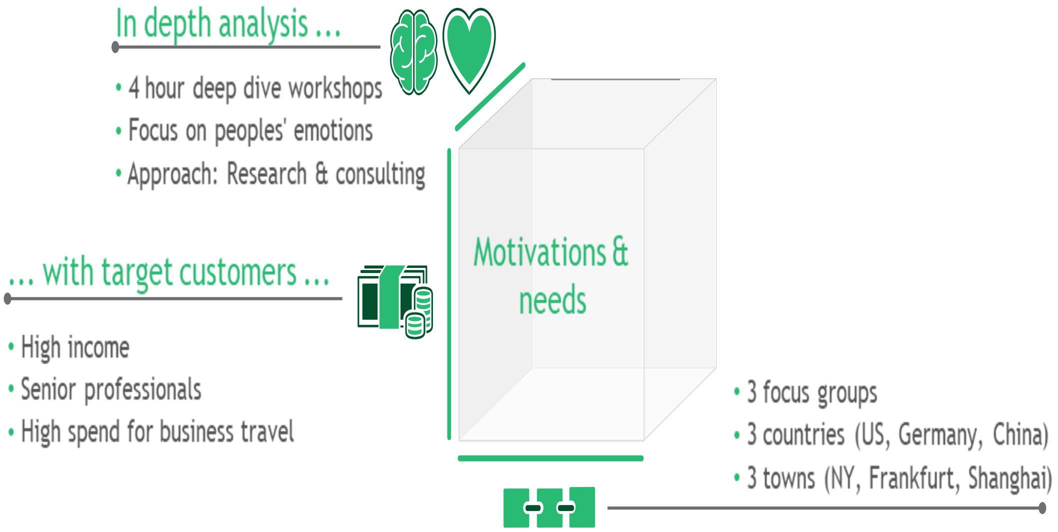


Fig. 5.1 Airbus Depth Analysis with Target Customer in Three Regions, source: Boston Consulting Group (2017).

As a general observation from all three focus groups, one could state that Airbus urban air mobility scenarios was with very positive spontaneous feedback. In summary it can be said that all three focus group discussions were very lively and insightful with good grades. The participants brought in a lot of personal opinions, comments, and valuable criticism regarding urban air mobility. They also made several suggestions regarding clear advantages such as reduced travel time, higher predictability, easily accessible with individual destination choice, secure technology, friendly environment, and questions instead of concerns (50 km reach sounds good when will it be 100 km? Are 6-8 hubs per city enough to reach it in max. 10 minutes? Can I prebook?). The question was not “do I want it?” but “when will I get it?”.

One of the main aims in the study was to understand how different archetypes see emerging eVTOL air mobility advantages. Understanding psychological predisposition will be key to tailoring the urban air mobility. Figure 5.2 provides value proposition for this purpose.

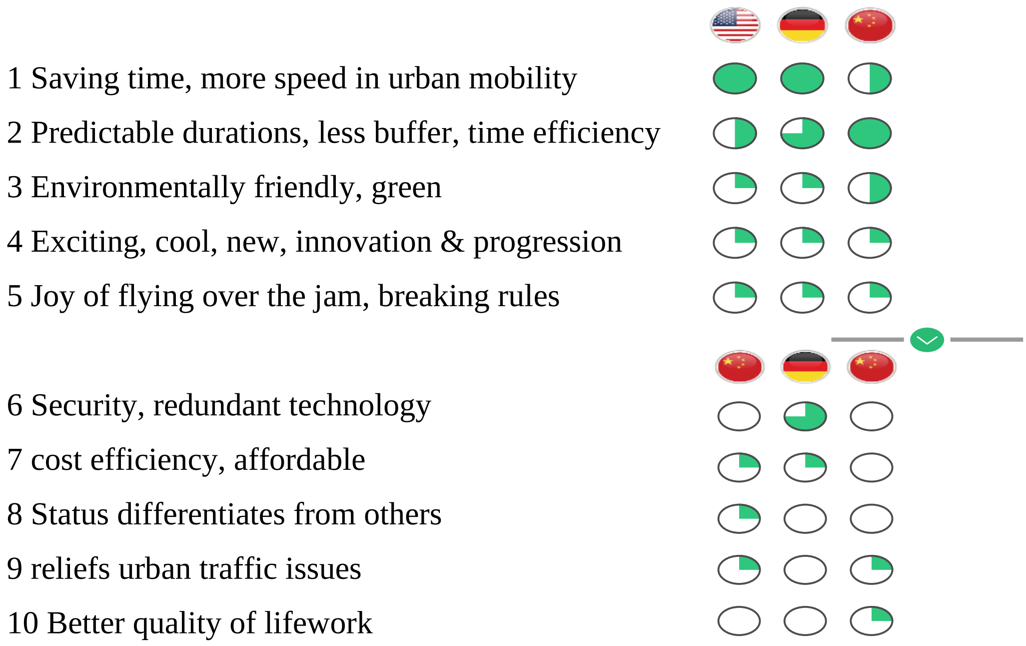


Fig. 5.2 Value Proposition, source: Boston Consulting Group (2017).

Figure 5.2 reveals that promises on saving time or winning relative time in terms of predictable duration and less buffer are very attractive. Green also helps positioning. But there are also highly emotional benefits that should be addressed too.

The urban air mobility use cases were also discussed in the focus groups. The Airbus study describes that airport transfer is first. The second is end-to-end city transfer and the third one is reaching offsite destinations. The fourth one is daily commuting to work. Top use cases also have high business impact.

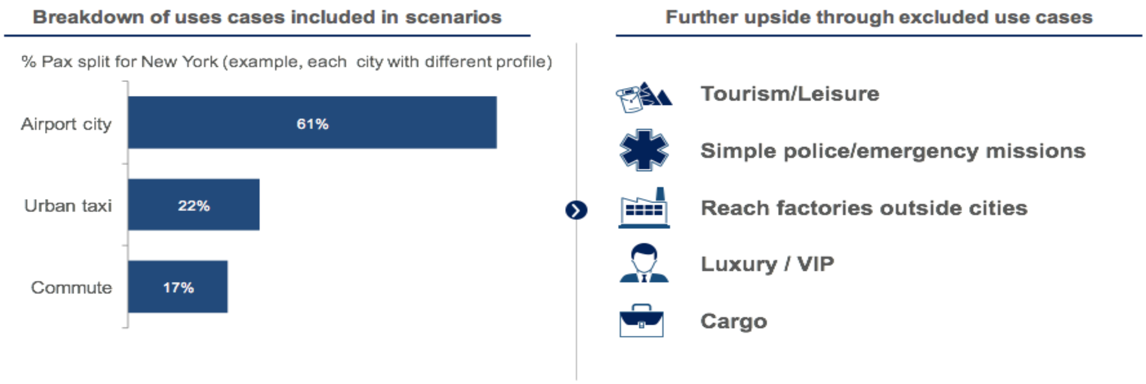


Fig. 5.3 Uses cases in New York City, source: Boston Consulting Group (2017).

The figure 5.3 reveals that airport transfers could be more than half the trips based on today's mobility pattern in New York city. The study also says that 80% of world's airports are within 40 km range and 90% of world's airports are within 50km range in figure 5.4 below.

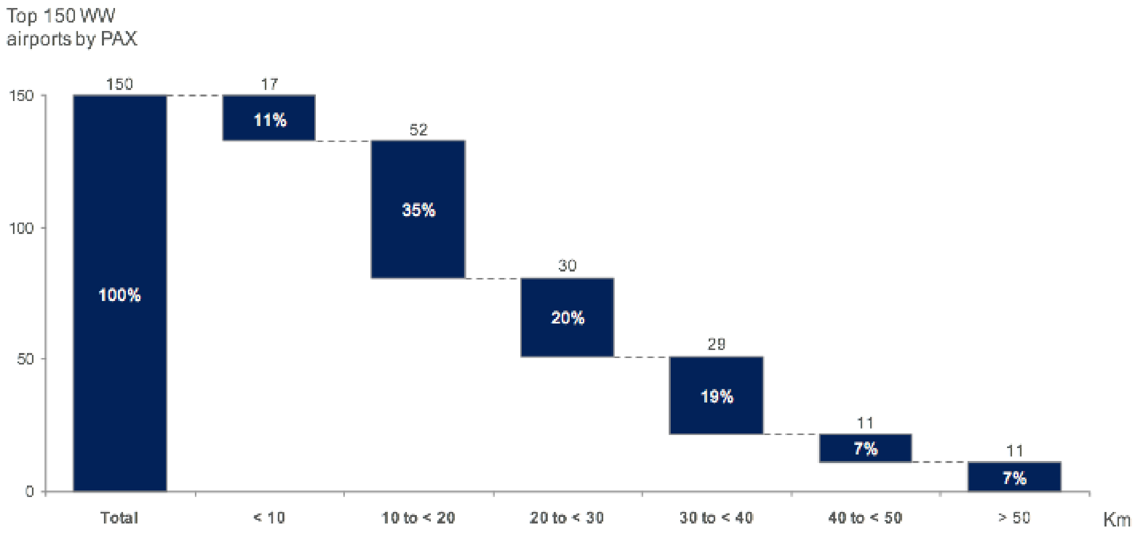


Fig. 5.4 Distribution of Top WW Airports by Distance from Nearest Big City Center, source: Boston Consulting Group (2017).

The participants in focus groups also argued pricing and seat logic to imply business potential of urban air mobility. The benchmark for pricing was taxi and for seat logic was car. Timing assumption was cutting travel hour in half. In focus group discussion, 2 Pax sharing was considered appropriate at the beginning and 4 Pax sharing could be the future standard and acceptable. 6 Pax and more results were in lacking credibility. With a time-reduction in half, taxi prices of 2 times in USA, 2.5 times in Germany and 6 times in China were accepted. “Air taxi” is what it should be called.

Another important source is the survey and the interviews that we have presented in detail in subsection 4.5 and intended to determine the perception, the concern and the expectation of the transportation planning staff and the regulator. The samples for the survey were only composed of individuals who were involved in two municipalities’ transportation planning departments (Istanbul and Izmir). The survey also included standardized interviews, as mentioned previously. The interviews targeted Civil Aviation Agency general manager, State Airport Operation Agency deputy manager, Izmir Municipality transportation department manager and one expert from Istanbul Municipality transportation planning department. The interviews were important not only to collect the same information as the questionnaires, but also to give space for new issues to arise during the conversation and to reach saturation of information.

We will provide a general observation here instead of discussing each question in detail again. As a general observation from all questionnaire and interviews one could state that the overall perception of the eVTOL PATS is significantly positive. Only, they are not clear about self-piloting. They prefer on-demand air taxi transportation mode. They also think that eVTOL PATS is likely to help congestion and to contribute business and daily life quality. The support for eVTOL PATS is significantly high. They expect a safe, on-demand and cost-effective affordable eVTOL PATS which should help to relief congestion and to lessen travel time while integrating existing transportation modes. Surprisingly they put the noise in the last. They concern safety and security the most, and air traffic and the number of air vehicles in airspace are also a matter of fact to handle. Results also show that environmental impacts, namely emission and noise, can influence the decision making. Flight safety and security is seen as the most important challenge. The safety issue was coming up in all straight away.

Overall, the perception of eVTOL PATS is strongly positive and the support for the concept is significantly high though they were not well informed. Interviews with regulators may also help explain the need to be well informed and trained about the emerging air transportation mode even though they are at the top decision making about air transportation.

On the other side, despite a large influx of autonomous aircraft development in 2017, most people are still unwilling to fly in an unmanned/pilotless aircraft. Helicopter Investor asked more than 1,200 US citizens whether they would be willing to fly in an unmanned aircraft and 84.8% said NO, with only 15.2% willing to take to the air.[29] This may explain a need for transformation period from single-pilot monitor to full autonomous air vehicles. The aircraft we have seen so far are designed with automation capabilities but will initially start flying passengers with a pilot.

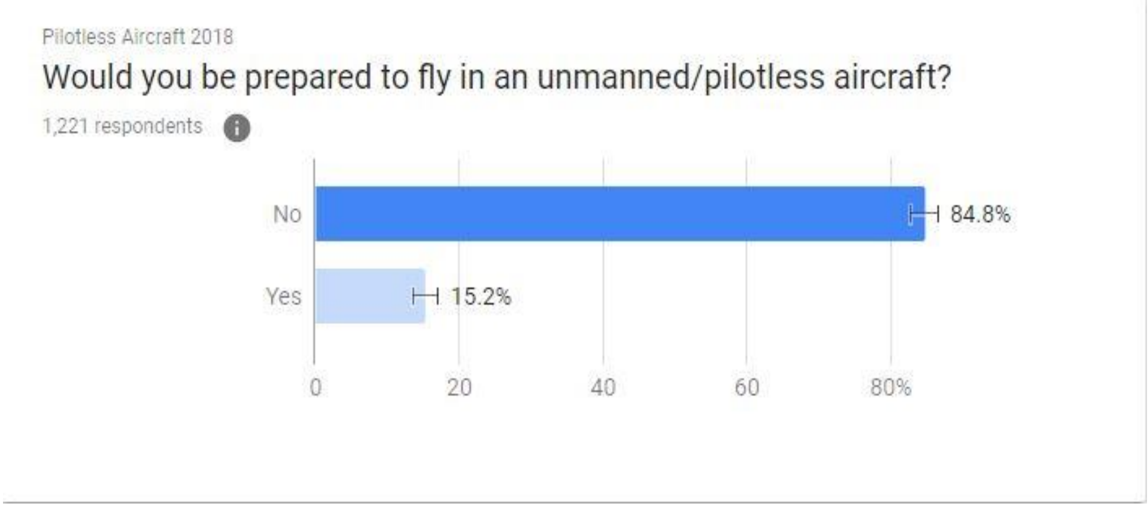


Fig. 5.5 Willing to Fly Pilotless Aircraft, source: www.vtol-investor.com

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[29] https://www.vtol-investor.com/blog/2018/5/21/almost-85-of-people-will-not-fly-in-an-unmanned-aircraft

Perhaps unsurprisingly, millennials are more willing than their elders to fly in unmanned aircraft, but not by much. Approximately 20% of the 18-24 and 25-34 age range would be prepared to fly in an unmanned aircraft. This drops to 14% for the 35-44 age range and 16.3% for the 45-54 range. According to the results, men are more than twice as likely than women to fly autonomously. 136 of the 668 men questioned said they would fly in a pilotless aircraft whereas less than 10% – only 55 of the 567 women – said they would.

The public's unwillingness to fly unmanned is, perhaps, something that OEMs pursuing an autonomous urban flight aircraft need to address. The publics unwillingness is perhaps understandable as the general populace is still unwilling to ride in driverless cars. Whilst a whole host of new cars feature autonomous options, and countries like the UK looking to bring driverless cars on the road by 2021, most people are still unwilling to ride in them. Image problem? Pilotless aircraft are linked to drones, with some of these new autonomous aircraft being designed by drone manufacturers, such as the new Ehang184. Outside of tech-focused publications, the times we generally hear most news about drones is when they crash. However, this is generally down to human error on the part of the person piloting the aircraft from the ground. While these drones are not autonomous, they are linked via namesake, with the Ehang 184 being dubbed a "passenger drone" by the manufacturer itself.

5.2 Is There a Significant Potential Benefit of Developing eVTOL Personal Air Transportation System?

This subsection tries to determine the positive impacts, in other terms the potential benefits, regarding stakeholders' expectations and the critical factors such as travel time, time saving, reliability, efficient door-to-door block speed and daily radius of reach in evaluating the benefits of the emerging air transportation mode.

As we have mentioned before, understanding the driving evolutionary forces permits an understanding of the pressures and where they may lead. We face serious challenges in areas of efficiency, accessibility, and affordability of intracity as well as intercity transportation. Daily commuting is reaching their limits during peak travel times, which results in environmental issues due to wasted fuel and loss of time and money. As the highway system has matured and filled, beyond capacities in many places, the excess costs in time and energy expended in ground travel continues to rise. In 2013, traffic congestion wasted the U.S. economy of $124 billion (Bruce, 2017). The average trip time is increasing due to suburban expansion and increased congestion, causing non-trivial changes in family life as travelers attempt to utilize nontraditional time slots, or suffer long nonproductive commutes. For example, urban transport which accounts for a significant part of total mobility and for even greater proportion of its negative consequences is related to a wide range of unsolved problems and challenges that need to be tackled to guarantee a high quality of life in cities. City population faces increasing emissions of pollutants and noise, as well as congestion and reduced accessibility. Experts predict that ground travel delays due to surface gridlock will get substantially worse in the next 20 years. Even when and if all cars become electric vehicles, the gridlock will remain. The rate of increase in the number of cars is likely to continue to outpace the capacity growth of our highways, whose average cost is $20M per mile (Oak Ridge National Laboratory, 2007). The need is great for technology-enabled solutions for personal mobility that are affordable, efficient, clean, and safe. The third wave of aeronautics could bring about great new capabilities for society that would bring aviation into a new age of being relevant in most people's daily lives and could provide personal mobility solutions.

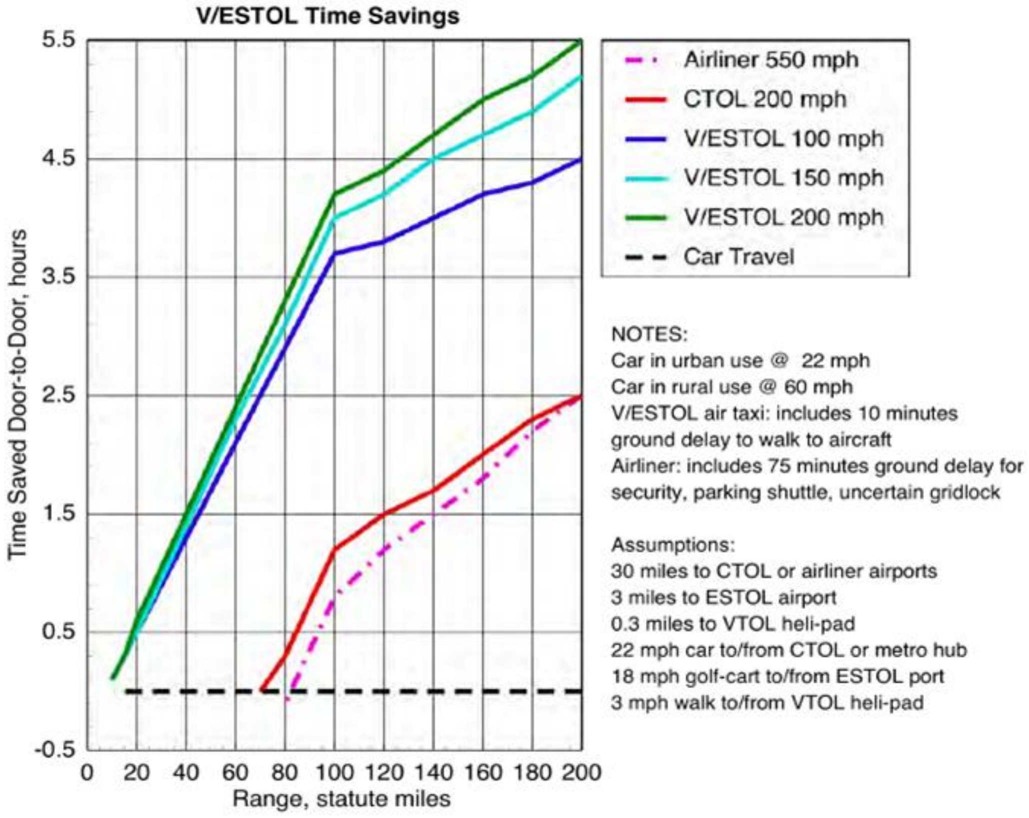
In this century, aviation has the potential to enable expanded air accessibility for more in our society. Current air travelers are predominantly served by large airlines using the traditional hub-and-spoke system. While this system is an efficient method in many ways and has increased its capability in recent years, air travelers are increasingly dissatisfied with the current air transportation system as it gradually becomes plagued by delays, long waits, and built-in inefficiencies both in the air and on the terminal areas (De Laurentis, 2002). In terms of door-to-door passenger time, comfort, convenience and satisfaction, the hub and spoke system is extremely ineffective for especially short to mid-range trips where the bulk of trips are taken (De Laurentis, 2002). A current study being conducted by Volpe in cooperation with NASA shows that 29% of the total door to door trip time is the actual gate to gate time of the airliner for trips under 500 miles. The rest are terminal time 33%, access egress time 18%, and wait time 20% (Driving many miles in congestion to reach a hub, arriving early for ticketing, security, baggage checks, connection through other hubs, driving again to reach destination, etc.) (Moore, 2003). Even more, aviation might go through catastrophic events due to the terrorist attacks, which rises an important issue. Currently with a weather delay at just one of the major hubs, the entire system experiences significant setbacks. While centralized systems are efficient, they do not provide a robust system solution. This robustness is essential to prevent a catastrophic loss in mobility that would yield disastrous effects on the economy. The current system is designed more for the benefit of the commercial airliner. The emergence of CTOL Light Sport Aircraft (LSAs) and Very Light Jets (VLJs) have both failed to produce the hoped-for transformation of aviation (Brien, 2010). Despite expensive advertising hype for beautiful new small jets and innovative new LSAs, the annual sales of these aircraft number in the dozens instead of in the thousands. No matter how glitzy, these aircraft are not able to avoid the time wasted on ground travel to and from CTOL airports. In contrast, on-demand eVTOL air transportation mode is the distant vision of aviation being designed around the needs of the travelling public. In our current built environment, the only feasible way achieves such reductions is by bringing forth a new class of small, green, quiet, safe, and high speed on demand eVTOL air transportation mode.

Nevertheless, there is both a need and an opportunity to include in the transportation mix eVTOL Personal Air Transportation System. While not solution to all travel, eVTOL Personal Air Transportation System is envisioned as the next logical step in the natural progression in the history of disruptive transportation system innovations and would provide, percentage wise, the same increase in speed as the auto provided over the horse and a better new choice up to 500-600 miles where airlines and automobiles provide poor block speed. The vision has been to enable people and goods everywhere to have the convenience of on-demand point-to-point travel, anywhere, anytime in less travel time, through a network of pocket airports and vertiports.

The operational benefits of an ability to take off and landing vertically are self-evident. Conventional aircraft must operate from a relatively small number of airports with long paved runways where is usually crowded causing delays in the air and on the ground. Freeing airplane operations from long runways has been a dream of aircraft designers and users. eVTOL air vehicles have advantages over helicopters and fix-wing aircrafts. eVTOL air vehicles will have higher cruise speed, lower noise, lower vibration, and superior economics than helicopters. In comparison to fix-wing, eVTOL air vehicles will provide more convenient downtown service, increased operational and mission flexibility, more competitive economics, and access to small cities and remote rural communities. The most important is no need long runways. Overall, eVTOL PATS will provide desired travel time, efficient block speeds and travel time savings, extend daily radius of the action five to ten times further, point to point travel from anywhere, comfort, less distances from doorstep to portals, increase trips per day, expand transportation choice and relive road traffic congestion. According to 5th Transformative Vertical Flight Workshop’s reports in 2018, the societal demands and the acceptance needs such as affordable on-demand air mobility, relief from ground and air traffic congestion, time savings, personal convenience, mission/business advantage, greater safety, energy savings and environmental benefits (noise, emission) should be met by emerging air transportation mode. Now, we will discuss the most important benefits in detail matching those demands and needs with eVTOL PATS capability.

As we have figured out in previous chapters, the value of travel time is a critical factor in evaluating the benefits of transportation investment and the most prominent goals of transportation investments are time savings and, to a lesser extent, improvements in the reliability (i.e., predictability) of travel time. In other terms, reduction of delay in passenger or freight transportation is a major purpose of investments. As William Seifert’s 1968 prediction is that “Any form of transportation that offers the lowest door-to-door travel time will always drive out lower speed competing modes unless the economics of the higher speed system are grossly unfavorable”. Within this context, it can be argued that a new socio technical transition will come about like the transition from horse drawn carriers to autos.

Hub Spoke airline travel achieves a far average speed, but once the true door-to-door travel time is considered, the advantages decrease significantly and is often less important than the flexibility produced by automobiles. Only 19% of all trips over 100 miles are captured by aviation, with automobiles being used for almost all the rest due to their freedom from prescheduled service. However, automobiles only achieve an average speed of less than 33 mph. In this context, eVTOL PATS have the potential that will provide better door-to-door block speed up to 500-600 miles where airlines and automobiles provide poor block speeds and can save travel time as we can see in the figures 5.6 and 5.7 below.

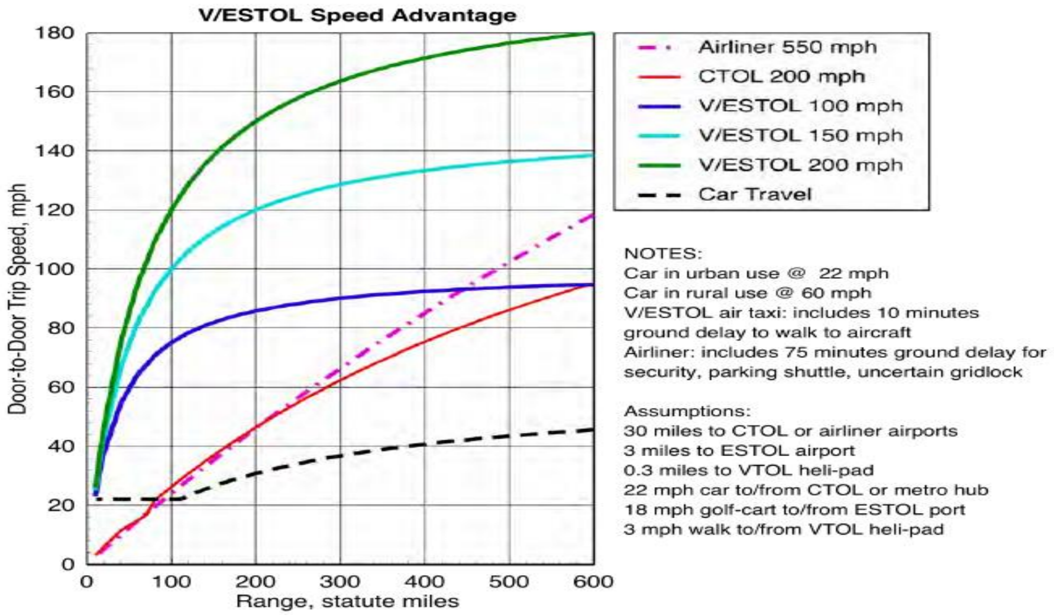


NOTES:
Car in urban use @ 22 mph
Car in rural use @ 60 mph
V/ESTOL air taxi: includes 10 minutes ground delay to walk to aircraft
Airliner: includes 75 minutes ground delay for security, parking shuttle, uncertain gridlock

Assumptions:
30 miles to CTOL or airliner airports
3 miles to ESTOL airport
0.3 miles to VTOL heli-pad
22 mph car to/from CTOL or metro hub
18 mph golf-cart to/from ESTOL port
3 mph walk to/from VTOL heli-pad

Fig. 5.6 Travel Time Savings by Mode, source: (Brien, 2010).

Figure 5.6 reveals that a large amount of time can be saved by V/ESTOL vehicles in air taxi service. The Time Saved Door-to-Door is highly dependent upon the ground travel time to and from the airport, both from one's departure doorstep and to one's destination doorstep. In the model presented in the figure, V/ESTOL is the only aviation modality with substantial time savings relative to car travel on trips of less than 80 miles. Note that in a round-trip commute scenario, the amount of "Time Saved" shown on in the figure is doubled, such that on as short as a 50 miles commute, one can save over 3 hours per day. The time savings depicted in Figure 5.6 (above) varies according to the type of airport being used. The typical conventional large airports for airliners and general aviation's conventional take-off and landing aircraft (CTOL) are presumed to be 30 miles distant. Future pocket airports are presumed to be < 3 miles distant if ESTOL and less than 0.3 miles distant if a VTOL helipad. Figure is modeled upon a 22-mph freeway gridlocked car speed enroute to airliner or CTOL departure. It presumes an 18-mph golf cart on residential streets enroute to ESTOL departure and walking at 3 mph enroute to VTOL departure. The corresponding ground travel times will be 82 minutes for airliners and CTOL but only 6 minutes for both ESTOL and VTOL. Note that these times apply to both the ground travel trip to the airport as well as the one from the airport.



NOTES:
Car in urban use @ 22 mph
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V/ESTOL air taxi: includes 10 minutes ground delay to walk to aircraft
Airliner: includes 75 minutes ground delay for security, parking shuttle, uncertain gridlock

Assumptions:
30 miles to CTOL or airliner airports
3 miles to ESTOL airport
0.3 miles to VTOL heli-pad
22 mph car to/from CTOL or metro hub
18 mph golf-cart to/from ESTOL port
3 mph walk to/from VTOL heli-pad

Fig. 5.7 Speed Advantage by Mode, source: (Brien, 2010).

Figure 5.7 reveals that the ground travel times are doubled to account for the travel to and from the airport involved in any one-way trip by air. This gives one-way ground travel times of 164 minutes for airliners and for CTOL and 12 minutes each for ESTOL and VTOL. The graphs also add an additional 75 minutes for each one-way flight by commercial airliner. This

75-minute delay does not apply to CTOL trips; it is due to airline baggage-check and shoes-off security check-in, park & fly shuttle, and the additional uncertain buffer time of 30 minutes for ground travel delays that one typically adds in order to assure not missing one's scheduled flight. Note that, with a round trip such as a daily commute by air, the ground travel time between the airport and one's doorstep must be quadrupled. The Door-to-Door Trip Speed of the 100 mph V/ESTOL aircraft surpasses that of cars, airliners and CTOL aircraft until trip length is more than 400 miles. Many of all single and twin engines GA flights today are trips of under 400 miles. The Door-to-Door Trip Speed of the 150-200 mph V/ESTOL aircraft surpasses that of cars, airliners and CTOL aircraft until trip length is more than 600 miles.

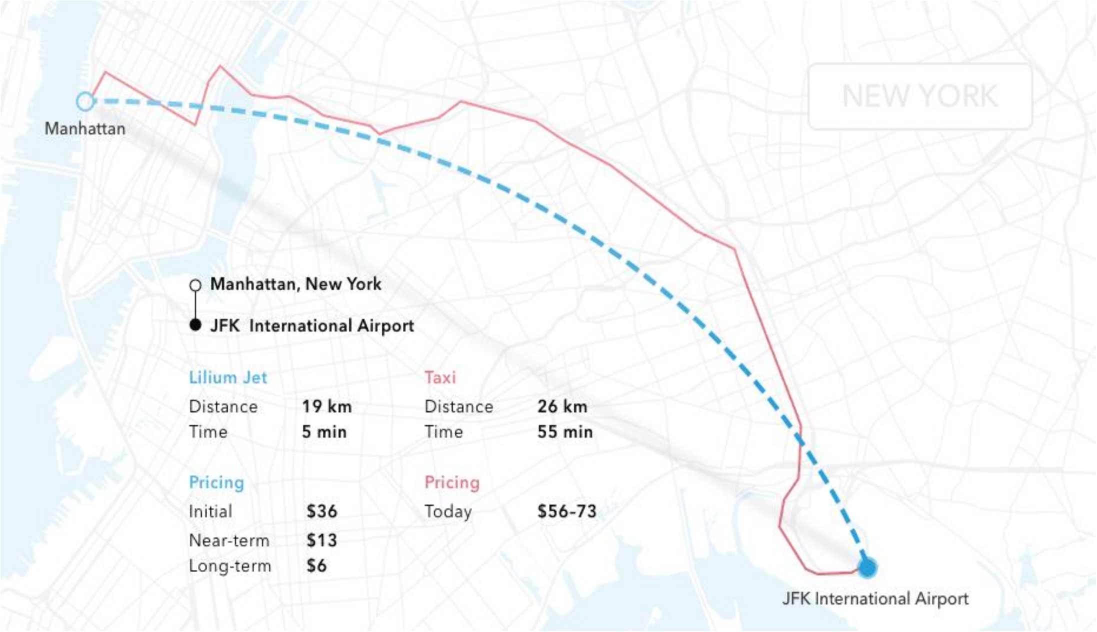

Fig. 5.8 Travel Time Saving in a Sample Mission Scenario, source: (Lilium, 2017).

Figure 5.8 reveals that you can reduce your one-hour (55 min) commute from JFK International Airport to Manhattan down to 5 minutes by eVTOL PATS. Imagine never being stuck in traffic again and paying no more than the cost of a train fare. Depending on your commute, you could save as much as 2 hours every day.

Another important benefit is that you can go further and wherever you want without access roads. Considering door-to-door block time, eVTOL PATS has the potential to achieve another five to ten-fold daily mobility reach increase over the auto today as seen in figure 5.9 below. Providing an improvement in trip speed provides a non-linear improvement in the regional area that can be accessed for daily use. Current ground travel provides average trip speeds of less than 33 mph, with a daily reach of about 2500 square miles (based upon an average radius travel time allocation of 1.25hr). eVTOL PATS could provide at least 4 times auto speeds, with 16 times the daily mobility reach.

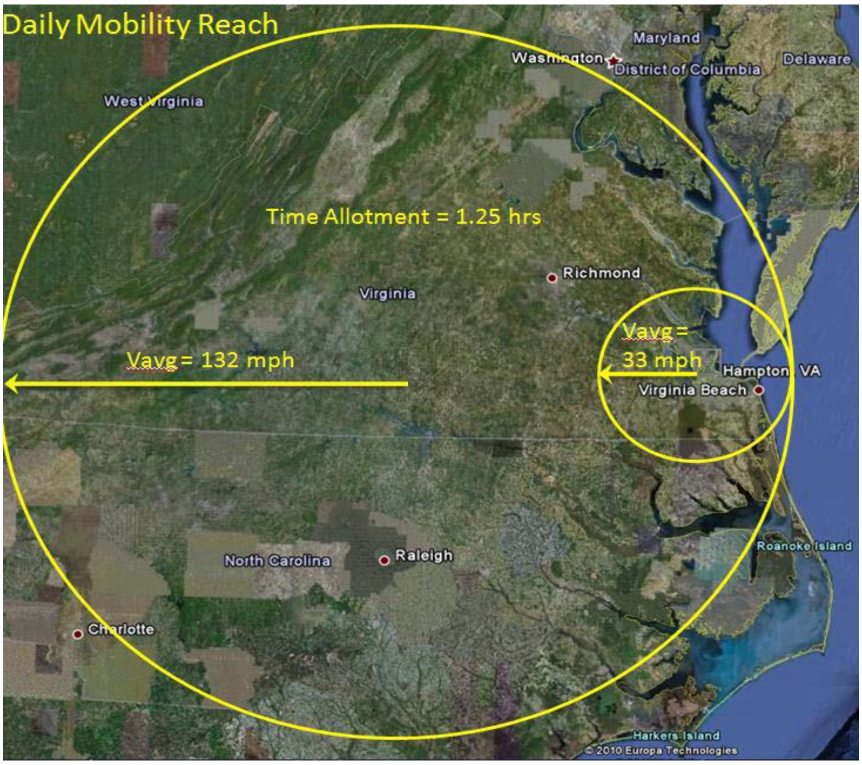

Fig. 5.9 Daily Mobility Reach Comparison of Car and eVTOL PATS

One of the important societal demands is affordable on-demand air mobility near car utility different from scheduled commercial airlines. For example, only 19% of all trips over 100 miles are captured by aviation, with automobiles being used for almost all the rest due to their freedom from prescheduled service. On-demand eVTOL PATS is a transportation mode that has the potential to provide immediate and flexible point-to-point air transportation. Users will dictate trip origin, destination, and timing. It will enable trips that are not time/cost effective with current transport modes. It will operate from near vertiport infrastructure and/or existing heliports, roof tops and barges (Antcliff, 2018). eVTOL PATS has the potential to provide on-demand mobility near car utility. Such opportunity for mobility freedom will help regional cities to preserve their urban growth boundaries by encouraging infill development (Brien, 2010). Pocket airports will also invite sustainable green surface transportation such as low-speed, electric vehicles, folding electric bikes, co-located mass transit stations, rentable bicycles as well as walking.

eVTOL PATS is free from large infrastructure requirements. Unlike surface transportation, flying can provide highways in the sky with unlimited numbers of lanes and overpasses, off-ramps, and merges. A highway in the sky is never blocked by accidents, toxic spills, “rubberneckers” or pedestrians. It can be dynamically reconfigured instantly and does not require public purchase of expensive land that must be permanently removed from open spaces or any other use. Unlike paving with asphalt and the urban heat islands it creates, building aeronautical highways does not require millions of barrels of crude oil. Current auto and airport hub-based travel would facilitate overcoming natural travel barriers that otherwise would require additional expensive bridges, roads, and highways (e.g., $20 million per mile) and commercial airports (e.g., $1 billion per major commercial runway) (Brien, 2010). Moreover, eVTOL small air vehicles that could achieve a low enough acoustic signature and require new high capacity vertiport or pocket airport infrastructures, affordable parcels as small as 2 acres that can be situated within a very short distance from one’s destination doorstep, to enable much closer proximity aviation operations to neighborhoods and businesses as shown in figure 5.10 below. That short distance, modeled as just 3 miles or less, can be traveled by walking, biking, golf cart or vehicles on low-traffic residential streets. Landing site cost tends to be proportional to the square of the runway length. A commercial takeoff and landing with 5000-foot runways, though 10 times longer than a pocket airport with 500-foot runways, can cost 100 times more (Brien, 2010). As a result, new emerging air transportation mode may reduce dependences on paved surfaces, highway maintenance and eliminate need for additional surface routes. Pocket airports or vertiports will also offer a redundancy for airborne disaster relief and a more distributed system for medevac air ambulance operations.

Fig. 5.10 Much Closer Proximity Vertiports to Neighborhoods

Improving travel options can benefit all travelers on a corridor, both those who shift modes and those who continue to drive. Shifting traffic from automobile to other travel modes not only reduces congestion on that facility, but it also reduces the amount of vehicle traffic discharged onto surface streets, providing downstream congestion reduction benefits. As we covered before, traffic congestion refers to the incremental costs resulting from interference among road users. These impacts are most significant under urban-peak conditions where traffic volumes approach a road's capacity. The resulting congestion reduces mobility and increases driver stress, vehicle costs and pollution. Traffic congestion is a nonlinear function, meaning that a small reduction in urban peak traffic volume can cause a proportionally larger reduction in delay. A 5% reduction in traffic volumes on a congested highway may cause a 10-30% increase in average vehicle speeds. As a result, even relatively small changes in traffic volume or capacity on congested roads can provide relatively large reduction in traffic delay.

For example, the INRIX Corporation (2009) uses a "SMART Dust Network" of GPS-enabled vehicles which report roadway travel conditions to evaluate highway traffic congestion. Their 2008 annual report indicates that U.S. traffic congestion decreases nearly 30% from 2007 to 2008, apparently due to a 4% reduction in total traffic volume. In another example, according to the Metropolitan Transportation Commission statistics, there are 88,500 road vehicles that cross either the Golden Gate Bridge or Richmond San Rafael Bridge every morning during commute hours in Northern California. Vehicles from Sonoma County comprise 13,500 of those morning bridge crossings. In accordance with traffic flow studies that show gridlock to be relieved by as little as 4% reduction in vehicle traffic, it appears that removing 3500 of those 88,500 morning bridge crossings could undo the surface gridlock that plagues commuters there. That county's morning gridlock ranks as the second worst in all Northern California. Assuming the same average occupancy rate as surface traffic, 3500 commuting SAVs operating each morning from pocket airports in Sonoma County could undo the surface gridlock there. Simply put, this would entail 350 aircraft departures from each of 10 pocket airports. If those airports were like the one where 240 operations per hour are possible, each airport could depart its 350 aircraft in 1.5 hours, such as between 6:30 AM and 8:00 AM (Brien, 2010).

However, planners find that the public is very resistant to giving up the security and autonomy of their cars. People place high value on privacy and personal space. Recent brain imaging studies confirm that human brains have innate 'hard-wired' alarms that are activated when personal boundaries are violated (Kennedy, 2009). The public resists using public transit for other reasons too. Buses and trains are inherently constrained to the limitations of twodimensional, single-file surface travel and they impose the added delay of multiple stops. People deem the waiting, transfer maze, delays, and limited distribution of transit stations to be unacceptable. These factors cast doubt on the likelihood that public transit solutions to gridlock will succeed. However, to attract travelers who have the option of driving, eVTOL PATS must be fast, comfortable, convenient, reliable, and affordable. In short, eVTOL PATS has the potential to attract travelers and to help relieve traffic congestion especially in the cities in figure 5.11 where they have highest potentials for eVTOLs in terms of time saving value.

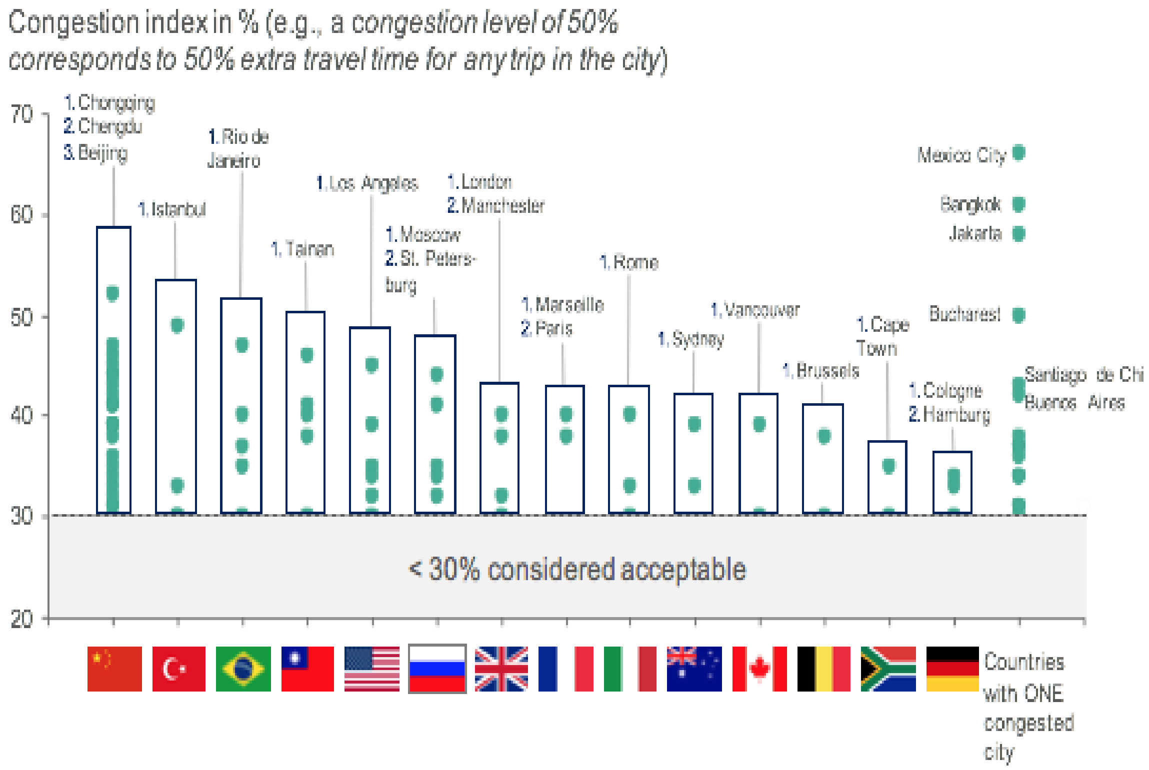

Fig. 5.11 Congestion Index and Highest Potentials for eVTOLs in terms of Time Saving, source: (Airbus Research by Boston Consulting Group, 2018)

Transforming air transportation system will also produce many societal benefits including growth in airspace capacity, great mobility, enhanced safety, green technology, jobs, and manufacturing. Developing a transformative mobility age for society would provide a similar economic productivity impact as the information age. As fully autonomous systems are achieved over the years, eVTOL PATS will enable more travelers to experience enhanced mobility. Transportation markets will provide disruptive investments that create while new industries and societal capabilities that don't currently exist. As typically happens in new product markets, the basis on which such aircraft will be chosen by early adopters and consumers will evolve from function to reliability to convenience to price. As this process proceeds to lower prices that enable high volume production. For example, NASA's Chief

Scientist has forecast that this can become “a potential Trillion Dollar Market”. Early applications such as small air vehicles could open a new market whose potential is predicted to approach $1 trillion. The projection of urban mobility in figure 5.12 supports that forecast (Dyment, 2018).

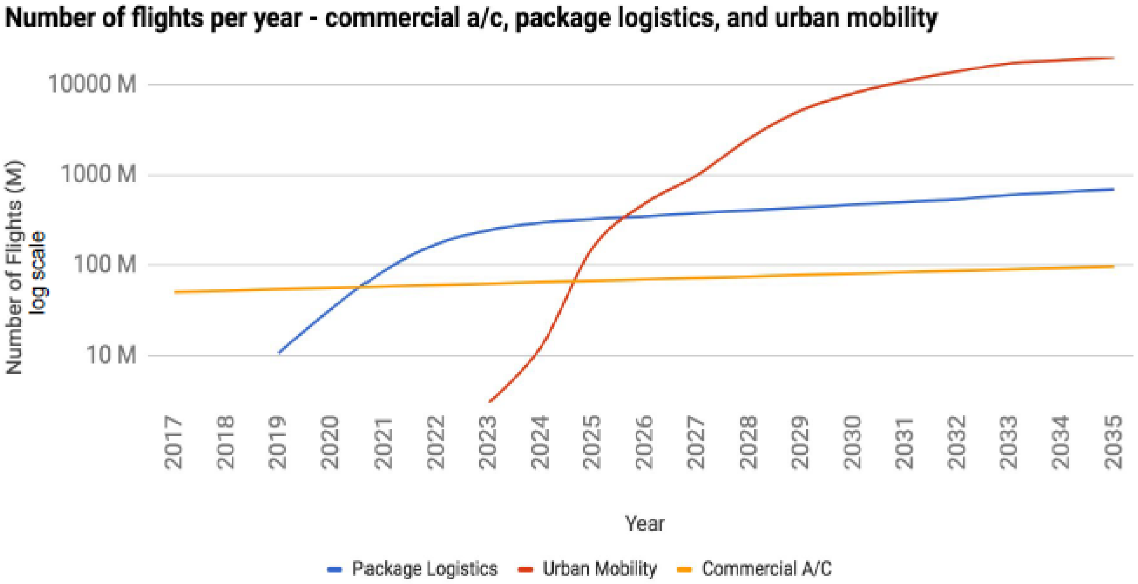

Fig. 5.12 The Projection of Urban Mobility, source: (Dyment, 2018)

Transportation engineers at Virginia Tech have predicted up to 15 million SATS passenger-trips/year if an air taxi service could be provided at a cost of $1.85 per passenger-mile in 2010 in a simulation. When technology matures, costs of $1.25 per passenger mile might be possible increasing the market share to 29 million passenger-trips/year. Today, business passengers travelling in commercial airlines pay $0.90 per passenger-mile in a typical 350-mile trip. However, SATS travelers would save an average of 3 hours per trip based on a nationwide analysis.

eVTOL PATS can also contribute security and safety. Small air vehicles will be less attractive than large airliners for any terrorism actions and for being used for unlawful acts since low mass and speed resulting in limited kinetic energy, low fuel capacity and limited payload capability (Tallec, 2012). Besides, an alternate approach to make the aviation system potentially less prone to attack is to decentralize (smaller and more numerous pocket airports/vertiports), downsize (reduce the value of individual targets by using smaller vehicles, with lower inherent destructive potentiality, and fewer number of passengers onboard them), and increase overall command and control (by tightly integrating autonomous systems into the airspace. High automation has also made significant progress on safety. eVTOLs will also enhance public services such as medical transport, law enforcement, search and rescue and emergency response etc.

In short, the main benefit of eVTOL PATS will be to enable people and goods to have the convenience of on-demand point-to-point safe travel, further, anywhere in less travel time, through a network of pocket airports and vertiports. Overall, after these contributions, if we try to list the main positive social and environmental impacts, they are:

- e VTOLs will reduce travel time by a factor 5, in other terms will increase daily radius of reach at least by a factor of 5.
- e VTOLs will enable you to access city centers and will reduce the need for a car which means there will be less transit traffic and less noise in cities.
- e VTOLs will not require infrastructure investments like roads, bridges, and runways. Landing pads can be developed by anyone, the relevant authorities will only provide the requirements and invest in the early phase.
- Quite eVTOLs will have almost zero operational environmental impact.
- e VTOLs will enable a variety of missions ranging from private use to urban air taxis to regional biz jets or air minibuses. eVTOLs will also enhance public services such as medical transport, law enforcement, search and rescue and emergency response etc.
- eVTOLs will bring personalized, clean, and affordable air travel to general people whenever we want and wherever we want.
- eVTOLs will contribute new business opportunities such as urban and regional air transportation services, manufacturing new vehicle types and systems, and new industry investments.
- eVTOLs will produce growth in airspace capacity and enhance better utilization of existing infrastructure.

5.3 What Are The Key Enabling Technologies?

This subsection tries to understand the key enabling technologies in which considerable progress will have to take place regarding the state of the flying prototypes. However, to analyze each technology’s maturity level is beyond the scope and possibilities of this thesis.

As we mentioned above, the vision has been to enable people and goods everywhere to have the convenience of on-demand point-to-point travel, anywhere, anytime in less travel time through a network of pocket airports or vertiports. If a new air transportation mode is to be developed, what goals would be established for this system? It appears that it would be a quite different set of objective functions than what the airlines used to shape the second wave of aeronautics. The third wave desired capabilities that appear to offer the most values are: (Moore, 2003)

- Vertical and extremely short takeoff and landing,
- Ease of use and automation of air vehicles, (Almost near all-weather condition),
- Operation at block speeds markedly faster than current combinations of land and air transportations,
- Increasing daily radius of action,
- Excellent reliability,
- Automated airspace control,
- Unit cost comparable to current luxury cars and small general aviation aircraft,
- Minimum environmental cost, the noise and emissions that are exposed to the local community are at levels proportional to the community use,
- Excellent safety comparable with airlines,
- Ability to integrate with existing land and air transportation system.

These goals imply integrating overall technology areas with practical everyday transportation requirements to design a class of air vehicle by constraints (Table 5.1) instead of performance (Vascil, 2018). For this vision, aerospace engineers have come up with numerous concept vehicles since the first flight by the Wright Brothers. Nevertheless, the public has not embraced any of them because the necessary technologies have not reached a readiness level to enable. However, with the results obtained lately from the research activities, revolutionary technologies and regulations are bringing us closer to an eVTOL PATS reality every day. A community of aerospace profession ranging from technologist to business entrepreneurs can transform air transportation by enabling new aviation transportation system (Dudley, 2018). When? The timeline for this to occur is as much a function of the required technologies becoming available, as it is to the development of new regulations, vehicle and airspace concepts, and an aerospace community more willing to take risk due to greater potential rewards.

Table 5.1 Design by Constraints, source: (Vascil, 2018).

DESIGN CONSTRAINTS	
1	Aircraft Noise and Community Acceptance
2	Availability of Takeoff and Landing Areas
3	Scalability of Air Traffic Control
4	Safety and Certification of Electric Aircraft Operations
5	Logistics of Network Operations (deadhead, charging, etc.)
6	Pilot Availability or Ease of Use
7	All-Weather Operation

The technical, business, and societal developments in recent years is driving an expectation of the third wave of aviation. Besides, there is a convergence of technological innovations and improvements in aviation that have been making it possible for the first time in history to make general people fly. Some eVTOLs are already flying (City Airbus, e-volo, Lilium jet, Aurora's Lightning Strike, Zee ZP1, Passenger Drone etc.,). Others will be soon. Many more are on the drawing boards[30] (Moore, 2016). However, even with the successful test flights, it will take a while before any of us are taking air taxis. A successful implementation and sustainable transition will depend on overcoming technological challenges.

The technology challenges that must be surmounted include ease of use, automated airspace control, improved propulsion systems, economically viable concepts, low noise, modern certification procedures, and near all-weather capability while achieving a factor of ten improvement in small aircraft safety. Achieving drastic improvements in ease of use, safety, and community low noise are the most critical steps towards the future feasibility of this market, as agreed upon by industry members in the PAV workshops that defined the sector goals (Moore, 2006). Multi-use demos, namely transformative vertical flight prototype field test operations, create public acceptance and understanding of potentials in technology for public good; use and learn in multiple application (Datta, 2017).

Increased utilization of our airspace has remained limited by four major factors: requirements for extensive pilot training, cost of aircraft and fuel, accessibility to specialized

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[30] A³ by Airbus Group, (2017), Available: www.Vahana.aero
Aurora Flight Sciences Corp, (2017), Available: www.Aurora.aero/lightining strike
e-Volo GmbH, (2017), Available : www.Volocopter.com
Ehang, Inc., (2017), Available: www.Ehang.com/ehang184

airport infrastructure, and FAA or EASA airworthiness, pilot training and certification, and airspace operations regulations. Several technological advances and societal trends, coupled with enlightened regulatory changes, could help mitigate these factors in the future. Advances in vehicle autonomy, led by the automotive (e.g., Google car) and UAV industries promise to make personal air travel as simple to the user as automotive travel is today, greatly reducing the need for extensive and expensive pilot training. Advances in hybrid and electric propulsion, new manufacturing and materials technologies, innovations in vehicle configurations, as well as the economics of reduced cost through production economies of scale could lead to significant reductions in Thin-Haul, urban eVTOL air mobility, and personal aircraft costs. In addition, increased adoption of smart phone, internet-based ride sharing approaches (e.g., Uber) currently in use for automobiles hold the promise to increase greatly the utilization rate of individual air vehicles, thereby reducing cost per passenger mile. Advances in safe, quiet eVTOL technologies such as distributed electric propulsion would help obviate the need for expensive and expansive airport infrastructure and allow more local and distributed take-off and landing sites (e.g., utilizing neighborhood Helipads or roadside rest areas). Increased market pressure for wide-scale use of UAVs is requiring the FAA and local governments to alter existing regulations to adapt to the inevitable democratization of the airspace. Advances in automation of air traffic management, autonomy of air vehicles, air-to-air and air-to-ground broadband Wi-Fi, trajectory-based optimization of flight path economics and safety, and sense-and-avoid technologies will enable an adaptation of future FAA regulations to new technological realities. Current NASA research includes exploration of moving airspace separation, sequencing, merging, and spacing functions from the ground to the cockpit, for example. A future FAA regulatory framework might be more similar in function to the Federal Highway Administration in certification of vehicles and defining and enforcing “rules of the road” with much of the collision avoidance decision making being distributed to the local networks of vehicles.

In sum, key technology developments driving these expectations are advances in automated/autonomous systems, enhanced airframe integration of electric propulsion, and improved energy storage systems (Dudley, 2017). Key technology areas with prioritization based on enablement are simplified vehicle operation and autonomy, distributed electrical propulsion, noise, safety systems, and airspace and advanced air traffic management systems (Moore, 2016). Especially intersection of electric propulsion and autonomy will enable successful urban mobility systems in the next decade (Buiten, 2018). They will be discussed in detail in the following subsections.

On the other hand, there are also external technology research areas that have high relevance with eVTOL: advanced battery and chargers, IT technologies for booking and operation, and autonomous cars. In addition, major innovations like 3D printing and rapid prototyping have taken the design, construction, and development of aerospace materials beyond the sole purview of large corporations, allowing a greater breadth of inventors and engineers to experiment with new tools, materials, and devices (Hirschberg, 2017). Through a focused research effort, led by NASA in collaboration with the FAA, industry and academia, the emerging technologies could combine with existing aviation system advancements to accelerate and amplify the improvements needed in eVTOL PATS systems performance and cost to enable a fundamentally new market in air mobility (Holmes, 2017). The convergence of aviation and non-aviation technologies include the following list of technologies (Holmes, 2017) from both the aviation and non-aviation domains that combine to serve as a foundation for transformational advancements in on-demand eVTOL air vehicle, airspace, vertiports and related operating capabilities and requirements:

- High energy-density batteries and fuel cells,
- High power-density electric motors,
- Additive (3D) manufacturing
- Hydrophobic material coatings,
- Rich broadband air-to-ground, air-to-air, and orbit-to-air digital, bi-directional, IP connectivity,
- Cybersecurity systems,
- Trusted autonomous systems,
- Multi-function materials and structures,
- Advanced material systems (increased strength-to-weight properties),
- Artificial intelligence,
- Biometric identification, registration, and authorization,
- Wearable and virtual or enhanced reality display systems.

5.3.1 Distributed Electric Propulsion Technology

Electric propulsion is a game changing technology for eVTOL air vehicles because it enables the eVTOL capability with high cruise efficiency and low community noise operations in all phases of flight. The idea of distributed electric propulsion is to replace the single complex rotor system-cyclic, collective, swashplate, transmissions, gearboxes, shafting, hydraulics, etc.-

with multiple simple thrusters. Distributed electric propulsion (DEP) opens a vast eVTOL design space for urban air mobility (Moore, 2018).

The ability to distribute the thrust across the airframe, without mechanical complexity and with a scale-free propulsion system, is a new degree of freedom for aircraft designers. Electric propulsion is scale-free in terms of being able to achieve highly similar levels of motor power to weight and efficiency across a dramatic scaling range. Applying these combined principles of electric propulsion across an eVTOL air vehicle permits an improvement in aerodynamic efficiency that is approximately four times the state of the art of conventional helicopter configurations (Fredericks, 2013). Advocates also believe distributed electric propellers, fans etc. have huge benefits in terms of safety, emissions, noise, and community acceptance.

Removing the engines removes a significant source of noise. Electric motors are far quieter than piston or turbine engines because they don’t need to ingest and expel large volumes of air through hydrocarbon combustion. Compared with propeller noise, the noise from an electric motor using a modern sine-wave controller can be inaudible (unlike early prototypes using square-wave controllers), while the noise of a piston or turbine engine is generally about as loud as the noise from the rotor and is heard as a spectrally distinct noise source, further increasing loudness (Uber, 2017). DEP also allows the design to be optimized for low noise much more easily, because within the scale of eVTOLs, the designer has a wide range of choices for speed and torque without needing to add gearboxes.

eVTOLs can take advantage of scale-invariant implementation of DEP. Scale invariant propulsion technology means designers can, on-demand, allow lift and thrust to be generated. If eVTOLs use DEP, they can use many motors with smaller propellers without performance or weight penalties. In contrasting the X-19 to the recent NASA GL-10 (which takes advantage of scale-invariant implementation of DEP), the GL-10 design is far less complex without major structures that themselves generate both noise and many possible points of failure (Uber, 2017). The independent propulsion also provides complete redundancy, so a single failure of a propeller or motor has only a minor effect on the vehicle thrust and control.

A further benefit of the flexibility of DEP is it becomes possible to consider designs with rotors that can be quickly turned on or off, and rotors that can be tilted. This approach can be used to avoid edgewise flow in forward flight so it’s possible to use tip speeds about half as fast as helicopters without blade stalling, thus achieving radically lower noise.

eVTOL designs provide a compelling solution; they generate zero in-flight carbon emissions and provide a pathway toward significantly lower carbon emissions as utilities adopt renewable energy solutions such as wind and solar. All-electric vehicles get their energy from the grid, so there is a high degree of centralization of the energy source versus hydrocarbon fuels. This means the true life-cycle vehicle emissions are highly linked to utility emissions (both the legacy electricity as well as the emerging electricity plants). However, while 90%[31] of all grid electricity generation today is powered by hydrocarbon fuels (petroleum, natural gas, or coal), development of new renewable electricity generation (wind, solar, and hydro) is outpacing development of new petroleum/coal sources by a factor of more than two, based on 2016 data. And electric vehicles (of all kinds) will increase demand for electricity, which will help create the motivation to move toward renewable grid sources, and the electric utilities becoming more CO2 responsible (Uber, 2017).

5.3.2 Energy Storage and Hybrid Technology

Air vehicles need to fly hours with significant payloads to expand into many real applications. Battery technology is rapidly improving as shown in Figure 5.13 below, but there are still key challenges related to battery such as system energy density (range), life cycle, charging rates, battery cost and weight (Ricardo, 2018). Battery energy density is still small compared to other fuel sources. Batteries are heavy, and they don’t get lighter as they deplete. On the other hand, on-board power generation may offer opportunities to overcome near-term battery limitations. However, on-board power generation covers with its own challenges such as design complexity, emission, noise, maintenance and fueling. The hybrid propulsion design priorities will drive the development and selection of appropriate technologies (Ricardo, 2018).

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[31] http://www.eia.gov/tools/faqs/faq.cfm?id=92&t=4

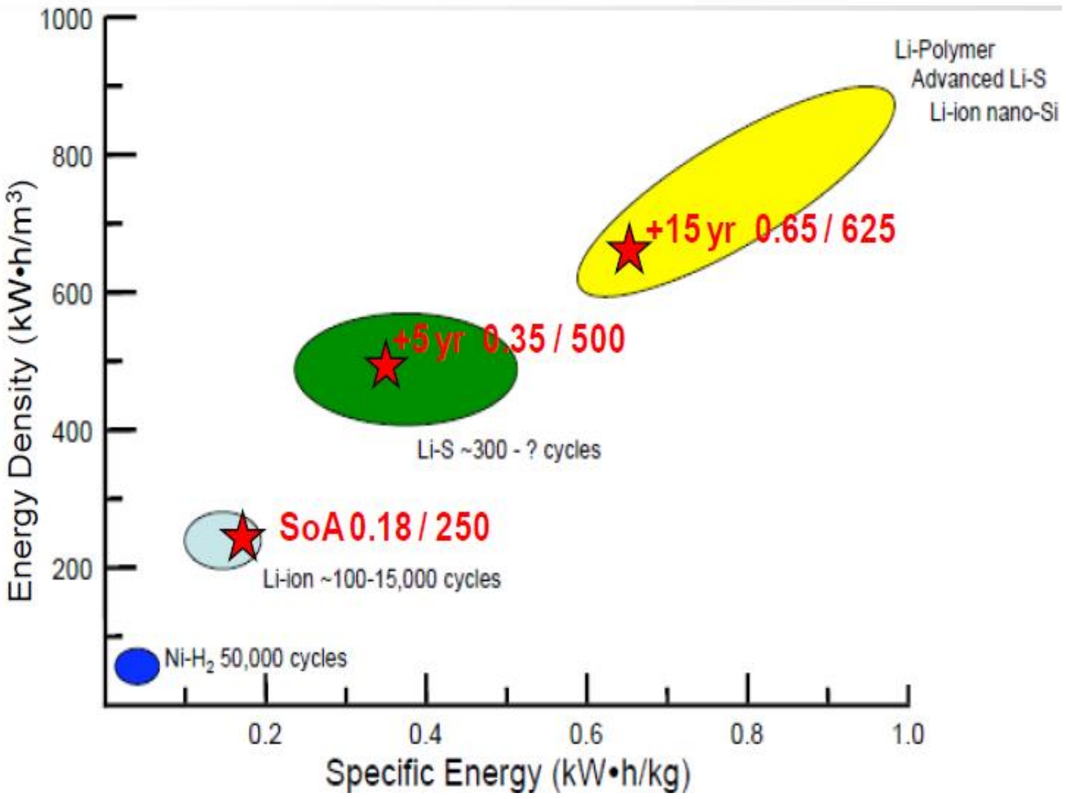

Fig. 5.13 Energy Storage Technology Development, source: (Ricardo, 2018)

Thus, one topic contributing to the environmental footprint and to the public acceptance is the question of how much energy the eVTOL PAVs will consume. To investigate this, a power requirement calculation for an example mission by the Reference PAV was undertaken by partners of the DLR Braunschweig. For the reference flight 30 km and a cruising altitude of 500 m above ground level with an average cruising speed of 175 km/h were assumed. The total energy consumption for this reference flight (Cref) was calculated to be Cref = 12.81 kWh. To set this into context it would mean that a Li-ion battery with an energy density of 150 Wh/kg (Zhao, 2013) with a weight of around 85 kg would be needed to full fill this task (Decker, 2013). These rough estimates show that the development regarding the energy storage is on the right way and in the necessary order of magnitude and examples like the e-volo development mentioned before show already today the possibility of a pure electric propulsion for eVTOL PAVs.

Meanwhile electric batteries take time to charge, degrade over time, and expensive. They present storage and end-of-life recycling challenges. For example, as we explained above Lithium-Ion battery power-to-weight ratio is not enough to power yet. The batteries dissipate heat, and they may also catch fire.

According to Uber’s analysis, the design mission range can likely be met within the next 5 years—this means embracing eVTOL designs that can achieve cruise aerodynamic efficiencies with a Lift/Drag ratio of greater than 10 (with 12 to 17 desirable) and battery cell specific energy of 400 Wh/kg[32]. eVTOLs will likely use large battery packs, nominally a 140-kWh pack for a 4-person aircraft. Use of a large battery pack ensures the specific power of the batteries is well matched to achieving high specific energy. Nominally, battery packs that can discharge at less than 3C ratings are able to avoid severe penalties to the specific energy. High vehicle utilization requires the ability to perform more than one average trip distance prior to requiring recharge, which further supports the use of a larger battery pack. Essentially this is like the way that Tesla designs electric cars versus others, with larger battery packs and improved specific energy due to the limited discharge rates. Trip range is further extended if the eVTOL infrastructure supports recharging even for just a few minutes with high voltage rapid rechargers as passengers are loaded and unloaded between trips.

There’s no question that battery specific energy will limit the range capability of eVTOLs. An important discrimination exists between the battery cell specific energy and the resulting effective battery pack specific energy. Optimal strategies for packaging batteries together are still being investigated to ensure that even if one battery cell fails, it won't propagate to neighboring battery cells. The weight overhead for this battery casing is quite high with cars (on the order of an additional 100% weight above the battery cell weight). However electric aircraft companies have been making progress in this area due to their weight sensitivity, with aircraft such as the Pipistrel Alpha Electro achieving less than 30% battery packing overhead.

Major investments are being made in batteries since so many products value higher specific energy (i.e., laptops, smart phones, cars, etc.), with many new chemistry approaches being tested. Particularly exciting are recent Department of Energy (DOE) investments which align so well with eVTOL priorities. The DOE Battery 500 project is spending $50 million over the next 5 years to develop 500 Wh/kg batteries along with high capacity 350 kW chargers. This collaboration between DOE labs and universities is focusing on lithium-metal batteries, overseen by an industry panel board including Tesla, IBM, and PNNL to ensure manufacturable solutions. While this effort is pursuing a 1,000-cycle life, it’s also pursuing a cost target of less than $100 per kWh. If this cost threshold can be achieved, the cycle life would be highly acceptable (Uber, 2016). Equally exciting are the high energy chargers which would be capable of recharging in as little as 10 minutes. Additional research into pulse chargers is already

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[32] The Department of Energy Battery 500 Project, http://www.hybridcars.com/federal-government-aims-to-develop-a-500-whkg-battery-350-kw-charging-system/.

showing improved cycle life and maintaining improved maximum charge capacity over time. Achieving rapid charging for large battery packs is as important, if not more important than achieving high specific energy batteries.

An alternative solution, hybrid, combines the gasoline or turbine engine, a generator, and a much smaller battery and you get the best of both worlds. This solution fuses the portability and instant power availability with high energy densities of gasoline while benefitting from the design flexibility of electric flight (DeBitetto, 2018). And it supports a path to higher payloads, longer endurance, more powerful, higher reliability, and lower system cost. In comparison to batteries, the key benefits of hybrid electric technology are fuel specific energy is about 75 times higher than batteries; it is still 15 times that of practical battery packages at 20% conversion efficiency; a hybrid system eliminates time spent on a charger; and engines have a long track record and well-understood reliability plan compare that to fast-discharge batteries operating over large temperature ranges (DeBitetto, 2018). In sum, the hybrid solution may provide more power, payload, and endurance. Increased performance of batteries and capacitors may also be enabling technologies, while improvements in autonomous systems will certainly be.

5.3.3 Autonomous Technology

Autonomy is a critical enabler for eVTOL PATS, because autonomy reduces mishaps and fatalities dramatically (human factors attributed for 79% of rotorcraft fatalities), enables routine operation in nearly all weather conditions and removes burden of following instrument flight rules, address pilot costs (direct operating costs of pilots triple the costs for energy), training overhead, pilot shortages (1 or 0 pilot onboard), and routine operation to/from small and uncontrolled areas (Drozeski, 2018). New control and stability systems developed for unmanned aircraft now allow previously unflyable configurations to be extremely controllable.

High automation has also made significant progress on safety. According to US congressional report (January 2012), USA unmanned aircraft inventory increased more than 40-fold from 2002 to 2010. In 2011, almost 1 in 3 U.S. warplanes is a robot. Global Hawk-class, Reaper, and Predator-class. UAS will grow from approximately 340 in FY 2012 to approximately 650 in FY 2021. The Predator has only 7.5 accidents per 100,000 hours of flight: down from 20 accidents over that time in 2005 which is comparable to a (manned) F-16 just under the 8.2 rate.

Automation has been changing the roles of both the pilot and the air traffic controller. Their roles are now as strategic managers and hands-off supervisors, only intervening when necessary. Autonomous technology, in the air and on the ground, is certain to be required if aviation is to break out of its niche and become a ubiquitous mode of transportation. Whether it is easy to fly personal air vehicles, optionally piloted air taxis or single pilot monitored mass commuter transports, aviation will have to go beyond automation to enable wider public use of aircraft. Autonomy design architectures should consider certification from concept stage including hardware redundancy, software level of assurance, sensor performance (obstacle avoidance, sense and avoid, vehicle proximity etc.), navigation performance and human machine interface. At least automation must support all weather takeoff and landing, emergency recovery, navigation, and crash avoidance. Computer monitored by pilot authority should be a possible automation level to enable all requirements. Certification of more autonomous new eVTOL air vehicles is the next step (Drozeski, 2018).

There are many similarities in automotive and ODM eVTOL air transportation mode autonomous system requirements, and autonomous automobiles will be developed and deployed years in advance of ODM systems, allowing great opportunity to learn lessons from successes and failures. Over the past several years, automobiles have become increasingly autonomous with the advent of Google Car, Tesla, Uber, and efforts by traditional automotive companies. An entire industry of second tier and third-tier suppliers have also emerged that develop the software, algorithms, sensors, and hardware to support these systems. In addition, the Society of Automotive Engineers (SAE), the International Standardization Organization (ISO), and the DoT are developing internationally harmonized standards for autonomous systems and operations. They will be leading the way for the on-demand eVTOL PATS industry in developing relevant sensors, algorithms, cybersecurity approaches, human-machine interfaces, connected vehicles, highly reliable architectures, path optimization within traffic networks, certification standards and approaches, and regulatory frameworks (Bruce, 2017).

5.3.4 Airspace and Air Traffic Management Technology

Autonomy alone will not lead to efficiency and large-scale disturbance management. eVTOL air mobility and airspace integration will be a key enabler. Considering the potential for on-demand urban eVTOL operations, one of the important issues will be significantly higher frequency and airspace density of air vehicles operating over metropolitan areas simultaneously. The aim is to enable efficient high-density operations with access to diverse platforms in airspace with integrated air-ground-cloud technologies. It will be critically important that the aircraft operating community, regulators, and others develop alternative solutions to enable safe, efficient and high-capacity operational urban environments to accommodate this dramatic increase in aerial traffic density.

The Unmanned Aerial Systems (UAS) industry has rapidly grown to be an over $10 billion industry in a few years and could double again in the next few years. Integration of UAS into the national airspace is perhaps the largest constraint preventing it from growing even faster. As the FAA works with the UAS industry in solving these issues and establishing viable technological solutions and a regulatory framework, these same advanced technologies can be leveraged to benefit the on-demand eVTOL industry (Bruce, 2017). In fact, most required on-demand eVTOL technologies have synergy with UAS; however, investments in UAS technologies will not be enough to enable eVTOLs because of the many unique requirements. eVTOL technology development can take advantage of UAS industry advancements in autonomy, sensors, algorithms, cybersecurity, electric VTOL propulsion, configuration approaches, connected vehicles, and airspace integration leadership.

eVTOL PATS infrastructure; namely Air Traffic Management (ATM) system, communication networks, emergency services and vertiports (Balakrishman, 2018) should be designed considering principles such as scalability and sustainability, no burden on current system, cooperative and interoperable with other users, performance and risk based, efficient and safe (Kopardekar, 2018).

Air Traffic management has real challenges. How crowded is the airspace? How many aircraft can the airspace handle? How well does the airspace react to unauthorized or bad actors? How many emergency landing zones do we need? How close to buildings should aircraft be allowed? Is the airspace open to the widest possible number of players? What happens when an aircraft needs to divert for any reason? It is probably built on the fundamentals of unmanned aircraft system. It should provide flexibility where is possible and structure where is necessary. Connectivity is crucial, and air-ground-cloud-infrastructure integrated operations and system (spacing, separations) will be key (Kopardekar, 2018). To enable scalability, the architecture, roles/responsibilities, and technology should allow self-management as much as possible. Tracking should be done via wireless, satellite, ADS-B, or beacon-based systems connected through Unmanned Aircraft System Traffic Management (UTM). Vertiport should be designed for multiple simultaneous arrivals and departure operations. Operator plans and schedules operations through UTM (Kopardekar, 2018).

Current aircraft traffic management and de-confliction advancements such as ADS-B technology are a great starting point for initial low-density operations, but more comprehensive low altitude airspace solutions will be required to meet near to long-term eVTOL PATS operational capacities (Uber, 2016). Emerging concepts such as the NASA UTM initiative are a start towards an airspace system that will enable the autonomous trajectory management systems necessary for the future operating environment. However, these steps alone are unlikely to be enough to handle the future of urban airspace, given the project demands of on-demand eVTOL networks. Following UTM, there are at least three compelling potential developments that would help to unlock operational efficiency of urban eVTOL networks and solve the airspace challenges they will bring:

- High volume voiceless air traffic control interactions,
- UTM-like systems that address higher altitudes intersecting with General Aviation aircraft,
- VTOL-related traffic integrating seamlessly with low-altitude commercial airline approach-and-departure trajectories near metropolitan hub airports.

For VTOL air vehicles, flights in Instrument Meteorological Conditions (IMC) need to be as simple and low burden to pilots as VFR flight. Voice-based pilot-to-airspace controllers create a serial capacity bottleneck that will limit the capability and scalability of an airspace system. Conventional voice messages between Air Traffic Controllers and pilots are not an option anymore. On board 4D trajectory management is required. ATC monitoring of aircraft compliance to planned 4D trajectory remains a problem for safety and efficiency. Transitioning to voiceless communication-and-navigation interaction has been ongoing for years as Future Air Navigation Systems (FANS) equipment such as Controller Pilot Data Link Communications (CPDLC) is being developed. This type of system replaces air traffic control instructions and read backs, automating ATC processes. However, the challenge of such systems is that they only complement, instead of replacing, voice communication so they’re expensive and can only reduce workload in a portion of situations, which means increased pilot training since the pilot needs to be familiar with both types. Operators will likely want to explore standard adoption across all aircraft types (UAVs, General Aviation, VTOLs, and Commercial Airlines) and determine how to enable this implementation.

NASA’s UTM system is currently focused on achieving an airspace management system for small UAVs operating below 500 feet altitude. This approach segregates small UAVs from other air traffic which typically flies at higher altitudes. However, it is unlikely that even small UAVs will be able to operate in a completely segregated fashion due to private property altitude restrictions and the need for separation assurances from General Aviation and Commercial traffic. A simpler approach, segregation of airspace across aircraft types, is likely not a long-term solution. Expanding the application of UTM to general aviation aircraft, both cooperative and noncooperative[34], through an expanded NASA-Industry-University collaboration would provide a comprehensive air traffic management solution up to several thousand feet. Like high volume voiceless ATC, NASA will need to point to demand for high-capacity airspace technologies to justify embracing this expanded scope in a timeframe that supports rapid market implementation.

Other challenges will also require attention as eVTOL traffic volume increases, such as efficiently managing the scheduling and sequencing of vehicle and vertiport resources in a manner that achieves high system capacity and efficiency while optimizing door-to-door travel times and variations for users of the system. Additionally, as we have seen with self-driving vehicles, it will be important to consider the standards that manage the way that different fleets govern their autonomous travel decision making. Small differences in how vehicles are programmed to respond to (or learn how to respond to) operational situations or impediments can lead to potential conflicts, particularly if the decision-making parameters or tolerances in interpretation of the rules of the sky differ across different network managers' fleets autonomy systems. Manufacturers, regulators, and fleet operators will need to reach consensus on suitable standards to manage these challenges, and discussions in this space are already underway. Increased vehicle behavior uniformity will result in more efficient and safer fleet management.

Fortunately, the technology for many of these advancements is available readily today—the major obstacle so far to adoption of these technologies, such as ADS-B, has been high cost due to inherently small-scale manufacturing of general aviation aircraft. Standardization of building blocks such as ADS-B has already been accomplished. Finally, operators that unlock latent customer demand will spur significant VTOL manufacturing demand, which will drive down the aviation technology acquisition costs to the point where utility and general aviation will be able to adopt new technology at low cost.

Development of infrastructure in the piloted phase will flow directly toward the requirements for autonomous operation. Primary navigation will be based on existing global navigation satellite systems (GNSS) with simultaneous reception of GPS, GLONASS and whatever other international systems become available in this time, such as GALILEO (Europe) and BeiDou (China.) Precision positioning for approaches to vertiports and vertistops may also be required, using a combination of WAAS augmented GPS and microwave transponder technology. As with UTM for unmanned vehicles, FAA is not expected to provide

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[34] Non-cooperative traffic (aircraft not carrying suitable equipment to cooperate) is likely not to be a problem in the urban areas where VTOLs will be launched, as nearly all of them will be subject to mandatory ADS-B operation by 2020.

separation services for low altitude VTOLs as they do for airline and GA traffic. It must be possible for eVTOLs to navigate independently of ATC while they are in airspace not used by conventional aircraft. All these requirements are shared with the UAS community, and it is likely that the same approach will evolve in parallel for eVTOL PATS operation, at a higher level of reliability for passenger-carrying flight.

The communications or datalink portion is likely to be a combination of ADS-B, existing cell phone and low earth orbit satellite networks, and low power terrestrial microwave datalinks. From the outset the system is expected to be triply redundant to handle all contingencies; full functionality will be maintained with at least two of the networks inoperative. The data bandwidth required is quite low for essential functions that require network-wide visibility. Higher bandwidth and shorter latency will be required when vehicles are near each other, but several approaches are already being developed in the UAS space with this capability; NASA’s UTM program is leading the way here.

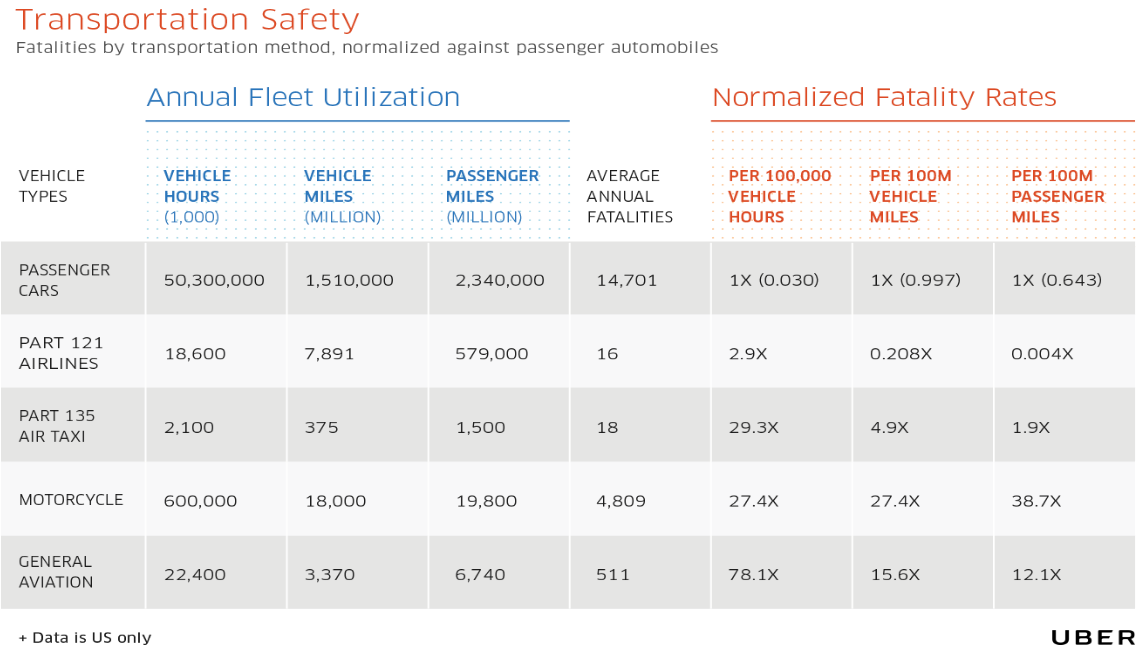
Sequencing and spacing will necessarily be vertically integrated through the airborne rideshare ecosystem. Not only must a vehicle and vertiport/stop space be available, but airspace for the flight must be reserved, and status and position of each vehicle monitored in real time. This field is under continuous development today for larger aircraft with the NASA/FAA NextGen program, and eVTOL PATS can use a similar approach scaled to meet their own flight requirements. This is an area where continuous development of microprocessor speed and memory capacity maps directly the ability to handle denser air traffic, to more precision.

5.3.5 Safety Systems Technology

For widespread public adoption of eVTOL PATS as a ridesharing option, riding in an eVTOL must be safer than riding in an automobile. Additionally, the public is very aware that flying commercial airlines is significantly safer than driving, which puts upward pressure on safety of any aviation offering, especially one intended for daily use. While scheduled airlines operating under Part 121 of the FAA Federal Aviation Regulations (FAR) will almost certainly remain the safest mode of transport, initial target is to achieve a safety level that is twice that of driving a car based on number of fatalities-per-passenger mile. Today, using Part 135 helicopter and fixed-wing operations as the closest proxy, the safety level in air-taxi aviation is two times worse than driving, which means we would need to see an improvement of four times (from 1.2 to 0.3 fatalities per 100 million passenger miles) to achieve that target. Additionally, the regulatory discussion will be complex because safety can be measured on several dimensions (e.g., injuries, accidents)[35].

General aviation accounts for many accidents due to private pilot inexperience and poor maintenance, as well as antique, warbird, and experimental amateur-built aircraft that similarly represent a large portion of accident incidents. eVTOLs will be manufactured, flown, and maintained to meet the more stringent levels of control and FAA supervision covered under Part 135. Additionally, eVTOL PATS operations, at least until autonomous operations become commonplace, will require commercial pilots who must have a higher level of training, experience, flight review, and medical certification than is the case for private pilots.

Table 5.2 Transportation Safety, source: (Uber, 2016).



Transportation Safety

Fatalities by transportation method, normalized against passenger automobiles

	Annual Fleet Utilization				Normalized Fatality Rates		
VEHICLE TYPES	**VEHICLE HOURS** (1,000)	**VEHICLE MILES** (MILLION)	**PASSENGER MILES** (MILLION)	AVERAGE ANNUAL FATALITIES	**PER 100,000 VEHICLE HOURS**	**PER 100M VEHICLE MILES**	**PER 100M PASSENGER MILES**
PASSENGER CARS	50,300,000	1,510,000	2,340,000	14,701	1X (0.030)	1X (0.997)	1X (0.643)
PART 121 AIRLINES	18,600	7,891	579,000	16	2.9X	0.208X	0.004X
PART 135 AIR TAXI	2,100	375	1,500	18	29.3X	4.9X	1.9X
MOTORCYCLE	600,000	18,000	19,800	4,809	27.4X	27.4X	38.7X
GENERAL AVIATION	22,400	3,370	6,740	511	78.1X	15.6X	12.1X

+ Data is US only

UBER

To understand the path to improving safety for urban air transportation, we need to understand the root causes of historical crashes.[36] Part 135 scheduled and air-taxi operations are especially common in Alaska, and about half of the fatalities were in Alaska due to pilot error described as controlled flight into terrain, mid-air collisions, and loss of control. Radar surveillance is nonexistent over most of the area, air traffic control is not real-time and weather

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[35] Ken Goodrich, http://www.nianet.org/ODM/presentations/Overview%20SVO%20Ken%20Goodrich%20and%20Mark%20Moore.pdf Slide 8, Kansas City ODM Workshop, Oct 21-22, 2015.

[36] http://www.ntsb.gov/investigations/data/Pages/AviationDataStats.aspx#

conditions are often not as forecast. Loss of control occurs when a combination of poor planning and judgement, diminished human ability and inclement environmental conditions combine to put the aircraft outside the pilot's ability to keep it on the desired trajectory.

These accident types could be prevented through relatively simple forms of vehicle autonomy that provide supplemental vehicle control while interfacing with improved navigational and weather information. The military has already implemented terrain collision avoidance pilot-aids, such as the Automatic Ground Collision Avoidance System which has been confirmed to have saved F-16 pilots[37]. Major improvements have been made in the midair collision rate in Alaska through aggressive adoption of better navigation sensors and aircraft-to-aircraft ADS-B systems, which will be included in all aircraft flying in most dense urban areas by 2020. eVTOLs will necessarily make use of digital fly-by-wire systems and adapting these systems to include pilot aids will be the key to significantly reducing failure modes attributable to pilot error. Pilot aids will evolve over time into full autonomy, which will likely have a marked positive impact on flight safety. Since half of the Part 135 crashes are related essentially to poor weather data and pilots not being where they thought they were, operating only in urban areas with real-time weather and air traffic control brings existing Part 135 operations to par with the safety of driving a car. Improving a further 2x through the adoption of advanced pilot aids and autonomous systems will bring eVTOLs the rest of the way toward our initial goal of being twice as safe as driving.

To improve eVTOL air vehicle safety beyond that of cars, we must consider the complexity of controlling multiple propulsion motors. The eVTOLs envisaged in this paper will be inherently "optionally piloted vehicles" in which pilot control is unnecessary except for visual avoidance of obstacles and other aircraft. Rather than physically commanding operation of engines and control surfaces, the pilot establishes a desired trajectory which the vehicle follows. Direct mechanical control workload is greatly reduced, leaving more of the pilot's attention for situational awareness, and this eliminates the need for pilot judgement in planning and executing vehicle state maneuvers to achieve a desired trajectory.

Beyond loss of situational awareness and control, the next highest accident cause is associated with engine failure, which accounts for 18% of general aviation accidents when combined with fuel management errors. Fortunately, both causes are also mitigated with implementation of Distributed Electric Propulsion technology (DEP) that forms the basis for these new vehicle concepts. The use of multiple (typically six or greater) electric motors,

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[37] https://theaviationist.com/2016/09/13/watch-an-f-16s-automatic-ground-collision-avoidance-system-save-anunconscious-pilot-from-certain-death/ http://www.cdc.gov/niosh/topics/aviation/

controllers, and a redundant battery bus architecture avoids the problems of catastrophic engine failure by having full propulsion system redundancy. An engine failure might result in diminished speed or climb capability, but full control authority within the aircraft's operating envelope can be maintained. Improvements in this area can be expected to reduce accident rates even further than the previously specified goal.

The use of DEP combined with autonomy provides the opportunity for the fully digitally controlled fly-by-wire control system to interact across digital systems without complex analog or mechanical interfaces. Digital data across each element of the propulsion system is managed through redundant master flight controllers, from battery cell voltage state of charge to motor temperatures that permit optimization of the system performance and health. Distributed propulsion provides not only redundancy, but also the potential for additional control robustness to be designed into the aircraft system such that any component can fail gracefully, enabling a controlled landing. Robust vehicle control provides the ability to deal with uncertainties or disturbances within the vehicle control system. Control robustness is also helpful to deal with high wind or gust conditions, especially when operating in an urban environment that promotes local flow disturbances.

Vertical flight imposes additional operational challenges that conventional takeoff and landing aircraft do not experience. DEP technology already mitigates most of these challenges; DEP eVTOL PAVs will likely have a higher downwash velocity that permits a more rapid descent, and when used in combination with multiple propeller-rotors will help to avoid rotor recirculation flow conditions (such as entering a vortex ring state). Downwash is the induced velocity of air deflected downward by the propulsion system prop-rotor to achieve vertical lift. For example, helicopters typically have a rotor downwash of 2 to 10 pounds of thrust per square foot. DEP eVTOL PAV configurations typically use 10 to 20 pounds of thrust per square foot.

An eVTOL PAV will typically have a Thrust/Weight of 1.15 or greater to provide extra power for climb and a control power margin. This Thrust/Weight ratio is typically measured at the continuous power rating. While turbines and piston engines are often able to provide a short time emergency rating that provides a 10-20% increase in power, electric motors are typically able to produce an additional 50%+ power for 1-2 minutes until they overheat. These peak ratings aren't accounted for in the Thrust/Weight but reserved for emergency operation such as failure of a motor. For the case of sizing the aircraft to accommodate a single engine (or motor) failure while maintaining the ability to complete the mission and land safely with power, a twin-engine helicopter would need to have a Thrust/Weight ratio of greater than 2.0 with the peak rating during the single engine emergency providing an effective Thrust/Weight ratio of

1.1 to 1.2. For a DEP eVTOL air vehicle with 6 prop-rotors, failure of a single motor causes a reduction of thrust of about 17%, with the peak ratings of the electric motors providing greater than this reduction during the single engine inoperative emergency case. This sizing to account for an engine (motor) inoperative case is one of the significant advantages that DEP offers to reduce the penalties previously associated with vertical lift aircraft. Helicopters can auto-rotate and conduct an emergency landing without power, while DEP eVTOL air vehicles are less likely able to auto-rotate (depending on the specific configuration). In any case, auto-rotation does not work well in dense urban areas from low altitude, because the poor glide slope of helicopters results in landings within a short distance.

The DEP eVTOL air vehicle flight safety value proposition becomes most powerful when combined with increased vehicle autonomy such that the autonomy prevents the eVTOL air vehicle from entering potentially hazardous states in the first place. Autonomous flight control will provide improved trajectory flight profiles that are able to minimize the extra power required for control by using the combination of optimal speed, climb angle, angle of attack, and propulsion/wing inclination angles throughout the hover to forward flight transition corridor.

Achieving high perceived safety is also valuable, especially during the initial adoption. By avoiding the use of a large rotor, an eVTOL PAV is also able to take advantage of Ballistic Recovery Systems (BRS) [38]: whole vehicle parachutes that can be deployed in an emergency to safely bring the vehicle to the ground, and it can avail itself of other evolving safety technologies being tested such as whole aircraft airbags. Multiple companies are developing even more capable BRS solutions that can provide additional safety across nearly all vehicle operating conditions, even if the vehicle is moving slowly and is near the ground.

Of course, innovation on the safety front will continue after the first eVTOLs are in production; full autonomy and large amounts of data from real-world operations fed back into the designs will push eVTOL PATS operations toward airline aviation levels of safety.

5.3.6 Priorities and Gaps

NASA, in collaboration with the National Institute of Aerospace, has conducted a series of government/industry workshops to identify the key technologies and capabilities required to enable transformational on-demand air mobility systems to be developed and deployed. The Aeronautics Research Mission Directorate (ARMD), NASA Headquarters, requested an

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[38] In fact, BRS systems have already been responsible for saving 358 lives through deployment on General Aviation aircraft, http://www.brsaerospace.com/brs_aviation_home.aspx

analysis of the strategic framework and public value proposition for on-demand mobility vision and concepts, to support decisions on research and technology development investments by the agency.

This analysis provides a high-level view from a team of subject matter experts experienced in all aspects of aviation innovation: aircraft, airspace, airports, operations, policy, regulation, technology, strategy, partnerships, and finance. After carefully examining the roadmaps and understanding the mission requirements, the strategic framework team reached the following distilled conclusions and related high-level recommendations about the following technology and capability development activities listed below a high priority:

- Airframe Integrated Distributed Electric Propulsion,
- High Specific Energy Long-Life Batteries with Rapid Recharging Capability,
- High Voltage Hybrid-Electric Power Systems and Range Extenders with Low EMI Interference,
- Adaptive High-Reliability Electric Motor Control Systems,
- Multifunctional Structures/Thermal Management/Energy Storage Systems,
- Electric Propulsion Standards (Reserves, Control, Charge Management, Testing),
- Highly Augmented Flight and Trajectory Control with Efficient On-Demand Routing and Sequencing,
- Highly Reliable Automated Detect, Sense and Avoid Systems That Allow Critical Human Intervention,
- Beyond NextGen Airspace Systems Able to Accommodate Orders of Magnitude More Vehicles,
- Certification for Autonomous Operations,
- Low-Altitude Full Aircraft Parachutes and Energy Absorbing Emergency Recovery Systems,
- VTOL Advanced Noise and Propeller Control Technologies and Modeling,
- Damage Tolerant, Self-Healing, Smart and Morphing Structures,
- Anti-Ice Coatings and All-Weather Systems,
- Flexible Robotic and Additive Manufacturing.

Although the proposed set of technologies and activities is quite comprehensive, several gaps remain that will require additional investments in technologies and capabilities. The gaps include the following technical fields:

- Cybersecurity/Trusted Communication,

- Consumer Acceptance/Human Factors Assessments – Ride Quality, Acoustics, Perceived Safety,
- Vertiport / Vertistop Infrastructure – Including Rapid Charging Stations,
- Smart/Reliable Sensors to Enable Autonomous Operations and Self Separation,
- On-Board Weather Detection and Robust Adaptation,
- Air Vehicle Design Optimization (Speed, Range, Payload) as a Function of Latent Demand Characteristics,
- High-Data-Rate Connected Aircraft for Airspace Operations,
- System and Subsystem Certification Requirements for automation and more autonomous capabilities (drawing on the automotive industry advancements),
- Robust Control Architectures to Engine-Out, Gusts, Weather, Obstacle Avoidance, Etc.
- Human/Machine Interfaces for Emergency Pilot/Passenger Intervention,
- Intermodal Network Real-Time Optimization Architectures and Approaches,
- Active Noise Control and Acoustic Metamaterials for Cabin and External Noise Abatement,
- Airspace Architectures/Flight Rules for ODM,
- “Pilot” Training/Certification.

Many of the identified technology needs for on-demand air mobility are already being addressed to varying degrees (sometimes with different requirements) in other ARMD projects, such as: rotorcraft, structures and materials, acoustics, autonomy, etc. Investments in many of the ODM technologies identified by the roadmaps and gap analyses will have “scale-up” benefits to larger commercial and general aviation aircraft. For example, investments in better batteries will benefit auxiliary power systems for larger commercial aircraft and provide augmentation during high-power demand (e.g., take-off and landing). Distributed electric propulsion could allow wing tip propellers that reduce vortex induced drag, thus saving fuel. This technology could also be applied to other areas of the vehicle, including improved aerodynamic performance. The major technologies investments identified as having significant scale-up synergy include the following:

- High Specific Energy Long-Life Batteries with Rapid Recharging Capability for Auxiliary Systems,
- Hybrid Electric Propulsion/Power Systems,
- Higher Levels of Autonomy for Reduced Crew Operations,
- Multifunctional Structures/Thermal Management/Energy Storage Systems,

- Highly Augmented Flight and Trajectory Control with Efficient On-Demand Routing and Sequencing,
- Damage Tolerant, Self-Healing, Smart and Morphing Structures with Integrated Structural Health Management (ISHM),
- Anti-Ice Coatings and All-Weather Systems,
- Flexible Robotic and Additive Manufacturing,
- Trusted Communications/Cybersecurity,
- High-Data-Rate Connected Aircraft for Airspace Operations.

Similarly, investments in many of these technologies identified by the roadmaps and gap analysis will have "scale-down" benefits to small and large UAS.

On-Demand Mobility Goals

(10) Prioritized Feasibility Barrier Goals

Goal	Metric
Ease of Certification	Time/Cost Required
Affordability	Total Operating Cost/Pax Mile
Safety	Fatal Accidents per Vehicle Mile
Ease of Use	Required Operator Training Time & Cost
Door to Door Trip Speed	mph
Average Trip Delay	Time
Community Noise	Perceived Relative Annoyance @ Community Stand-off Distance
Ride Quality	Passenger Comfort Index
Efficiency	Energy/Pax Mile
Lifecycle Emissions	Total Emissions /Pax Mile

Fig. 5.14 NASA On-Demand Mobility Prioritized Feasibility Barrier Goals

Within this context, Prioritized Feasibility Barrier Goals in Figure 5.14, summarizing prospective figures of merit for on-demand mobility transportation, was presented to the government, industry, and academia attendees at the second workshop "On-Demand Mobility Roadmapping Workshop" conducted in Kansas City, Missouri, October 21-22, 2015. The purpose was to gather a sense of the community around the value of the approach to understanding priorities for on-demand mobility metrics and goals. The chart was well-received for this purpose.

5.4 Main Challenges

This subsection addresses the challenges that facing eVTOL PATS implementation from different perspectives. The emerging air transportation system should ensure the mobility of people and goods, fostering safe and secure commuting, without negative impact on other parties. However, the innovations underway in new forms of air mobility involving autonomous aircraft flying in automated airspace management systems may have unintended consequences and unpredictable paths of development. Much the same as it was difficult to foresee the positives and negatives of the internet or mobile telephony, so it will be challenging to foresee the facets of more widely distributed air mobility available to more consumers between more origins and destinations than we could imagine in the last century.

Whenever the idea of personal air vehicles is presented and discussed, many questions regarding not only the technical feasibility of the pure vehicles but especially concerns about safety (collision avoidance, controlled flight into terrain, terrorist threats, etc.) are expressed. Further questions arise on how air traffic management for them could look like and on where the aircrafts would be allowed to fly and at what times. Other major challenges are the topics of certification and regulation and the question of how to integrate the PAVs into the existing ground transportation but also into the existing air transportation system (Muller, 2010). In the field of environmental issues, the uncertainty about energy consumption and emissions is noticeable; especially the issue of noise disturbance seems to be a key one that comes up whenever people are confronted with the idea of PAVs flying around in higher counts in a city environment. To look in detail into all these questions is well beyond the capacity of this study but some of these key issues will be discussed further in the following subsections.

5.4.1 Safety and Security

Safety plays a dominant role in government and public acceptance of aviation as a transportation system. As we have discussed in detail in subsection 5.1, one key issue for potential users, service providers and regulator for sure is safety and security for the user inside and for the people around. The safety and security issue were interestingly coming up in all focus groups and in our survey straight away at the beginning, expressed as a concern and then again right at the end. It is argued that social acceptance of a transportation system depends mainly on actual and perceived safety of the system (LeTallec, 2013).

In myCopter project, regarding on-board safety, misuse by terrorists, laser attacks, computer hacking into the system and danger through PAV parts dropping of one PAV down to another one was envisioned. Also, the problem of induced fire due to a PAV crashing into buildings was raised. The problem of overhead lines (power, trams) that could prevent a secure landing in emergency cases and would be a handicap for PAV operations in cities generally was mentioned too. Also, problems with aerodynamics during landing at places where buildings around could embrace the air flow were considered. In terms of emergency cases, a distinction was made between an emergency for the person inside because of medical reasons and a system failure (loss of power, computer malfunction, etc.). An additional major challenge is surely the weather situation and how the PAV would be able to cope with strong winds, snow, icing, and heavy rain (Meyer, 2014).

Regarding actual safety, it is obvious that such a system needs to be designed according to standards carefully defined to guarantee the level of safety that will be requested by authorities. PPLane project’s conclusions indicate that careful design using practices leading to high reliability should enable creation of safe system (LeTallec, 2013). Thus, it is understandable that accidents have been drivers for significant legislation dealing with aviation as well as private sector response (Bruce, 2017). For example, loss of a Fokker F-10 Trimotor flown by Trans World Airlines on March 31, 1931, resulted in the deaths of all occupants. Public outcry in response to that accident lead to sweeping changes in many aspects of aviation, ranging from aircraft design (e.g., abandonment of wooden wing spars for air transports) to government oversights of air carriers. The catastrophic midair collision between a TWA Lockheed L-1049 Super Constellation and a United Airlines Douglas DC-7 over the Grand Canyon in June 1956 resulted in significant changes in air traffic management, including mandatory use of instrument flight plans for scheduled air carriers and greater application of radar within ATC. Regulations affecting on-demand carriers were profoundly altered by the loss of a chartered Martin 4-0-4 airliner carrying members of the Wichita State University football team in early October 1970. Often accident-generated changes were subject-specific and not all-encompassing. FAA rules impacting operational control of air charter companies were found in need of major revision following the NTSB’s investigation of a Challenger CL600 that aborted its takeoff and crashed at Teterboro Airport on February 2, 2005, 35 years after the regulatory reform for OnDemand operators resulting from the Wichita State accident. Truly profound changes in air transportation resulted from the terrorist attacks of September 11 2001, when four airliners were hijacked (Bruce, 2017).

Several technical and human induced errors can lead to accidents or unsafe situations in aviation. Today, accidents caused by humans are a major part of the total number of aviation accidents. In fact, depending on the aircraft class, according to the Aircraft Owners and Pilots Association Nall Reports – published every year, by technical failures as a cause of an accident are only around 10% of all causes (indicate around 16% of all accidents contributed to "mechanical/maintenance" problems, and only around 8% of fatal accidents related to the same cause). Therefore, a higher level of automation (when properly designed) can lead to improvements in safety. Safety statistics show that automation has contributed greatly to the current level of safety: the accident rate of recent aircraft is half that of the previous generation of aircraft. The global level of safety now appears to be equal to that of the nuclear industry or railways (in Western Europe). The only apparent concern is that this remarkable level of safety has not significantly improved since the 1970s (LeTallec, 2013). Another important issue that arises is the safe and secure data transmission through air data links. This issue opens a brand, new area of protection against unlawful use. This is not related to simple reliability as it was known on conventional aircraft; it therefore requires new approaches and technologies. Despite potential problems, higher automation shows promising potential to enhance safety in future transportation systems.

Perceived safety is a more complex issue as it deals with human perception based on many types of information. Basically, the emerging air transportation mode will first be perceived through the preliminary analysis of the measures that are taken to provide adequate safety. Then, its hazardousness will be shaped according to the events that might occur, and especially through their explanation. We still have catastrophic aircraft accidents killing hundreds of people every year. Those accidents are very often due to human errors. Safety is mainly perceived by the community through these catastrophic accidents that appear on the news. The strong belief of the PPlane project team is that human errors can be easily handled if humans have a supervisory role only, having to intervene only in particular situations (LeTallec, 2013). In that case, the safety level of the system is determined by the safety elements of its design. Consequently, the design of the system should significantly reduce the rate of accidents.

The possible problem we may have with the introduction of eVTOL PATS would be to have accidents in the early life of the system. These accidents could compromise building confidence in the system although there would be means to make the system better and safer along the years, as it has been the case since 1903 (first flight of the Wright Brothers) for manned aircraft in aviation. Once this initial period is over, we expect a low number of problems due to automated systems, enabling a smooth social acceptance of this efficient and safe system. This situation means that the design of an automated system must be done considering the very large emphasis that will be put on any accident, and even incidents, no matter how small, that could compromise human life. One way to deal with the safety issue is to propose a transition period whereby PAVs will be used to carry cargo only and no passengers. This period can be used for detailed analysis and suggested improvements that will be implemented in the system prior to passenger transport.

One main topic regarding flight safety and reliability is the weather. Because this topic was seen as a potential major hurdle for a frequent and reliable use of eVTOL PAVs. Due to the increased consequences of a failure enroute, environmental conditions and weather have more acute implications for aircraft than automobiles. Weather is a complicating factor for flight, with serious challenges created by fog, icing, wind, and thunderstorms and a big topic for air traffic in general. Thunderstorms that create large wind shear, icing, and low visibility during the takeoff, departure and landing approaches are the largest sources of aircraft operations interference. Heavy precipitation and wind gustiness create volatile conditions that cause further disturbances during takeoff and landing can make it difficult to maintain vehicle control and reasonable safety margins. eVTOLs will need to leverage additional technologies to augment visibility, maneuver effectively in gusty wind conditions, handle most icing concerns, and take advantage of enhanced weather information and prediction to maximize the percentage of operational time available, all of which in turn will maximize vehicle utilization and economic feasibility. Technologies ranging from auto-deicing to autonomous piloting, which will increase both vehicle control precision and the uniformity of flight suitability decision making, should significantly increase eVTOL PATS availability over time. Ensuring the highest safety without embracing operational complexity (i.e., spraying vehicles to remove ice prior to takeoff such as airliners) will be particularly important in the early years of any large eVTOL PATS network, which has implications for the specific urban locations.

Currently, many aircrafts are not approved for flight in known icing (FIKI) conditions according to the FAA (FAA Aviation Safety, 2010). Snow and ice stick to and can form on rotors and airframe components, adding weight and changing the shape of the airfoil. Icing conditions are not solely a cold-weather environment phenomenon; these conditions exist even at certain altitudes during occasional weather conditions. This means that pilots should not fly in areas where visible moisture (fog, rain, or clouds) exists, and the temperature is below 5°C. As icing is not only a topic on cold and wet days but might also occur on warmer days with a high humidity (QBE Aviation, 2011), it is seen as an import issue to be addressed regarding the Reference eVTOL PAV to attain a good usability over the year performance. The icing issue seems to be quite difficult to cope with though and even aircrafts with an approval to fly into known icing conditions are not advised by the FAA to really do this (Federal Aviation Administration, 2008). While not available today, the combination of icephobic coatings and electric propulsion would enable much colder markets. Icephobic coatings[39], which are in the very exploratory stage of development by NASA and others, repel ice formation on the wings and propellers to eliminate the need for costly active de-icing systems (i.e., pneumatic boots and heating leading edges). While eVTOL PAVs are unlikely to operate at higher altitudes where they would routinely encounter airframe ice, electric propulsion offers a unique operational safety advantage of permitting extremely high levels of power to be generated for short periods of time until the motor reaches its thermal limit (typically 30 to 120 seconds of operation). This capability can be used for short bursts of power in an emergency condition, or for short term high rates of climb to penetrate an altitude icing layer rapidly before ice can build up (Uber, 2016). For the Reference eVTOL PAV, the discussion resulted in the decision that the PAV should be able to fly in icing conditions although the explanations above have illustrated that this ability is not easily obtained. The consortia also agreed that a flight in a thunderstorm was completely unacceptable due to unfavorable conditions such as turbulences, the potential of lightning strikes, hail stones, etc. and that the flight path of the PAV should be re-routed in such an event or be delayed.

Even with traditional IFR operations (apart from a few very expensive aircraft), the last few seconds of flight must allow the pilot to see the landing environment. An airport "below minimums" means that at the closest safe approach point, this ability to see the landing environment doesn't exist. eVTOL PAVs can fly an approach at much slower speeds than conventional airplanes, leading to reduced requirements (as permitted also for helicopter approaches), but until they are fully autonomous, visual conditions will still be needed. Vision systems that can use the infrared spectrum to see through fog have already been developed and deployed on business-class jet aircraft. This type of vision enhancement is typically combined with mapping data creating synthetic vision systems that provide clear terrain depictions (typically derived from the worldwide NASA Space Shuttle Radar Thematic Mapper dataset) while also capturing atypical obstacles (e.g., cranes). These types of systems augment low visibility conditions but can't work in zero visibility conditions. Comprehensive vision systems that combine all these solutions are not yet available, and projections indicate they would introduce a significant weight penalty for smaller aircraft. However rapid progress is taking place, and there is considerable confidence that highly capable synthetic vision systems will be able to permit operation in lower visibility conditions.

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[39] https://en.wikipedia.org/wiki/Icephobicity

Gusts can be particularly challenging around high-rise buildings in urban environments. eVTOL PAVs will need to observe safe clearances from any man-made object, with the FAA requiring any fixed-wing aircraft to maintain at least 500-foot separation from any structure. Such buffers will need to be built into the map systems for eVTOL PATS to ensure that they avoid these safety zones, especially in dynamic cityscape environments where a crane can be erected in a few hours. The extra power available for short periods is also applicable here, as additional control authority is available to counteract gusty conditions. Operating a network of linked eVTOL PAVs that monitor and share the atmospheric conditions they experience permits real-time and historical mapping of gusty locations enabling dynamic routing and approach procedures that minimize exposure to gusts. This type of detailed and highly distributed weather sampling will also be able to improve local weather prediction accuracy.

To get a first impression about how tricky it might be to get a similar level of “reliability” or usability for the eVTOL PAV as the car, a weather analysis for a transect was conducted in Germany (distance 30 km; location: near Frankfurt). The myCopter project investigated to realize the high requirements on the “usability over the year” of 90% for the reference PAV of myCopter. This requirement of 90% seems to be at the lower end of what could be accepted and competitive against a car (Decker, 2013). The aim was to see on how many days of a given year a flight from A to B in this region would have been possible at certain times of the day. Although this analysis was only looking at one certain area in one year, it illustrates that the dependency on weather conditions is quite high.

In short, as the technology underlying eVTOL PATS evolves and operational capacity in a diverse range of more challenging weather environments becomes possible, wider eVTOL PATS adoption across various markets is likely to be supported further if a set of key hurdles such as density altitude, ice, visibility, and gusty winds is overcome.

Another main topic regarding flight safety is the autonomy. As we mentioned before, autonomy is a critical enabler for eVTOL PATS, because autonomy reduces mishaps and fatalities dramatically (human factors attributed for 79% of rotorcraft fatalities), enables routine operation in nearly all-weather conditions and removes burden of following instrument flight rules, address routine operation to/from small and uncontrolled areas (Drozeski, 2018). New control and stability systems developed for unmanned aircraft now allow previously unflyable configurations to be extremely controllable. It is clear that high automation has made significant progress on safety. Ultimately, autonomy will ensure vehicle/obstacle avoidance and clear path to a landing site in the long term through Light Detection and Ranging (LIDAR) and laser scanning systems. These systems are already used on UAVs with increased range and tolerance to rain and dust vision obstruction; their costs are rapidly decreasing due to their mass fabrication spooling up for implementation on self-driving cars (Uber, 2016).

In myCopter project, the focus groups had also covered the potential solutions for an engine failure etc. with suggestions to have an airbag or parachute to handle system failures. Some participants also discussed the impact of PAV on people on the ground, both because of their (potential) ability to land everywhere or because of emergency situations.

The other aspect, security, is seamlessly integrated into the smooth operations of the eVTOL PATS and ensuring security screening will be essential. App-based operators are uniquely positioned to leverage technology to integrate and minimize the inconvenience of any security requirements while eliminating time-consuming steps which riders are subjected to today in aviation. For example, Uber's self-driving cars in Pittsburgh feature tablets in the backseat which will one day verify the rider's identity without any human oversight in-car (Uber, 2016). Additionally, the data required to verify a rider's identity and associated preferences will likely be persistent as part of a ridesharing provider's mobile app; as such, operators may develop systems like the FAA TSA Precheck[40] which permits rapid and reduced airport security screening if the passenger is determined to present a low risk through machine learning and other inputs. While Part 135 aircraft operations do not require the same levels of security screening as if a passenger were boarding a commercial airline, eVTOL PATS operators will want to explore the optimal mix of pre-flight, technology-enabled screening with sensible on the ground security parameters to enable safe, secure, and enjoyable journeys (Uber, 2016).

In summary, while safety is primarily the concern of regulators, communities will also worry about safety. Operators will need to communicate the safeguards inherent in the eVTOL PAV design to develop the level of trust needed. Local communities will also have concerns regarding the security of these aircraft, including their vulnerability to hijacking and hacking. Local law enforcement and national transportation security agencies will necessarily be closely involved in the operational details of any new eVTOL PATS service, but local communities will be given a complete understanding of the security safeguards that have been put in place. While not fully autonomous initially, eVTOL PATS is inherently trajectory-controlled rather than state controlled, which means that the flight path can be modified remotely if needed. With suitable safeguards for network security, capability can be provided for remote pilots to override the on-board pilot in an emergency. Operators will appreciate that vertiports and vertistops will become new or more visible features of urban landscapes. Ensuring the safety

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[40] https://www.tsa.gov/precheck

and security of these sites for both operational purposes and seamless, unobtrusive integration into the fabric of cities will undoubtedly be a joint effort across local communities, law enforcement, national security agencies and network operators.

5.4.2 Ease of Use and Autonomy

Industry's current perception of ease of use is that the small aircraft market would be considerably larger if this vehicle technology group were able to provide simple and standardized auto-like operation. This logic is based on a comparison of the percentage who can afford to fly, desire to fly, but don't. Besides, recognizing the potential benefits of automation to the primary causes of accidents in general aviation also initiate efforts to explore more affordable approaches to implementing these types of systems. For example, ease of use could have a major impact in the improvement of safety since operator error accounts for approximately 65% of accidents alone (Decker, 2003). Autonomous eVTOL PAVs will improve the safety of their operations, just as self-driving cars have the potential to reduce the number of automobile accidents which cause 1.3 million fatalities per year globally[41]. However, eVTOL PAV autonomy is likely to be implemented over time, as users and regulators become more comfortable with the technology and see statistical proof that autonomy provides greater levels of safety than human pilots.

After this explanation, I think that first, there is a need to explain what ease of use involves. Ease of use involves everything from time and cost for proficient training, to interaction with the national airspace system, to operation of the aircraft. Simplified user vehicle interfaces include intuitive instrument panel with auto-like simplicity and safe, blunder resistant controls with the equivalent of a co-pilot on a chip. Pre-flight simplification, terrain and obstacle avoidance, envelope protection, intuitive vehicle health/knowledge systems, synthetic and enhanced vision, velocity vector with haptic control, decision aids, propulsion management systems, weather information and avoidance, autonomous emergency procedures, automatic takeoff/landing, and even incapacitation detection are all part of the ease-of-use problem to be worked (Uber, 2016).

It is anticipated that eVTOL PAVs will feature significant automation/autonomous technology but also a degree of occupant involvement in the flight management. There is a broad-spectrum range of definitions of autonomy, from a vehicle simply following a pre-programmed function to sentient machines interpreting their internal states as well as their

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[41] World Health Organization. http://www.who.int/mediacentre/factsheets/fs358/en/

environment to enable them to make decisions about future to achieve pre-programmed or even learned goals (Mills, 2011). Just as mobility solution providers are experiencing with self-driving cars, there’s a nearer term approach that includes having reversionary modes where the pilot can always overpower the vehicle-recommended control. eVTOL PAV pilots will derive substantial benefit from obstacle detection and sense-and-avoid systems that can alert the pilot of concerns and provide operating envelope protection. This approach provides a path to decreased pilot workload (as well as reduced training) in urban environments while potentially achieving a lower certification burden due to the reliability of the combination of pilot along with the autonomy components and software.

The evolution of autonomous capabilities is currently progressing through with automobiles. Uber has begun carrying passengers with Level 3 autonomy in cars equipped with safety drivers to intervene if needed. Tesla has announced[42] that all their cars will be sold with at least the hardware required for level 5 autonomy, full self-driving capability. While these advancements have excited the self-driving car community, establishing the software[43] to ensure safe operation across all off nominal conditions will take many more years (Uber, 2016). Self-flying eVTOL PAVs will progress across a similar autonomy scale and while autonomous cars won’t directly enable autonomous aircraft, their constituent technologies have a strong commonality. Compared to ground vehicles, the environment in which eVTOL aircraft operate is far more open and uncluttered, except during takeoff and landing when operating near the ground, buildings, and people. While there may be airspace restrictions and other eVTOL PAVs to be aware of, compared to self-driving cars (which need to deal with everything from construction to road obstructions, as well as reacting with only small separation distances), the challenge of automation for eVTOL PAVs seems to be less daunting.

It is tempting to think that a future eVTOL PAV will be fully automated and the „driver“ will be a passenger, perhaps only entering a destination into the navigation system. For some journeys, this may well be the case and may provide extra time in the day to catch up on work, read the newspaper etc. Full automation is currently achieved for some unmanned vehicles in specific scenarios, but the integration of eVTOL PAVs into densely populated airspace and the associated requirements for collision avoidance and vehicle motion coordination are still unsolved research topics.

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[42] https://www.wired.com/2016/10/elon-musk-says-every-new-tesla-can-drive/

[43] Tesla includes a disclaimer in their level 5 statements that “self-driving functionality is dependent upon extensive software validation and regulatory approval, which may vary widely by jurisdiction. It is not possible to know exactly when each element of the functionality described above will be available as this is highly dependent on local regulatory approval.”

Longer-term solutions for autonomy will likely provide distributed avionics and control architectures that can prove a greater system reliability at a lower cost than current approaches. This longer-term solution will also likely embrace moving the pilot out of the vehicle and onto the ground to improve the vehicle productivity and economics. “Bunker pilots” are already used in the military to handle the remote control of unmanned drones and it is expected that in the mature state, a pilot on the ground would be able to monitor and manage a few eVTOL PAVs at the same time. Ground-based operators—just like the pilots who will initially fly these eVTOL PAVs—will need to be trained and licensed. As part of certification of a new vehicle, manufacturers will need to define ways an operator can monitor vehicle airworthiness and its ability to make flight safety decisions remotely. This move to remote piloting will likely need close coordination with the FAA Unmanned Aircraft Systems efforts as they address similar issues with large drones in civilian airspace (Uber, 2016).

The uncertainty and possibility that self-flying aircraft will experience off-nominal conditions that the software and sensors can’t resolve during cruise flight is relatively low. The challenge for ensuring self-flying aircraft software is primarily focused on ensuring safe takeoff and landing autonomous operations. Because the risk can be limited to specific locations, there’s the potential that the path to ‘level 5’ self-flying eVTOL PAVs will involve ground-based vehicle autonomy aids that provide a behavioral check of the eVTOL PAV sensors and decision making. Having an automated ground-based sensor backup that can communicate with the vehicle and verify the autonomous software actions, could also provide a path towards early autonomy adoption.

Due to the combination of backup alternatives that exist for eVTOL PAVs to ensure safe operation (remote bunker pilots and automated vertiport vehicle flight verification mentioned above), self-flying eVTOL PAVs have the potential to progress at a rapid pace, perhaps even more rapidly than cars (Uber, 2016). However, since this level of control system software is new in small aircrafts, it raises the question of how these systems will be certified for safety and how long that process will take. This is a significant challenge in time and cost since only large commercial aircraft have been certified previously with fly-by-wire systems. Fortunately, the AgustaWestland AW609 civil tiltrotor and the Bell 525 helicopter are paving the way for GA aircraft to be certified with fly-by-wire systems, with certification of both rotorcrafts well underway (Uber, 2016).

5.4.3 Environmental Impacts: Noise and Visual Disturbance

A major issue was seen in the fact that eVTOL PAVs would cause their negative effects like noise and visual disturbance everywhere and people would have no chance to escape (Meyer, 2014). In this section, we look at a set of more restrictive noise goals for eVTOL PAVs, analyze the underlying design features that cause noise, and explore the technological advancements that we believe hold the most promise for delivering quiet eVTOL PATS operations. The construction of new vertiports/vertistops or alterations of flight patterns around airports are understandable and important issues of concern. It will be essential to determine what level of noise, both from eVTOL PATS operations and any related increase in vehicle traffic around vertiports, is acceptable to communities in return for offsetting benefits, such as the possibilities of reduced commute times.

Every neighborhood has a unique soundscape that is part of the life of the people who live and work there, and it will be important to provide eVTOL PATS service without significant acoustic impact. This requires planning around and close coordination between vehicle design, landing site and route planning, and dynamic scheduling of each flight. Siting of infrastructure and planning of eVTOL PATS operational patterns will rely on ensuring that flight patterns can be accomplished without exceeding the target noise level at the endpoints and over the route to be flown, based on actual acoustic monitoring. Measuring physiological loudness and annoyance terms in real time can enable dynamic operational planning to address the community noise standards that are developed.

In contrast to adverse effects by cars which are bound to visible infrastructure on the ground which could be avoided by living far away from major streets and so on, this was seen as difficult to achieve with eVTOL PAVs assuming that they could use most of the airspace. eVTOL PAV will operate directly overhead densely populated urban areas. It is important that eVTOL PAVs do not disrupt communities, and as such it is important that eVTOL PAV developers keep noise mitigation firmly in mind. While communities tend to tolerate public safety flights (such as medical helicopters) because the flights are infrequent and have clear community value, they historically oppose other uses due to noise. This conflict is sharpened by the aspect that helicopters (beside the helicopter flights for emergency and police services) are often perceived as a rich man`s toy, a transport option for only a very few people which effects a lot of people negatively, though, who never will have an advantage from their operation (London.gov.uk, 2006).

Noise pollution is of major concern of citizens not only in the EU, but also in Japan and in the United States (Schomer, 2001). The European Commission stated in their Green Paper on Future Noise that environmental noise is one of the main environmental problems of Europe (CEC, 1996). For this reason, the FAA and other regulators have set thresholds for community noise around airports for fixed-wing aircraft, as well as thresholds for helicopters and tiltrotors [44]. But to enable widespread commercial use, eVTOLs need to meet a stricter noise standard. Use of the current FAA helicopter noise regulations make it challenging to enable high volume, proximity eVTOL PATS urban operations that communities can embrace. The emerging eVTOL PATS community will benefit from defining and tailoring acceptable operational noise levels for vehicles and the vertiports/stops at which they will operate. For communities to accept sizeable fleets of eVTOL aircraft, vehicle noise will need to blend into the existing background noise wherever they fly (Uber, 2016).

Achieving eVTOL PAV noise levels like ground transportation is essential for widespread eVTOL PATS adoption. Medium-sized trucks traveling through neighborhoods at speeds of 35 to 55 mph[45] generate sound levels of 75-80 dB(A) sound pressure level (SPL) at 50 feet, which are roughly perceived to be acceptable by a listener at an average distance in adjacent buildings. However, given that eVTOL PATS network would deploy a fleet of potentially hundreds of PAVs, we understand that so many simultaneously operating eVTOL PAVs would also not be acceptable at noise levels merely equal to trucks. As such, we feel that a reasonable goal for vehicles is half that of medium-sized trucks today—67 dB(A) at ground level from eVTOL PAV at 250 ft altitude, which appears from early analysis to be achievable (Uber, 2016).

Sound pressure level alone is necessary but insufficient to specify the noise parameters that should govern eVTOL PATS. This is due to the concept of annoyance, a phenomenon associated with the physiological perception of loudness, duration, and repetition. Two different kinds of annoyance responses are triggered in people: (1) some notice individual disturbing events that they remember and tend to count how many times this disturbing event has happened, and (2) others assess noisiness of an area by averaging noise over the long-term, expressing their assessment as, for example, a “busy or “noisy” neighborhood. Short-term noises also create individual alerting events and can awaken people from sleep.

Fortunately, there are established methods for measuring annoyance. Since the development of turbofan jet airliners, cities and the FAA have worked on the long-term noise issue, which has led to the creation of the Day Night Level (DNL)[47]. DNL is the averaged sound pressure

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[44] 14CFR36, Subpart H and Subpart K

[45] http://www.fhwa.dot.gov/environment/noise/traffic_noise_model/old_versions/tnm_version_10/tech_manual/tnm10te chmanual.pdf

[47] Plotkin, Kenneth J, Wyle Labs et al (2011) Updating and Supplementing the Day-Night Average Sound Level (DNL). Wyle Report 11-04, DOT/FAA/AEE/2011-03, June 2011

level for a 24-hour period, with a sensitivity offset of 10 dB between 10 PM and 7 AM, so a constant sound of 70 dB(A) in the daytime and 60 dB(A) at night would define a neighborhood with 70 dB DNL. The FAA uses a yearlong running average of DNL when reporting the noise impact of airports. Day Night Level guidelines differ by type of neighborhoods. For example, targets in industrial neighborhoods are not as stringent as those for residential or suburban areas[48]. As eVTOL PAVs begin operation it will be valuable to characterize the ambient noise of landing sites individually, rather than using arbitrary targets. Doing so would be operationally very powerful as this will enable operations to be sensitive to the characteristics of each takeoff and landing location and contribute only the amount of additional noise that won't disturb the neighboring community. To achieve more tailored and responsive noise levels at vertiports and vertistops, operators will compute the maximum number of operations of each vehicle that can be conducted at each site while not increasing the long-term average Day Night Level (DNL) by more than 1 dB, which is the smallest change in loudness that a person can detect.

While long-term annoyance is measured in DNL, short-term annoyance is typically measured (around hospital heliports, for instance) with single event noise equivalent level (SEL[49] or SENEL[50]) metrics, which attempt to capture the likelihood that an individual takeoff or landing will disturb everyday activities like speech or sleep. The target for short-term annoyance that has been used in hospital heliport studies is for events not to increase the number of nighttime awakenings by more than 10%. This is typically predicted using SEL, which is the A-weighted sound pressure level lasting one second that contains the same energy as an entire aircraft event such as takeoff or overflight.

Several design approaches for eVTOL PAVs have already been built and tested. While details are not publicly available, we know that the different design approaches have significantly different acoustic signatures. This variety of designs makes it challenging to define quantitative noise measurements that are strictly neutral. Simple sound level measurements to compare two sounds aren't accurate when the spectral character of the sounds is different.

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http://www.faa.gov/about/office_org/headquarters_offices/apl/research/science_integrated_modeling/noise_impacts/media/WR11-04_Updating%26SupplementingDNL_June%25202011.pdf

[48] 14 CFR 150

[49] Sound Exposure Level

[50] Single Event Noise Exposure Level

Once the noise emissions of each vehicle are characterized, the next activity is to project how many operations at what time of the day or night will result in reaching the 1 dB DNL increase threshold, or the 5% awakening-increase threshold in the community. This requires integrating the emission of each vehicle (the sound leaving the vehicle) and its distance from the community (determined by the path loss in the air) so that the sound reaching the listener at the closest community point can be predicted. Real-time tracking of site noise will permit documentation that target noise levels are not exceeded, and that thresholds can be adjusted if the noise background changes. A quieter vehicle means more operations are possible at a given site. While computationally difficult a few years ago, this analysis is practical and low-cost today. This approach to site-level analysis will enable operators to measure and tailor noise requirements not only by vertiport/stop, but also enable us to adapt dynamically to operations at the level of specific sites. Doing so would be an efficacious approach to aircraft-related noise measurement and management, which we believe will enhance the capacity for quiet and efficient eVTOL PATS network operations in and around communities.

Currently there are very modest noise regulations that are based more on legacy products than community acceptance. Current flyover noise ratings are on the order of 70 dbA, though to be considered acceptable to communities, a level more on the order of 55 dbA is required (Decker, 2003). For the PAV operation there will, certainly, be specific noise standards to be respected. Besides the pure actual design of the eVTOL PAV should, of course, be as little noisy as possible, the flight heights and routes as well as the location of the landing and take-off sites and their operational hours could also be changed to allow for a quieter operation.

The other environmental negative impact that eVTOL PATS will have on city skylines and in areas of natural beauty when flying at much higher altitudes between A and B is harder to imagine. The overall associations people had regarding larger quantities of eVTOL PAVs were quite negative. Especially the expected swarm traffic during rush hour was a major source of concern. Simulations can be produced to visually model different densities of eVTOL PAVs from the perspective of a person standing on the ground to determine any locally specific challenges. Visual pollution concerns can be addressed via trip route modifications to avoid particularly sensitive vistas or consolidating traffic to existing commute corridors such as above highways (Meyer, 2014). The idea to have eVTOL PAV “streets” or routes above the lake of Zurich for example was seen as not acceptable and people there were very aware of and concerned about their surrounding landscape and the potential impact eVTOL PATS might have on them. eVTOL PAV traffic was seen by many participants as more suitable for big cities like New York or Frankfurt where already a lot of background noise exists and the general setting fits better in terms of atmosphere and architecture (skyscrapers, the movie the Fifth Element was very much present in the minds of the participants).

As one potential solution to the visual disturbance problem created through hundreds of small air vehicles flying around everywhere, clear routing and tracks will do a good job, create hardly any noise, and will not disturb people’s view. The option to bundle and concentrate eVTOL PAV traffic to certain “streets in the air” possibly connected to already existing major main traffic routes (highways) on the ground was seen as very reasonable and helpful for acceptance. At these routes, already, a lot of noise would exist, and the recreation value would be minimal. Therefore, additional traffic would not do as much harm. A kind of compromise for their own cities (Tübingen & Zurich) could be imagined if only certain days during the week or certain times of the day would be allowed for eVTOL PAV operation (morning and afternoon rush hour times). Quite common was the opinion that weekends should be eVTOL PAV free and that this would increase and ease their acceptance (Meyer, 2014).

Overall, the impression from all reports is that air traffic noise, despite technological improvements, will remain a sensitive issue especially if a high number of flight operations are expected to occur. This means that even if individual noise signatures of the eVTOL PAVs were decreasing, the general trend of increased ground and air traffic, makes it very likely that this topic will remain of high priority. It is not the agenda to mandate new noise regulations for small aircraft, but instead to recognize that new large volumes of small aircraft will need to be acceptable to communities.

5.4.4 Ground Infrastructure: Landing, Parking and Charging of eVTOL PAVs

Every transport option relies on its own specific infrastructure. To enable on-demand eVTOL PATS operations within a city, it will be essential to tailor the infrastructure and operation needs based on patterns of local demand. Regarding eVTOL PAVs, it was thought about where these would be able to land and stored and if this would be partly possible together with cars or not (shared car parks). The extent of infrastructure that will need to be developed in any given metropolitan area will be dependent not solely on demand and models of efficient operations, but on the current infrastructural footprint and if that infrastructure requires any repurposing. In many instances, both the suitability of existing infrastructure and scale of relevant infrastructure may be lacking. The greatest operational barrier to deploying eVTOL PATS fleet in cities is a lack of sufficient locations to place landing spots and parking. Even if eVTOL PAVs were certified to fly today, cities simply don’t have the necessary takeoff and landing sites for the air vehicles to operate at fleet scaling. A small number of cities already have multiple heliports and might have enough capacity to offer a limited initial eVTOL PATS service, provided these are in the right locations, are readily accessible from street level, and have space available to add charging stations. But if eVTOL PATS is going to achieve anything approaching its potential, infrastructure will need to be added. Thus, effects and implications on future architecture should be also discussed.

Developing a city’s required eVTOL PATS infrastructure will require a data-driven understanding of current transport demand and modelled future patterns of commuting. Operators must also proactively engage with local resident communities and with local, and national governments to help identify and mobilize private sector investment to develop eVTOL PATS-related infrastructure that benefits consumers, communities, and the network’s sustainable operations. What follows is an initial overview of the infrastructure and operational issues that a city and its many partners will need to carefully evaluate as they consider the prospect of eVTOL PATS service. Engagement across multiple levels of government, local communities, and the private sector will surface many additional concerns that will need to be factored into infrastructure development and flight operations, as well as vehicle design.

If we assume a conventional business model (“individual ownership”) and limited autonomy (no ability of fully automated flying) of PAV, the scenario indicates a required storage capacity for 7.000 to 20.000 PAVs within the city (Decker, 2013). The topic of parking space which is needed to store all these thousands of PAVs in the city will be an important problem and well known for cars since a long time. While the parking and storing possibilities might be less critical in the sparsely populated areas this issue seems more complex in already congested inner city areas were also parking space for cars is limited and costly (Rodrigue, 2009). Strongly connected with the question of where to park the PAVs is the question if they can fly autonomously or not and if they fit into the current automobile dominated infrastructure of the present urban environment. For PAVs with greater dimensions exceeding this “car infrastructure compatibility” the situation would be different.

NASA has studied the idea of VTOL air-taxis operating in dense urban areas (Anticliff, 2016). Specifically, they chose San Francisco as one metropolitan area to provide detailed geographic, land use, infrastructure, weather, and operational constraint considerations to bring real world issues into their study. This permitted NASA to develop a detailed Concept of Operations (CONOPs) for how the vehicles would be used and where the required supporting infrastructure could be placed. This NASA study provides a few insights that help better understand the feasibility of conducting very dense operations (far more than any existing city experiences with helicopters today).

Initially, eVTOL PATS is unlikely to carry passengers directly door-to-door, but instead between vertiports and vertistops. However, depending on local regulations and space constraints, eVTOL PAVs could potentially take off and land at private residences. The locations would need to be registered and surveyed for approach and departure routes. eVTOL PATS fleet will likely be supported in a city through a mixture of both vertiports and vertistops. Vertiports would be large multi-landing locations that have support facilities (i.e., rechargers, support personnel, etc.) for multiple eVTOL PAVs and passengers. Following the heliport examples used in New York City and other locations, vertiports would be limited to a maximum capacity at any given time to achieve a compact infrastructure size while enabling capacity for multiple simultaneous eVTOL PAV takeoff and landings to maximize trip throughput. Vertistops, on the other hand, would be single vehicle landing locations where no support facilities are provided, but where eVTOL PAVs can quickly drop off and pick up passengers without parking for an extended time. A combination of different approaches to determine potential vertiport and vertistop designs and they are summarized below.

Floating barge vertiports, shown in figure 5.15 below, were proposed in the San Francisco city area to provide approach and departure aircraft paths over the water that limit community annoyance and risk, as well as the need to build infrastructure among existing, densely packed buildings. To accommodate increased flight operations, these vertiports could use a short-range, ground-based navigational aid that can sequence the timing of the approach and departures of VTOLs automatically.

Fig. 5.15 Floating Barge Vertiports

Another novel NASA proposed vertistop solution is shown in the figure 5.16 below for a highway cloverleaf. In this case, major roadway cloverleaves are re-purposed with raised helipad structures. FAA guidance documents[51] for heliport setbacks and operational concerns were used to compare with typical cloverleaf diameters. Typical cloverleaves were found to be approximately 225’ diameter to accommodate car deceleration and turning. A typical helipad requires a 50’ pad, a 115’ diameter Final Approach and Touchdown (FATO) area, and a ~200’ diameter Public Safety Area (PSA). NASA suggested a raised platform to permit the vertistop to be at the same height as the overpass to provide the maximum height clearance above any road traffic and minimize distraction to ground traffic. An elevated platform also permits the underneath area to be used for additional vertistop functionality, such as a passenger pickup and waiting area. These types of public vertistop locations are meant to be highly synergistic to current ridesharing trends, and not meant to require parking or storage of either eVTOL PAVs or ground cars.

Fig. 5.16 Highway Cloverleaf-based Infrastructure Approach

This highway cloverleaf-based infrastructure approach has several operational advantages including the re-use of existing transportation land. Aircraft approach and departure trajectories could be performed over major roadways with no flights over neighboring private property below 500 feet. Also, existing highway noise is well matched to the proposed noise levels of eVTOL PAVs to assist in limiting community annoyance. This type of infrastructure couples into existing ground roads to help minimize ground travel time and provides a good fit with

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[51] http://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5390_2c.pdf

emerging ride-sharing business models to avoid the need for ground or air vehicle parking facilities.

The NASA study also noted that one potential form of vertiports could be at private company campuses, which have large setbacks to neighboring property. Similarly, the top level of parking garages offers a particularly compelling opportunity to repurpose otherwise unused real estate as a vertiport. Raised parking structures additionally provide operational advantages, such as helping to ensure that unobstructed glide path angles can be achieved to satisfy FAA guidance for safe operations. Such structures have already been proposed as shown in the figure 5.17 below left relating to the Los Angeles airport (Uber, 2016). In terms of considering use of different potential air portal infrastructure, vertiports offer a compact footprint with eVTOL PAVs operating at steep glide slope angles to avoid overflying neighboring properties. Using anything other than vertical flight capable aircraft would require significant ground resources and land use.

Fig. 5.17 Potential Form of Vertiports Could be at Private Company Campuses and Top Level of Parking Garages

Uber developed the artist’s rendering above right in Figure 5.17 to illustrate many of the potential vertiport features and better visualize the type of infrastructure envisioned for use with on-demand eVTOL PATS as part of a ridesharing network. In this example, the top of an eight-story downtown parking garage has been converted to a vertiport capable of supporting 12 eVTOL PAVs. Since eVTOL PATS ridesharing operators will conduct regular service at a given vertiport, Uber has depicted two 50’ diameter touchdown pads. Although there is no formal requirement regarding spacing, pads will need to be maximally separated to minimize operational risk. The separation helps to avoid interference between the two pads, and potentially offer simultaneous arrivals and departures. The touchdown pads are classified by the FAA as Touchdown and Lift Off (TLOF) areas, with another larger area classified as the

Final Approach and Takeoff (FATO) area. The FATO is approximately 100’ diameter, and mandates that there are no structures, lighting, or other obstacles in this area to ensure flight safety. Typically, a vertiport or vertistop will also have a Public Safety Area (PSA) that provides an additional setback of about a 200’ diameter which must be controlled. However, for rooftop locations, the PSA is not required since if it extends beyond the rooftop (since the area is controlled). Parked eVTOL PAVs are kept away from the touchdown areas unless actively arriving or departing. Each of the parking spots provides a conventional charger with offering rapid chargers. During peak operations, eVTOL PAVs will be flying so most of the parking spots would be empty. The two touchdown pads would each offer rapid chargers, as well. These rapid chargers will enable eVTOL PAV that only intends to land and then reload passengers to recharge for a short time, which will maximize the amount of time in flight (Uber, 2016).

The active flight operation area is restricted by a building that provides the security, screening, waiting area, and other functions with access to the touchdown pads only through the building. The customers only walk a short distance to the touchdown pad, and only when the aircraft propulsion is inactive. The parked eVTOL PAVs are kept away from users to minimize interaction with the vehicles. eVTOL PAVs will require the ability to taxi with a wheel motor on the ground short distances to move between pads and parking areas. eVTOL PAV will need to move off the landing pad at vertiports to accommodate other eVTOL PAVs if they need to recharge, or if another passenger trip isn’t already scheduled. However, if energy is enough and if passengers are ready, then the eVTOL PAV will only stay on the pad long enough to deplane and enplane passengers. In short, achieving a minimum turnaround time is important to achieve high vehicle productivity. Another portion of the rooftop permits customers to be dropped off and access automobile or pedestrian egress points to complete their trip (Uber, 2016).

Another aspect regarding infrastructure is the locations for parking and storing eVTOL PAVs. The difference between the ability of the eVTOL PAVs to fly itself into a suitable parking spot or ride sharing model and private ownership model means a lot in terms of parking location. This could mean that the eVTOL PAV would transport the user to its desired place and then fly autonomously to the next free eVTOL PAV garage or parking spot. On the parking spot an automated parking system such as they are already in place for cars could be used to store the eVTOL PAVs in an automated and space saving manner. These systems use lifts and carriers to move vehicles through the parking system; the user parks the vehicle at an entrance point and gets it returned upon request in only a few minutes (Patrascu, 2010). The same could be imagined for eVTOL PAVs with the difference that the eVTOL PAV would check-in and out by itself without a person on board. For the "augmented flight scenario" the requirements for the storing or parking infrastructure would increase though.

Handling the "parking problem" also relates to the business model. Imposing private ownership vehicle models on vertiports or vertistops would increase the size of the required infrastructure and increase the cost as well for parking. Extensibility of diverse vertistop infrastructure ideas is currently being investigated by NASA and MIT in joint studies of other metropolitan areas such as Los Angeles (Uber, 2016). If the eVTOL PAVs are shared in private communities or offered in renting concepts, they do not have to be parked that often, but are used most of the time, which would reduce the pressure on parking space.

The other aspect belonging to the infrastructure complex is the issue of maintenance. The prechecks from the commercial airliners are present in people's heads. The need for prechecks was not questioned but it was doubted whether the average user would be competent to do them. The service issue for eVTOL PAVs was seen with a high amount of trained people needed to provide it associated with the question of costs and practicability (availability of eVTOL PAV for operation). Any city or region will also require maintenance and support locations for the hundreds of eVTOL PAVs to be serviced, inspected, and parked when not in use. This function will certainly be distinct from the vertiports or vertistops (although a maintenance base would also serve as a vertiport for passengers), and likely be part of a local Fixed Based Operator (FBO) support role for this new market. Mobile maintenance will be required at any vertiport to address nonairworthy aircraft. In the case that an emergency landing or equipment failure results in eVTOL PAV requiring service, this would require maintenance personnel to be deployed to the location, like current helicopter operations. This is another reason for eVTOL PAVs to embrace fully redundant propulsion and control design that can provide a 'limp home' mode of operation.

Another infrastructure topic contributing to the environmental footprint and to the public acceptance is the facilities which support that energy need. Each vertiport will have multiple high voltage rapid chargers, as well as enough lower voltage chargers for each vehicle vertiport parking slot to recharge at a slower rate. Uber's current vertiport modeling assumes that one-third of the chargers be high voltage/high capacity based on the ratio of required recharging to achieve a greater than 2000-hour annual vehicle utilization. However, high voltage chargers are significantly more expensive than conventional slow chargers, and rapid charging can introduce significant damage[52] to the battery, reducing projected battery life. Providing the right mix of chargers is a market-specific fleet optimization question. However, infrastructure will likely have chargers for every eVTOL PAV to enable overnight recharging. Matching the battery charge and discharge characteristics (specific power and C rating which indicate how quickly electrons can be added or taken from the battery) are critical requirements across the vehicle, mission, and infrastructure. On the other side, electrification is leading to a higher frequency of high load deployments, notably in urban areas. Large charging loads can impact the distribution system. Location specific factors will determine costs and timelines for site development, and site location flexibility can be beneficial in some cases. Early dialogue with the utility can help with preferred siting (Sawaya, 2018).

Battery swapping is another alternative to help maximize vehicle productivity and utilization. Tesla invested in developing a robotic battery exchange system capable of a battery swap within 90 seconds. While swapping optimizes the vehicle performance, it causes a significant logistics burden, which was one reason for Tesla’s discontinuation of their battery swapping program. Ensuring an appropriate distribution of batteries across all vertiports is required, which may require ground trucking of batteries between vertiports. An additional factor is that batteries are a major expense and requiring multiple battery sets per vehicle would be a significant additional fleet expense.

5.4.5 Airspace and Air Traffic Management

The operational footprint and demand within urban airspace today varies by city with large aerial transit hubs having significant commercial airline activity and other metropolitan environments much more modest in terms of the demands on their airspace. Considering the significant potential for on-demand urban eVTOL PATS operations, the latent demand for eVTOL PATS travel will likely necessitate a significantly higher frequency and airspace density of vehicles operating over metropolitan areas simultaneously. Thus, one of the important issues regarding increasing number of air traffic is efficient high-density operations with access to diverse platforms in airspace with integrated air-ground-cloud technologies. To meet this demand, it will be critically important that the aircraft operating community, regulators, and others develop alternative solutions to enable safe, efficient and high-capacity

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[52] Tesla super chargers use a high voltage, smart charging system that’s able to use the battery management system to closely monitor cell voltages to avoid damaging batteries. If a typical battery is charged rapidly without high voltage or closely monitoring cell temperatures than damage can result that will reduce the cycle life of the battery. https://techcrunch.com/2013/06/20/tesla-shows-off-a-90-second-battery-swap-system-wants-it-at-superchargingstations-by-years-end/

operational urban environments to accommodate this dramatic increase in aerial traffic density. For example, assuming 300.000 people that commute every day into a major city, modal shares typical for European cities and a substitution rate of 10% of car traffic by eVTOL PAV, an "automated" ATM for such a prototypical city would have to handle between 2.500 and 10.000 approaches per hour. Between 40 and 160 independent landing sites for eVTOL PAVs would be needed (assuming turnover times of 30 seconds and 30 seconds separation) (Decker, 2013).

These rough calculations show a few challenges associated with the eVTOL PATS air traffic management. This is the high number of approaches which the take-off and landing sites would have to handle during the rush hours. These means that an efficient air traffic management system would need to be in place to handle the distribution of incoming air traffic to the available landing sites.

As part of the process of gathering information for a report for NASA Headquarters Aeronautics Research Mission Directorate, operators currently engaged in Air Charter or Business Aviation (presumably among first adopters of a future on demand eVTOL PATS) were asked to respond to the questions (Bruce, 2017). A common theme emerged from the selected set of operators who responded to the questionnaire. To fully realize the benefits that air transportation could provide, a more capable air traffic management and control system is required. Operators want the ability to fly on-demand great circle routes in a wider range of reduced visibility and weather conditions. Interviewees suggested that today's ATC system is inefficient, difficult to utilize without sophisticated training, and requires high levels of recent experience by operators. Whether utilized by commercial or private operators, on-demand eVTOL PATS will demand a more capable air traffic management system. The objective of an advanced ATM system would be as follows (Bruce, 2017):

- Accommodate greater traffic density while reducing the labor needed to achieve separation; significantly lower or eliminate pilot workload and significantly reduce dependency on human monitoring of traffic.
- Direct, most efficient, or operator-desired routing must be provided to all current airports and ultimately to landing facilities yet undefined.
- Air traffic services from the ground to the flight levels everywhere, beyond the current architecture serving a relatively small total volume of the airspace at a relatively small fraction of the total landing facilities in operation today and in airspaces that will become valuable for operations in the future.

The main airspace integration challenges are (Prevot, 2018): airspace access, communication, controller and pilot workload, separation and surveillance, security, skyport capacity, throughput, multimodal trips, noise and acceptability and vehicle mix. It is argued that the approach for the controlled airspace integration should be the segregation of urban air mobility operations through airspace corridors and carveouts. The approach for uncontrolled airspace should be integration of urban air mobility operations through network services and information sharing (Prevot, 2018).

The airspace integration principles of on-demand eVTOL PATS urban air mobility will be as follows (Prevot, 2018):

- Safe: multiple safety layers; network, aircraft, pilot.
- Secure: built-in security, threat monitoring and response.
- Predictable: known routes, corridors and skyports.
- Cooperative: flight intent shared across the network.
- Self-managed: avoid burdening air traffic control.
- Scalable: service-oriented approach.
- Reliable: ultra-high completion rate of confirmed flights.

Another way of handling the number of eVTOL PAVs in the airspace relates to the attractive business models encouraging high occupancy rate. One of the net results of the low occupancy rate is the congestion on the roads. If the eVTOL PAVs are shared in private communities or offered in renting concepts such as ride sharing up to their design seat capacity, one eVTOL PAV will be used in the airspace instead of two or more eVTOL PAVs most of the time, which would reduce the pressure on air traffic management and visual disturbance.

eVTOL PAVs will need a route structure from any one location to any other to make integration with air traffic control practical. While there is no provision yet for dedicated eVTOL PATS routes, an equivalent construct is simple to define by negotiation with ATC, just as news reporting and medical aircraft have defined routes. For the foreseeable future, aircraft operating in urban areas will still use voice communications with ATC to allow for the variety of traffic, but in the next few years all aircraft will have readily available cockpit displays showing all the other nearby aircraft. Through experience with piloted operations along the same routes, it will be possible to demonstrate the basis of an autonomous route structure, which will evolve to avoid conflict with existing aircraft operations. The tools for developing routing are the same as employed today for other low altitude traffic. This is another area where careful routing optimization will be key. Low altitude, maneuverable and quiet air vehicles present unique opportunities that have not been present in previous air traffic planning scenarios.

5.4.6 Legal Aspects

Before eVTOL PATS can operate in any country, they will need to comply with regulations from aviation authorities charged with assuring aviation safety. These regulations enforce standards for air vehicle design, production, pilot licensing, and maintenance and operating requirements. The FAA and EASA function as regulators for 50% and 30% of the world's aviation activity, respectively, which means eVTOL PAV developers will ultimately need to secure their approval to achieve mass-scale adoption. Cooperation between the FAA and EASA has resulted in reciprocal arrangements[53] so an aircraft approved in one jurisdiction can be flown in another. Pilot training and commercial operator certification vary by country, but the requirements are similar.

Developing a certification path involves several steps. First the regulatory authority and the manufacturer must agree on the certification basis. This is the set of rules that will apply to a particular aircraft (e.g., in the U.S., Part 23 for general aviation airplanes, Part 27 for small helicopters). Then the regulator and the manufacturer must agree how to determine the compliance of the air vehicle with the certification basis. Since this is a new type of aircraft, in the United States it would be certified under Part 21.17(b) with "equivalent level of safety" once it has been proven in an experimental program. Preliminary work has been done by the FAA for a powered-lift certification basis to accommodate tiltrotors like the AgustaWestland AW609 Tiltrotor[54], but it is not fully defined. Next, the manufacturer demonstrates the compliance of the vehicle to the standards accepted by the regulator to obtain type certification; this is an iterative process. Following type certification, manufacturing can begin[55] while the manufacturer seeks a production certificate to demonstrate the capability of producing many copies of that aircraft to the same standards. Before an aircraft is produced for commercial sale or use, it is given a special airworthiness certificate in the experimental category for research and development. This is a short part of the development process for piloted aircraft and involves negotiating operating limitations which allows flight testing away from congested areas. It does not require any special action or new rules from the FAA. Other experimental purposes such as market research are also permitted, but not with paying passengers.

Traditionally, the end-to-end certification process (type and production) for a simple case, like a new model of conventional general aviation aircraft, takes about two to three years for a

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[53] https://www.faa.gov/aircraft/repair/media/EASA_EU_roadshows.pdf

[54] http://newatlas.com/agustawestland-aw609-tiltrotor/21466/

[55] https://www.faa.gov/aircraft/air_cert/production_approvals/prod_under_tc/

type certificate, plus another year for a new production certificate. The introduction of a new type of aircraft, however, requires a new certification basis, developed in parallel with the type certificate, and this could extend the end-to-end certification process to 4 to 8 years.

Uber sees a few potent ways to accelerate the eVTOL PAV certification process and thus time to market for on-demand urban air transportation (Uber, 2016).

First, flight-based ridesharing is a very specific use case. Uber understands its customers' needs exceptionally well and they bring an existing large global customer base that very much wishes this vision were a reality today. This is an unusual situation: the demand side of the market is ready to go. The rapid growth of ridesharing has demonstrated a strong desire for on-demand transportation, and the time-savings value proposition of on-demand flight is a natural evolution. To complement the demand-pull, Uber has the interest, resources, and relationships to work closely with cities to understand infrastructure and operational requirements. These factors should enable the wider ecosystem to explore the implications of this demand and use cases to constrain the goals and designs of the aircraft. All of this should help accelerate development and testing.

Second, as mentioned above, both the FAA and EASA have adopted consensus-based standards processes as a replacement for their previous very slow internal standards development processes. In relation to eVTOL PAV certification, the FAA and EASA will imminently adopt American Society for Testing and Materials' (ASTM) F44 specification as a replacement for Part 23, which governs small fixed-wing aircraft. Once the adoption of F44 is complete, this opens the door to developing standards for eVTOL PAV under this FAA adopted framework. For the standards development process to happen, in this case for powered-lift aircraft, leadership is required to assemble a coalition of stakeholders (e.g., interested vehicle manufacturers) and approach the ASTM to create a committee tasked with creating the set of standards for submission to the FAA and EASA.

Third, aircraft manufacturers can apply to the FAA to issue an experimental airworthiness certificate for their aircraft before the type certification basis is defined. The approval process is very lightweight, and this enables the vehicle to be flown under constrained circumstances[56] (e.g., only required flight crew, no revenue-earning operation). As more flight time is accumulated, the constraints can be relaxed somewhat to allow demonstration flights[57]. This

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[56] FAA Order 8130.2H

[57] FAA Part 21.191 specifies use of experimental aircraft that includes "Research and development. Testing new aircraft design concepts, new aircraft equipment, new aircraft installations, new aircraft operating techniques, or new uses for aircraft." Further Part 21.195 specifies use of experimental aircraft "for purposes of conducting market surveys, sales demonstrations, and customer crew training."

allows demonstration of capabilities and characteristics that can impact operational certification and will likely be essential for the public to hear and accept the substantially lower level of noise these aircraft will produce. Another example is that Part 135 has specific requirements relating to energy reserves that assumed that the aircraft is flying for long distances where weather could change significantly over the flight time and there are few alternate airports at which to land. For urban eVTOL PAVs, which are designed to fly over short distances, e.g., 30 minutes, and where there are many potential landing points, a 20-30-minute reserve likely does not make sense.

Fourth, the FAA and EASA have traditionally been responsive to the concept of Equivalent Level of Safety (ELOS). As an alternative to complying with a standard requirement directly, evidence can be presented that the same level of safety is achieved through other means. This approach would apply well to full vehicle autonomy, for example. Once piloted operations are in place, autonomous systems can be introduced, enabling large-scale data collection demonstrating with statistical significance that autonomous flight is at least as safe as piloted flight (much like the process occurring today with autonomous cars, beginning with semiautonomous operations assisted by safety drivers). This could circumvent a very lengthy standard specification process for autonomy, while providing the FAA with the statistical safety proof that the FAA needs to move forward with confidence.

Commercial air-taxi services in the US are regulated under Part 135 which allows scheduled commuter and non-scheduled air taxi (on-demand) flights. Uber expects there to be little adaptation of these rules needed for eVTOL PATS once the aircraft is produced under a type certificate. An individual can obtain a simplified certificate as a single-pilot operator; or a full Part 135 operation can be developed for a company with many pilots on staff with defined responsibilities for directors of operations and maintenance and chief pilots. eVTOL PATS pilots will come from both fixed-wing and helicopter backgrounds; the total PIC time requirement may be met using any aircraft.

As described in the safety section, eVTOL PAVs with autonomous capabilities will significantly shift pilot skill requirements. Presently, pilots must monitor both the vehicle's trajectory in relation to the desired path and adjust many vehicle state parameters to force the trajectory to conform to the desired route. Autonomy refers to the ability of the vehicle to make these adjustments itself; pilot inputs are limited to commanding a desired trajectory rather than the means to achieve it. Uber anticipates that demonstrating successful operation with early vehicles will reduce the requirements for pilot experience in conventional aircraft based on reduced pilot task-loading, and more fundamentally, the reduced scope of tasks for which the pilot is responsible. This is like what the FAA has done in the definition of the light-sport pilot license which requires roughly half the time that a private pilot license does. Not only must the FAA be convinced, but the insurers who cover the risk of the operation will need to see that pilot skill and experience requirements are reduced. In pilot training, certification is based on demonstrated competence in handling failure modes, continuing to fly the aircraft safely in a diminished condition. Once all these failure modes are addressed by autonomous system design, navigation is suitably redundant, and the pilot does not need take corrective measures to assure safe flight, it can be demonstrated that a far shorter training period is required to achieve safe operation over all the potential failure modes of the aircraft.

6. Conclusions

It was important to conduct this research to provide a holistic vision on the potential consequences of the introduction of emerging eVTOL air transportation mode, in particularly eVTOL Personal Air Transportation System, and to contribute to the public and policy opinion forming since it might be an answer to the issue of current means of transportation issues which result in environmental impacts and loss of time and money or the next logical step in the natural progression and a profound influencer upon the pattern of life of people in the near future. This technology assessment study is meant for innovators, entrepreneurs, regulators, service providers and national and local decision makers to be able to realistically assess the status of eVTOL air transportation mode to form their own roadmaps.

From the beginning of the research, instead of looking from a detailed vehicle design viewpoint, the research aimed to understand the need, the key entities in the system, the impacts, and the perception of the stakeholders within the context of a new socio technical system transitions at transportation system. For this purpose, it was set a framework and methodology starting with technology assessment point of view in the light of transportation system analysis because of the increased visibility of technology's role in shaping society. Although there was difficulty since the system was complex and an emerging air transportation mode, an interdisciplinary study has been conducted to assess the impacts of such a capability through with the literature review, secondary focus group studies, annual forum and workshop reports, presentations, primary and secondary questionnaire, and interviews addressing the research questions.

This research started with problem-oriented assessment which examined the need and the means of solution for the current mobility issues and took the form of technology-oriented assessment which addressed emerging eVTOL air transportation mode and analyzed its impacts. This research also intended to provide a holistic technology assessment framework to analyze different facets of an emerging technology implementation. As the study was discussing future-oriented knowledge generation, the methodological approach was of outmost relevant.

The central trigger question to begin this research was the question whether an inclusion of eVTOL air transportation mode into the scenarios and policies of the future should be considered. For this purpose, first, the research set the design approach and the research objectives to assess emerging eVTOL air transportation mode. Setting the research objectives provided the landscape to identify the scope and the research questions as well as to organize the analysis and results addressing research questions. The research discussed the potential benefits and the major challenges of emerging eVTOL PATS and aimed to understand the perceptions of the service provider, regulator, and user. The main contribution of the research is the policy advice addressing challenges related to the implementation of eVTOL air transportation mode.

During the first phase, the scoping decisions were made, the analysing dimensions were determined, and the researcher continued to build on the situation analysis work and gather more background information. The researcher refined the research questions, and identified appropriate research methodologies, approaches, data sources and analysis tools. To develop the assessment and the policy advice contained in this study, we have conducted the following process:

- Carefully examined NASA’s and AHS International’s annual forum and workshop presentations, reports regarding eVTOL air transportation mode and urban mobility technology roadmaps.
- Reviewed existing myCopter Project results especially Screening Report of Socio-technological Environment and User Perspectives and Expectations report (developed by Prof. Michael Decker team) that could be leveraged by eVTOL air transportation development efforts and attended to the final Project Day conference in Karlsruhe.
- Carefully examined Uber’s workshops and reviewed the Uber’s published White Paper, and NASA Strategic Framework for On-Demand Air Mobility report for NASA Headquarters Aeronautics Research Mission Directorate.
- Interviewed the key actors in the regulatory environment and the transportation planning and held questionnaire with Izmir and Istanbul Municipality Transportation Planning Department staff in Turkey.
- Carefully reviewed and examined eVTOL News, Urban Mobility News, and relevant organizations and companies’ web sites.
- Carefully reviewed the relevant scientific literature on technology assessment.
- Listened to the discussions with key industry personnel developing eVTOL air vehicles and technologies, especially, in Germany and Turkey.
- Researched existing technology development efforts in Europe and USA that could be leveraged for eVTOL air transportation mode applications.
- Reviewed existing relevant project reports that could be leveraged by eVTOLs air transportation mode, small aircraft transportation system, personal air transportation system, urban air mobility development efforts.

The first step was to discuss the current state of mobility and eVTOL air transportation mode to scope and state the problem and to understand the need for a new transportation mode. Mobility studies show that the ability to travel is one of the most basic human needs and the current transportation system is under pressure to improve. The two main transportation modes, auto and air-hub, are reaching their limits which results in environmental issues and loss of time and money. Urban inhabitants face increasing emissions and noise as well as congestions, and thus reduced mobility capacity. New intended developments in ground transportation results in increasing congestion. The actual scheduled gate to gate air travel time is 29%, the rest is waiting, access and terminal time which results in poor block speed. In other terms, limitations of the current ground and airline transportation systems, increasing congestion and poor block speed, combined with expanding population and demand for affordable on-demand mobility are driving the development of future transportation technology and policy. In this context, the user centric third wave approach of aeronautics could bring about great new capabilities for society that would bring aviation into a new age of being relevant in most people's daily lives.

According to eVTOL Aircraft Directory (2021), there was only a half-dozen known designs in 2016, there are more than 300 eVTOL air vehicle concepts representing some 215 different companies/developers now. These 300 eVTOL air vehicle concepts include everything from conceptual studies and defunct projects to air vehicles that are currently being flown for certification testing. An average of two new eVTOL air vehicle concepts are added each week. 43 companies were at the large-scale demonstrator phase, a dozen had flown engineering or certification prototypes, and three air vehicles had gone into production. However, significant technology advances across key enabling technologies are still required prior to the ability of eVTOL air transportation mode to provide a benefit to a more significant portion of the public than current general aviation aircraft.

After a literature review that sheds light on the emergent developments of key enabling technologies and regulations, it seems that eVTOL PATS is technically feasible and the time has been arriving and the early implementation will most probably be seen in the next decade. Although this assumption could be a separate topic to discuss, it would be nonsense from technology assessment point of view for an emerging eVTOL air transportation mode. It was evaluated that assessing the potential impacts and understanding the perceptions of stakeholders would be more contributive to develop policy and to prevent or diminish the potential negative impacts caused by the uncritical application of emerging eVTOL air transportation mode. Nevertheless, a new socio technical transition will come about like the transition from horse drawn carriers to autos. There is both a need and an opportunity to include in the transportation mix eVTOL PATS which would provide, percentage wise, the same increase in speed as the auto provided over the horse which means travel time saving and reliability. In short, there are significant potential benefits that stakeholders especially regulator and service providers should pay more attention to the ongoing developments in the eVTOL PATS sector.

The research suggests that there is a convergence of technological innovations and improvements in aviation that have been making the long hold dream possible for the first time in history to make general people fly. With the results obtained lately from the research activities, revolutionary technologies and regulations are bringing us closer to an eVTOL PATS reality every day. However, even with the successful test flights, it will take a while before any of us are taking air taxis.

From the technology assessment point of view, the first research question aimed to discuss the potential benefits of eVTOL PATS for user and society. The research suggests that the technical, business, and societal developments in recent years are driving an expectation that the third wave of aviation will cut urban daily commute times dramatically, enable faster emergency response and allow inter- and intra-city transportation at costs competitive to traveling by car, bus, or train. Many actions taken by transportation agencies were designed to reduce the travel time. In case of evaluating the potential benefit in terms of travel time, eVTOL air transportation mode can reduce travel time by a factor 5, in other terms increase daily radius of reach at least by a factor of 5. eVTOL air transportation mode can reduce travel time by increasing block-speed. eVTOL air transportation mode can be a better new choice up to 500-600 miles where airlines and automobiles provide poor block speed Such quite transportation mode with almost zero operational environment impact can enable a variety of missions ranging from private use to urban air taxis to urban air minibuses to regional biz jets and air transportation to public services. This can enable people to access city centers and reduce the need for a car which means there will be less transit traffic and less noise in cities.

eVTOLs will not require expensive infrastructure investments like roads, bridges, and runways. Pocket airports or vertiports can also offer a redundancy for airborne disaster relief and a more distributed system for medevac air ambulance. eVTOL air transportation mode can help reduce traffic congestion. Traffic congestion is a non-linear function, meaning that a small reduction in urban-peak traffic volume can cause a proportionally larger reduction in delay. Relatively small changes in traffic volume or capacity on congested roads can provide relatively large reductions in traffic delay. Shifting traffic from automobile to other travel modes not only reduces congestion on that facility, it also can reduce the amount of traffic discharged onto surface streets, providing downstream congestion reduction benefits. The quantitative samples of travel time saving were also studied based on Lilium and Georgia Tech`s mission scenarios and Istanbul case study. According to the mission scenarios, in New York, it can take 5 min by eVTOL air transportation mode instead of 55 min travel time by taxi. In Istanbul case study travel scenarios, it was assessed that end-to-end city travel could take 30 min by eVTOL air transportation mode instead of min 2 hrs. travel time by taxi. The value of travel time saving and the value of reducing travel costs in Istanbul were also calculated based on average statistic and assuming necessary shifting to eVTOL air transportation mode. The value of travel time saving was approximately U.S. $ 22 billion and the value of reducing travel cost was U.S. $ 33 billion. As a result, there is a potential to enable people and goods to have the convenience of on-demand eVTOL point-to-point safe travel, further, anywhere in less travel time, through a network of pocket airports and vertiports. Policy makers, regulators and big metropoles' transportation planning departments should consider an inclusion of this form of transportation mode into the scenarios and policies of the future. This leads the first policy advice of an inclusion of eVTOL air transportation mode into the scenarios and policies of the future should be considered to lessen the budget and the time to get ready in case of implementation.

The research suggests that introducing the emerging eVTOL air transportation mode into the transport system is not possible without a certain extent of acceptance by its users and community. Therefore, like any innovations, eVTOL air transportation mode must be adapted by the users and accepted by the public. Moreover, understanding psychological predisposition will be key to tailoring emerging eVTOL air transportation mode. Against this background, addressing the second researchable question is of utmost importance to understand the perspectives and expectations of potential users and society when carrying out a technology assessment of eVTOL PATS. However, executing a meaningful survey with a sample of required number of potential users in Istanbul was beyond the power of this study. Thus, this study tried to understand the perceptions of potential users based on myCopter project and Airbus focus group studies, Helicopter Investor`s questionnaire and of service providers and regulator based on this research survey.

As a general observation from all three myCopter project focus group studies, one could state that the major raised issues regarding Personal Air Vehicles were safety problems (on the ground and in the air for the air vehicle itself), environmental issues (visual impacts, noise), challenges with respect to infrastructure (city architecture, integration into existing ground traffic, maintenance & service), organizational and business models, level of autonomy, system design & operational aspects, privacy & legal issues, as well as thoughts about user groups and areas of application. However, it was impossible to draw a single generalized conclusion. The picture was rather mixed in various ways. People switched between two perspectives that of the potential user who saw attractive and that of the people on the street who might be affected. Even more, myCopter project was technically pessimistic. Generally, a major part of the participants judged the idea as “Over-Engineering”.

In another study, Helicopter Investor asked more than 1200 U.S. citizens whether they would be willing to fly in a pilotless air vehicle. 85% said no and it seems that most people are still unwilling to fly in a pilotless air vehicle.

As a general observation from Airbus focus group study, one could state that Airbus urban air mobility scenarios was with very positive spontaneous feedback. The participants brought in a lot of personal opinions, comments, and valuable criticism regarding urban air mobility. They also made several suggestions regarding clear advantages such as reduced travel time, higher predictability, easily accessible with individual destination choice, secure technology, friendly environment, and questions instead of concerns. Promises on saving time or winning relative time in terms of predictable duration and less buffer were very attractive. The urban air mobility use cases were also discussed in the focus groups. The first one was city-airport transfer. The second one was end-to-end city transfer and reaching offsite destinations was the third.

The third research question addressed the main challenges including technology, regulation, operation, social and environment aspects to enable eVTOL air transportation mode. The analysis points that the new form of air mobility involving autonomous air vehicles flying in automated airspace management systems may also have unintended consequences and unpredictable paths of development. Much the same as it was difficult to foresee all the positives and negatives of the internet or mobile telephony. As the technology underlying eVTOL PATS evolves, wider eVTOL PATS adoption across various markets is likely to be supported further if the key hurdles such as safety and security (collision avoidance, controlled flight into terrain, terrorist threats, near all-weather operations etc.), ease of use and autonomy, noise, infrastructure, airspace and air traffic management, and legal aspect (certification, regulation, and insurance) are overcome. The research suggests that achieving drastic improvements in safety and security, ease of use and automation, and acceptable noise are the most critical steps toward the social acceptability and widespread commercial use. One key issue for potential users, service providers and regulator for sure is safety and security for the user inside and for the people around. The safety and security issues are interestingly coming up in all focus groups and in our survey straight away at the beginning. Social acceptance of eVTOL air transportation mode depends mainly on actual and perceived safety of the system. Ensuring the security will be a joint effort across local communities, law enforcement, security agencies and operators.

In the field of environmental issues, the issue of noise and visual disturbance seems to be key ones that come up whenever people are confronted with the idea of eVTOL air vehicles flying around in higher counts in a city environment. For communities to accept sizeable fleet of eVTOL air vehicles, the noise will need to blend into the existing background noise, and it will be important to provide eVTOL PATS service without significant acoustic impact. The critical step will be determining what level of noise is acceptable to communities in return for offsetting benefits such as the possibility of reduced travel times or public-good of flights. The other environmental negative impact on city skylines and in areas of natural beauty when flying at higher altitudes in larger quantities is visual disturbance. Especially the expected swarm traffic during rush hour is a major source of concern. Another critical step to enable widespread commercial use is ease of use and automation.

Pre-flight simplification, terrain and obstacle avoidance, envelope protection, intuitive air vehicle health/knowledge systems, synthetic and enhanced vision, velocity vector with haptic control, decision aids, propulsion management systems, weather information and avoidance, autonomous emergency procedures, automatic take off/landing and even incapacitation detection are all part of the ease of use to be improved. It is tempting to think that a future eVTOL PATS will be fully automated and the driver will be a passenger who only enters a destination. Full automation is currently achieved for some specific scenarios, but the integration into densely populated airspace and the associated requirements for collision avoidance and air vehicle motion coordination are still unsolved topics.

Other major challenges are the topics of certification and regulation, airspace and air traffic management and the question of how to integrate eVTOL air transportation mode into the existing ground and air transportation system. eVTOL Personal Air Transportation System operations will likely necessitate a significant higher frequency and airspace density of air vehicles operating over metropolitan areas simultaneously. This means that the take-off and landing sites would have to handle high number of approaches during the rush hours. Thus, one of the important issues regarding increasing number of air traffic is efficient high-density operations with access to diverse platforms in airspace with integrated air-ground-cloud technologies. This necessitates an efficient air traffic management system would need to be in place to handle the distribution of incoming air traffic to the available landing sites.

Even if eVTOL PATS is certified to fly today, cities simply don’t have the necessary take-off, landing, maintenance and charging sites for the operation at fleet scaling. Thus, the greatest operational barrier to deploying eVTOL air transportation mode in urban areas is a lack of sufficient locations to place landing spots and parking. Operators must proactively engage with local resident communities, local and national governments to develop eVTOL air transportation mode related infrastructure. It will be essential to tailor the infrastructure and operation needs based on current transport demand and patterns of commuting. Handling the number of eVTOL air vehicles in the airspace and the parking issue relate to the attractive business models encouraging high occupancy rate such as sharing in private communities, and it will reduce the pressure on air traffic management, parking, noise, and visual disturbances. The last critical challenge is legal issues. Before eVTOL air vehicles can operate in any country, they will need to comply with regulations from air transportation authorities charged with assuring aviation safety. These regulations enforce standards for air vehicle design, production, pilot licensing, maintenance, and operating requirements. Overall, the analysis shows that the key reason that many PAV concepts have failed is because the operational infrastructure and socioeconomic issues have not been properly addressed; rather, the start point has been the design of the vehicle itself.

A successful implementation and sustainable transition will depend on overcoming a set of key technological hurdles. Key technology areas with prioritization based on enablement are: simplified vehicle operation and autonomy to make general people fly and increase safety; distributed electrical and new propulsion technologies to increase speed, capacity and safety; hybrid and energy storage systems to increase range for commercial operations; noise reduction technologies for community acceptance; safety systems to increase flight safety for user and community acceptance; and airspace and advanced air traffic management systems to handle increasing number of air traffic and provide efficient high-density operations. As we mentioned above, achieving drastic improvements in ease of use, safety, and community low noise are the most critical first steps towards the feasibility of this market in the next decade. As fully autonomous systems are achieved over the years, eVTOL PATS will enable more travelers to experience enhanced mobility.

The final step is synthesizing the policy advice addressing the potentials, the challenges, and the negative impacts related to the eVTOL PATS for service providers, regulator, metropoles, investors, and decision makers. This research intended to provide a methodology and framework starting with technology assessment point of view for emerging eVTOL air transportation mode, and a holistic vision on the potential consequences of the introduction of eVTOL PATS. This research contributed to the forming of public and policy opinion about eVTOL air transportation mode.

The research assesses that a new socio-technical transition will come about like the transition from horse drawn carriers to cars. Even if it is still a long way to go and there are compelling vehicle technology needs that must be resolved prior to the development of a successful market, it seems rather likely that the time has been arriving in the next decade and there is a significant potential benefit. The timeline for this to occur is as much a function of the required technologies becoming available, as it is to the development of new regulations, vehicle and airspace concepts, and an aerospace community more willing to take risk due to greater potential rewards. Even more, there is also a pressing need for a faster on-demand mobility system over the next years.

Against this background, eVTOL air transportation mode existence and operation would therefore need to be taken into consideration for future planning scenarios and policies to be able to have this emerging air transportation mode available. From the perspective of policy making, it is important to get prepared for future transport options. Transport infrastructures are long-lasting systems. It is crucial to early anticipate future transport innovations to be able to govern them in a most responsible and sustainable way. A community of aerospace profession ranging from technologist to business entrepreneurs to regulators can transform air transportation by enabling eVTOL air transportation mode through with overcoming issues of safety, noise, infrastructure, technology, regulation, and societal acceptance. Focused technology investments by government coupled with infrastructure investments and planning by local authorities are essential to enabling this vision.

The research assesses that an evolutionary path transitioning from current General Aviation operations will occur. The first years of the eVTOL PATS S-curve will be shaped by demonstrations of key capabilities and technologies in ease of use, quiet propulsion, and safe operations, because these technologies can only be understood by the public as they interact and learn to accept this new form of travel. The multi-use successful demos in early phase can also create public acceptance and understanding of potentials in emerging eVTOL air transportation mode for public good and use.

The research assesses that the issues of handling the increasing number of eVTOL air vehicles in the airspace, parking and support infrastructure capacity, noise and visual disturbance are also related to the attractive business models encouraging high occupancy rate such as sharing in private communities since it will reduce the pressure on them. This needs further discussion among the stakeholders to figure out an optimum number of eVTOL air vehicles in the airspace.

In our literature review search, we understand that most people are still unwilling to fly in a pilotless eVTOL air vehicle. This may explain a need for transformation period from single-pilot monitor to full autonomous eVTOL air vehicles.

The research assesses that the interviews with the regulator and transportation planning departments as the top decision makers show the need to be well informed and trained about the emerging eVTOL air transportation mode.

Last, it is important to reflect on the limitations of this study. In fact, this document is meant to be alive. The pace of change is generally much higher nowadays than it was about twenty years ago. It is by no means complete primarily due to technology changes with time so quickly. Since the subject was very specific, the study had to depend on leading organizations' reports, presentations, and papers in the sector such as NASA, AHS International, EU Framework Projects, Vertical Flight Society, eVTOL News and as a private company Uber while assessing the research subject. On the other hand, this research was designed to provide a first insights into a broad set of perceptions and impacts rather than a detailed discussion of pros and cons. Investigation in greater depth especially about challenges and operation business models must be done in future focus group studies including regulator, service provider, municipalities, and developer with more detailed eVTOL air vehicle design parameters or real eVTOL air vehicles in more realistic simulation including real-life traffic situation and scenarios.

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Annexes

Annex 1 eVTOL Personal Air Transportation System Questionnaire

Thank you to take a survey. It should not take you more than 10 minutes to complete the survey; you can discontinue the survey at any time. There are no direct benefits to you in this survey, including compensation. Indirect benefits of completing this study may include contributing to the body of knowledge concerning the usage of Small Aircraft Transportation Systems, especially for the long-term vision, VTOL Personal Air Vehicle and Mass Air Transportation System for urban and regional transportation.

This study's results may be reviewed by the NOVA University departments responsible for regulatory and research oversight. No identifying information will be collected or attached to the results of this project. If you have any questions, you can contact A Mete Yazan at a.yazan@campus.fct.unl.pt. Please complete your survey no later than *deadline*.

1. Aviation Experience; Have you flown before with any air vehicle?
o Yes
o No

2. Are you familiar with the concept of Small Aircraft Transportation Systems (SATS), in particularly Vertical Take-off and Landing (VTOL) Personal and Mass Air Transportation System?
o Yes
o No

3. Do you think that it would be a promising idea to develop VTOL Personal and Mass Air Transportation?
o Yes
o No
o No opinion due to the lack of enough information about the concept

4. Perception of the System; Please rate your personal perspectives on the following activities using the scale below.

1 – Strongly Disagree, 2 – Somewhat disagree, 3 – Neither Agree nor Disagree,
4 – Somewhat Agree, 5 – Strongly Agree

I would be comfortable with flying in a self-piloting personal air vehicle …………...1 2 3 4 5
I would be comfortable with flying in an aircraft flown by a fully autonomous pilot. 1 2 3 4 5
I would prefer on demand air transportation rather than a scheduled airline...………1 2 3 4 5
I would be comfortable with flying in air taxi..............……………………………...1 2 3 4 5
I would be comfortable with flying in a single pilot monitored mass air vehicle….…1 2 3 4 5
Using personal air vehicle for transportation is likely to help relief urban congestion.1 2 3 4 5
VTOL personal and mass air transportation system for urban and regional transportation can contribute business profit, traffic congestion relief, and daily life quality …................1 2 3 4 5

5. Please rate your highest priority expectations from highest 1 to 7 in case of implementing VTOL Personal and Mass Transportation System for urban and regional transportation.
o Acceptable noise level
o Flight safety and security
o Less door to door travel time
o Affordable operation cost
o On-demand or near on demand air transportation
o Transportation mode integration
o Traffic congestion relief
o Other, please define

6. Please rate your highest priority concerns from highest 1 to 9 in case of implementing VTOL Personal and Mass Transportation System for urban and regional.
o Noise
o Safety
o Security
o Operation cost affordability
o Emission
o Number of air vehicles in the airspace
o Air traffic management
o Parking
o Land and infrastructure costs for vertiports
o Other, please define

7. Please rate main challenges to enable VTOL Personal and Mass Air Transportation System for urban and regional transportation, from highest 1 to 6.
o Technology maturity
o Air Traffic Management
o Regulation
o Social acceptability
o Flight safety and security
o Parking and Land for vertiports in the cities
o Other, please define

Annex 2 Transformative Vertical Flight Working Group 2, Current eVTOL Concepts

The first documented manned all-electric VTOL flights occurred during 2011-12 (Schneider, 2012). They were a co-axial twin-rotor helicopter (Chretien, 2012) and a multicopter (Schneider, 2012). They were bare-bones aircraft, with a solo pilot, enabled by light-weight permanent magnet synchronous motors and compact Li ion batteries. They flew for only a few minutes (5-10) and lacked all attributes of a practical aircraft – payload, range, endurance, and safety – but even so, demonstrated the feasibility of electric-VTOL, which, if brought to fruition in practical scale, could open new opportunities in aviation due to its many inherent strategic advantages.

Very soon there was an explosion of interest in personal drones and a frenzy of design and development of small electric vertical takeoff and landing aircraft (Whittle, 2017). On 3 March 2016, DARPA awarded Aurora Flight Sciences (now a Boeing Company) U.S. $89.4 million to develop a VTOL distributed hybrid-electric experimental plane (designated XV-24A) further solidifying interest in this area.

After six years from the first manned electric-VTOL demonstrators, a total of at least 55 documented designs / commercial ventures can be found in public domain. AHS has compiled a comprehensive list of all these aircraft. Very limited data is available, nevertheless a short version of this list below for completeness of documentation (Datta, 2017).

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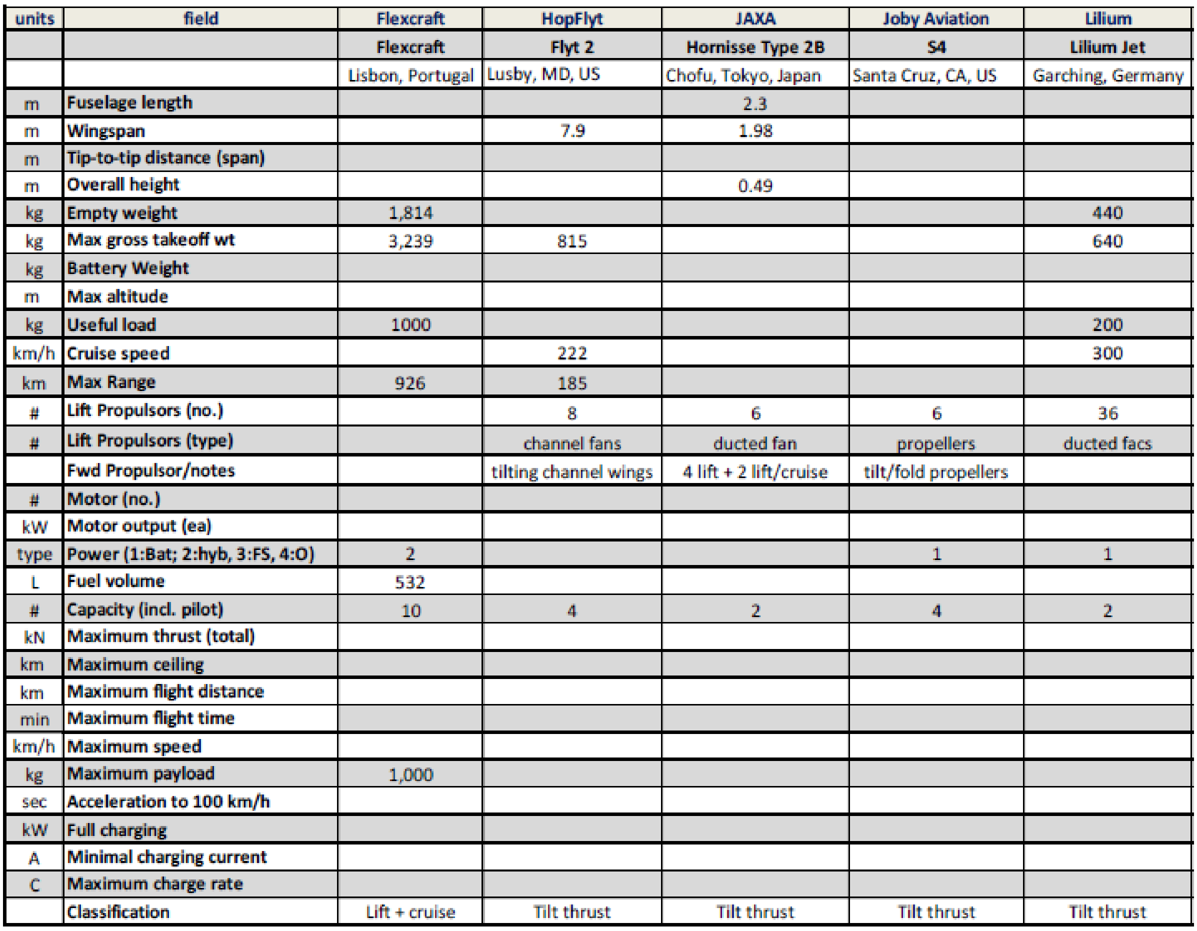
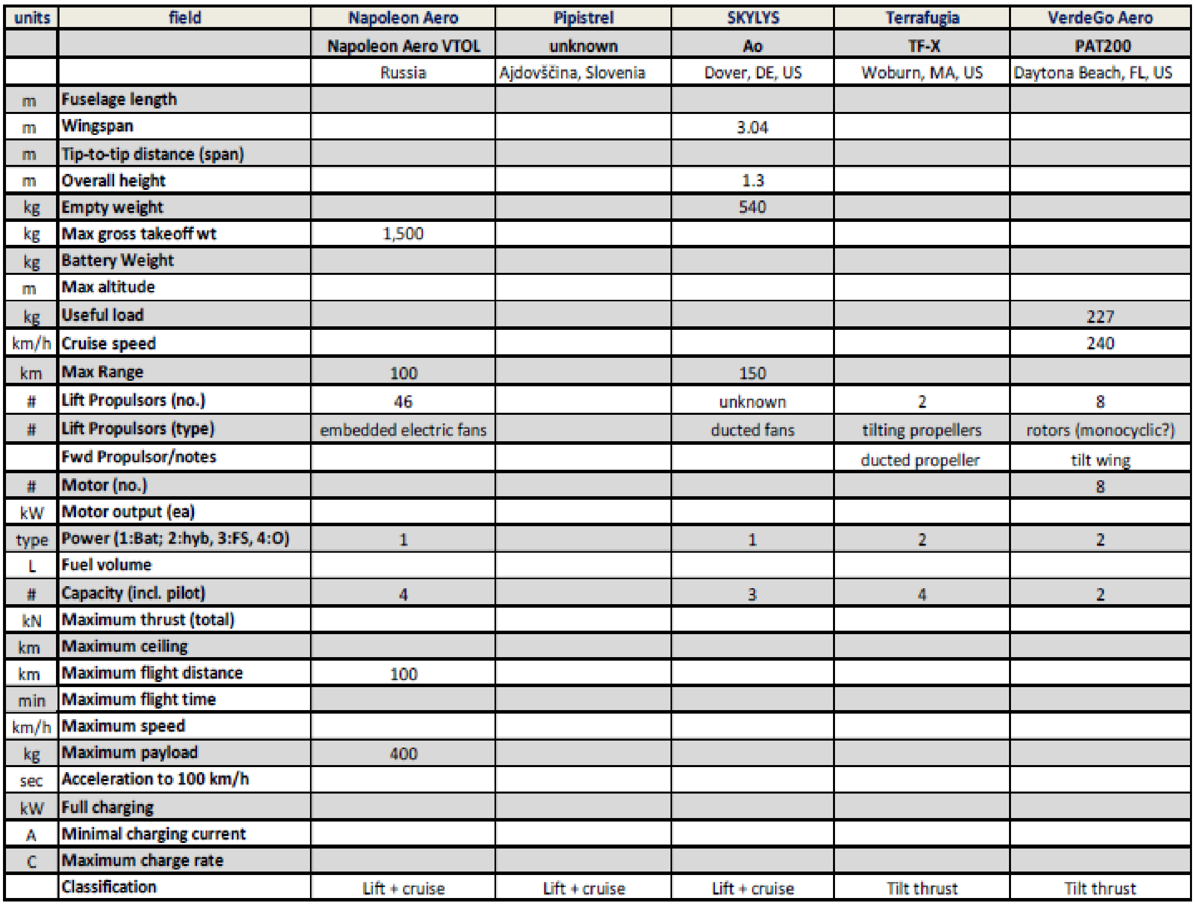
units	field	Alauda	A^3 by Airbus	AirspaceX	Aurora	Aurora	Bell Helicopter
		Airspeeder	Vahana	MOBi	LightningStrike	Aurora eVTOL	Bell Air Taxi
		Australia	Santa Clara, CA, US	Birmingham, MI, USA	Manassas, VA, US	Manassas, VA, US	Ft Worth, TX, US
m	Fuselage length		5.8		11.8	8	
m	Wingspan		6		18.2	8	
m	Tip-to-tip distance (span)		7.3		18.2	8	
m	Overall height		2.75		4.3		
kg	Empty weight				5160	575	
kg	Max gross takeoff wt	120	725		5900	800	
kg	Battery Weight						
m	Max altitude						
kg	Useful load				737	225	
km/h	Cruise speed		175	241	555	180	
km	Max Range			115			
#	Lift Propulsors (no.)	4	8	6	24	8	
#	Lift Propulsors (type)	propellers	propellers	propellers	ducted fans	propellers	
	Fwd Propulsor/notes					1 cruise prop	
#	Motor (no.)	4	8	6	24		
kW	Motor output (ea)	50	45		116.25		
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)	1	1	1	2	1	2
L	Fuel volume						
#	Capacity (incl. pilot)	1	1	4	0	2	4
kN	Maximum thrust (total)	200 kN					
km	Maximum ceiling						
km	Maximum flight distance						
min	Maximum flight time						
km/h	Maximum speed						
kg	Maximum payload						
sec	Acceleration to 100 km/h		6				
kW	Full charging		154				
A	Minimal charging current		6A at 220 VAC	15A at 110 VAC			
C	Maximum charge rate						
	Classification	Hoverbike	Tilt thrust	Tilt thrust	Tilt thrust	Lift + cruise	Tilt thrust

units	field	Carter Aviation Technology	DeLorean Aerospace	Digi Robotics	DigiRobotics	Electric Visionary
		CarterCopter	DR-7	DroFire (unmanned)	Droxi	X01
		Wichita Falls, TX, US	Laguna Beach, CA, US	Dubai, UAE	Dubai, UAE	Toulouse, France
m	Fuselage length					4.3
m	Wingspan	10.4				
m	Tip-to-tip distance (span)					
m	Overall height					2.7
kg	Empty weight	1450				
kg	Max gross takeoff wt	1815				
kg	Battery Weight					
m	Max altitude					
kg	Useful load					
km/h	Cruise speed	281				
km	Max Range					
#	Lift Propulsors (no.)	1	2	6		16
#	Lift Propulsors (type)	10.4 m slowed rotor	ducted fans	propellers		fans
	Fwd Propulsor/notes	compound	Tilt thrust			4 different sizes
#	Motor (no.)					
kW	Motor output (ea)					
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)	1				1
L	Fuel volume					
#	Capacity (incl. pilot)	4	2	0	6	
kN	Maximum thrust (total)					
km	Maximum ceiling					
km	Maximum flight distance					
min	Maximum flight time			150	660	
km/h	Maximum speed			250		
kg	Maximum payload				1000	
sec	Acceleration to 100 km/h					
kW	Full charging					
A	Minimal charging current					
C	Maximum charge rate					
	Classification	Lift + cruise	Tilt thrust	Tilt thrust	Tilt thrust	Tilt thrust



units	field	Flexcraft	HopFlyt	JAXA	Joby Aviation	Lilium
		Flexcraft	Flyt 2	Hornisse Type 2B	S4	Lilium Jet
		Lisbon, Portugal	Lusby, MD, US	Chofu, Tokyo, Japan	Santa Cruz, CA, US	Garching, Germany
m	Fuselage length			2.3		
m	Wingspan		7.9	1.98		
m	Tip-to-tip distance (span)					
m	Overall height			0.49		
kg	Empty weight	1,814				440
kg	Max gross takeoff wt	3,239	815			640
kg	Battery Weight					
m	Max altitude					
kg	Useful load	1000				200
km/h	Cruise speed		222			300
km	Max Range	926	185			
#	Lift Propulsors (no.)		8	6	6	36
#	Lift Propulsors (type)		channel fans	ducted fan	propellers	ducted facs
	Fwd Propulsor/notes		tilting channel wings	4 lift + 2 lift/cruise	tilt/fold propellers	
#	Motor (no.)					
kW	Motor output (ea)					
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)	2			1	1
L	Fuel volume	532				
#	Capacity (incl. pilot)	10	4	2	4	2
kN	Maximum thrust (total)					
km	Maximum ceiling					
km	Maximum flight distance					
min	Maximum flight time					
km/h	Maximum speed					
kg	Maximum payload	1,000				
sec	Acceleration to 100 km/h					
kW	Full charging					
A	Minimal charging current					
C	Maximum charge rate					
	Classification	Lift + cruise	Tilt thrust	Tilt thrust	Tilt thrust	Tilt thrust



units	field	Napoleon Aero	Pipistrel	SKYLYS	Terrafugia	VerdeGo Aero
		Napoleon Aero VTOL	unknown	Ao	TF-X	PAT200
		Russia	Ajdovščina, Slovenia	Dover, DE, US	Woburn, MA, US	Daytona Beach, FL, US
m	Fuselage length					
m	Wingspan			3.04		
m	Tip-to-tip distance (span)					
m	Overall height			1.3		
kg	Empty weight			540		
kg	Max gross takeoff wt	1,500				
kg	Battery Weight					
m	Max altitude					
kg	Useful load					227
km/h	Cruise speed					240
km	Max Range	100		150		
#	Lift Propulsors (no.)	46		unknown	2	8
#	Lift Propulsors (type)	embedded electric fans		ducted fans	tilting propellers	rotors (monocyclic?)
	Fwd Propulsor/notes				ducted propeller	tilt wing
#	Motor (no.)					8
kW	Motor output (ea)					
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)	1		1	2	2
L	Fuel volume					
#	Capacity (incl. pilot)	4		3	4	2
kN	Maximum thrust (total)					
km	Maximum ceiling					
km	Maximum flight distance	100				
min	Maximum flight time					
km/h	Maximum speed					
kg	Maximum payload	400				
sec	Acceleration to 100 km/h					
kW	Full charging					
A	Minimal charging current					
C	Maximum charge rate					
	Classification	Lift + cruise	Lift + cruise	Lift + cruise	Tilt thrust	Tilt thrust

units	field	Vimana	XTI Aircraft	Zee Aero	Airbus
		unnamed AAV	Trifan 600	Z-P1	CityAirbus
			Englewood, CO, US	Mountain View, CA, US	Marignane, France
m	Fuselage length		11.8		
m	Wingspan	10	11.5		
m	Tip-to-tip distance (span)				
m	Overall height				
kg	Empty weight		1,588		
kg	Max gross takeoff wt				
kg	Battery Weight				
m	Max altitude				
kg	Useful load				
km/h	Cruise speed	280	500		120 km/h
km	Max Range	900	1,270		
#	Lift Propulsors (no.)	8	3	8	8
#	Lift Propulsors (type)	propellers	ducted fans	propellers	ducted propellers
	Fwd Propulsor/notes	tilt wing	tilting/1 fixed in fuselag	1 pusher prop	
#	Motor (no.)	8		8	8
kW	Motor output (ea)				100
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)	1	2	1	1
L	Fuel volume				
#	Capacity (incl. pilot)	4	6	4	4
kN	Maximum thrust (total)				
km	Maximum ceiling	3,000			
km	Maximum flight distance				
min	Maximum flight time				
km/h	Maximum speed				
kg	Maximum payload				
sec	Acceleration to 100 km/h				
kW	Full charging				
A	Minimal charging current				
C	Maximum charge rate				
	Classification	Tilt thrust	Tilt thrust	Lift + cruise	Wingless

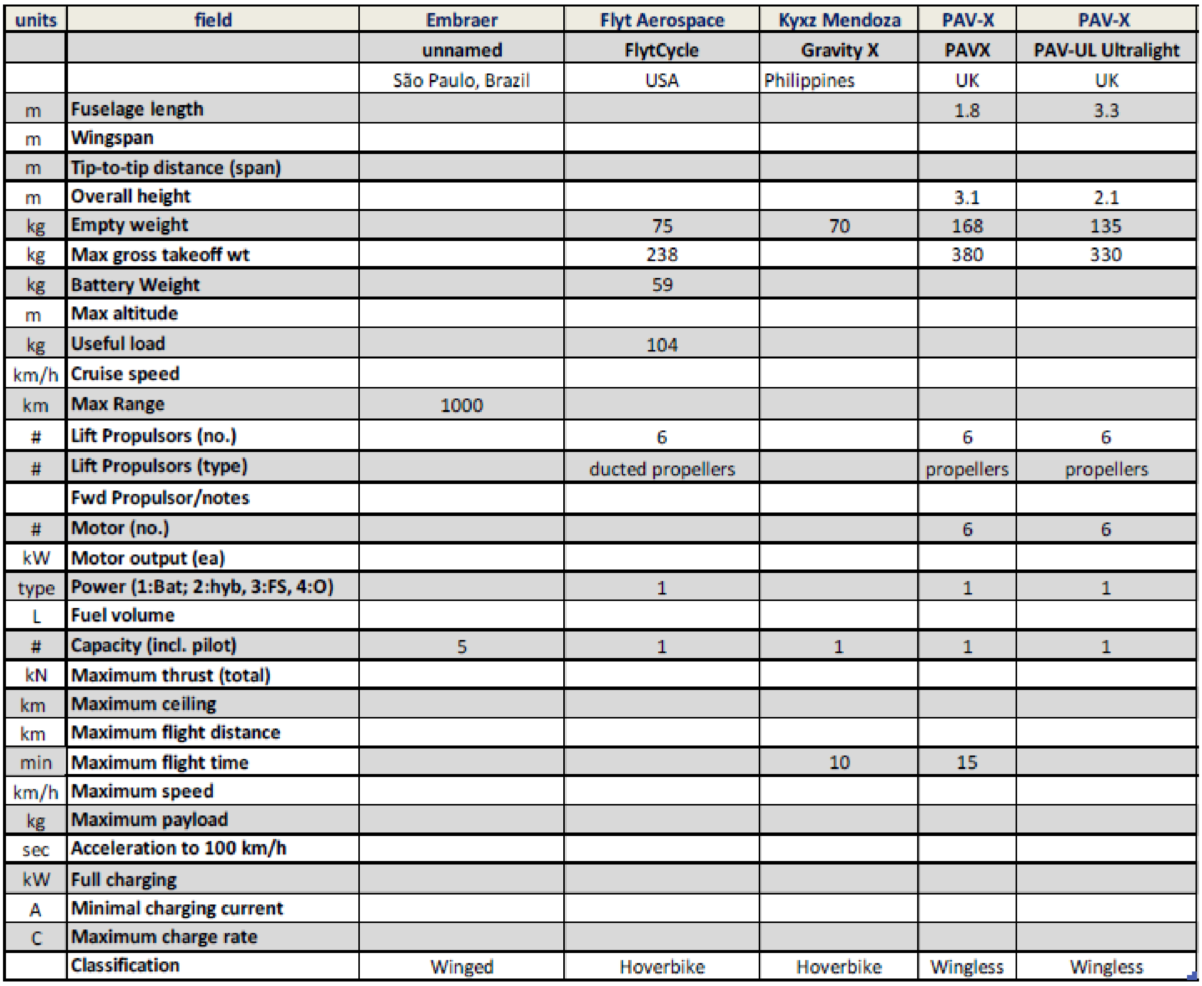
units	field	Avianovations	Avianovations	Bartini	Cartivator	Dekatone
		Hepard Urban	Hepard Sport	Flying Car	SkyDrive	Flying Car
		Russia	Russia	Skolkovo, Russia	Toyota City, Japan	Toronto, Canada
m	Fuselage length	3.3	3.3	5.2	2.9	
m	Wingspan					
m	Tip-to-tip distance (span)					
m	Overall height	1.6	1.6	1.7	1.1	
kg	Empty weight	390	510			
kg	Max gross takeoff wt			1,100		
kg	Battery Weight			320		
m	Max altitude			1000	10	
kg	Useful load					
km/h	Cruise speed			300		
km	Max Range	75	76	150		
#	Lift Propulsors (no.)			4	4	4
#	Lift Propulsors (type)			ducted propellers	ducted propellers	ducted fans
	Fwd Propulsor/notes				roadable ducts	
#	Motor (no.)			8		
kW	Motor output (ea)			40		
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)					
L	Fuel volume					
#	Capacity (incl. pilot)	1	2	4	1	8
kN	Maximum thrust (total)					
km	Maximum ceiling					
km	Maximum flight distance					
min	Maximum flight time	15		30		
km/h	Maximum speed				100	
kg	Maximum payload	130	240	400		
sec	Acceleration to 100 km/h	6	3			
kW	Full charging	154	207			
A	Minimal charging current	6A/220 VAC, 15A/110 VAC				
C	Maximum charge rate					
	Classification		Wingless	Tilt thrust	Wingless	Wingless

units	field	Ehang	Hoversurf	Jetpack Aviation	Kalashnikov Concern	Passenger Drone
		184	Formula	unnamed	unnamed	Passenger Drone
		Guangzhou, China	Moscow, Russia	Van Nuys, CA, US	Izhevsk, Udmurtia, Russia	Zurich, Switzerland
m	Fuselage length	4				4.2
m	Wingspan					
m	Tip-to-tip distance (span)	5				
m	Overall height					1.8
kg	Empty weight	240				240
kg	Max gross takeoff wt	360				360
kg	Battery Weight					
m	Max altitude					
kg	Useful load	120				
km/h	Cruise speed	60				
km	Max Range		450			
#	Lift Propulsors (no.)	8	48	12	16	16
#	Lift Propulsors (type)	propellers	venturi fans	propellers	propellers	propellers
	Fwd Propulsor/notes		4 thruster fans			
#	Motor (no.)	8		12		
kW	Motor output (ea)	152				
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)	1			1	1
L	Fuel volume					
#	Capacity (incl. pilot)	1	5	1		2
kN	Maximum thrust (total)					560
km	Maximum ceiling					
km	Maximum flight distance					
min	Maximum flight time					25
km/h	Maximum speed		320			70
kg	Maximum payload					120
sec	Acceleration to 100 km/h					
kW	Full charging					
A	Minimal charging current					
C	Maximum charge rate					
	Classification	Wingless	Lift + cruise	Wingless	Hover bike	Wingless

units	field	Urban Aeronautics	Urban Aeronautics2	Volocopter	Volocopter2
		CityHawk	Falcon XP	VC200	2X
		Yavne, Israel	Yavne, Israel	Bruchsal, Germany	Bruchsal, Germany
m	Fuselage length			2.9	3.2
m	Wingspan			0	0
m	Tip-to-tip distance (span)			9.15	9.15
m	Overall height			2	2.15
kg	Empty weight	1,170	2,000	300	290
kg	Max gross takeoff wt	1,930	3,500	450	450
kg	Battery Weight				
m	Max altitude				
kg	Useful load			150	160
km/h	Cruise speed			100	100
km	Max Range	150	180		
#	Lift Propulsors (no.)	2	2	18	18
#	Lift Propulsors (type)	large fans	large fans	propellers	propellers
	Fwd Propulsor/notes	2 small fan thrusters	2 small fan thrusters		
#	Motor (no.)			18	
kW	Motor output (ea)			3.9	
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)			1	1
L	Fuel volume				
#	Capacity (incl. pilot)	5	14	2	2
kN	Maximum thrust (total)				
km	Maximum ceiling				
km	Maximum flight distance				
min	Maximum flight time				
km/h	Maximum speed	270	216		
kg	Maximum payload	760	1,500		
sec	Acceleration to 100 km/h				
kW	Full charging				
A	Minimal charging current				
C	Maximum charge rate				
	Classification	Wingless	Wingless	Wingless	Wingless

units	field	VRCO	Workhorse	Flike	HoverSurf	Hoversurf	Kitty Hawk
		NeoXCraft	SureFly	Flike	Drone Taxi R-1	Scorpion	Flyer
		Nottingham, UK	Loveland, OH, USA	Hungary	UAE	Russia	Mountain View, CA, US
m	**Fuselage length**					2.027	
m	**Wingspan**						
m	**Tip-to-tip distance (span)**						
m	**Overall height**					1.047	
kg	**Empty weight**					104	
kg	**Max gross takeoff wt**		680	400			
kg	**Battery Weight**					54	
m	**Max altitude**						
kg	**Useful load**						
km/h	**Cruise speed**	333		100	300	70	
km	**Max Range**		112		400	21	
#	**Lift Propulsors (no.)**	4	8		4	4	8
#	**Lift Propulsors (type)**	tilting ducts	propellers		propellers	propellers	propellers
	Fwd Propulsor/notes				1 small prop thruster	124.5 cm prop	
#	**Motor (no.)**					4	8
kW	**Motor output (ea)**						
type	**Power (1:Bat; 2:hyb, 3:FS, 4:O)**	1	2	1	2	1	1
L	**Fuel volume**						
#	**Capacity (incl. pilot)**	2	2		1	1	1
kN	**Maximum thrust (total)**						
km	**Maximum ceiling**		1200	30		28.5	
km	**Maximum flight distance**						
min	**Maximum flight time**	60				20	
km/h	**Maximum speed**		112	100			
kg	**Maximum payload**		181	100			
sec	**Acceleration to 100 km/h**						
kW	**Full charging**						
A	**Minimal charging current**						
C	**Maximum charge rate**						
	Classification	Tilt thrust	Wingless	Hover bike	Hover bike	Hover bike	Hover bike

units	field	Malloy Aeronautics	Neva	Autonomous Flight	Davinci	Davinci
		Hoverbike	AirQuadOne	Y6S	ZeroG (Prototype)	ZeroG (Design)
		Surrey, UK	Falmer, Brighton, UK	Sevenoaks, Kent, UK	Hanoi, Vietnam	Hanoi, Vietnam
m	**Fuselage length**				1.6	2.5
m	**Wingspan**					
m	**Tip-to-tip distance (span)**				2.4	
m	**Overall height**					
kg	**Empty weight**				55	90
kg	**Max gross takeoff wt**				135	240
kg	**Battery Weight**				32	50
m	**Max altitude**					
kg	**Useful load**					
km/h	**Cruise speed**					
km	**Max Range**			130		
#	**Lift Propulsors (no.)**			3	12	12
#	**Lift Propulsors (type)**			ducted propellers	81 cm propellers	
	Fwd Propulsor/notes				coaxial	coaxial
#	**Motor (no.)**				12	12
kW	**Motor output (ea)**				6	30
type	**Power (1:Bat; 2:hyb, 3:FS, 4:O)**				1	
L	**Fuel volume**					
#	**Capacity (incl. pilot)**	1	1	2	1	
kN	**Maximum thrust (total)**					
km	**Maximum ceiling**					
km	**Maximum flight distance**					
min	**Maximum flight time**				20	25
km/h	**Maximum speed**			113	70	70
kg	**Maximum payload**		100			
sec	**Acceleration to 100 km/h**					
kW	**Full charging**					
A	**Minimal charging current**					
C	**Maximum charge rate**					
	Classification	Hover bike	Hover bike	Tilt-thrust	Wingless	Hoverbike



units	field	Embraer	Flyt Aerospace	Kyxz Mendoza	PAV-X	PAV-X
		unnamed	FlytCycle	Gravity X	PAVX	PAV-UL Ultralight
		São Paulo, Brazil	USA	Philippines	UK	UK
m	Fuselage length				1.8	3.3
m	Wingspan					
m	Tip-to-tip distance (span)					
m	Overall height				3.1	2.1
kg	Empty weight		75	70	168	135
kg	Max gross takeoff wt		238		380	330
kg	Battery Weight		59			
m	Max altitude					
kg	Useful load		104			
km/h	Cruise speed					
km	Max Range	1000				
#	Lift Propulsors (no.)		6		6	6
#	Lift Propulsors (type)		ducted propellers		propellers	propellers
	Fwd Propulsor/notes					
#	Motor (no.)				6	6
kW	Motor output (ea)					
type	Power (1:Bat; 2:hyb, 3:FS, 4:O)		1		1	1
L	Fuel volume					
#	Capacity (incl. pilot)	5	1	1	1	1
kN	Maximum thrust (total)					
km	Maximum ceiling					
km	Maximum flight distance					
min	Maximum flight time			10	15	
km/h	Maximum speed					
kg	Maximum payload					
sec	Acceleration to 100 km/h					
kW	Full charging					
A	Minimal charging current					
C	Maximum charge rate					
	Classification	Winged	Hoverbike	Hoverbike	Wingless	Wingless

Aurora eVTOL

Bell Air Taxi

X01

DeLorean DR-7

Joby S-2

Lilium Jet


© Terrafugia / Barcroft Cars

TF-X

PAT 200

XTI Trifan 600

CityAirbus

SkyDrive

Bartini

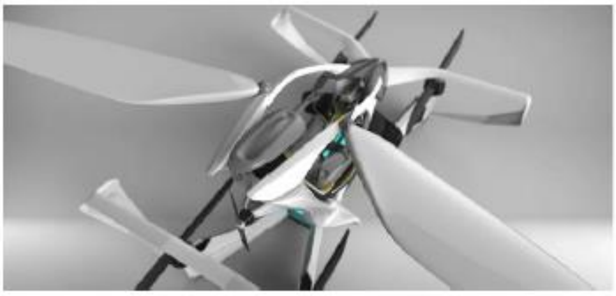
Ehang

Passenger Drone

Volocopter VC200

Volocopter 2X

Sure Fly



Drone Taxi R-1

Y6S

DaVinci ZeroG

PAV-X

Hoversurf Scorpion

Annex 3 eVTOL Timeline

1. First Flight of the Solution F Helicopter in Venelles, France. August 4, 2011

2. First Flight of the SkyKar Rebel (Opener BlackFly) in Warkworth, Canada. October 5, 2011

3. First Flight of Volocopter VC1 in Karlsruhe, Germany. October 21, 2011

4. First Flight of the Zee Aero Z-P2 in Hollister, California. December 1, 2011

5. First Flight of Volocopter VC200 in Rheinstetten, Germany. November 17, 2013

6. First Flight of Aquinea Volta in Castelnaudary, France. February 17, 2016

7. First Manned Flight of the Volocopter VC200 in Karlsruhe, Germany. March 30, 2016

8. First Flight of the Tier 1 in Los Alamitos, California. September 13, 2016

9. First Flight of the Lilium Jet nearby Munich, Germany. April 20, 2017

10. First Flight of the Astro AA360 in California. May 1, 2017

11. First Manned Flight of Zee Aero Z-P2 in Hollister, California. August 1, 2017

12. First Manned Flight of the Astro AA360 in California. August 1, 2017

13. First Flight of Kitty Hawk Cora in Hollister, CA. November 1, 2017

14. First Flight of the A³ Vahana in Pendleton, Oregon. January 31, 2018

15. First Public Manned Flight of EHang 184 in Guangzhou City, February 6, 2018

16. First Flight of the Workhorse SureFly in Cincinnati, Ohio. April 30, 2018

Source: http://evtol.news, retrieved in October 2018

Annex 4 eVTOL Air Vehicles

Vectored Thrust

An eVTOL aircraft that uses any of its thrusters for lift and cruise*:*

1. A³ Vahana
2. aeroG Aviation aG-4
3. AgustaWestland Project Zero
4. AirisOne
5. AirspaceX MOBi
6. Aston Martin Volante
7. Aurora Flight Sciences LightningStrike (defunct)
8. Autonomous Flight Y6S
9. Bartini Flying Car
10. Bell Air Taxi
11. Carter Aviation Air Taxi
12. DeLorean Aerospace DR-7
13. Digi Robotics DroFire
14. Digi Robotics Droxi
15. Dufour aEro2
16. EVA X01
17. HopFlyt Venturi
18. JAXA Hornisse 2B
19. Jetoptera J2000
20. Joby Aviation Lotus (defunct)
21. Joby Aviation S2 (defunct)
22. Joby Aviation S4
23. Karem Butterfly
24. KARI PAV
25. Lilium Jet
26. Moller Skycar M200
27. Moller Skycar M400
28. Neoptera eOpter
29. Opener BlackFly
30. Piasecki eVTOL
31. Pipistrel (unnamed)
32. PteroDynamics Transwing
33. Rolls-Royce EVTOL

34. Sabrewing Draco-2
35. Sikorsky VERT
36. SKYLYS Aircraft AO
37. Starling Jet
38. Supervolant Pegasus
39. Terrafugia TF-2 Tiltrotor
40. Terrafugia TF-X
41. Transcend Air Vy 400
42. VerdeGo Aero PAT200
43. Vertical Aerospace (unmanned)
44. Vertiia
45. Vickers WAVE eVTOL
46. Vimana AAV
47. Vision VTOL
48. VTOL Aviation Abhiyaan
49. XTI Aircraft Trifan 600
50. Zenith Altitude EOPA

Lift + Cruise

Completely independent thrusters used for cruise as for lift:

1. AeroMobil 5.0
2. Aergility ATLIS
3. Aurora Flight Sciences eVTOL
4. AutoFlightX BAT600
5. EAC Whisper
6. Embraer DreamMaker
7. Flexcraft
8. Hi-Lite Lynx-us
9. HoverSurf Formula
10. Kitty Hawk Cora
11. Napoleon Aero VTOL
12. Pipistrel (unnamed)
13. Ray Research VTOL Aircraft
14. Terrafugia TF-2 Lift + Push
15. Urban Aeronautics CityHawk
16. Zee Aero Z-P2

Wingless (Multicopter)

No thruster for cruise – only for lift.

1. Airbus Helicopters CityAirbus
2. Alauda Airspeeder
3. Astro Elroy (“Passenger Drone”)
4. Avianovations Hepard
5. Axix SkyRider SuvA
6. Boeing Cargo Aerial Vehicle
7. Cartivator SkyDrive
8. chAIR Multicopter
9. Davinci ZeroG
10. Dekatone (unnamed)
11. EHang 184
12. EHang 216
13. Jetpack Aviation (unnamed)
14. Kármán XK-1
15. Kenyan Passenger Drone
16. Kitty Hawk Flyer
17. ManDrone
18. NUS Snowstorm
19. PAV-UL Ultralight
20. PAV-X
21. Pop.Up Next
22. Skypod Aerospace Skypod
23. Sky-Hopper
24. Swarm Multicopter
25. Varon V200
26. Volocopter 2X
27. Volocopter VC1/VC2 (defunct prototypes)
28. Volocopter VC200
29. VRCO NeoXCraft
30. Workhorse SureFly

Electric Helicopters

An eVTOL aircraft that utilizes a helicopter frame

1. Sikorsky Firefly
2. Solution F
3. Tier One Modified Robinson R44
4. Volta

Hover Bikes/Personal Flying Devices

The following single-person eVTOL aircraft are considered to be in the general class of hover bikes or personal flying devices with the primary differentiation being that the pilot sits on a saddle or is standing, or something similar. All are multi-copter-type wingless configurations.

1. Aeroxo ERA Aviabike
2. Assen A1
3. Bay Zoltán Flike
4. Electric Jet EJ-1
5. Flyt Aerospace FlytCycle
6. Georgia TechHummingBuzz
7. Gravity X
8. Hero Flyer
9. HoverSurf Drone Taxi R-1
10. HoverSurf Scorpion
11. Kalashnikov (unnamed)
12. Kitty Hawk Flyer (defunct prototype)
13. Leap Vantage
14. Malloy Aeronautics Hoverbike
15. NASA Puffin
16. Neva Aerospace AirQuadOne
17. Penn State University Blue Sparrow
18. Ray Research Dart Flyer
19. Scoop Pegasus 1
20. Silverwing S1
21. teTra 3
22. Texas A&M University Harmony
23. Trek Aerospace FlyKart 2
24. University of Kansas Mamba

Source: http://evtol.news, retrieved in October 2018