Submission to European Transport Conference 2013

Title: Personal air vehicles as a new option for commuting in Europe: vision or illusion?

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Theme: Future mobility services

Abstract

Based on preliminary findings from the FP7 project "MyCopter", the paper assesses the presuppositions for and the potential implications of "personal air vehicles" as a future mobility service.

1 Introduction

A broad range of technology trajectories can be observed enabling new mobility options and services in future transport system (Wiesenthal et al. 2011). Usually, Information and Communication technologies (ICT) are playing a key-role in this context. Well in line with the objectives of sustainable transport there usually is a focus on making transport modes cleaner (Skinner et al. 2010), reducing mobility needs or enabling a modal shift to more efficient modes of transport (Banister 2008, CEC 2011). But the future is open and hardly predictable, even if there surely is a potential for governing also complex socio-technical systems such as a transport system in a desired direction.

Nevertheless, it is always possible and should not be ignored that "surprises" emerge on the scene which have not been really anticipated by the majority of experts in the field. In an ex post analysis these development are reconstructed as "disruptive" innovations (Markides 2006). Prominent examples can be found in the ICT sector, with the extremely fast diffusion of personal computers and cell phones. To give an example from the transport sector: for long time it has not really been envisioned that the market penetration of e-mobility will make its first success story in the bicycle sector (Hurst 2013). "Disruptive" innovations are difficult to identify ex ante. However, foresight or "monitoring" activities are useful approaches to enable an early detection of such developments and to prepare for early measurers to support societal desirable innovation.

Against this background, this paper will have a closer look at the potentials of personal air vehicles (PAV) to gain market shares in the transport sector. The paper to be presented is based on work carried out in context of the FP7 project "MyCopter" (www.mycopter.eu).[1] The central idea of the project is to avoid the typical problems associated with ground-based transportation by using the

[1] Please note: this paper is built up of content which was mainly produced by work package 7 of the myCopter project, major parts of the text were taken from the first two deliveries Del. 7.1 and Del. 7.2.(Meyer et al. 2011 & Fleischer et al. 2013) of this work package.

third dimension, combining the best of ground-based and air-based transportation. The solution pursued in MyCopter is the creation of a personal air transport system (PATS) that can overcome the environmental and financial costs associated with current methods of transport. To enable this personal air transport system PAVs are envisioned for traveling between homes and workplaces. They should be flying at low altitude in urban environments. Such PAVs should be fully or partially autonomous without requiring ground-based air traffic control and operate outside controlled airspace. They should be designed in a way that allows for using battery based electric propulsion systems.

The paper will illustrate how scenarios for a future integration of PAVs into the transport system could look like and discuss whether more attention needs to be put on developments in the PAV sector regarding the preparation of transportation scenarios and policies for the coming decades. According to the project specifications, the focus will be on commuting. Using examples from German cities (which are among the most congested cities in Europe (TomTom 2013) and where a financially strong group of potential “early adopters” can be expected) the paper assesses the presuppositions for and implications of a market penetration of PAVs. One scenario to be discussed will be offering air vehicles as a sort of taxi-like service, flying fully autonomous and carrying two people at maximum. But other scenarios will be outlined as well. Based on this work, it will be possible to provide a clearer picture on the advantages and disadvantages of PAVs – in particular with regard to potential impacts on sustainability.

2 The flying car an old and ongoing dream

Visions about PAVs can be traced back to the early 20th century (Hall 2001) and found their way into tv series like the Jetsons but can also be found on magazine covers and newspapers (see Figure 1).

Adverts in the early 60th`s pictured the situation of Mr. and Mrs. America having not only one to several cars in their garage but also an airplane and perhaps even a small helicopter (N.N. 2005).

Figure 1: Picture showing the vision of a „helicopter for everybody" and its use in daily life

Source: Mechanix Illustrated, January 1951

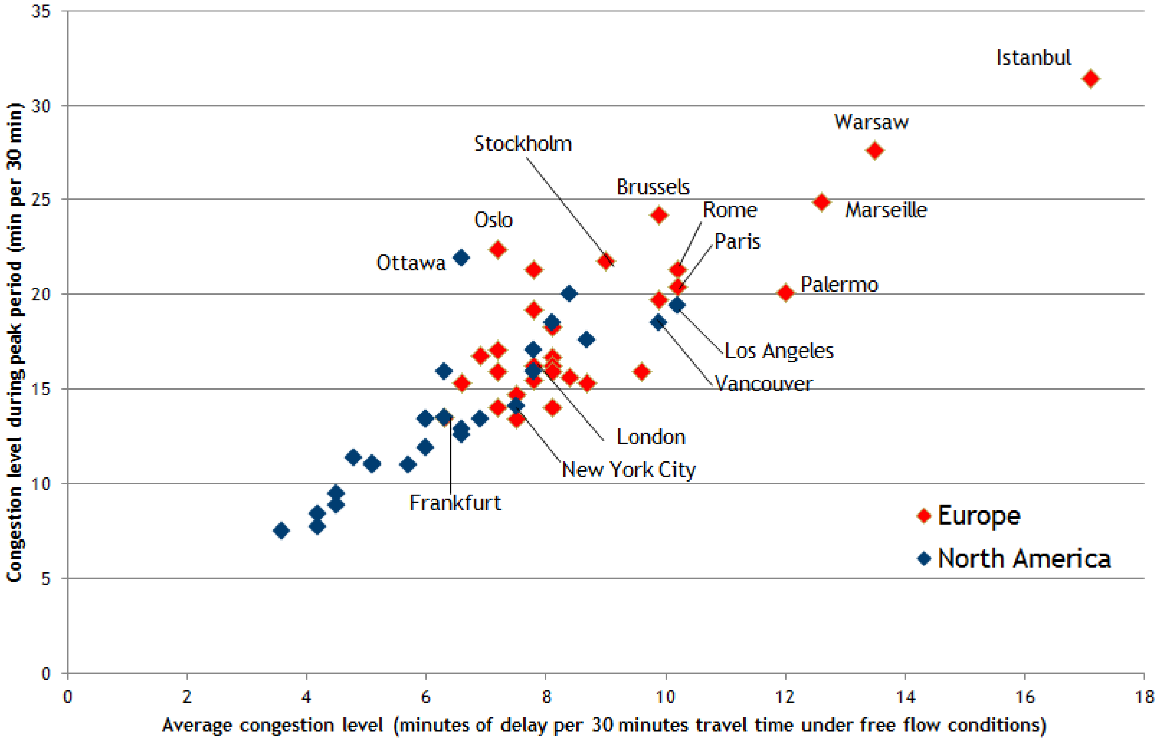
Interestingly a book from 1945 from the American Historical Association about the potential of helicopters and personal airplanes sees the helicopter as a mode of travel complementing the car. While the helicopter is thought to be a good solution for longer inter regional trips it is not seen as an answer for the transportation in urban areas.

*"You can use your car in crowded congested urban areas and your helicopter for all other travel" (*American Historical Association 1945)

But this is exactly the challenge the MyCopter project wants to address, it is thought to be a solution for trips which are in our days prone to congestion which are mainly the trips to and from work (de Borger 2009) during peak hours in the inner city areas.

Congestion is an area of growing concern, especially in the densely populated urban areas and regions in Western and Central Europe as well as in North America (see Figure 2).

Figure 2: Comparison of average and peak hour congestion levels in major European and North American cities (based on floating car data for Q2/2012 from TomTom)



The overuse of transportation networks leads to increasing journey times, reduced reliability of the transportation system and adverse environmental impacts since congestion results in increased air and noise pollution and higher fuel consumption. Transportation economy scholars who discuss (and sometimes quantify) the economic impact of congestion – which, according to CEC data costs Europe about 1% of Gross Domestic Product (GDP) every year (CEC 2006) – have identified time cost as the dominant factor of the overall congestion cost. In the Reference Scenario of the European Commission's "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system" of 2011, congestion costs are projected to increase by about 50%, to nearly 200 billion € annually, by 2050.

Approaches to deal with the congestion problem are manifold such as road pricing or incentives for avoiding peak hour travel (Eran & Dick 2011), building of new road infrastructure, use of ITC (Dimitrakopoulos 2012) and as a kind of niche strategy also the development of new transport modes such as PAVs. Nowadays, considerable amounts of demonstrators (also known as flying cars or roadable aircraft) are being developed, for some of them commercialization is announced to come soon.[2] One recent development in this direction is the small company e-volo based in Karlsruhe (Germany) who has gained an immense media interest by their internet video showing the first manned flight of a purely electrically powered VTOL in 2011 (http://www.e-volo.com/). These approaches are often neglected in transport related visions and scenarios or simply denounced as being not realistic or outright fantastic.

3 The MyCopter project: central idea & approach

[2] e.g. the Terrafugia Transition a dual-mode roadable Light Sport Aircraft for 2 persons, expected first delivery 2015 (Woodyard 2013)

The project MyCopter is a project funded by the European Union under the 7th Framework Programme and involves six partners: the Max Planck Institute for Biological Cybernetics in Tübingen, the University of Liverpool, the Ècole Polytechnique Fédérale in Lausanne, the ETH Zürich, the Karlsruhe Institute of Technology and the DLR in Braunschweig. It is looking into the idea of personal air transportation via small air vehicles which are used in an urban context for the purpose of commuter traffic.[3]

The challenge the project wants to address is the problem of road congestion mainly during rush hours. In order to do this the idea is to take aspects seen as helpful from the two –until now- quite separated and for different trip lengths used air- and ground transport systems.

In the commercial air traffic sector trips are generally a few hundred kilometers, the travel speeds are much higher than with the ground based transport modes (car, train, tram etc.) and the vehicle is controlled – in contrast to the private car – by a trained person and not self-operated by the user itself. In contrast to the car, which can most of the times be used straight away without much preparation time and is often located really close to the users point of departure, this is seldom the case for an air trip. Air travels are bound to specific locations for their starts and ends, but these locations are seldom the desired destinations. This means that pre- and after trip distances are to overcome and other forms of transportation might be required. One disadvantage of the commercial air transportation system is the time loss connected with the surrounding procedures such as check in and security controls which are reducing the potential advantage of the higher travel speed. It will therefore be important to also look at these pre- and after trip procedures and necessities for the PAV system.

As already mentioned in the context of MyCopter the focus is on the target group commuter and the offer of an alternative to the private car use. The "commuter scenario" addressed in the project consists of rather short trip distances of at most 100km (bidirectional) and is therefore firstly looking into "intra city" or "outskirts to city" transportation rather than inter-city transportation. The shorter trip distances do put less pressure on the speed requirement for the PAVs itself and the speed range will therefore be more oriented towards car rather than aircraft capabilities.

The more general vision of small vehicles being able of short or vertical takeoffs and landings (STOL/VTOL) used by the general public for their daily commutes was further refined by the project consortium in order to be able to touch deeper questions and consider challenges associated with the design and mission of the vehicle itself more precisely .

4 Reference PAV & Travel Scenarios

In order to do this so called travel scenarios were developed which consist of five modules. Every module is characterized by its position in the flight procedure: start, in flight or landing and the settlement density in which it occurs (see Figure 3).

[3] for a detailed description of the project aims, the involved institutions and work packages see: http://www.mycopter.eu/ or Jump et al. 2011

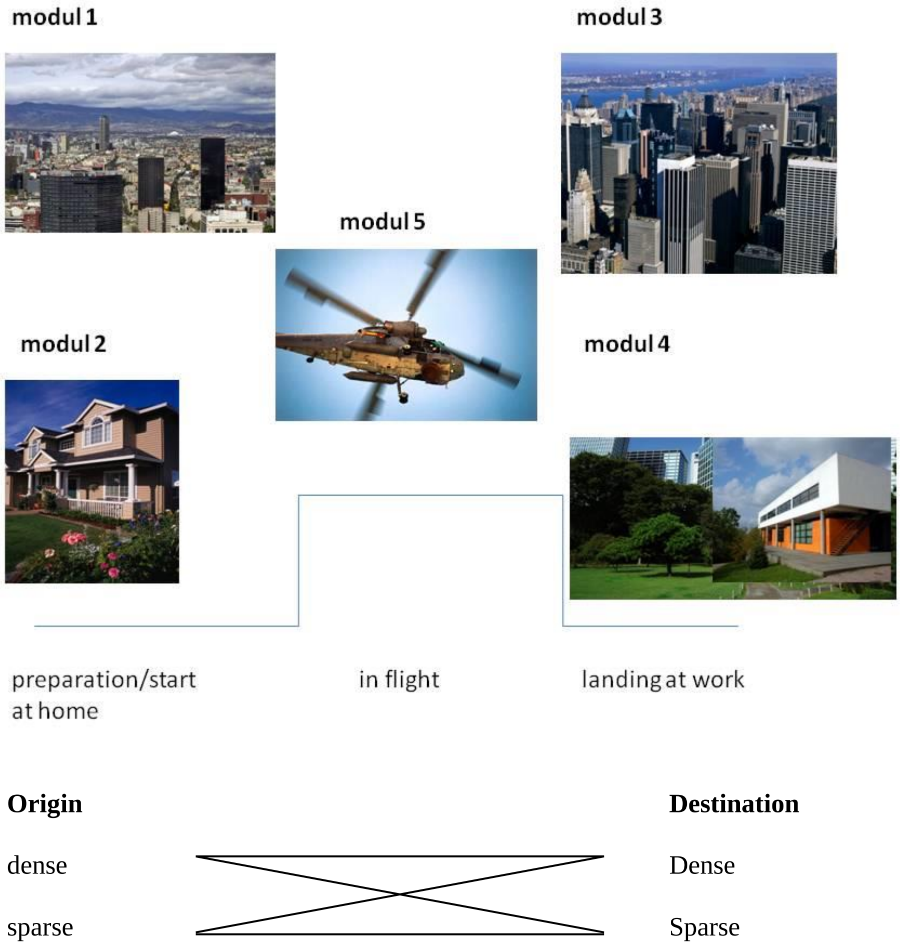


Figure 3: Division of flight procedure according to settlement density into five modules

The settlement structure was seen as a key point in the discussion which determines much of the required infrastructure on the ground but has also strong consequences for the internal design of the PAV itself (e.g. maneuverability on the ground, sensor equipment…).

Below follows a short description of every module which points out questions arising from the specific start or landing situation.

Module 1: Starting from Your City Block

Here the concept is that the PAV user lives in a densely populated urban district and wants to start from there to commute to work. Questions arise, such as how the user gets to its PAV, if the PAV is able to drive on streets (to get to a take-off area for example), and how communication with other flying vehicles in the air and to the target location is accomplished. Further key aspects are the location, the organisation, and the equipment of the take-off sites as well as the exchange of information regarding weather situation and air traffic.

Module 2: Starting from a Suburb / own Property

The idea in this module is that the user lives in a sparsely populated neighbourhood. The PAV could be parked in the user's own garden, the question would be if he can and is allowed to start from there. The own property would probably be less well equipped than take-off areas in module 1:

Therefore, refuelling and availability of detailed information (weather, air traffic) could be tricky. The advantage would probably be less traffic in the take-off area and in the air.

From these two modules, questions arise, for example, regarding the size of the PAV itself (implication for storing options), its ability to manoeuvre actively on the ground or to be moved, and regarding the big issue of noise disturbance.

Module 3: Flying Phase

During the flight the autopilot would probably be in charge and the main task for the PAV or the system would be navigation, the avoidance of mid-air collisions, and, optionally, the joining of other PAVs to form swarms. Alternatively, the user could be in the loop and could control the PAV, however, assisted by the system.

This module shows that different levels of automation are thinkable, one level representing full automation and another one representing partial automation where the user still has some control and needs pilot skills with all its resulting consequences in terms of cockpit design, training requirements, etc.. Additionally, this module illustrates again the need for communication or data exchange between different vehicles and gives a hint on what requirements might exist in terms of navigation and sensors.

Module 4: Landing in CBD

In this module the user prepares to land in a densely populated inner city area. The challenge here could be plenty of traffic in the air and many obstacles around the landing site. The approach corridor could be narrow due to the fact that buildings tend to be very close together in inner city areas. As many users would have the CBD as their destination, the landing areas could be full and parking space also could be scarce. One option to handle the restricted parking space could be, that the PAV drops out the user and moves on alone (autonomously) to a place where parking space is more easily available. Advantages of this landing situation in CBD would be a good connection to other modes of transport and a well-equipped landing site assuming that landing sites used by many PAVs would make it attractive to develop special service facilities. In this module the collision avoidance not only with other vehicles but also with obstacles on the ground plays a major role, and this interrelates with the requirements regarding the sensor technology and the whole performance of the navigation system. If non-skilled users are envisioned, the feature of automatic landing is added to the list of requirements.

Module 5: Landing at an Office Park

In opposition to module 4 the user in module 5 prepares to land in a more open environment which could be a business park located on the outskirts of a city. Questions connected to this landing situation are what the user has to decide during the landing procedure and how automatically the landing approach works. After landing, a solution to park the vehicle or to hand it over to another user must be considered. Additionally, formal things might have to be handled by the user such as to register or to pay service fees. As it cannot always be expected that the landing site is also the final destination, the question emerges of how far away the workplace is and of how this distance is bridged.

These last two modules point out the questions associated with the infrastructure for PAVs, the storage of the PAVs when not in use, and the connection of PAVs to other modes of transport.

It is clear that these modules could be modified in any direction and questions of one module often also apply to other ones. Nevertheless, they help to imagine how PAVs could be used in daily live and requirements for the layout of a future PATS and the PAVs operating in it can be derived from them.

4.1. The Reference PAV

Based on the understanding that a decision for one performance requirement, for example the seating capacity of the PAV does have an influence on other requirements of the PAV (internal dependency) and that some requirements are also strongly connected to the mission the PAV shall provide for, it is necessary to consider these requirements not separately but to be aware of these interactions.

This means that, regarding the design of a PATS, internal dependencies of "performance requirements" of the PAV exist and further on a dependency of the PAV requirements on the system and the desired mission, which the single vehicle shall allow for, are given.

In the context of MyCopter one consistent PAV vision (called Reference PAV) with the associated performance requirements was developed over the first two years of the project by thinking through these modules. Around twenty requirements regarding the physical specification of the vehicle itself as well as performance criteria were agreed on by the partners and can be found on the following Table 1.

Table 1: Specifications of the "Reference PAV" in MyCopter

physical specifications	
number of seats	1+1
dimension of PAV	"garageable": size of a large/mid-size car
kind of propulsion technology	preferable electric
max. take-off weight of PAV	450kg
performance	
maneuverability on ground	yes, but only for short distances, no "roadable aircraft"
ability to come autonomously to the user	included in the "full level of automation"
take-off capability	VTOL required
ability of IMC (Instrument Meteorological Conditions)	yes
ability to fly in darkness	yes
ability to fly in clouded environment	in degraded visual environment, not into clouds, probably
av. cruising altitude	< 500 m above ground level
total range	100 km
cruising speed	150 - 200 km/h

level of automation	two different levels (“fully autonomus” and “augmented flight”)
capability of automatic collision avoidance	Yes
capability of automatic landing/start	yes
further requirements:	
usability over the year	90 % per year

Three of these specifications are thought to be especially important for the following travel scenario development. First of all the decision for a two seater driven by the knowledge that average car use for the purpose commuting is 1.1 to 1.2 persons. Secondly the decision to go for a VTOL vehicle with all the consequences regarding start and landing abilities connected with the present agreement of the project partners to have only a quite limited maneuverability of the vehicle on the ground. And thirdly the existence of two different levels of automation the full autonomous one and a second option where the system overtakes tasks such as collision avoidance, start and landings.

4.2. Travel Scenarios

In order to gain a better understanding of the expectations the society might have regarding the actual use of PAVs in daily life and the impacts of a broader introduction of such a technology on the environment so called travel scenarios in a narrative format were developed. They will be used as an input for empirical studies such as questionnaires and focus group discussions to be conducted in three countries (Germany, England and Switzerland) in the second half of the MyCopter project .

4.2.1 Full autonomy

The first scenario describes the situation of a full autonomous PAV which manages the whole flight procedure by itself. Besides the destination input and the initial “call” of the PAV no further input from the user at all is needed. This opens up a broad user group (no expensive, time-consuming and challenging training requirements) also old people without a car driver license are thinkable, but does at the same time raise the requirements enormously regarding the vehicle abilities and the system standards.

It is 8 in the morning. Jim Wamugi is late. He is looking for this homeTab, a tablet computer-like device that he uses to manage and control communication, entertainment and household appliances at his recently acquired home, some 20 miles away from downtown Sogal. There it is. While opening the ezPAV app, he grabs another cup of coffee. 'Good morning sir, what can I do for you?" buzzes the machine. "I need a lift to the office in about five minutes.", Jim growls. "No problem, sir. The next myCopt will be at your door in six minutes."

He enters the myCopt and confirms the destination at the HMI. "We will arrive at the FreeDesign PAVpad at 8.25. Do you want to have e-New York Times projected on the big screen? And continue listening to Robbie Williams' last album? …" Jim smiles. The guy must be in his sixties now, but he is still recording music for twentysomethings.

The myCopt gently lifts off, gains speed and gets into a thick stream of other PAV in a virtual highway in the sky towards the Central Business District. A pretty soft ride at 100 mph today, Jim thinks.

Close to the FreeDesign office building, the myCopt leaves the swarm and descends to the landing pad on the roof. Jim disembarks, and the PAV silently disappears. In the entrance hall he meets his new boss who has arrived a minute before him. "Did you watch the game yesterday evening?", she asked with a grin …

4.2.2 Augmented Flight

The second scenario reduces the PAV capabilities and puts more responsibility and tasks on the human user.

"Frank, did you plug-in the copt yesterday evening?" "Of course, honey." Mary Tsu leaves her family home and heads toward to the garage right next to it. If he wouldn't have forgotten it from time to time, she wouldn't have asked… She presses a button on the remote, the garage door opens and the myCopt slides out. Mary walks around it, checking for visible damages. Then she boards the PAV and calls automated flight control. "Mary Tsu, Registration HS15456MC, Destination SingBang CBD." "Flight control. Your dedicated parking lot is PL1328. You are scheduled to arrive at the SingMed landing facilty at 8.37. Good to go in three minutes."

Mary lifts off. Apart from the altitude control stick, flying the PAV feels like driving the car she used to have 15 years ago. OK, projections of permitted flight paths on the windscreen weren't common back then… After the heavy rainfalls in the last week, the flooding around the river was still enormous. She decided to have a closer look and flew another loop, almost hitting a goose that was crossing her path. After that, she returned to the virtual highway in the sky and switched the PAV to automatic.

Close to SingMed, flight control called. "Due to your flight route changes, you have lost your landing slot. You are now rescheduled to land at 8.44. We will put you in position 8 in the arrival cue." "Dammit", she thought.

After landing, she manoeuvres her PAV to lot PL1328 and secures it. "OMG, one of the most remote places in this huge facility. A 10 minutes walk to my office…"

5 Existing challenges and problems

> „Designing the air vehicle is only a relative small part of overcoming the challenges. It seems likely that this small part will be solved in this century. The other challenges remain, although they too are receiving attention" (EC 2007, p.52)

Whenever the idea of personal air vehicles or flying cars 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 et al. 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.

Because of all these uncertainties and questions the first year of the project work from partner KIT was spent to explore the socio-technological environment of PAVs and to look into the infrastructural environment such a development would need. To look in detail into all these questions is way beyond the capacity of this paper but some of these key issues will be discussed further in the following pages. For a much more in detail discussion and description of topics like air traffic management and airspace regulation for such PAVs, the questions regarding qualification of the user (license), the legal and certification aspects as well as the already touched topic of the level of automation please refer to Del. 7.1. Screening Report of Socio-technological Environment of the myCopter project (Meyer et al. 2011).

5.1 Impact on congestion

As one main goal of the project is to reduce the negative impact of congestion in European metro areas through the use of PAVs, a look into the potential effect on the traffic situation on the ground seems reasonable. Because a general assessment of the overall impact of PATS on European road traffic will be difficult for methodical reasons and beyond the possibilities of this project we will present here a rough estimate based on a set of good estimates and heuristics.

Assuming a number of approx. 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 PAV[4], 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 PAV would be needed (assuming turnover times of 30 seconds and 30 seconds separation). Further assuming a conventional business model (“individual ownership”) and limited autonomy (no ability of fully automated flying) of PAV, this scenario indicates a required storage capacity for 7.000 to 20.000 PAV within the city.

These rough calculations show a number of challenges associated with the PATS. First of all 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. Secondly it points out the topic of parking space which is needed to store all these thousands of PAVs in the city and this problem is well known for cars since a long time.

[4] Please note that these considerations do not take into consideration possible rebound effects (e.g. more car use due to less congested road situation)

5.2 Safety

One key issue for sure will be the one of safety for the user inside and for the people around. A number of technical and human induced errors can lead to accidents or unsafe situations in aviation. A main topic regarding flight safety is the weather. Because this topic was seen as a potential major hurdle for a frequent and reliable use of PAVs it was investigated in more detail in the first year of the project. This weather analysis will be presented in condensed form in the next subchapter.

weather

Weather conditions are a big topic for air traffic in general. Even large commercial aircrafts flying under IFR (instrument flight rules) are affected by snow events, freezing rain or other hazards, and airport closures. For smaller air and rotorcrafts with a lower level of instrument equipment even greater restrictions in terms of weather can be expected. This subchapter investigates how tricky it might be to realise 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.

As a first step, potentially limiting weather phenomena and the amplitude at which they must occur to prevent a safe PAV flight were collected. Although the propulsion system for the Reference PAV is not fixed, the fact that it will have VTOL abilities and be a quite light weight vehicle gives some clues about where to look for orientation regarding reasonable “no-fly criteria” (e.g. current rotorcraft directives).

Weather phenomena which are addressed in such directives are, for example, surface winds (including gusts), turbulences or the absence of de-icing conditions. Currently, many aircrafts are not approved for flight in known icing (FIKI) conditions according to the FAA (FAA Aviation Safety (2010)). 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 PAV in order 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)).

For the Reference 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 unfavourable 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.

To get a first impression about how tricky it might be to get a similar level of “reliability” or usability for the PAV as of the one of a car, a weather analysis for a transect was conducted in Germany (distance 30 km; location: near Frankfurt). 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. Weather data from the German meteorological service (Deutscher Wetterdienst) were used to check days (split up in morning and afternoon blocks because of the commuting context) for their weather suitability following pre-defined "no-fly" criteria. The German meteorological service provides special weather forecasts for VFR and IFR pilots at different flight levels which are actualised several times per day. For the following weather analysis input data from the GAFOR (General Aviation Forecast) were used.

The GAFOR generally breaks the weather situation down into categories following a stepwise division of the visual flight possibilities based on the horizontal visibility on the ground in km and on the cloud base height in ft (for details see Table 2). The data are structured in five main flight visibility categories (C – Charlie = clear, O – Oscar = open, D – Delta = difficult, M – Mike = marginal, X – X-Ray = closed)

<table>
<tr><th></th><th>< 1.5 km</th><th>1.5-5 km</th><th>5-8 km</th><th>8-10 km</th><th>> 10 km</th></tr>
<tr><td>> 5000 ft</td><td rowspan="4">X</td><td rowspan="2">M6</td><td rowspan="2">D3</td><td rowspan="2">O</td><td>C</td></tr>
<tr><td>2000 – 5000 ft</td><td>O</td></tr>
<tr><td>1000 – 2000 ft</td><td>M7</td><td>D4</td><td colspan="2">D1</td></tr>
<tr><td>500 – 1000 ft</td><td>M8</td><td>M5</td><td colspan="2">M2</td></tr>
<tr><td>< 500 ft</td><td colspan="5">X</td></tr>
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Table 2 Overview of the Flight visibility categories of the German GAFOR based on the criteria of visibility on the ground in km (first row) and cloud base height in ft over reference height in ft (first column)

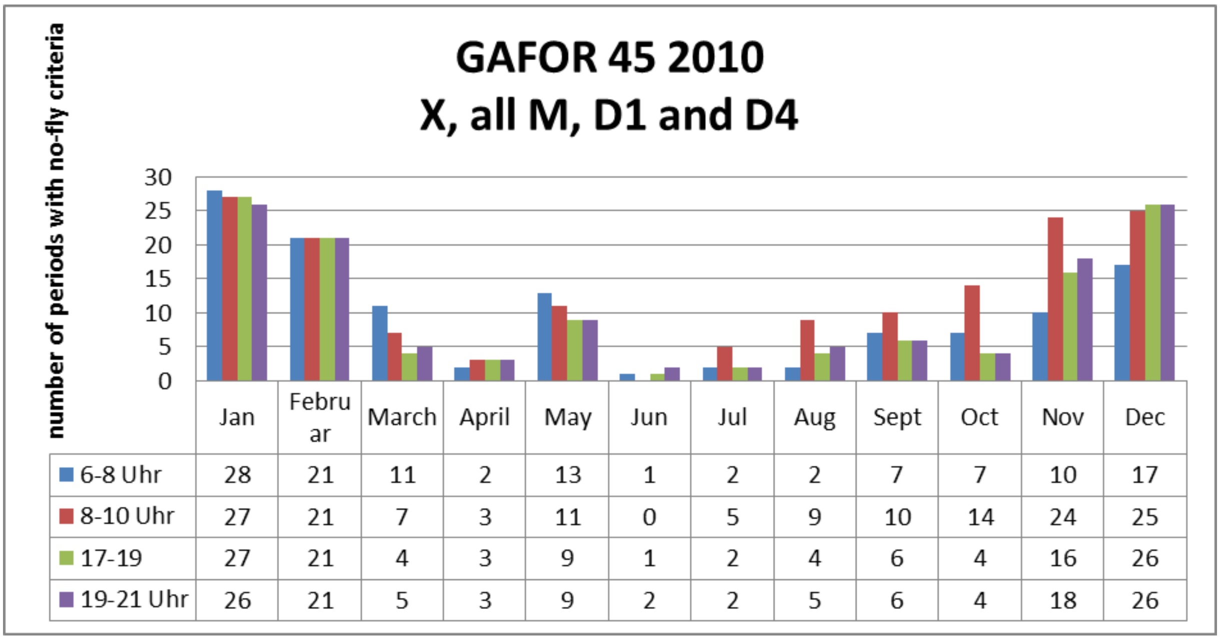
Source: Deutscher Wetterdienst – Abteilung Flugmeteorologie (2008)

For a first analysis, the situation of a PAV able to cope with quite difficult weather conditions was envisioned, and the four flight visibility categories X, M8, M5 and M2 were used as no-fly criteria for the analysis. These four categories represent bad weather situations with a cloud base lower limit of 1000 ft or less and / or a very low ground visibility of 1.5 km or less for parts of the X-Ray category. The result shows that especially the winter months (November – February) have a high number of days with time periods belonging to the four no-fly categories.[5]

In a second analysis only the "good" flight visibility categories (C, O and D3) were used as acceptable situations for the PAV flight realisation and all other categories (X, all M, D1 and D4) were used as no-fly criteria to cover the range of decreasing requirements for the vehicle and potential user abilities. This second analysis also gives an impression of the occurrence of days with a higher flight comfort level (assuming that good weather means less turbulences, etc.) The results for this second analysis with more flight visibility categories used as "no-fly" criteria shows the following result:

[5] For the detailed results please see Meyer et al. 2011

Figure 4: Number of time periods with a GAFOR flight visibility category of X-Ray, M8, M7, M6, M5, M2, D1 or D4 for the year 2010 and four time periods for the GAFOR subpart 45 (“Rhine-Main area and Wetterau”)



For this preconditions the numbers of no-fly periods increases sharply, and the winter months are nearly completely blocked for PAV flights under these assumptions.

One last analysis, taking into consideration only the X-Ray category as no fly-criteria, was also done to identify the lowermost limit for the year 2010 when flights would have been possible (under the assumption of only X-Ray as exclusion criteria). Although the results now look quite promising, it should be noted that, right now, the X-Ray category is used for weather situations in which flights following visual flight rules are not possible. Even if the Reference PAV shall have the ability of flying in a visually degraded environment, the flying into clouds is not seen as desirable and, therefore, it is debatable if, in the end, flights in M8, M5, and M2 conditions will be manageable in a safe manner by the Reference PAV. This will also depend on the actual design, especially on the propulsion type and on the sensor equipment of the Reference PAV as well as on the distribution of flight tasks between the human being and the system.

To return to the original aim of the weather analysis, the usability comparison of the PAV versus a private car; the three analyses lead to the following result on the usability over the year:

Table 3: Percentage of time periods belonging to the “no-fly” criteria of the three different weather analyses for the year 2010 and GAFOR subpart 45

	6-8	8-10	17-19	19-21
only X-Ray	6.58	3.29	2.47	3.56
X, M8, M5, M2	22.47	15.89	12.05	14.52
X, all M, D1 and D4	33.15	42.74	33.70	34.79

As one can see in Table 3, the aim of a 90 % usability over the year for the PAV is only reached in the X-Ray category for all four time blocks, and nearly achieved by the X, M8, M5, and M2 group for the 17 - 19 o`clock period with 100 – 12 % = 88 % usability.

Although this analysis was only looking at one certain area in one year, it illustrates that the dependency on weather conditions is quite high, and that the topic of how to expand the operability of the PAV into challenging weather conditions will have to be considered further.

5.3 Energy consumption

One topic contributing to the environmental footprint and to public acceptance is the question of how much energy the PAV 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 a distance of 30 km and a cruising altitude of 500 m above ground level with an average cruising speed of 175 km/h were assumed.[6]

The total energy consumption for this reference flight (C_{ref}) was calculated to be C_{ref} = 12.81 kWh. To set this into context it would mean that a Li-ion battery with an energy density of 150 Wh/kg (state of the art according to Zhao et al. 2013) with a weight of around 85 kg would be needed to full fill this task.

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 PAVs.

5.4 Noise

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). Although individual noise levels of cars, trucks, and aircrafts are decreasing, this success is offset by traffic growth on the ground and in the air (CEC 1996).

The noise pollution topic in the context of myCopter does affect both residents living close to helipads, airports or flight routes and their users, today's pilots, who could feel restrictions and forces to use noisy friendly flight profiles especially for take-off and landings. 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).

For the PAV operation there will, certainly, be specific noise standards to be respected. Besides the pure actual design of the PAV - the PAV should, of course, be as little noisy as possible - also the flight heights and routes as well as the location of the landing and take-off sites and their operational hours could be changed to allow for a quieter operation.

The impression from the authors 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 PAVs were decreasing, the general trend of increased ground and air traffic, makes it very likely that this topic will remain of high priority.

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[6] For the detailed information on this calculation see Gursky 2011 internal mycopter report

5.5 Parking and Storing of the PAVs

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. The last question can be answered positively assuming that the dimensions of the Reference PAV will be in the range of a conventional car and, further, assuming a certain ground moving ability. For other PAVs with greater dimensions exceeding this “car infrastructure compatibility” the situation would be different.

The first question regarding the ability of the PAV to fly itself into a suitable parking spot should not be very different to the full autonomous level of flying described in the previous chapters. This could mean that the PAV would transport the user to its desired place and then fly autonomously to the next free 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 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 PAVs with the difference that the 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.

Another way of handling the “parking problem” is connected with the business model. If the 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.

5.6 Perceptions from the public

Next to the mentioned more technical challenges an uncertainty exists what the general public would think about such a new form of transportation. 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 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 have also 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 the 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.

6 Discussion & Conclusion

The central question we formulated to the beginning of this paper was the question whether more attention should be paid to the ongoing developments in the PAV sector and whether an inclusion of this form of transportation into the scenarios and policies of the future should be taken into account.

After the challenges and problems discussed in this paper it has to 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 has to be said that today’s existing demonstrators are still far away from the described “myCopt” in the full autonomy scenario. Even if for helicopter pilots the described scenario of travelling to work might seem not too far away, their realization for the general user it surely is. Next to the issues regarding the pure vehicle and user competences it has to be said that the surrounding infrastructure for PAVs is as important. Their existence and operation would therefore needed to be taken into consideration for todays planning considerations and construction projects in order to be able to have this transport option available in the future.

In summary it can be said that a broad range of uncertainty remains. To a certain extent this is surely a somewhat superficial statement, since is actually accounts for all future developments. However, in the case of PAVs it is particularly difficult to assess whether experiences from other transport modes can be transferred to PAVs or if such a new form of mobility will co-evolve with new patterns of demand and usage. If we take nowadays experiences and settings as a basis, it appears to be hard for PAVs to compete with the well-established transport infrastructure in terms of economy, comfort and speed. For example, it seems as if nowadays ground-based transport systems are much more independent from extreme weather conditions as PAVs are. Because of dense urban structures it seems unlikely (but not impossible) that PAVs will deliver real door-to-door services for a high number of users.

These examples illustrates 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. It is important to acknowledge that the transport system is not static but is changing under several aspects. Also the other transport modes experience a modernization. It might be even harder for MyCopter to compete with autonomously driven cars in the future, since these have the potential to offer a high degree of comforts (office on four wheels) and real door-to-door service (the car find a parking facility by itself). Nevertheless, there are also some reasons why MyCopters can make their way. Establishing PAVs in the transport sector would mean a significant change to the established technology-infrastructure system - as it was illustrated in this paper. However, significant changes are rather the rule than an exemption in the transport system. New transport modes such as railways or cars were always confronted with highly skeptical attitudes towards the new technologies (see Meyer et al. 2011 chap. 5.2). 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 definitely come along with benefits. The analysis conducted so far in the MyCopter project revealed that, amongst others, the issue of automatisation is a highly crucial enabler for a broader market penetration of PAVs. From that perspective, it is imaginable that the ongoing automatisation of other transport modes (including the upcoming automatisation 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. The questions regarding the mode of automatisation as well as the questions referring to the user acceptability will be answered in the final report presented in 2014.

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