myCopter – Enabling Technologies for Personal Aerial Transportation Systems

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ABSTRACT

Current road transportation systems throughout the European Union suffer from severe congestion problems. A solution can be to move towards a Personal Aerial Transportation System, in which vehicles would also have vertical space at their disposal. In the myCopter project, funded by the European Union under the 7th Framework Programme, the viability of such a system will be investigated. It is argued that this should be done by taking into account the required operational infrastructure, instead of starting with the design of a vehicle. By investigating human-machine interfaces and training, automation technologies, and socio-economic impact, the myCopter project aims to provide a basis for a transportation system based on Personal Aerial Vehicles. In this paper, an outline of the project is given. Early research results are detailed and provide a basis for the remainder of the project.

Nomenclature

FHS	Flying Helicopter Simulator
FP7	Seventh Framework Programme
HMI	Human-machine interaction
HQR	Handling Qualities Rating
MTE	Mission Task Element
PATS	Personal Air Transport System
PAV	Personal Aerial Vehicle
PPL	Private pilot license
UAV	Unmanned Aerial Vehicle

1. BACKGROUND

Innovation in air transport is evolutionary in nature. Until now, this approach has provided significant improvements in terms of performance, efficiency, and safety. To accelerate the progress of innovation, the European Commission funded the “Out of the Box” study to identify new concepts and technologies for air transport of the future [1].

This study focused on several radical changes to the air transport system. In the first part of the project, 100 ideas were generated, which were subsequently reduced to the six most promising ones. It was the intention to select ideas that were radical rather than evolutionary; were forward-looking rather than fulfilling a specific need; had specific technological challenges; and offered the best prospect of high impact and benefits to the air transport system.

These final concepts were recommended to the European Commission to be included in the research calls of the 7th Framework Programme (FP7). One of these concepts focused on the establishment of a Personal Air Transport System (PATS), in which air vehicles are used to transport a small number of people. For such a system to succeed, it is first necessary to define the operational concept, before effective deployment on a large scale. The current paper elaborates one of the projects funded under the FP7 framework: myCopter. This project seeks to investigate enabling technologies for a PATS.

First, we will introduce existing problems with personal transportation and previous concepts for Personal Aerial Vehicles (PAV). Second, the approach that the myCopter project will pursue is elaborated. Third, some initial progress will be detailed and conclusion will be drawn.

2. Problem Description

The volume of road transportation continues to increase and the financial and environmental impact that this implies fuels public concern [3, 4]. Since 1980, the average number of trips per individual has declined, the average distance travelled has remained approximately the same, but the average travel time has increased [3].

As shown in Figure 1, the mean occupancy rate in vehicles in Western Europe has remained fairly constant at approximately 1.5 persons per car [2]. Occupancy rates are higher in Eastern Europe, but growth in car ownership has resulted in a steady decline.

Occupancy rates for business and commuting travel are generally lower than illustrated in Figure 1. European data from 1997 suggests rates of 1.1–1.2 for workplace commuting [5]. These numbers are supported by a more recent study from Germany [6]. In the UK, 84% of business and commuting trips had only a single occupant in the vehicle [3].

This low occupancy rate in commuting traffic has resulted in congestion on European roads. Efforts have been made to increase the occupancy rates and to encourage alternative forms of transport. Still, these attempts have not lead to significant reductions in congestion, and 75% of journey distances in Europe are still accounted for by cars [7]. Approximately 100 billion Euro, 1% of the GDP of Europe, is lost to the European economy every year as a result of congestion [8].

In terms of time that is lost due to congestion, drivers spend more than 50 hours per year in road traffic jams in London, Cologne, Amsterdam, and Brussels. In Utrecht, Manchester and Paris, they spend more than 70 hours stationary on the road [9].

The “Out of the Box” study proposes a radical solution to overcome the problems associated with the predicted volumes of traffic of the future. It is suggested to include the vertical dimension for personal transportation rather than relying on current two-dimensional transportation modes.

Of course, the third dimension is already used for transportation purposes. However, air transport systems differ greatly from ground-based systems. Journeys are made at higher speeds and over longer distances, and the vehicle is controlled by highly trained pilots. Passengers cannot use this transportation from their own homes and have to travel to an airport. Also, the advantages of higher travelling speeds are partly negated by long check-in times and extensive security checkpoints.

Private citizens can use a personal air transportation system by obtaining a private pilot license (PPL). However, the number of licenses is low compared to driving licenses, approximately 0.04% compared to 60% for Germany and the United Kingdom [10–13]. The relatively high costs that are associated with obtaining and maintaining a PPL, and chartering or purchasing an airplane, are the main reason for this difference. Furthermore, PPL-holders are restricted to when and where they can fly, and similar infrastructure is required to operate a general aviation aircraft as for airline operations, such as a suitable take-off and landing area.

The current road and air transportation system

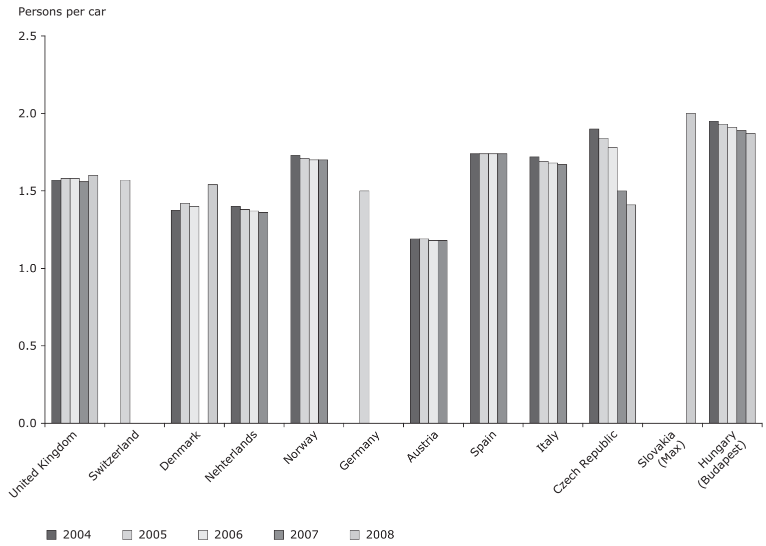

Figure 1: European car occupancy rates (from Ref. [2]).

can be summarised as follows. The road system is accessible to a large portion of the population, and is a widely used means for business and leisure transportation. The large amount of users of this system, together with the high number of single-occupant journeys, result in severe congestion problems on the road. On the other hand, air transport provides a faster means for transportation on longer journeys, but is currently not suitable for commuting purposes. The high complexity regarding organisational procedures and the high costs of the current general aviation prevent it from being a genuine alternative.

A logical solution would be to combine the best aspects of both systems to provide the possibility of door-to-door congestion-free travel at reasonably high speeds. The idea would be to move towards a PATS in which PAVs would have three-dimensional space at their disposal.

3. Previous Efforts on PAV design

One PAV concept that has been pursued over the years is the so-called roadable aircraft, which is a combination between a car and an aircraft into a single vehicle. One of the first inceptions was the Taylor Aerocar, a car with detachable wings [14]. Current versions of this concept are the Carplane Road/Air Vehicle and the Transition developed by Terrafugia [15, 16]. An advantage of this concept is that it uses existing infrastructure that is available for both modes of operation. However a roadable aircraft demands very careful and precise design. Otherwise the vehicle is likely to have poor performance both as an airplane and as a car due to conflicting requirements for both modes of operation. Furthermore, this concept still requires the user to drive to an airfield, which could minimise any expected benefits in terms of time savings.

A different concept for personal transportation is based on a rotary wing. One of the first examples was based on a small co-axial helicopter and was actually developed to bypass traffic jams [17]. Recent PAV concepts such as the PAL-V and the CarterCopter use auto-rotating rotors [18, 19]. The PAL-V is also capable of travelling on the roads because its design is similar to a motorcycle when the rotor is folded. The CarterCopter includes the ability to power up the rotor for take-off, performing a jump-start. However, the autogyro concept has a questionable safety record, which will have to be addressed if this concept is to become a mainstream form of transport.

Instead of using open rotors, ducted fans can also be used to provide thrust for a vertical lift vehicle. Examples of this concept include the Moller Skycar and the X-Hawk from Urban Aeronautics [20, 21]. The advantage of this rotor configuration is that the rotor blades are shielded and pose a lower safety hazard for people in close vicinity. However, ducted fans are optimal with respect to performance and may have disadvantages if low fuel consumption or high power requirements are primary design criteria.

4. MYCOPTER PROJECT

4.1. Approach

Previous projects related to PAVs have focused on the design of the vehicle itself, whereas the surrounding issues such as the concept of operations, business models and target users have not been comprehensively considered [1]. Therefore, the myCopter project adopts a different starting point and approaches the problem by investigating the technologies that are needed to deliver the operational infrastructure required for a transportation system with PAVs to be used on a large scale.

MyCopter seeks to address three key research areas. First, the interaction between the pilot and a vehicle will be investigated, including the level of training that will be required to fly a PAV effectively. Even though it is likely that a PAV will be autonomous to a high degree, the pilot will be expected to interact with the vehicle. Thus, human-machine interfaces should be as intuitive as possible, e.g., by employing haptic feedback cues and novel guidance displays.

Second, the technology for PAV automation will be investigated. This research will focus on algorithms for guidance and navigation through cluttered environments, for choosing safe landing positions, for collision avoidance, and for formation flying to facilitate smooth traffic flow.

Finally, the socio-economic impact of a PATS will be examined. Questions surrounding the expectations of potential users and how the public would react to and interact with such a system will be addressed.

(a) CyberMotion Simulator (b) HELIFLIGHT-R

Figure 2: Research simulators operated by the consortium.

4.2. Aims and Objectives

The aim of the myCopter project is to investigate the technologies that could form a basis for a PATS. The following objectives were formulated:

1. Develop an operational concept for a PATS,
2. Investigate and test technologies that support the envisaged concept of operations,
3. Demonstrate several of the key technologies and,
4. Examine the potential wider social and technological impact if a PATS were to become reality.

4.3. Key Facilities

The partners in the myCopter project have state-of-the-art research facilities that will be used in the project. The CyberMotion Simulator at the MPI for Biological Cybernetics and the HELIFLIGHT-R simulator from The University of Liverpool, see Figure 2, will be used for experimental evaluations with pilots in the loop.

The CyberMotion Simulator is based on an anthropomorphic robot and can provide motion in 6 degrees of freedom with its 7 actuated axes. The cabin features an active control loading devices that can provide participants with haptic cues and adjustable control device dynamics, as well as a stereoscopic display system. This simulator will be used to evaluate novel human-machine interfaces.

HELIFLIGHT-R is based on a conventional Stewart platform configuration and features a setup with helicopter control inputs. The simulator will be used to evaluate the models of PAV dynamics and for the investigations into training for operating a PAV.

To investigate the automation of PAVs, different Unmanned Aerial Vehicles (UAV) will be used as demonstrators for the automation algorithms. The platform that will be used is based on a quadcopter design with embedded stabilisation algorithms that can carry enough payload for autonomous operation.

The UAVs will be equipped with traditional sensors such as GPS, an Inertial Measurement Unit, and a magnetometer. Furthermore, a down-facing camera with a fish-eye lens and front-facing camera will be used for vision-based control algorithms. As fast technology advancements are expected in this area of research, it is foreseen that other sensor types and hardware upgrades will be implemented during the course of the project.

The most promising concepts that will be developed in the project will be tested in real flight on the Flying Helicopter Simulator (FHS) from DLR, see Figure 3. The FHS has a highly flexible experimental system setup and features a safety concept that allows the integration, testing and evaluation of new algorithms, HMI designs and control laws in flight.

Figure 3: Flying Helicopter Simulator.

5. Initial Progress

5.1. Social and Economic Impact

The success of transport system innovations depend not only on the relevant technological aspects but also on demand patterns, expectations, perceptions and attitudes of relevant actors, and many more factors. Currently, little is known about the groups of society that will constitute the main consumers of PAVs; and for which purposes PAVs will be used. It is also unclear what the demand and preferences of society at large are in relation to PAVs.

A common methodology is used to study these questions by defining example scenarios. These scenarios will simulate the design of a PATS in different geographical contexts. The main focus of the myCopter project is on using a PAV for commuting or business travel. Thus, different requirements for a PAV can be imagined: vertical take-off and landing (VTOL), roof-top landing in a central business district (CBD), number of occupants, level of vehicle manoeuvrability on the ground, degree of automation, propulsion technologies and acceptable noise levels, the vehicle ownership model (aircraft in the garage, PAV sharing or PAV-Taxis) and so on.

Initial travel scenarios have been set up that focus on potential peer groups. These take into account the density of the population, and hence the surrounding infrastructure, at the origin and destination of the commute [22]. Sparse and densely populated areas are considered, which respectively refer to housing or an office building in a suburban location or the city centre. A journey with a PAV could be made between all destinations.

The key requirements for a reference PAV that would fit within the envisioned scenarios have been identified by the project partners. The reference PAV would be a vehicle with a single seat and the option to take an additional passenger at the cost of reduced baggage capabilities. For commuting purposes the range should be around 100 km, with a cruising speed of 150-200 km/h.

The PAV should have vertical take-off and landing capabilities. The vehicle automation should range from minimum requirements to safely navigate to full automation on several selectable levels. It should be able to fly in Visual and Instrumental Meteorological Conditions (VMC/IMC) and should be useable 90% of the year in different weather conditions. It will not be a road-

Table 1: Handling qualities ratings awarded by the test pilot.

MTE	Configuration		
	RCAH L1	RCAH gL1	ACAH gL1
Precision hover	3	2	2
Hover turn	-	2	2
Vertical manoeuvre	-	2	2
Lateral reposition	-	2	2
Depart/Abort	-	3	2
Pirouette	4	3	1

able aircraft, but should be manoeuvrable on the ground for parking and storage.

These requirements specify the reference PAV for the myCopter project, which will be used for model development and socio-technological evaluations. It will also serve as a reference for the design of automation algorithms and human-machine interfaces.

5.2. Model for a Generic PAV

The aim of designing a generic PAV dynamics model is to adapt the handling qualities of the vehicle to the capabilities of a PAV user. This approach will be used to assess the levels of automation that a PAV operator would require and a training scheme that would provide the required competencies for flying. In addition, the model will provide a baseline for the development of novel HMIs and automation algorithms. The modelling approach is detailed in Ref. [23].

An initial non-physical PAV model has been developed that represents the typical responses of a highly augmented rotorcraft [22]. The translational motion is based on rigid body flight dynamics, combined with a lifting force in the vertical plane of the vehicle. As the vehicle rolls and pitches, the direction of the lifting force is tilted, producing translational accelerations.

Usually, the handling qualities of a vehicle model are determined after establishing the dynamic characteristics. However, for the myCopter project the handling qualities of the generic vehicle model needed to be specified first. Then, the model parameters should be determined to deliver the specified the handling qualities. This can be done in an analytical manner with a method that includes tuneable parameters, such as damping ratios, time constants, time delays, and natural frequencies, which determine the character of the vehicle's response to control inputs [24].

Three model dynamics configurations have been developed: a rate command response type with handling qualities close to Level 2 (adequate) (RCAH L1), a rate command type with handling qualities well within the Level 1 parameter region (RCAH gL1), and attitude response type with handling qualities well within the Level 1 region (ACAH gL1).

The predicted model handling qualities were evaluated in the HELIFLIGHT-R simulator at The University of Liverpool by a test pilot in a 1-day simulation trial. Six standardised test manoeuvres were flown, based on so-called Mission Task Elements (MTE) from the specification for handling qualities for military rotortcraft ADS33-E [25]. This specification contains the most specific requirements on achieving optimal handling qualities for rotorcraft. For the RCAH L1 condition only 2 of the 6 MTEs were tested. Each task was flown three to four times until the level of performance was consistent, after which the pilot was asked to rate the handling qualities of the vehicle using the Cooper-Harper Handling Qualities Rating Scale [26]. Ratings 1 to 3 equal Level 1 handling qualities that are acceptable without improvement. If a rating of 4 to 6 (Level 2) is returned, improvements are deemed necessary. And ratings above 6 are unacceptable (Level 3).

The results are shown in Table 1. It is clear that the handling qualities ratings for the RCAH gL1 and ACAH gL1 configurations fall within the Level 1 region. The RCAH L1 configuration was rated at the border between Level 1 and Level 2 handling qualities.

Thus, the results indicate that our adopted model structure is indeed capable of delivering the intended handling characteristics. The additional benefit of the model is that it can be rapidly reconfigured to represent different sets of required handling qualities. In the near future, more evaluations will be performed on updated versions of the model with naive pilots.

6. Conclusion

The work presented in this paper reflects the initial stages of the myCopter project. In this project, the enabling technologies for a Personal Aerial Transportation System will be investigated under three research themes: Human-Machine Interfaces and training issues, automation of Personal Aerial Vehicles, and the socio-economic impact of a PATS.

The initial requirements for a reference PAV for the project have been set and are focused on a small vehicle for commuter and business travel. Furthermore, a non-physical generic model for PAV dynamics has been created and its wide variety of handling qualities characteristics have been tested in piloted simulations.

In future work, the descriptions and requirements of the PATS and PAVs will be expanded and refined. One approach, amongst others, will be by conducting group interviews with potential users of PAVs to learn more about their expectations towards PAVs. Special focus will be put on the desired level of automation to inform the design of automation algorithms and the HMI. The PAV dynamics model will be expanded to different speed regions by using physical modelling principles and by the addition of automatic flight modes and more command types.

The generic PAV dynamics model is currently being implemented by the project partners for, e.g., evaluations of novel HMI concepts. Also, a selection has been made for the sensors and hardware for a UAV testbed for automation algorithms. Results from this work will be the subject of future publications.

7. Acknowledgements

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