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MYCOPTER: ENABLING TECHNOLOGIES FOR PERSONAL AIR TRANSPORT SYSTEMS – AN EARLY PROGRESS REPORT[1]

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ABSTRACT

This paper describes the European Commission (EC) Framework 7 funded project myCopter (2011-2014). The project is still at an early stage so the paper starts with a discussion of the current transportation issues faced, for example, by European countries and describes a means to solve them through the use of a personal aerial transportation system (PATS). The concept of personal air vehicles (PAVs) is briefly reviewed and how this project intends to tackle the problem described. It is argued that the key reason that many PAV concepts have failed is because the operational infrastructure and socio-economic issues have not been properly addressed; rather, the start point has been the design of the vehicle itself. Some of the key aspects that would make a PATS viable include the required infrastructure and associated technologies, the skill levels and machine interfaces needed by the occupant or pilot and the views of society as a whole on the acceptability of such a proposition. The myCopter project will use these areas to explore the viability of PAVs within a PATS. The paper reports upon the early progress made within the project. An initial reference set of PAV requirements has been collated. A conceptual flight simulation model capable of providing a wide range of handling qualities characteristics has been developed and its function has undergone limited verification. Results from this exercise show that the model behaves as intended and that it can deliver a predictable range of vehicle dynamics. The future direction of the project is then described.

NOMENCLATURE

q_{pk}	peak pitch rate (deg/sec)
$\Delta\theta_{min}$	first pitch attitude change minimum following the maximum change in pitch attitude (deg)
$\Delta\theta_{pk}$	maximum change in pitch attitude (deg)
$\tau_{p\theta}$	phase delay in the pitch axis (sec)
$\omega_{BW\theta}$	pitch attitude bandwidth (rad/sec)
2D	2-dimensional
3D	3-dimensional
ACAH	Attitude Command, Attitude Hold
ATS	Air Transport System
CBD	Central Business District
EC	European Commission
GA	General Aviation
HQ	Handling Qualities
HMI	Human-Machine Interface
IMC	Instrument Meteorological Conditions
KIT-ITAS	Karlsruher Institut für Technologie - the Institute for Technology Assessment and Systems analysis
MTE	Mission Task Element
NASA	National Aeronautics and Space Administration
PATS	Personal Air Transport System
PAV	Personal Air Vehicle
PPL	Private Pilot's License
RCAH	Rate Command, Attitude Hold
UoL	University of Liverpool
VCR	Visual Cue Rating
VMC	Visual Meteorological Conditions
VTOL	Vertical Take-Off and Landing

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BACKGROUND

There has been concern both within and beyond the aerospace community regarding the state of innovation that will support future air transport development. There are good reasons for the evolutionary development approach that has been adopted; it carries much less risk than revolutionary development. Of course, significant innovations have been made in vehicle technologies over the last 50 years at the individual component level, conferring upon them greater efficiency, performance and safety. However, to try to counteract the perceived low innovation trend at the transport system level, the European Commission (EC) funded the 'Out of the Box' project to identify potential new concepts and technologies for future air transport [1], looking ahead to the second half of the 21st century. The first part of this project generated 100 ideas that might stimulate new technologies and concepts within the air transport field. These were then reduced to a final 6 in the second phase of the project. The intention was to choose ideas that were radical rather than evolutionary; were forward-looking rather than have an immediate application or meet an immediate demand; had specific technology challenges; and, of course, offered potentially significant impact and benefits to the Air Transport System (ATS) [1]. The recommendations from Ref. [1] were then used to help inform the direction of EC Seventh Framework Programme (FP7) research calls. One of the successful candidate ideas in [1] was for a Personal Air Transport System (PATS). This paper introduces one of the FP7 projects established to investigate the enabling technologies that surround a PATS - myCopter [2, 3]. The paper is constructed as follows. The 'Background' and 'Introduction' Sections introduce the transportation problems that exist today, the previous concepts that have been put forward for personal air vehicles (PAVs) and how the myCopter project intends to move the topic forward. The 'Initial Progress' Section details some of the early outcomes of the project and the 'Further Work' and 'Concluding Remarks' Sections bring the paper to a close.

INTRODUCTION

Problem Description

The volume of road transportation continues to increase despite the many concerns regarding the financial and environmental impact that this implies [4, 5]. Whilst the average number of road trips per individual has declined since 1980, the average distance travelled has remained approximately the same and yet the average time spent travelling has increased [4]. The average number of occupants in a vehicle in the UK has remained approximately constant at 1.6 from 1997 to 2008 [4]. Elsewhere in Western Europe, car occupancy rates have stabilised at around 1.5 persons per car whilst in Eastern Europe, occupancy rates are higher but are in decline, reflecting the growth of personal car ownership in that region [6]. In the period 1999 to 2004, for example, this metric increased by an average of 38%, but varied from +14% to +167%, depending on country [7]. Figure 1 shows these data in more detail, broken down by year and individual country. Occupancy rates for business and commuting purposes are generally lower than those illustrated in the Figure. For example, in the UK, 84% of both business and commuting trips had only a single occupant in the vehicle [4]. European data from 1997 suggests occupancy rates of 1.1 – 1.2 for commuting to/from the workplace [8] whilst more recent data from Germany suggests little change with occupancy rates of 1.2 for commuting and 1.1 for business trips [9].

One of the net results of this low occupancy rate is the congestion on European roads. An obvious solution to this problem would be to encourage higher occupancy rates and/or alternative forms of transport usage. However, efforts to achieve this have struggled to find traction. Transport in general and urban transport in particular has become heavily dependent upon motorised individual transport - 75% of journey distances are accounted for by cars in Europe [7]. The resulting congestion not only occurs in inner cities but also on urban ring roads. Every year, approximately 100 billion Euros, which is 1% of the EU's GDP, are lost to the European economy as a result of congestion [10].

None of these statistics will come as any surprise to those drivers constrained to travelling to and from their work place at peak times of the day. In London, Cologne, Amsterdam and Brussels, drivers spend more than 50 hours a year in road traffic jams. In Utrecht, Manchester and Paris, they spend more than 70 hours per year stationary on the road network [11].

One radical, rather than evolutionary solution to the existing problems (which will only become worse if traffic volume continues to grow as predicted and no action is taken) is to use the third dimension for personal transportation systems instead of relying on 2-dimensional (2D) roads.

Of course, the third dimension is already used for transportation purposes. In the main, however, air transport is used very differently from ground-based systems. Journeys made by air tend to be made at higher speed and for longer distances and the vehicle is controlled (or at least monitored) by highly trained pilots. The passengers cannot participate in this single form of transport directly from their own home. Instead, they must travel to an airport and the advantages of the higher speed of travel is reduced by such requirements as having to check-in up to

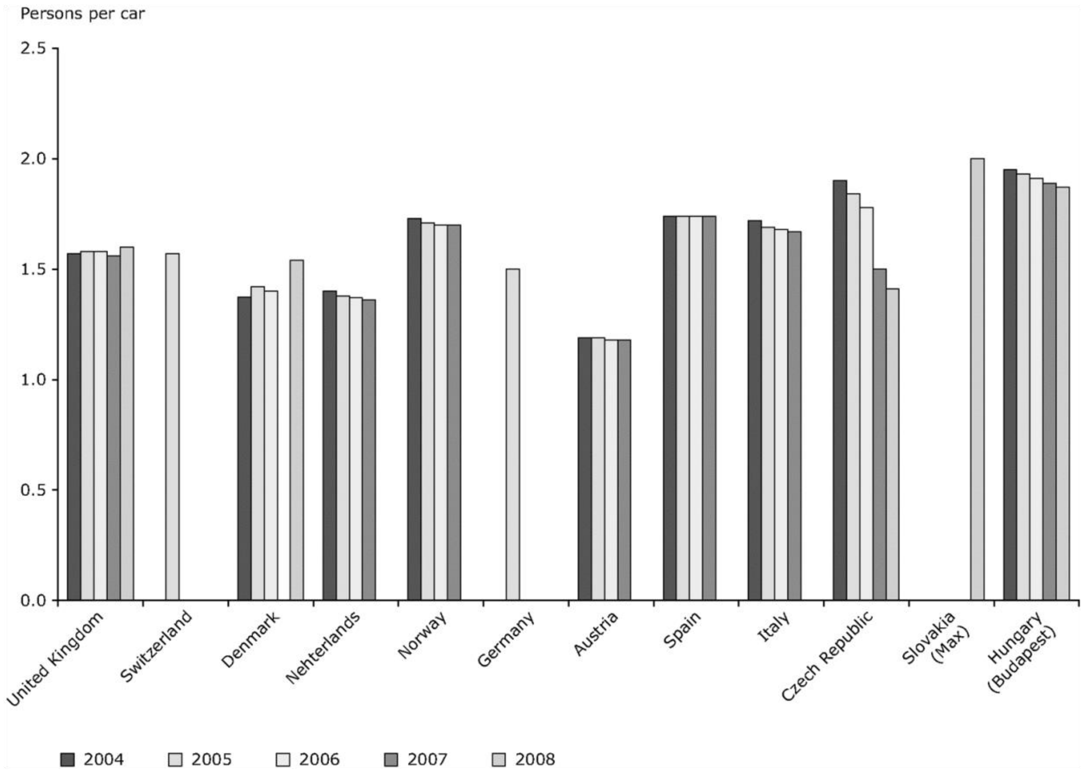

Figure 1. European car occupancy rates (courtesy Ref. [6])

3-hours before travelling, progressing through security etc., often doubling or trebling the journey time.

Perhaps the closest that private citizens come to a personal air transport system is through the gaining of a private pilot's license (PPL) and the subsequent privileges that this confers upon them. However, numbers are very low compared to road usage. In 2008, just short of 23,000 PPLs of one sort or another were held in the UK (data from Ref. [12]). This is compared with nearly 37 million full driving licenses in Great Britain alone (data from Ref. [13]). These represent approximately 0.04% and 60% of the population respectively. In Germany, the situation is similar. In 2004, just over 53 million driving licenses were active (64% of the population at the time) [14] whilst 37,634 PPLs were active in 2008 (0.04% of the population) [15]. Some of the reasons for this are obvious: the cost of obtaining and then maintaining a PPL are significantly greater than those associated with obtaining a driving license; the basic PPL-holder is restricted to when and where they can fly (in sight of the ground, clear of cloud, clear of restricted airspace etc.) and the skill levels required to fly current general aviation (GA) aircraft are higher than that for driving a car. Finally, to operate an aircraft, a similar infrastructure is required as for airline operations i.e. airport or at least a suitable take-off and landing area. For small aircraft, of course, this may simply be a short grass strip. This still implies the requirement for access to a nearby small field that does not have built-up environs to be able to operate an aircraft.

The current road and air transportation systems can therefore be summarised as follows. The road system is a popular means of business and leisure transport. A significant proportion of the population hold a license to drive and this, coupled with the number of single-occupancy journeys, combine to cause severe congestion on the roads. Air transport is used for longer high speed journeys but, in its current form, would not be suitable for a daily commute. Only a small proportion of the population hold a PPL and various factors surrounding the holding of such a license also prevent it from being considered as a viable means of transport either for commuting or business purposes as a replacement for the car or other forms of road-based commuter journeys.

A logical step would be try to combine the best aspects of both of these systems i.e. the possibility of door to door travel at reasonably high speed and free of congestion. The idea would be to move towards a PATS in which PAVs would have three-dimensional (3D) space at their disposal. Unlike cars or current public transportation systems, the ideal PATS would not require any new large-scale facilities or infrastructure such as roads, rails, stations or airports, which are expensive to set-up and maintain. An ideal PATS, however, would have to provide effective solutions to the issues surrounding pilot-vehicle interaction, collision avoidance, the maintenance of heavy traffic flow and environmental impact which may be in direct conflict with the first requirement for no new infrastructure. In any event, to avoid the failure of the idea as a whole, the PATS should be designed with consideration given to the general population's needs and wants, which would have to include the cost effectiveness and affordability of any proposed solutions.

Previous Work

It is clear, then, that to release the third dimension for personal transportation purposes, something different has to be conceived from that which currently exists. PAVs, of course, are not a new idea. Indeed, it might be argued that the vision for GA in the United States has always been to have 'an aircraft in the garage'. The following provides a brief overview of some of these PAV concepts.

There have been a number of attempts to combine a car and an aircraft into a single vehicle – the so-called roadable aircraft. The Taylor 'Aerocar' of 1949 [16] is an early example of this kind of vehicle, with the 'Carplane' road/air vehicle [17] and Terrafugia's 'Transition' [18] bringing a modern approach to this concept. An advantage of this type of vehicle is that it uses existing infrastructure and the driving element of the operation will be familiar to existing road-users. The key disadvantages are two-fold. Firstly, even with careful design, the resulting vehicle is likely to be both a poor road-vehicle and a poor aircraft. This outcome results from the additional weight that must be carried in terms of structure and equipment that are required for the individual road and air phases of the journey. Secondly, for a commuting journey of moderate distance, even if a one-way journey of about one hour travel time or 50 km distance is assumed, the benefits of having to drive to an airfield, fly to another airfield and then drive from the destination airfield to the work place, in terms of time saving, are likely to be minimal. At this stage, the project definition of a reference commuting journey is still to be completed. However, Ref. [19] provides a possible foundation for this task.

To avoid having to use traditional runways and to provide a capability that would potentially allow flight from or close to the user's home, one option for a PAV is to use a rotary wing aircraft with vertical flight capability; ideally, without having to resort to the significant complexity and skill levels required to pilot a traditional helicopter configuration. The PAL-V [20] and Carter PAV [21] concepts both make use of auto-rotating rotors that, strictly, do not have vertical flight capability. The PAL-V concept combines an autogyro with a road-going capability. A form of vertical flight can be achieved in the Carter PAV concept by powering the rotor up using the vehicle's engine and then performing a 'jump take-off'. Such a manoeuvre does put a significant amount of energy into the rotor quickly and both careful and robust design would be required to achieve acceptable levels of reliability/safety. There is also a question over the safety of the autogyro concept. Fatal accident statistics such as those reported in Ref. [22] show that current UK autogyro operations are far more hazardous than other means of flight. There are several reasons posited for this, mainly surrounding the previous experience of pilots who embark upon this type of flying. This issue will need to be addressed if such concepts are to become a mainstream form of transport.

A different means of providing vertical lift and translational propulsion is via the use of ducted fans. The Moller 'Skycar' [23] and Urban Aeronautics 'X-Hawk' [24] demonstrate different variants of this concept. Problems with this type of vehicle relate to its potential instability, marginal performance in terms of achieving high speed and its load-carrying capability [24]. An un-ducted fan arrangement can be seen in NASA's Puffin concept [25], but the reduced safety implications of un-shrouded rotors, despite their increased efficiency when compared to their shrouded counterparts, might limit their utility in any mass-produced PAV concept.

myCopter Approach

So, the question remains as to why, if all of these vehicles are in development, are PAVs not already in widespread use? Ref. [1] provides a number of possible explanations. Previous and more recent attempts at PAV design have concentrated on the vehicle itself. The surrounding issues, for example, concept of operations, infrastructure, business models and the target user(s) have been given much less coverage in the publications. The myCopter project therefore has a different starting point; that of the operational concept and the technology that will be required to deliver the operational infrastructure. As such, three key challenges will be addressed. Firstly, the desired level of interaction between 'driver' or 'pilot' and vehicle will be established, including the level of training that will need to be employed. It is anticipated that PAVs will feature significant automation/autonomous technology but also a degree of occupant involvement in the flight management. There is a broad spectrum of definitions of autonomy, from a vehicle simply following a pre-programmed function to sentient machines interpreting their internal states as well as their environment to enable them to make decisions about future plans to achieve pre-programmed or even learned goals [26]. The myCopter project's autonomy focus is likely to be at a level between these two extremes. The level of autonomy in a PAV will be considered as a partnership between the human and the machine such that the human can provide the strategic goals whilst the machine converts them into optimal tasks which are carried out to achieve them [26]. In this model, the level of authority shared between the operator and machine can be varied. Secondly, the technology required to deliver the desired level of autonomy will be investigated in the project. This will include guidance and navigation through cluttered environments, choosing safe-arrival landing positions, mid-air collision avoidance and formation flying to facilitate smooth traffic flow. Thirdly, the socio-economic impact of a PATS will be examined. Within this aspect of the project, questions surrounding the expectations of potential users and how the public would react to and interact with such a system will be addressed.

A more detailed overview of the myCopter project: its aims and objectives; the project partners; their roles and facilities and the project schedule can be found in Ref. [3]. The remainder of the paper will concentrate on some of the early progress made and results achieved within the project itself.

INITIAL PROGRESS

Although myCopter is still in its early phases, this Section outlines the progress made in a number of the research themes within the project.

Social and Economic Impact

The success or failure of any transport system innovations not only depends on the relevant technological aspects but also on the demand patterns, travel habits, the expectations, perceptions and attitudes of relevant actors (e.g. users, operators, environmental groups, regulators), geographical settings and many more factors. The exploration of the socio-technical environment of PAVs will influence the technology-aspects of the project. The term co-evolution is used to describe this mutual relationship between the socio-economic environment and the development of enabling technologies for PAVs. However, currently, little is known as to what extent the existing infrastructure could be adapted to the needs of PAVs, and, although we can speculate, there is no clear idea about which groups of society might be the main consumers of PAVs and for what purposes they will be used. There is also a lack of insight as to what extent the design of PAVs might be adapted to existing infrastructure and what the demand and preferences of society at large in relation to PAVs are. Group interviews with potential users will be conducted to learn more about their expectations towards PAVs with a special focus on the desired level of automation.

A common methodology in transport research is to use example scenarios and this technique will be adopted in myCopter. The scenarios will simulate the design of PATS in different geographical contexts. From the user's perspective, the PAVs in the PATS are of utmost relevance since the PAV will be the technical entry point to the PATS. A rough concept of the PAV is needed as a starting point for the scenario building. During the project these scenarios need to be further developed in an iterative process.

The Introduction to this paper illustrates that a wide range of rather different visions about the design and mission of a PAV have been developed in the past. In the proposal for this project, it was specified that the main focus will be on using a PAV for commuting or business travel. However, even in this context, somewhat different requirements for such a vehicle 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. To explore these issues further, KIT-ITAS designed some initial travel scenarios that focus on potential peer groups. The start point for the definition of these scenarios came from a consideration of the density of the population and hence the surrounding infrastructure at the origin and destination of the envisaged commute. Table 1 shows the options considered.

Origin	**Destination**
Dense	Sparse
Sparse	Dense

Table 1. Population density options for the envisaged PAV commute

If the journey to the work place is considered, then a densely populated journey origin might be a city-centre apartment block location, whilst a more sparsely populated location might be in a suburban or rural area. A densely populated destination for this journey might be a CBD e.g. City of London, whilst a more sparsely populated location might be an office within an out-of-town industrial complex. It should be noted that all combinations of journey are possible. The layout of Table 1 is intended to imply that, for example, a journey starting in a densely populated area could just as easily finish at either a sparsely or densely populated destination.

With the scenario's described above in mind, the key requirements for a "myCopter"-PAV have been partially identified during an internal workshop with the project partners. Whilst not yet fully 'specified', the agreed initial PAV requirements are as follows:

- Seating configuration: 1+1. Given current car utilisation statistics, it is anticipated that most PAV journeys will be undertaken by single occupants with some form of associated baggage (brief case, laptop etc.). However, to allow for some flexibility in the usage of the vehicle, the option to have sufficient vehicle performance to carry a second individual with a more limited baggage capacity was considered to be a desirable feature.
- Speed/Range: with the payload described above, and for the commuting scenario envisaged, a safe range of 100km was considered to be sufficient. The cruise speed of the vehicle is required to be

in the 150-200km/h range. This speed-range combination was considered to be appropriate to be able to give a PAV a clear time-to-commute advantage over road transportation methods.

- VTOL capability: this is considered an essential requirement, particularly to allow a commuting journey to/from densely populated regions.
- Availability: the target availability for a PAV has been initially set at 90% (the remaining 10% being consumed by maintenance of the PAV). This implies that the system would not be useable 1 day in every 2 weeks. This falls somewhat short of that which can be achieved for a well-maintained modern car. However, flexible ownership models may mitigate against resistance to such a figure.
- Flight in Visual or Instrument Meteorological Conditions (IMC/VMC): the PATS should allow the PAV to fly in both VMC and IMC conditions and also at night. The ability to only be able to use a PAV during daylight hours in VMC was considered to be too restrictive, particularly considered the target availability given above.
- Level of automation: variable. Part of the myCopter study will be to establish this requirement more fully. However, it is anticipated that to achieve safe operations, a full automation option will have to be available, specifically but not exclusively for the take-off and landing phases of flight and for flight in IMC.
- Ground handling. The envisaged PAV will not be a 'roadable-aircraft'. Ground handling requirements are therefore limited to manoeuvring the vehicle to/from its parking or storage areas.

The "myCopter"- PAV requirements described above serve as the start point for a reference vehicle within a PATS which will be used during the project as a common benchmark, but does not prohibit other design ideas in the project.

Dynamics Modelling for a Generic PAV Vehicle Model

The philosophy and modelling approach adopted within this research theme is described in more detail in Ref. [3]. One of the initial project tasks within the theme was to create a vehicle dynamics model to allow a range of vehicle handling qualities to be configured and assessed. This, and its subsequent developments, will be used to assess the levels of automation that a PAV operator will require to use the vehicle for a daily commute, the level of degradation of that automation that can be tolerated and hence the training regime that will be required to provide an operator with the competencies required to safely control a PAV. In addition, the model will provide a baseline platform from which novel human-machine interfaces and automation algorithms can be developed and tested.

Model Development to Provide Variable Handling Qualities Characteristics

An initial PAV simulation model has been developed using non-physical processes to represent the typical responses of an augmented rotorcraft. The translational motion of the model (surge, sway and heave) is based on standard rigid body flight dynamics (as described in [27]), combined with a lifting force acting in the vehicle's vertical plane. As the vehicle pitches and rolls, the direction in which the lifting force acts is tilted, producing translational accelerations.

The model has been developed to offer two different response types for the pitching and rolling motion. These are a rate response type (i.e. a constant control deflection commands a constant angular rate) and an attitude response type (a constant control deflection commands a constant pitch or roll attitude). The rate response type is implemented through a first order transfer function model, while the attitude response type is implemented through a second order transfer function, as described in [28].

The more usual practice in HQ analysis, at The University of Liverpool (UoL) at leaste, is to create a model of a vehicle which then determines its dynamics characteristics. Predicted and simulated flight test handling qualities can then be established for that vehicle model. However, for the myCopter project, and specifically to develop a generic vehicle dynamics model of a PAV, it was required to be able to run this process in reverse; that is, to specify the HQ requirements first and then to determine the model parameters that would confer these HQs on the vehicle. Ref. [28] describes a method of quantifying the handling qualities of a model using transfer function responses in a purely analytical manner. These analytical handling qualities expressions have been used in the myCopter vehicle dynamics model to allow its parameters to be defined to provide a desired set of vehicle handling characteristics. The method provided by Ref. [28] includes tuneable parameters that determine the character of the vehicle's response to a control input e.g. damping ratios, time constants, time delays and natural frequencies etc.

The final step in the dynamics model calculation process is to obtain the Euler angles from the commanded angular rates (in the case of the rate response type) or the angular rates from the commanded Euler angles (in the case of the attitude response type). These conversions have been performed using the standard methods described in [27].

Overview of Handling Qualities Requirements

The HQ requirements used to configure the myCopter vehicle model are those contained with the United States Army military rotorcraft HQ design guide, ADS-33E-PRF, Ref. [29]. For hover and low speed operations, Ref. [29] breaks down the requirements by vehicle response magnitude and frequency, as illustrated in the *dynamo construct*, Figure 2, [30]. The four regions of the dynamo construct are as follows:

- Small amplitude, high frequencies – applicable HQ criterion: Attitude bandwidth (ω_{BW}) and phase delay (φ_{bw});
- Small amplitude, low to medium frequencies – applicable HQ criterion: Open-loop Stability;
- Moderate amplitude, low to medium frequencies – applicable HQ criterion: Attitude quickness and
- Large amplitude, low frequencies – applicable HQ criterion: Maximum achievable rate/attitude response.

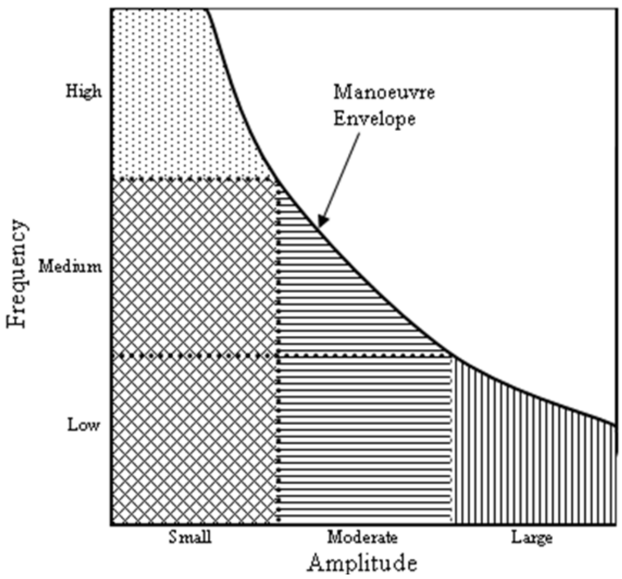

Figure 2. Dynamo construct for HQ engineering

Bandwidth is a measure of the closed-loop stability of a pilot-vehicle system, characterised as the frequency at which a suitable gain and phase margin exist between the vehicle response and neutral stability (neutral stability being the frequency at which the vehicle's open-loop attitude response is 180° out of phase with the pilot's input).

The open-loop stability, on the other hand, measures the frequency and damping of any oscillations that occur either following a vehicle disturbance or pilot input, when the controls are fixed. For the rate responses described in Section 3, this criterion will never result in deficiencies, as the model effectively specifies a damping ratio $\zeta = 1$. For the attitude response type, however, damping ratios less than or greater than 1 can be specified, and therefore the stability requirements must be considered.

Quickness is a measure of the closed-loop agility of a vehicle, calculated as the ratio of the peak in angular rate divided by the attitude change for a maximum amplitude pulse (for a Rate Command Attitude Hold (RCAH) response type), or variable amplitude step (for an Attitude Command, Attitude Hold (ACAH) response type), control input.

The maximum achievable angular rate (for a RCAH system), or attitude (for an ACAH system) is again a measure of the agility of the vehicle, but in an open- rather than closed-loop sense.

For each of the HQ requirements introduced in this Section, Ref. [29] provides boundaries that place a given response into one of three Levels, where Level 1 handling ensures that pilots will always be able to achieve the required performance standards with a minimal workload. Level 2 handling mean that only adequate performance standards are achievable with maximum tolerable workload while Level 3 means that task performance is unachievable. It is envisaged that a future PAV will require a new higher Level 1 or XL1, where manoeuvres can be commanded with virtually no pilot compensation; characteristics yet to be achieved in conventional rotorcraft. The location of the HQ Level boundaries varies depending on the task that the vehicle is intended to accomplish. HQ boundaries for a utility role, accomplishing lower precision tasks have been adopted as the most applicable to the myCopter PAV scenario.

In addition to these criteria, further requirements are placed on inter-axis coupling effects and the translational response in the heave axis. As the vehicle dynamics model explicitly excludes coupling effects from the mathematical representation, these criteria have not been considered here. However it is anticipated that to confer excellent Level 1 handling, specific couplings will need to be introduced to any PAV design to ensure that manoeuvres are essentially single axis; for example, turn coordination, flight path changes at constant speed etc.

Model Handling Qualities Performance Verification

The PAV vehicle dynamics model has been created in both the MATLAB/Simulink and FLIGHTLAB [31] environments; the former for ease of distribution amongst the myCopter project partners and the latter for ease of implementation on the University of Liverpool's (UoL) HELIFLIGHT and HELIFLIGHT-R simulation facilities [32, 33]. The verification exercise consisted of assessing the HQs of the vehicle model in a number of different configurations with those predicted by the analytical expressions. For the planned work going forward, it was

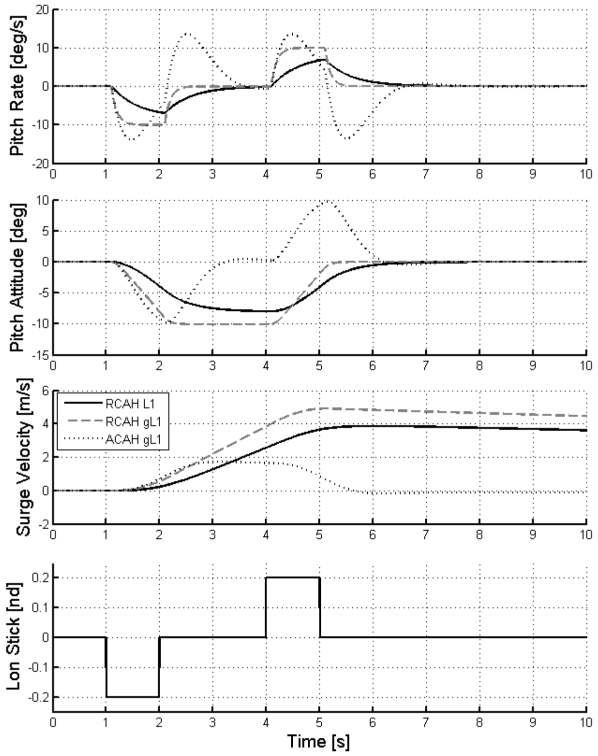

Figure 3. Vehicle dynamics model pitch bandwidth

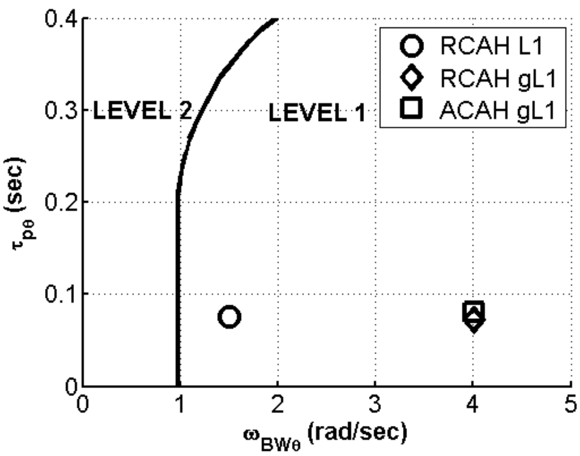

Figure 4. Vehicle dynamics model pitch bandwidth

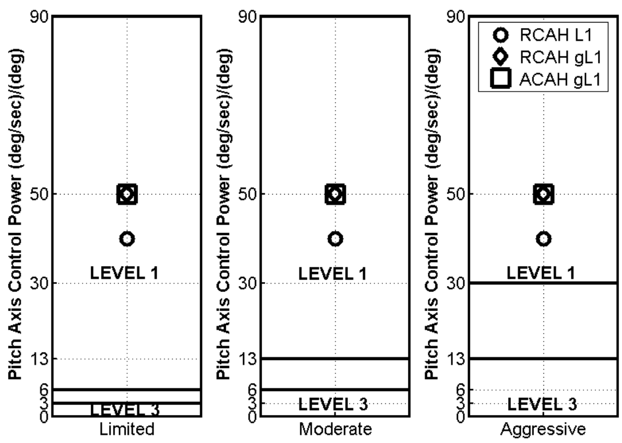

Figure 5. Large amplitude pitch response HQ characteristics

considered important to verify that the analytical methods used to determine the model parameters delivered the desired HQs.

Analytical HQs Offline Assessment

For this initial phase of the project, 3 vehicle configurations were tested:

- RCAH with HQ predictions that lay within the Level 1 (desirable) but close to the Level 2 (adequate) HQ characteristics parameter space (RCAH L1);
- RCAH with HQ predictions well within the Level 1 parameter region (RCAH gL1) and
- ACAH with HQ predictions also well within the Level 1 parameter region (ACAH gL1).

Figure 3 shows an example model response in the pitch axis to a doublet pitch input for each of these configurations.

The pitch and roll responses show similar trends. The rise time for rate and attitude is significantly lower with the RCAH L1 configuration, while the RCAH gL1 and ACAH gL1 configurations exhibit similar rise times. As the ACAH response type leads to the system attempting to hold a steady attitude for a given control displacement, the angular rate peaks, and then begins to decay back to zero within the duration of each of the input pulses, while the RCAH configurations attempt to maintain a steady rate, and so here the rate does not decay until the control is returned to zero.

Figure 4 shows the shows bandwidth/phase-delay calculation for the three model configurations. In each case, the calculated pitch axis bandwidth is coincident with that specified in the model. The phase delay, however, varies by a small amount depending on the configuration.

The large amplitude response (Figure 5) is determined to be exactly as specified for all three configurations.

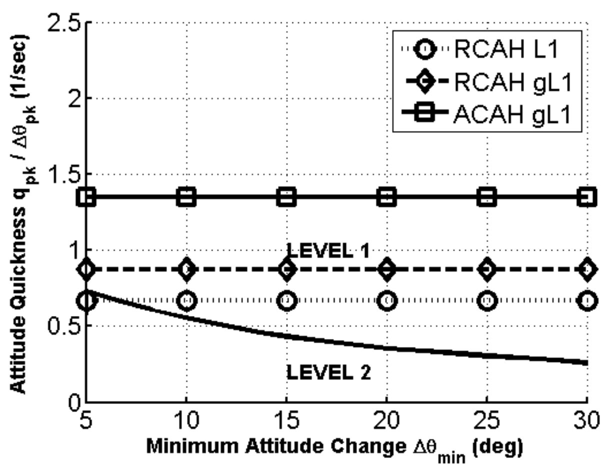

Figure 6. Vehicle dynamics model predicted pitch quickness

The pitch attitude quickness (Figure 6) shows a steady increase in the quickness as the configuration is changed from RCAH L1 to ACAH gL1. With the RCAH configurations, the limited range of model parameters precludes a large degree of modification of the quickness result – it is affected by the specified bandwidth and large amplitude responses, which determine the only two model parameters available. More flexibility is available with the ACAH configuration; the transfer function damping ratio being able to affect the quickness while the large amplitude response and bandwidth are held constant. A lower damping ratio leads to a higher quickness result, although setting the damping ratio too low will clearly lead to stability issues.

Figure 7. UoL HELIFLIGHT-R simulation facility

Pilot-in-the-loop Assessment

As previously stated, it was considered important to establish that the predicted model HQs are reflected by the handling qualities ratings (HQRs) awarded by ‘test-pilots’ flying a particular model configuration. An initial simulated flight trial was conducted in the UoL HELIFLIGHT-R simulator (Figure 7) for this purpose. A visual database containing appropriate task cues for each of the Ref. [29] Mission Task Elements (MTEs) was used for the model evaluation. A total of six test manoeuvres were flown, which were (relevant Ref. [29] paragraphs in brackets for information):

- Precision Hover (3.11.1);
- Hover Turn (3.11.4);
- Vertical Manoeuvre (3.11.6);
- Lateral Reposition (3.11.8);
- Depart-Abort (3.11.7) and
- Pirouette (3.11.5).

All of these tests were based around the hover and low speed region of the flight envelope. The hover manoeuvres were selected to assess the vehicle dynamics in a single axis (hover turn, vertical manoeuvre, depart abort and lateral reposition), and in more demanding, multi-axis scenarios (precision hover and pirouette).

The three vehicle configurations were assessed by a single test pilot in a 1-day simulation trial. Due to time constraints, it was not possible to assess all of the configurations in all of the tasks. The RCAH gL1 and ACAH gL1 configurations were assessed in all MTEs, as these are considered to be closest to the handling qualities that may be required of a future PAV i.e. it is likely that for any PAV manual control tasks the skill level of the ‘pilot’ will be sufficient to, at best, cope with nothing worse than good Level 1 HQ characteristics. The RCAH L1 configuration was assessed in the Precision Hover and Pirouette MTEs only.

For each MTE, the pilot flew the task until the level of performance was consistent, at which point the pilot was asked to rate the HQs of the vehicle using the Cooper-Harper Handling Qualities Rating Scale (Ref. [34]).

Table 2 shows a summary of the HQRs awarded for each MTE and each vehicle dynamics configuration. The results presented indicate that, for the low speed range considered, the model structure that has been adopted is indeed capable of delivering the intended handling characteristics, both in terms of the HQs that result from the analytical expressions, and in piloted evaluations. HQRs in the Level 1 region (HQRs 1 – 3) for all three configurations that have been investigated were achieved across all of the MTEs. The RCAH L1 configuration was rated by the pilot, as expected, at the Level 1/Level2 border across the manoeuvres tested.

	Configuration		
MTE	**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

Table 2. Summary of HQRs awarded

It has previously has been stated that the project expectation is that any PAV pilot will not be able to tolerate handling qualities any worse than good Level 1 and that, what might be termed ‘Super Level 1’ (or XL1) handling qualities, will need to be achieved. The meaning of this term has yet to be defined but it is likely that any manual control inputs will only be required to guide and navigate, rather than to stabilise the vehicle motion.

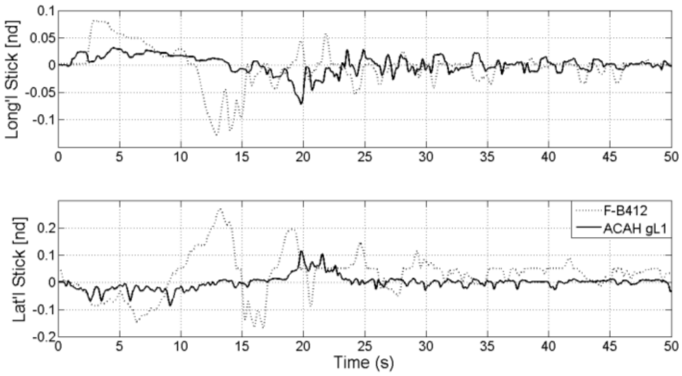

Figure 8. Lateral and longitudinal cyclic stick time history for precision hover MTE

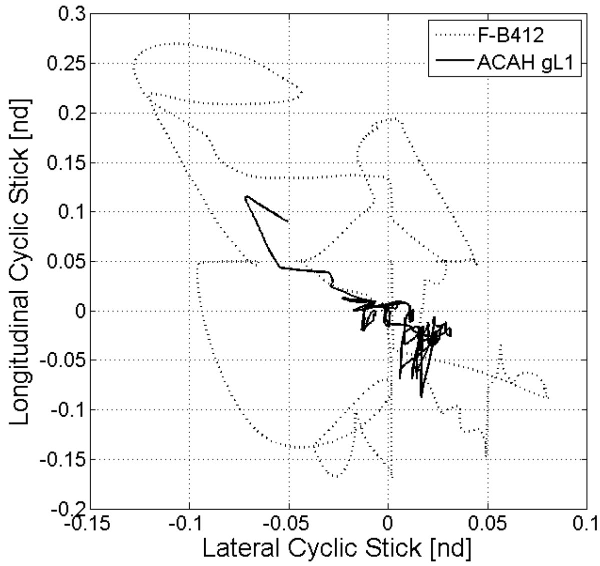

Figure 9. Lateral and longitudinal cyclic stick activity during a precision hover MTE

To illustrate some of the issues surrounding this point, Figure 8 and Figure 9 show a comparison of longitudinal and lateral stick displacements, normalised by full stick deflection, between the ACAH gL1 PAV model created for this project and the FLIGHTLAB Bell-412 (F-B412) helicopter, as described in Ref. [35], during a precision hover MTE. The F-B412 model is not part of the myCoter project and is used here to provide a comparative example of an existing conventional rotorcraft response. Figure 8 shows the MTE in its entirety. The larger stick motions indicate the initial part of the manoeuvre, where the aircraft is brought to the desired hover location. It can be seen that both vehicles reach this point at around 25 seconds. Figure 9 shows the comparative stick activity in the longitudinal and lateral axes up to this time. A number of differences are evident. Firstly, stick motion amplitude is reduced for the ACAH gL1 configuration when compared to the F-B412. However, this is to be expected, given the relative gearing of the attitude command systems implemented in both models. Secondly, the ACAH gL1 has a reasonably linear relationship between lateral and longitudinal stick displacement when compared to the F-B412, suggesting a well harmonised control configuration in these axes. This implies control system that would be more intuitive to use. Thirdly, there does appear to be a slightly higher frequency content to the myCopter ACAH gL1 configuration's control inputs, which may be indicative of a higher workload. However, in both cases, the test pilot will have attempted to achieve the best possible level of performance allowable by the vehicle's HQs. The smaller amplitude, higher frequency control inputs evident in the ACAH gL1 model may have been used to achieve the observed reduced hover ground envelope (Figure 10). For normal operations, this increased positional accuracy may not be required, and the improved ACAH gL1 improved HQs could be used to reduce pilot workload in a more general sense.

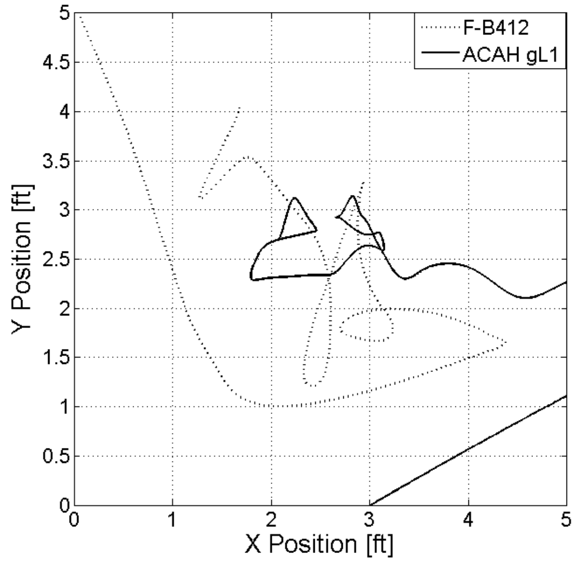

Figure 10. Hover MTE ground envelope

Overall then, the results presented in this paper show that the conceptual PAV simulation model is well suited for its intended purpose, with the additional benefit that it can be rapidly reconfigured to represent different sets of required handling qualities. However, further improvements to its HQ characteristics are anticipated to be required to achieve a vehicle that is capable of being controlled by a typical PAV user i.e. not a highly trained pilot.

FUTURE WORK

In the context of the work presented in this paper, a number of further tasks are required. Firstly, the description and requirements of both the PATS and its constituent PAVs need to be both expanded and refined. This will include interviews with key stakeholders to identify further PATS requirements. Variations from the reference PAV requirement set will also need to be explored. Secondly, the PAV dynamics model will be tested further using additional test pilots to verify that the commanded vehicle HQs are those that manifest themselves 'in-flight'. The model test set will be expanded beyond the hover/low-speed region presented in this paper. It is suspected that even Level 1 HQs will not be sufficient to allow the safe control of a PAV. As such, the vehicle dynamics-related tasks will try to establish what has been called in this paper 'Super Level 1' or XL1 HQ. It is anticipated that this will be achieve, in part at least, using features such as turn coordination, speed/height/position hold/control etc. The associated operational and safe envelopes for which such HQs can be achieved and whether such HQs can actually be conferred onto a real vehicle will also have to be considered. Future developments will be reported in subsequent papers.

Concluding Remarks

This paper has described some of the issues that society faces with respect to current road transport systems and hence the motivation for the myCopter project, which is supported by funding from the EC FP-7 and is currently in its early stages. An apparent reduction in innovation in Air Transport has led to a European study proposing a number of radical, rather than evolutionary, ideas for possible air transport systems in the 2nd half of the 21st century. The actual and forecast increasing use of road transport and the subsequent congestion and environmental impact that this implies led to the idea of using the third-dimension for personal transport. The PAV concept is not a new one but, it was argued, concentrating on the vehicle design alone is to miss out on the other important issues that must be considered to make a PATS a viable option. The myCopter project will therefore set out to evaluate enabling technologies that will support PAV usage within a PATS under 3 main research themes, namely:

1. Vehicle concept modelling, training and HMI;
2. PAV automation and
3. Socio-economic impact.

Initial progress in the first and third of these topics has been described. The initial requirements for a reference PAV that will reside within a PATS have been started and these will be focussed around the commuter/business concept of operations. Furthermore, the development of a conceptual simulation model that can achieve a wide variety of handling qualities characteristics has been described. The initial verification of this model's ability to deliver the required HQs was reported and it was shown that, for the limited testing conducted, the model performed as expected.

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