Towards the Development of a Flight Training Programme for Future Personal Aerial Vehicle Users

Philip Perfect[1], Michael Jump[2], and Mark D. White[3]
School of Engineering, University of Liverpool, Liverpool, UK, L69 3GH

Interest in personal aerial vehicles (PAVs) is resurgent with several flying prototypes made possible through advances in the relevant technologies. Whilst the perceived wisdom is that these vehicles will be highly automated or autonomous, the current regulatory framework assumes that a human will always be able to intervene in the operation of the flight. This raises the possibility of manually operated PAVs and the requirement for an occupant flying training program. This paper describes the development of training requirements for PAV pilots. The work includes a Training Needs Analysis (TNA) for a typical PAV flight. It then describes the development of a training program to develop the skills identified by the TNA. Five participants with no real flying experience, but varying levels of driving experience, undertook the training program. Four completed the program through to a successful simulation flight test of a commuter flight scenario. These participants evaluated the effectiveness of the training program using the first three Levels of Kirkpatrick's method. The evaluation showed that the developed training program was effective, in terms of both trainee engagement and development of the handling skills necessary to fly PAV mission-related tasks in a flight simulator. The time required for the four successful participants to develop their core flying skills was less than five hours. This duration indicates that future simulation PAV training would be commensurate with the training duration for current personal transportation modes.

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[1] Research Associate, Centre for Engineering Dynamics, School of Engineering, now with Blue Bear Systems Research, UK.

[2] Senior Lecturer, Centre for Engineering Dynamics, School of Engineering, Member AIAA, mjump1@liverpool.ac.uk

[3] Senior Lecturer, Centre for Engineering Dynamics, School of Engineering, Member AIAA

Nomenclature

β = sideslip angle [rad or deg]

γ = flightpath angle [rad or deg]

1. Introduction

1.1 Background

The European Union (EU) recognises air transport as "*the principal way of conveniently satisfying the growing demand for diffused, flexible point-to-point connections"* for travel in its long term vision for aviation, Flightpath 2050 [1]. This document sets forth ambitious goals for aviation including the development of air vehicles for the future and the significant reduction of overall door-to-door travel times.

It is clear that existing road and air transportation systems are not the optimum solutions for point-to-point travel. They aggregate trips along established routes which penalises travel time. The number of road network users, coupled with a high incidence of single-occupant journeys [2], result in regular and frequent congestion. Even in the most environmentally conscious countries, alternative solutions such as car-sharing have not worked[4]. This situation is set to deteriorate in the future. Ref. [3] projects that the annual cost associated with road congestion in Europe will increase to €200billlion by 2050. Meanwhile, the current air transport system, whilst providing higher speeds over longer distances, cannot significantly reduce journey times over typical commute distances. Confined to regional or hub airports, the time-consuming journey to the airport, the check-in/bag-drop procedures and the all-important security checks well before the flight is due to depart all contribute to extended door-to-door journey times. For smaller aircraft, the ownership costs associated with General Aviation (GA) also prevent it from being a credible transport alternative, for all but a small percentage of the total population [4].

1.2 Personal Aerial Transport Systems

The situation described above has led to the idea of combining the best aspects of both road and GA aerial transport to create a Personal Aerial Transport System (PATS). The desire for personal aerial transportation has existed for decades [5], but in recent years, perhaps due to the development of relevant technologies, its popularity has re-surfaced. Several concepts at an advanced stage of development already exist for PAVs which would operate

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[4] See: http://www.telegraph.co.uk/news/worldnews/europe/germany/11072530/Germanys-car-sharing-schemes-doing-nothing-to-reduce-traffic.html

within a PATS. These include ‘roadable aircraft’ such as Carplane[5], the Transition[6] and TF-X[7] from Terrafugia, Aeromobil[8] and PAL-V[9]. Whilst all are interesting engineering achievements, they do retain some practical drawbacks. Only the Carplane concept currently appears capable of being certified for both road and air use (most use engines that are not compliant with current road emissions legislation). Even if certification is achieved, they all rely heavily on existing GA infrastructure (e.g. runways) and will require the owner to obtain and maintain either or both of a valid driving and recreational/Private Pilot’s License (PPL). The design compromises required to make them road- and airworthy also limit their efficiency.

Further evidence of a market for PAVs exists with the recent Press and public interest in concepts such as the Volocopter V200[10] and the EHANG 184[11]. However, the concept is not only the preserve of new, small entrants to the market. NASA’s Puffin concept[12] has existed for a number of years now and, most recently, AIRBUS has announced Project Vahana[13], aimed at developing urban air-transport projects. These latter concepts overcome some of the issues raised with roadable-aircraft in that they all incorporate vertical lift technology.

1.3 *myCopter* Project

With all of the above in mind, the EU Framework Programme 7 funded project *myCopter*[14] investigated the technologies required to realize the concept of the PAV and hence make their mass adoption possible [6]. The work presented in this paper relates to the Human-Machine Interaction (HMI) theme of the project. This theme included the investigation of cockpit technologies for inceptors and displays as well as desirable vehicle handling characteristics. This paper reports on the culmination of the latter of these tasks, which was an initial flight simulation study conducted to assess how occupants of a PAV with Vertical Take-off and Landing (VTOL) capability might be trained to use such vehicles reliably and safely and how they might be able to satisfactorily demonstrate this competence.

The *myCopter* project was not a PAV design project. The dynamics model developed for the work presented in this paper is a generic representation of a VTOL aircraft (with the cross-couplings present in a conventional

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[5] See http://carplane.de/
[6] See http://www.terrafugia.com/aircraft/transition
[7] See http://www.terrafugia.com/tf-x
[8] See http://www.aeromobil.com/
[9] See http://pal-v.com/
[10] See http://www.volocopter.com/index.php/en/
[11] See http://www.ehang.com/ehang184
[12] See http://www.nasa.gov/topics/technology/features/puffin.html
[13] See http://aviationweek.com/commercial-aviation/airbus-reveals-urban-air-transport-projects
[14] See http://www.mycopter.eu/

helicopter removed – it was assumed that these undesirable responses would be removed from any future VTOL PAV). As such, the results presented in this paper are considered to be generic and can be read across to any VTOL-capable PAV design with handling quality characteristics similar to those tested.

1.4 Autonomous vs. Augmented Flight

The V200 features a highly augmented Flight Control System (FCS) whereby the human occupant is retained within the control loop whilst, for example, the EHANG 184 has a completely automated FCS i.e. the human occupant is not in the flight control loop. The future of PAVs within a PATS is widely regarded to be fully autonomous i.e. the occupant's role is solely one of being a passenger. The latter situation is not compliant with current aviation requirements for the pilot (who may be remote) to always be able to intervene in the conduct of a flight [7]. An interesting parallel can be drawn with autonomous car technologies currently being introduced by the likes of Tesla[15]. Here, the cars are delivered with 'full self-driving' hardware and 'autopilot' software can be downloaded onto it. The driver is supposed to maintain their hands on the steering wheel and monitor their surroundings in order that they can take back manual control if required. However, there have been documented incidents where this has not happened and the system has not worked [8]. At the same time, these functions have also been claimed to have helped drivers who have found themselves in difficulty [9]. It can be argued that the more cluttered road environment is significantly more challenging for the automated systems to sense, interpret and respond appropriately to compared to the (currently) sparsely populated equivalent airspace. Nevertheless, these cases do highlight both the positive and negative outcomes that can arise from the early adoption of advanced automated functions in transportation systems destined for use by members of the general public. A control system paradigm that provides the PAV occupant with a manual control option was therefore considered to be a valid avenue of investigation. It might even be considered that such a 'manual mode' could be used as a 'reversionary mode' to be made available to the PAV occupant if the automation was not able to cope with the situation presented to it. Of course, such a system would present its own challenges in terms of how to alert to the occupant that this situation had arisen and how to keep the occupant 'in the loop' such that taking control would not make the situation worse. Such considerations however, were well beyond the scope of the current study.

As discussed above, two approaches to the operation of a PAV were considered within the scope of the project. The first is conceived as the fully automatic or autonomous vehicle, capable of completing an entire flight by itself,

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[15] See https://www.tesla.com/en_GB/

with input from the occupant only in terms of routing and (in the case of the automatic vehicle) observation and monitoring of the vehicle's systems [10, 11]. The second approach, perhaps for earlier versions of a PAV and the subject of this paper, would require the human occupant to control some, or all, of the piloting functions of the vehicle. For mass adoption of PAVs to be feasible, it is considered necessary for the PAV to be much less costly to acquire and operate than existing GA aircraft, either fixed- or rotary-wing. One aspect to the cost of operation is training, both initial and that required to remain in current practice. It was hypothesized that savings could be achieved here by improving the Handling Qualities (HQs) of the PAV, particularly in relation to existing GA rotorcraft, creating vehicle responses that are highly intuitive and can be learned and understood quickly.

1.5 PAV Vehicle Model

Response types (i.e. the manner in which the vehicle responds following a cockpit control input) were identified previously [12, 13] that permitted 'flight-naïve' pilots (those with no/limited previous flight experience) to rapidly develop the skills required to operate a PAV simulation safely and repeatedly with a high degree of precision. This work showed that a vehicle with a Translational Rate Command (TRC) response type (i.e. the vehicle moves at a constant velocity over the ground for a constant control inceptor deflection) in hover and at low speeds could be operated by a wide range of test subjects, with minimal training This was found to be the case in both good environmental conditions, and in the presence of atmospheric disturbances and a degraded visual environment. This previous work adopted the HQ approach of Ref. [14] which uses Mission Task Elements (MTEs) to assess the pilot-vehicle HQs whilst performing specific tasks that form a subset of the tasks that might have to be performed during a flight [12].

For the sake of completeness and reader comprehension, the following section outlines the response characteristics defined by the PAV dynamics for the project, although for the rationale behind the selection of the different response types, the reader is directed to Ref. [13]. Table 1 shows the response types exhibited by the PAV model used for this study. Figure 1 provides an illustrative vehicle model response for each response type for a longitudinal control inceptor step input, whose magnitude is tuned to give the same initial pitch acceleration for the three cases shown.

It can be seen that for the Rate Command (RC) Attitude Hold (AH) case, a fixed control input results in a constant rate response (Figure 1 a) and when this input is removed, the vehicle holds the attitude at the point of removal (Figure 1b). For the Attitude Command Attitude Hold (ACAH) case, a constant control input results in a constant attitude being attained (Figure 1b) and held until the control input is removed, at which point the attitude returns to its neutral or ‘zero’ position. For the TRC response type, it can be seen that a constant translational rate parallel to the ground (defined as ‘surge’ in the case of Figure 1c) is maintained until the stick input is removed. Finally, for the Acceleration Command Speed Hold (ACSH) response type, a fixed stick input commands a fixed acceleration and the vehicle then holds the speed achieved upon stick release. For the flight path angle, γ, command response type (not shown in the Figure), the vertical or lateral flight path angle is commanded by the control position. For the sideslip angle, β, command response type (also not shown in the Figure), a pedal input is proportional to a change in the vehicle heading.

Table 1. PAV Response Types per Control Axis

Configuration	**Speed Range**	**Pitch**	**Roll**	**Yaw**	**Heave**
myCopter PAV dynamics	< 15kts	TRC	TRC	RCAH	RCAH
	Blend	Instantaneous at 15kts (accel) and 0kts (decel); internal logic to eliminate transients	Smoothed transition between 15-25kts	Smoothed transition between 15-25kts	Smoothed transition between 15-25kts
	> 25kts	ACSH	ACAH	β command + turn coordination	γ command

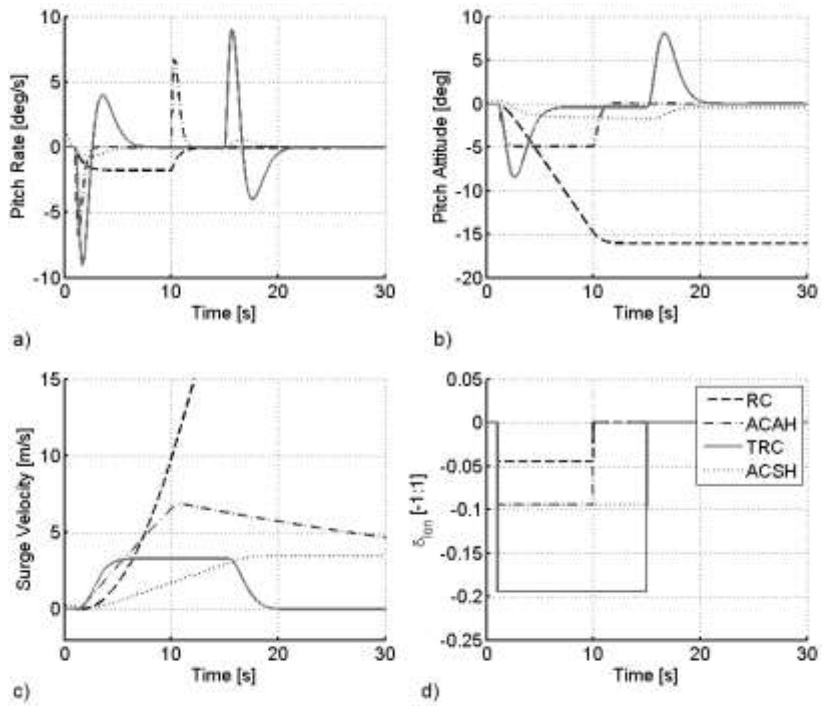

Figure 1. Response types used for PAV flight dynamics model

The vehicle model was also equipped with pilot-selectable heading and height hold autopilot functions.

1.6 PAV Vehicle Occupant Flight Training

For a PATS to be feasible within the manual flight control paradigm, PAV occupants would need to be able to safely conduct an entire flight. This paper presents the results of a study to investigate the quantity and type of training that would be required by prospective PAV occupants to acquire the manual flying skills necessary to enable the safe operation of the vehicle. A PAV training syllabus was developed and used to train a group of volunteers who had no previous real flying experience. One of the participants had limited flight simulator experience (~20 hours) on both fixed- and rotary-wing aircraft models in the facility used for the work reported in this paper. The paper describes the development of the syllabus, based on a TNA [15] for PAV flight, and current 'best practice' for the training of private pilots and car drivers. While current PPL training may be thought of as being more directly applicable to the PAV, in the scenario where mass adoption of PAVs becomes a reality, it is assumed that many trainee PAV occupants would already have some knowledge and experience of car driving. Therefore it was posited that commonality with driving instruction (where feasible) would permit more effective transfer of this knowledge to the PAV training.

1.7 Training Programme Simulation Facility

This paper presents the results of trials conducted using the University of Liverpool’s (UoL) HELIFLIGHT-R flight simulator, described in detail in Ref. [16], in which the volunteers were trained using the syllabus developed. The aims of the trials were to study the effectiveness of the training syllabus and to explore the likely length of time required to complete the training for a range of test subjects. The facility features conventional helicopter controls i.e. longitudinal and lateral cyclic to (primarily in the case of a conventional helicopter) control motion in the pitch and roll axes, a collective lever to control vertical motion as well as tail-rotor pedals to control motion in the yaw axis. It was acknowledged within the project that the ability to pilot a PAV could well be made easier by using controls that the majority of users would be more familiar with i.e. the car, featuring a steering wheel with brake and accelerator pedals. Some initial studies into this concept were conducted and some promising early results as well as some of the issues encountered can be found in Refs. [17, 18]. These will be the subject of a future paper. However, all of the work leading to the development of the training programme was rooted in the discipline of helicopter handling qualities and so the use of conventional helicopter controls was considered logical and appropriate for the initial assessment of any training programme developed in terms of the read-across from that discipline’s state-of-the-art. This paper therefore reports on the results achieved using conventional helicopter controls.

1.8 Structure of the Paper

The paper is structured as follows. A review of the existing training requirements for car drivers and private pilots is provided in the next Section. This is followed in Section 3 by the results of the TNA process for PAV flight, and a description of the process used to convert this into a training syllabus. Analysis techniques of and results from the implementation of the training syllabus in the UoL simulator are presented in Sections 4 and 5. Section 6 provides a discussion of the results presented. Finally, the paper is brought to a close with concluding remarks in Section 7.

2. Existing Practice for Car Driver and Private Pilot Training

Although this review is United Kingdom (U.K.)-focused, flight training is largely harmonized throughout the European Union. In the paper, the situation in the United States (U.S.) is also considered and differences between the European and U.S. systems are highlighted where appropriate. The primary sources for the information discussed on actual practice in this Section are interviews conducted with highly experienced driving and flying instructors, each with more than 15 years of practical training experience.

2.1 Car Driver Training

U.K. car drivers must meet certain standards in terms of their actions on the road and their knowledge of the rules that govern their driving behavior. These standards are set out by the U.K.'s Driver and Vehicle Standards Agency (DVSA) [19]. The DVSA also publishes a national driving syllabus [20] that covers all points of learning, including the development of skills and abilities and the acquisition of knowledge and understanding, required to meet the published standards. The means by which the national syllabus is trained for, however, is not mandated by the Agency. The accepted practice is that individual driving instructors develop their own methods by which to train their students to obtain the required skills. This often involves breaking down the learning process into separate, grouped, components, for instance basic vehicle control, road skills, and interacting with other road users. Within each of these groupings, there can be up to 10-20 individual skills or knowledge items to be covered. These would include, for example, changing gear, steering, braking and clutch control etc. in the 'basic vehicle skills' category, and signaling, road markings and junctions in the 'road skills' category.

For each item of learning, an instructor will typically introduce the concept using graphical aids (traditionally paper-based, but increasingly using electronic means such as videos), and will then ask the student to attempt the skill. Progress is monitored according to the amount of guidance that the instructor needs to supply to the student. At the beginning, this would consist of comprehensive guidance of every stage of a given task, with the instructor telling the student exactly what they need to do. As the student develops their skills, the instructor will be able to reduce their input to prompts only, and eventually the student should be able to complete the task independently. The judgement as to when a learner driver is performing to an acceptable standard is typically a subjective decision made by the instructor.

The U.K. driving examination takes place in two stages. The first, a computer-based theory test, assesses the candidate's knowledge of the rules of the road. The second, the practical driving test, has a duration of 40 minutes. During this time, the examiner will ask the student to conduct a set of 'standard' manoeuvres (such as reversing around a corner, hill starts etc.) in addition to general driving, as directed by the examiner. More recently, an 'independent driving' element has been introduced to the test in order to check on a student's driving ability whilst following traffic signs and making their own driving decisions. The examiner will subjectively judge whether the candidate is performing to an acceptable standard. Minor driving faults do not directly result in test failure, but an accumulation of a sufficient number will result in a test failure. More serious faults, or dangerous manoeuvres, will result in immediate failure of the test.

In the U.S., the detail of learning to drive differs between individual states. However, the process is broadly similar to the U.K. model. To learn to drive, the student must obtain a learner's permit and then undertake a driver's education class or pass a written test. This is followed by the requirement in most states to pass a practical test. Unlike the U.K., in some states, passing the education class and then accruing a number of hours with an instructor exempts the learner from the requirement to take the practical test.

2.2 Private Pilot Training

Pilot training in the U.K. is standardized to a much greater extent than is the case for driver training. For fixed-wing aircraft, 19 standard 'lessons' have been specified by the European Aviation Safety Authority (EASA), and are taught by all flying schools. For helicopters, there are 27 'lessons', the additional lessons focusing on hover and low speed operations. Each lesson covers a particular subject (e.g. the effect of the controls, straight and level flight, turning flight etc.) and begins with a pre-flight briefing in which the subject will be introduced, and the appropriate terminology defined. In the air, the instructor will demonstrate the correct procedure, and then hand control to the student to make their own attempt. By coaching the student through the procedure, appropriate behaviours are instilled and refined until an acceptable standard has been achieved.

Pilot training involves the use of some objective measures with associated tolerances in height, heading, airspeed etc. (e.g. maintain ±150ft of assigned height and/or ±15 knots of assigned airspeed [21]) to judge whether a student pilot has attained an acceptable level of performance. A subjective element remains however, with the instructor making judgements regarding the appropriateness of the student's actions in terms of ensuring safe operation of the aircraft (for example, planning ahead and anticipating the next action rather than flying in a reactive manner). In addition, three 'Progress Tests' are defined in the PPL syllabus. These are designed to verify that the student pilot is able to demonstrate the techniques that have been learned during the lessons.

As with learning to drive, becoming a licensed pilot involves the completion of both theory and practical exams. A PPL student must pass 9 theory exams, covering subjects such as Air Law, Human Performance and Navigation. The practical flying skills test includes navigation, circuits and a simulated engine failure, in addition to general handling. The examiner will use both the quantitative tolerances of height, heading and airspeed, and subjective judgement to determine whether or not a student has successfully passed the practical test.

2.3 Discussion of Existing Training Regimes

There are a number of similarities in terms of the methods used to train pilots and drivers, particularly, in terms of the way that new techniques are introduced to a student and the manner in which progress is assessed. In both scenarios, learners are introduced to new concepts progressively, and are not expected to master control of all aspects of their vehicle simultaneously. Similarities also exist in the methods used to examine competency; using theory exams and practical tests in both cases.

While there are common elements to the methods described above for car driving and flying instruction and examination, a number of additional limitations are imposed on a PPL student. Firstly, it is a legal requirement that a trainee pilot must accumulate a certain amount of ‘hands-on’ learning prior to being able to acquire a license. This is a minimum of 45 hours (35 in the U.S.), which must include at least 25 hours of ‘instructed’ flight and 10 hours of ‘solo’ flight (5 in the U.S.), and should also include at least 5 hours of ‘cross-country’ flying which requires the student to exercise their navigation skills. In the U.S., the training must also include at least 3 hours of dual night flying training. There is no requirement for night flying training in the U.K. (pilots can remove this restriction from their license via an additional course and 5 hours of night flying which should include a solo flight) but there is a requirement to demonstrate both the ability to maintain control in instrument meteorological conditions and to return to visual meteorological conditions. PPL students are also required to meet more stringent medical standards but a discussion of these is beyond the scope of the paper.

Secondly, a newly-qualified U.K. driver can drive any four-wheeled vehicle with a total mass of less than 3.5 tonnes, in any environmental conditions. A newly-qualified PPL(A)-holder[16] is limited to basic Single Engine Piston (SEP) aircraft. Any additional features that complicate the operation of the aircraft (retractable undercarriage, multiple engines etc.), require separate ‘type ratings’ for that particular aircraft. With the PPL(H)[17], the aircraft types that can be flown are even more restricted because every individual helicopter type has its own type rating.

2.4 Assessment of Training Programs

A large number of methods have been developed to assess training programs. Perhaps the most widely-used is Kirkpatrick’s Four Level model [22, 23]. The four levels of evaluation allow the effectiveness of the training given

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[16] PPL(A) – Private Pilot’s License Aeroplanes

[17] PPL(H) – Private Pilot’s License Helicopters

to be evaluated in terms of the trainee's engagement and satisfaction (Level 1, the degree to which participants find the training engaging, favourable and relevant), immediate demonstration of the learning that has been achieved (Level 2, the degree to which the participants acquire the intended knowledge, skills, attitude and confidence based upon their participation in the training), longer-term application of the learning (Level 3, the degree to which participants are able to apply their training to situations they encounter outside of the training environment) and finally the wider benefit to external parties derived from the trainee's new skills (Level 4, the degree to which targeted wider tactical or strategic outcomes occur as a result of the training of the participant). The first 3 Levels were used to assess the effectiveness of the training conducted during this study.

For the PAV training syllabus, the first level assessment was accomplished using questionnaires completed by each participant at the end of their training (see Section 4.1). For the second level evaluation, the participants undertook a final skills test, flying a series of clinical manoeuvres related to the PAV's role (see Section 4.2). The third level evaluation took the form of a 'real-world' PAV commuter flight that the participants were asked to fly which required them to utilise the skills that they had learned in the training programme in a new, unfamiliar but realistic simulated scenario (see Section 4.3). For both the second and third level evaluations, the measurement of the precision achieved and level of control activity used allowed the degree of learning to be measured. Level 4 of the evaluation really applies to the degree to which the goals of the organisation that has sent the participant on the training have been met in the longer term. A simple example of this, for the myCopter project, would have been a follow-up study to check that the skills gained were useable over a longer period of time and in more complex air traffic scenarios (all the while ensuring that the participants flying skills remained 'current'). It might also have included a study into the improvements in, say, road congestion due to the introduction of PAVs. Due to the project timescales however, it was not feasible to conduct this fourth level evaluation and so is out of scope of this paper.

The structure of the evaluation of training can take several forms [23]. These generally involve a period of training followed by a post-training test to measure final performance. A pre-training test can also be included to measure initial performance prior to training. More complex evaluation structures can also involve the use of control groups who do not receive training, in order to evaluate the impact of external factors on the evaluation.

For the PAV training evaluation, time restrictions, in terms of the availability of the simulator and participants, prevented the use of a control group. Pre-testing of role-specific tasks (i.e. actual flying in the simulator) would have significantly impacted on the outcomes of the evaluations due to the (intended) highly intuitive nature of the system being trained i.e. the participants would have been able to self-learn to a considerable extent while completing the pre-training test, which would affect the quantity of training required while following the syllabus. Hence, evaluation of the efficacy of the PAV training syllabus has been performed on the basis of post-training performance only. The ability to successfully complete the skills test and 'real-world' evaluations were used as the means to show that the participant has acquired the necessary skills to conduct a PAV flight. Whilst the absence of a pre-training test evaluation does impinge on the direct measurement of the skills gained during the training program, the use of an aptitude test to assess natural flying ability (e.g. hand-eye coordination) allowed the performance of each participant to be placed in context. The methods developed and used during the project can be found in Ref. [12]. For the four participants who possessed no real or simulated previous flying experience and hence had no pre-existing directly-relevant knowledge, it can be considered that these participants started the training program from an equivalent level of pilotage knowledge. The participant with some simulator flight experience did have the knowledge regarding the use of the facility and how, in general terms, a flight control inceptor can be used to control an air vehicle.

3. Personal Aerial Vehicle Training Syllabus Development

The following section outlines the creation of the PAV training syllabus, program and how it was subsequently assessed.

3.1 Key Skills for PAV Pilots

At an early stage in the *myCopter* project, an outline 'commuting' scenario was developed to inform the subsequent research [6]. This scenario requires the PAV to perform a vertical take-off from a residential location, climb and accelerate to cruising flight. Upon reaching the destination in the Central Business District (CBD) of a city, the PAV must descend and decelerate to a hover above the landing point, followed by a vertical landing. Using this description as a basis, a list of manoeuvres that would need to be performed by a PAV pilot was developed. These were used to identify the skills that the PAV pilot would need to demonstrate for manual flight, based on the ideal PAV response characteristics identified in the earlier *myCopter* research [12, 13].

In total, 24 key skills that relate to manual PAV handling, assuming a 'conventional' vertical flight-capable cockpit i.e. cyclic and collective sticks plus 'rudder' pedals, were identified. These are as follows:

1. Use of longitudinal inputs in hover to control forward speed (TRC response type);

2. Use of lateral inputs in hover to control lateral speed (TRC response type);
3. Combined use of longitudinal and lateral inputs to control horizontal flight path angle;
4. Use of pedals in hover to control heading and yaw rate (RC response type);
5. Use of the collective lever in hover to control height and vertical rate (RC response type);
6. Combined use of pedals and lateral inputs at low speed (<25kts) to improve turn coordination;
7. Use of longitudinal inputs in forward flight to control speed (ACSH response type);
8. Use of lateral inputs in forward flight to control heading (ACAH response type);
9. Use of the collective lever in forward flight to control vertical flight path angle (γ response type);
10. Function of the pedals in forward flight (sideslip angle command (β) response type);
11. Combined use of lateral inputs and collective in forward flight to perform climbing and descending turns;
12. Combined use of lateral and longitudinal inputs in forward flight to perform accelerative and decelerative turns;
13. Combined use of longitudinal inputs and collective in forward flight to perform accelerative and decelerative climbs and descents;
14. Combined use of longitudinal and lateral inputs and collective in forward flight to perform accelerative or decelerative climbing or descending turns;
15. Longitudinal transition from TRC to ACSH;
16. Lateral transition from TRC to ACAH;
17. Collective transition from (vertical) RC to γ command;
18. Pedals transition from RC to β command;
19. Longitudinal transition from ACSH to TRC;
20. Lateral transition from ACAH to TRC;
21. Collective transition from (vertical) γ command to RC;
22. Pedal transition from β command to RC;
23. Use of secondary ‘automation’ functions (such as height hold, direction hold etc.) and
24. Use of instrumentation – including Head-Up Display (HUD) symbology for guidance and navigation.

It is acknowledged that additional knowledge and skills would be required in terms of cockpit procedures, navigation, communications etc., although it is anticipated that training requirements here would be minimized by effective cockpit design [24] and the provision of automatic functionality for route-planning etc. Another important element of both driving and flight training is preparation for failures and other emergency scenarios. The study of the training requirements for these situations was beyond the scope of the current work.

3.2 Personal Aerial Vehicle Training Program

The 24 skills identified above were grouped into four lessons, each focused on a specific part of the PAV flight envelope, as follows:

Lesson 1: Hover and Low Speed Flight. This lesson covered skills (1)-(6) and introduced vehicle operation at speeds below 15kts.

Lesson 2: Cruising Flight. This lesson covered skills (7)-(14) and introduced vehicle operation above flight speeds of 25kts.

Lesson 3: Transition. This lesson covered skills (15)-(22) and covered the changes in response characteristics between hover and low speed flight (< 15kts) and cruising flight (> 25kts).

Lesson 4: Advanced Functions. This lesson covered skills (23)-(24). It introduced the height and heading hold functions as well as the HUD symbols.

In addition to these, a fifth lesson was created that focused specifically on the conduct of typical PAV manoeuvres e.g. precision hovering, vertical landings and descending approaches to hover [12]. These manoeuvres might be considered as being the equivalent of the ‘reverse around a corner’ or ‘parallel parking’ manoeuvres associated with driver training, or standard flying manoeuvres such as performing circuits around an airfield.

For each skill within a lesson, a series of exercises designed to introduce and subsequently refine the skill, were taught. For example, from the first lesson, for the skill of forward speed control, the exercises were:

- Use longitudinal stick input to set a desired forward speed
- Accelerate/decelerate from one forward speed to another forward speed
- Decelerate to hover and
- Control deceleration to hover at a specific point above the ground.

A complete listing of the training exercises for all skills is included in Appendix A. The five lessons constituted the Training Programme to be assessed by the participants.

For each exercise, a briefing was conducted, introducing the purpose of the exercise and what would be attempted. A demonstration was provided by the instructor (a member of the *myCopter* project team who was very familiar with the characteristics of the simulation), with the required control inputs and visual observations (i.e. the outside world features that the trainee should be monitoring) highlighted. The student then attempted the exercise, and, through repeated practice with coaching from the instructor in terms of how to modify their technique to ensure safe and precise control of the PAV, improved until a good, repeatable standard was attained. As with driver and flying training, this was judged subjectively based upon observations regarding the correct use of the controls and the subsequent response of the vehicle. Progress was tracked using training record sheets that allowed improvements in competency to be followed and for the length of time spent on each skill to be recorded (Appendix B).

4 Personal Aerial Vehicle Training Program Assessment Method

Five Test Subjects (TSs) undertook the PAV training syllabus developed as part of the *myCopter* project. Their ages ranged from 22 to 45. Four of the TSs were male, one female. All were car drivers, with experience levels that corresponded to their age (ranging from 5 to 25 years). None of the TSs had any previous flying experience. The number of participants is commensurate with flight handling qualities test programs (see, for example, Ref. [25] where 5 pilots were used and note that Ref. 14, on which the methodology of the study was based, recommends a minimum of only 3 pilots for handling qualities analyses). Table 2 shows the normalized results of the aptitude testing that each participant undertook prior to participating in the Training Programme. The aptitude scores were normalized against the highest result achieved (the raw numeric value has no specific meaning beyond a comparison with other subjects who took the same test). The data show that 4 of the participants had reasonably equivalent aptitude scores (>0.9) whilst one had a noticeably lower aptitude for flight tasks. This will be returned to later in the paper.

Table 2. Normalised Aptitude Test Score per Training Programme Test Subject

Test Subject				
1	2	3	4	5
0.99	0.99	0.90	1.00	0.68

The training was conducted to fit in with the participants' other commitments. This meant that they attended one or two sessions per week. Each training session lasted between 60 and 90 minutes. Each participant worked through the program at their own rate. This Section describes how each phase of the training was assessed.

4.1 Level 1 Evaluation: Participant Satisfaction

Each of the participants who completed the Training Programme i.e. all five lessons, was asked to complete a questionnaire regarding their satisfaction with the training received. The questionnaire contained five questions with quantitative answers, plus a number of 'open' questions allowing the participant to expand upon their numeric answers. The five quantitative questions were:

1. To what extent do you feel that you have learned the skills necessary to fly a PAV from the programme?
2. Was the programme stimulating?
3. Was the pace of the programme appropriate for you?
4. Was the programme sufficiently flexible to meet your needs?
5. Was the programme challenging?

'Satisfaction' is a bi-polar construct i.e. can be both positive and negative. The degree to which a participant is subjected to such a construct is generally considered using a 7-point scale, which allows a middle or neutral rating point [26]. However, for this work, it was considered desirable that the participants were not given a neutral option and that they should be required to make a decision on their satisfaction in one way or the other. For this study therefore, the participants were asked to respond on a scale from 1 to 8. A score of 8 indicated strong agreement with the statement, while a score of 1 indicated strong disagreement. In the case of question 3, a score of 8 indicated too rapid a pace, while a score of 1 indicated too slow a pace.

4.2 Level 2 Evaluation: Skills Test

Four of the five TSs completed the Training Programme within the available project timescales. Each of these four then undertook a skills test which consisted of five MTEs defined in Ref. [12]. The MTEs are representative of various elements of the *myCopter* commuting scenario: Precision Hover; Vertical Reposition; Landing; Decelerating Descent and an Aborted Departure and the reader is directed to this reference for more detail on the rationale behind their selection.

As per Ref. [14], for each MTE, a set of 'desired' performance boundaries were identified (for the Hover for example, in height (±2ft) and heading (±5°) deviation, and in plan position (±3ft either laterally or longitudinally) during the steady hover phase of the task). These are identified to the pilots using reference objects placed in the outside world visual scene. The TSs were asked to attempt to stay within these boundaries whilst flying the MTEs.

4.3 Level 3 Evaluation: Commute Scenario

To assess whether the participants in the training program had developed the skills required to fly the 'real-world' commute task, a simulation scenario was developed for the PAV pilot to fly from 'home' (Kingsley Green) into Liverpool City Centre. Figure 2 shows the planned lateral and vertical route as well as the planned speed profile. It was not a direct route as Liverpool's international airport (EGGP) is located on the direct route between the departure point and the City. A deviation inland from the direct route was incorporated, with the PAV avoiding the airport's GA circuit patterns. The enroute planned altitude was 800ft, to give sufficient clearance from the normal operating altitude of the airport's traffic. It was assumed for the virtual scenario that all required airspace clearances were in place and so no other air traffic was introduced enroute. To simulate anticipated noise abatement procedures for the more densely populated areas of the region, the route follows the River Mersey on the approach to Liverpool City Centre. These deviations from the direct path provided an opportunity to incorporate manoeuvering flight elements into the evaluation. The total flight duration for this task was approximately 11 minutes. The flight was in daytime Visual Flight Rules (VFR) conditions (i.e. good visibility, clear of cloud and in sight of the ground), and there was no wind or other atmospheric disturbances introduced to the simulated environment. Limited airline operations from the airport were incorporated into the scenario in the form of one aircraft departing and one aircraft arriving whilst the PAV was in the vicinity of the airfield.

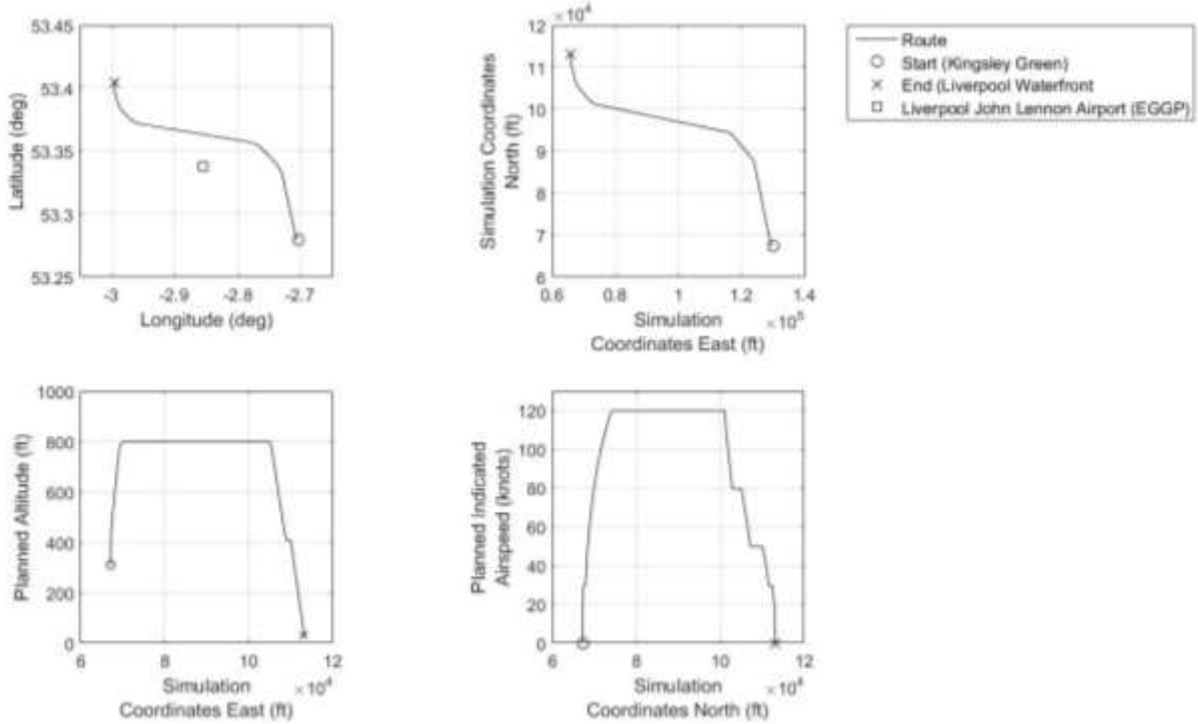


Figure 2. Route details for the commuter journey

The participants in this study used a Highway-in-the-Sky (HITS) [27, 28] display to navigate along the planned route (Figure 3). The HITS is an attractive option for use in PAVs due to its intuitive and conformal (i.e. can be directly related to real terrain features) nature. The size of the boxes (±100ft laterally and vertically) that formed the HITS informed the pilot as to the allowable discrepancy between planned and actual routing. It is anticipated that PAVs would operate at considerably higher traffic densities than existing commercial or private aviation. This leads to a requirement for precise positioning, and rigour in the maintenance of position in order to avoid conflicts with other PAV traffic. The HITS also provided desired airspeed indications to the pilots, presented in the form of U.K.-style road speed limit boards, albeit displaying limits as knots rather than miles per hour (airspeed readouts for the PAV were also displayed in knots on the HUD).

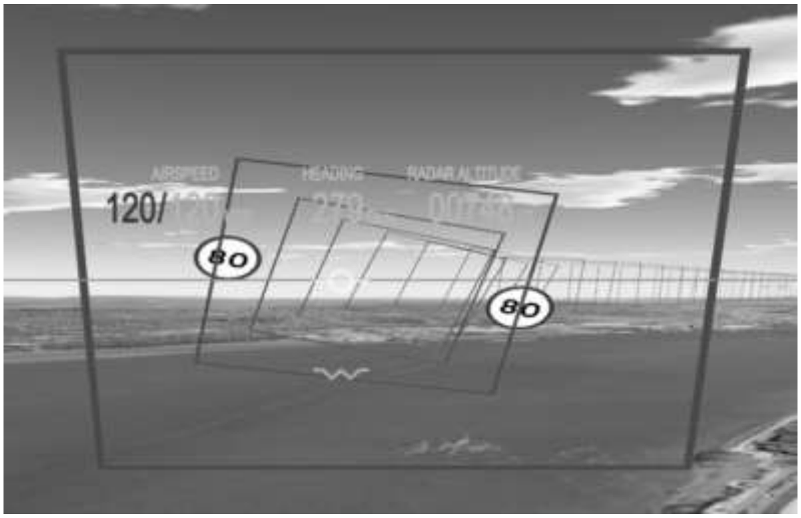


Figure 3. Pilot's-eye view of the Highway-in-the-Sky used for PAV navigation

At the start of the route, a vertical take-off was performed from the ground in front of a row of houses, as though departing from the street in front of the occupant's home. The take-off area was clear of any other vehicles and obstacles in the immediate vicinity of the PAV. The PAV was required to be achieve a height of 75ft above the ground to clear the surrounding buildings and trees. It was then accelerated towards the cruise speed whilst simultaneously climbing to the cruising altitude of 800ft and turning onto the course for the first leg of the route. When the PAV neared the City Centre, this process was reversed, descending and decelerating, eventually coming to a hover above an open area close to the city's financial centre. The PAV was then repositioned to a marked parking place, onto which a vertical landing was performed. The airspeed limits for the different phases of the flight were120kts, 80kts, 50kts and 30kts respectively (Figure 2). Figure 4 shows the PAV-occupant's eye view of some key elements of the scenario. These show the level of scene content detail provided to the test subjects.

Figure 4. PAV occupant's-eye view of: take-off position (left); typical enroute scene (centre) and approach to the landing location in the financial centre of Liverpool (right)

Following completion of the commute scenario, each TS was asked to rate their workload using the NASA Task Load Index (TLX) rating scale [29]. This system asks a participant to evaluate workload using 6 factors – mental demand, physical demand, temporal demand, performance, effort and frustration. Each factor is then weighted by its relative contribution to the overall workload to create a single workload score between 0 and 100. A TLX of 0 indicates no workload at all, while a TLX of 100 indicates that the participant is at their maximum level in every area.

5 Results

5.1 Training Duration

Figure 5 shows the total amount of time required by each TS to progress through the Training Programme syllabus, broken down by individual lessons. It can be seen that four of the five TSs were able to complete the syllabus in fewer than 5 hours. Test Subject 5, however, progressed at a much slower pace, and was unable to complete all 5 lessons within the project timescales. This is not to say that this test subject could not have completed the training, it is simply that the slow rate of progression through the training meant that the reported result is what the participant had completed by the end of the project. It is interesting to note that the aptitude test taken prior to the start of the training identified this TS as being more likely to struggle with the demands of the training than the other TSs (see Table 2). This TS also reported that they have always required a lot of time and practice to become proficient with new 'manual' skills – for example, when learning to drive a car. For more information regarding the aptitude testing and scoring, the reader is directed to Ref. [13]).

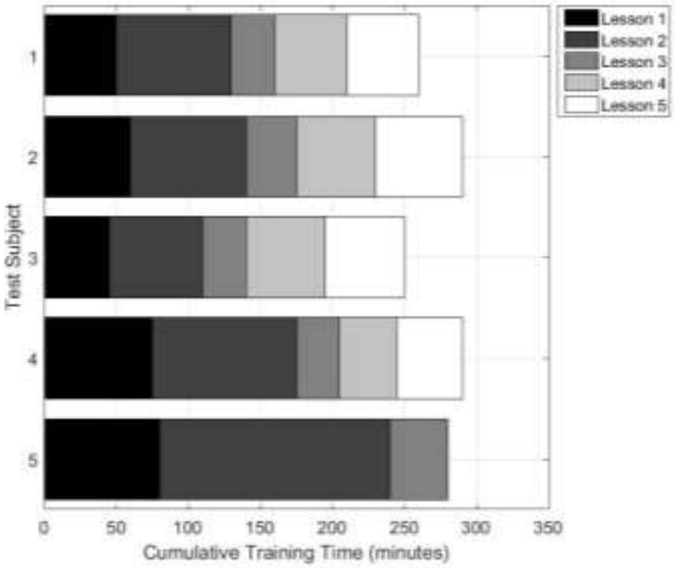


Figure 5: Training time for individual test subjects

It can be seen in Figure 5 that the individual lessons required different amounts of time to complete per TS. There is, however, a good level of consistency between the TSs in terms of which lessons required more or less time. The lesson that consistently required the greatest amount of time was Lesson 2. This covered control of the aircraft in forward flight. Whilst the characteristics of the individual control axes could be learned quite quickly, all of the TSs found that more time was required to reach the acceptable standard when simultaneous, coordinated multiple control inputs had to be made (skills 11-14). As with the single-axis tasks, moving the controls to start the PAV moving in the correct sense was not demanding for the TSs. The main complexity introduced by the exercises for these skills was the requirement to regularly monitor two or more of the controlled vehicle states (e.g. airspeed, heading, altitude etc.). The requirement to share attention across a number of information sources required all of the TSs to spend time developing their instrument scan patterns, and to build sufficient confidence in their knowledge of the vehicle's responses. Prior to reaching this point in the syllabus, the TSs had generally only been asked to apply control inputs in a single axis, allowing them to focus on the way in which the controlled parameter was changing. For the multi-axis exercises in Lesson 1, more readily available outside visual cues allowed the TSs to assimilate flight information without the requirement for the comprehensive scan that was required in Lesson 2.

Lesson 3, in contrast, was straightforward for all of the participants and required significantly less time to complete than the others. The TSs did not require significant practice to transition between the low and high speed flight regimes. A short period of practice to reinforce the theoretical knowledge was all that was required to complete the objectives of this lesson.

5.2 Level 1 Evaluation: Participant Satisfaction

Figure 6 shows the average score given by the participants for each question, together with the upper and lower bounds of the ratings awarded. The participants found the training program to be effective at teaching them the skills they felt they needed (Question 1 from Section 4.1) and was stimulating and flexible (Questions 2 and 4 from Section 4.1). The participants found the pace of the training to be neither too fast nor too slow (Question 3 from Section 4.1). The participants generally found the training to be moderately challenging (Question 5 from Section 4.1), indicating that the characteristics of the PAV were relatively straightforward to learn, but that there remained sufficient challenge to engage and stimulate them.

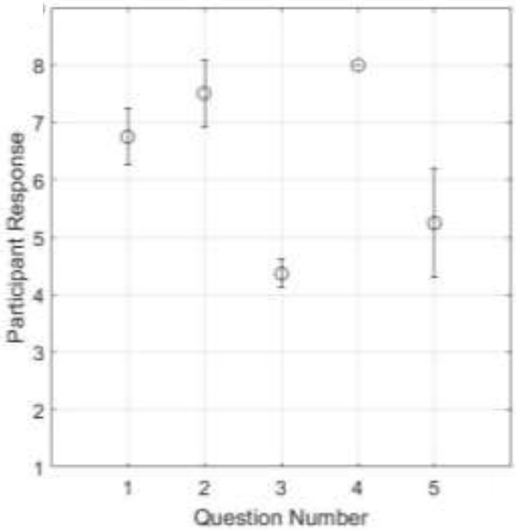


Figure 6. Level 1 participant satisfaction scores

5.3 Level 2 Evaluation: Skills Test

Figure 7 shows the average time spent within the desired performance boundaries for each MTE across the TSs who completed the skills test (marked ‘Trained’ in the Figure). Also shown for comparison is data from earlier *myCopter* testing [12] in which a different set of TSs were asked to attempt the MTEs without having had any formal training (marked ‘Untrained’ in the Figure). These data were collected from participants that had a much more varied set of previous experience, from no flying or driving experience to holders of PPL(A)s and PPL(H)s. It can be seen that those TSs who received training in the characteristics of the PAV simulation were consistently able to achieve an excellent level of precision (>98% time spent in the desired performance region) in all five MTEs. Although the ‘untrained’ TSs were also able to achieve very good precision (confirming the highly intuitive nature of the response characteristics of the PAV simulation developed in [13]), the precision achieved by the ‘trained’ TSs was somewhat better than the average precision achieved by the ‘untrained’ TSs in every task (between 1% and 5%). This was particularly true in the Landing and Decelerating Descent tasks. These two tasks, perhaps more so than the others, demand the application of developed technique by the pilot, particularly in terms of use of the ‘advanced’ functions and HUD symbology. Whilst the overall difference between trained and untrained TS’s may seem small, the reader should remember that the data is averaged across participants in each cohort and that the ‘untrained’ cohort averaged data includes data from participants with considerably more real and simulated flying experience than was provided during the Training Programme to the ‘trained’ participants.

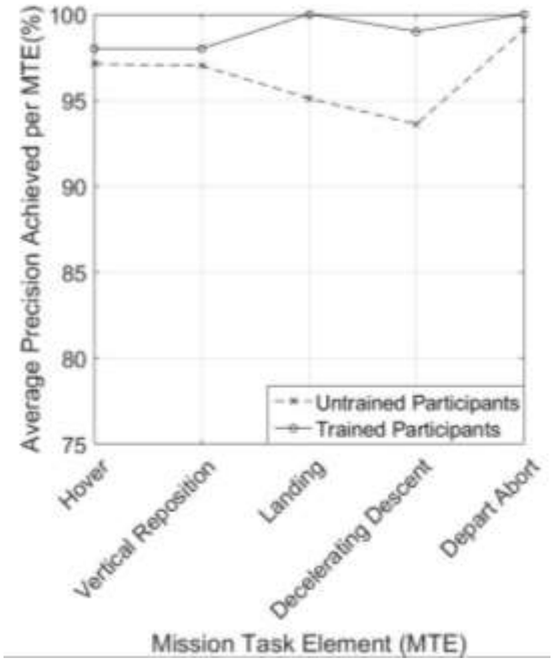


Figure 7: Improvement in task precision following the training program

5.4 Level 3 Evaluation: Commute Scenario

Figure 8 shows the flight path and forward speed accuracy achieved by the test subjects who underwent the commuting scenario test in the form of root-mean-square (RMS) errors and standard deviations from the planned route parameters shown in Figure 2. The axis maxima on the lateral and vertical flight path plots have been set to 100ft to provide a visual cue with regards to the accuracy achieved compared to the HITS provided.

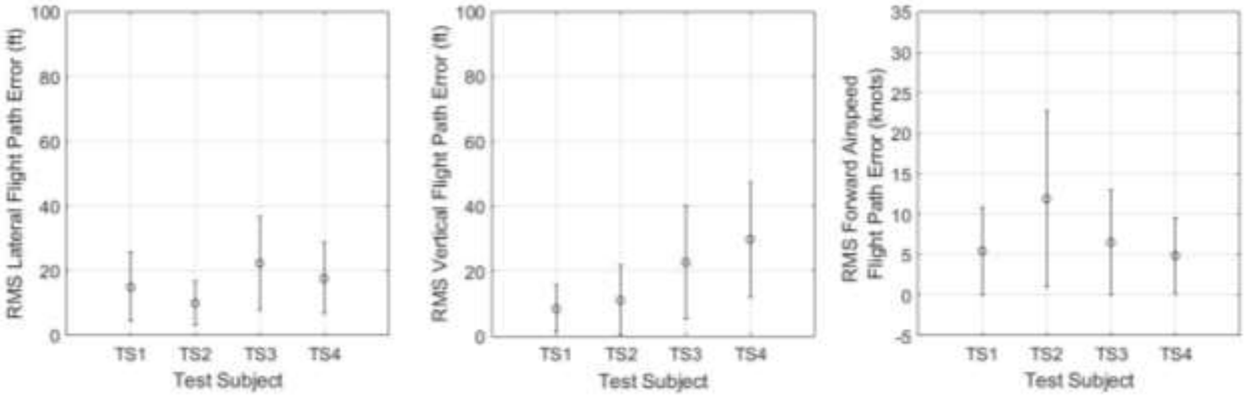


Figure 8: Deviation from desired flight path during the commute scenario flight test

It can be seen from Figure 8 that all of the TSs were able to fly the PAV along the HITS desired flight path accurately, having been instructed to stay within its limits. Adherence to the planned airspeed perhaps appears slightly less impressive. However, Figure 9, which shows example results from TS2 and TS4 respectively, provides an explanation for this. This shows that, whilst there is a planned speed profile for the acceleration and deceleration phases between constant speed legs of the flight, different TSs applied differing levels of these compared to the planned profile. The TSs were only provided with speed limit markers but were not provided with acceleration/deceleration guidance. The error computations were performed with respect to simulation coordinate position and this will have resulted in the observed discrepancy. It can be seen from Figure 9 however, that, for the two cases presented (which are typical of the results), the planned constant speeds were captured successfully.

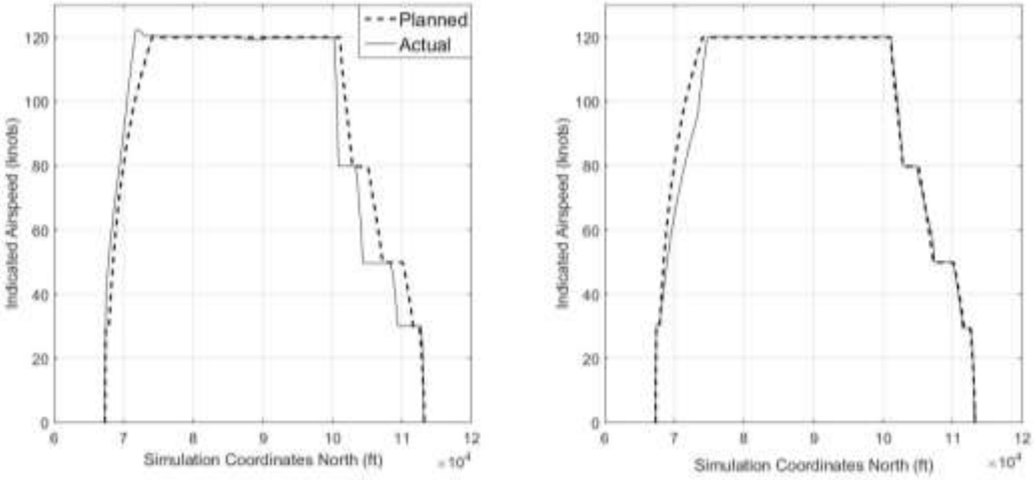


Figure 9. Example adherence to planned forward velocity comparison

The TSs returned TLX ratings between 18 and 30 for the commute scenario. They commented that the workload general was generally very low. There were, however, occasions where the workload increased. These were generally the points at which the route required the pilot to perform two or three actions simultaneously e.g. airspeed change, heading change and/or altitude change.

6 Discussion of Results

The results presented above indicate that the training syllabus developed as part of this research was an effective method by which to transfer the required knowledge and skills to the participants to allow them operate a PAV safely (i.e. within defined performance tolerances) and reliably (i.e. could achieve this on a number of different occasions). The precision achieved in the manoeuvres used for the ‘skills test’ was improved in comparison to a dataset for a group of ‘untrained’ test subjects. While in absolute terms the magnitude of the improvement was not large, it should be noted that the ‘untrained’ subjects were already able to fly the PAV to a high level of precision, demonstrating the intuitive nature of the PAV’s responses; this was the original intent of the design exercise. In this context, the improvement in achieved precision with the 'trained' subjects is useful. In none of the MTEs did the trained subjects average less than 98% of time spent inside the task's desired performance boundaries.

The 'trained' test subjects were also able to complete the 'real-world' test, the commute scenario, with a good degree of accuracy and with low workload. To contrast with the results reported here (TLX of 18 – 30 for the commute scenario), TLX ratings in the region of 58-65 have previously been reported for driving a car in an urban environment [30]. Given the potential duration of a typical PAV flight (10-30 minutes), it would be unacceptable for the workload to be continuously high, as this would lead to pilot fatigue. It is not the intent of this comparison to claim that piloting a PAV would necessarily be easier than driving a car (as the task in Ref. [30] is not directly comparable to the urban commute used in this study). Rather, the inference is that the workload that a PAV occupant might experience would not be objectionably high.

Based on the subjective questionnaire completed by the TSs, all found the training to be engaging and stimulating. This is an important consideration in training program development, as, without trainee engagement in the process, learning typically occurs at a much slower rate [31]. Given that one of the objectives of the *myCopter* project has been to determine the most effective methods by which to reduce the costs associated with a PAV, a training program that delivers high levels of participant engagement is an obvious requirement and seems to have been satisfied by the program detailed in this paper.

The participants generally reported that they felt that they had received a comprehensive level of training for the tasks that they were asked to carry out in the final evaluations. Two main items were identified where the participants felt that additional training could have been delivered:

1. Additional time to practice the various skills that were taught during the training. Further practice and experience will always be of benefit in terms of developing a thorough understanding of how the vehicle will respond to any given control input. This is in common with driving and flight training whereby the expectation is that newly-qualified drivers or pilots will need additional time at the controls of their vehicle to become proficient.
2. The procedures to be followed in the case of something going wrong, either with the vehicle itself, or with external factors (such as encroachment by other aircraft). As noted earlier, training for these 'emergency' situations was deliberately excluded from this phase of the research.

Finally, it was reported above that four of the five TSs in this study were able to complete the training program in less than five hours, while the fifth was somewhat behind, having completed three of the five lessons in just under five hours. Although, as discussed above, certain aspects of the required training have been excluded from this study, and testing was exclusively simulation based (which might remove the 'startle' and 'fear' related to real-world operations), these numbers compare favorably with those typically expected for car driving (generally 20-40 hours) and flying (45-100 hours). The authors are not claiming here that training for PAV operation would be significantly less than for conventional activities, but that training for the core operation of PAV flight can be achieved in a realistic timescale in relation to conventional personal transportation training. For a 'real' PAV training program, it would be desirable to conduct at least some of the training in simulation in order to reduce costs (in much the same way that the airline industry and, to some degree, the GA community) does today with ground-based simulators. The training would then progress to the actual aircraft.

7 Conclusions

This paper has described, for the first time, the creation and evaluation of a training syllabus to equip the occupants of a Personal Aerial Vehicle (PAV) with the handling skills required to allow them to fly a representative commuter flight scenario in a benign flight environment. The work has assumed that the PAV is to be flown manually, and that it responds according to the best response characteristics identified during the authors' previous work. The following conclusions can be drawn from this investigation:

- The principles of current driver and private pilot training can be used to train flight-naïve PAV pilots to successfully handle an air vehicle configured with good handling qualities characteristics in a benign simulation environment.
- The training programme developed for PAV operators in this paper using those principles was subjectively rated by the participants as being effective for the resultant testing that they were asked to undertake, was taught at the correct pace and was sufficiently challenging to keep the students engaged and stimulated.
- Flight skills-focussed aptitude testing developed for use within this work provided a good indication as to the length of time that individual PAV occupants would take to reach a suitable level of handling skill, at least in a benign simulated flight environment. Such aptitude testing would usefully form part of any training program for manually flown PAVs, as it does for flying (but not driver) training selection today.

- A typical training duration of less than five hours was required in a simulation environment to develop the skills necessary to successfully pilot a PAV through a simulated commuter flight scenario in a good visual environment. This duration, assuming that it is representative given the small sample size use in this study, indicates that PAV simulation handling training would be feasible within the training durations for current personal transportation modes.

The work described in this paper covers the basic handling skills that would be required by a prospective PAV pilot. Further training would be required for handling of emergency situations, and any other aspects of conventional private aviation that would not be eliminated by the incorporation of automatic or autonomous functions within the PAV. This should be the focus of future work on this topic.

Appendix A

This appendix lists each of the skills identified earlier in the paper. For each skill, the exercises used to develop that skill are listed.

1) Use of longitudinal inputs in hover to control forward speed (TRC response type)
    a. Use longitudinal stick input to set a desired forward speed
    b. Accelerate/decelerate from one forward speed to another forward speed
    c. Decelerate to hover
    d. Control deceleration to hover at a specific point above the ground
2) Use of lateral inputs in hover to control lateral speed (TRC response type)
    a. Use lateral stick input to set a desired forward speed
    b. Accelerate/decelerate from one lateral speed to another lateral speed
    c. Decelerate to hover
    d. Control deceleration to hover at a specific point above the ground
3) Combined use of longitudinal and lateral inputs to control horizontal flight path angle
    a. Use of simultaneous longitudinal and lateral stick inputs to generate 45° trajectory
    b. Use of longitudinal and lateral stick inputs to modify trajectory
    c. Slalom using lateral stick inputs
    d. Decelerate to hover
    e. Control deceleration to hover at a specific point above the ground

4) Use of pedals in hover to control heading and yaw rate (Rate Command (RC) response type)
   a. Use of pedal input to set desired yaw rate
   b. Use of pedals to modify yaw rate
   c. Decelerate yaw to stop at specific heading
   d. Slalom using pedal inputs
5) Use of the collective lever in hover to control height and vertical rate (Vertical Rate Command (VRC) response type)
   a. Use of collective input to set desired vertical rate
   b. Use of collective input to modify vertical rate
   c. Decelerate to stop at specific height
6) Combined use of pedals and lateral inputs at low speed (<25kts) to improve turn coordination
   a. Demonstration exercise of effect of flight path lead/lag when using either pedals or lateral stick individually
7) Use of longitudinal inputs in forward flight to control speed (Acceleration Command, Speed Hold (ACSH) response type)
   a. Use of longitudinal stick input to set acceleration/deceleration rate
   b. Capture of new forward speed
8) Use of lateral inputs in forward flight to control heading (Attitude Command, Attitude Hold (ACAH) response type)
   a. Use of lateral stick input to set bank angle
   b. Changing from one bank angle to another
   c. Capture of a new heading
   d. Capture of defined track over ground (e.g. along runway centreline)
   e. Effect of speed on turning dynamics
9) Use of the collective lever in forward flight to control vertical flight path angle (flight path angle command (γC) response type)
   a. Use of collective lever to set climb or descent angle
   b. Capture of new height
   c. Effect of speed on climbing dynamics

10) Function of the pedals in forward flight (sideslip angle command (βC) response type)
    a. Demonstration of sideslip angle response type
11) Combined use of lateral inputs and collective in forward flight to perform climbing and descending turns
    a. Commencing lateral and collective inputs simultaneously
    b. Turning to new heading while climbing or descending to new height
    c. Capture of defined ground track while climbing or descending to new height
    d. Pacing turn and climb/descent to complete both simultaneously
12) Combined use of lateral and longitudinal inputs in forward flight to perform accelerative and decelerative turns
    a. Commencing lateral and longitudinal inputs simultaneously
    b. Turning to new heading while accelerating or decelerating to new speed
    c. Capture of defined ground track while accelerating or decelerating to new speed
    d. Pacing turn and acceleration/deceleration to complete both simultaneously
13) Combined use of longitudinal inputs and collective in forward flight to perform accelerative and decelerative climbs and descents
    a. Commencing longitudinal and collective inputs simultaneously
    b. Accelerating/decelerating to new speed while climbing/descending to new height
    c. Pacing acceleration/deceleration and climb/descent to complete both simultaneously
14) Combined use of longitudinal and lateral inputs and collective in forward flight to perform accelerative or decelerative climbing or descending turns
    a. Commencing inputs on all three controls simultaneously
    b. Turning, climbing/descending and accelerating/decelerating to new heading, height and speed
    c. Capture of defined ground track while climbing/descending and accelerating/decelerating
    d. Pacing manoeuvres to complete all three simultaneously
15) Longitudinal transition from TRC to ACSH
    a. Discuss theory of mode change
    b. Accelerate from hover to forward flight – slowly
    c. Accelerate from hover to forward flight - rapidly
16) Lateral transition from TRC to ACAH

   a. Discuss theory of mode change
   b. Demonstration of why lateral inputs during transition should be avoided where possible

17) Collective transition from VRC to γC
   a. Discuss theory of mode change
   b. Use collective control to perform height change while accelerating from hover to forward flight

18) Pedals transition from RC to βC
   a. Discuss theory of mode change
   b. Demonstration of why pedal inputs during transition should be avoided where possible

19) Longitudinal transition from ACSH to TRC
   a. Discuss theory of mode change
   b. Decelerate from forward flight to hover

20) Lateral transition from ACAH to TRC
   a. Discuss theory of mode change
   b. Demonstration of why lateral inputs during transition should be avoided where possible

21) Collective transition from γC to VRC
   a. Discuss theory of mode change
   b. Use collective control to perform height change while decelerating from forward flight to hover
   c. Use collective control to track ground object while decelerating from forward flight to hover

22) Pedals transition from βC to RC
   a. Discuss theory of mode change
   b. Demonstration of why pedal inputs during transition should be avoided where possible

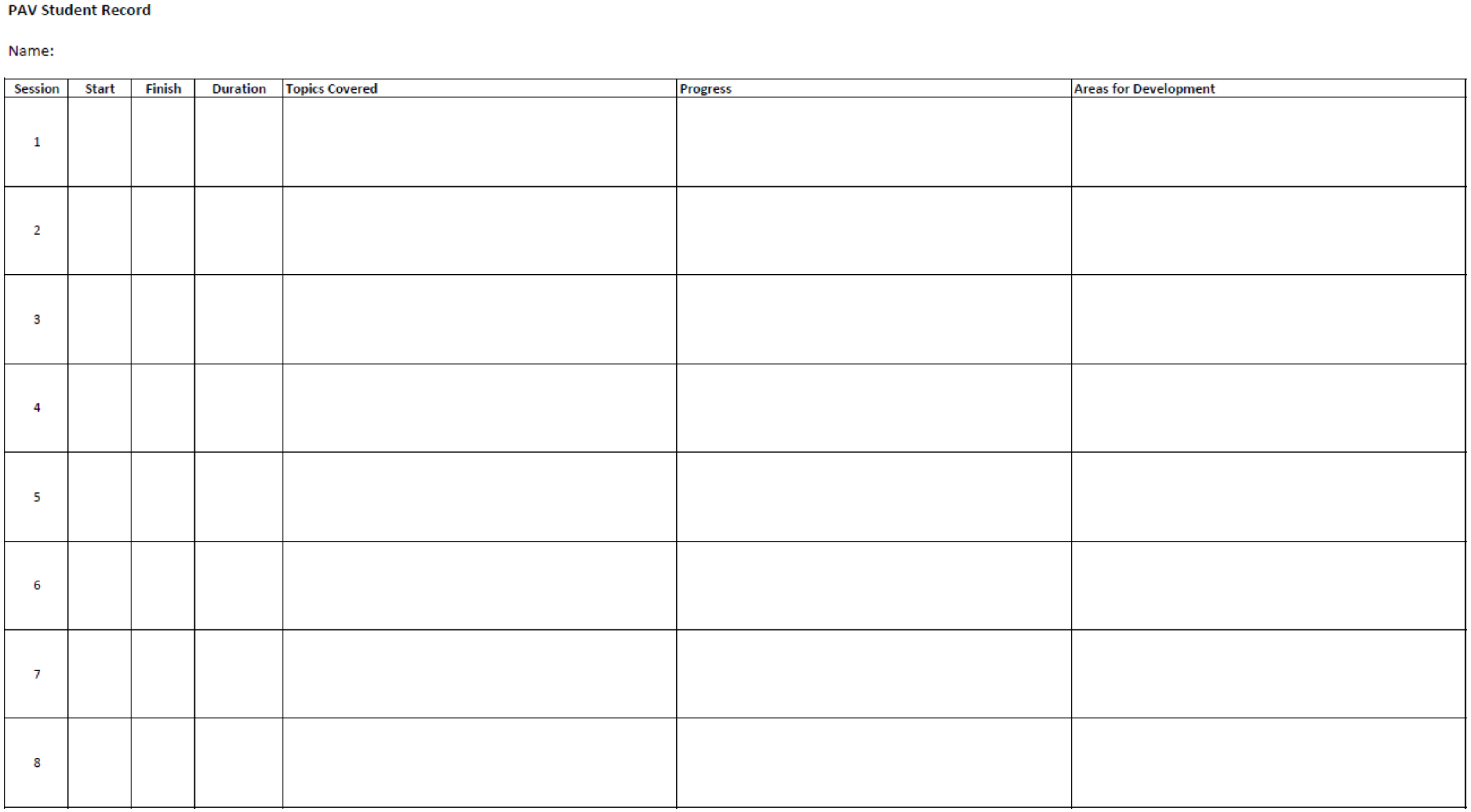
23) Use of secondary ‘automation’ functions (such as height hold, direction hold etc.)
   a. Use of height hold function – when to use, how to engage
   b. Use of direction hold function – when to use, how to engage
   c. Use of speed beep function – when to use, how to operate

24) Use of instrumentation
   a. General use of head down and head up symbology
   b. Use of HUD flight path marker

c. Use of HUD deceleration rate indicator

d. Use of HUD highway-in-the-sky display

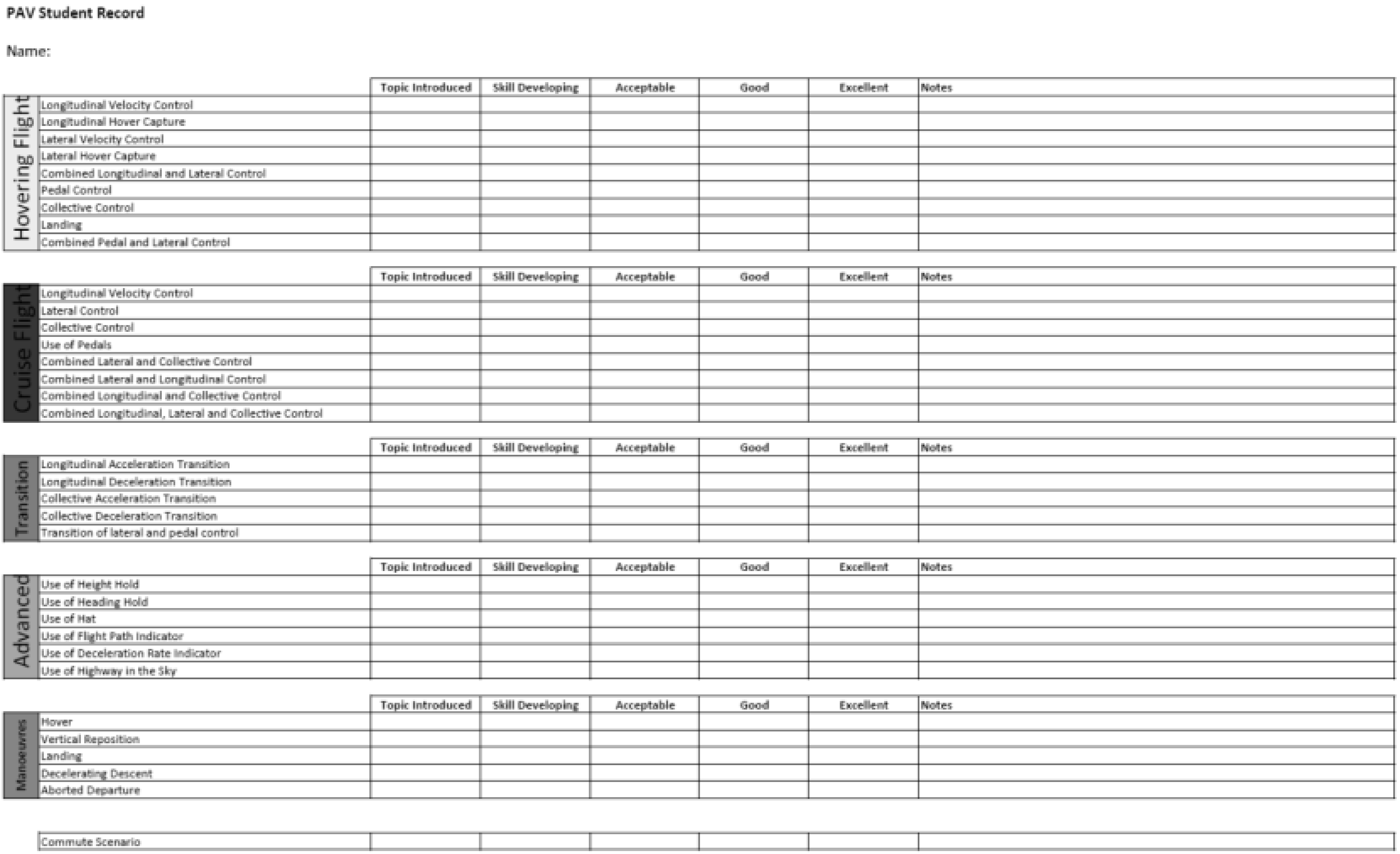
Appendix B



PAV Student Record

Name:

Session	Start	Finish	Duration	Topics Covered	Progress	Areas for Development
1						
2						
3						
4						
5						
6						
7						
8						



PAV Student Record

Name:

		Topic Introduced	Skill Developing	Acceptable	Good	Excellent	Notes
Hovering Flight	Longitudinal Velocity Control						
	Longitudinal Hover Capture						
	Lateral Velocity Control						
	Lateral Hover Capture						
	Combined Longitudinal and Lateral Control						
	Pedal Control						
	Collective Control						
	Landing						
	Combined Pedal and Lateral Control						

		Topic Introduced	Skill Developing	Acceptable	Good	Excellent	Notes
Cruise Flight	Longitudinal Velocity Control						
	Lateral Control						
	Collective Control						
	Use of Pedals						
	Combined Lateral and Collective Control						
	Combined Lateral and Longitudinal Control						
	Combined Longitudinal and Collective Control						
	Combined Longitudinal, Lateral and Collective Control						

		Topic Introduced	Skill Developing	Acceptable	Good	Excellent	Notes
Transition	Longitudinal Acceleration Transition						
	Longitudinal Deceleration Transition						
	Collective Acceleration Transition						
	Collective Deceleration Transition						
	Transition of lateral and pedal control						

		Topic Introduced	Skill Developing	Acceptable	Good	Excellent	Notes
Advanced	Use of Height Hold						
	Use of Heading Hold						
	Use of Hat						
	Use of Flight Path Indicator						
	Use of Deceleration Rate Indicator						
	Use of Highway in the Sky						

		Topic Introduced	Skill Developing	Acceptable	Good	Excellent	Notes
Manoeuvres	Hover						
	Vertical Reposition						
	Landing						
	Decelerating Descent						
	Aborted Departure						

Commute Scenario						

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