myCopter: Enabling Technologies for Personal Air Transport Systems[1]

M. Jump, G.D. Padfield, & M.D. White[‡], D. Floreano, P. Fua, J.-C. Zufferey & F. Schill[§], R. Siegwart & S. Bouabdallah[§§], M. Decker& J. Schippl*, M. Höfinger, F.M. Nieuwenhuizen & H.H. Bülthoff [†]**

Abstract

This paper describes the European Commission Framework 7 funded project myCopter (2011-2014). The project is still at an early stage so the paper starts with the current transportation issues faced by developed countries and describes a means to solve them through the use of personal aerial transportation. The concept of personal air vehicles (PAV) is briefly reviewed and how this project intends to tackle the problem from a different perspective 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 personal aerial transport system (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 provides an overview of the project structure, the roles of the partners, and hence the available research resources, and some of the early thinking on each of the key project topic areas.

Nomenclature

2D	2-dimensional
3D	3-dimensional
ATS	Air Transport System
CBD	Central Business District
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EC	European Commissions
EPFL – CVLab	Federal Institute of Technology (École Polytechnique Fédérale) Lausanne, Computer Vision Laboratory
EPFL – LIS	Federal Institute of Technology (École Polytechnique Fédérale) Lausanne, Laboratory of Intelligent Systems
ETHZ	Eidgenössische Technische Hochschule Zürich
FHS	Flying Helicopter Simulator
GA	General Aviation
GPS	Global Positioning System
HQ	Handling Qualities
HMI	Human-Machine Interface
IMU	Inertial Measurement Unit

[1]Submitted to RAeS Rotorcraft Conference: The Future Rotorcraft – Enabling Capability Through the Application of Technology, London, UK, 15 – 16th June 2011.

[‡]University of Liverpool, Liverpool, UK (**corresponding author: M. Jump**, mjump1@liv.ac.uk, + 44 (0) 151 794 6845)
[§]Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
[§§]Eidgenössisch Technische Hochschule,_Zürich, Switzerland
*Karlsruher Institut für Technologie, Institute for Technology Assessment and Systems Analysis, Karlsruher, Germany
**Deutsches Zentrum für Luft und Raumfahrt, Braunschweig, Germany
[†]Max-Planck-Institut für biologische Kybernetik, Tübingen, Germany (Project Coordinator: H. Bülthoff, heinrich.buelthoff@tuebingen.mpg.de, +49-7071-601-601)

KIT-ITAS	Karlsruher Institut für Technologie - the Institute for Technology Assessment and Systems analysis
MTE	Mission Task Elements
MPI	Max Planck Institute for Biological Cybernetics
NASA	National Aeronautics and Space Administration
PATS	Personal Air Transport System
PAV	Personal Air Vehicle
PPL	Private Pilot's License
SLAM	Simultaneous Localisation and Mapping
UAV	Unmanned Aerial Vehicles
UoL	University of Liverpool
VTOL	Vertical Take-Off and Landing

1. Background

There has been concern both within and beyond the aerospace community regarding the state of innovation to support future air transport development. In the fixed-wing arena for example, at first glance, a Boeing 707, first flown in the 1950's looks very much like an Airbus A380 of the modern era, Figure 1. In the rotary-wing world, the configuration of the modern Agusta-Westland AW-101 is not dissimilar from that of the Sikorsky Sea-King from 40 years earlier, Figure 2. Of course,

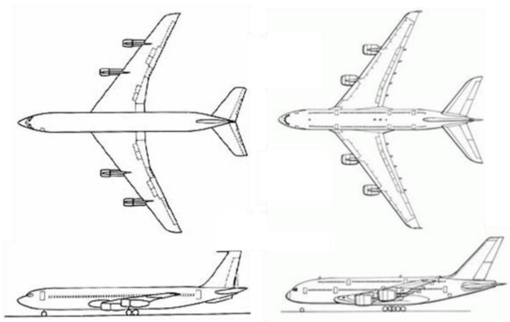

Figure 1. Boeing 707 (left) and Airbus A380 (right). (not to scale)

Figure 2. Sea King (top) and AW-101 (bottom, not to scale)

there are good reasons for this evolutionary development; it carries much less risk than revolutionary development, and looks can be deceiving - significant innovations have gone into these vehicles at the individual component level, conferring greater efficiency, performance and safety upon them. To try to counteract this perceived trend, 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 100 ideas 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]. The paper is constructed as follows. Section 2 introduces 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. Section 3 provides more detail on how the project is structured, the project partners and the facilities that each of these provide access to. Section 4 details some of the early outcomes of the project. Section 5 concludes the paper.

2. Introduction

2.1 Problem Description

The volume of road transportation continues to increase despite the many concerns regarding the financial and environmental impact that this implies [3, 4]. Whilst the average number of trips per individual has declined since 1980, the

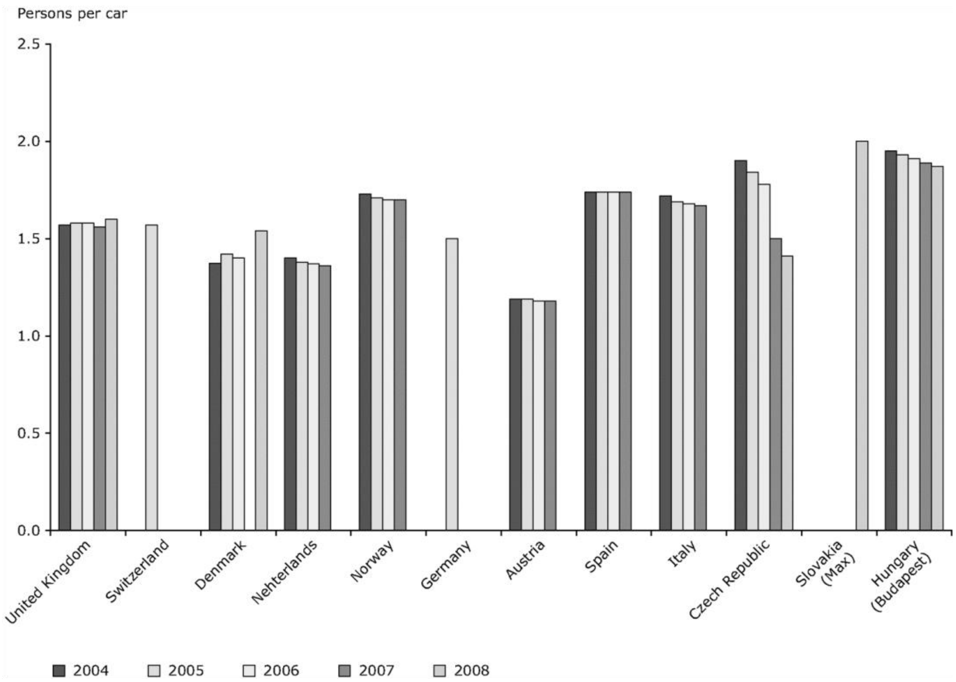

Figure 3. European car occupancy rates (courtesy Ref. [5])

average distance travelled has remained approximately the same and yet the average time spent travelling has increased [3]. The average number of occupants in a vehicle in the UK has remained approximately constant at 1.6 from 1997 to 2008 [3]. 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 [5]. 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 [6]. Figure 3 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 [3]. European data from 1997 suggests occupancy rates of 1.1 – 1.2 for commuting to/from the workplace [7] whilst more recent data from Germany suggests little change with occupancy rates of 1.2 for commuting and 1.1 for business trips [8].

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 attempt 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 [6]. 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 [9].

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 stationary on the road network [10].

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 several 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. [11]). This is compared with nearly 37 million full driving licenses in Great Britain alone (data from Ref. [12]). 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) [13] whilst 37,634 PPLs were active in 2008 (0.04% of the population) [14]. 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.

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. In any event, to avoid failure of the idea, the PATS should be designed with consideration given to the general population's needs and wants.

2.2 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 [15] is an early example of this kind of vehicle, with the 'Carplane' road/air vehicle [16] and Terrafugia's 'Transition' [17] 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, without 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 nugatory structure and equipment that are required for the individual 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, a useful start point can be found at Ref. [18].

To avoid having to use traditional runways and to provide a capability that would potentially allow flight from the user's home, one option for a PAV is to use a rotary wing aircraft; ideally, without having to resort to the significant complexity and skill levels required to pilot a traditional helicopter configuration. The PAL-V [19] and Carter PAV [20] concepts both make use of auto-rotating rotors. The PAL-V concept combines an autogyro with a road-going capability. 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. [21] 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' [22] and Urban Aeronautics 'X-Hawk' [23] 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 [23]. An un-ducted fan arrangement can be seen in NASA's Puffin concept [24], 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.

2.3 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 range of definitions of autonomy, from a vehicle simply following a pre-programmed function to sentient machines interpreting their internal states as well as their environment to enable them to make decisions about future plans to achieve pre-programmed or even learned goals [25]. 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 [25]. In this model, the level of authority shared between the operator and machine can be varied and this will be discussed in more detail later in the paper. Secondly, the technology required to deliver the desired level of autonomy will be investigated. 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. Finally, 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.

3. myCopter Project Overview

3.1 Aims and Objectives

The aim of the project is to ascertain the types of technologies and system(s) that would need to be in place to allow a PATS to be implemented. To support this aim, the project has the following objectives:

1. develop a concept of operations for a PATS;
2. investigate and test technologies that support the envisaged concept of operations;
3. demonstrate a selection of the key required technologies and,
4. examine the potential wider social and technological impact if a PATS were to become reality.

These objectives map onto the project's 3 key research themes:

1. PAV modelling, 'pilot' training and human-machine-interaction (HMI) requirements;
2. Automation of the PAV and,
3. Social and economic impact of a PATS.

These research themes are discussed in more detail in the remainder of the paper.

3.2 Project Partners

In order to deliver the project, a Europe-wide consortium of 6 partners has been formed.

1. The project is led by The Max Planck Institute (MPI) for Biological Cybernetics in Tübingen, Germany. MPI specialise in studying the psychophysical and computational aspects of visual and haptic recognition, sensorimotor integration and spatial cognition. MPI is responsible for the overall project management. Its research activities will primarily focus on understanding the perceptual underpinnings of the design of an effective HMI using their knowledge in the area of human perception and human-machine interaction.
2. The Flight Simulation Group based in the School of Engineering at The University of Liverpool (UoL) will provide specialist knowledge in the aeronautical disciplines of flight dynamics, control, simulation and handling qualities design and assessment. UoL is responsible for modelling the vehicles that will be used in this project (PAV concepts, micro unmanned aerial vehicles (UAV) and medium scale unmanned aerial vehicles). UoL will work towards understanding how to make flying as accessible as driving and developing an efficient paradigm to train people with a range of skills and abilities to make this happen.
3. The Laboratory of Intelligent Systems at the Swiss Federal Institute of Technology (École Polytechnique Fédérale), Lausanne (EPFL-LIS) uses principles of biological self-organisation for the design of technological artefacts with autonomous and adaptive intelligence. It is engaged in the fields of flying robotics, collective intelligence, and adaptive systems. The EPFL Computer-Vision Laboratory (CVLab) focuses on shape and motion recovery from video sequences. This includes human body modelling, fast object detection, and real-time reconstruction of deformable 3D surfaces. The results from an example algorithm is illustrated in Figure 4 and further detail on typical algorithms to be used in the project can be found in Refs [26, 27]. EPFL-LIS will develop control strategies for mid-air collision avoidance and formation flying. They

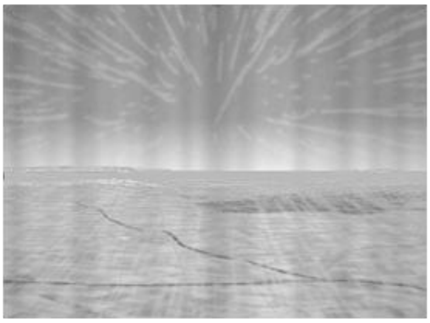

Figure 4. Automated image-based airfield localization developed by CVLab for the EU

will also contribute to unmanned platform development. EPFL-CVLab will develop image-based algorithms for automated landing and take-off, including field selection, obstacle avoidance, and guidance during final approach. A subset of such algorithms will be integrated into a full-scale helicopter test-bed for validation purposes.

4. The Swiss Federal Institute of Technology (Eidgenössische Technische Hochschule Zürich), Zürich (ETHZ) autonomous systems laboratory designs vehicles such as wheeled locomotion systems, autonomous micro-aircraft and autonomous cars with 3D navigation and mapping capabilities in rough terrain. Their major research areas are cognitive mapping, feature-based simultaneous localisation and mapping (SLAM) using multiple modalities and path planning in highly dynamic environments. ETHZ will also define and develop control strategies for automating the flight of a single PAV including automatic take-off, navigation and landing.

5. The Institute for Technology Assessment and Systems Analysis at the Karlsruher Institut für Technologie (KIT-ITAS) creates, evaluates and communicates knowledge on the impact of human action with respect to the development and use of new technologies. Its work focuses on environmental, economic, social, political and institutional issues. For this purpose, the institute applies and develops methods of technology assessment, systems analysis and technology foresight. KIT will contribute to explore the socio-technological context, the infrastructural environment, the potential impact on society and social expectations of a PATS.
6. Deutsches Zentrum für Luft- und Raumfahrt (DLR) DLR is Germany's national research centre for aeronautics and space. It will contribute knowledge on various aspects of vertical lift aircraft and UAVs. Specialist research topics include modelling, simulation, flight testing of new approaches to improve handling qualities and pilot’s situational awareness, as well as functionalities to increase vehicle autonomy and automation. DLR operates the variable stability experimental helicopter, the EC-135 “Flying Helicopter Simulator” (FHS). DLR will provide the FHS as a simulation platform for evaluation of experimental PAV dynamics and technologies developed in the project in a manned flying vehicle. Furthermore, DLR will support the development of dynamic models and experimental displays for evaluation at UoL and MPI.

3.3 Key Facilities

The project consortium has been devised such that each of the partners provides a facility or capability that will enable the project aims and objectives to be achieved. The following Section briefly outlines some of the key facilities that will be used during the project.

UoL will be developing flight dynamics models of typical PAV configurations to share with the project partners. These will be developed initially using FLIGHTLAB software [28].

Figure 5. UoL Simulation Facilities

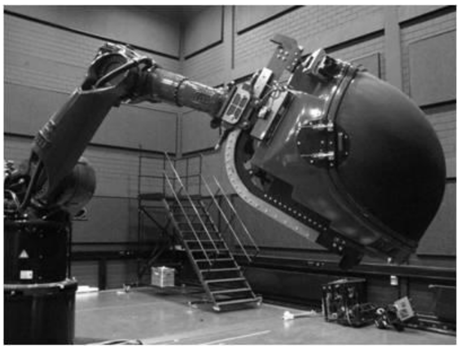

Figure 6. MPI's Cybermotion Simulator

This allows integration for real-time piloted simulations with UoL's HELIFLIGHT [29] and HELIFLIGHT-R simulators, Figure 5. It is planned that MPI will make use of these models to test HMI concepts in their Cybermotion Simulator [30], which is based on an anthropomorphic robot arm. It has can provide motion in 6 degrees of freedom with its 7 actuated joints, features an stereoscopic projection system, and uses active control loading devices to provide participants with haptic cues and adjustable control device dynamics and is shown in Figure 6.

EPFL-LIS and ETHZ have state of the art robotics, electronics and computing facilities that will allow development of algorithms and vehicles on which to test them. EPFL-LIS have developed a fleet of ten autonomous fixed-wing UAVs that can operate as a flock, Figure 7; both ETHZ and EPFL-LIS also have a range of VTOL UAVs for indoor and outdoor use. Existing vehicles will be utilised where possible and appropriate. For the 'Experimental and Simulation Research' phase of the project, ETHZ will develop a VTOL system in collaboration with EPFL to specifically explore selected automation issues surrounding the vertical phases of flight.

Whilst computer and piloted simulation and small-scale aerial vehicle testing are an important part of the project work, one of the exciting aspects of the planned work is that the most promising concepts from the various research themes will be flight tested using DLR's Flying Helicopter Simulator (FHS) [31], shown in Figure 8.

Figure 7. EPFL-LIS autonomous UAVs

Figure 8. DLR's Flying Helicopter Simulator

The FHS has several unique features which make it ideal for the myCopter project. First, its highly flexible experimental system set-up and the corresponding safety concept will allow the integration, testing and evaluation of new algorithms, HMI designs and control laws in flight. Second, DLR has experience with testing any new sensor technology requirements which will feed in to the proposed PAV automation architecture defined primarily by EPFL and ETHZ. Finally, they have the safety protocols, the trained pilots, and the flight operations organisation necessary to conduct such operations.

The technological aspects of the project are clearly important. However, the paper has already stressed the equally important socio-economic aspects of a PATS. At KIT, the existing know-how and data for the modelling of PAV integration into the transport system will be used to provide quantitative support for different PATS scenarios (see Refs [32, 33] for examples).

3.4 Schedule

The myCopter project commenced on 1st January 2011 and is planned to be of 4-years duration. The outline schedule is shown in Figure 9.

The **Sharing Information Phase** will start with a requirements capture exercise to establish what it is that a PATS and a PAV will be expected to do. This will inform the process

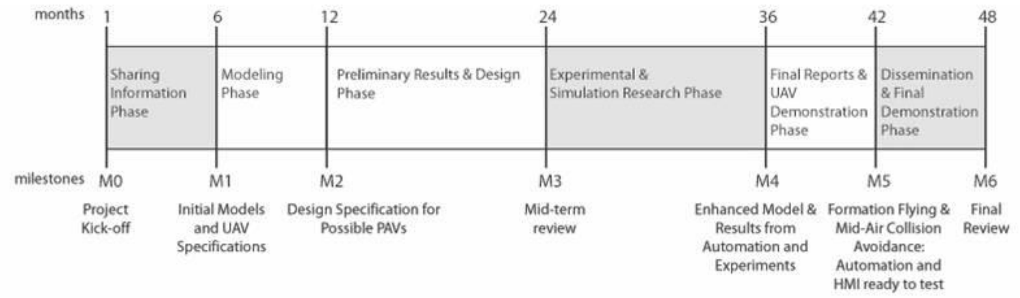

Figure 9. myCopter outline schedule

that will eventually define possible HMIs, the equipment needed for any autonomous control and the training parameters that will need to be used later in the project. An initial list of interest groups and industry partners will be gathered for the purpose of socio-economic assessment. At Milestone M1, the results will reviewed and the components to be included in the modelling phase will be determined.

During the **Modelling Phase,** information will be shared between the project partners to allow PAV system dynamics to be modelled in simulation. Navigation algorithms will be prepared to begin the envisaged advanced automation research. In parallel, there will be an initial overview of the socio-technological key issues.

The **Preliminary Results Phase** relates to the consideration of the level of occupant interaction with the flight management system. The design of psychophysical tests to establish the types of control and visual displays to be used in a PAV will be started. At Milestone M3, the selected aspects of the project to be used to collect more detailed results in the following two phases will be determined. This milestone also includes the reporting of preliminary results. First, for the HMI and training studies, some initial design considerations will be reported. For the automation theme, preliminary tests of mid-air collision avoidance in simulation and automatic flight based on Global Positioning System (GPS) and Inertial Measurement Unit (IMU) technology will be performed. Finally, initial documentation and reports from interviews towards evaluating the socio-economic issues will be created.

The **Experimental and Simulation Research Phase** will cover the experimental tests for both the HMI and training scenarios, resulting in a preliminary description of the training paradigm, control dynamics and a potential human-machine interface for PAVs. Also, all automation algorithms will be tested in simulation and prepared for the installation and tests on a model UAV in the next phase. A preliminary assessment of which of the autonomous algorithms and parts of the HMI will be able to be integrated into the planned simulated and actual flight tests will be made.

The **Final reports and UAV Test Phase** covers the reporting of all of the innovations made in the project. Novel HMI components for use in PAVs based on psychophysical experiments will be reported. Design criteria for acceptable PAV components and an overall PATS will be produced. Plans for integrating the successful autonomous algorithms and parts of the human-machine interface into the modelled PAV concept(s) for final evaluation will be made.

The **Dissemination and Final Test Phase** is primarily concerned with the evaluation and validation of the final myCopter results in the form of reports and tests in the project simulators and test aircraft. Potential technology route maps to bring PAVs to the market place, perception-based guidelines for HMI variants, and guidelines for vehicle handling qualities and pilot/driver training will be produced. In addition to the main testing of potential PAV handling qualities on the helicopter flight test aircraft, there will be tests of the automation algorithms including formation flying (up to 4 unmanned vehicles) and simulations of various scenarios involving up to 40 PAVs per cubic kilometre (an average value posited by Ref. [1]).

4. Initial Progress

Although the project is still in its initial phase, this Section outlines the progress made in each of the research themes. Of course, these themes are not independent and will be running concurrently and so the results in one topic will inevitably impact on the others. For example, the social expectation might be for full automation of a PAV in the belief that this ensures a specified level of safety. This 'requirement' implies demands not only for the robustness of the technologies to be used to provide this level of automation but also on the information that a display system might provide to a PAV occupant and on the level of skill that this individual might then need for normal and abnormal operation of the vehicle. As such, whilst the following sub-Sections are based around the individual research themes, the interactive and iterative nature that will be needed to satisfy the PATS/PAV requirements should not be forgotten or underestimated.

4.1 Modelling, Training and User-Centred HMI

The approach being taken in the modelling of PAVS is to start in the abstract and refine to the specific as required. This will also mean starting with 'simple' conceptual models and developing them into more complex and sophisticated (i.e. more realistic) models as the project demands. UoL expertise resides in flight dynamics and control and handling qualities (HQ) assessment and it is this background that will inform the modelling and training aspects of this research theme. As such, UoL is developing a basic vehicle flight model with variable dynamic characteristics. This model will be used to establish the envelope of parameters that define the vehicle handling characteristics that a PAV pilot can successfully cope with. Boundaries for a range of typical skill levels will be established for the parameters i.e. it is expected that a skilled pilot would be able to cope with more complex dynamics than a less skilled pilot. The dynamics model has been developed to offer a range of possible response types – rate response, attitude response and translational rate response, as reported in Ref. [34]. The rotational dynamics are modelled using first order transfer functions for the rate response and second order transfer functions for the attitude response. The translational rate response type is created by closing a feedback loop around the attitude response transfer function. The Euler angles and rates thus calculated are fed into the model's translational dynamics, where they are combined with aerodynamic damping and gravitational effects to determine the vehicle's translational accelerations.

The normal process in handling qualities engineering is for the 'predicted' handling parameters such as attitude bandwidth and quickness to be evaluated based on the vehicle response, or, in the case of a simple simulation model, the model's parameters [35]. For the myCopter handling investigations, it is of benefit to be able to 'reverse-engineer' this process; that is, to determine the model parameters based on the desired vehicle handling qualities. An example result of this process is shown in Figure 10, where the desired roll bandwidth has been varied between 4.0 rad/s and 2.0 rad/s for the model in attitude response mode. The second order transfer function allows this to be accomplished while maintaining the same overall sensitivity to control inputs.

The concept of operations or 'mission analysis', will be de-constructed into mission phases and then mission task elements (MTEs) as defined in Ref. [36]. For each of the MTEs, a number of aspects that relate to the PAV will have to be considered. Firstly, the piloting task and functions will need to be understood. It is considered unlikely that the envisaged 'pilot/driver' of a PAV will be able to cope with a 'bare airframe' rotorcraft of any description. However, a highly stabilised or augmented vehicle may allow the pilot to 'drive' the vehicle 'easily' in 3D, if this is deemed necessary; in handling qualities parlance, this might be described as achieving 'Super Level-1' HQ. Secondly, the vehicle dynamics and associated operational and safe envelopes will have to be considered. Whether the PAV is to be flown manually or automatically, the vehicle's dynamic characteristics will have to be such that the control system can keep the vehicle safely within its flight envelope, whilst not limiting performance. Of particular interest

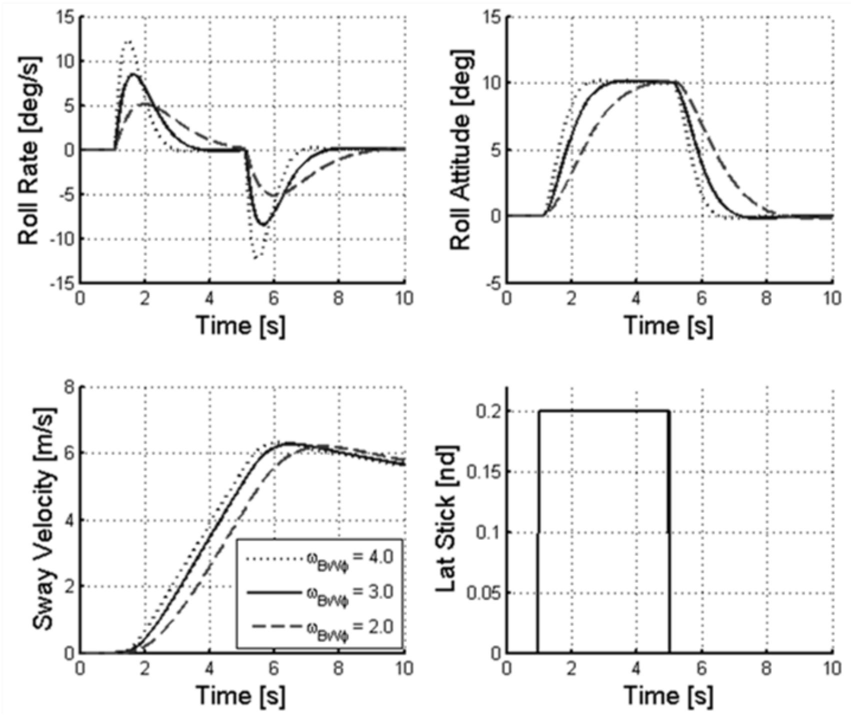

Figure 10. Sample results of initial variable handling qualities simulation model

here will be how the pilot-vehicle system interaction changes in response to, for example, system failures. Finally, and related to this last point, the pilot and the required flight management information will need to be considered carefully. What, when and how to display information will be considered. Within the project, various sources of information transfer will be investigated. Not only will conventional visual displays with aircraft state information be considered, but also haptic feedback and perspective displays will be used such that the HMI is as intuitive as possible. This will allow a pilot to interact with the PAV such that car drivers with a typical range of abilities can safely guide and navigate it.

All of the considerations mentioned above will help to define the type of training required to reach a given level of proficiency in a particular MTE. Once this has been established, a means to reach the integrated piloting competency will be formulated and tested.

4.2 PAV Automation

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

However, not all journeys are taken for solely pragmatic reasons. Car and motorcycle owners may simply go for a drive/ride. PPL-holders will sometimes 'simply go flying' for the sheer pleasure of the experience, not actually going anywhere particular in the process. Users of PAVs may actually want to 'fly' the vehicle (or, at least, be given the illusion of flying the vehicle). Whilst these may not be the primary design drivers for a PATS and/or PAV, it might be argued that a 'manual flight' option could be much quicker, in some instances, than using a navigation-level interface and may, therefore, be more suited to spontaneous journeys where the destination is not precisely known in advance. One possible solution would be a fully automated system with a selected level of transparency, allowing the user to steer the vehicle interactively whilst maintaining stability and hence safety in the background.

One further related question that arises is, in the event of an emergency, if the human occupant is not engaged in at least the monitoring and management of the journey, will they be able to engage with the vehicle/situation sufficiently quickly to make a difference to the outcome? In conventional aviation it is recognised that the piloting skill required to deal with flight failure related emergencies is at a higher level than for normal operations. This suggests that a PAV operational concept that relies on the occupant taking control in emergencies is perhaps unrealistic.

The brief discussion above points to a possible requirement for variable levels of automation/autonomy to be available in a PAV. There will almost certainly be an underlying stabilisation system operating but the higher level guidance, navigation, decision-making and planning flight management functions may be made by either the human or the PATS systems (which may or may not be on board the PAV). One means to quantify the level of delegation of authority that the human will give to the PATS is via the Pilot Authority and Control of Tasks taxonomy [37]. This taxonomy supposes that the pilot makes a PACT contract with the autonomy by allocating tasks to PACT modes and levels of automation aiding [38]. The original PACT taxonomy has since been modified to add more granularity between the top two levels of delegation of authority. The refined PACT levels, taken from Ref. [38] are shown in Table 1. One area of study therefore will be to ascertain what is the minimum level of autonomy/automation that can safely be tolerated for a given mission phase or even MTE. For example, it may be that the take-off, climb and transition to cruise is always PACT level 5b (computer does everything autonomously) whilst the cruise itself may be PACT level 3 (computer suggests options and proposes one of them e.g. a heading change). If during the cruise, an emergency collision avoidance manoeuvre is required, the PACT level 5a (computer chooses action, performs it and informs human) might then need to be invoked until the emergency is over. The discussion above is important because it will impact across the whole of the project, for example:

- informing the training requirements for a given mission phase/autonomy level;
- defining the information that an HMI might be required to convey and the level of human-machine interaction required
- defining the design requirements for the on-board automation and
- establishing the acceptability of a given level of automation in a PAV/PATS that society as a whole are comfortable with.

4.3 Social and Economic Impact

The success or failure of any innovation to a transport system 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.

PACT Locus of Authority	Computer Autonomy	PACT Level	Level of HMI
Computer Monitored by pilot	Full	5b	Computer does everything autonomously
		5a	Computer chooses action, performs it & informs human
Computer backed up by pilot	Action unless Revoked	4b	Computer chooses action & performs it unless human disapproves
		4a	Computer chooses action & performs it if human approves
Pilot backed up by computer	Advice, and if authorised, action	3	Computer suggests options and proposes one of them
Pilot assisted by computer	Advice	2	Computer suggests options to human
Pilot assisted by computer only when requested	Advice only if requested	1	Human asks computer to suggest options and human selects
Pilot	None	0	Whole task done by human except for actual operation

Table 1. Modified PACT Taxonomy

users, 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 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 the demand and preferences of society at large in relation to PAVs. 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 (see Table 1).

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 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: 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 have designed some initial travel scenarios that focus on potential peer groups. Out of the scenario's key requirements for the "myCopter"-PAV have been identified during an internal workshop with the project partners. This "myCopter"- PAV will be used as reference point during the project as a common benchmark, but does not prohibit other design ideas in the project. The consortium agreed on a reference PAV which would have the ability to fly under Instrument Flight Rules, with varying levels of automation, including full automation for automated take-off and landings, as well as automated collision avoidance. The vehicle will have a 1+1 seat configuration with a VTOL capability.

5. Concluding Remarks

This paper has described the myCopter project which is supported by funding from the EC FP-7 programme and is currently in its formative phase. An apparent reduction in innovation in Air Transport 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 is 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.

The project consortium has been described and the role and expertise of each partner outlined. Initial progress has been described. The PATS concept of operations will inform a handling qualities approach to assessing acceptable vehicle dynamics for a PAV. Variable levels of automation will be assessed and used to inform the training needs of a PAV occupant such that the use of PAVs can complement the use of 2D modes of travel used today and envisaged for the future. The formative requirements for a reference PAV that will reside within a PATS to be used for discussion purposes have been reported.

Acknowledgements

The work reported in this paper is funded by the EC FP-7 research funding mechanism.

References

1. Anon., *Out of the Box. Ideas About the Future of Air Transport. Part 2.* November 2007, European Commission: Brussels.
2. Anon. *myCopter: Enabling technologies for Personal Aerial Transportation Systems*. 2011 [cited 2011 17th May]; Available from: http://www.mycopter.eu/.
3. Anon., *Transport Trends: 2009 Edition*. 2009, Department for Transport: London.
4. Anon., *Energy, Transport and Environment Indicators. Eurostat pocketbook.*, EUROSTAT, Editor. 2009, Publications Office of the European Union: Luxembourg.
5. Anon. *Occupancy rates of passenger vehicles (TERM 029) - Assessment published Jul 2010*. 2011 . Available from: http://www.eea.europa.eu/data-and-maps/indicators/occupancy-rates-of-passenger-vehicles/occupancy-rates-of-passenger-vehicles-1.
6. Anon., *Sustainable Urban Transport Plans Preparatory Document in relation to the follow-up of the Thematic Strategy on the Urban Environment.* 25 September 2007: Commission of the European Countries, Brussels.
7. Anon. *Indicators of Energy Use and Efficiency - Understanding the link between energy and human activity*. 1997. Available from: http://www.iea.org/textbase/nppdf/free/1990/indicators1997.pdf.
8. Anon. *Mobilität in Deutschland 2008 Ergebnisbericht Struktur – Aufkommen – Emissionen – Trends, Bundesministerium für Verkehr, Bau und Stadtentwicklung*. 2010. Available from: http://www.mobilitaet-in-deutschland.de/pdf/MiD2008_Abschlussbericht_I.pdf
9. Anon., *Green Paper –Towards a new culture of urban mobility. COM (2007) 551 final*. 25th September 2007: Commission of the European Countries, Brussels.
10. Anon. *Roadmap to a Single European Transport Area* 2011. Available from: http://ec.europa.eu/transport/strategies/facts-and-figures/putting-sustainability-at-the-heart-of-transport/index_en.htm.
11. Anon. *Civil Aviation Authority - Statistics - Licence By Age and Sex - between 2000 / 2008*. [cited 2011 17th May]; Available from: http://www.caa.co.uk/default.aspx?catid=175&pagetype=90&pageid=11765.
12. Anon. *Driver and Vehicle Licensing Agency - Driver License Statistics*. [cited 2011 17th May]; Available from: http://www.dft.gov.uk/dvla/foi/Disclosure/Driver%20Licence%20Statistics.aspx?keywords=statistics.
13. Anon. *DESTATIS wissen.nutzen. Bevölkerung nach dem Gebietsstand.* 2010. Available from: http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Zeitreihen/LangeReihen/Bevoelkerung/Content75/lrbev03a,templateId=renderPrint.psml.
14. Strecker, R., *Aktuelle Pilotenzahlen - Plus bei höhren Qualifikationen*, in *Aerokurier, Vol.3*. 2008, Motor Presse: Stuttgart. p. 32 - 33.
15. Anon. *Aerocar 2000*. 2002 [cited 2011 18th May]; Available from: http://www.aerocar.com/.
16. Anon. *Carplane Road/Air Vehicle*. [cited 2011 18th May]; Available from: http://www.carplane.com/.
17. Anon. *Terrafugia*. 2010 [cited 2010 7th December]; Available from: http://www.terrafugia.com/.
18. Anon. *Personal Travel Factsheet: Commuting and Business Travel*. April 2011. Department for Transport, London. Available from: http://www.dft.gov.uk/pgr/statistics/datatablespublications/nts/factsheets/commuting.pdf.
19. Anon. *PAL-V. Personal Air and Land Vehicle*. 2010 [cited 2010 7th December]; Available from: http://www.pal-v.com/.
20. Carter, J., *CarterCopter -- A High Technology Gyroplane* in *American Helicopter Society Vertical Lift Aircraft Design Conference*. 2000, AHS: San Francisco, CA.
21. Robinson, S. and M. Jump, *Progress in the Development of Handling Qualities Critical Design Guidelines for an Autogyro*, in *American*

Helicopter Society 67th Annual Forum. 2011, AHS: Virginia Beach, VA.
22. Anon. *Moller International*. 2009 [cited 2011 18th May]; Available from: http://www.moller.com/.
23. Anon. *Urban Aeronautics X-Hawk Aerial Vehicle*. 2005 [cited 2011 18th May]; Available from: http://www.urbanaero.com/Frame-X-Hawk.htm.
24. Anon. *The Puffin: A Passion for Personal Flight*. 2010 [cited 2011 18th May]; Available from: http://www.nasa.gov/topics/technology/features/puffin.html.
25. Mills, N. *Bridging the Auronomous Divide*. in *Bridging the Auronomous Divide*. 31st May 2011. London: Aerospace and Defence Knowledge Transfer Network.
26. Lepetit, V. and P. Fua, *Keypoint Recognition using Randomized Trees.* Transactions on Pattern Analysis and Machine Intelligence, 2006. **28**(9): p. 1465 - 1479.
27. Ozuysal, M., et al., *Fast Keypoint Recognition using Random Ferns.* IEEE Transactions on Pattern Analysis and Machine Intelligence, 2010. **32**(3): p. 448 - 461.
28. Anon, *FLIGHTLAB Theory Manual (Vol. One)*. March 2004, Advanced Rotorcraft Technology: Mountain View, California.
29. Padfield, G.D. and M.D. White, *Flight simulation in academia; HELIFLIGHT in its first year of operation.* The Aeronautical Journal of the Royal Aeronautical Society, September 2003. **107**(1075): p. 529-538.
30. Teufel, H.J., et al., *MPI Motion Simulator: Development and Analysis of a Novel Motion Simulator*, in *AIAA Modeling and Simulation Technologies Conference and Exhibit*. 2007, AIAA: Reston, VA, USA. p. 1-11.
31. Kaletka, J. and U. Butter. *FHS, the New Research Helicopter: Ready for Service*. in *Proceedings of the European Rotorcraft Forum*. September 2003. Friedrichshafen, Germany.
32. Schippl, J., et al., *The Future of European long-distance transport. Scenario report.* October 2008, European Parliament: European Technology Assessment Group, Brussels.
33. Zumkeller, D., et al., *Erhebungswellen zur Alltagsmobilität (Herbst 2009) sowie zu Fahrleistungen und Treibstoffverbräuchen (Frühjahr 2010)*. 2010, Institut für Verkehrswesen, Karlsruhe Institute of Technology: Karlsruhe.
34. Schönenberg, T., *Design of a Conceptual Rotorcraft Model Preparing Investigations of Sidestick Handling Qualities*, in *67th Annual Forum of the American Helicopter Society*. 2011, American Helicopter Society: Virginia Beach, VA, USA.
35. Anon., *Aeronautical Design Standard Performance Specification. Handling Qualities Requirements for Military Rotorcraft*. 21 March 2000, United States Army Aviation and Missile Command, Aviation Engineering Directorate.
36. Padfield, G.D., *Helicopter Flight Dynamics: The Theory and Application of Flying Qualities and Simulation Modelling*. 2 ed. 2007, Oxford: Blackwell Publishing Ltd.
37. Taylor, R.M., et al., *Cognitive Cockpit Systems: Information Requirements Analysis for Pilot Control of Automation*, in *Engineering Psychology and Cognitive Ergonomics*. 2001. p. 81-88.
38. Hill, A.F., F. Cayzer, and P.R. Wilkinson, *Effective Operator Engagement with Variable Autonomy*, in *2nd SEAS DTC Technical Conference*. 2007: Edinburgh.