

NOVEL STEERING CONCEPTS FOR PERSONAL AERIAL VEHICLES

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Abstract

Against the background of constantly growing ground-based traffic and consequently increasing congestion problems, solutions have to be found for meeting the future demand of personal transportation. The European project myCopter is addressing this issue by investigating technologies for future Personal Aerial Vehicles (PAV). These rotorcraft are meant to be available to the general public with a minimal necessary amount of training.

This paper is looking for answers to the question of the most suitable control concept for future PAVs. Car-like steering concepts would be a candidate for flight-naïve PAV users. Several concepts have already been designed for rotorcraft but have not further been investigated. DLR is now facing this challenge. In the paper an overview of the historical development of control devices in automobiles and helicopter is given. From this development and research results from related projects a novel control concept for PAVs is proposed. The intention is to offer a control concept that is intuitively understood by PAV users who are already used to steering automobiles. The concept as well as the underlying PAV flight dynamics are explained and a short outlook is given on the planned future research at DLR.

NOMENCLATURE

AC	Attitude Command
AcC	Acceleration Command
ACT	Active Control Technology
FHS	Flying Helicopter Simulator
PATS	Personal Aerial Transportation System
PAV	Personal Aerial Vehicle
RC	Rate Command
RPM	Revolutions Per Minute
TC	Turn Coordination
TRC	Translational Rate Command
β C	Sideslip Angle Command
γ C	Flight Path Angle Command

1. INTRODUCTION

The global volume of traffic is constantly growing which goes along with increasing congestion problems. It can be expected that the currently implemented ground-based transportation system will someday reach its limits. One solution to extend this limit is the extension of the currently ground-based personal transportation into the third dimension. The European project myCopter [1] is investigating the implementation of such a Personal Aerial Transportation System (PATS). The idea was original brought up by the 'Out of the Box' study funded by the European Commission [2]. This study was conducted in order to fructify the development of revolutionary transport concepts to overcome the otherwise rather evolutionary trends in air transport development.

The myCopter project aims at enabling technologies that are required to provide Personal Aerial Vehicles (PAVs) to the general public. FIGURE 1 shows the artist's impression of such a PAV. It is a light one- to two-seated rotorcraft. Nevertheless, the myCopter project is not concerned with actually designing such an aircraft. On the

contrary, the opposite approach has been selected. The project goal is to develop essential technologies that will be needed for a PATS to become functional. Six partner institutions from Germany, Switzerland and the United Kingdom are conducting research in the areas of human-machine interaction and handling qualities, autonomous flight technologies as well as socio-economic aspects.



FIGURE 1. Artist's impression of the myCopter Skyrider PAV Concept (©Flight Stability and Control).

In order to ensure the usability of PAVs for the general public, handling of such a vehicle must become feasible also for non-professional users. PAVs must have vertical take-off and landing capabilities like helicopters in order to be manoeuvrable even in densely populated city centres. At the same time they must be as easily manoeuvrable as cars in order to be flyable by the general public. It is desirable to minimize the training needed to safely navigate a PAV through the airspace. Additional to an advanced flight control system and the implementation of

extended automation functionalities, the human-machine interface should be tailored towards the needs of a future PAV pilot. Flight-naïve users should be able to understand intuitively the control concept of their PAV.

The control concept of automobiles is well known to the general public. These controls have barely changed over the past century. Although new controllers like joysticks are technically feasible, all of the modern production vehicles rely on the conventional arrangement of steering wheel, accelerator and brake pedals, gear stick, and optionally clutch pedal for manual transmission. A driver's license holder can intuitively connect the usage of these controls to the movement of any typical car. On the other hand, conventional helicopter controls are not at all intuitive for non-expert pilots. The question is now how this intuitively understood concept can be transferred to a helicopter-like PAV. Some inventors have already proposed car-like steering concepts for rotorcraft but these concepts have not been further investigated. DLR is now facing this challenge.

This paper first gives an overview of the development of control devices in rotorcraft and automobiles and then describes already existing steering concepts for PAVs. Furthermore, the development of a novel car-like control concept together with connection to the underlying flight dynamics is explained. Finally, an outlook is given on how this steering concept will be further refined and tested.

2. HISTORICAL DEVELOPMENT OF CONTROL CONCEPTS

After the early years of development today's conventional control concepts have been well established for both helicopters and automobiles separately.

2.1. Helicopter Controls

Soon after the first motorized flights of the Wright brothers in 1903, helicopter prototypes also began to successfully take off. In those early days of rotary wing technology, leaving the ground was the major concern of the aviation pioneers. This can be derived from the fact that the first two machines to take off vertically had almost no means to influence the direction of their movement. The "Breguet-Richet No. 1" had to be stabilized by several men once it lost ground contact. The pilot could only control the rotational speed of the rotors by changing the RPM of the engine [3]. Paul Cornu's helicopter prototype of 1907 was at least equipped with one control surface in the downwash of each of the two rotors, which were supposed to make longitudinal movement possible. They were controlled by the pilot with the help of two handles but proved to be not effective for control [3].

Raul Pescara was more successful in 1925 when he had found a way to manipulate the cyclic pitch of the blades on his coaxial rotors. He used a control stick for this task that was mounted in front of the pilot. It was similar to the one found in airplanes with an additional small hand wheel on top of it. That wheel's purpose was to control the yawing movement by differential adjustment of the collective pitch angles of the two rotors [3].

Another pioneer that has to be mentioned was Georgrij de Bothezat, whose prototype could lift two people in 1923 [3]. He also used handles like Cornu instead of a centred

control stick but his design included a hand wheel for yaw control like in Pescara's concept.

The first example of today's conventional helicopter control concept was implemented in Igor Sikorsky's VS-300 in 1940 [4]. Being equipped with a piston engine, it still had a throttle in the shape of a twisting grip mounted on the collective stick. This device was later abandoned in turbine-powered designs, as they tend to have an automatic engine speed regulation. Apart from that, the control concept remained the same from 1940 until today: a control stick for cyclic pitch angle control, mounted between the pilot's legs, a collective lever on the pilot's side for collective pitch angle control and pedals for yaw control.

However, research on helicopter controls shows that there are promising alternatives to conventional controls, such as sidesticks. Among others, Landis and Aiken have assessed the applicability of various sidestick configurations in the 1980s [5]. One of the most recent examples can be seen in DLR's Active Control Technology Flying Helicopter Simulator (ACT/FHS) [6]. This unique Eurocopter 135 modification is equipped with Fly-by-Wire and Fly-by-Light technology, which is crucial for flexible implementation and fast evaluation of innovative control devices. It has been equipped with two active sidesticks [7]. Among DLR's current research activities is the development of haptic pilot assistance functions based on these active sidesticks [8].

2.2. Automobile Controls

Having been built in 1886, Carl Benz's "Motorwagen Nummer 1" is considered to be the world's first automobile. It had a crank handle for steering and a long hand lever that combined the functions of a clutch, a brake and a gear switch [9]. Pushed forward, it moved the driving belt onto a pulley on the axle and thus connected wheels and engine. In the middle position, the belt hung loose and the wheels were free to move, whereas pulling back the lever activated the brake.

Later in 1886, Daimler and Maybach revealed their "Motorkutsche" (motor carriage). Steering was enabled by a star handle that directly turned the front axle [10]. Another design from 1889, the so called "Stahlradwagen" (steel wheel car), featured a tiller for the steering task.

The disadvantage of these steering concepts became apparent when more powerful engines were developed and precise steering became more difficult as driving speeds increased. In 1894 Alfred Vacheron participated in the "Competition for Horseless Carriages" from Paris to Rouen with a "Panhard et Levassor 4HP", which he had equipped with a steering wheel. The idea is likely to have been inspired by the helms of ships. Although Vacheron did not win, the benefits of his modification had been noticed and by 1898, all Panhard et Levassor models were built with a wheel as the steering control [11].

In the following years other automobile manufacturers followed. When the Ford Model T was released in 1908, the steering wheel had already been accepted by the public as standard equipment [11]. This remains unchanged until today despite the development of and research on innovative steering devices for automobiles. For example, Lutz Eckstein designed a concept consisting of two active sidesticks [12]. His idea was to use the sticks

not only for steering, but also for accelerating and decelerating. Being identical, they were meant to be mounted on the left and right side of the driver's seat, thus offering the driver the choice which hand (if not both) to use for the driving task. Although Eckstein's simulator studies gave good results, the concept failed to be picked up by car manufacturers.

Since the steering wheel concept is well proven for automobiles the question arises if it also be a suitable concept for an aerial vehicle. For the general public this might be a better solution than adopting helicopter controls that are known to be hard to handle for untrained individuals.

3. EXISTING STEERING WHEEL CONCEPTS FOR ROTORCRAFT

Several inventors have already pursued the idea of using a wheel for controlling rotary wing aircraft. Some of these concepts shall be introduced here.

3.1. Gazda Helicospeeder Prototype

The first example dates back to World War II as reported in [13]. In 1942 Antoine Gazda, a Swiss aircraft manufacturer, employed Harold Lemont, an engineer who had worked for Igor Sikorsky, to design a helicopter for him. Due to Lemont's rather limited experience with helicopters, which were solely based on his work for Sikorsky, the draft he came up with was similar to the VS-300 in many aspects. Still, there were some distinct differences. The control stick is of special interest here. It was mounted between the pilot's legs and worked like a conventional cyclic stick. In addition to that, it had a steering wheel for yaw control on top and could be raised and lowered to control the main rotor's collective pitch angle. Thus, the pilot was able to make inputs in all four control axes with only one device as shown in FIGURE 2.

As he was a World War I flying ace, Gazda tested the Helicospeeder himself although he did not have any experience with rotary wing aircraft. Being unable to control the prototype without considerable training, he decided that it was too hard to fly and abandoned the project in 1945 [13].

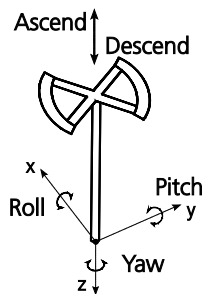


FIGURE 2. Helicopter control concept with four axes combined into one device as in the Gazda Helicospeeder.

3.2. Drees' Helicopter Concept for Everybody

In his Alexander A. Nikolsky Lecture of 1987 Jan M. Drees revisited the idea of a "Small, Low Cost Helicopter [...] for everybody, easy to fly, affordable, and safe" [14]. This idea had been on the minds of engineers since the 50s.

Only through the introduction of Fly-by-Wire technology it was now becoming technically feasible to install innovative flight controls. In combination with suitable control laws the steering task should be simplified even further, according to Drees [14].

He came up with a design sketch that consisted of two devices, one being similar to a steering wheel and the other being a brake pedal. They are shown in FIGURE 3. Remarkable is especially the use of two thumbwheels, one to control lateral and the other to control vertical movement. Drees suggested making inputs for acceleration and deceleration by using a slidable steering device, which should remind users of the steering wheel in a car [14]. Although Drees' design seemed rather promising, it is not known to have ever been implemented in any prototype.

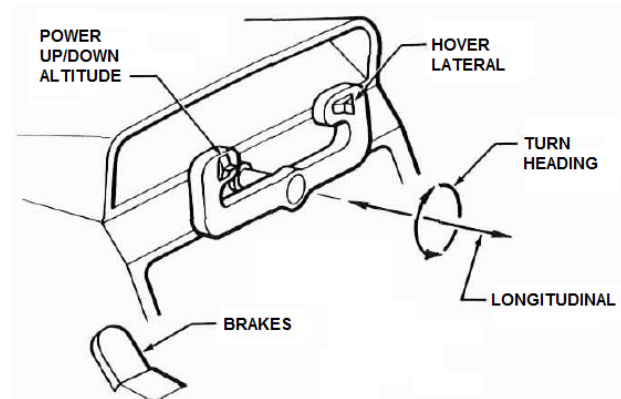


FIGURE 3. Drees' car-like controls for an easy-to-fly helicopter for everybody. The "steering wheel" is slidable to command acceleration or deceleration. The left and right thumbwheel control vertical and lateral movement, respectively. The figure is taken from [14].

3.3. Flemisch's Simulator Study

The next example is a concept that has actually been tested in simulation. Scientists of DLR and the Technical Universities in Munich and Darmstadt used the "Horse-Metaphor" or H-mode in short. It describes the idea of a vehicle acting autonomously like a well-trained horse [15]. The horse can move along a given path even without guidance by its rider. Nevertheless, it responds to commands the rider makes or even requires his intervention in more complex situations.

Implemented in a car, the H-mode would be designed to control the vehicle using driver assistance functions. These functions would include highly advanced lane-keeping or obstacle-avoidance. The driver is kept in the control loop with the help of active control elements that are configured for tactile cueing [15]. Following the metaphor, this behaviour is referred to as "Loose Rein". "Tight Rein" means that the driver is given the majority of control over the vehicle, which can be initiated both by the automation or the driver himself.

In the opinion of the involved scientists, the H-Mode is not limited to cars but can be applied to any form of vehicle. A universal control concept was developed that could be used in both air and ground vehicles. Thus, training on

two different kinds of control sets would reduce to training on one set and synergies could be used to improve the driver's performance in both domains [15].

Under the direction of Frank Flemisch simulation trials were conducted to find out if the H-Mode idea could be applied to such a universal control concept. The simulated vehicles were an automobile with the driving dynamics of DLR's FASCar prototype and an unmanned helicopter, both implemented with hardware-in-the-loop components and controlled from the same control station [15]. The control concept that is of interest here consisted of a steering wheel together with a sidestick. Its principle is shown in FIGURE 4. In automobile mode, the stick commanded longitudinal movement and the wheel was used for the steering task. In helicopter mode (in the simulator the screen displayed the aircraft's ego perspective to simplify the task) the stick was additionally used for lateral movement control. A hat switch on top of it controlled the vertical movement. Control in the other two directions was the same as in automobile mode.

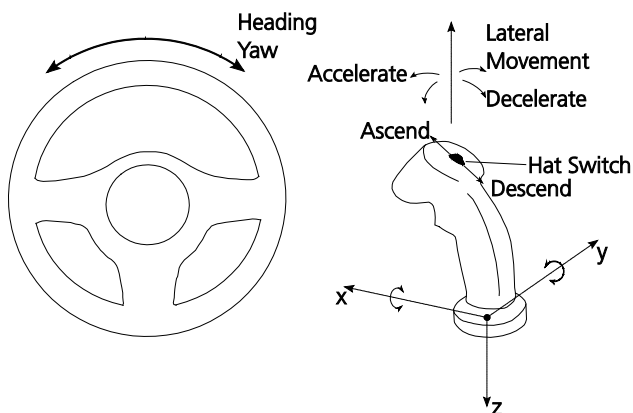


FIGURE 4. Control concept of Flemisch's simulator study. The steering wheel controls the heading and the sidestick the longitudinal movement of the vehicle. In helicopter mode the stick is also used for lateral and (via the hat switch) vertical control inputs.

Despite being focused on the benefits of the H-Mode and its assistance systems, the results show that the guidance task for the simulated unmanned helicopter can be simplified with the wheel-stick-combination compared to the conventional remote control [15]. However, research in that direction was not continued as the scientists concentrated on the H-Mode in ground vehicles.

3.4. PAL-V's Steering Concept

The Dutch company PAL-V Europe NV began to work on a "Personal Air and Land Vehicle" in 2001. On April 2nd of 2012, they released a statement about the successful maiden flight of their PAL-V One prototype [16]. The PAL-V is basically a roadworthy gyrocopter. It uses an auto-rotating rotor for lift and a foldable push propeller for forward speed. In ground mode, the tail and rotor are stowed away on the back of the vehicle, making it narrow enough for conventional traffic.

A recently published video [17] shows that the PAL-V has a steering wheel which is only used for driving. For flying a cyclic stick is pulled up from under the pilot's seat and then works in the same way as in a conventional gyrocopter. This concept clearly deviates from the

myCopter vision as the project does not cover dual use vehicles. The PAVs envisioned in myCopter would be purely airborne vehicles. Therefore, it is necessary to identify a control concept that brings the advantages of the well-known automobile steering wheel into a flying PAV. Continuing the work that has been described in this section, DLR now takes the next steps, which are implementation and evaluation of innovative concepts for the intuitive control of aerial vehicles.

4. PAV RESPONSE TYPES

The ideal control concept for a PAV does not only depend on the preferences of the user but also on the vehicle's flight dynamics. When different control concepts are compared it is important to investigate them on the same aircraft. Otherwise the handling qualities of the aircraft might influence the suitability of a certain steering concept more than the concept itself.

The University of Liverpool has developed a generic PAV dynamics model for research within the myCopter project [18]. This simulation model can be configured to provide a number of different response types with predicted Level 1 handling qualities according to the requirements of the Aeronautical Design Standard ADS-33E-PRF [19]. The "hybrid" configuration of this model offers two different settings, one for the low speed regime (up to 15 kts) and one for higher speeds (above 25 kts). Between the two regimes a smooth blending is designed for the change from hover to forward flight. The intention of splitting between hover and forward flight characteristics is to minimise the needed control inputs for performing manoeuvres.

Pitch	TRC		AcC
Roll	AC		
Yaw	RC		β C + TC
Collective	RC		γ C
	0	15	25
	Airspeed /kts		

FIGURE 5. Hybrid response type configuration of the PAV dynamics model with changes over airspeed.

FIGURE 5 shows an overview of the selected response types. In the pitch axis a translational rate command (TRC) is implemented. This response type connects control deflection to forward speed linearly. When the inceptor is returned to the neutral position, the PAV returns to hover. Above 15 kts blending starts towards the forward flight mode which is an Acceleration Command (AcC) in this axis. The aircraft's longitudinal acceleration is proportional to the inceptor's deflection in the forward flight mode. This implies that the current airspeed is held when the inceptor is returned to neutral.

The roll axis has a speed independent behaviour. For all airspeeds an Attitude Command (AC) with attitude hold is implemented. A lateral control input results in a proportional roll angle.

In hover and up to 15 kts forward speed the yaw axis is designed as Rate Command (RC) response type. The yaw rate is proportional to the pedal inputs. In faster forward flight the response type changes to a Sideslip Angle Command (β C) with Turn Coordination (TC). This

increases directional stability and allows flying coordinated turns (free of sideslip) in forward flight without additional pilot inputs [18].

The altitude is controlled via RC response type in hover mode and changes to Flight Path Angle Command (γ C) in forward flight. Inter-axis coupling is not present in the selected response type configuration. This behaviour will make piloting easier for flight-naïve PAV pilots.

The described PAV dynamics model has extensively been tested at the University of Liverpool. Both pilots and flight-naïve test participants had the chance to fly a PAV in a motion simulator [18]. The hybrid model configuration generally received very good ratings regarding handling qualities and is foreseen to be most suitable for future PAVs.

The simulator used in the study was equipped with conventional helicopter controls: a two-axis stick for longitudinal and lateral control, a collective lever for the heave axis and pedals for controlling the yaw motion. The original question that was raised at the beginning of this paper is which control concept is most suitable for future PAVs. The development of steering devices in rotorcraft and automobiles has shown that a steering wheel is a promising concept to be tested in PAVs. For comparing different control concepts it is important to keep the flight dynamics constant. This means to answer the question of the most suitable PAV inceptors, an alternative steering concept has to be found that matches the demands of the PAV's flight dynamics.

5. NOVEL STEERING CONCEPT

As the historical overview at the beginning of the paper shows, the steering wheel is still the dominant control device in automobiles. Although several studies have shown that novel concepts such as sidesticks are technically feasible, they have not reached the mass production regime. Drivers still prefer the conventional steering wheel.

PAVs can be foreseen to be a future alternative to ground-based traffic bound to conventional automobiles. PAVs would lift personal transport to the third dimension. In order to keep this transportation system open to the general public it must be easily understood even by flight-naïve users. Let us assume that transferring the steering wheel control concept to a PAV will indeed make the change from car to PAV easier for the user. When concentrating on car drivers, the novel PAV steering concept should be as similar to the already known control schemes as possible. Therefore, a control concept has been developed that takes over as many known features as possible but is at the same time compatible to the developed PAV response type configuration.

To begin with, the acceleration command can easily be transferred from the automobile concept to a PAV. Gazda and Flemisch used the longitudinal movement of a stick for pitching and resulting forward movement. This is typical for conventional helicopter control. Drees went one step further in bringing rotorcraft and automobile controls together by introducing a brake pedal. To make the two steering concepts even more alike, a second pedal should be included in the PAV. This accelerator pedal will be used for speed commands. This matches the TRC and AcC response types of the PAV dynamics model well.

From hover to forward flight a constant pedal deflection would result in a constant airspeed. After blending to the forward flight mode, the pedal deflection causes longitudinal acceleration. This means the pedal can be released to hold the current velocity. This behaviour is analogue to a cruise control in the automobile sector. Cruise control is especially effective on long tours e.g. on a highway where the same speed can be maintained for several kilometres. This will be equally helpful in cruise flight in a PAV.

The function of the automobile's brake pedal can be transferred in the same manner like Drees had imagined it for his easy-to-fly helicopter. Pressing the pedal decelerates an automobile to stand whereas it would decelerate a PAV to hover.

Aligning the lateral control of automobile and PAV is more complex as a rotorcraft cannot only rotate along the yaw axis but also along the roll axis. Gazda and Flemisch set their concepts up with the steering wheel giving yaw commands. They had an additional lateral control axis for roll commands (on the same device or on a second stick). In contrast to that, Drees is assuming that a steering wheel alone is enough for initiating turns. This becomes possible by implementing a Turn Coordination. This TC feature is already available in the forward flight mode of the hybrid response type configuration. Thus, the steering wheel can command coordinated turns and the pilot will be relieved from directly controlling a sideslip angle. In cases where flight with sideslip angle would be advantageous, e.g. under strong winds, the flight control computer will have to control the sideslip automatically. This results in the control strategy becoming simpler for the PAV user but at the same time limits the manual manoeuvrability of the vehicle. For the concept of a PAV that is tailored towards the needs of flight-naïve users, this compromise seems to be reasonable.

The problem of yaw and roll interaction with a one-axis steering device remains to be solved in the hover and low speed regime. The question is which of the two movements is more important to be controllable from hover. With conventional controls and AC response type in the roll axis, the PAV would perform a roll, followed by a sideward translational movement when the control stick is moved laterally. This movement cannot be performed with a conventional automobile although it would definitely be helpful for parking into a parking space alongside the street. On the other hand, initiating a turn along the yaw axis of the PAV from hover would turn it on the spot. Yawing on the spot is also not possible with an automobile. Nevertheless, turning on the narrowest possible turn radius with an automobile is closer related to a yawing motion than to a roll motion. In order to make the two control concepts alike, the PAV steering wheel should therefore command a yaw rate in hover. With increasing flight speed the yaw control becomes less important as turns are mainly initiated by a roll motion. The steering wheel's yaw command is therefore blended over to a roll command. The response type configuration described above is modified in a way such that a smooth blending between yaw and roll control occurs between hover and 5 kts forward speed. In the mode transition regime between 15 and 25 kts the turn coordination is activated and blended in. An alternative for the slow regime would be to use a low speed TC like it is already implemented for higher airspeeds.

Finally, an inceptor must be provided for controlling the PAV's vertical movement. Gazda used the vertical axis of his four-axis long pole stick, whereas Flemisch and Drees proposed additional switches on the sidestick or the steering wheel. In order to find the most suitable position for the vertical control device, the experience of automobile users should be taken into account. Owners of a driver's license are used to control steering wheel, pedals, as well as gear shift lever. The gear shift is typically located between the two front seats. This is the same position where many rotorcraft would have their collective lever. It seems to be logical and straight forward to use a lever at this position for height or flight path angle control. This device could either be a conventional collective lever or a sidestick. A disadvantage of this concept is that during climb or descent flight the PAV user must operate the steering wheel with one hand while having his or her second hand at the height control lever. To overcome this disadvantage an alternative would be to follow Drees' suggestions and install switches directly on the steering wheel for vertical control. This would allow initiating climbs or descents without taking the hands from the steering wheel.

The steering wheel selected for this novel PAV concept has only one primary axis. In contrast to that, both Gazda and Drees incorporated multi-axis steering wheels in their concepts. Research on multi-axis sidesticks as conducted by Landis [5] showed that increasing the number of axes on one device can increase the likelihood of unintentional coupling between inputs in different axes. Landis tested a four-axis sidestick with the same functions as Gazda's long pole prototype. It received worse ratings than a three-axis sidestick with additional collective lever. Drees steering wheel resembles more the yoke of a fixed wing aircraft. As the concept developed in this paper is tailored towards the needs of automobile-experienced users and not of fixed wing pilots, a single-axis wheel seems to be the better choice.

The primary control functions as described above are summarised in the cockpit concept in FIGURE 6. The control concept that has been described so far allows controlling a PAV in a similar way like steering a conventional automobile. Movements that have been ignored so far are the reverse as well as lateral translational movements. These manoeuvres are foreseen to be suitable only for slow airspeeds, e.g. for precise manoeuvring around hover close to the ground. Therefore, it is rated to be unnecessary to integrate these functions with the primary control axes described above. Instead, it is proposed to have an additional switch on the steering wheel that controls precise horizontal movements. An example for this type of switch would be a hat switch like it has been used in Flemisch's concept. An alternative that would integrate well with the steering wheel would be a ring switch in the centre of the wheel. This 8-way switch could be used for commanding precise translational movements horizontally along the longitudinal or lateral axis or along the diagonals. This secondary control function is similar to the switch Drees had foreseen on the steering wheel for lateral control.

FIGURE 7 shows the modified response types for the control concept with steering wheel as they have been described above. Pedals are used for commanding longitudinal control inputs (by varying pitch angle and rotor thrust). Both roll and yaw motion are solely

controlled by the steering wheel. The transition between them depends on the forward airspeed. A collective lever is used to control vertical movements. Finally, an additional 8-way switch allows precise manoeuvring in longitudinal and lateral directions with a TRC response type being limited to 5 kts.

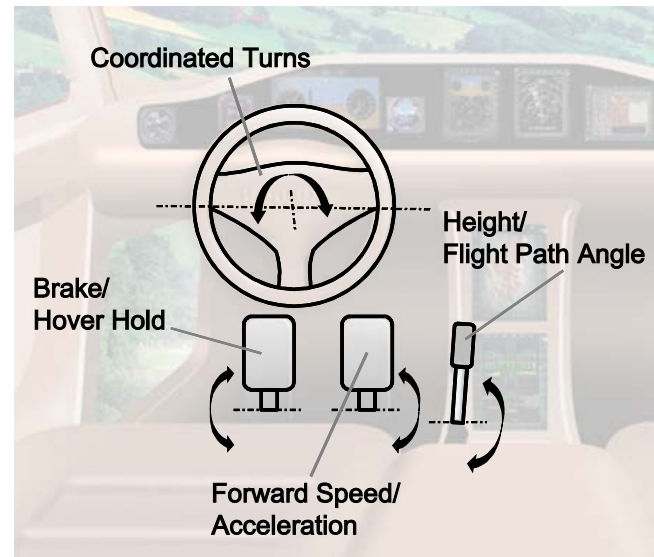


FIGURE 6. Primary control functions of a PAV control concept with steering wheel for coordinated turns.

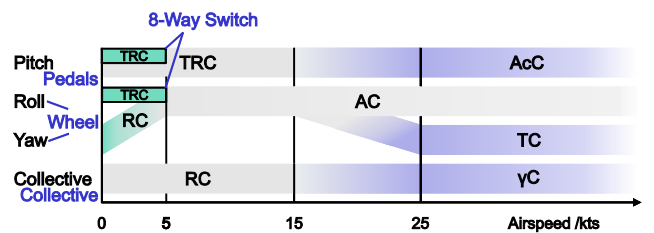


FIGURE 7. Response type modifications for control concept with steering wheel. The steering wheel controls both roll and yaw axis.

6. CONCLUSION AND OUTLOOK

This paper has given an overview of the development of control devices in rotorcraft as well as in automobiles. Derived from the historical development and previous research a novel steering concept for future PAVs has been proposed. The control concept combines a conventional helicopter interface with a car-like steering wheel. The necessary response type modifications for the implementation of this control concept have been described in detail. The developed concept is foreseen to be especially suitable for driver's license holders who will want to switch from ground-based transportation to personal aerial transportation with a minimal amount of training as soon as PAVs will be available.

In order to prove the assumption on the suitability of the described steering concept, it is currently being integrated into DLR's ground-based helicopter simulator. A PAV flight simulation with the necessary response types and mode changes has already been implemented and will be controllable either by conventional helicopter controls, sidesticks, or the novel steering wheel. In order to rate the

suitability of the control concept, simulated flight tests are planned to be undertaken with three different control groups: helicopter pilots, flight-naïve driver's license holders, and inexperienced test persons with neither flight nor driving background. Furthermore, the flight worthiness of a prototype steering wheel to be integrated into DLR's research helicopter ACT/FHS [6] is currently under investigation.

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