Simulator Study on Gyrocopter Pilot Performance in Different Takeoff Procedure Scenarios

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Abstract

This paper deals with different takeoff procedures of gyrocopter. Most common takeoff procedures for current gyrocopter are very similar to those of airplanes. Nevertheless, there are distinct differences in performing a takeoff with an airplane in contrast to a conventional gyrocopter. A further takeoff procedure highlighted in this work is the vertical takeoff of the gyrocopter, the so called jump takeoff procedure.
To compare the two takeoff procedures with respect to pilot's behavior and performance the unique gyrocopter simulator at the Institute of Flight Systems is used for an extensive pilot-in-the-loop simulator study.
Three groups of participants were invited to the experiment: fixed wing pilots, gyrocopter pilots and unexperienced persons without any pilot license. Each participant got the task to perform a series of takeoffs at different wind conditions using the conventional takeoff procedure and the jump takeoff procedure. During the experiment the participant's interaction with the simulator as well as their eye movements were logged. During each experiment the participants had to fill in a questionnaire on subjective pilot ratings.
The paper presents a short theoretical introduction on gyrocopter technology and explains the two takeoff procedures as well as their particularities, advantages and challenges. Furthermore the experiment on the two takeoff procedures and the results of the comparison of the both takeoff procedures are shown.

1. INTRODUCTION

Since gyrocopters were certified in the Ultra-Light class in 2004 the number of licensed gyrocopters in Germany increases continuously even if the boom of the first years seems to be broken.
They are popular especially with private pilots. Their main advantages are low acquisition costs, low operating costs and affordable spare parts. Furthermore gyrocopters offer unique flight characteristics which are attractive for a vast range of customers.

The German Aerospace Center investigates the flight physics of gyrocopters for many years. For several test campaigns and projects two flying demonstrator are operated: an MTOsport and Cavalon. Both types are produced by the manufacturer Autogyro Ltd.

Figure 1: Modern Gyrocopter Configurations

One main research goal is to look beyond the borders of current vehicle designs and respective regulations. The possibility of taking off vertically, changes the gyrocopter's flight envelope radically.

The rotating wing of a gyrocopter creates lift independent from airspeed as long as a sufficiently strong upward airstream through the rotor plain is assured. Therefore stall is not a threatening issue for gyrocopter pilots. Due to the high maximum angle of attack of the rotor disk very low forward speeds are achievable.
Ultralight gyrocopters can perform level flights with flight speeds of 18 to 20 kts. Decelerating the autogiro to zero forward flight speed evokes the transition to vertical autorotation. At zero forward speed the gyrocopter sinks with a stabilized sink rate after a short transition phase.
The gyrocopter is the only flying vehicle that is operated in an autorotative state within the complete flight regime. The transition from forward flight to vertical autorotation is often performed by pilots as a normal flight maneuver.
Low disk loadings and a favorable thrust to weight ratio of current ultra-light gyrocopter allow short takeoff roll distances (~120 m) and thanks to low landing speeds very short landing roll distances (~20 m). Moreover, due to comparatively small moments of inertia, those vehicles show a high agility.
Especially during landing the pilot can use the rotor's characteristics perfectly to flare and to stop the aircraft within a short distance. To slow down the vehicle on the ground the rotor is tilted backwards and the rotor force is used to decelerate.
For the conventional takeoff procedure the rotor has

to spool up during the takeoff run to reach a sufficiently high rotor RPM for flight. At the same time the gyrocopter has to accelerate to reach a velocity high enough to fly.
Since the ground run ought to be as short as possible those two purposes are contradictory, because the rotor and the resulting rotor force are highly inclined to enable a significant airstream through the rotor itself. Due to this inclination the rotor generates a braking force, which counteracts the thrust of the propeller and decreases the acceleration.
The gyrocopter leaks one main advantage of the helicopter. This is the ability to takeoff and climb vertically.
However this gap can be filled by the realization of the so-called jump takeoff, which would make the gyrocopter more competitive for rotorcraft applications.
There have been several activities in the field of jump takeoffs already in the 1930th.
The first successful demonstration on a C30 gyrocopter took place in 1935.

Figure 2: Cierva C40 in jump takeoff 1938 [1]

Some of the current autogyro designs are already equipped for jump takeoffs. Examples are the Carter Copter PAV [2], the Carter GyroDemonstrator or the Groen Brothers Hawk 4.

While the technical realization has already been demonstrated, the particular demands on pilot's abilities during such a takeoff have not been fully investigated. This simulator study on jump takeoff is one first step to investigate in how far the jump takeoff could be an alternative to current takeoff procedures with respect to the necessary pilot actions.

The following research questions were addressed by this study:

- How do pilots accept such a jump takeoff system?
- Are they capable to act with a modified gyrocopter properly and safely?
- How do they evaluate such a takeoff procedure?

2. THE TAKEOFF PROCEDURE

2.1. The Conventional Takeoff

The conventional takeoff is the current standard takeoff procedure for gyrocopter with an acceleration phase on the ground, similar to fixed-wing takeoffs.

2.1.1. Conventional Takeoff Procedure

The takeoff procedure comprises 6 distinct phases. The first step is the preparation phase (PP). In that phase the pilot starts the engine and releases the rotor brake. This phase is followed by the pre-rotation (PR) of the rotor. While the gyrocopter stands on the ground the pilot couples the rotor with the engine and the rotor rotational rate is increased to a takeoff value (approx. 200 rpm).
In the third phase (G-AC) the rotor is tilted backwards and after a pilot throttle command the gyrocopter accelerates rapidly. In that phase the rotor rotational rate increases after a short decay at initially low forward speeds.
The fourth phase (RT) starts with a pitch-up movement of the gyrocopter which has to be counteracted by pilot inputs at a moderate pitch angle. The moment that rotates the gyrocopter about the main landing gear axis is caused by a strongly tilted rotor thrust vector in combination with an increasing rotor thrust. The pilot has to balance the gyrocopter in a pitch-up attitude to further accelerate the rotor to the maximum rate possible without pitching further up before reaching sufficient lift to take off safely. (Figure 6)
As soon as a sufficient amount of lift is provided by the rotor, the gyrocopter lifts off. This indicates the beginning of the fifth phase, the in-air-acceleration phase (A-AC).

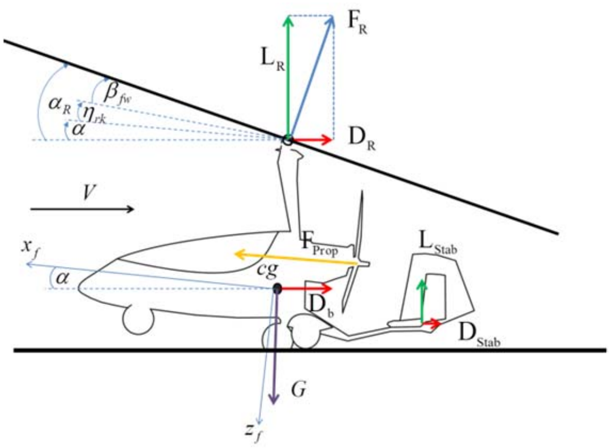

Figure 3: Gyrocopter at a conventional takeoff in the moment of rotation

Depending on its weight the gyrocopter lifts off with different speeds. To enhance safety margins the gyrocopter is accelerated close to the runway to a speed that gives sufficient time to react in case of engine breakdown or any other major failure. More-

over a speed of best climb has to be reached to perform an efficient and safe climb.
As soon as that speed is reached the gyrocopter starts to climb to the desired altitude, this is the last phase of the takeoff (CL). Figure 4 shows key parameters for the conventional start.

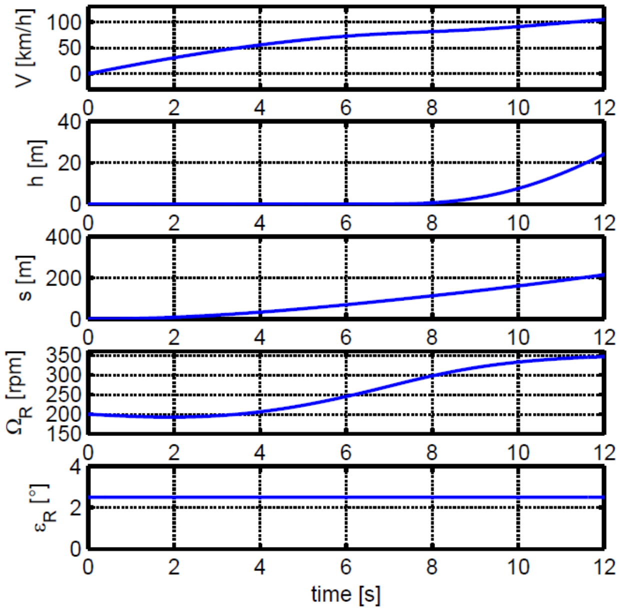

Figure 4: Simulated conventional takeoff data [3]

2.1.2. Hazards

In general the gyrocopter shows very good flight characteristics. Nevertheless some flight maneuvers should be avoided. One of such conditions is the slow flight close to the ground or to obstacles. Figure 5 shows the drag curve of a reference gyrocopter. Minimum drag is reached at approximately 90 km/h. At slower velocities the drag increases. This region is often designated as the backside of the curve.

Due to the increase of drag slowing further down requires more thrust. At very low speeds the gyrocopter has to sink to accelerate and to decrease drag because the engine thrust is insufficient.
To prevent any accidents due to that circumstance low altitude and low speed combinations that make any recovering from flying on the backside of this curve impossible are prohibited.
Due to the low altitudes at takeoff knowledge of this behavior is very important for the takeoff procedure. A very steep climb may lead to a loss of speed and an increased drag resulting in a flight on the backside of the curve. Pushing the stick gently and accelerate again is the only way to escape such situation.

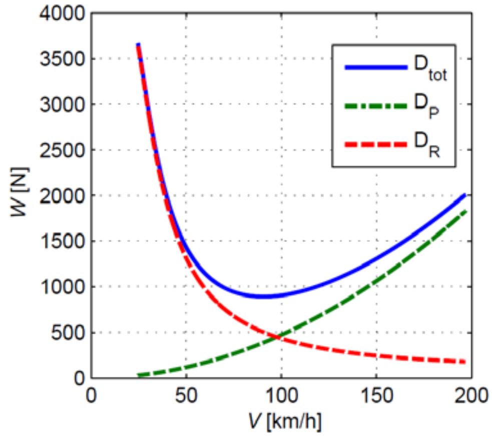

Figure 5: Drag curve of a reference gyrocopter

Other typical hazards in takeoff might be the following pilot errors:

- Pulling the Stick to late at already high forward speed or not to far enough → blade flapping on the ground
- Inclining the rotor with the wind → possible rollover due to wind passing the rotor from below
- No reaction to strong pitch up movement in takeoff run → tail strike
- Contact of front wheel with runway while rudder deflected at speeds above taxi speed → strong yaw moment and tipping danger

2.2. The Jump Takeoff

The jump takeoff differs strongly from the conventional takeoff. The gyrocopter lifts off vertically and the acceleration phase is done in the air.

2.2.1. Jump Takeoff Procedure

Similar to the conventional takeoff the first phase of the jump takeoff is the preparation phase (PP) too. It is also followed by the pre-rotation phase (PR). The differences to the conventional takeoff are that the rotor rotational rate is increased far above the normal flight value and that the rotor incidence angle is reduced to create only a small lift force and a minimum of drag. The reduction of the incidence angle is required to prevent an unintended lift off.
In the third phase (CU) the collective angle of the rotor blades and thus the rotor thrust have to be increased. The amount of thrust is proportional to the blade pitch angle, which is equivalent to helicopters. Nevertheless the time to accomplish the maneuver is limited by the amount of energy stored in the rotating system. That is why the following steps have to be well prepared. In order to enable a momentum-free lift off the rotor is controlled in a way that the tip path plane is aligned with the ground (gentle inclination to the back to compensate

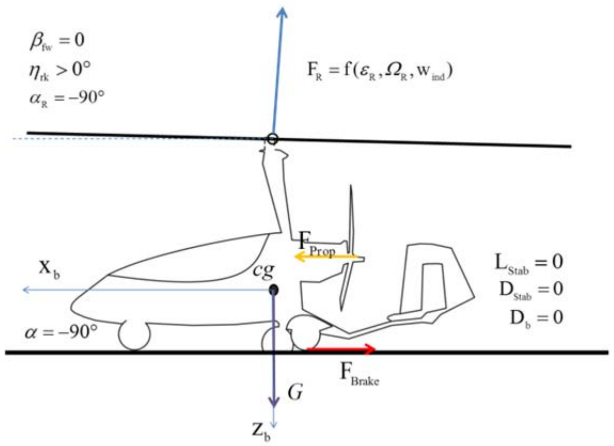

Figure 6: Autogyro in jump takeoff configuration at the moment of lift off

propeller thrust). At the same time the pilot uses the collective lever to lift off vertically.

The fourth phase (CD) begins as soon as the gyrocopter has reached a sufficiently high airspeed and height. The collective pitch angle of the blades has to be reduced then to prevent excessive blade flapping, which could damage the rotor steering.

In the fifth phase (AC-A) the gyrocopter is already reconfigured to the standard configuration after the collective angle has been reduced to the standard flight value and goes on accelerating to a higher airspeed required to climb. As soon as the gyrocopter reaches the required speed the pilot begins a continuous climb flight (CL).

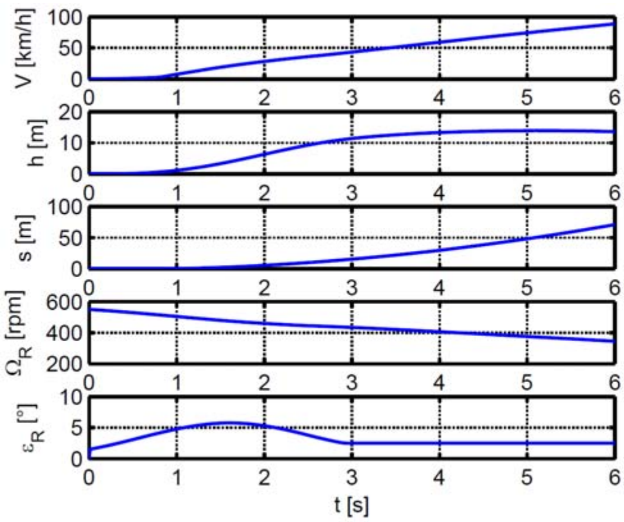

Figure 7: Key parameters of a calculated jump takeoff (analytic calculation)

2.2.2. Hazards

Flying low and slow is as dangerous for the jump takeoff as it is for the conventional takeoff. Typical additional hazards might result from the following pilot errors:

- Abort pre-rotation to early and take off
- Uncoordinated use of thrust lever and collective lever commands → insufficient gain of speed during takeoff
- Inappropriate reaction to wind effects
- Excessive or insufficient pitch input after lift off → excessive attitudes close to the ground
- Abrupt use of collective lever → high structural stress
- Flying at high speed with increased collective angle → danger of flapping
- Keeping high collective angle to long and provoking a rotor rotational rate drop below recommended rate → significant loss of rotor thrust while lowering the collective angle

2.3. Takeoff Procedure Differences

The two takeoff procedures demand very different pilot actions. To make them comparable in this paper each takeoff procedure was subdivided in 6 phases, which are presented in Table 1. The abbreviations introduced will be used in all subsequent sections.

Table 1: Phases of takeoff

Phase	Jump Takeoff	Conventional Takeoff
1	PP – Preparation	PP – Preparation
2	PR – Pre-rotation	PR – Pre-rotation
3	CU – Collective Lever up	AC-G – Acceleration on ground
4	CD – Collective Lever down	RT – Rotation
5	AC-A – Acceleration in the air	AC-A – Acceleration in the air
6	CL – Climb	CL – Climb

The designs of the vehicles are different for the two types of takeoff. For the jump takeoff there is one variable more to control. And even worse, it is time-restricted. The amount of energy must be well used to accomplish the takeoff mission. An inappropriate time or energy management leads to unintended flight states close to the ground. Table 2 shows procedure characteristics that might make the jump takeoff more demanding in comparison to a conventional takeoff:

Table 2: Comparison of demanding factors of both takeoff procedures

Conventional Takeoff	Jump Takeoff
All phases have clearly separated tasks for the pilot for all control axes	Phase three requires pitch commands to accelerate as well as to climb
Left arm has only one task	Left arm and hand have to work coordinated
Climbing is a relatively slow and comparatively continuous process	Climbing starts abrupt and a small descent phase during the transition must be anticipated
Acceleration phase begins in two dimensions	Flight begins in three dimensions
Four control inputs after brake release	Five control inputs after brake release

2.4. Safety Considerations

During conventional takeoffs flights on the backside of the thrust/drag curve close to ground shall be avoided to prevent dangerous situations in case of an engine breakdown. Therefore H-V-diagrams define an area of altitude and speed combinations that has to be avoided during the flight. Examples are given in [4] and [5]. For the comparison of the two takeoff procedures an H-V-diagram from [6] is shown in Figure 8. The jump takeoff flight profile has been added. The recommended flight profile is for a conventional gyrocopter and the jump takeoff flight profile is derived from data of Figure 7.

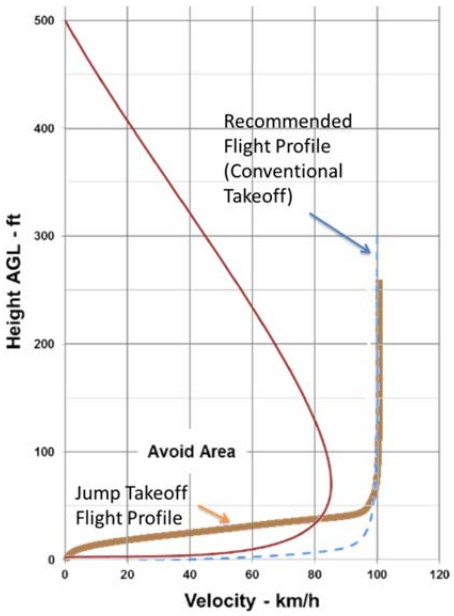

Figure 8: Flight profiles in current H-V-diagram [6]

The jump takeoff needs to be performed in an area that is restricted for the conventional takeoff. Nevertheless it is possible to operate in this area as long as a safe landing also with a loss of the engine can be carried out. To perform such a safe landing after an engine breakdown at the very beginning of takeoff the pilot has to utilize the rotational energy stored in the rotor to sink and to flare close to the ground using collective inputs.
To evaluate whether such landings are generally feasible using the experimental set-up a test series of 10 jump takeoffs with the presented procedure and in case of engine failures at different times had been conducted. It turned out, that a safe landing was feasible in all cases.

3. THE EXPERIMENT

3.1. Experimental Setup

To perform pilot-in-the-loop studies for the assessment of the jump takeoff procedure the gyrocopter simulator of the institute for flight systems of DLR Institute of Flight Systems has been used. This simulator comprises an Autogyro MTOsport nonlinear 9-degree-of-freedom simulation model, which is used for the conventional takeoff procedure in this study. The model is presented in [7].
The further simulator hardware consists of original airplane parts such as pedals, the seat, stick and thrust lever. To improve the immersion the stick is movable and provides force feedback. The field of view is 180° wide and 60° high. It is presented on a curved screen with a radius of 2 m. The simulator hardware is described in [8].

Figure 9: Simulator setup with eye tracking

To simulate the jump takeoff several changes had to be applied to the standard simulator model and the simulated cockpit displays. Those are:

- Additional command inputs and additional outputs
- Adjustable collective angle
- Enforced pre-rotation power supply independent from main motor
- Rotor blade mass increase by 33% (radial distribution unchanged).
- Additional indications for rotor collective angle and stick position during pre-rotation

Also the simulator cockpit controls had to be adapted to the new jump takeoff task. Especially for jump takeoffs a combined collective and thrust lever had been developed. The lever rotation about the bottom hinge (Figure 10) is the thrust input, while pulling or dwindling of the hand lever increases or decreases the incidence angle of the rotor blades up and down.
Pushing the whole lever to the front is an increasing and pulling the lever back is a reducing thrust command.
A fully upward pulled hand lever gives six degrees of rotor blade incidence (collective). At the lowest position it is zero degrees. To prevent an unintended release of the collective lever down to zero degrees it is locked at several positions. The upmost lock position is the continuous flight position (2.5°).
To lower the collective angle before a new takeoff takes place the lever can be unlocked by the unlock pin which resets the position to zero.

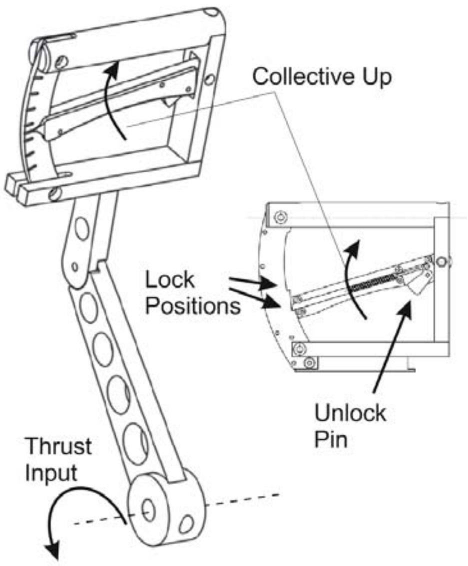

Figure 10: Combined collective and thrust lever

Especially for the jump takeoff additional instruments were installed in the gyrocopter cockpit (Figure 11). To help the pilot to find the optimum prerotation rotor position a control light is positioned on the lower left side of the display. If all necessary preconditions are correct (rotor brake released, collective angle zero and stick in predefined postion) the light will turn green and the prerotation can be started. As soon as any condition becomes abnormal the prerotation motor will be turned off.
The second indication to support the pilot is a collective angle scale. That one is to find on the lower left side of the cockpit instrument panel. The basic idea of this indicator was to find out if such a scale can be used in the vertical climb phases of the takeoff maneuver and if it will be helpful.


Figure 11: Cockpit instrument panel

Additionally, an eye tracking tool was installed to follow the participant's eye movement [9]. The system monitors the line of sight of the pilot's eyes as well as the position of the pilots head.
The pilot's field of view was separated in 6 relevant planes as shown in Figure 12. Four of them represent the external view, one was for the lever and one for the instrument panel. The central forward plane is positioned in front of all other planes of the screen. It represents the direct forward view, which is generally directed along the runway on takeoff starting position.

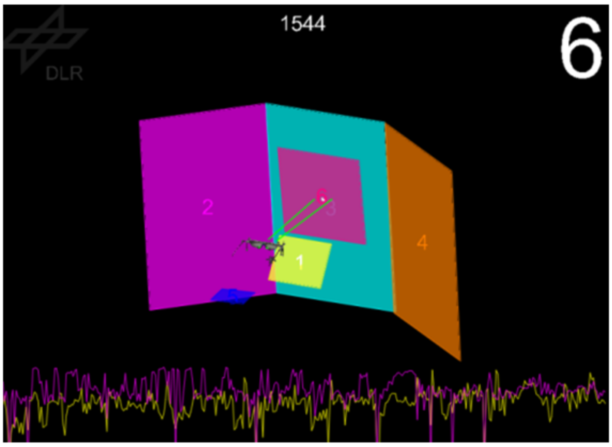

Figure 12: Position of eye tracking plains in the simulator

3.2. Participants

Regarding the participants there is a wide spread in age and in flight experience. The youngest participant had an age of 18 years and the oldest participant was 74 years old.
Another spread could be seen in flight experience. The minimum was 0 flight hours and the maximum several ten thousand flight hours. Table 3 shows a summary of the participant distribution.

Table 3: Participants number and age

Expertise Groups	Number	Age Ø	old-est	young-est
Gyrocopter Pilots (GP)	9	48	67	34
Airplane Pilots (AP)	11	36	74	22
No license, but Prior knowledge (PK)	8	40	69	22
Without prior knowledge (WK)	11	25	55	18

The age distribution of the particular groups was quite different. Not all participants had a prior interest in aviation applications. There was even a group of those with no flight experience who even had no prior subject knowledge. That group (WK) can be considered as totally unprejudiced. They are displayed separately in the following plots.
While the group of participants without prior knowledge was rather young, the gyrocopter pilots were middle-aged and the airplane pilots rather of mixed age. The results of that group are useful to evaluate some data of the other groups in context of the prior knowledge.

3.3. Experimental Design

A pseudo experiment with a 4x2x3 factor design was conducted. The between factor was the participants experience and the repeated measurement of takeoff types. They are displayed in Table 4. Each participant had to perform 2 starts with each wind condition. Therefore six starts were necessary for each of the two takeoff types. Consequently each participant had to perform 12 takeoffs in total.

Table 4: Experimental factors

<table>
<tr><th colspan="12">Expertise group</th></tr>
<tr><td colspan="3">Gyrocopter Pilots (GP)</td><td colspan="3">Airplane Pilots (AP)</td><td colspan="3">No license, with prior knowledge (PK)</td><td colspan="3">No license, without knowledge (WK)</td></tr>
<tr><th colspan="12">Wind condition</th></tr>
<tr><td colspan="4">No wind</td><td colspan="4">Head wind</td><td colspan="4">Cross wind</td></tr>
<tr><th colspan="12">Takeoff type</th></tr>
<tr><td colspan="6">Conventional/Horizontal Takeoff</td><td colspan="6">Jump Takeoff</td></tr>
</table>

To thoroughly analyze the influence of the takeoff types in relation to the participants group the following hypotheses were formulated.

1. Jump takeoffs are feasible. Best performance will be shown by the pilot groups (GP, AP).
2. The error rate of trained pilots will be higher with jump takeoff for GP and AP but it will be comparable for PK and WK.
3. Jump takeoff is more complex for the air segment and less complex for the ground segment. Due to unusual coordination tasks the first issue will have more influence on the rating.
4. The procedure compliance will be comparable for the expertise groups independent from takeoff types.
5. Hand arm coordination of the left arm will be challenging for the jump takeoff independent from the expertise groups.
6. The new instruments in the cockpit are perceived as useful.
7. GP and AP will check the speed during the jump takeoff acceleration phase more than during the horizontal takeoff acceleration phase.

The dependent variables are mapped directly to the metrics presented in Table 5. Data according to the metrics was logged during the experiments. The date logging process is described in detail in section 3.6.

Table 5: Independent variables and the connected metrics

Independent Variable	Metric
Attention and reaction	Tail strike
	Collective lever control at increasing speed
Procedure compliance	Stick use according to procedure
	Collective lever use according to procedure
General performance	Aborted takeoffs
	Excessive attitudes
	Flight path deviations
Jump takeoff complexity	Pilot questionnaires
Hand-arm coordination	Pilot questionnaires
Usefulness	Pilot questionnaires
Change in eye tracking behavior	Number/duration of fixations on areas of interest

3.4. Briefing

The briefing was the same for all participants. First the vehicle was presented and a small introduction in flight physics was given.
Possible maneuver inputs were presented and the vehicle reaction resulting from these inputs was explained. Special focus was put on the takeoff procedure and the climb flight segment.
Further the background of the experiments was highlighted and the schedule for the experiment was presented. Jump takeoff and conventional takeoff were explained before the simulator session. The conventional takeoff was designated as “horizontal takeoff” to prevent biasing the group of participants without experience.
Additionally the simulator was explained. Special focus was put on inputs that have to be applied by

the experimenter and those that have to be applied by the participant.
The last part of the briefing described the two takeoff maneuvers in detail. Especially the procedures from section 2.1 and section 2.2 as well as further tasks like keeping the aircraft aligned to the centerline were explained.

3.5. Simulator Session

In the simulator a checklist for each takeoff was handed out to the participant. It contained the procedure and could be examined before each takeoff.

The participant got a short in-situ presentation of the simulator cockpit and the simulator functions followed by an familiarization phase. As soon as the test person felt comfortable enough with the simulator and the takeoff procedure the experiment began. After each trial the subjective ratings for each takeoff had to be evaluated. After each takeoff the own performance, the personal mood and the overall safety were rated by the participant by answering six questions. For each takeoff type six trials had to be carried out. The first takeoff was always without any wind. The two remaining variables being crosswind and head wind conditions were randomized.

In the experiments the setup of the simulator was changed. Either the conventional thrust lever or the jump takeoff lever was used. As soon as the jump takeoff lever had to be used the conventional lever had been hidden by a black case. The other way round, covering of the jump takeoff lever, was not necessary, because it is situated at a peripheral position of the cockpit.

3.6. Data acquisition

All data concerning cockpit inputs and flight physics was recorded via the simulator interface. The complete simulator record stream contains 60 channels.
Further data was generated by the eye tracking tool. Especially the planes of viewpoint as well as the focus on special instruments were taken into account in the evaluation. Questionnaires concerning the personal impressions were used as subjective data.

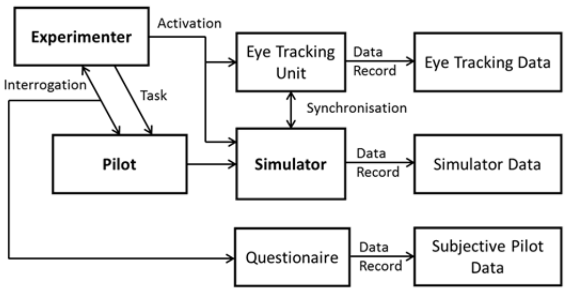

Figure 13: Data sources and data recording

All data were brought together in SPSS [10] to evaluate and to present the results in an appropriate manner.

4. RESULTS

4.1. Objective Data

Each subsection of this section is dedicated to an exemplary dependent variable to briefly present the outcomes of the experiment.

Aborted Takeoffs
All takeoffs that have been carried out were classified into successful takeoffs or aborted takeoffs. Each takeoff procedure that ended in a normal climb phase was registered as a successful takeoff. The other trials were takeoffs that had to be aborted due to severe piloting errors on the ground or due to crashes. The gyrocopter pilot group did not cause any aborted takeoff, for the airplane pilots 5% of the conventional takeoffs ended unsuccessfully but all jump takeoffs were successful. In case of the two groups without any license the number of aborted takeoffs was close to 10%.
Obviously gyrocopter pilots as well as fixed-wing pilots were able to adapt quite fast to the new procedure for the jump take off. Only one conventional takeoff trial of a fixed-wing pilot had to be aborted.

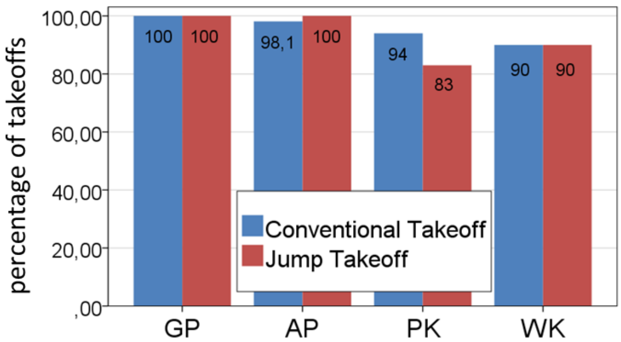

Figure 14: Rate of successful flights according to groups

The results for the group of participants without any knowledge were expectable due to a complete lack of flying experience. Interesting is the performance of those participants that have some simulator experience or aviation knowledge. They performed better for the conventional takeoff, which is the most common type of takeoff in aviation. Moreover, they performed even worse in jump takeoffs than those without any knowledge.

Tail Strike
A very typical pilot error for gyrocopter student pilots is the tail strike with the runway. The quickly increasing pitch-up moment surprises the pilot who has to react as fast as possible to counteract the pitch-up motion.

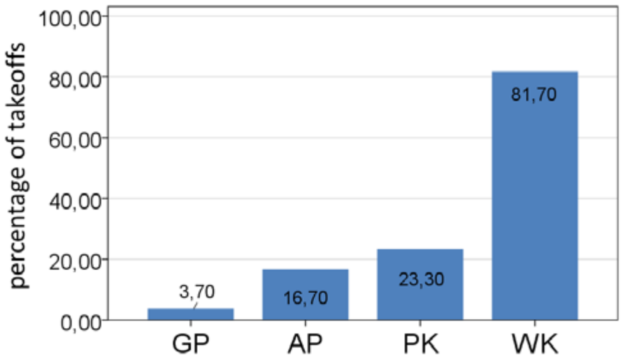

Figure 15: Rate of tail contacts according to groups

As expected most tail contacts occurred in the group of participants without prior aviation knowledge. The high percentage of 80 % shows that these participants were in general hardly capable to prevent that situation.

In the briefing the tail contact was not highlighted as a major error that necessarily leads to an aborted takeoff. Pilots and those with some pre-knowledge are aware that the tail contact is a threat to the aircraft and causes potentially harmful damages to the latter.

Stick Position Control in Conventional Takeoff

Pulling the stick to the full aft position in the beginning of the takeoff is a very important issue. Every participant was explicitly told to do so. Some of the fixed-wing pilots, who also started too late to pull, did not reach the end position because they moved the stick too smoothly.

A very remarkable effect is that those without aviation knowledge followed the instruction in each case, while those who had some experience did not. Either they thought to know better and did not follow the instruction or their attention was bound by any other aspect that did not influence the group of participants without prior knowledge.

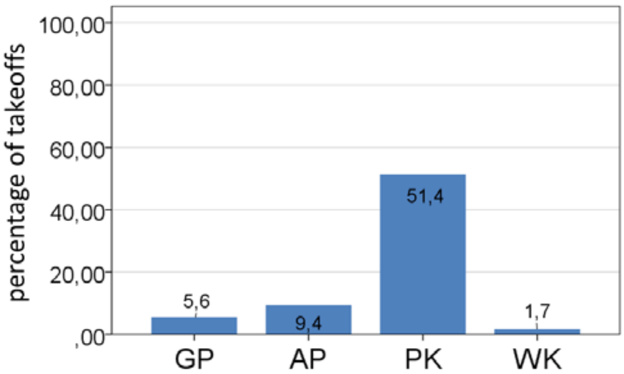

Figure 16: Inappropriate stick use in takeoff run (pulling to the limit)

In some other cases the use of the stick also did not comply with the conventional takeoff procedure. The procedure demands a fully pulled stick in the acceleration phase on ground. Pulling the stick from the front most to the rearmost position shall be done smoothly within roughly one second. Figure 17 shows in how many cases the stick was moved rather slowly and in the meantime the gyrocopter already accelerated to 30 km/h. A very clear peak could be seen for the fixed-wing pilots. For them pulling the stick at beginning of the takeoff is very different to their normal fixed-wing takeoff procedure.

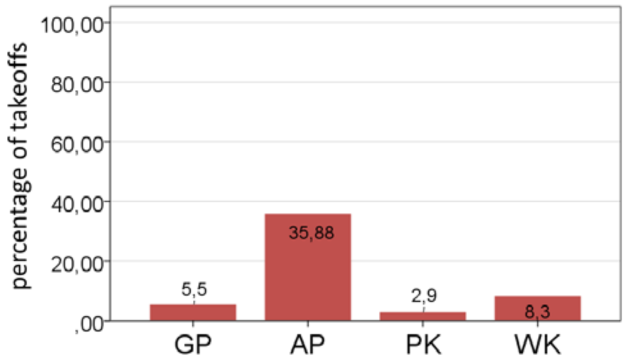

Figure 17: Inappropriate stick use in takeoff run (stick reaches rearmost position after gyrocopter accelerates to more than 30 km/h)

Collective Lever Control in Jump Takeoff

To use the rotors full lift potential it is not absolutely necessary to apply the collective lever to its maximum extent. However, to facilitate the procedure and to design it similar to the conventional procedure the pilots were advised to move the lever to the maximum deflection possible and to hold it. Again the participants without prior experience followed the procedure in most of the cases. The other groups began to modify the maneuver and did not move the lever to its maximum in more than 10% of all cases.

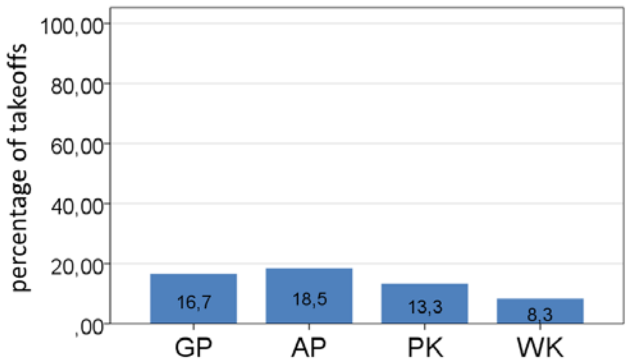

Figure 18: Inappropriate use of collective lever (not fully thrown)

The difficulty in using the collective lever is to release it as early as possible. To prevent a strong flapping motion of the rotor blades the pilots should monitor the speed and reconfigure the rotor to a blade incidence angle of $\varepsilon = 2.5°$ until a speed of 75km/h is reached.

Figure 19 shows in how many cases the collective had not been brought down to the first lock position before 80 km/h were reached. The group of fixed-wing pilots performed best. Airspeed is the most important indication for general aviation airplane pilots. They are trained to be aware what their airspeed is. Hence their good performance is explainable. For gyrocopter pilots the airspeed normally plays only during approach and landing a very important role. Pilot actions are not triggered by speed but by particular events like the upcoming pitch-up moment.

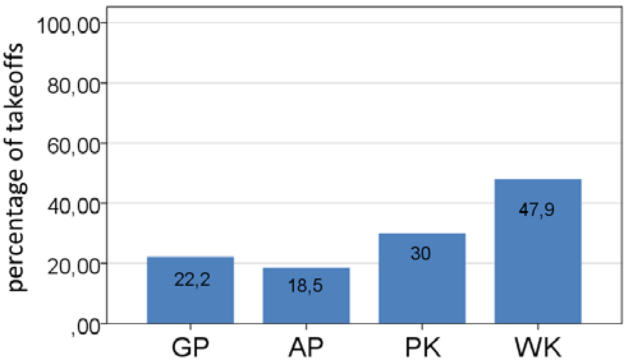

Figure 19: Collective lever not yet released at speeds higher than 80 km/h

For each blade incidence value during the jump takeoff there is a speed limit at which the flapping of the blades becomes too intense. This limit depends on rotor rotational rate, blade geometry and airspeed.
Analytical analysis shows that at a flight speed of 100 km/h and at a blade incidence of 6° a flapping angle of 5° is reached. Moreover to get to those 5° the rotor rotational rate has to drop down to the steady state value of 260 rpm. This should be prevented by a correct use of the jump takeoff procedure. But even if this flapping is prevented the remaining angular margin for control inputs is always limited by growing flapping angles.

Excessive Attitudes

In order to evaluate pilot performance the Euler angles of the vehicle were logged. Difficulties in controlling the aircraft do not necessarily lead to an aborted takeoff or a loss of the airplane. But they can be identified in past data analysis by comparing the recorded Euler angles with the expected Euler angles in the corresponding maneuver.
The best indicator for classifying the overall performance of all participants is the comparison of the roll attitudes. In general for takeoff maneuvers the magnitude of the roll angle should be as small as possible (cf. Figure 20). Only the maximum values during the whole takeoff are displayed. The pitch angle of both maneuver are not compared, as the expected pitch angle characteristics are completely different for both procedures.

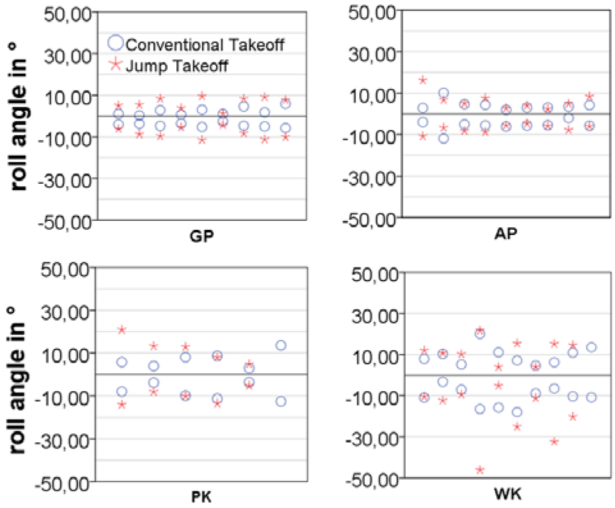

Figure 20: Excessive attitudes, maximum values roll angle for cross wind takeoffs

Flight Path Deviations

Figure 21 displays the maximum distance to the runway centerline during the whole takeoff maneuver. Most of the pilots show only minor displacements. But those displacements of the pilot groups are in general bigger for the jump takeoffs. As expected both groups without license show a worse performance, but there are no significant differences when comparing the two takeoff procedures.

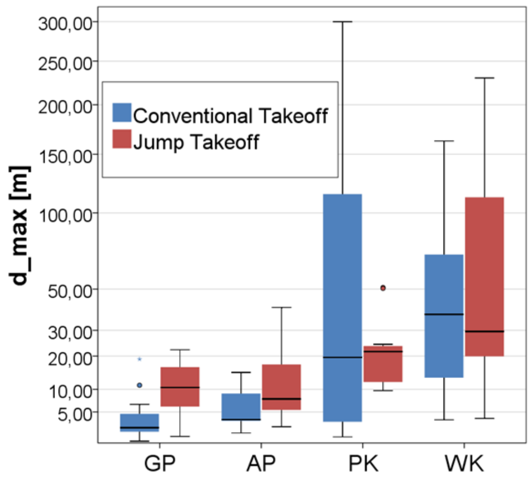

Figure 21: Maximum distance to centerline

Trajectories

Figure 22 and Figure 23 show some good examples of trajectories flown in the experiment. Since the conventional takeoff begins horizontally and generally is flown with a constant rate of climb, those takeoffs in general appear smother than the jump takeoffs. Most of the pilots had some variations in their takeoff trajectories. During the jump takeoff the pilots reduced the collective in different altitudes, because also the acceleration phase and the speed,

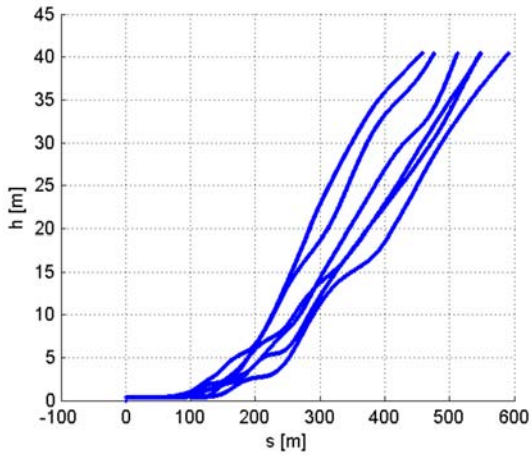

Figure 22: Typical trajectories for a series of six conventional takeoffs

that triggers the reduction of the collective was characterized by some variations. Those variations were caused by the difference in the coordination between the collective input, the thrust input and and the cyclic input to stabilize and to accelerate. All of the participants were untrained for jump takeoffs. So variations in this high gain task are very likely. The most demanding phase of the takeoff is very short and at the beginning of the flight segment. That influences the following phases of the takeoff, where possible deviations must be compensated.

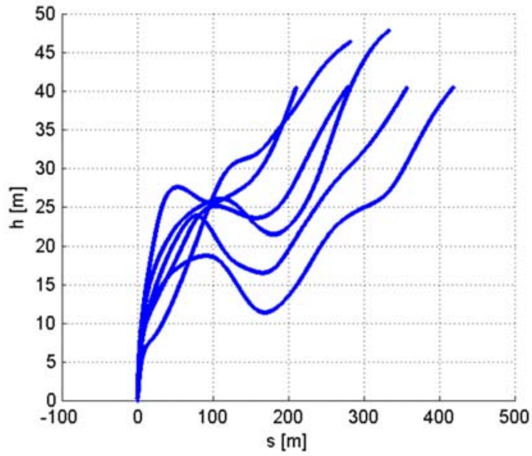

Figure 23: Typical trajectories for a series of six jump takeoffs

4.2. Subjective Data

Pilot Questionnaires
As additional data source questionnaires were answered by the pilots. Examples of those questions are:

- Which takeoff demands more difficult hand coordination?
- Which takeoff procedure was more stressful?
- Which takeoff procedure would you recommend as the standard?

Figure 24 presents the answers to the question on the hand coordination. The answers to this question are balanced between the groups. Roughly 80% of the test persons emphasized, that the hand coordination is easier for the conventional takeoff procedure. Especially the use of the combined collective and thrust lever was absolutely new to all of the participants. The introduction and exercise phase seems to be too short to sufficiently adapt to the new system.

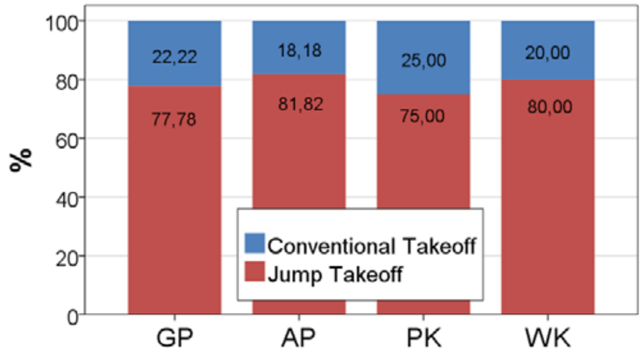

Figure 24: Questionnaire: Which takeoff demands more difficult hand coordination?

Figure 25 shows the results for the question: Which start procedure was more stressful?
Gyrocopter pilots as well as all participants without a license replied to a rate of approx. 80% that the jump takeoff is the more stressful takeoff procedure. The airplane pilots, who are used to takeoff in a comparable manner to the conventional gyrocopter takeoff, answered to 100% that the jump takeoff caused more stress.

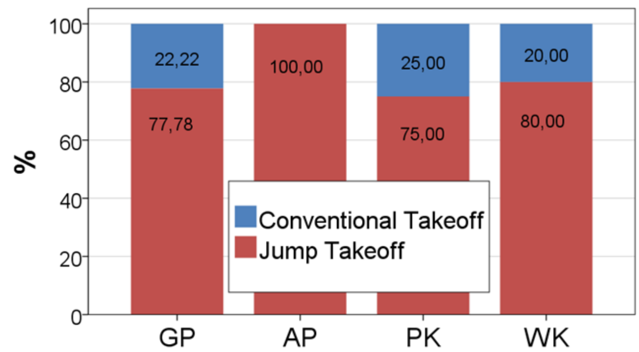

Figure 25: Questionnaire: Which takeoff procedure was more stressful?

At the end of the experiment the pilots were asked which takeoff procedure they would recommend to define as the standard procedure.
The answer to this question might reflect also a certain enthusiasm of some participants facing the possibility of taking off vertically. The majority of the gyrocopter pilots, who performed well, recommended the jump takeoff, even if they described it to be more challenging and more stressful.

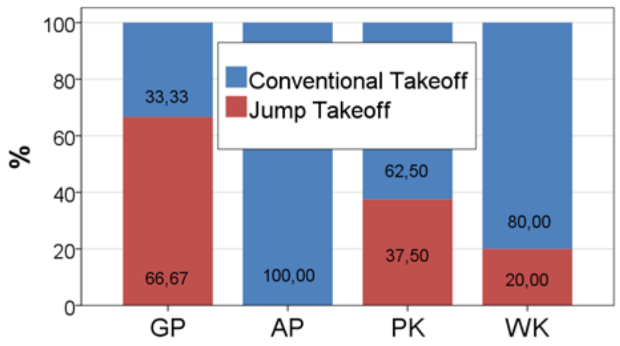

Figure 26: Questionnaire: Which takeoff procedure would you define as the standard?

4.3. Eye tracking Data

The tracking of the pilots eye focus provides information on what the pilot concentrates on at a certain moment. Figure 27 presents the distribution of areas of interest for the conventional takeoff. Predominant for the pre-rotation phase (PR) is the focus on rotor and engine indications. As soon as the gyrocopter accelerates in phase 3 (G-AC) the view is focused on the runway and the airspeed.

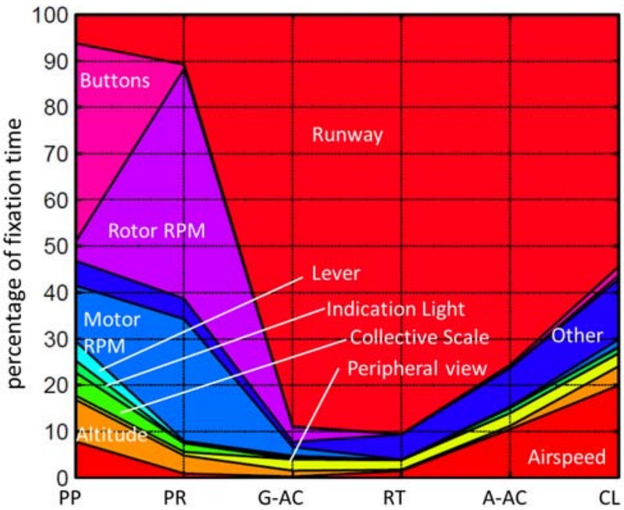

Figure 27: Eye-tracking data for conventional takeoff and gyrocopter pilots (PP preparation, PR pre-rotation, G-AC ground acceleration, RT rotation, A-AC air-acceleration, CL climb)

Figure 28 shows the corresponding data for the jump takeoff. During the whole takeoff procedure the pilots pay comparatively more attention to the peripheral field of view. As expected instruments especially designed for jump takeoff such as the control light and the collective angle indication scale are used in the preparation and pre-rotation phase.

In phases 5 and 6 (in-air acceleration A-AC and climb CL) the focus of the view is wider spread than for the conventional takeoff case. Especially at the end of the flight the pilots monitor various instruments and also the collective lever.

In general more attention is given to the airspeed in phase 5 (A-AC) and to the altitude in phase 6 (CL).

The graphs show, that for a conventional takeoff procedure only airspeed and the view straight forward are sufficient to fly for a gyrocopter pilot, but for the jump takeoff also the peripheral field of view is relevant.

The focus on the cockpit instruments in the climb segment (CL) can be understood as general check-up to ensure that the takeoff was successful and all parameters are as desired.

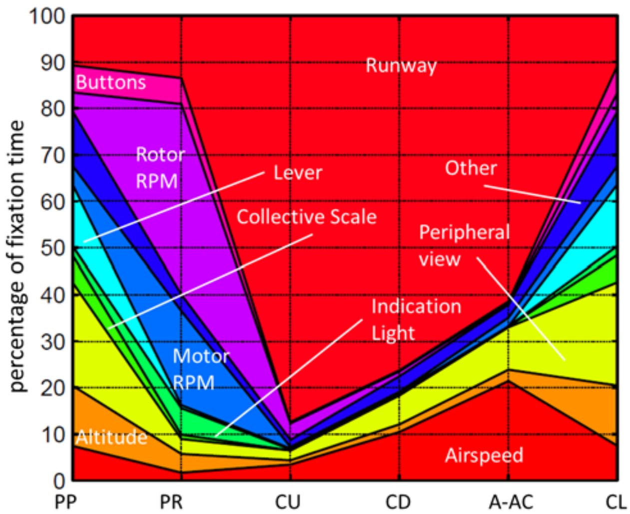

Figure 28: Eye-tracking data for jump takeoff for gyrocopter pilots (PP preparation, PR pre-rotation, CU collective up, CD collective down, A-AC air-acceleration, CL climb)

The results of the fixed-wing pilot group are presented in Figure 29 and Figure 30. Comparing the fixed-wing pilot's focus of attention to the gyrocopter pilots shows that the fixed-wing pilots use the airspeed indication more intensely during both takeoff procedures.

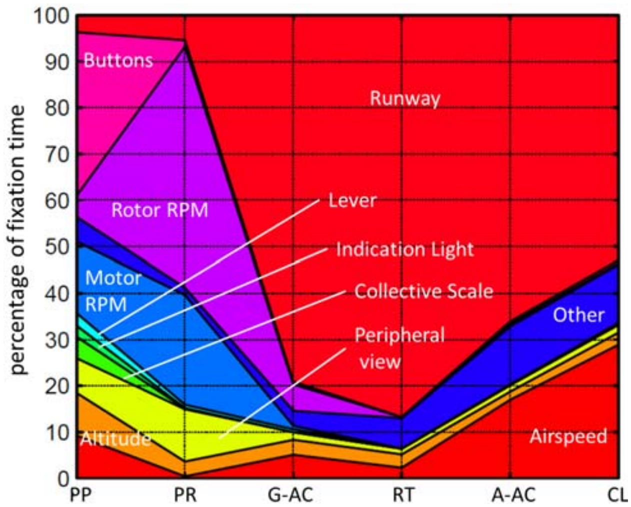

Figure 29: Eye-tracking data for conventional takeoff and fixed-wing pilots (PP preparation, PR pre-rotation, G-AC ground acceleration, RT rotation, A-AC air-acceleration, CL climb)

During all jump takeoff phases the airspeed indicator is significantly used and during the conventional takeoff as soon as the rotation took place.

Similar to the group of gyrocopter pilots for the fixed wing pilots the use of the altitude indication is more relevant for the jump takeoff.
The use of the indication light and the collective scale are within the same range in which they were for the group of gyrocopter pilots.

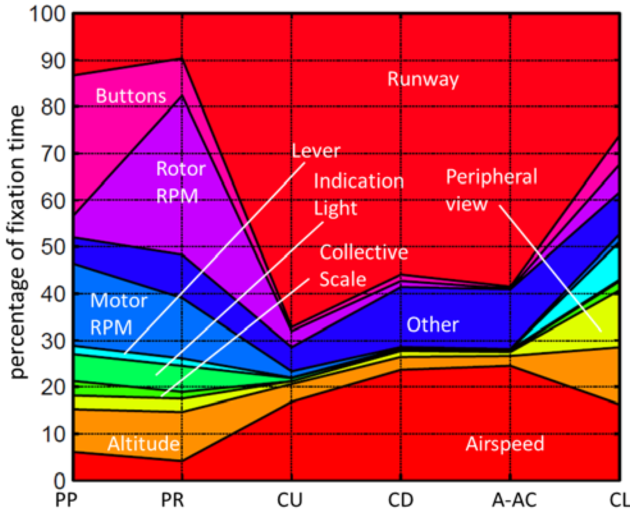

Figure 30: Eye-tracking data for jump takeoff for fixed-wing pilots (PP preparation, PR pre-rotation, CU collective up, CD collective down, A-AC air-acceleration, CL climb)

While for gyrocopter pilots during the jump takeoff some attention is shifted to the airspeed indication, peripheral view and altitude indication the fixed-wing pilots focus more on the combination of speed indication and altitude indication.

It can be found, that the rotor rotational rate instrument is nearly not used after the pre-rotation phase. This is not surprising for the airplane pilots, because they are not used to have such an indication. But even the gyrocopter pilots didn't use it during the jump takeoff. Nevertheless, the knowledge of the rotor rotational rate might be of great importance for energy management tasks.

5. CONCLUSION AND OUTLOOK

The experiment underlined that the jump takeoff is feasible for most of the pilots with flight experience. Already after a short introduction of half an hour all takeoffs performed by gyrocopter pilots were successful. Also airplane pilots showed good results.
Errors arising from a lack of concentration like the tail strikes during the conventional takeoff or the over-speed cases during the jump takeoff are of a comparable number for both groups without any license.
The procedure related errors appear in both takeoff scenarios. Particularities depending on the participants group could be found especially for the conventional takeoff procedure. Especially fixed-wing pilots and the group of those with pre knowledge and no license did pull the stick to gentle or not to the end positon in the beginning of takeoff run.
The comparison of maximum roll attitudes and maximum distances to the centerline for both takeoff procedures underlines that the piloting performance was better for the conventional takeoff for the groups of gyrocopter pilots and fixed-wing pilots.
In some cases the mental abilities were brought to the edge during the untrained and unknown maneuver. The subject ratings underline that the jump takeoff requires more concentration and causes more stress.
The eye tracking data showed that in certain phases of the jump takeoff the attention is bound to a higher extend to multiple areas of interest than for the conventional takeoff case. The fixation on instruments such as the airspeed and altitude indicators reduces the potential to monitor the forward airspace and the runway.
The collective angle indication was not used in phases even when the collective lever was moved. Consequently such an instrument does necessarily not need to be installed in the instrument panel. Another outcome is that the rotor rotational rate was not monitored, even if it could provide important feedback on the remaining energy stored in the rotor.
The study showed that normal piloting skills are adequate to perform jump takeoffs. Even most of the airplane pilots could safely perform the new type of takeoff procedure. Nevertheless the stress during the jump takeoff is higher than for the conventional takeoff. Additionally reactions in failure cases have to happen very quickly with a perfect awareness of the rotor states and the vehicle speed and height.
Training of such events is strongly recommended. For such training sessions simulators should be used as soon as the first jump takeoff systems are installed. Furthermore an aural feedback on the rotor rotational rate might help to increase the pilot's awareness on the available rotor energy (similar to a variometer in a glider), while being able to focus on the view outside to control the aircrafts attitude and on the speed indication. A semi-automatic use of the collective could also help to perform ideal collective inputs and reduce the pilot's workload.
Each jump takeoff violates the H-V-diagram for conventional gyrocopters. But this diagram cannot be applied to the jump takeoff, because it does not consider the energy reservoir of the rotor. To design new energy-based emergency procedures for the jump takeoff more research in this field has to be conducted.

Nomenclature

Variable	Description
$C_{w,tot}$	Total drag coefficient
D_b	drag of fuselage
D_{Bl}	Bladeelement drag
D_{Stab}	Stabilizer drag
D_{tot}	Overall drag
D_P	Parasitic drag
D_R	Rotor Drag
E_{Rot}	Rotational energy
E_{Kin}	Kinetic energy
F_{Prop}	Propeller thrust
F_R	Rotor Force
G	Weight
J_R	Rotor inertia
$K_{\beta 0}$, $K_{\beta 1}$	Constants of flapping equation
L_{Bl}	Blade element lift
L_{Stab}	Stabilizer lift
R	Resulting force vector
V	Airspeed
V_{Bl}	Blade element inflow velocity
d_max	Maximum distance to centerline
h	Altitude
r_R	Rotorradius
s	Distance
t_{Bl}	Blade chord
u_{Bl}	Blade element horizontal inflow
v_i	Induced velocity
w_{Bl}	Blade element vertical inflow
x_f	Fuselage x-axis
z_f	Fuselage z-axis
α	Angle of attack
α_{Bl}	Blade angle of attack
α_R	Rotor angle of attack
β_{fw}	Longitudinal flapping angle
ε_R	Rotor blade incidence
η_{RH}	Rotor head pitch angle
μ_R	Advance ratio
ρ	Air density
Ω_R	Rotor rotational rate

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