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Abstract: This study examines the impact of alcohol concentration on the precision of unmanned aerial vehicle (UAV) operations. While the impact of alcohol impairment on various activities is well documented, its specific influence on drone piloting accuracy remains less studied. To address this, we carried out empirical research using an original methodology and a real-world environment. The study involved a group of 35 participants performing a series of flights using a selected drone (DJI Mavic2 Pro) on a bespoke obstacle route. Between each flight series, participants consumed a measured amount of alcohol, designed to incrementally increase their blood alcohol concentration monitored via breath tests. The precision of the drone pilot was evaluated by comparing various parameters from successive test flights, such as time, distance, average speed, and incident frequency, against a baseline trial executed with zero alcohol concentration. Our results indicate a noticeable decline in UAV piloting precision corresponding with increasing alcohol concentration. Parameters such as flight time, distance, speed, and incident frequency all demonstrated this trend. We conclude that alcohol consumption detrimentally affects the accuracy of drone operations. These findings underscore the need for clear policies and guidelines regarding the operation of UAVs under the influence of alcohol.

Keywords: UAV; alcohol impact; flight precision; UAV control

1. Introduction

Unmanned aerial vehicles (UAVs), often referred to as remotely piloted aircraft systems or simply drones, have significantly revolutionized many areas of human activity. They initially provided considerable support for monitoring and data collection processes for military purposes. Undoubtedly, the dynamic development of UAVs is influenced by modern technologies, such as CAx (Computer-Aided techniques) that increase the precision of the design of drone components, incremental methods used in the manufacture of components that improve their durability, as well as advanced information systems that support communication between the UAV and the operator or algorithms that optimize energy management [1–5]. Nowadays, drone manufacturers market offers a wide range of solutions with a variety of parameters, dedicated to performing specific types of aerial operations. UAVs are increasingly utilized in various civil and commercial fields, such as

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entertainment, agriculture, forestry, mining, disaster management or climate change monitoring, to name but a few [6–10]. This rapid development is fueled by both technological improvements and regulatory changes that have opened up new avenues for drone usage [8,11]. The global market for civilian drones has been valued at a substantial $73.5 billion from 2017 to 2026, a figure that mirrors the combined annual GDP of Lithuania and Latvia. Meanwhile, the European market claims a significant portion, with an estimated worth of $20.7 billion [12]. It showcases the growing trend of civilian drone use and potential market opportunities [13].

One of the most important aspects of the use of unmanned aerial vehicles is safety, relating to the correct preparation for operations and the correct execution of the flight [14]. For instance, possible effects of collisions between UAVs and representatives of natural world, such as birds, could be detrimental both to the systems, as well as living and non-living components of the environment [15]. Human collisions with drones can lead to significant injuries, the severity of which may span from minor to potentially life threatening. Such occurrences can feasibly precipitate in fractures of the ribs [16]. Factors affecting flight safety include conditions related to the device (e.g. technical health of the drone or the employed safety systems), environmental circumstances (e.g. weather conditions or presence of airborne objects at the flight location) and the pilot of the unmanned aircraft (e.g. skills or psychophysical state), of which the key influence on safety is the human, as the active element of the system responsible for decision-making [17–21]. Reducing the risk of a crash is achieved through the implementation of sensors to detect the possibility of a collision [22–24].

This article explores the safety aspects related to flight operations of the UAVs with specific focus on the pilot's ability to accurately maneuver the device, which is significantly affected by the pilot's psychophysical condition. Factors such as fatigue, stress, illnesses or consumption of various intoxicating substances such as alcohol can greatly influence the pilot's capacity to effectively control the drone [25].

The pervasive impacts of alcohol on human cognitive function are widely acknowledged. This issue has been extensively researched, specifically in the realm of aircraft piloting, long before drones became easily accessible to the public. Alcohol consumption severely impairs a pilot's ability to operate an aircraft, impacting essential functions such as coordination, instrument interpretation and navigation, with detrimental effects persisting even hours after drinking [26]. Alcohol consumption has far-reaching physiological and psychological effects, notably impairing liver function, heart contractions, and cognitive abilities, which directly impact a pilot's capacity to safely operate aircraft, including UAVs. Moreover, visual acuity, critical in aviation, can be significantly compromised by increased alcohol usage, therefore, stringent regulations for pilots and drone operators, including registration, licensing, and alcohol prohibition, are enforced globally to ensure public safety and minimize the risk of accidents [27–29].

A review of the references disclosed a number of scientific publications dedicated to the issue of alcohol-induced effects on the human body. However, analysis of the literature revealed a significant lack of studies specifically addressing the aspect of UAV pilot precision as a function of alcohol concentration. This paper aims to fill that gap, undertaking a thorough analysis of alcohol's impact on human cognitive abilities. Paper [30] investigates the impact of hypoglycemia and minor alcohol concentration on pilot reaction time, finding that a blood alcohol concentration (BAC) of 0.2 ‰ translated into slower reaction times and an increased number of erroneous decisions. The impact of physiological factors on pilot ability and flight safety was addressed in a paper [31], which comprehensively explored the effects of factors such as hypoglycemia, fatigue, heat and noise on pilot proficiency and flight safety. Notably, hypoglycemia and fatigue were the leading contributors to errors committed by pilots. The influences of alcohol, hypoglycemia, and noise on pilot precision during simulation testing were examined in paper [32], with results pointing to hypoglycemia and alcohol as substantial detractors from flying precision. Paper [33] describes the detrimental effects of various levels of alcohol concentration on human performance. For instance, it was observed that a concentration of 0.1‰ causes distraction 0.2‰ prolongs perceptual time, 0.3‰ impairs coordination and shape perception, 0.5‰ hinders judgement, 0.8‰ induces misjudgment of personal abilities, and a concentration exceeding 1.0‰ leads to impaired intellectual performance, delayed reaction time and instigates recklessness. The research in paper [34] evaluates drivers' reaction times in relation to blood alcohol concentration. The results showed that reaction times nearly doubled at a concentration of 1.5‰, with measurements based on braking distance of 50 km/h, and footage from two cameras. Lastly, the study [35] investigated the deleterious effects of alcohol on vehicle operators, analyzing their behavior and performance during simulation tests at varying alcohol concentrations. Results indicated that a concentration of 0.03‰ leads to physiological disturbances.

Across various countries, the regulatory landscape concerning drone operation is broad and nuanced. Stringent rules often prohibit drone operation under the influence of alcohol or drugs, as this can lead to diminished control precision and increased potential for accidents [36]. Moreover, many jurisdictions necessitate an operator to be in a satisfactory psychophysical state, without fatigue or impairment, to ensure safe and responsible drone flights. This approach reflects an international consensus on the detrimental impact of alcohol on the operation of unmanned aerial vehicles [37,38]. Current regulations in the European Union stipulate that unmanned aircraft operators are prohibited from undertaking their duties while under the influence of alcohol, psychoactive substances, or drugs. This restriction also applies in instances of fatigue, illness, or any other conditions that could compromise their ability to concentrate [39].

The main objective of this paper was to evaluate the impact of alcohol concentration on the precision of unmanned aerial vehicle control throughout a series of test flights. The research was conducted based on the original methodology, involving six flight tests using a DJI Mavic2 Pro drone along a pre-determined route. A group of 35 participants was chosen for the study and each consumed a designated dose of alcohol between successive flights. The body's alcohol concentration level was ascertained by analyzing exhaled air, measured with a breathalyzer. Pilots' precision was gauged through factors such as distance covered, flight duration, average speed and number of incidents, all compared against a baseline flight completed sober.

The article is structured into several sections. Section 1 provides an introduction to the issues under examination. Section 2 reviews the literature concerning the effects of alcohol on the pilot of an unmanned aircraft, referring findings from previous studies Section 3 outlines the research methodology employed, detailing the procedures used gathering measurements, along with the materials and equipment involved. Section 4 discusses the results collected during the measurements, including the distance covered, flight times, average speed and the number of mistakes committed by individual pilots. Section 5 presents the conclusions drawn from the study and provides a thoughtful discussion of the results.

2. Materials and Methods

2.1. Research Group and Equipment

The study's research group comprised a representative sample of 35 individuals of both sexes, aged between 22 and 42, all with varying levels of UAV piloting experience. Every participant confirmed that they were in good health and that there were no contraindications preventing them from taking part in the measurements. Participants were categorized into three groups according to their drone flight hours: beginner pilots (less than 10 hours), intermediate pilots (between 10 and 50 hours) and advanced pilots (more than 50 hours). The beginner group included 12 pilots, the intermediate group included 15 pilots and the advanced group comprised eight pilots.

Test flights were conducted using a Mavic2 Pro drone, produced by DJI, a rather popular choice among users. The basic parameters of the unmanned aircraft used are presented in Table 1.

Table 1. DJI Mavic2 Pro basic parameters.

No.	Parameter	Value
1.	Take-off weight	907 g
2.	Dimensions (unfolded)	322×242×84 mm
3.	Dimensions (folded)	214×91×84 mm
4.	Maximum speed	72 km/h

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5.	Maximum altitude	6000 m n.p.m.
6.	Maximum flight time	31 min
7.	Range	8 km
8.	Climbing speed	5 m/s
9.	Descent speed	3 m/s
10.	Collision avoidance system	Omnidirectional sensors, positioned at the top, bottom, front, rear and sides of the drone.

Source: [40].

The testing took place at the Aviation Research Center of the Warsaw University of Technology, situated in Przasnysz (53°00′35.8″N 20°55′59.5″E). The execution of the flights required the design and preparation of a test route, marked by bollards and wooden slats enclosed by lagging. Pairs of bollards along the flight paths formed 1.5m-wide gates. Distances between each gate varied, requiring pilots to execute turns at diverse angles. The course also included straight sections where pilots could increase their speed. The starting point served as the finish line as well, marking completion of a full lap around the predetermined flight path. The total length of the route was approximately 400 m with twelve gates placed along its length. The test route is depicted in Figure 1.

Figure 1. Test route.

The amount of alcohol consumed by the participants was measured using a scale accurate to 0.1 g. To gauge the concentration of alcohol in exhaled air, a Promiler ALP-1 LITE breathalyzer was employed with a measurement range of 0.00 ‰ to 5.00 ‰ and an accuracy of 1.0 ‰ ± 0.03 ‰. device automatically converts the concentration in exhaled air to a blood concentration value.

2.2. Research Process

The research employed an original methodology developed specifically for this study and the utilized equipment. According to this methodology, the precision of the UAV pilot was evaluated based on the following parameters: the time taken to complete the track from drone lift-off to crossing the final gate, measured with a stopwatch; the number of incidents involving the gate posts, determined through observation of the flights; and the distance covered by the drone during flight, as reported by the device's control system via Global Positioning System (GPS). Flights were carried out at approximately 1.6 m height, which did not require prior notification of the operation. The flight site was secured against unauthorized access in order to maintain an adequate level of safety during the trials.

The methodology of the study design included six flight series along the same route for each participant, conducted in First Person View (FPV) control mode. Successful completion of a single flight required navigating through all 12 gates along the route. The initial flight was performed sober, providing a reference for the subsequent five flights, between which participants consumed individually determined doses of alcohol. These doses were calculated based on each participant’s

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BMI derived from their weight and height, and an interview conducted prior to the study. Flights were spaced roughly 30 minutes apart. Before each flight, a breathalyzer measurement was taken to determine the participant's BAC.

3. Results

Table 2 presents a summary of all collected results from each series of test flights for all participant groups (Beginners - B, Intermediate - I, Advanced - A). It includes recorded values for alcohol concentration, distance travelled during flight, time taken to complete the course, average flight speed and number of errors.

Table 2. The summary of all the results.

No.	Parameter	Group	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6
1.	Alcohol concentration of participants [‰]	B	0,00	0,12	0,34	0,51	0,78	1,04
		I	0,00	0,15	0,37	0,61	0,75	1,02
		A	0,00	0,19	0,40	0,67	0,82	1,04
2.	Distance travelled [m]	B	485,3	527,0	545,1	542,3	558,3	561,7
		I	429,2	442,5	434,2	445,5	471,4	466,0
		A	420,9	427,9	427,9	430,2	425,7	440,0
3.	Time taken to complete track [s]	B	251,0	275,8	288,8	295,5	301,7	303,2
		I	216,9	226,0	223,0	231,7	243,8	250,4
		A	201,1	209,2	211,7	213,9	217,8	228,3
4.	Average velocity [m/s]	B	1,93	1,91	1,89	1,84	1,85	1,85
		I	1,98	1,96	1,95	1,92	1,93	1,86
		A	2,09	2,05	2,02	2,01	1,96	1,93
5.	Number of committed mistakes	B	2	3	4	8	10	15
		I	1	2	4	6	8	10
		A	0	1	2	5	6	10

Figures 2–6 provide graphical representations of the results garnered from the tests. Figure 2 displays measurements of alcohol concentration, while Figure 3 presents the averaged distance flown, Figure 4 depicts the flight time results and Figure 5 illustrates the average speed maintained during the entire flight. Finally, the number of incidents that occurred were indicated in Figure 6.

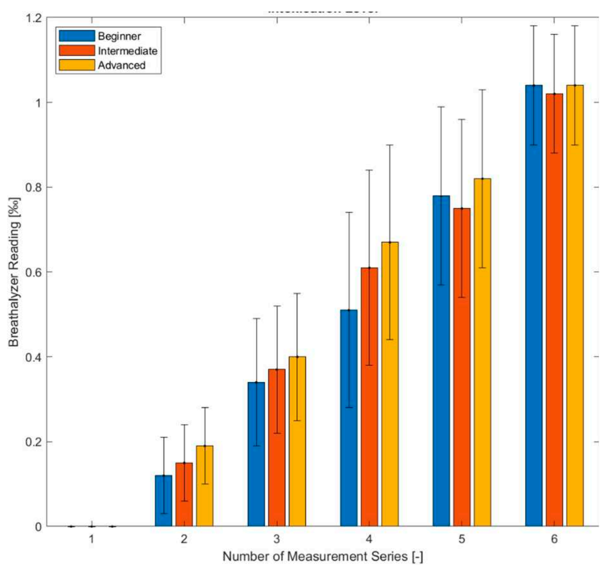

Figure 2. Alcohol concentration of participants [‰].

Figure 2 illustrates that the blood alcohol concentration of participants increased in a linear manner. Based on this figure, a similar proportion of increase in alcohol levels across all participant groups was observed. According to the World Health Organization (WHO) [41], alcohol concentrations exceeding 0.6‰ are associated with impaired attention, impaired concentration, delayed reaction time, deteriorated motor coordination, and reduced patience. This can also negatively affect decision making and judgement. When alcohol levels exceed 1.00‰,the reaction time is further delayed, and could translate into vision impairment. Breathalyzer tests performed before the final flight series indicated participants had reached concentrations exceeding 1.00‰. This suggests that the participants were operating UAV in a state that significantly impeded concentration and delayed reaction time.

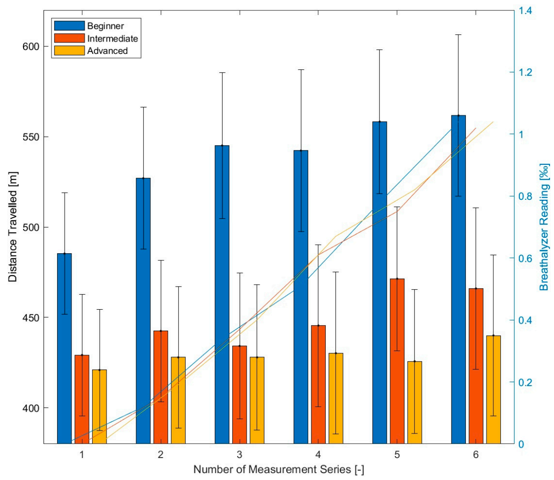

Figure 3. Distance travelled [m].

Figure 3 reveals that during each series of test flights, the participants in the beginner group (B) covered the longest distances, significantly exceeding those measured for intermediate (I) and advanced (A) participants. This could be linked to the lack of experience of the beginner group (B), corresponding to lower precision in piloting the UAV, which in turn resulted in the need for frequent flight path corrections. The shortest distances were registered for the advanced participants (A), reflecting their high precision in piloting. Furthermore, Figure 3 reveals that as the alcohol concentration rose, the distance travelled by all participants also increased, suggesting a degradation in the precision of UAV maneuvering capabilities.

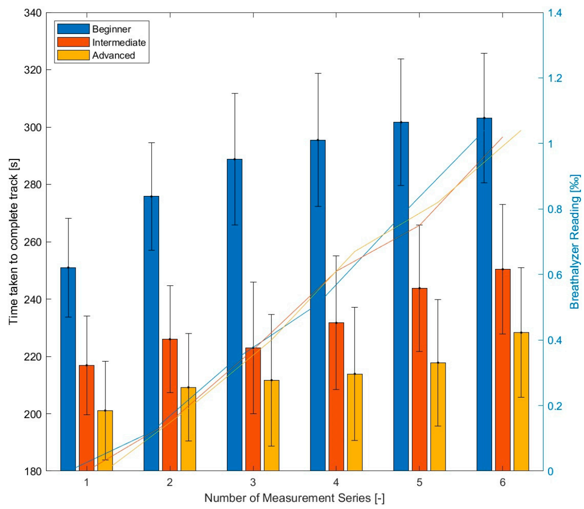

Figure 4. Time taken to complete track [s].

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The time required to complete the flight route, as depicted in Figure 4, aligns with the distance measurements, indicated in Figure 3. Participants in the beginner group (B) took significantly more time to complete the route relative to those in the intermediate (I) and advanced (A) groups. As with the distance data the time taken to complete the route increased as alcohol concentration levels rose across all participants groups. Advanced participants (A) displayed the best performance, which can be attributed to their high UAV piloting skills. The increase in flight duration could be linked to longer distances traversed during successive runs and correspondingly lower speeds.

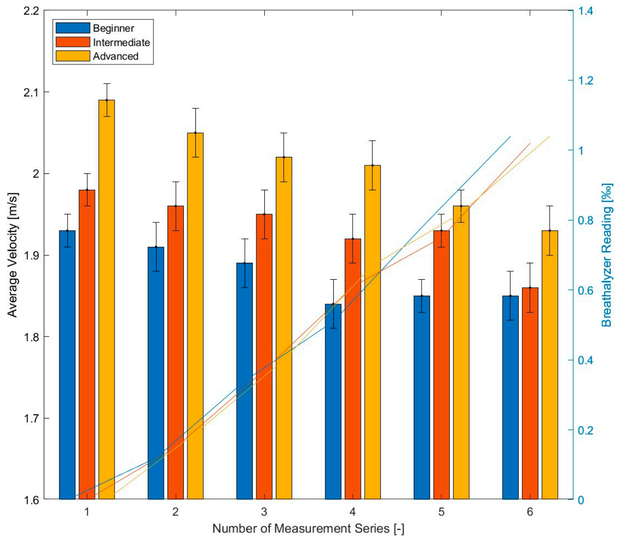

Figure 5. Average velocity [m/s].

The average flight speed results, presented in Figure 5, show that the advanced group (A) consistently attained significantly higher speeds throughout each measurement series. On the contrary, the lowest average flight speeds were registered for the beginner group (B). By the final flight series, the average speed for the beginner group (B) was comparable to the results achieved by the intermediate group (I). As the participants' alcohol concentration increased, a substantial decline in average flight speed was observed across all groups.

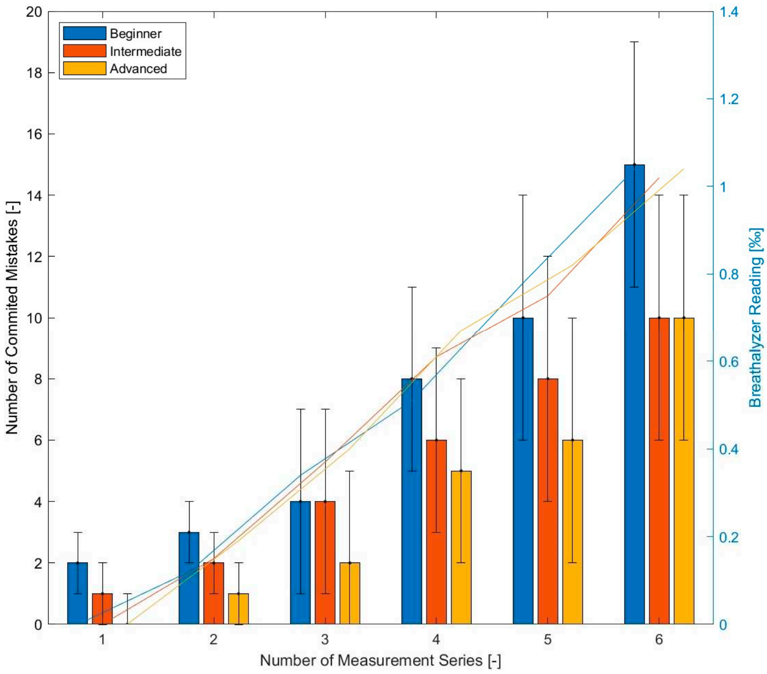

Figure 6. Number of committed mistakes.

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Figure 6 illustrates a rise in the number of errors committed during successive flight series correlating with increased alcohol concentration across all participant groups. The beginner participants (B) recorded the highest count of errors in each flight series with the exception for series 3, where the intermediate participants (I) matched their error number. The advanced group (A) made the fewest mistakes, except for series 6, where the intermediate participants (I) equaled their error count.

Reviewing Figures 3–6, the impact of participants' skill level on the recorded flight precision parameters is evident. The beginner group exhibited the longest flight times, largely due to the number of errors, average speed and distance covered, while the advanced group demonstrated the highest level of flight precision.

4. Discussion

The assessment of the precision of the pilots' maneuvers in relation to their blood alcohol concentration was carried out by analyzing four parameters: distance flown, flight time, average airspeed and the number of collisions with the gates on the track. Table 3 provides a summary of the differences between the sober flight and the subsequent series of flights.

Table 3. The summary of the differences between the flight performed while sober (series 1).

No.	Parameter	Group	Series 2	Series 3	Series 4	Series 5	Series 6
1.	Differences in distance travelled [m]	B	41,66	59,73	56,96	72,95	76,39
		I	13,31	5,07	16,31	42,19	36,78
		A	7,05	7,09	9,31	4,86	19,16
2.	Differences in time taken to complete track [s]	B	24,8	37,8	44,4	50,7	52,1
		I	9,1	6,1	14,8	27,0	33,6
		A	8,2	10,6	12,8	16,7	27,2
3.	Differences in average velocity [m/s]	B	-0,02	-0,04	-0,10	-0,08	-0,08
		I	-0,02	-0,03	-0,05	-0,05	-0,12
		A	-0,05	-0,07	-0,08	-0,14	-0,17
4.	Differences in number of committed mistakes	B	1	2	6	8	13
		I	1	3	5	7	9
		A	1	2	5	6	10

Figures 7–10 highlight the changes in the individual parameters across successive flight series compared to the initial, with zero blood alcohol concentration. Figure 7 illustrates the variation in the distance covered throughout each flight series Figure 8 displays the differences in the time needed to complete the course. Figure 9 reveals the fluctuations in average speed over the flight route. Figure 10 indicates the differences in the number of errors committed by participants across the flight series..

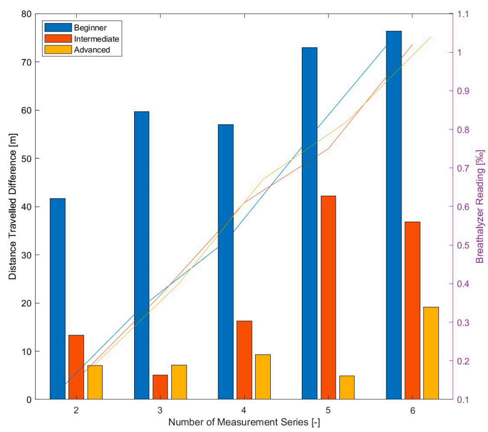

Figure 7. Differences in distance travelled relative to first flight [m].

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According to Figure 7, the most substantial increase in distance traveled during the test flights was displayed by participants from the beginner group (B). As the alcohol concentration increased, the participants (B) covered more distance reflecting their declining precision in piloting the unmanned aircraft. Their concentration levels and reaction times deteriorated, impending their ability to follow the optimal flight path. In addition, as the alcohol level increased, beginner participants (B) demonstrated great difficulty in navigating each gate, performing additional maneuvers to steer the UAV through the posts. Similar patterns were observed for intermediate (I) and advanced (A) participants, who also experienced increases in distance covered across successive flight series. However, the deviations from the baseline flight were less pronounced for these groups compared to the beginner group (B), attributable to their greater piloting experience. The least variation in the distance flown was recorded for the advanced group (A).

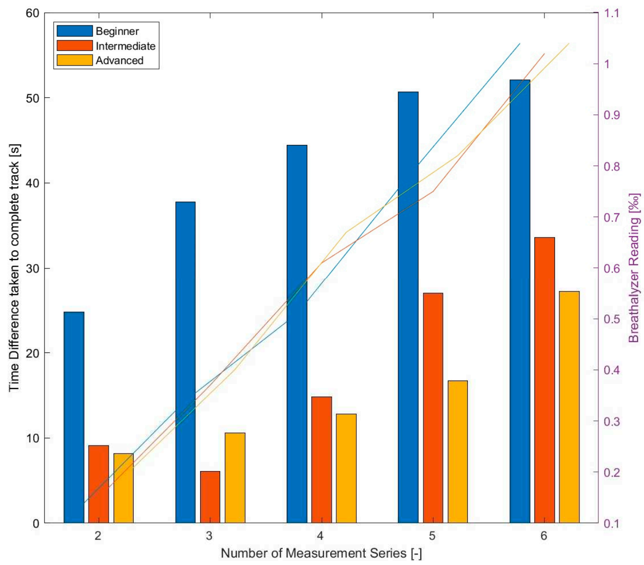

Figure 8. Differences in time taken to complete track relative to first flight [s].

The data presented in Figure 8 reveals the most significant increase in the time taken to complete the flight track occurred among the beginner participants (B), who required more time to finish the prescribed track with each subsequent flight series. This increasing time to commitment can be linked to their declining concentration and slower reaction times due to escalating alcohol levels, resulting in difficulties in flawless navigation through the gates. In addition, a reduction in flight speed likely contributed to the lengthened track completion time. A similar trend was observed among the intermediate (I) and advanced (A) participants, however the rise in time to complete the flight path was not as significant as it was for the beginner group (B). The results indicate that the smallest increase in the track completion time was recorded for the advanced group (A), reflecting their experience in UAV piloting.

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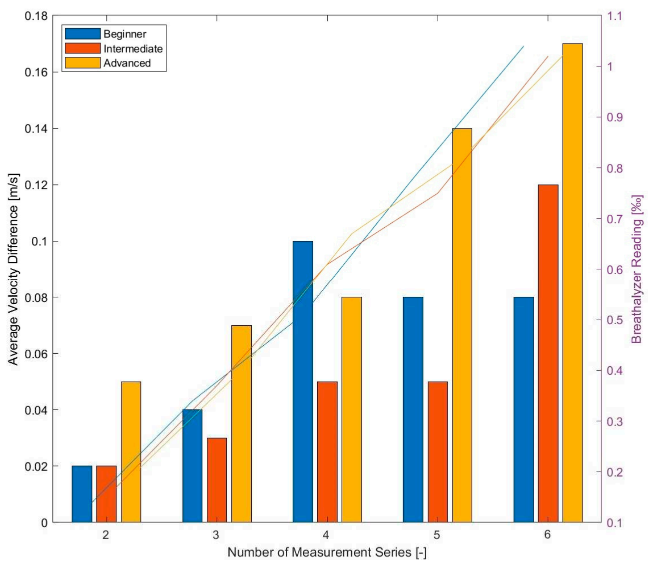

Figure 9. Differences in average speed relative to first flight [m/s].

Figure 9 displays a direct correlation between increased alcohol concentration and decreased average flight speed, a primary factor contributing to longer flight times. This phenomenon of diminishing speed was observed all participant groups throughout the successive flight series. The results of the measurements reveal that the most substantial variance in average speed between the initial and final flight series was among the advanced group (A), with the smallest difference recorded for the group of beginner group (B). The marked speed variation in the advanced group (A) reflects the pilots' performance during the flights conducted sober, when they achieved the highest speeds. The increase in alcohol concentration and negative consequences in the form of impaired concentration and prolonged reaction time led to a decrease in average flight speed.

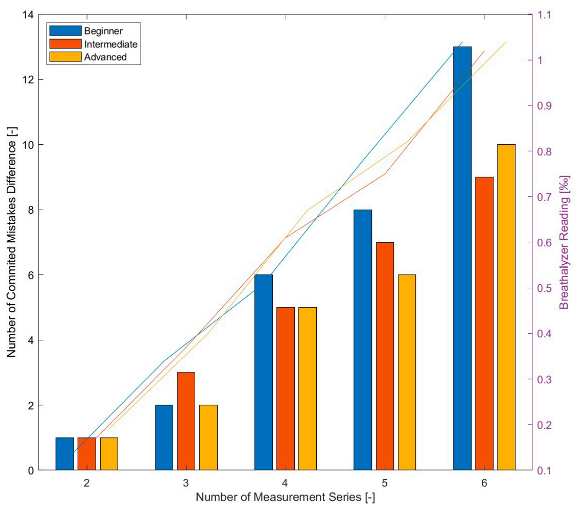

Figure 10. Differences in number of incidents relative to first flight.

Figure 10 shows that the number of errors made by all participant groups (B, I, A) increased in correspondence with rising alcohol concentration. As the flight series progressed, participants committed successively more mistakes, a trend likely associated with decreased concentration and slower reaction times. The most notable escalation in errors compared to the initial series was observed among the beginner group (B). It is noteworthy that there was also a discernible increase in errors committed by the intermediate (I) and advanced (A) groups, yet these groups still maintained a higher average speed relative to the beginner group (B).

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5. Conclusions

The article was focuses on examining the influence of alcohol on a pilot's capability to perform precision operations using an unmanned aircraft. The applied research methodology introduces four parameters defining flight precision: distance flown, flight time, average speed and number of errors. The findings from the measurements suggest that alcohol consumption significantly hampers the precision of drone navigation, which notably deteriorates as blood alcohol concentration increases. It was observed that more experienced pilots demonstrated less susceptibility to the adverse effects of alcohol, relative to their lesser experienced counterparts.

The data gathered during the study reveals declining trend in UAV maneuvering precision across all participants groups, coinciding with increased blood alcohol concentration. Each successive flight series marked an upsurge in errors, extended distance covered, and a reduction in average cruising speed, which in turn amplified the time required to complete the route. The most pronounced decline in maneuvering precision was exhibited by the beginner group (B). An analogous trend also applied to the intermediate (I) and advanced (A) groups, who similarly experienced noticeable deterioration in the recorded parameters (distance, time, velocity, number of errors) as alcohol concentration escalated over successive flight series. Notably, the deterioration in the UAV handling precision amongst the intermediate (I) and advanced (A) participants was less severe than the beginner group (B), a fact that can be associated with the higher skill level and greater piloting experience. The main factors contributing to this declining precision among the study's participants are decrease in concentration and an elongated reaction times, both consequent in increased alcohol concentration.

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