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Training of Pilots Using Flight Simulator and its Impact on Piloting Precision

V. Socha*, L. Socha, S. Szabo*, K. Hana***, J. Gazda**, M. Kimlickova**, I. Vajdova**, A. Madoran****, L. Hanakova*, V. Nemec*, T. Puskas**, J. Schlenker*****, R. Rozenberg****

**Czech Technical University in Prague, Faculty of Transportation Sciences, Horska 3, 128 03, Prague, Czech Republic, E-mail: vladimir.socha@fbmi.cvut.cz, szabo@fd.cvut.cz, lenka.hanakova@fbmi.cvut.cz, nemec@fd.cvut.cz*
***Technical University of Košice, Faculty of Aeronautics, Rampová 7, 04001, Kosice, Slovakia, E-mail: lubos.socha@tuke.sk, gazda@etcc.sk, mkimlickova@etcc.sk, iveta.vajdova@tuke.sk, tomas.puskas@student.tuke.sk, robert.rozenberg@tuke.sk*
****Czech Technical University in Prague, University Centre for Energy Efficient Buildings, Trinecka 1024, 273 43, Bustehrad, Czech Republic, E-mail: hana@fbmi.cvut.cz*
*****AT&T Global Network Services Slovakia, Einsteinova 24, 851 01, Bratislava, Slovak Republic, E-mail: andrej.madoran@gmail.com*
******Czech Technical University in Prague, Faculty of Biomedical Engineering, Sitna Sq. 3105, 272 01, Kladno, Czech Republic, E-mail: jakub.schlenker@fbmi.cvut.cz*

Abstract

One of the basic requirements to obtain pilot license is to demonstrate flying skills as to perform maneuvers and procedures with a required level of expertise. Considering the involvement of flight simulators in basic pilot trainings, one may ask how this impacts the extent of real flights necessary to acquire the required flying proficiency. This article focuses on the evaluation of precision (or error rate) of flight maneuvers performed over the course training of pilots. A sample of 35 student pilots was chosen for the study. Flight schedules and the training itself was adjusted for the purposes of this study, while the emphasis was put on the uniformity of flights and their conditions. Participants completed 11 flight hours on a flight simulator and one flight hour on the Diamond DA40 aircraft, followed by further three hours on a simulator and two flight hours in real traffic. The performed maneuvers included 180° climbing and descending turns with 30° bank at vertical velocity of 500 ft/min. During the flight hours, deviations from the requested flight parameters were recorded by the instructor. The results show that maneuver performance error ratio gradually decreases, however then significantly increases with the switch to the real aircraft compared to flight simulator, and again decreases during flights in air traffic. The findings suggest that the use of flight simulators as a tool for practicing flying skills appears reasonable, as well as that monitoring of performance precision may prove as a useful basis for adjusting the pilot training process.
KEY WORDS: *piloting precision, flight simulator, human factor, pilot, training process, safety*

1. Introduction

The development of aviation emphasizes the improvement of the air traffic. With the process of the implementation of new technologies, here comes also the increase of the demands on theoretical and practical skills of the crew including pilots themselves. Studies focusing on aircraft accidents cite the human factor as one of the most common causes [1-3]. The lapse of the human factor happens in situations when the pilot's skills are lacking or when the pilot is surprised by adverse situation and reacts inadequately. Although the results differ, it can be concluded that human factor partakes in approximately 70 to 85 percent of the aircraft accidents [4]. The most common faults caused by pilots are those related to their skills (80 percent of failures are caused by human factor). Approximately half of these faults initiate series of events [5] that lead to flight accidents. The main task in decreasing the faults caused by human factor might be the improvement in the pilots' education, simulation of solving unexpected situations which might appear during the flight and training itself.

Recently, flight simulators have become a significant element in pilot training due to their ability to recreate the virtual reality of flights. Thanks to the modern technologies, this virtual reality recreates real flights accurately enough to eventually eliminate worries and doubts among pilots, airlines, aircraft manufacturers or regulatory bodies regarding their use in trainings. This caused their significant expansion and made them become tools for training and examination of civil and military crews' proficiency. International standards and regulations reacted to this development by defining and specifying requirements for their operational use [6]. Certified flight simulators are thus routinely used during trainings, practicing flight procedures, as well as during pilots' testing.

Incorporating flight simulators into pilot trainings resulted in reduced risks and enhanced quality of trainings, while enhancing the overall flight safety as well as reducing training costs and aircraft operation costs [6, 7]. Flight simulators further increase the effectiveness of trainings due to the possibility to adjust the course of the training based on a pilot's skills or the results of the completed flights. Also, it is possible to create non-standard situations (due to weather conditions or technical conditions of the plane) which may occur and practice ways of handling them. The flight records are immediately available and used to provide an accurate feedback for pilots, enhancing their progress [8-10].

The critical part of the use of flight simulators, however, is their incorporation in the training process, especially considering basic forms of pilot's licenses such as Private Pilot's License (PPL), or Ultralight Pilot's License (ULL). The required training involves the assessment of skills, experience, and proficiency of the student pilot. The training is considered complete when the minimum requirements are met and the student pilot is ready to demonstrate skills to fly an aircraft, perform procedures and maneuvers according to the level of PPL and further demonstrate ability to pilot an aircraft within the scope of its limitations, carry out maneuvers continually and accurately, show sound judgement and developed sense for flying, apply theoretical knowledge in practice and pilot the plane in a way that does not raise questions about the accuracy of performed procedure or maneuver. This points to the necessity to observe and evaluate the training progress which is in most cases the very initial part. Generally, the training required to obtain PPL (or ULL) focuses on theoretical preparation involving flight rules, technical knowledge about the aircraft, planning and performing flights, meteorology, navigation, traffic procedures, flight basics etc. The crucial factor, however, is the actual mastering of a basic piloting technique. As for the training type required for PPL, out of the mandatory 45 flight hours, it is possible to spend five hours on a certificated flight simulation training device.

The article will therefore aim at the evaluation of pilot training using flight simulators, focusing on the basic flying skills. The objective of the study is to evaluate the potential of a flight simulator for basic flying skills practice via the assessment of error rates in the performed maneuvers, which is one of the basic criteria for obtaining a pilot's license. Another objective, arising from the analysis of the recent state, is the evaluation of the impact of the switch from simulated flights to real flights as to the progress/deterioration in the performed maneuvers.

2. Participants and Methods

A sample of subjects who were to complete aviation training in basic piloting technique was created for the purposes of this study. Subjects were recruited from among the students of Faculty of Aeronautics of Technical University of Kosice. Thirty-five students (27 men and 8 women) participated in the study, mean age 23 ± 4 years, who met the medical requirements for flight crew licensing (JAR-FCL 3.105), and did not own pilot's license (ULL, PPL, or higher) at the time. Furthermore, the selection was conditioned by theoretical knowledge of flight basics as well as mental fitness, which were examined by a quiz and a test. The selection criteria were set so as to provide the highest possible level of sample uniformity.

The training methodology consisted of 11 flight hours on a flight simulator and one flight hour on an aircraft, followed by further three flight hours on a simulator and two hours of piloting a plane in real traffic (see Fig. 1). The actual piloting exercises were preceded by a two-hour theory class on acquiring basic flying skills, which also aimed at introducing the cockpit, instrument panel (flight deck) and its use during flight. The piloting was then practiced using a TRD40 flight simulator and Diamond DA40 aircraft in accordance with the set methodology and supervised by a professional instructor. Analog visualization of flight, navigation and motor data on the flight deck was selected during simulated as well as real flights which were performed in terminal maneuvering area of Kosice International Airport (ICAO code: LZKZ). Each real flight was realized under weather conditions in accordance with VFR (Visual Flight Rules).

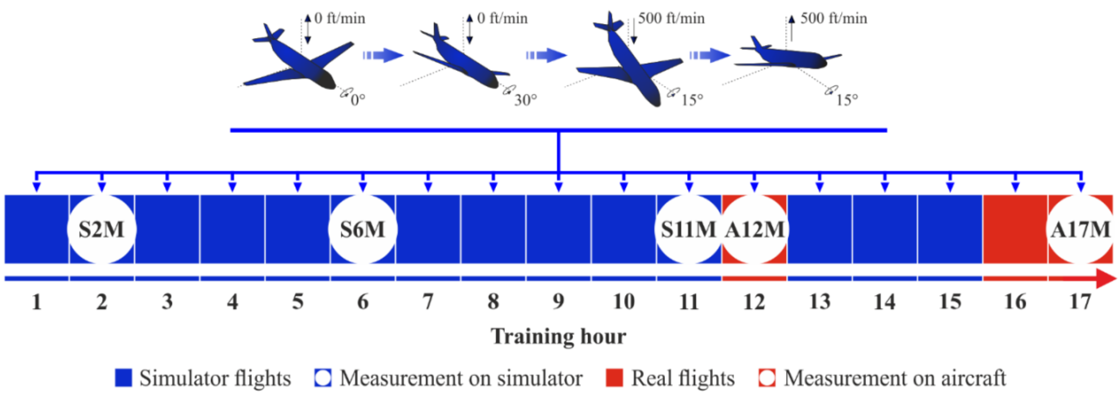

Fig. 1 Concept of the training process showing intervals of piloting precision measurements

The way the flight hours were realized involved specifically defined flight maneuvers focused on following the set flight parameters for steady horizontal flight, 360° horizontal turn with 30° bank, 180° climbing and descending turns (C/D180) with 15° bank at vertical velocity of 500ft/min. The set order of maneuvers was strictly followed and the respective maneuvers were repeated three times during a single flight. Besides the take-off and landing, a series of three maneuvers in the above sequence were performed (see Fig. 1), providing for the uniformity of trainings and measurements.

For the purposes of this work, only precision of the set vertical speed and the C\D180 bank of 15° was measured.

The choice of the maneuvers was due to their complexity which the subjects were required to demonstrate. Compared to other mentioned maneuvers, the student pilots had to demonstrate the ability to change from steady horizontal flight to climbing or descending turn while following the 15° bank as well the 500 ft/min vertical speed which represented a change in two flight parameters. Another reason for the choice of C180 and D180 for the purposes of measuring precision (or error rates) in piloting skills was the selected maneuvers' mutual comparison.

Data collection consisted in recording deviations from the prescribed flight parameters while performing C180 and D180 by a qualified flight instructor (in accordance with the Regulation 1178/2011, Section FCL-J) in the form of maximum deviations from the prescribed vertical speed and bank. This concept has been used in a previous study which confirmed a strong correlation between the error rates measured by the instructor and error rates computed from the simulated flight records [11]. The error rates were measured during five periods – flight hour 2 on the flight simulator (S2M), flight hour 6 on the simulator (S6M), flight hour 11on the simulator (S11M), as well as flight hour 12 (A12M) and flight hour 17 (A17M) during real flights (see Fig. 1).

3. Data Processing and Statistical Analysis

The evaluation of piloting precision followed the flight instructor's notes. The data had the form of the recorded maximum deviations from the prescribed flight parameters, specifically from the 15° bank and the vertical speed of 500 ft/min. The calculation is to be understood as X_{-LE}^{+UE}, while X being the requested value, UE is the maximum plus error and LE being the maximum minus error. The total error Δ for a particular parameter would then follow the formula:

$$\Delta = UE - LE. \tag{1}$$

Proceeding from Eq. 1 it is apparent that this represents the absolute error. Data characterized by Δ were divided into datasets describing the precision of performing the prescribed flight parameters (vertical speed and the bank for C180 a D180) and subdatasets describing the measurements (S2M, S6M, S11M, A12M and A17M). In other words, every error ratio for each observed flight parameters and each subject was incorporated into the measurement categories. Within the statistical evaluation, Kolmogorov-Smirnov test was used to evaluate the normal distribution of data in subdatasets during the first phase at the level of significance $p = 0.05$, which fails to reject the normal data distribution hypothesis for $p < 0.05$. As normal distribution of subdatasets was not found in all cases, non-parametric Wilcoxon test was used to identify statistically significant differences among the groups. Hypothesis on significant differences between subdatasets' medians failed to reject for $p < 0.05$, while all datasets were mutually compared.

Boxplots were used to interpret the measured data and the course of the training. Each boxplot sums up the distribution of piloting error ratios for respective maneuvers, while a single boxplot represents (from the bottom up) the minimum, the first quartile, median, the third quartile and the maximum of the group distribution of an observed parameter for a particular training phase (S2M, S6M, S11M, A12M and A17M). Values found outside the division are marked by a red cross in the chart as extremes which were not considered in the final evaluation.

The described statistical evaluation (see also [12]) was used for the purposes of comparing respective training phases with the main focus on the progress or deterioration in the piloting precision. Further purpose was the comparison of piloting precision following the switch from simulated to real environment.

4. Results

In the statistical evaluation of the piloting precision while keeping the vertical speed on the set level of 500 ft/min while performing a climbing turn, significant differences were found between all measurements except S6M and A17M (see Table 1). Visual representation of the results and the course of the recorder error ratios is illustrated in Fig. 2. The error ratio therefore dropped between S2M and S6M, while the mean value of error ratio in subjects dropped from 160 ft/min to 100 ft/min. A significant drop in the mean value of error ratio from 100 ft/min to 70 ft/min was also found between S6M and S11M. A significant increase in the error ratio was then observed during the first real flight A12M (med = 240 ft/min) followed by a drop during the second real flight A17M (med = 110 ft/min) to the value of S6M.

Table 1

Results of the Wilcoxon test in the form of p-values for the evaluation of the precision of keeping the requested vertical speed during the 180° climbing turn

	S2M	S6M	S11M	A12M	A17M
S2M	-	$8\cdot10^{-4}$	$4\cdot10^{-13}$	$2\cdot10^{-3}$	0.02
S6M	$8\cdot10^{-4}$	-	$3\cdot10^{-4}$	$4\cdot10^{-9}$	0.16
S11M	$4\cdot10^{-13}$	$3\cdot10^{-4}$	-	$2\cdot10^{-20}$	$6\cdot10^{-6}$
A12M	$2\cdot10^{-3}$	$4\cdot10^{-9}$	$2\cdot10^{-20}$	-	$8\cdot10^{-7}$
A17M	0.02	0.16	$6\cdot10^{-6}$	$8\cdot10^{-7}$	-

Table 2

Results of the Wilcoxon test in the form of p-values for the evaluation of the precision of keeping the requested bank during the 180° climbing turn

	S2M	S6M	S11M	A12M	A17M
S2M	-	$3\cdot10^{-7}$	$1\cdot10^{-14}$	$2\cdot10^{-3}$	0.93
S6M	$3\cdot10^{-7}$	-	0.41	$2\cdot10^{-9}$	$6\cdot10^{-6}$
S11M	$1\cdot10^{-14}$	0.41	-	$6\cdot10^{-17}$	$1\cdot10^{-11}$
A12M	$2\cdot10^{-3}$	$2\cdot10^{-9}$	$6\cdot10^{-17}$	-	$4\cdot10^{-3}$
A17M	0.93	6.10^{-6}	$1\cdot10^{-11}$	$4\cdot10^{-3}$	-

Statistical analysis of piloting precision while keeping the 15° bank at a 180° climbing turn identified significant differences between all measurement, except for S2M and A17M as well as S6M and S11M (see Table 2). Graphic representation of the results and the course of the recorded error ratios is presented in Fig.3. Error ratio therefore dropped between S2M and S6M from 3° to 2.5°. Median values dropped between S6M and S11M (from 2.5° to 1.75°), however this decrease did not prove statistically significant considering the data distribution in these groups, so it can be concluded that the error ratios remained the same for S6M and S11M. Error ratios increased significantly with the first real flight A12M (med = 4.75°) compared to the preceding measurements.

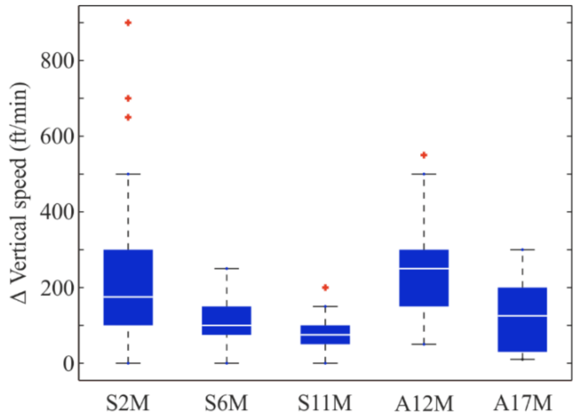

Fig. 2 Distribution of the measured deviations from the requested vertical speed in subjects during the climbing turn

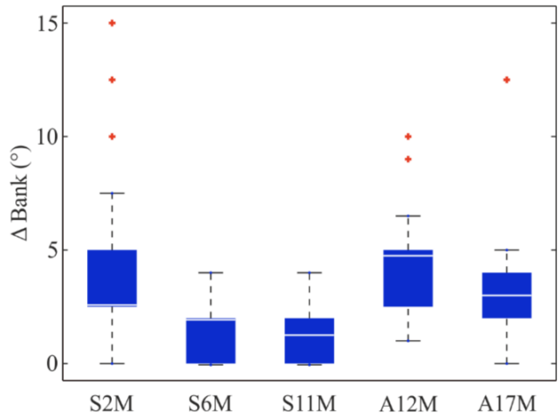

Fig. 3 Distribution of the measured deviations from the requested bank in subjects during the climbing turn

In the statistical evaluation of the piloting precision while keeping the vertical speed on the set level of 500 ft/min while performing a descending turn, significant differences were found between all measurements except S6M and A17M (see Table 3). Visual representation of the results and the course of the recorder error ratios, having a similar development as in the previous cases is illustrated in Fig. 4. In this case, the mean value of vertical speed error ratio drops significantly when comparing S2M (med = 200 ft/min) and S6M (med = 150 ft/min). Drop in error ratio was identified also between S6M and S11M (from 150 ft/min to 80 ft/min). The first real flight A12M then reflected in a significant increase as the error ratio mean value escalated to 220 ft/min. During the final phase of the training, the mean value saw a drop to 170 ft/min which is statistically similar to S6M, while $p \approx 1$.

Table 3

Results of the Wilcoxon test in the form of p-values for the evaluation of the precision of keeping the requested vertical speed during the 180° descending turn

	S2M	**S6M**	**S11M**	**A12M**	**A17M**
S2M	-	0.03	$2 \cdot 10^{-11}$	0.01	0.01
S6M	0.03	-	$2 \cdot 10^{-6}$	$7 \cdot 10^{-5}$	1
S11M	$2 \cdot 10^{-11}$	$2 \cdot 10^{-6}$	-	$7 \cdot 10^{-19}$	$1 \cdot 10^{-4}$
A12M	0.01	$7 \cdot 10^{-5}$	$7 \cdot 10^{-19}$	-	$3 \cdot 10^{-6}$
A17M	0.01	1	$1 \cdot 10^{-4}$	$3 \cdot 10^{-6}$	-

Table 4

Results of the Wilcoxon test in the form of p-values for the evaluation of the precision of keeping the requested bank during the 180° descending turn

	S2M	**S6M**	**S11M**	**A12M**	**A17M**
S2M	-	$4 \cdot 10^{-6}$	$5 \cdot 10^{-18}$	0.02	0.35
S6M	$4 \cdot 10^{-6}$	-	0.04	$9 \cdot 10^{-8}$	$3 \cdot 10^{-6}$
S11M	$5 \cdot 10^{-18}$	0.04	-	$2 \cdot 10^{-17}$	$2 \cdot 10^{-15}$
A12M	0.02	$9 \cdot 10^{-8}$	$2 \cdot 10^{-17}$	-	0.21
A17M	0.35	$3 \cdot 10^{-6}$	$2 \cdot 10^{-15}$	0.21	-

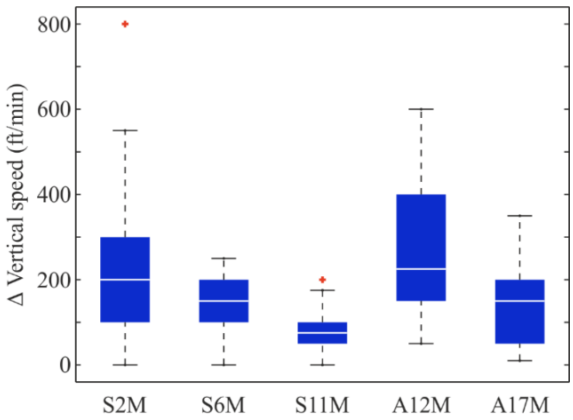

Fig. 4 Distribution of the measured deviations from the requested vertical speed in subjects during the descending turn

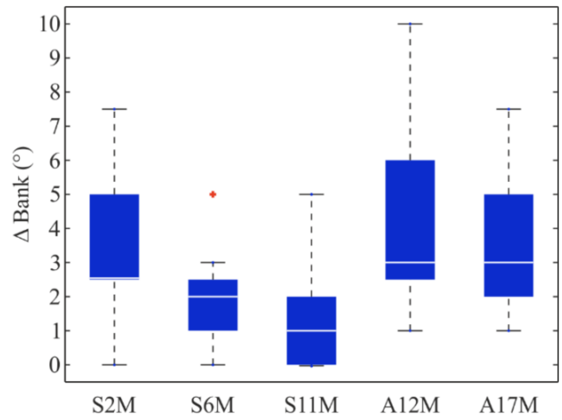

Fig. 5 Distribution of the measured deviations from the requested bank in subjects during the descending turn

Statistical evaluation of piloting precision while following the 15° bank during 180° descending turn found significant differences between all measurements with the exception of A12M and A17M as well as between S2M and A17M (see Table 4). The Wilcoxon test returned p-values higher than the set significance level $p = 0.05$. Error ratio gradually dropped significantly over the course of training on the flight simulator. The mean value of error ratio dropped from 2.5° to 2° when comparing S2M and S6M and continued to drop further to reach the level of 1° for S11M. The first measurement during the real flight on the DA40 airplane found a significant increase in error ratio in comparison with the earlier measurements (med = 3°) reaching the results of S2M. For the following flight (A17M), the values remained on the level of 3°, i.e. no significant difference was identified between A17M and A12M. Fig. 5 presents the results and the development of the observed error ratios.

5. Discussion

During climbing and descending turn, piloting precision was evaluated as for following the set bank and vertical speed. The results show that the error ratio has the tendency to decrease with the developing skills of the pilots, or the number of completed flight hours. This has been confirmed mainly when observing the progress in piloting precision on a flight simulator. The evaluation of the bank during 180° climbing/descending turn on a flight simulator did not identify significant errors. The mean value of the error ratio when keeping the set bank ranged between 1° - 3°, while the set value was 15°. In both cases (C180 a D180), the error ratio values gradually decreased over the course of flights on the simulator. When switching to the real flights, values of error ratio for bank grew steeply, and in both cases (C180 and D180) settled on the level of S2M or higher. Proceeding from the above it can be stated that the initial simulator training (11 hours in this case) has only little or no impact on the ability to keep the aircraft at the requested bank. Different results for a different type of maneuver might be naturally possible to observe. Nevertheless, taking into consideration the fact that by the designed training, which totaled 17 flight hours and repeating maneuvers, the results may not be considered satisfactory.

When evaluating error ratios regarding the vertical speed, development similar to the precision of following the requested bank was observed for both maneuvers (C180 and D180). The error ratio was relatively high in the first phase (160 ft/min for C180 and 200 ft/min for D180 during S2M). However, these values were reduced significantly, reaching the level of the mean value (70 ft/min and 80 ft/min, respectively). Also, better adaptation to the real aircraft was observed. Even though a significant rise in error ratio was experienced during the first real flight compared to the simulated flights, the values eventually dropped in both maneuver scenarios (C180 and D180) for A17M to the level of S6M. In this case it can be thus concluded that the change from the flight simulator to real aircraft did not have effect on keeping the set vertical speed of climbing/descending, however identified acquired piloting habits which have shown during real flights. This is due to the fact that during real flights, error ratio dropped significantly, to the level of S6M.

The results suggest that the use of flight simulators in pilot trainings is partially reasonable, however insufficient to master basic flying skills considering the extent of five flight hours (for PPL). Habits influencing precision of selected maneuvers are clearly visible during flight hour 11 on the flight simulator. It is obvious that the flight simulator is not used only for practicing steady and accurate maneuvers, but furthermore serves to create and master proper flying habits in following prescribed procedures, most of all when handling non-standard situations which may occur in air traffic and which might be difficult to handle while following safety rules.

The findings suggest that the use of flight simulators as a tool for practicing flying skills appears reasonable, as well as that monitoring of performance precision may prove as a useful basis for adjusting the pilot training process.

6. Conclusions

The presented article evaluates the potential of flight simulators in the process of pilot training to enhance the flying precision as piloting errors may negatively influence air traffic safety. This study evaluated error ratios measured during maneuvers of descending and climbing turns. Failures in keeping the requested bank values impact the turning radius, turning time and eventually cause digressions from the planned trajectory. If the set climbing or descending speed is not followed, this may impact time required for reaching particular altitudes etc. These errors may result in reduced flight safety, in beginner pilots especially before the landing phase, during heavy traffic etc.

The focus on only one kind of maneuver (180° climbing/descending turn) may pose a limitation of this study. Future studies could further elaborate on the development of error ratios during other types of maneuvers, or on the evaluation of complex maneuvers [13]. It might also prove beneficial to optimize the effectiveness of flight simulators in trainings considering the piloting precision evaluation, and possibly incorporate also the assessment of physiological parameters [14-17], which determine the levels of mental stress impacting piloting precision.

As the study suggests, flight simulators already have proven, and will continue to prove themselves irreplaceable in pilot trainings. Their potential is mainly in providing correct flying habits, eliminating errors, teaching flight procedures, offering crisis management etc.

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