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FLIGHT SIMULATOR AS AN ESSENTIAL DEVICE SUPPORTING THE PROCESS OF SHAPING PILOT'S SITUATIONAL AWARENESS

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INTRODUCTION

Flight simulators[1] play a significant role both in pilot training and in sustaining pilot currency. The safety level of modern general, commercial and public aviation depends largely on simulation technologies, used not only for training purposes, but also in air accident investigations, studies of aircraft design or air traffic simulation and on a better understanding of the interactions present in the pilot-aircraft-mission environment system. Conclusions drawn from the analysis of the reference literature[2] suggest that the role of flight simulators increases with the growing complexity of modern aircraft systems, which means that simulator training is now an integral part of the processes of pilot training and professional development, or conducting the research studies related to adapting aircraft design to human capabilities and limitations. Ever increasing degree of fidelity of representing the pilot natural work environment by the simulator makes flight simulators an invaluable tool used in the process of air accident investigations.

[1] Simulation (Latin *simulato* – pretending, imitating). In the dictionary of contemporary Polish language the term simulation is defined as creating appearances, pretending something, appearance, feigning sickness, artificial reconstruction of a phenomenon occurring in nature: aircraft flight simulation. In colloquial language, this term has adopted a negative sense and means the act of pretending or feigning something to put someone in error, or achieve benefits. The simulator should not be, however, solely with negative or harmful acts. From the beginning of the 20th century, this word began to acquire a positive meaning. The immediate cause of the change in the approach to the concept of simulation, was the emergence of the concept of simulation as a research method for determining the specific phenomena of human activities, machinery operation, etc. This method is applied whenever there is the need of the repetition, testing or detailed preparation of a detailed, complex process without the involvement of the assets usually participating in it. The success of research carried out using this method amounts to the creation of a model of environmental conditions and the device under test in a manner as close to the reality as possible. Multi-author work, *Słownik współczesnego języka polskiego*, PWN, Warszawa 1996, p. 1080.

[2] G. Lintern, S.N. Roscoe, J.M. Koncoe, L.D. Segal, *Transfer of landing skills i beginning flight training.* Human Factor Nº 32/1990; R.T. Hays, J. Jacobs, C. Prince, E. Salas, *Fligcht Simulator training effectiveness. A-meta-analysis,* Military psychology Nº 4/1992; R. Leszczyński, *System selekcji kandydatów do Sił Powietrznych,* Praca badawcza, WSOSP, Dęblin 2000; W. Bezdek, R. Powell, D. Mays, *The history and future of military flights simulators,* AIAA modeling and simualation technologies conference and exhibit – 2004, Providence, RI, AIAA Paper 2004 – 5148; N.D. Macharella, P.K. Arban, S. M. Doherty, *Transfer of training from flight training devices to flight for ab initio pilots*, International Journal of Applied Aviation Studies Nº 5/2005; A.T. Lee, Flight Simulation, ASHGATE, Burlington 2005.

FLIGHT SIMULATORS – GENERAL CHARACTARESTIC

How complex has been the development of simulators can be seen from the example of the first flight simulator "Aeronautical Link Trainer", which consisted only of a basic set of cockpit flight instruments and a very basic platform for simulating the aircraft movement. It did not support the function of displaying the external mission environment for the pilot3. Modern flight simulators apart from the faithful reproduction of the internal and external mission environment can also be equipped with motion simulation platform. Modern flight simulator has become the essential type of ground equipment for pilot training and professional development[4]. Currently, it is difficult to imagine modern flight training without the use of flight simulators. The effectiveness of practical training using flight simulators is determined by a number of factors, including, among other things, such as: safety, economic, technical, methodological, etc. Due to the desired level of simulator training efficiency and flight simulator versatility these devices must fulfill a number of functions. The essential, desired functions of a flight simulator designed for pilot training and professional development can include:

- Demonstration function – it relates to the enrichment of the theoretical training process with demonstrating the trainee the elements of specific procedures, methods and the uses of aircraft instruments, controls and systems.
- Education function – it relates to such elements as: developing/perfecting trainee's skills and habits with regard to practical implementation of operations in the cockpit, the use of operational procedures, onboard emergency procedures, improving multi-crew cooperation, and the skills in the use of aviation phraseology, developing /perfecting training skills of flight instructors, etc.
- Personality function – it is associated with the formation and development of the desired personality and professional traits of the pilot (trainee), preparing him for it, among others, for air mission execution under high workload and/or time deficit, and in new situations (onboard and in the mission environment) from the point of view of the current pilot (trainee) experience, etc.
- Adaptive function – it amounts to improving the pilot (trainee) "recurring" actions on board the aircraft, including actions related to complex and emergency situations. Exercises performed within this function are particularly important with regard to the preparation for the execution of the mission which is new from the point of view of the pilot's current experience.
- Research function – it is related to checking the behavior of the pilot (trainee) at different stages of the planned mission execution, taking into account the specific solutions relating to the design, ergonomics, and automation of a particular aircraft type. It also amounts to verifying the validity of theoretical assumptions related to the way of solving problems onboard the aircraft by the crew, for example, the validity of assumptions concerning the crew actions in the event of certain onboard emergencies. This function is also applied when it is necessary to confirm the conclusions of the air accident investigation board's proceedings, relating to the causes of undesirable flight-related events.
- Selection function – it consists in eliminating permanently or temporarily from further aviation training those candidates who have no predispositions (competencies, knowledge, skills) to work as a pilot/perform specific flight tasks.
- Control-examination function – it allows to carry out control/examination

[3] W. Bezdek, R. Powell, D. Mays, *The history and future of military flights simulators,* AIAA Modeling and simulation technologies conference and exhibit – 2004, Providence RI, AIAA Paper 2004–5148.

[4] In the present work, the author refers mainly to simulators applied in the process of training and professional development of pilots. It should also be emphasized that at present simulators are an essential tool applied in the process of training and professional development of the remaining air personnel (aircraft technicians, air traffic controllers, etc.).

exercises in relation to the specific license or aviation rating[5].

It should be noted that the effectiveness of the use of flight simulators in the recruitment, selection, training and professional development of pilots, air accident investigations, or research is dependent on an understanding of their capabilities and limitations that apply to specific areas of aviation. On the other hand, in the process of the flight simulator design, it is very important that the designer, apart from applying specific, high-tech aviation technologies, should also strive to create a mission environment model as close to the reality as possible, and take into consideration the knowledge of human capabilities and limitations, including those relating to the ability to perceive and process information, as well as the cognitive factor concerning the operational capabilities of the simulator. Modern flight simulators are also treated as an essential tool for developing the pilot's ability to "automate" the actions in the cockpit and for the efficient reception and selection of signals related to the aircraft status. Many psychologists hold the view[6], that in relatively simple situations habits can replace thinking – automatic execution of tasks. In complex, unexpected situations – non-routine air incidents – an important role is played by the quick assessment of the situation and the appropriate action programming. From the point of view of situational awareness, the pilot's ability to automatically perform actions on board the aircraft is of primary importance to the perception, selection and analysis of large amounts of information within the time limit and to the construction of the aircraft status mental images. One of the simplest examples of such actions is the cockpit pre-flight check. Research conducted by the author shows that the time differences between a trainee pilot and a pilot in continuous training[7], can range from tens of seconds to several minutes, depending on the aircraft type. Too frequently, especially in the initial stage of flight training, the preparation of a future pilot amounts to learning specific definitions and points of instruction during the theoretical training course, and learning to control certain actions (often without understanding the phenomena of e.g. aerodynamics and flight mechanics) during the practical training.

Meanwhile, with the development of aircraft design, including the more recent introduction of the solutions relating to the areas concerning the aircraft management, pilot's initiative and independent thinking based on vast general and specific knowledge and practical skills, including the skills relating to performing certain actions automatically, become more and more important for the safety and efficiency of air mission execution.

In addition to socialization techniques and teaching techniques, such as brainstorming, decision-making exercises with a limited amount of information and in time deficit, an increasing role is played by flight simulator exercises. A good example of such activities

[5] Author's own work, taking into account the specific functions identified in R. Pielacha, *Imitatory kierowania samolotami w kształtowaniu nawigatorów wojskowych*, Research Study, PAFA, Dęblin 1994, (in:) Op.cit. R. Leszczyński, *System selekcji kandydatów…*, p. 58.

[6] J. Terelak, *Higiena psychiczna i pilot*, MON, Warszawa 1975, p. 237.

[7] Continuous training – a term applied to fully trained air force pilots participating annually in a training program aimed at maintaining/improving pilot currency with regard to handling a particular aircraft type.

are exercises in acquiring habits relating to pilot conduct in the event of an onboard emergency. By modern flight simulator we mean a flight training device characterized by a faithful simulation of both the internal (aircraft cockpit with instrumentation and indicators) and the external mission environment (everything that the pilot observes during the flight outside the cockpit), sound and air services, events changes that occur during aircraft position in three planes of reference - pitch, roll and yaw, simulation of mechanical and functional control system that allows the aircraft to acquire and consolidate skills to effective decision-making and the efficient and secure management of aircraft, especially in the situation of a heavy workload and with a time limit. Very important in terms of forming correct situational awareness habits is to enable the participation of the pilot in a training covering receiving and processing the data to be used in order to create a status image for particularly complex situations which may be encountered when executing a specific air mission.

Therefore, it should be considered particularly important that the engineer-designer should understand how big an impact on the effectiveness of the simulator is its degree of reality representation in relation to the type of aircraft operated. The simulator designer should then apply the technology which is the most useful from the point of view of the user to re-create the functional and physical characteristics of the aircraft and external mission environment.

Today's flight simulators, regardless of the nature and extent of their use in flight training, prove that their designers are well aware of the fact that a flight simulator is not just a machine equipped with modern computer software. Flight simulator designers also understand that in the design of the flight simulator particular attention should be given to adapting the newly created equipment to the capabilities and limitations of the pilot and his tasks conducted on a specific aircraft type in a particular mission environment.

Until the second half of the 1970s, flight simulators had often been perceived by the majority of the civil aviation community as a kind of attraction. Taking into account the economic factors and impracticality, many airlines and smaller aviation organizations had rejected the use of flight simulators for training purposes. However, with more and more evidence of the simulator training effectiveness, commercial aviation sector became increasingly interested in those devices. The final breakthrough came during the oil crisis in the 1970s, when flight simulators became a widely used training tool in commercial aviation. In fact, flight simulators were regarded as a low-cost training tool, used as an alternative to flight training. Over the years and with the development of aviation technology, flight simulators have become a commonly used training tool which is also used for basic flight training of young aviation adepts. Today, we can say that flight simulators are an essential element of pilot training and professional development, regardless of the kind of aviation and aircraft type taken into consideration.

USEFULLNES OF THE FLIGHT SIMULATORS IN THE GENERAL AVIATION PILOTS TRAINING

However, due to the economic aspects related to the purchase and operation of a flight simulator, there are still some restrictions on its use, particularly in relation to *general aviation* where trainer aircraft still remain a major tool used in instruction and training[8]. The exception is the PPL (Private Pilot Licence) training, where simulator training (simulator or FNPT BITD Class)[9] may be substituted for 5 hours of practical training, and procedural training for IFR

[8] The authors have not addressed the training of helicopter pilots, due to the fact that in Poland, as of 1st July, 2012, only Polish Medical Air Rescue had a certified FNPT II helicopter simulator. The remaining helicopter pilot training organizations in Poland did not use flight simulators. This is primarily due to the relatively high purchase price (approx. € 650,000) and maintenance costs of the simulator with a small number of trainees – several people each year. Such a small number of trainees is primarily due the fact that the cost of training one candidate for professional license CPL(H) is approximately € 125,000–170,000, depending on the training organization and the helicopter type used in the training.

[9] Section 1 Part-FCL 1.120 Practise and credits.

flights, where 55 hours of flight training may be conducted as: 40 hours of practical Simulator training (FNPT II class simulator) and 15 hours of training on a trainer aircraft[10]. To sum up, in accordance with the current regulations, *20% of the total* practical air training *time* of the pilot trained for *CPL licence and IFR rating,* can be assigned to simulator training. However, it is not only because of regulations that, despite its number of advantages, simulator training, is rarely used in daily flight training. The second limitation is the fact that the vast majority of training can be conducted using the FNPT-II class simulator, whose purchase price is approx. € 400,000. In addition, the decreasing number of air training candidates each year makes the purchase, operation and maintenance of such equipment in general aviation become increasingly irrational in economic terms. Because of this barrier, as of 1st July, 2012, only 7 Flight Training Organizations in Poland possessed FNPT-II class, and 3 centers BITD class simulators. Bearing in mind that as of 1st July, 2012, there were more than 50 accredited Flight Training organizations, the above-mentioned number of flight simulators seems to be very modest. On the other hand, the results of comparative analysis of the training costs for IFR flights with and without the simulator use shows that the first variant is cheaper by more than 50%[11].

The main argument in favor of a wider use of simulators in flight training are the results of studies related to the transfer of knowledge and skills from the flight simulator to the aircraft with regard to basic flight training. Studies carried out so far clearly confirm the usefulness of flight simulators, including the simplest (BITD), in the basic aviation training process. Lintern et.al.[12] in their research studies analyzed the degree of transferring the landing skills from the simulator training to the trainer aircraft at the beginning of the pilot flight training. The first group of trained pilots held two simulator training sessions covering the landing skills prior to the commencement of practical training in the air. The second group – the controls – did not receive this kind of training before the start of practical training in the air. The investigators demonstrated that the first group of trainees needed approx. 1.5 hours of training flights less before the first solo flight, as compared with the second group, which had not undergone the simulator training. In this case, we refer to only one, particularly important and difficult element of air training – learning to land[13].

[10] Annex 1 to Part-FCL 1.205, pt. 10.

[11] Assuming the cost of one hour of the Cessna-172 flight to be € 225 and one hour of the FNPT II simulator use to be € 60, at 40 hrs. of simulator training and 15 hrs. of practical training conducted on the Cessna-172, the total cost of the training would be € 5,775. If the whole training were conducted on The Cessna-172, the total cost of the training would be € 12.375. The analysis was based on the average price of 1 hour of the Cessna-172 aircraft flight and 1 hour of the FNPT-II simulator use as of 1st July, 2012 – author's own analysis.

[12] G. Lintern, S.N. Roscoe, J.M. Koncoe, L.D. Segal, *Transfer of landing skills in beginning flight training.* Human Factor Nº 32/1990, pp. 319-327.

[13] Usefulness of the simulator training for basic training of pilots was also confirmed by the study team of N.D. Macharella – for further details, see N.D. Macharella, P.K. Arban, S. M. Doherty, *Transfer of training from flight training devices to flight for ab initio pilots*, International Journal of Applied Aviation Studies Nº 5/2005, pp. 25-39.

Dennis and Harris[14] examined the impact of the simulator training on the practical flight training using Microsoft Flight Simulator (v4.0) – a PC computer-based game program. Each trainees performed straight and level flight and coordinated turns for 1 hour. Then, the trainees commenced practical training in the air. The results of the comparative analyses concerning the performance demonstrated by the trainees who had received a simulator training session with those who had not explicitly confirmed that it was easier for the first group to assimilate the elements of the exercises which had been carried out before on the flight simulator. Furthermore, these studies confirmed the view that simple PC simulators are an effective tool in the development of flight skills in the initial phase of flight training.

On the other hand, the results of the research study conducted by Vaden and Hall[15] pointed to the fact that the platform imitating the motion of an aircraft does not serve an important role in the acquisition of skills by the pilot. Using the method of meta-analysis they examined the impact of the aircraft's plane of motion, which is an integral part of the aviation simulator, on the development of the pilot's skills. The study showed little effect of the use of such devices on increasing the flight training effects in cargo aircraft pilots . They also pointed to the fact that the cost of upgrading the simulator with this feature, as well as additional physical load experienced by the pilot during the exercises on a Full Flight type simulator, do not have a significant impact on reducing the number of hours of practical training carried out by the crew in the air. The authors do not comment on the impact of this training on enhancing the crew's skills in the use of the available resources during the flight.

The interviews conducted by the author with a group of instructors from flight training organizations in Poland[16] indicate that FNPT-2 simulators provide highly effective training and selection, particularly in relation to the exercises concerning: IFR flights, emergency procedures, maneuvers performed by the aircraft during mission execution, and cockpit pre-flight check.

Given the above findings, it is possible to formulate a thesis that modern flight simulators ensure a high degree of basic flight training efficiency[17]. Other air training equipment, due to its purpose and specific use is not used by general flight training organizations.

USEFULLNES OF THE FLICHT SIMULATORS IN THE COMMERCIAL AVIATION PILOTS TRAINING

Commercial aviation organizations following the current regulations conduct the simulator training within the scope of training for certain aircraft type, MCC, CRM, and mandatory periodic training. The main document regulating the air operator's duties regarding the preparation and professional development training of the crews belonging to commercial aviation organizations is OPS-1, and Part-FCL1 in relation to the training for particular aircraft type. As is the case with general aviation, each flight simulator or air training equipment item replacing the aircraft for training and testing purposes must be certified in accordance with the requirements applicable to air training equipment[18]. Under the current regulations, any member of the flight crew prior to commencing flight operations below the standard set for Cat. I, operations outside the standard of Cat. II and operations within Category II and III[19] must

[14] K.A. Harris, D. Harris, Computer-based simulation as an adjunct to ab initio flight training, International Journal of Aviation Psychology N° 8/1998, pp. 261–276.

[15] E.A. Vaden, S. Hall, *The effect of simulation platform motion on pilot training transfer: A meta-analysis*, International Journal of Aviation Psychology N° 15/2005, pp. 375–393.

[16] The author conducted research by interviewing a group of 10 instructors representing the leading fligcht training organizations which conduct simulator training.

[17] Training up to CPL (A) license and IFR (A) rating.

[18] In relation to simulators, these requirements are set by JAR-FSTD A: Aeroplane flight simulation training devices.

[19] These categories refer to the categories of ILS (Instrumental Landing System) applicable to certain airports. The basis of category allocation is the possibility of making a safe landing at a minimum cloud ceiling and visibility: Cat. I – DH (Decision Height) no less than 200 ft (60 m) and RVR

complete the training courses and tests which use flight simulators. These courses include reduced visibility operations, including multi crew cooperation. It is emphasized that MCC and CRM trainings[20] ought to be conducted with The maximum use of flight simulators. In the case of aircraft for which the flight simulator has not been produced, the operator must ensure that the phase of simulator training specific to the visual scenarios of Category II operations is conducted in a specifically approved flight simulator[21]. Moreover, each crew member shall undergo periodic training and testing appropriate to the type or variant of aircraft in which he operates flights. Those trainings are usually conducted using the flight simulator which corresponds to a given aircraft type[22]. As part of ongoing operations the operator must ensure that:

– the pilot is not assigned to operate an aircraft as a member of the minimum approved crew, either as pilot flying or pilot non-flying, if during the past 90 days he has not performed three take-offs and three landings as pilot flying in an aircraft or in a flight simulator of the same type/class;

– the pilot who does not have a valid IFR rating is not assigned to perform night flights as a crew commander, if during the past 90 days he has not performed at least one landing at night, as pilot flying in an aircraft or in a flight simulator of the same type/class[23].

– Moreover, each operator is required to provide transition training involving such elements as:

– ground training and tests concerning aircraft systems, routine, non-routine and emergency procedures;

– trainings and tests in order to familiarize trainees with emergency and safety equipment, which must be completed before the commencement of the practical air training. It should be noted that an important element of these courses are exercises and tests performed with the use of flight simulators[24].

Importance attached to the simulator training of commercial aviation aircrews in the above-cited regulations as well as the results of analyzes relating to the opinions of pilots from commercial aviation organizations clearly show that simulator training is an essential element of professional development training in this type of organizations. Flight simulators used in the training described above facilitate, on the one hand, a continuous improvement of the flight crew skills, and, on the other hand, they are a valuable tool to determine the level of flight crew preparedness for the tasks facing them. Moreover, taking into consideration the scale and frequency of training it is difficult to imagine a commercial aviation organization capable of affording to conduct the training in full using only the aircraft.

USEFULLNES OF THE FLIGHT SIMULATORS IN THE MILITARY AVIATION PILOTS TRAINING

(Runway Visual Range) no less than 2040 ft (800 m). Cat. II – DH no less than 100 ft (30 m) and RVR no less than 1,050 ft (350 m). Cat. III has been subdivided into three subcategories: - IIIa – DH = 0-100 ft, RVR no less than 600 ft (200 m); IIIb – DH= 0–50 ft, RVR no less than 150 ft (50 m); IIIc – DH = 0, RVR = 0 – Developed on the basis of: T. Compa, J. Rajchel, *Podstawy nawigacji lotniczej*, WSOSP, Dęblin 2011, p. 297.

[20] MCC – Multi Crew Cooperation; CRM – Crew Resource Management.

[21] Developed on the basis of: Appendix 1 OPS 1.450.

[22] Further details, see Appendix 1 OPS 1.950.

[23] Developed on the basis of: Appendix 1 OPS 1.970.

[24] Developed on the basis of: Appendix 1 OPS 1.945.

In Military aviation, which is less dependent on the financial factor, flight simulators are widely used in daily operations and training relating to the acquiring/maintaining pilot currency. Flight simulators used in military aviation can be divided into two main groups, according to the tasks performed with them:

1. Simulators for schools and military pilot training organizations. Their use is associated with familiarization of beginner pilots with the aircraft, its handling, navigation and basic combat missions. They are used for the selection and training of pilot candidates, advanced flight training, training of all flight phases, assessing the implementation of specific air missions, and crew training and coordination within the scope of MCC and CRM training. The syllabus of pilot training for Polish Air Force Academy (PAFA) officer cadets includes 120 hours of specialized simulator training during the four years of study. The situation is somewhat different in the case of training/professional development of jet pilots in the units of the Polish Armed Forces. Simulators of this aircraft type alongside handling and navigation functions support the functions related to performing combat missions. The number of simulator training hours depends on the intensity and the type of tasks performed by the pilot. Apart from the above-mentioned applications, flight simulators are treated in air force units as a valuable tool for preparing to resume pilot currency and skills in the event of long time break between flights.

2. Simulators of the Polish Armed Forces units, where the main emphasis is placed on improving aircraft handling skills associated with aerial combat techniques.[25] Individual training tasks carried out in the air are generally preceded by the training on a flight simulator which is an exact copy of the aircraft operated. As a rule, the trainee is allowed to conduct the tasks in the air after successfully conducting them on a simulator. Simulators are used for a variety of reasons, including those related to the low unit cost of simulator training hours compared to the cost of flight hours. U.S. Air Force estimates that the cost of one hour of training on the C-5 aircraft is approximately $ 10,000, while one hour of training on the C-5 simulator is $ 500[26]. Especially with regard to military pilots and airline pilots the key advantage of simulators is the fact that they allow pilots to perform simulated flight tasks and train the behavior in non-routine situations, which if performed on the trainer aircraft would involve too high risk of undesirable flight-related events.

Another reason for the use of simulators in the Air Force is the knowledge transfer degree, which is comparable with that acquired during practical training in the air. The results of research concerning the aspects related to the effectiveness of simulator training clearly show that the knowledge, skills and habits acquired during such training exert a direct influence on the pilot's readiness to perform air missions in the air. R. Moorman et al. conducted research relating to knowledge transfer involving flight simulator. Their study covered the period 1957–1986[27]. The authors conducted a study using the meta-analysis method[28] and the results allowed them to

[25] The division of simulators used in military aviation was made on the basis of: C. Szczepański, *Symulatory lotnicze, stan i perspektywy* – raport , Warszawa 1998, p. 4.

[26] T.R. Moorman, *The civilian looping military*, MS&T Magazine, N° 6/2002, p. 16-20.

[27] R.T, Hays, J. Jacobs, C. Prince, E. Salas, *Flight simulator training effectiveness. A-meta-analysis,* Military psychology Nº 4/1992, pp. 63-74 .

[28] Meta-analysis is a research method which involves the use of statistical techniques for connecting the results of several tests in order to find an answer to one research problem. This method comprises several phases, i.e.: formulation of the research problem, identification of the research area (person, location), encoding the test (preparation of test material, e.g. surveys), meta-analysis - analysis of results and their presentation. For example: The investigator is interested in carrying out research in order to find out whether the psychological test that measures the level of the candidate's spatial intelligence can be a tool used for the selection of pilot candidates. In this case, first of all, the test is administered to the pilot candidates, and then its results are compared with their flight training performance. The results obtained constitute the material which allows making comparisons in order to determine the correctness of the construction of the test and its questions (tasks), and therefore, they are a measure of its usefulness in the selection process of pilot candidates. Developed on the basis of: M. Marlinussen, D.R. Hunter, *Aviation*

conclude that simulator training contributed to a permanent increase of the training effects in jet pilots, which are equal to those of practical training carried out on the specific aircraft type. However, this regularity was not confirmed for helicopter pilots.

In another study, Corveta and Dunlap[29] focused the research on the effectiveness of simulator training involving jet pilots, with respect to such items as landing maneuver, IFR flights and tasks performed at the firing ground (*aerial bombardment*). In all of the above areas of research, the results clearly indicate a *high degree of usefulness of* flight simulators for pilots' skill development.

From the situational awareness perspective, flight simulator plays a particularly important role in military aviation. Despite the high level of automation of modern combat aircraft, because of the complex character of air mission environment – unknown flight zone, limited possibility of using radio navigation instruments, low and very high altitudes, high speeds and G-loads, unpredictable enemy, conducting missions in radio silence, often as a member or head of the combat group, the pilot conducts air missions under heavy psychophysical load. Therefore, the degree of pilot mastery concerning cockpit actions, or the degree of "automation" of these actions has a major impact on the pilot's ability to maintain the desired level of situational awareness at various stages of air mission execution. The results of the analysis of serious air incidents which concerned combat aircraft of the Polish Armed Forces in the years 1970–2004 show that the vast majority of them was caused by insufficient situational awareness of the pilot – approx. 70%[30].

The growing complexity of technical systems increases the burden on the operators. Mastering operator actions is a long and costly process which is dependent on technological advancement and the complexity of actuating devices. The essential feature of operators is the necessity of receiving, analyzing, and responding to information which is frequently acquired from several different sources. The pilot is a special type of an operator since he is constantly subjected to pressure affecting his psychomotor (operator's) skills because of the work environment, and is facing the serious consequences of errors committed during reception (interpretation) of stimuli and responding to them.

Forming pilot's habits confirmed by research studies points out to the desirability of using flight simulators in aviation training.

From the data obtained during the tests performed on the simulator and on the aircraft, it is clear that the number of errors is similar in both cases. The above ensures the suitability and necessity of using flight simulators for training pilots.

The effectiveness of the training is verified by the practical performance of air missions, and it constitutes a basis for changing the contents, methods and forms of the simulation training.

Simulator training can be divided into three areas[31]:

psychology and human factors, CRC Press, New York 2010, p. 43.

[29] T.R. Carreta, *Transfer of training effectiveness in flight simulation: 1986 –1997* (technical report AFRL-HE-AZ-TR-1998-0078), Mesa, AZ: U.S. Air Force Research Laboratory, Human Effectiveness Directorate, (in:) Op.cit., M. Martinussen, D.R. Hunter, *Aviation Psychology and Human Factors…*, p. 114.

[30] The analysis has been conducted on the basis of the available post-accident materials.

[31] A. Bondaruk, *Metodyczne uwarunkowania konstruowanina programów szkolenia symulatorowego*

- flight maneuver training;
- procedural training (IFR);
- tactical training;

[Methodological considerations of designing simulator training syllabi] , Conference on "The Instructor Preparing Trainees for Difficult and Dangerous Professions", Dęblin, February, 2014.

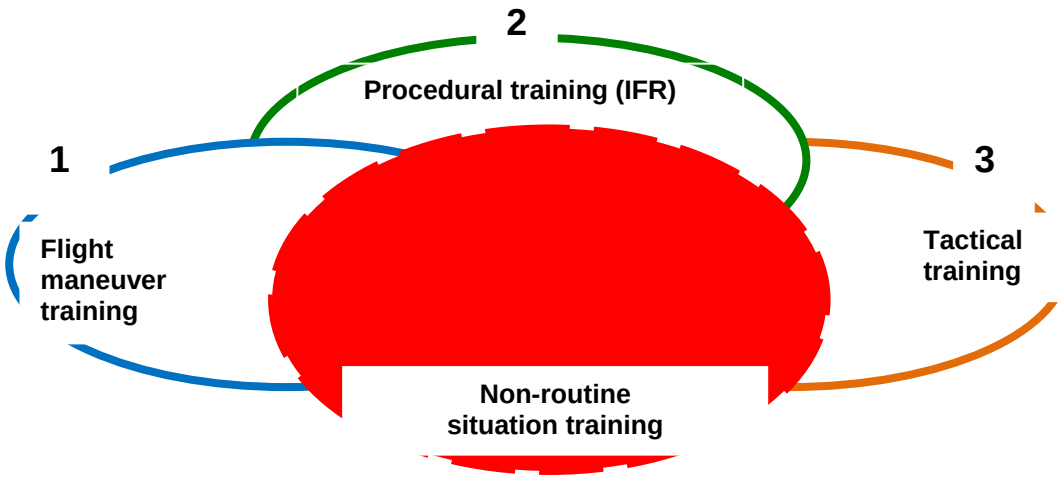

Fig. 1. Simulator training areas.

It is advisable that simulator training program should include elements of subsequent training areas that prepare the trainee for more difficult tasks, but are not the main training objective. To sum up, the areas of training overlap at particular stages. The degree of their implementation depends on the main objective and complexity of training, as well as on the level of training of a particular pilot. Training of emergency flight procedures is implemented throughout the entire flight training program.

In 2012, a research study was conducted taking into account the above considerations, with the use of an FFS (Full Flight Simulator) simulator. The purpose of the research was to determine the training susceptibility of pilots and the appropriateness of the applied simulator training program.[32].

The number of pilots tested accounted for approximately 20% of the population of F-16 pilots in the Polish Armed Forces, who have completed the basic training (acquired a minimum wingman rating).

For the purpose of the analysis, a set of "measurable" data was determined, i.e. those which have been obtained by means of measurements. This data set included the pilots' time before reaction to deviation from the prescribed (standard) flight parameter values, and the "countable" data - the number of errors made when performing certain tasks on the simulator.

The study included the completion of four sessions on the multi-role F-16 aircraft simulator by every pilot. Each session was carried out according to identical profile consisting of two scenarios (missions). The study was divided into two phases. In the first phase, the pilot being tested performed three sessions at intervals that allowed for discussion, and the analysis of errors having been made when executing the task, as well as for the preparation for the subsequent flight. Before the commencement of the first session, the pilot was briefed only on the tactical background and the task to be accomplished. The element of a non-routine situation remained unknown for the pilot until its occurrence. The second phase included the execution of the last, fourth, flight after at least one month from the completion of phase 1

Elements being assessed in scenario 1:

- making the decision to abort the mission in a particular non-routine situation;
- maintaining the IFR flight parameters;
- maintaining the preparatory procedures for landing at the alternate airport;
- maintaining the prescribed heading during the vectoring;
- descending to the final approach point (FAP), maintaining the

[32] A. Bondaruk, *Badanie wpływu uszkodzeń i niesprawności samolotu wielozadaniowego na bezpieczeństwo lotów [Study of failure and malfunction effect in multi-role aircraft on flight safety]”,* Doctoral Dissertation, Air Force Institute of Technology (ITWL), Warsaw 2011.

minimum flight altitude H in accordance with the approach chart;
- maintaining flight parameters during descent;
- maintaining flight parameters at decision height/altitude (DH/DA);
- maintaining the missed approach procedures (MAP);
- performing the landing.

Elements being assessed in scenario No. 2:
- making the decision to abort the mission;
- maintaining flight parameters during emergency procedure execution;
- recognition of a subsequent emergency situation (observation of engine control instruments during emergency procedure execution);
- making the decision to perform the simulated flameout (SFO) landing procedure;

• if made:
- maintaining flight parameters during SFO approach in accordance with the standards of the appropriate procedure;
- performing the landing;

• if not made:
- recognition of turbine stoppage;
- performing the procedure of preparation for the ejection.

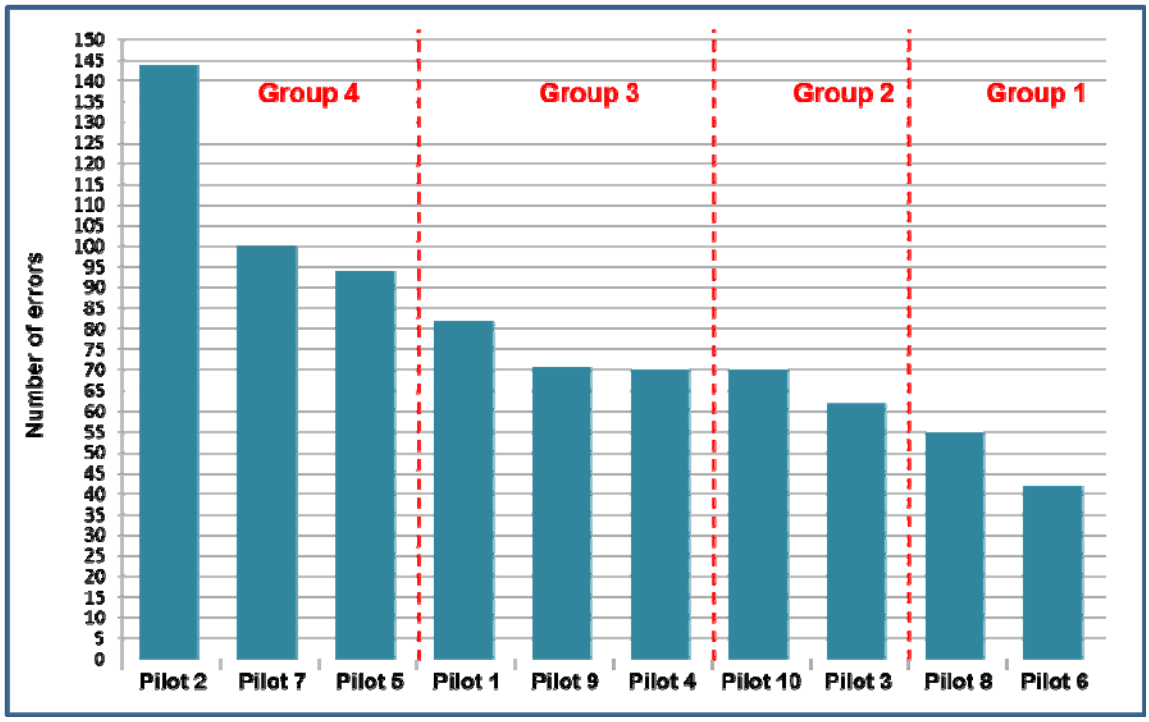

Fig. 2. The total number (sum) of errors committed by pilots during the execution of tasks in accordance with scenario No. 1

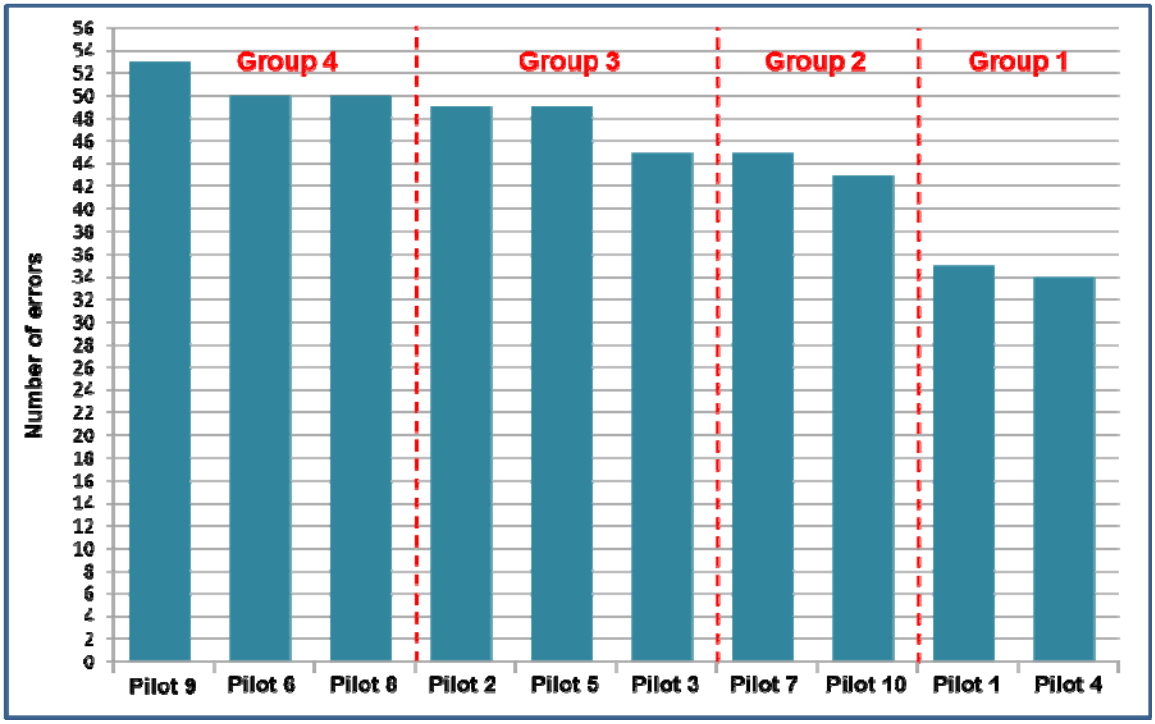

Fig. 3. The total number (sum) of errors committed by pilots during the execution of tasks in accordance with scenario No. 2

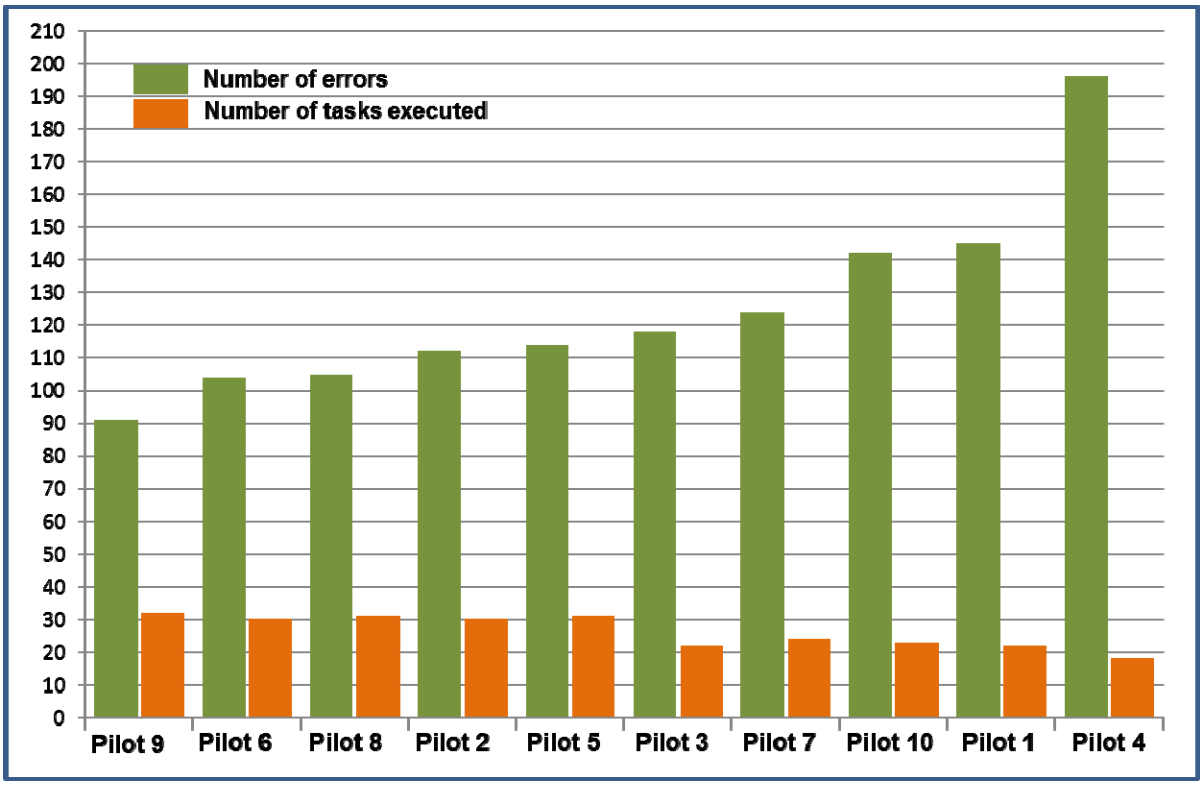

Fig. 4 Sums of the numbers characterizing the errors made during the task execution by the pilots, and the execution of tasks during an emergency situation according to the developed scenarios No. 1 and No. 2 (number of errors number of tasks executed)

Analyzing the number of errors made and the tasks executed, one can conclude that during the execution of tasks in accordance with scenario No. 1 and No. 2, pilot No. 6 was best prepared for the emerging situations, whereas pilot No. 2 was the worst.

Acting in accordance with the presented scheme does not allow one to draw definite conclusions concerning the proper way of approaching the problem of pilot training. The characteristics under analysis are different in their nature, and it cannot be decided unequivocally which pilot has to undergo additional training and which does not, and what number of additional flights will allow a given pilot to acquire the appropriate responses to simulated specific situations in the air. At the same time, there is a noticeable decrease in the number of errors as a function of the number of repetitions of a given scenario.

Basic statistics, including mean values and standard deviation, were calculated on the basis of the data obtained during the simulation of specific situations that characterized the level of training of a particular group of pilots who executed tasks using an F-16 aircraft simulator.

Presentation of these values in a scatter graph [Figure 5] allows for the disclosure of the four basic structures of meeting the requirements by pilots involved in the training system. Those structures have been defined on the basis of an analysis of the number of errors made in emergency situations.

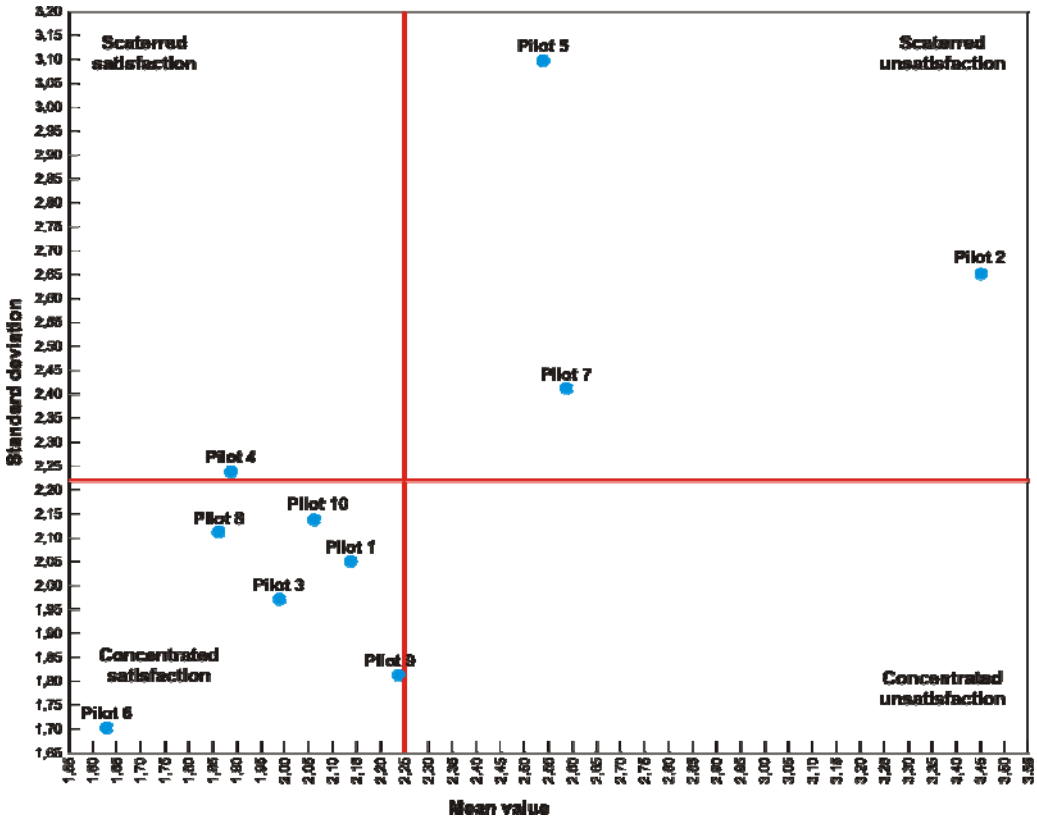

Fig. 5 Distribution of meeting the requirements by pilots, obtained on the basis of error analysis results.

The system is characterized by concentrated satisfaction with the results achieved by pilots, No. 1, 3, 6, 8, 9, and 10. Scattered satisfaction relates to pilot No. 4.

Scattered dissatisfaction relates to pilots No 2, 5, and 7.

Basic statistics, including mean values and standard deviation, were calculated on the basis of the data obtained from the analysis of information characterizing the level of pilot training, and on the basis of numbers characterizing the execution of specific tasks for a specific group of pilots, who were assessed using an F-16 simulator. Presentation of these values in the scatter graph [Figure 6] allows for the disclosure of the four basic structures of meeting the requirements by pilots involved in the training system. Those structures have been defined on the basis of an analysis of the number of errors committed during the execution of specific tasks.

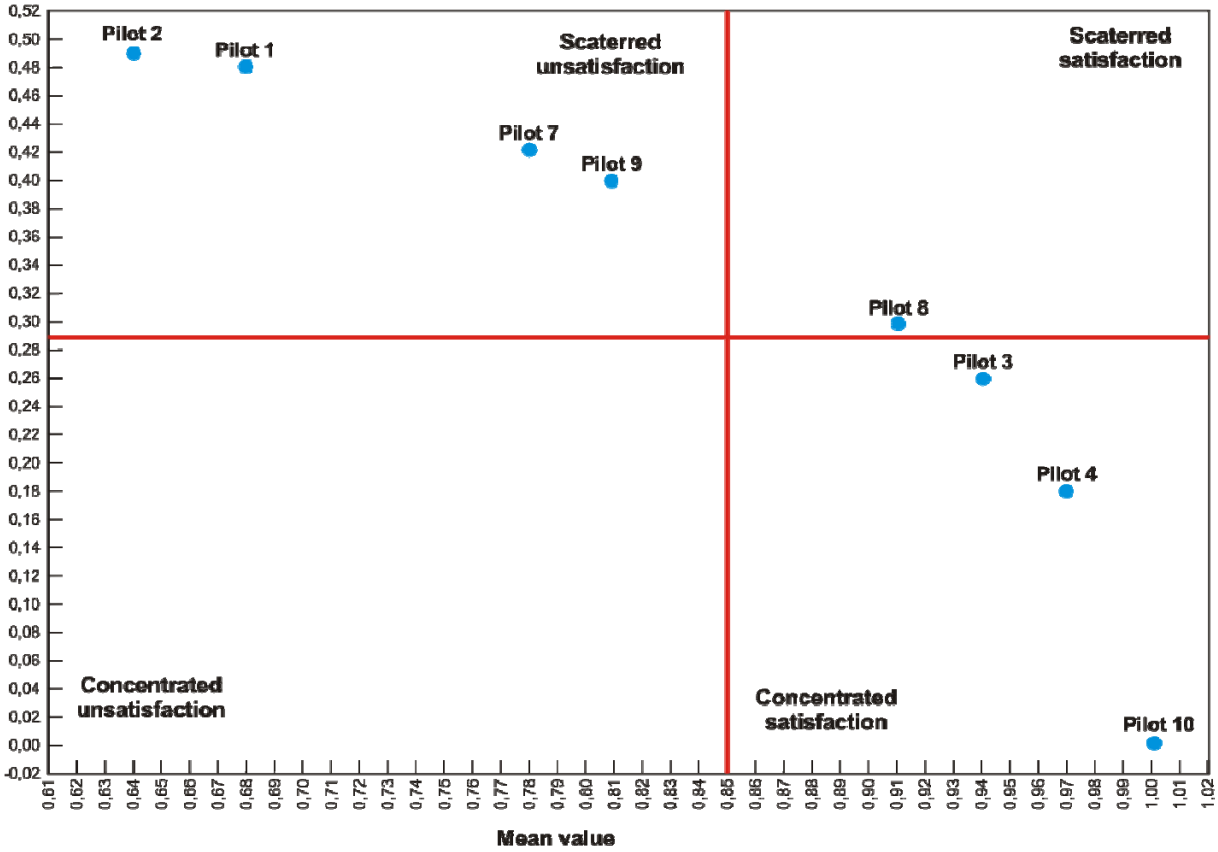

Fig. 6. Distribution of meeting the requirements by pilots, obtained on the basis of the number of executed tasks

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The system is characterized by concentrated satisfaction with the results achieved by pilots, No. 3, 4, 6, and 10. Such a situation is perceived by the training system in a coherent and consistent manner.

Scattered satisfaction relates to pilot No. 8. Scattered dissatisfaction relates to pilots No. 1, 2, 5, 7, and 9.

Scattered dissatisfaction frequently results from errors in the adaptation of pilots to the specific requirements of the training system.

The training system is characterized by a lack of concentrated dissatisfaction with the results obtained by the pilots in the simulator training, and determined on the basis of the number of errors made during emergency situations and the execution of specific tasks. It can, therefore, be concluded that the training system is functioning properly and there is not a single pilot who would not have achieved any results within the framework of a functioning training system

The analysis conducted in this manner does not allow for a holistic approach to the problem of assessing the level of training of the pilots on the basis of the results obtained in the simulator tests. However, it was possible to identify the elements common to the number of errors committed and the number of tasks executed. Pilots were divided into training groups in accordance with the analysis conducted in this manner. Group 1 (achieving the best results) includes pilots No. 6 and 10, group 2 includes pilots No. 4 and 3, group 3 consists of pilots, No. 1, 5, and 8, whereas group 4 consists of pilots, No. 7, 2, and 9.

The advantages of using flight simulators in daily professional development training of military pilots which have been presented in this chapter point to the fact that flight simulators are an effective tool for the development of the essential elements that affect the level of air mission execution safety tasks, including the desired degree of situational awareness The confirmation of this thesis may be made by the recommendations of the UK Royal Air Force (RAF) following a large number of air accidents which resulted from the introduction of jet aircraft in 1960's. One of the key corrective actions aimed at preventing the similar events in the future was the decision to purchase flight simulators and intensify simulator training of jet pilots.

CONCLUSION

Regardless of the type of aviation and the stage of flight training/professional development, flight simulators are a widely used pilot training tool. The results of reference literature analysis, expert opinions, flight simulation studies, and the author's own air permit the conclusion that the essential benefits of the flight simulator, including those relevant to the pilot's situational awareness can include the following:

1. *High training effectiveness*. The tests related to measuring the effectiveness of flight simulation training demonstrated that the trainees develop knowledge and skills at a level similar to that achieved in a real flight. During simulator training, due to lack of necessity to physically control the aircraft, the instructor can fully focus on the student and the activities that the student performs. Modern simulators support the function of recording and collecting data from simulated air operations carried out during the training. This facilitates multiple analyses of the compatibility of flight parameters as defined in the exercise scenario with the values registered during the training flight.

2. *Maintaining high standards of training safety.* Due to the necessity of maintaining a certain level of safety during training, simulators sometimes provide the only way to learn some maneuvers, the elements of air operations performed in the event of dangerous weather conditions (wind shear, turbulence, icing, jet streams, etc.). Performing the above-mentioned maneuvers in a real flight would involve putting the trained crew at high risk. A similar situation occurs in the event of critical aircraft component failure, including, among other things, failures concerning the engine, flight instruments, or control systems, etc.

3. *Availability*. The fact that the use of the flight simulator in flight training is not dependent on the current ambient weather conditions, the state of the airport, or the good working condition of ground navigation equipment allows for a more methodical approach to the training from the human factor perspective. Moreover, it is possible to simulate non-routine in-flight situations without the necessity to wait for their occurrence in the real air mission execution environment.

4. *Repeatability*. The simulator does not require the implementation of the full cycle of a given air operation (pre-flight check,

take-off, mission execution, landing, psot-flight check) to discuss and repeat a specific part of the exercise by the trainee. It facilitates the repetition of each flight element and making breaks for an exchange of views between the trainee and the instructor.

5. *Predictability***.** Simulator training prevents the occurrence of such dangerous phenomena as air traffic collision, wind shear, icing, weather deterioration, turbulence, closure of airports, etc. Of course, all of these situations are possible to simulate, but the exercise of this kind are carried out by the trainee at the time specified by the instructor, according to the trainee's progress made in the training.

6. *"Learning from mistakes"* – with unlimited possibilities of applying a number of ways to solve an in-flight operational problem with "zero" risk level, the simulator allows the student to select the solution which is the most optimal from his perspective and to test it. This capability allows the trainee to physically "prove to himself" that some solutions considered by him to be more useful and safer than those recommended by the instructor or the instruction manuals are not a good option in operational reality and, consequently, they are eliminated by the trainee once and for all.

7. *Maintaining pilot currency and proper attention allocation*. Systematic training exercises on the flight simulator allows the trainee to consolidate the desired habits (maintain pilot currency) and, what is equally important, allows him to permanently master the optimal attention allocation in various phases of the air mission execution. It allows the beginner pilot, on the other hand, to adequately master the basic elements of cockpit preflight check and such actions as starting up the engine and other aircraft equipment. This allows both to save the time and reduce the costs of practical training.

8. *Credibility as a tool applied in air accident investigation*. Flight simulators ensure accurate *reconstruction* of flight conditions, the situation onboard, and the evaluation of the actions taken by the crew of the aircraft in the event of an undesirable flight-related event. The conclusions of these analyses and corrective actions taken in the aspects related to the event – the pilot-operator, the aviation organization, the environment, the aircraft allow to avoid or safely respond to undesirable flight-related events in the future.

9. *Simulators can be used for training for the prototype aircraft under design, or aircraft employing new solutions (systems).* Performing this task in practice, without the prior simulation and practice of selected flight maneuvers could be associated with a high level of risk and, in extreme situations, with high probability of undesirable flight-related event.

10. *High comfort of performing the training tasks by the instructor.* An undoubted advantage of the flight simulator in comparison with the aircraft is the fact that the instructor can focus his attention fully on the trainee and the task performed. Equipping the simulator with a module recording the operating parameters, including the correspondence between the instructor and the trainee, allows for deep analysis of multiple elements of the flight in order to draw the appropriate conclusions and facilitates methodological development of corrective

actions to be taken in relation to the trainee[33]. In contrast to a training flight conducted in the real mission environment, the instructor may but does not have to immediately correct to the trainee's errors. The instructor's actions may only amount to monitoring the situation on board the aircraft in a particular mission execution environment, and assessing the trainee's response time to committed errors. Such a situation is favorable in that the trainee can fully see the effects of his improper actions on board the aircraft. In real flights allowing such a situation could lead to an excessive risk of an undesirable flight-related event.

11. *Optimizing the use of financial resources*. The use of the simulator can significantly reduce the training costs as compared to those incurred for the use of the aircraft. Furthermore, simulator training implemented instead of the training on the aircraft allows for significant savings resulting from the extended *service life* of the aircraft. Taking into account the detailed analysis of the cost vs. effectiveness relationship, Orlansky and String proved that the costs of applying flight simulators in the training of military flight personnel account for 5%–20% of the cost of the same operation performed on trainer aircraft. This allows for the reduction of the flight training cost on average by approximately 12%. They also found that commercial aviation organizations can expect a return of the total purchase price of the simulator within approximately 9 months, and the return of the costs of the necessary training facilities within about two years.

12. *The use of simulators significantly reduces the number of hours flown by the trainee,* which is beneficial for aircraft operating costs, and the costs resulting from the use of airspace and airports, both controlled and uncontrolled.

Despite the advantages mentioned above, no simulator can currently be defined as a device that can replace the hands-on training in the air. It is still considered as a very important form of preparing or supplementing practical training in the air.

The use of flight training simulator, like any other training device, has a number of disadvantages, which can include:

1. *Purchase price of the* simulator. The most important barrier resulting in a limited number of simulators available in our country is their purchase price.

2. Insufficient levels of environmental impact on the trainee which is present in real air operations. In a simulated emergency (dangerous weather phenomenon, onboard system failure), the trainee does not experience the same degree of stress as in the case of the same situation enocuntered in the air. However, mastering the proper execution of actions related to a specific emergency situation using the simulator makes it easier to take appropriate action in the event of encountering a similar phenomenon in the air. On the other hand, because of too strict adherence to procedures and not allowing the trainee to experiment and learn from mistakes in preventing dangerous situations during simulator training, the trainee is not able to move beyond the learned schema, and thus is often not able to properly respond to a non-routine situation in the air. This usually leads to an undesirable flight-related event. The proof of that is provided by the results of

[33] The simulator facilitates collecting the flight data related to the level of compliance. As a part of the diagnostic process, the instructor-pilot can compare the established criteria of conducting a given exercise with those defined by the recorded flight parameters. In addition, the instructor can make a comparative analysis of the quality of performing the tasks by trainees who are at the same stage of training (the diagnosis of the state). Having the results of progress made by the trainee during the training, the instructor can understand more deeply the causes of mistakes made by the trainee, and offer him a new approach to an element of the exercise, which will allow him to achieve acceptable results. The instructor may also evaluate the feasibility – measurability of the quality of performing various elements of the exercise can be used to enhance the effectiveness of training by changing the approach to the training of selected elements of the exercise.

studies conducted by a NASA research team who used the data from the Aviation Safety Reporting System (ASRS).

3. Shorter flight duration in comparison with real flights. Too frequently, selective treatment of certain flight elements causes the effect of mental fatigue and weariness to occur during simulator training with less severity than in a real flight. As a result, it is difficult to assess the resistance of the trainee to weariness or mental fatigue usually present in *long lasting flights*.

4. No faithful reproduction of "radio traffic reality" of the real mission environment. While conducting simulator training, instructors often place less importance on the so-called "radio traffic reality". Because of that, the trainees with less operational experience have difficulty in understanding the radiotelephony communication and performing air operations in the "congested" areas of controlled aerodromes.

Currently, flight simulators, in addition to aircraft are considered as one of the essential tools for selection, training, and developing/maintaining currency of flight crews. They are also viewed as a reliable tool for testing pilot knowledge and skills in specific aspects of aircraft operation and air mission execution. Because of the above-mentioned advantages of these devices, simulator training, in addition to theoretical and practical training in the air, plays a crucial role in shaping the competencies needed to achieve the desired level of situational awareness by the pilot at various stages of air mission execution. Therefore, the use of these devices for forming and consolidating the pilot capabilities necessary, among others, for the efficient execution of the situational awareness process should be considered as justified.

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