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THE ROLE OF THE HUMAN FACTOR IN MAINTAINING THE DESIRED LEVEL OF AIR MISSION EXECUTION SAFETY

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INTRODUCTION

Flight safety is neither the objective nor is it the task of aviation. Flight safety is a condition in which all planned objectives are realized, while at the same time potential hazards that could affect the course of their realization are kept under control. The role of the "human factor" in the aviation safety system has been known for a long time. It was also the subject of studies in many research centers, but only in the late twentieth century, was that research given the appropriate importance. Today we recognize that the "human factor" has been "institutionalized".

THE CONCEPT OF SAFETY IN AVIATION

Aviation is a special type of human activity, which is the fulfillment of man's age-old dream of the conquest of the skies. With time, dreams of the pleasure of soaring in the skies turned into a desire to use the aircraft as a tool to do more practical, commercial tasks. Quite soon it became clear that that activity is accompanied by a number of risks[1] that contribute to undesirable flight-related events. That phenomenon is exacerbated when safety standards in aviation are violated, regardless of who, with how vast experience, and flying what type of aircraft, is executing an air mission. Risks in aviation varied depending on the stage of aviation development. By the early 1950s, causes of undesirable flight-related events[2] were associated first of all with technical factors[3]. On one hand, aviation was seen as a very effective tool in the battle field, but on the other hand the importance of the aircraft as an extremely important element of the transportation industry was constantly growing. Low level of aviation technology, compared with the present day, low strength of materials used in aviation and too frequently repeated design flaws were key factors influencing the level of flight safety. That situation caused the research in the areas of aviation safety to focus on the improvement of technical factors. In reference publications, that period is referred to as the "technological age". However, one should not be confused by this name, because, according to the author, even at that time an important role was already

[1] At the time of World War I losses caused by air accidents reached 72%–83%, and during World War II and the Korean War reached the level of 52–55% – H. Michałowski, *Wysoki poziom bezpieczeństwa lotów podstawowym warunkiem gotowości bojowej lotnictwa*, Wyd. CW, Warszawa 1973, WPL N° 3/73, p. 3.

[2] For the purpose of this publication it is assumed that the term "undesirable flight-related event" refers to air accidents and incidents described in Article 134, *Polish Aviation Law Act* of 03 July, 2002 (Journal of Laws from 2006, No. 100, item 696, as amended) and § 20 of the *Flight Safety Instruction of the Polish Armed Forces*, WLOP, Warszawa 2004,WLOP 346/2004

[3] Developed on the basis of – ICAO, *Safety Management Manual*, Doc. 9859-AN/474, ULC, Warszawa 2009, Second Edition, pp. 2-2 – 2-5.

given to the significance of man in the system of aviation safety and to appropriate preparation of man to executing air missions. The evidence of that is the importance that was attached to the development of aviation subjects – navigation, aerodynamics, flight mechanics, etc., and techniques used in the training and professional development of flight crews as well as to the tools used in that process – flight training devices. Technical factor did not always come first in preventive actions taken in response to undesirable flight-related events.[4] The 1970s brought about significant advances in technology and materials used in aircraft construction. With the progress in aviation old threats were replaced by others, as a consequence of the introduction of new, often revolutionary, design solutions. Examples of such risks, can be found – among other things – in the causes of undesirable flight-related events connected with aircraft automation[5], or in the increased maneuverability of combat aircraft resulting in a high incidence of high G-loads which affect the operator – the pilot of the aircraft[6]. Steady progress in the development of aviation technology meant that increasingly sophisticated designs were put at man's disposal, which meant that ever greater demands were to be met by operators and support personnel. On the other hand, those designs were characterized by larger and larger spatial-temporal, technical and functional capabilities. This meant the beginning of the era referred to as the "human factor". The focus in the areas of aviation safety was moved to the human factor and the associated human activities, including, i.a., crew resource management, line-oriented flight training, operating highly automated aircraft, which was oriented on man and the role of other aviation personnel in the preparation and implementation of flight tasks. Unfortunately, despite large-scale efforts to reduce human errors, human factor was still the "weakest link" of the aviation system. The reasons for this state of affairs was sought in the fact that too much attention was given to individual actions of the pilot and other aviation personnel, leaving in the background broadly understood mission environment and its impact on aviation safety. In the early 1990s, these findings led to the initiation the era of "organizational factor", which put special emphasis on issues related to the manner in which mission environment – organizational, environmental, and task-related factors, [7] etc., can affect the safety and

[4] After the introduction of jet aircraft, the Headquarters of the Royal Air Force (RAF) was forced to take action to counteract the causes of a series of accidents resulting in the deaths of dozens of pilots. Those actions were aimed primarily at improving the elements related to the human factor, and consisted in: reduction of aircraft type number flown by a single pilot; supervision of the training process in the air force units by experienced pilots (required flying time of unit commanders – min. 400 hours on jet aircraft); putting a large emphasis on flying personnel's knowledge of aircraft design, operating principles and piloting techniques; emphasizing the need to abide by the principles of operation – procedures – related to aircraft equipment; obliging pilots to do 5 simulated flameout trainings a year; putting particular emphasis on the use of flight training devices in training – Developed on the basis of: K.S. Sulikowski, W. G. Kowalski, M. Żebrowski, *Wypadki w lotnictwie wojskowym i cywilnym*, (in) K. Klukowski (Ed.), *Medycyna wypadków lotniczych*, PZWL, Warszawa 2005, pp. 177-185.

[5] DC-10 Air New Zealand collided with Mount Erebus, 1981 – the crew entered incorrect data to the navigation system of the aircraft; B-747 Chine Airlines, Pacific, 1985 – gradual loss of power in number four engine, autopilot trying to maintain a prescribed heading and altitude led to the stalling of the aircraft. Airbus A320 Lufthansa, 1993 – computer interference in the decisions of the pilots.

[6] In 1986 – 1996, the cause of 14 air accidents in the U.S. Air Force was attributed to exceeding the allowable G-load– J. Auten, *GLOC...is the clue bag half full or half empty?*, Flying Safety, June 1996, p. 6.

[7] When speaking of the mission environment, the author has in mind two of its main areas:

1. Internal environment – the aircraft – degree of automation, aerodynamic properties, maneuverability, degree of standardization, ergonomics, warning systems (e.g.. TCAS, stall warning in the event of exceeding the critical angle of attack), the availability of maintenance, reliability, ease of piloting, etc.; pilot (crew) – selection, health condition, personality and professional qualities, resistance to stress, level of training, level of communication, teamwork, experience, continuous specialized training, motivation, etc.

2. External environment – environmental conditions (weather, altitude, terrain features, etc.) as well as services and means of securing the implementation of

the effective implementation of air operations. It should be noted that regardless of the stage of aviation development, all of the above-mentioned safety factors (human, technical, organizational) were taken into consideration, to a greater or lesser extent, in the investigation of the causes of undesirable flight-related events and in the development of preventive measures. Despite making extensive efforts to reduce the impact of the above-mentioned factors on the occurrence of undesirable flight-related events, those factors are still the main cause of them. Therefore, contemporary theories of aviation safety deal with issues related to aviation safety (broadly understood) through the prism of the above-mentioned factors (Fig. 1).

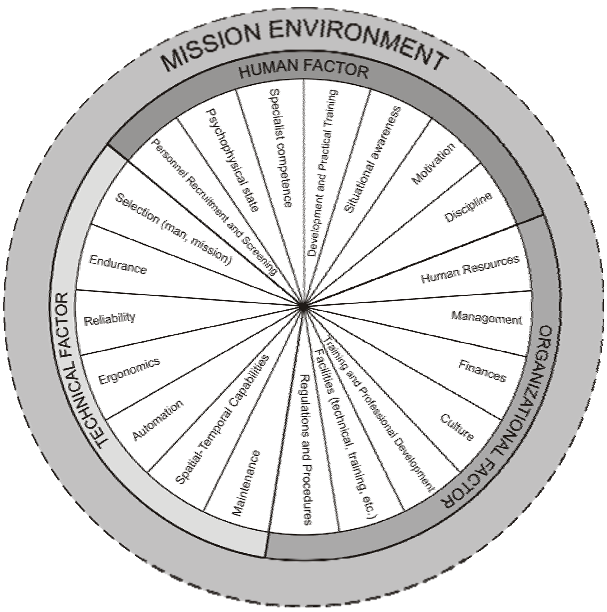

Fig. 1. The approach to the theory of aviation safety from the point of view of safety factors. Author's own work, developed on the basis of: Op. cit. ICAO, *Safety Management Manual ...* , p. 2-4; *Model systemowego ujęcia problemów bezpieczeństwa wg Łomonowa i Płatonowa,* (in:) E. Klich, J. Szczygieł, *Bezpieczeństwo lotów w transporcie lotniczym*, PIB, Radom 2010, p. 50 and the results of the author's own studies.

When discussing the essential safety factors in the context of determining the level of air mission safety, we must always subject them to analysis from the point of view of internal interactions taking place between the components of each factor as well as the external interactions that occur between particular safety factors. The higher the level of compliance of the interactions concerning the safety factors and their individual components with the nature of the tasks performed, the less "problems" will be encountered in their mutual relations – interactions, and thus the higher the level of air mission safety will be. Confirmation of this view is also found in generally accepted theories of safety, including, i.a. in C.O. Miller's 5M model,[8] Edwards and Hawkins's SHELL model, or J. Reason's model[9].

The concept of safety in aviation can have different connotations, i.e. it may refer to absence of air accidents, reduction of threats to air operations or elimination of errors committed during their execution. Regardless of the connotation taken into account, the

air operations – maintenance services, air traffic control services, radio navigation assets, airports, etc.

[8] Initially, that model was named 4M and contained four elements: Man – Machine – Medium – Management. It was then extended to the 5M Model by isolating the fifth element, Mission (task), from the already existing elements.

[9] More details can be found in: J. Kozuba, *Impact of human factor on likehood of aircraft accident*, TRANSPORT SYSTEMS TELEMATICS – TST-11, Katowice 2011, pp. 29-36; J. Kozuba, *Czynnik ludzki – rola symulatora lotniczego w szkoleniu lotniczym*, Poznań 2011, Logistyka Nr 6/2011, pp. 1817-1829.

aircraft operator [10] as well as technical and navigation personnel have to meet one condition necessary from the perspective of aviation safety, i.e. they have to gain control over all elements of the mission which are within their competence, in order to achieve the desired level of safety during the preparation and execution of air missions. Past experience has shown that the ideal situation should be such, when the tools at the disposal of aviation organization managers allow them to identify all the variables that can lead to undesirable flight-related events. Gaining total control over the factors bringing about undesirable flight-related events would be highly likely owing to eliminating such events or minimizing their impact by taking actions commensurate to the expected or perceived threat (risk group). However, because of the fact that the environment of air mission preparation and execution is open and dynamically changing, this goal is impossible to achieve in practice. Therefore, today's safety in aviation can be seen through the degree of adapting these undesirable variables, which accompany the execution of air missions, to the mission environment.

The experience in various areas of aviation safety seems to confirm the view that "no human activity or man-made system is guaranteed to be completely free from internal threats, operational errors and violations"[11]. In light of the above, it is essential to use even the most unpleasant experience from undesirable flight-related events in daily implementation of preventive activities concerning aviation safety. It should be emphasized that each undesirable flight-related event, despite a number of similarities to past events, should be treated on a par with undesirable flight-related events previously unheard of, and the lessons to be learned from it should be widely publicized. In summary, undesirable flight-related events have occurred, are occurring, and will occur in the future, regardless of the scale of the efforts made by aviation organizations to prevent them. Therefore, the main objective of activities carried out in the areas of aviation safety should be to minimize the probability of undesirable flight-related events, and when they occur, the supreme objective should be to minimize the negative effects associated with them.

Taking into account the conclusions of the foregoing considerations, safety in aviation should be treated as a concept that fits more to the theory of probability rather than to the theory of certainty, according to which an increasing threat to safety is a consequence of risks that are necessary to be accepted in the environment of preparation and execution of air missions. Therefore, the quality, and thus the safety of air mission execution largely depends on the style of management and the effectiveness of the two main systems implemented in the operation of aviation organizations, i.e the Safety Management System (SMS) [12] and the Quality Management

[10] In this publication, the author uses alternately the terms pilot, pilot-operator, operator of the aircraft, and (air)crew to refer to one- or multi-person crew responsible for managing the aircraft.

[11] Operational errors are defined as acts or omissions having a direct negative impact on an air mission being executed. They are usually regarded in retrospect as dangerous activities. Operational errors are usually associated with the first line of aviation personnel – pilots, air traffic controllers, engineers, aircraft technicians, etc., and they may lead to undesirable flight-related events. The first line of the air personnel has the potential to break through the so-called first line of defense created by aviation organizations, in order to maintain the desired level of safety during air operations. Errors committed by aviation personnel can be the result of "inadvertent" activities leading to the risks in the areas connected with air missions execution – normal errors, or the result of conscious actions involving violations of the rules and procedures of aviation law – violations. Most result from operational procedures which are defective or incompatible to the reality and which allow air personnel to make attempts to override them, usually in order to accomplish the air mission objective. They are divided into routine, which in time become a "normal" way to execute air missions, and situational, which occur in specific situations favorable for violating the existing rules and procedures (time constraints, a large number of steps to complete, external conditions, etc.). Developed on the basis of: Op. cit. ICAO, *Safety Management Manual …*, pp. 2-5; A.S. Kolman, *Human Performance & Limitations*, KLM Flight Academy 2010, pp. 9-1 – 9-6.

[12] SMS – Safety Management System of an aviation organization assumes that safety is a priority in the activities carried out by aviation organizations. SMS

System (QMS) [13]. As long as undesirable flight-related events within a given aviation organization occur at an acceptable level, i.e., they are not arousing a sense of danger to users of air equipment, aviation will be regarded as safe, regardless of the type and the application of aircraft involved. Thus, technical failures and operational errors occurring at an acceptable rate will be tolerated by the safety systems of aviation organizations.

Due to the complexity and high degree of openness, there are different approaches to defining aviation safety. J. Lewitowicz [14] defined safety in aviation by analyzing the relationship of air system components, M-AC-ME[15], and described it as "a set of characteristics of the system, which includes aircraft, ground control and navigation assets, air traffic control, flight crew and ground personnel who support and provide airworthiness of an aircraft, in order to prevent any situation of emergency, to protect the persons involved in the flight from potential damage and to ensure their rescue in the event of equipment failures, errors of the flight crew or ground services, as well as in cases of adverse external influences". Roland and Moriarty on the other hand, taking into account the system theory claim that"safety of the system can be defined as the property that allows the system to function with predefined specific risk factors which are characterized by an acceptable level of probability of occurrence." J. F. Federer expressed the opinion that the safety of a system is the "creation of an assessment of the organization from the temporal perspective, based on risk identification and management".[16] In conclusion, aviation safety can be defined as a condition in which the probability of an undesirable flight-related event is reduced and maintained at or above the acceptable level of risk through implementation of a continuous process of identifying hazards and managing their level in the areas related to the preparation and execution of air missions.[17]

Undesirable flight-related events constitute a factor that has negatively affected the development of aviation since the first time when such an event occurred. On the other hand, they are an element that should be considered as a motivation to introduce new solutions. These activities should be carried out in all areas related to the theory and practice of flight safety regarding basic elements of the aviation system, man – aircraft – environment, in order to avoid similar incidents in the future.

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regarded as a process is based on eight key elements: organization management commitment to the problem of safety management; effective safety reporting system; continuous monitoring; careful study of undesirable flight-related events; promoting safety awareness and experience in the field of aviation safety; integration of security training in for operational personnel; effective implementation of standard operating procedures SOPs); continuous development of the organization and its members in the areas of safety. Op. cit., ICAO, *Safety Management Manual …,* pp. 3-9 – 3-15.

[13] QMS – Quality Management System of an aviation organization is based on the integral structures of organized quality control in each organization and on specific regulations– FTO – PART –FCL1 (FCL2), MTO – Part-147, MO – Part – 66 etc. Op. cit. ICAO, *SMS – Safety Management Manual …*, pp. 7-8 – 7-10

[14] J. Lewitowicz, *Podstawy eksploatacji statków powietrznych, vol. 3 – Systemy eksploatacji statków powietrznych,* ITWL, Warszawa 2006, p. 264.

[15] M – man, AC – aircraft, ME – air mission environment

[16] The SMS project team of the Air Line Pilots Association, International, *Background and Fundamentals of the Safety Management System (SMS) for Aviation Operations,* Second Edition, February 2006, p.10.

[17] Op. cit., ICAO, *Safety Management Manual …,* p.2-2

Currently, safety in aviation is increasingly seen as an outcome of managing the major processes implemented by an aviation organization, whose aim is to achieve and maintain the desired level of safety resulting from threats in the operational context. Previous experience in aviation and analyses of air accident reports clearly show that man is still the most unreliable element of the aviation system. That is why so much attention is paid to the human factor in all areas of aviation safety.

HUMAN FACTOR – THE CONCEPT AND THE IMPORTANCE TO FLIGHT SAFETY

According to the Polish Ergonomics Society, ergonomics is the applied science whose object is the optimum adaptation of tools, machinery, equipment, technology, organization, physical work environment and consumer items to the requirements and needs of physiological, psychological, and social needs of man.[18] In other words, projects created with taking into account the principles of ergonomics help to maintain prescribed standards of health and safety of workers. Ergonomics is the term preferred in European countries, Australia and New Zealand. The Americans, however, preferred to use the term "human factor" for the same concept. Currently, these concepts are used by the Americans alternately. In Europe, the concept of "human factor" is used more liberally, and is applicable to all human-related factors affecting the preparation and execution of all kinds of tasks by man. This term includes also issues related to areas such as ergonomics, psychology, environment, etc. Therefore, in relation to aviation, ergonomics is often treated as a sub-discipline of areas related to the human factor, with the exception of those related to the design.

In the basic model of ergonomics, Man - Machine - Environment, man plays a key role in all phases of the "life" of the machine (e.g. aircraft) through exerting an influence on it, i.e. the human factor. It is assumed that that role can be positive, but it can also be negative as it may, e.g. bring about undesirable flight-related events, as a result of negative action or of the lack of such an action which is considered to be positive (including remedial action) in a given situation connected with mission execution. Man may also find himself in a situation where he will not be able to counteract emerging threats, by opposing their predicted consequences. The reason for this may be, among other things: time deficit, lack of skills, lack of knowledge or insufficient availability of resources to cope with the evolving situation threatening the mission execution safety (technical failure, error in handling, error in design, etc.). Thus, the concept of the human factor should be seen in the relationship between the human operator (pilot, air traffic controller, aircraft technician, etc.), and other areas relevant to the operation of machines (aircraft).

A similar approach to the concept of "human factor" is presented by the International Civil Aviation Organization (ICAO). ICAO documents claim that the concept of "human factor" is so broad that it is difficult to be clearly defined. It is treated from a multidisciplinary perspective and its main focus is on the interactions that occur between members of air organizations – the people and the environment they live and work in, and delivering solutions for good fit of man to the environment. In the multidisciplinary approach "human factor" is recognized as a source of knowledge from a wide range of scientific disciplines, such as psychology, physiology, anthropometry, biomechanics, biology, chronobiology, design, statistics, etc. Ergonomics is a term which is often used instead of the term "human factor", but only with regard to the relationship between human beings and technology.[19]

A widely recognized model, which facilitates a deeper understanding of the "human factor", used for illustrating the interactions between man and the elements of

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[18] Developed on the basis of: http://ergonomia.ioz.pwr.wroc.pl/klasyczna-ergonomia-definicje.php, 25th April, 2011

[19] Developed on the basis of: http://aviationknowledge.wikidot.com/aviation:icao-human-factors, 17th March, 2011

the aviation system in the organizational and operational context, is known as the SHELL model (Fig. 2). The SHEL model was originally developed and described by Edwards in 1972, and it was later supplemented by the second element of L by Hawkins in 1975, since when it has been referred to as SHELL. Man-operator (L_1) is not as predictable and reliable as certified devices present in aviation work environment due to the fact that as a human being he has certain capabilities and limitations. Therefore, this model refers to the interaction between the central element of L_1, and the rest of its components, i.e. S,H,E and L_2[20]. It does not refer, however, to interactions outside the areas directly related to the human factor, i.e. S-H, S-E and H-E. Man, being in the center of the model (L_1), is an element susceptible to adaptation to the surrounding environment, which includes legal-procedural and training (S) environment, technical (H) environment, work environment (widely understood) (E), and the personnel of an aviation organization (L_2). Therefore, the considerations concern, on one hand, the possibility of adapting the above-mentioned elements of the model to the human being (design stage), and, on the other hand, the possibility of adapting the human being to the elements of the model (design, implementation and operation stage). A gap between man and the other four elements of the model – in the interactions taking place – usually leads to human error during the preparation or execution of air operations.

[20]For the purpose of this work, in order to better distinguish between the elements of the model, for the elements marked with the letter L, the following notation was used: L_1 – man (operator), L_2 – factor relating to the function of man within an organization.

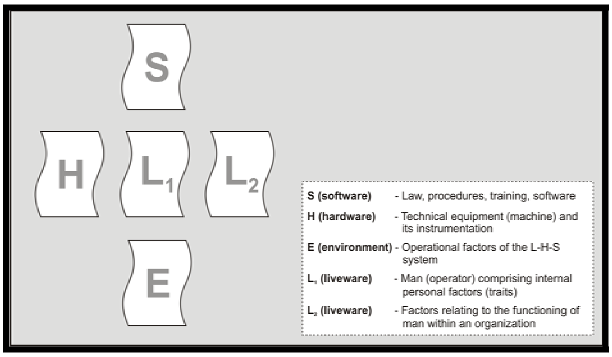

Fig. 2. SHEL(L) model. Author's own work, developed on the basis of: Op. cit. *Safety Management Manual* …, p.2-13.

Taking into consideration the above, the relationships between the individual elements of the SHELL model are as follows:

1. Man – Machine (L_1-H). This relationship is one of the most widely examined issues related to the working environment of an air personnel member. For example, when designing a pilot's seat the designers must take into account the characteristics resulting from the construction of the human body, and when designing an instrument panel monitor or a dial of a cockpit instrument they have to match the characteristics of sensors with perception and information processing capabilities of a human being by using coding system, type, size and color of the markings, etc that are the most appropriate in terms of ergonomics. In the case of instruments (monitors), no less important than the visualization of information is the location of data sources on the dashboard, taking into account optimization factors from the perspective of the deployment of other instruments and equipment in the aircraft cockpit. The operating parameters and the arrangement of all instruments and indicators
in the cockpit should be based on the characteristics of adaptation resulting from the

nature of man (construction, capability of perception and information processing in a complex work environment, etc.), and thus minimize the risk of erroneous instrument reading or an incorrect interpretation thereof by the pilot. A pilot-operator who meets the criteria set out in the relevant aviation legislation (health, knowledge, skills, flight experience, etc.), and who takes into account the experience of the past operation of technical equipment such as aircraft, should not worry about the effects of the interactions taking place between L_1-H. Adaptive capacity based on his experience, knowledge, skills, and general human nature should allow such a pilot to optimize the system L_1-H, and, consequently, to neutralize any deficiencies which were impossible to anticipate in the earlier stages of the development of technical equipment (e.g. aircraft).

2. Man – Law, Procedures, Computer Control and Management Software, etc. (L_1-S). This interaction includes the relationships between man and the supporting systems in the workplace, such as regulations, operating instructions, documentation defining or implementing maintenance activities, particular in-flight events, standard operating procedures (SOPs), trainings and supporting computer programs, etc. These relationships concern the ease of use and the uniqueness of the above-mentioned elements. This is possible when they are characterized by: universality, accuracy, clarity of visualization / transmission, specialist vocabulary, clarity, and standard symbols. This means that specialized terminology which should be used in information transmission should not be ambiguous, confusing or too complicated. Specialized software used in aviation should be structured in such a way as not to become a challenge to the operator who has average skills in programming and software use. At the same time, the information they send should be clear, legible and should meet the requirements of the certification standards for machines, equipment, instruments, etc., used in aviation. The term "procedures", in this case, refers to the personnel's theoretical and practical knowledge concerning the operating procedures and the accuracy of their implementation, including knowledge of emergency situations and how to counteract them, adherence to air traffic regulations and airport procedures, as well as procedures relating to pre- and post-flight activities. The term "training" refers to the compliance with clearly defined procedures and training programs, as well as to the use and operation of modern training tools (flight training devices, e-learning) and the current regulations, specialized instruction manuals and guides. Experienced instructional personnel having wide range of expertise still remains an important element of the training. Moreover, the training facilities being at the disposal of the aviation organization should allow the prevention of operational errors by facilitating continuing self-education of air personnel.

3. Man – Environment (L_1-E). This relationship refers to the interactions between man and the internal and external environment of his activities. Internal work environment of air personnel includes such elements as: temperature, ambient light, noise, and vibration. External work environment of air personnel includes such elements as: visibility, weather conditions (rain, turbulence, icing, wind shear) and the height of land above sea level. It should be noted that all elements characterizing the external and internal work environment of air personnel have a high level of volatility and unpredictability, also in relation to the normal biological rhythm (time of day, time of year). Furthermore, aviation personnel carries out operational tasks in a given organizational environment, vulnerable to economic change, which in turn can have a great impact on the environmental elements of the organization such as technical equipment, support infrastructure (training, technical, social, etc.), the financial position of the company and its employees and thus significantly affect maintenance of the desired safety level of missions executed by the members of the organization.

4. Man – Organization (L_1-L_2). L_1 – L_2 interface is seen through the interactions between the members of the organization in the work environment, with particular regard to the interaction operator – management

personnel. These relations are seen through the prism of the organization of work, the prevailing relations between people at different levels and areas of management and their understanding of safety issues. Training of air and support personnel, especially in the early stages of their gaining professional ratings, is carried out in relation to the individual, not the crew (team). Many years of experience have shown that the lack of understanding and inadequate teamwork skills in the crew were the cause of a number of undesirable flight-related events, despite the highest level of specialized knowledge and skills presented by individual crew members. The authors of the SHELL model suggested specific strategies aimed at preventing and eliminating operational errors committed by the team (crew). In the early 1990s, those strategies were defined as CRM (Crew Resource Management) for air personnel, TRM (Team Resource Management) for operational staff of air traffic services (ATS), and MRM (Maintenance Resource Management) for maintenance personnel[21]. Implementing effective training programs for flight crew training, operational teams of air traffic services and technical services in order to prepare them to better cooperation and communication should result in a significant reduction in the probability of committing errors concerning the $L_1 – L_2$ relationship.

Conclusions from the analysis of the interaction between the human operator, and the other elements of the $SHEL_1L_2$ model , show that the maintenance of an acceptable level of safety in the preparation and execution of air operations will be subject to fulfillment of i.a. the following conditions:

- When designing the aircraft, the designer should take into consideration a number of ergonomic factors.The pilot-operator should meet high standards concerning health, knowledge and skills (L_1-H).
- Every aviation organization should have flight training facilities which would allow adequate preparation of its personnel to carry out the their tasks. It should also have such equipment that may be defined as "friendly" to the operator (L_1-S).
- The personnel of the organization shall be prepared to respond to the challenges arising from the specific work environment in such a way as to take into consideration: existing standards and procedures, optimum disposition of available funds, and elements having a significant impact on safety (L_1 – E).
- Members of flight crews, air traffic control services and maintenance services should be adequately prepared to work in a crew/team (L_1-L_2).

In summary, the human factor refers to the human being in the environment of his work and life, to the interactions between him, machines, and air mission environment as well as to the relationships between particular members of an aviation organization in their work environment. In aviation, the term human factor is also used in relation to

[21] CRM as MRM emphasizes the team approach to reducing human error through application of certain rules to improve communication, situational awareness, problem solving, decision making and teamwork. In contrast to the traditional orders and top-down hierarchical safety programs, it supports decentralized approach to safety. In MRM teams are encouraged to communicate in order to avoid operational risk regardless of rank and position of particular team members, thus enabling rapid response to crises. However, the objectives of TRM come down to the optimum use of all available resources – people, equipment and information – in order to optimize the safety and the effectiveness of air traffic services activities.

seeking ways to adapt the human being characterized by his abilities and limitations – personal, medical, biological, etc. – to carry out specific tasks using specific aircraft dedicated to these tasks. Taking into account the above considerations, it can be argued that air mission execution safety depends on the adaptation of the pilot to operate under certain technical (aircraft) or environmental (aviation organization and mission environment) conditions . Thus, the degree of adaptation of the pilot for the air tasks in which he is engaged under certain conditions can be considered as a measure of the probability of undesirable flight-related events, and, what it involves, the measure of aviation safety.

HUMAN FACTOR AND UNDESIRABLE FLIGHT-RELATED EVENTS

Z. Baranowski, when considering the relationship of the human factor and the undesirable flight-related event[22], highlights the inadequacy of the actions taken by operators – pilots and other aviation personnel who remained in close connection with flights, their organization and safety, to the situation that occurred in a certain phase of flight. Such action usually leads to an undesirable flight-related event. That situation occurs if threats caused by factors independent from human control were not, despite the real possibilities, removed, or reduced to an acceptable level. Every action is the result of a particular decision and the related decision-making process. The factor that conditions the occurrence of an undesirable flight-related event is usually the occurrence of several consecutive errors in the system of directing (management) an aviation organization, errors in handling the aircraft or in air traffic control and / or operational errors committed by the air crew. The causes of erroneous decisions made by the pilot-operator are sought for at various stages of investigation whose aim is to discover them, taking into account the particularly complex characteristics of the aviation system and its environment. Therefore, when discussing the causes of undesirable flight-related events, errors committed by the crew of the aircraft at various stages of the decision making and implementation process are generally regarded as the key factor bringing about more or less serious consequences.

The history of air accidents is as old as the aircraft. The first air accidentoccurred during the flight of Orville Wright with Lieutenant Thomas Selfridge, U.S. Artillery, on 7th September, 1908 in Fort Myer, California. According to the statistics of the Geneva-based Aircraft Crashes Record Office, in the years 1905 – 2010 129,920 people were killed in 19,908 air accidents around the world.[23] The main causes of these events were classified into three main groups, namely: human error – 68%, technical failure – 22%, and other (sabotage, bird strike, unexplained, etc.) – 10% (Fig.3).

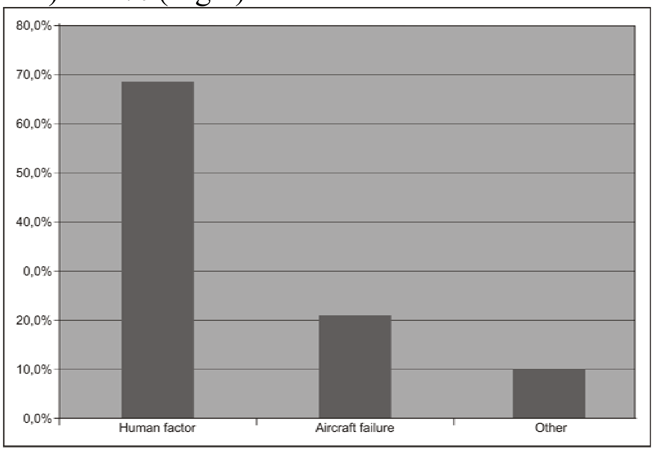

Fig. 3. Causes of air accidents between 1905 – 2010. Source: Author's own work, developed on the basis of: Aviation Crash Statistic – http://www.baaa-acro.com/statistics.html, 20th November, 2011r.

The Boeing Aircraft Company while adopting a more detailed breakdown of the main causes of air accidents also points to the flight crew error (55%) as a major cause of 183 accidents which occurred in 1996-2005. It should also be noted that operating errors (4%), air traffic services errors (6%) or aeronautical communications errors / incomprehension (8%) can also be included in

[22] R. Błoszczyński, *Psychologia lotnicza – wybrane problemy*, BWW Warszawa 1976, p. 472.

[23] Aviation Cash Statistic – http://www.baaa-acro.com/statistics.html, 20th November, 2011r.This statistic does not include general aviation aircraft accidents. In the military aircraft category only transport aircraft have been taken into account.

the flight crew error category (55%), which indicates that the major cause of about 73% of the analyzed aviation accidents involving transport aircraft was the human factor. The cause of the remaining 27% of the undesirable flight-related events was weather conditions and aircraft failures (Fig.4).

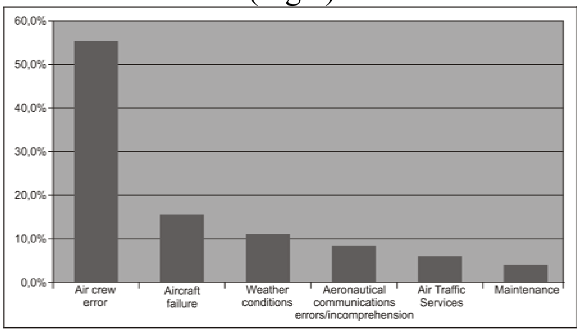

Fig.4. Causes of air accidents of Boeing transport aircraft between 1996–2005. Author's own work, developed on the basis of: N. Ehsan, K. Rafique, „Probable cause factors in UAV accidents based on human factor analysis and classification system" p. 1., Proceedings of 27th International Congress of the Aeronautical Sciences – ICAS 2010.

The results of the analysis of air accidents that occurred in the Polish Armed Forces, in the years 1946–2003 show that 71% of them were caused by human errors (crew, maintenance personnel, flight management services), 16% by the aircraft failure, and the remaining 13% by other factors, such as weather conditions (Fig. 5).

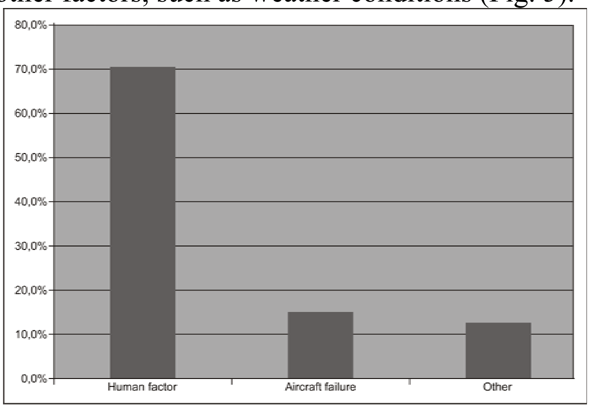

Fig. 5. Causes of air accidents[24] in the Polish Armed Forces between 1946–2003. Author's own work, developed on the basis of: J. Zieliński (Ed.), „Pamięci lotników wojskowych 1945-2003", Dom Wydawniczy Bellona, Warszawa 2003, pp. 177-462.

In the case of the U.S. general aviation in the years 2000–2009 values describing the main causes of air accidents differ only slightly from those shown in the charts above. Of the total number of 2,799 accidents, the cause of 75% was the human error, 10% the aircraft failure, and the remaining 15% other causes (Fig. 6).[25]

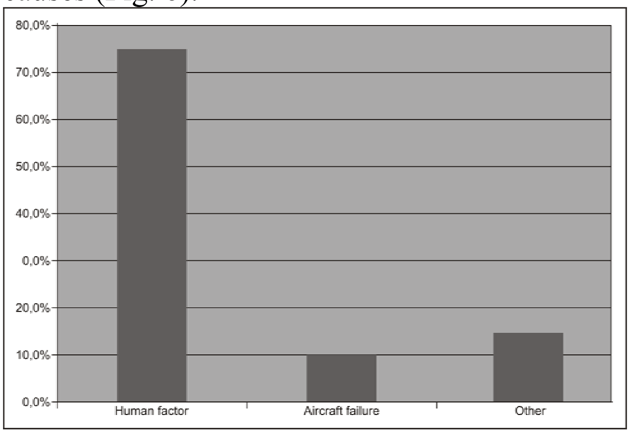

Fig.6. Causes of air accidents in U.S. general aviation between 2000–2009. Author's own work, developed on the basis of: "NALL Reports–AOPA Aviation Safety Foundation, 2001 – 2010".

[24] air accident – according to § 20 *Flight Safety Instruction of the Polish Armed Forces,* MON, Warszawa 2004,WLOP 346/2004**,** An accident means an occurrence associated with the operation of an aircraft, which takes place from the time any person boards the aircraft with the intention of flight until such time as all persons on board have disembarked, and in which any person suffers at least serious injury or the aircraft sustains damage and/or structural failure, or the aircraft is missing, and the official search has been called off, or the aircraft is completely inaccessible. Air accidents are categorized as accidents (W_C) and serious incidents $W_{(L)}$.

[25] "NALL Reports – AOPA Aviation Safety Foundation, 2001 – 2010".

The results of above analyzes of air accidents clearly show that – regardless of the type of aviation, aircraft type, nationality of the aircraft, and the time period taken into account in the analysis – it is man, described from the perspective of the human factor, who is the cause of approximately 70% of events of this type in aviation. In the context of those analyses it is particularly important to apply the appropriate accident investigation methodology, draw appropriate conclusions and take consistent preventive actions aimed at preventing the occurrence of similar undesirable flight-related events.

What lies at the root of this situation? The complexity of the tasks performed during the preparation and execution of air missions makes it clear that it is not possible to give a definite answer to such a question.

A broader analysis of accident reports[26]lead to the conclusion that the pilot not always has the right "tools" (specialized knowledge, skills, flying currency, experience, etc.) to properly perform the role assigned to him in the cockpit. In general, pilots are trained to perform specific tasks in specific environments. An exception is the preparation of the pilot to deal with common emergency situations, which result from previous experience gathered from operating a given aircraft type – engine failure, the failure of the landing gear extension subsystem, etc. This results in, among other things, the fact that pilots are not able to effectively identify a number safety hazard symptoms during air mission execution and the point at which they begin to perceive them comes too late to take effective preventive measures against undesirable flight-related events.

Another reason for this may be the fact that it is more and more difficult for pilots to achieve the desired level of adaptation to rapidly evolving aviation technology, including the ever increasing degree of automation. The factor that intensifies that state is the level of the pilot work load in different stages of air mission execution, which is particularly important in maintaining the desired level of situational awareness. The term mental workload refers to the relationship between the total mind's capacity of the pilot, determined by his ability to process information which he is able to assimilate within a specific period of time, and the requirements of the task that he has to perform.[27]

On the other hand, R.M. Yerkes and J.D. Dodson understand the term "workload" as the outcome relating to varying relationships between the performance of ongoing operations by the operator under standard conditions of the mission environment and the performance of the same actions under the conditions of very low or very high workload level.[28] Situational awareness is particularly important for the pilot in understanding the mission environment. It plays a crucial role in pilot decision-making.[29] The high level of situational awareness possessed by the pilot is necessary for his acting within the complex system at each stage of mission execution. Many flight-related events take place in mission environments which demand high level of situational awareness from the pilot. The results of analyses related to the degree of pilot workload in each stage of air mission execution show that this factor has a direct impact on the probability of an undesirable flight-related event (Fig. 7).

[26]The conclusions provided by the author are based on the air accident reports available in the archives of the Polish Armed Forces as well as those relating to general aviation in the Republic of Poland, available on the website: www.ulc.gov.pl, 01th January 2011.

[27] S. G. Hart, L.E. Staweland, Development of NASA TLX (Task Load Index): *Results of empirical and theoretical research*, (in:) P.A. Hancock, N. Meshkahi (Ed.), Human Mental Workload, North Holland, Amsterdam 1988, pp. 139–183.

[28] R.M. Yerkes, J.D. Dodson, The relation of strength of stimulus to rapidity of habit-formation, Journal of Comparative Neurology and Psychology № 18/2008, pp. 459–482.

[29]The issues related to situational awareness and its importance to safety in air mission execution are presented in more detail in Chapter III of this work.

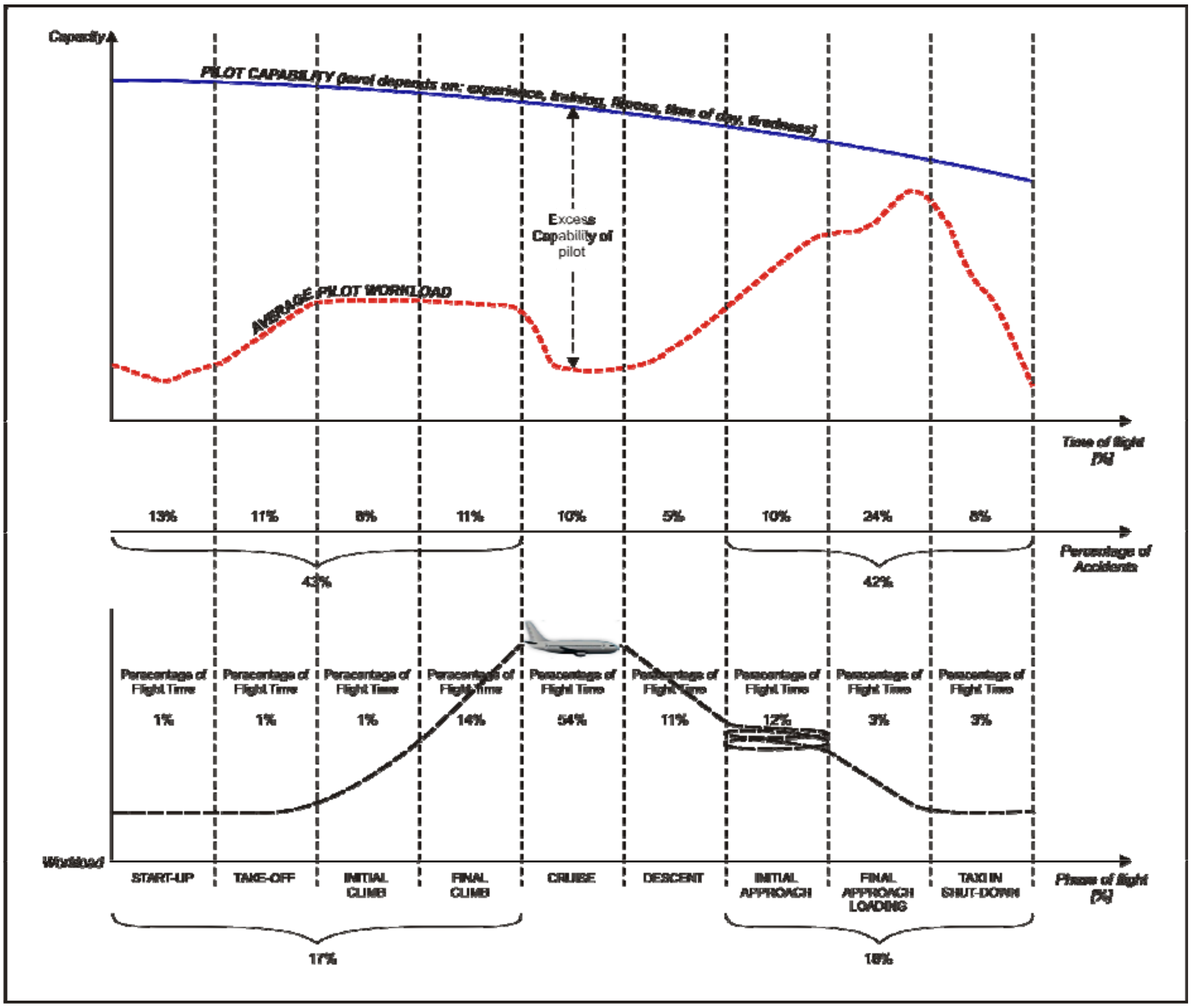

Fig.7. Pilot workload in particular stages of air mission execution and statistics concerning undesirable flight-related events. Developed on the basis of: Op. cit. E. Klich, J. Szczygieł, *Bezpieczeństwo lotów w transporcie ...*, p. 138, T. Thom, *The Air Pilot Manual*, Vol. 6, *Human factors and Pilot Performance*, Airlife, Shrewsbury 1995, p.110.

As it is clear from the above comparison of the data depicted in the figure, the most dangerous phases of flight, which are also characterized by a high degree of workload, include the takeoff and the initial as well as the final climb segments – 43% of air accidents, and also the initial, final approach and the landing, taxi in and shut down segments – 42% of accidents. The remaining flight phases, which represent 35% of the time of flight have an accident rate of 85%. This disproportion becomes understandable when we consider that the flight phases which are characterized by the highest accident rate are those in which the flight crew workload is the highest. The above disproportion also results from the fact that those phases are executed at medium and low altitudes, in high traffic congestion, as well as from the fact that the pilot while implementing various procedures related to those flight phases has to operate a number of aircraft systems and equipment to maintain the prescribed conditions.

All of the above seems to support E. Klich's opinion that "The existing methods and means of developing the awareness of the risks, which are limited mainly to one-off actions organized after an accident, seem to be insufficient. Used temporarily, to a limited extent, and irregularly, such measures become forgotten in a short time. Recurring accidents caused by identical slight errors confirm the low effectiveness of actions taken so far" in the area of safety.[30] The statistics presented show that this statement focuses on man, a member of aviation personnel. Preventive measures identified by air accident investigation boards in relation to a member of the flight crew, an aircraft maintainer or an air traffic controller were too frequently confined only to the perpetrator of the undesirable flight-related event, and they were actions of limited scale, carried out immediately after the event. Scientific and research resources currently available to organizations which investigate undesirable flight-related events facilitate wide-range analyses of the causes of errors committed by flight crews. The results of these studies should help to define the areas of risk and develop a methodology of taking appropriate actions in order to neutralize those risks. Such activities should be system-wide and should include aviation personnel group(-s) selected from the perspective of characteristic traits of the perpetrator (or perpetrators) of undesirable flight-related events. Knowledge of the threats should result in finding a way to avoid or neutralize them, even if not all threats are possible to eliminate.

Previous experience of the author, the conclusions from air accident investigation reports[31] and analyses of reference publications indicate that each perpetrator of an undesirable flight-related event can be characterized by specific factors that affected the error committed by him. With regard to the pilot, these factors can include, among others:

- age – to determine the age range in which the pilots of a specific task group committed the most errors;
- total flight time, including the specific type of aircraft on which the undesirable flight-related event occurred – to determine the influence of the level of aviation experience possessed by the pilot on the probability of his committing errors under certain conditions;
- the level of pilot training from the perspective of his professional ratings – to determine the influence of the level of air training received by the pilot on the probability of his committing errors under certain conditions;
- last leave/vacation with a particular focus on the time between flights (pilot currency), including the pilot currency issues associated with health problems – to determine the influence of currency on the piloting skills;
- the most recent undesirable flight-related event (if any) – to determine the the impact of that event on the pilot's psychophysical condition and piloting skills;
- weather conditions, with particular emphasis on hazardous meteorological phenomena (fog, wind shear, icing, etc.) – to determine the impact of the weather conditions on the probability of pilot error;
- terrain, where the event occurred (mountains, sea, etc.) – the effect of topography on the probability of a given type of event;
- type of aircraft on which the flight was conducted – to determine the influence of ergonomic factors and handling characteristics of the aircraft on the probability of errors being committed by a pilot having a certain aviation experience;
- type of air mission – to determine the influence of task complexity on the probability of errors being committed by a pilot having a certain aviation experience;
- aviation phraseology and radio communications congestion – to determine the

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[30] E. Klich, *Bezpieczeństwo lotów – wybrane zagadnienia.* AON, Warszawa 1999, p. 50.

[31] (a.o.) Cdr B.K. Umesh Kumar, Gp Capt. H. Malik, *Analysis of fatal human error aircraft accidents in IAF,* Aerospace Med № 47(1)/2003, pp. 1-7.

influence of the manner of conducting radiotelephony communication on the probability of pilot error under certain conditions of mission execution.

Systematically collected databases categorizing undesirable flight-related events into specific groups e.g. loss of spatial orientation during flight in the clouds, in-flight icing, etc., taking into account the above-mentioned factors concerning the perpetrators of such events, may be used by aviation organizations to determine high-risk groups among their personnel and to take appropriate preventive measures e.g. refresher training, simulator training, health care, etc.

Examples of this type of activities can be found in the history of aviation. After the introduction of the new generation of jet aircraft in the 1960s, the number of air accidents in the RAF grew significantly. Taking into account the fact that the causes of most of the accidents were related to the human factor, a number of recommendations were made and implemented to enhance the safety level of air operations, including, among others:

- Limited range of cockpit equipment standardization and the lack of uniformity of distribution of flight instruments in the cockpit, necessitated the introduction of a limit of aircraft types to be flown by an individual pilot.
- Only experienced pilots with a minimum of 400 hours total flying time on jet aircraft were appointed instructors and air unit commanders.
- Only the most experienced instructors were assigned to supervise the training process in air units.
- Specific requirements were raised relating to the flight crews' level of knowledge concerning aircraft construction, operating rules and piloting techniques for particular aircraft types.
- Procedures were introduced in order to enhance the supervision over the observance of the operating rules concerning onboard equipment (oxygen system, ejection seat);
- Simulated flameout trainings became mandatory – each pilot was obliged to take five such trainings per year.
- The simulator training program was supplemented with new exercises; existing exercises were revised.

The above-mentioned actions were based on, among others, the conclusions from the past undesirable flight-related events. It was determined, among others, that undesirable flight-related events occurred mainly during the approach to landing and the landing phase and were caused by the fact that the approach-to-landing speed was increased twice compared to that of piston engine aircraft. It was pointed out that most accidents were caused by pilots aged 19 to 21 years, and at the fewest by pilots aged 26-35 years. With the emergence of jet aircraft, the change of speed parameters brought about hitherto unknown phenomena, such as high-altitude hypoxia, faster G-load increase, canopy glass condensation or frosting, and changing the characteristics of the aircraft especially at transonic speeds.[32]

The results of these analyses indicate that a person working as an aircraft operator, aircraft technician or air traffic controller continues to be the weakest element of M-AC-ME system. They also indicate the need for constant preventive measures aimed at improving the level of flight safety,

[32] Developed on the basis of: K. Klukowski (Ed.), *Medycyna wypadków w transporcie*, Wydawnictwo Lekarskie PZWL, Warszawa 2005, pp. 178-179.

particularly in relation to the areas of the so-called human factor. Taking such measures is justified not only by the deaths of flight crews and passengers, but also by huge losses to property and equipment.

CONCLUSION

The use of safer and safer, but also more and more complex aircraft systems in mission environment characterized by high levels of volatility causes that flight crews and teams supporting air operations have to meet higher and higher requirements. In the twenty-first century, it is man, not the technological development, that is a limitation affecting the aircraft specifications. So we should take advantage of all the possibilities, even the most expensive, in order to improve the level of flight safety. Therefore, undesirable flight-related events should be treated as those which set out further stages of flight safety development. Lessons to be learned from undesirable flight-related events and preventive recommendations set by air accident investigation boards should be treated as a source of knowledge to build new and enhance existing strategies to prevent errors committed by aviation personnel. These activities should be carried out at all levels of aviation organizations, with particular emphasis on personnel directly involved in the preparation and execution of air missions. Man, who created that system and who always takes care of its development, too often forgets that he is the key element of it and it is he who determines the level of air mission safety. Despite efforts being taken, the human factor is still essential, and yet the most unreliable part of the aviation system.

BIBLIOGRAPHY

1. Auten J., *GLOC...is the clue bag half full or half empty?*, Flying Safety, June 1996
2. Błoszczyński R., *Psychologia lotnicza – wybrane problemy*, BWW Warszawa 1976
3. Cdr Umesh Kumar B.K., Gp Capt. Malik H., *Analysis of fatal human error aircraft accidents in IAF,* Aerospace Med N° 47(1)/2003
4. Ehsan N., Rafique K., *Probable cause factors in UAV accidents based on human factor analysis and classification system*, Proceedings of 27th International Congress of the Aeronautical Sciences – ICAS 2010
5. *Flight Safety Instruction of the Polish Armed Forces*, WLOP, Warszawa 2004,WLOP 346/2004
6. Hart S. G., Staweland L.E., Development of NASA TLX (Task Load Index): *Results of empirical and theoretical research*, (in:) Hancock P.A., Meshkahi N. (Ed.), *Human Mental Workload*, North Holland, Amsterdam 1988
7. ICAO, *Safety Management Manual*, Doc. 9859-AN/474, ULC, Warszawa 2009, Second Edition
8. Klich E., *Bezpieczeństwo lotów – wybrane zagadnienia.* AON, Warszawa 1999
9. Klich E., Szczygieł J., *Bezpieczeństwo lotów w transporcie lotniczym*, PIB, Radom 2010
10. Klukowski K. (Ed.), *Medycyna wypadków w transporcie*, Wydawnictwo Lekarskie PZWL, Warszawa 2005
11. Kolman A.S., *Human Performance & Limitations*, KLM Flight Academy 2010
12. Kozuba J., „Czynnik ludzki – rola symulatora lotniczego w szkoleniu lotniczym", Poznań 2011, Logistyka Nr 6/2011Lewitowicz J., *Podstawy eksploatacji statków powietrznych, vol. 3 – Systemy eksploatacji statków powietrznych,* ITWL, Warszawa 2006
13. Kozuba J., *Impact of human factor on likehood of aircraft accident*, TRANSPORT SYSTEMS TELEMATICS – TST-11, Katowice 2011
14. Michałowski H., *Wysoki poziom bezpieczeństwa lotów podstawowym warunkiem gotowości bojowej lotnictwa*, Wyd. CW, Warszawa 1973, WPL N° 3/73

15. NALL Reports – AOPA Aviation Safety Foundation, 2001 – 2010
16. *Polish Aviation Law Act of 03 July, 2002* (Journal of Laws from 2006, No. 100, item 696, as amended)
17. Sulikowski K.S., Kowalski W. G., Żebrowski M., *Wypadki w lotnictwie wojskowym i cywilnym*, (in) K. Klukowski (Ed.), *Medycyna wypadków lotniczych*, PZWL, Warszawa 2005
18. The SMS project team of the Air Line Pilots Association, International, *Background and Fundamentals of the Safety Management System (SMS) for Aviation Operations,* Second Edition, February 2006
19. Thom T., *The Air Pilot Manual*, Vol. 6, *Human factors and Pilot Performance*, Airlife, Shrewsbury 1995
20. Yerkes R.M., Dodson J.D., *The relation of strength of stimulus to rapidity of habit-formation*, Journal of Comparative Neurology and Psychology № 18/2008
21. Zieliński J. (Ed.), *Pamięci lotników wojskowych 1945-2003*, Dom Wydawniczy Bellona, Warszawa 2003

Internet sources:

22. http://aviationknowledge.wikidot.com/aviation:icao-human-factors
23. http://ergonomia.ioz.pwr.wroc.pl/klasyczna--ergonomia-definicje.php
24. http://www.ulc.gov.pl
25. http://www.baaa-acro.com/statistics.html