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SAFETY OF AIR OPERATIONS IN TRAINING COMPETITION AND AEROBATIC SHOWS

A question of exact determination of an aircraft (a/c) position and of its basic parameters is very important for the process of pilots training and for aerobatics performance. Therefore, a need for implementation of an intelligent and autonomic system enabling real-time flight control has arisen. Methods of flight course control and of aerobatic or training flight assessment used so far are not adequate in 21st century. The perspective of implementation of a real-time system for control and flight operations safety will enable conducting operations and analyses of flight course on a higher level than it is now.

Keywords: flight safety, safety models, safety management, navigation systems

1. INTRODUCTION

Strong need for developing an autonomic and mobile system which would enable active control over flights made during show or training has grown over years. Increasing number of aviation incidents and accidents results in a demand for a system enabling flight control in real time, immediate interven-tion of the flight

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instructor or coordinator as well as analysis of flight records. So far, there has not been a tool enabling the on-ground technical personnel to determine precise position of an aircraft during training, aerobatic or competitive flight. Knowledge of basic parameters of the aircraft will limit dangerous incidents and minimize the risk of collision.

From the report published by Państwowa Komisja Badania Wypadków Lotniczych (PKBWL) [State Commission on Aircraft Accidents Investigation] during the conference Krajowa Konferencja Bezpieczeństwa Lotów Lotnictwa Cywilnego [National Conference on Civil Aviation Safety] it results that the number of aviation incidents has grown for years. Term "air incident" com-prises fatal accidents, incidents, severe incidents and other occurrences im-pacting on the safety level. Figure 1 presents the graph of the considered sta-tistics. Table 1 illustrates numerical data referring to notifications to PKBWL.

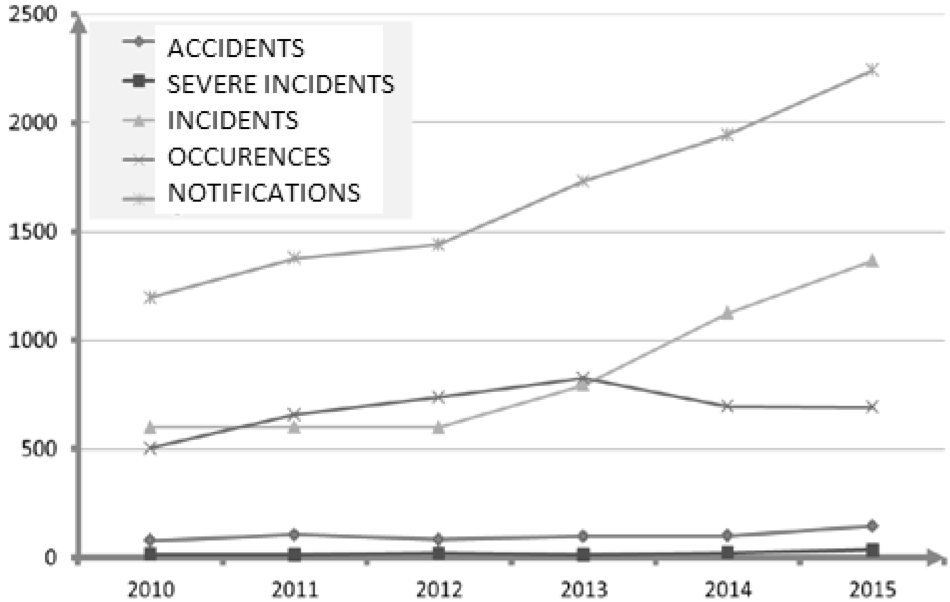

Fig. 1. Aviation occurrence notifications from 01.01.2010 to 26.10.2015 (accidents; severe incidents; incidents; occurrences; notifications) [Lasek 2015]

Table 1. Number of occurrence notifications to PKBWL (own elaboration based on [Rejestr zdarzeń… 2016; Lasek 2015])

Year	Occurrences	Including				
		Accidents	Severe incidents	Incidents	Aviation occurrences/ Severe aviation occurrences	Other
2003	203	94	2	107	–	–
2004	314	98	15	201	–	–
2005	291	73	28	190	–	–
2006	384	99	11	274	–	–
2007	542	88	14	409	30	1
2008	962	79	9	467	407	–
2009	1088	107	16	601	345/19	–
2010	1455	84	14	676	666/15	–
2011	1602	112	17	688	781/4	–
2012	1755	89	23	674	968/1	
2013	1987	106	14	935	945/2	
2014	2265	104	25	1266	859	

As the above data show, in 2003 there were 203 occurrences, while in 2014 this number grows to 2265. One of reasons why the number of incidents increases is growing air traffic[1]. However, observation of the discussed ten-dency brings worrying results. Therefore, Urząd Lotnictwa Cywilnego [the Civil Aviation Office] issuing every year a document called ”Informacja Prezesa ULC o Poziomie Bezpieczeństwa Lotniczego” [Information of the president of Civil. Aviation Office on safety level] not only presents a statistic list of oc-currences, but also refers to methods and manners for effective rising the safety level [Informacja Prezesa ULC… 2016].

[1] According to statistics published by the Boeing Aircraft Company (Statistical Summary… 2016), in 2000 worldwide passenger aircraft fleet consisted of approx.15 thousand aircrafts, while in 2014 this number grew up to almost 24 thousand aircrafts [Statistical Summarry 2016].

2. SAFETY MODELS IN CIVIL AVIATION

Simplified form of flight safety scope comprises of factors related to on-ground personnel, aircraft staff, flight operation process as well as to the air-craft airworthiness [Bielski, Krawczyk 2016]. Safety principles are the same in all fields of civil avia-tion. Hazardous situation is a result of a series of events, and responsibility for their occurrence is shared by the whole team performing the given air operation. Therefore, it is very important to control each stage of flight, starting from flight plan till turning off aircraft engine after the flight is ended.

Many theories (models) describing safety of light operations can be found in the source literature. Dynamic technological development and increasing popularity of air transport have influenced on the form of model safety approach to occurring aviation incidents. Additional aspects, which influenced on the efficient performance of any task in flight, including a human factor, have been noticed over years [Kałużna, Fellner 2014].

W. T. Singleton, a professor of Applied Psychology at the Aston University [Compa, Kozuba, Pila 2013], presents his model based on safety optimization by three concepts shown in fig. 2 [Kopczewski, Szwarc 2016].

SAFE OPERATOR	**SAFE SYSTEM**	**SAFE CLIMATE**
characteristics of man-machine relation	even distribution of operations in man-machine-external environment relation	cooperation in the air-craft unit and orientation to issue of safety, self-improvement and collective responsibility

Fig. 1. Singleton theory (own elaboration based on [Kopczewski, Szwarc 2016])

Slightly different approach is presented by the *C. O. Miller's* theory, referred to as 4M model. It describes correlation existing between factors appearing in the sphere of aviation operation safety [Kopczewski, Szwarc 2016]. This model is presented in fig. 3.

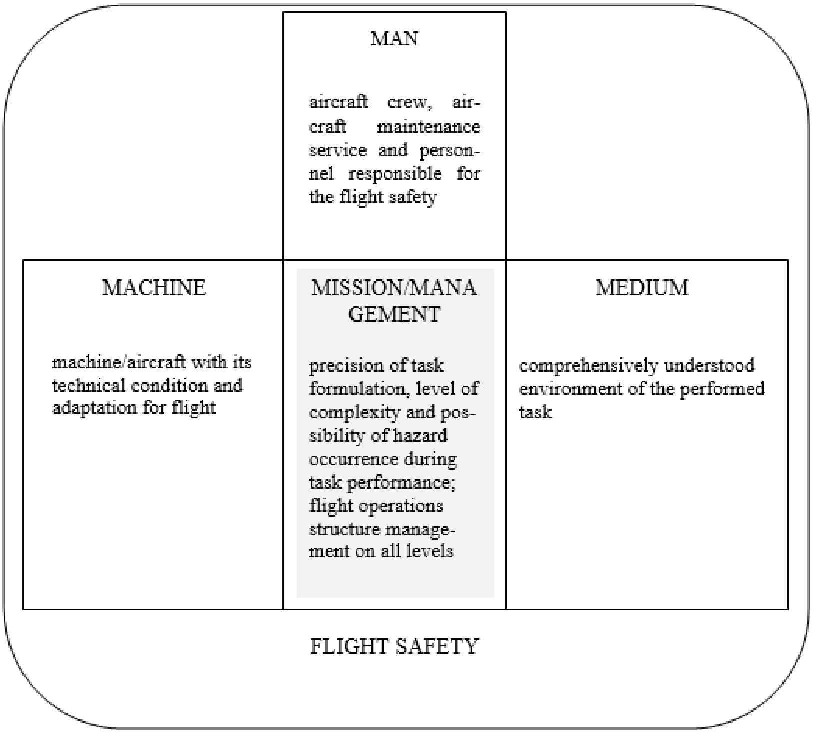

Fig. 3. Graphic presentation of Miller's 4M model (own elaboration based on [Kopczewski, Szwarc 2016])

Miller's 4M model was developed into the *5M Theory* by adding an element of the performed flight operation (task – *mission*). It was developed in the 1960s and was called a theory of "*5M hazards*" (fig. 4) [Kopczewski, Szwarc 2016].

Fig. 4. Graphic presentation of 5M model elements [Kopczewski, Szwarc 2016]

Both theories focus on fundamental elements of safety system for air operation performance. Due to a clear classification of system components, risk analysis and minimization of failure risk can be efficiently carried out.

Next popular theory is *SHELL* Model presented in 1975 by F. H. Hawkins. This theory is a kind of supplement to E. Edwards' concept. Edwards in 1972 presented a system approach including human factor in the process of flight safety analysis (*SHEL* model). *SHELL* is a name consisting of the first letters of model components (fig. 5). This theory focuses on showing correlations between a man and the other elements of air operation environment [Kopczewski, Szwarc, 2016; Kałużna, Fellner, 2014; Compa, Kozuba, Pila 2013]. Liveware (L_1), being in the central point of the model, is an element susceptible to adaptation to the surrounding environment, including legal and procedural and training environment (S), technical environment (H), broadly defined work environment (E), personnel of aviation organization (L_2). Therefore, on the one hand, a possibility to adapt the above-mentioned elements of the model to a man is considered, and on the other hand, a possibility to adapt a man to elements of the model is considered (design, implementation and operation) [Compa, Kozuba, Pila 2013].

SHELL theory describes the following interactions occurring in the air operation environment:

− Man–Machine (L_1-H) – interaction of these two factors is a hard core of air operation functioning. Each aspect concerning this relation is closely related to the optimization of factors supporting the process of flight performance. An example of such relation is design of flying instrument panel to minimize the possibility of wrong or obstructed reading the instrument indication by a pilot. Due to a detailed recognition of the considered relation, the operator of an aircraft, meeting all requirements (in terms of health, law, professional experience), will not have any difficulty with performing the task and the possibility of unforeseen situation will be minimized.

− Man– non-physical aviation aspects (L_1-S) – relation comprising all procedures, law, regulations, technical documentation, training, etc. Special attention is focused on readability and explicitness of guidelines as well as on careful examination and observation of regulations by on-ground and air personnel.

− Man–surrounding of air operation (L_1-E) – elements of external environment (such as cloud cover, wind, turbulences) and of internal environment (such as noise, vibrations) and their interaction with aviation personnel.

− Man–aviation organization (L_1-L_2) – mutual relation of all members of the aviation organization on different levels, process of pilots and service personnel training, work organization. In the past, malfunctioning of particular individual in a given team/ crew was a reason of many hazardous situations, therefore, it is of great importance to control the situation in the aviation organization. Edwards and Hawkins, due to their many years' experience, propose some strategies for elimination errors made by the members of team performing the flight (*CRM* – Crew Resources Management, *TRM* – Team Resources Management, *MRM* – Maintenance Resources Management) [Compa, Kozuba, Pila 2013; Kopczewski, Szwarc 2016].

Analysing the domain of safety theory, no one should omit the widely used model of James Reason, so-called Swiss cheese model. This method is used by such organizations as PKBWL [Kałużna, Fellner 2014]. According to the Reason's theory (fig. 6), hazardous situation or accident occurs when at all stages of a task performance some negligence occur, not being eliminated on time. Each slice of the cheese presents separate layer of defence which in ideal conditions would be a smooth plane. However, in real world each layer has gaps resulting in hazardous situations and accidents. What is important, negligences move with the change of environmental conditions. First barrier are people performing together the air operation. Subsequent blocks are aimed at finding and elimination of situations being hazardous to the successful task performance, that is at blocking the movement of *risk into the direction of accident*. Systems used in contemporary aviation are very tight, therefore accidents occur relatively rarely. Graphical form presented by Reason shows also how difficult is for an accident to occur (many layers, gaps in different places of the slice, which only in specific circumstances align along the line running from *hazard* to *loss*) [Łaskarzewska 2016; Reason 1998].

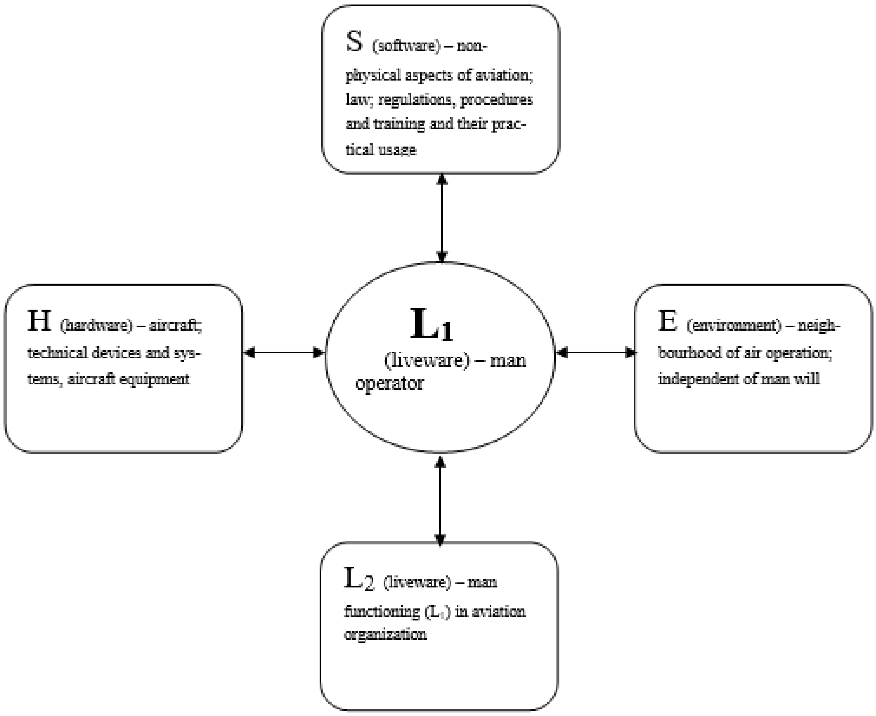

Fig. 5. Graphic presentation of the SHELL method [Kopczewski, Szwarc 2016; Compa, Kozuba, Pila 2013]

The most frequent cause of irregularities is the first element in each model, from which the safety system analysis starts, that is a man. When compare to other system components, it occurs that it is the on-ground personnel or aircraft crew fail most often [Bielski, Krawczyk 2016, Copma, Kozuba, Pila, 2013, Klich 2012, Reason 1998]. Figure 7 presents percentage share of individual causes of aircraft accidents. Human factor has the greatest part of this share, and it comprises crew errors (55%), communication errors/ misunderstanding (8%), air traffic services (6%) and on-ground services (4%). The remaining part comprises aircraft technical failure and bad weather conditions [Compa, Kozuba, Pila 2013, Statistical Summary… 2016]. Accident statistics for General Aviation, comprising training, air shows and air competitions, are similar. Human error is here a cause of 75% of all failures, technical problems cause 14% failures and the remaining 11% is caused by other reasons [24th NALL Report… 2016].

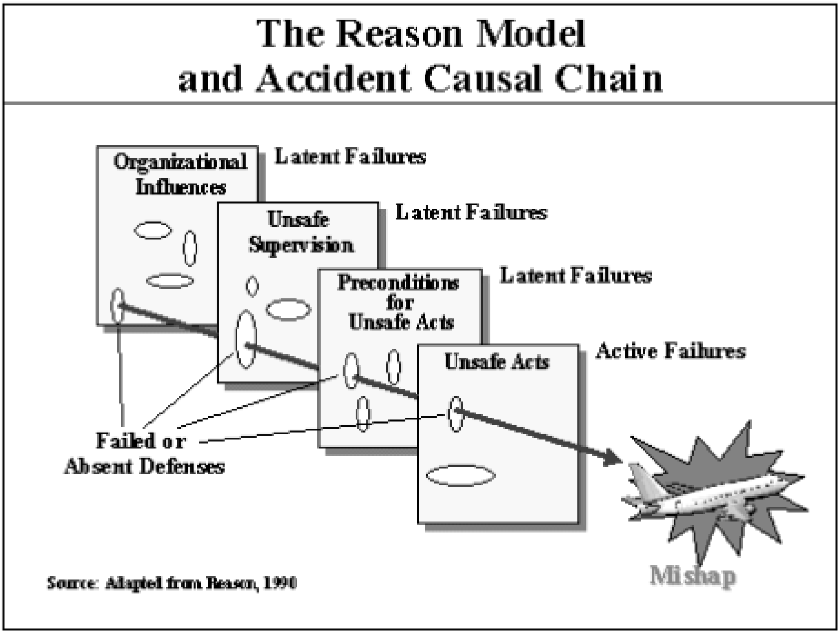

Fig. 6. Graphical presentation of J. Reason’s model (Mutual interaction of local factors; Management – high level; Managing – low level of management; Control; Facilitators; Operator (crew); malfunction; Protective system (support; alert); Accident; Hidden threads (delayed effects); Hazard areas; immediate effects; Unprotected area) [Klich 2012; Reason 1998].

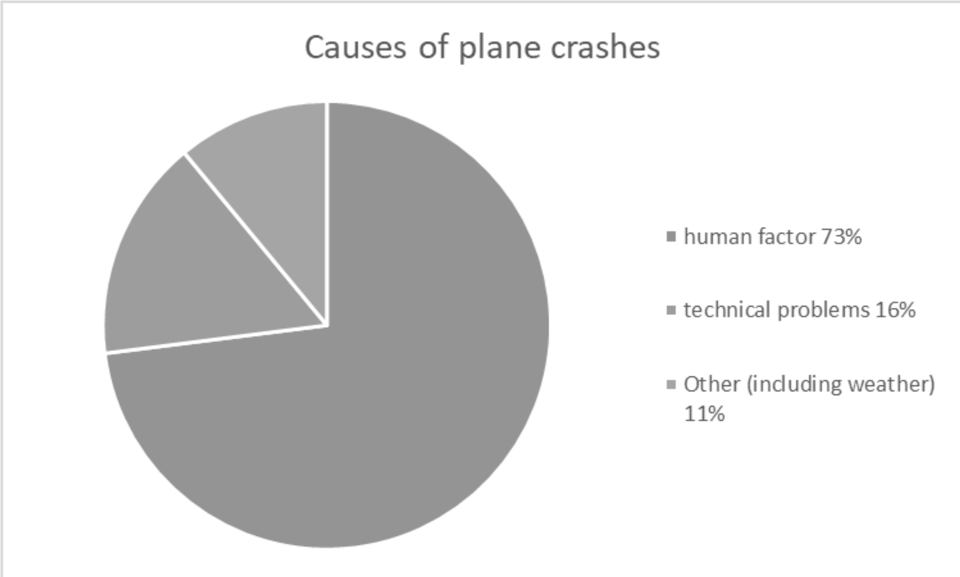

Fig. 7. Plane crush reasons in years 1996-2005 (Human factor; Technology; Other (including weather)) [Statistical Summary… 2016]

Despite implemented, observed and strictly supervised procedures, accidents difficult to explain still occur. Therefore, automation of all flight stages has been developed for many years. While in commercial and scheduled aviation many modern technical solutions were implemented, in the General Aviation it is very difficult to provide such solutions due to limited funds and also due to the characteristic of performed flights. Presented considerations indicate that systems operating efficiently in the scheduled aviation do not perform well in an aerobatic flight. Development of safety systems for aerobatic and training flights opens new research field.

3. SELECTED ANTI-COLLISION, WARNING AND NAVIGATION SYSTEMS

Due to the necessity of continuous improvement of performed air operations safety, numerous radar systems (from the airport level) and navigation transponders, based on the global satellite navigation system (from the aircraft level), are operating for air tasks being fulfilled [Kiciński 2014].

- Radar systems can be divided into the following groups:
- Air Route Surveillance Radars (ARSR),
- Airport Surveillance Radars (ASR),
- Precision Approach Radars / Instrument Landing Systems (PAR/ILS),
- Airport Surface Detection Equipment (ASDE) [Kiciński 2014].

All aforementioned systems are stationary installations, except for ILS which is a mobile system. Their main task is to supervise determined airport surface and its neighbourhood to minimize the probability of aircraft collision. Radars enable supervision even from the distance of more than 300 km (ARSR). Given group of devices are subsequently used for observation of a decreasing space by controlling the so-called airways (ARSR), supervising the aircraft approach to the airport area (ASR) and precise approach (PAR/ILS), by observation of the airport surface (ASDE). The described systems are used in civil and military aviation [Kiciński 2014].

Due to financial and logistic issues as well as taking into account the specificity of the performed flights, in general aviation (GA), transponders installed on the aircraft board are used (what still is not a rule for such flights). Placing radar systems on the aprons and general aviation landing fields is not practised, therefore there arises the need to use alternative devices enabling the improvement of the air tasks safety level.

Not many systems enabling the control over the flight are available for the general aviation. Some devices used in this field are presented below:

− FLARM – warning system used mainly in gliding; it detects approaching aircraft and informs the pilot about it; it works on the basis of on-board transponders' response; one of the most widely used collision avoidance systems in the world [Systemy antykolizyjne… 2016]

− TAWS (*Terrain Awareness and Warning System*) – system warning the pilot of approaching terrain; C-class model is used by the general aviation [Tooley, Tooley, Wyatt, 2008]

− PCAS (*Portable Collision Avoidance System*) – passive and cheaper version of TCAS[2] for the general aviation [PCAS… 2016].

All mentioned system are aimed at as early as possible warning of approaching thread (irrespective of what it is: the ground, an obstacle or another aircraft). Their significance for the air operation safety improvement is considerable, and they belong to basic on-board instruments. Although they have many merits, they do not perform well in the case of flights done within the frames of aerobatic competitions or air shows.

4. SAFETY OF AEROBATIC AND TRAINING FLIGHTS

As it is shown in the statistics published by cpt. pil. Wiesław Jedynak (member of PKBWL) in 2014 (fig. 8), much more irregularities are observed in the field of

[2] *Traffic and Collision Avoidance System* – system preventing the collision in the air, used widely in the scheduled aviation; it warns the crew of approaching aircraft [Kulczycki 2016]

the general aviation, where training and sport flights belong, therefore this domain is the main area of interest for authors of this article.

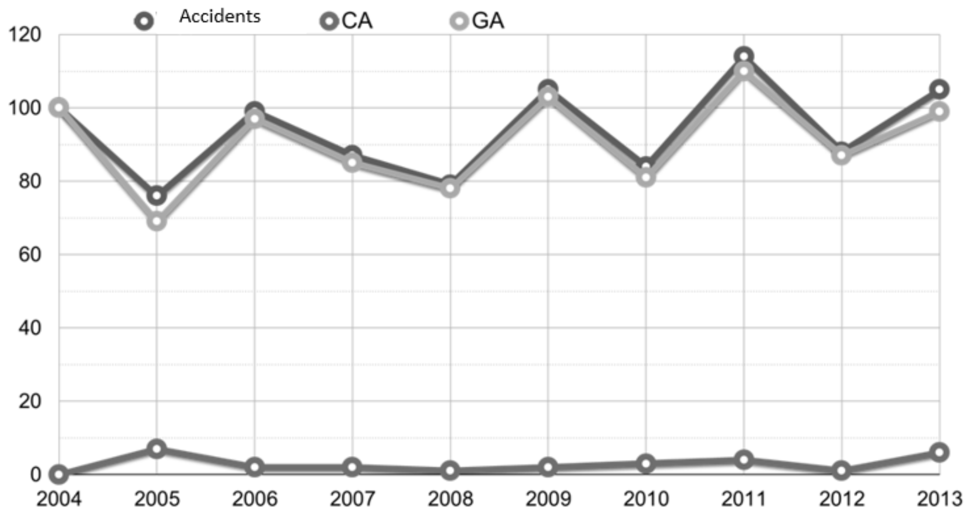

Fig. 8. PKBWL notification statistics [Jedynak 2014]

Increasing air traffic means that the tendency of hazardous occurrences is growing. Therefore, special attention is given to pilots' training at the first stage of their education. When tasks are performed by a glider or an aircraft, of great importance is the possibility to notice and correct by instructors all, even the smallest, errors and irregularities. Further part of this article (chapter 5) discusses the tasks within the frames of the flight training process and the possibilities to supervise them using modern technology.

Aerobatics differ significantly from the standard flights for both, the pilot and the flight observer. Flight parameters changing dynamically makes the precise assessment be very difficult for the instructor. Aerobatic shows are usually organized outside the airport area, what is an additional impediment to supervise the flight.

Within the glider and the aircraft aerobatic championship aerobatic manoeuvres are made in the cuboid space mainly of 1000x1000x1000 m (fig. 9). Jurymen became familiar with this space by flying along the perimeter of the cuboid at different heights. This cuboid space is not permanently marked any way, what can influence on a wrong assessment of a given competition flight. Moreover, each case of leaving the zone by the aircraft (particularly, breaking the lower border of the zone) is scored negatively, what influences on the final results.

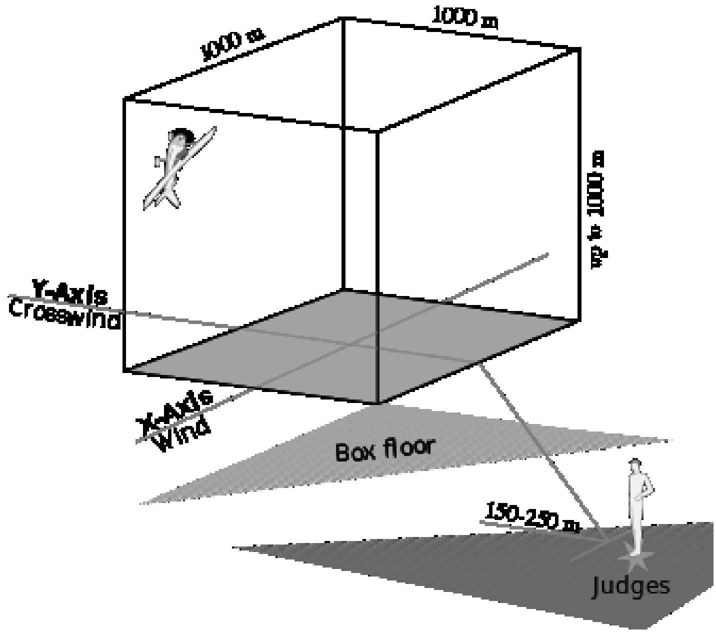

Fig. 9. Aerobatic zone for flight championship [16] [buffer area; jury line; corner marker; T markers, main axis, auxiliary axis; Note: markers in a scale of 10:1]

Navigation systems used nowadays are not sufficient for precise analysis of the flight in real time and after the flight completion. This situation inclined the members of the Żelazny Aerobatic Group and researchers from the Poznan University of Technology to start cooperation in order to develop completely mobile system for security and surveillance of operations made in the air (the main field of interest is aerobatic competition and show and the process of pilot training).

5. SECURITY AND SURVEILLANCE SYSTEM FOR FLIGHT OPERATIONS IN REAL TIME

From the presented safety model and from the analysis of existing systems of visualisation aircrafts in the space it results that there is a need to develop the system of air traffic surveillance in limited spaces. This determined area may be:

- airport terrain (completely 3D barrier),
- space concerning, for example, traffic in the plane of the airport (2D barrier),
- urban spaces in the neighbourhood of selected points (for example, search operations).

All the above functions are fulfilled by the AeroSafetyShow Demonstrator+PL (ASSD) system. Research work on this system has been started in 2013. It comprises:

− mobile controller – base station equipped with, among others, operating computers, screens of the base station, radio stations with the voice recorder, aerial mast with antennas collecting signal from mobile devices installed on the board of the aircraft

− ASSD application – visualization of aircrafts positions in the determined space (fig. 10)

− mobile modules – transmitters equipped with, among others, GPS module, module of two-sided ground-to-air wireless communication, critical situation indicator for the pilot.

ASSD system is mainly applied for air shows and glider and the aircraft aerobatic championship. This tool was developed in such a way that it would be possible to keep the space, where approx. 50 objects are moving, under surveillance in real time. Completely mobile and autonomic system enables observation in any place in the world.

Visualization of aircrafts'' positions is possible due to installation of the module inside the aircraft, which sends a signal stream to the base station by radio. At the same time its position is recorded on the SD card of the module; this card is able to carry out recording incessantly for a several hundred hours.

Fig. 10. Application visualizing aircraft flight in a zone of aerobatics performance

Among the most important functionalities of the ASSD system there are:

− current surveillance of flights and direct interference to their run,

− determination of any surveillance zone,

− supervision of many parameters at the same time (speed, height, position with respect to the determined zone),

− aircraft tracking – visible contrail,

− archiving all flights with their parameters – current recording by the base station and independent recording on the SD card of the mobile module,

− archiving in a paper form all reports printed after completing the flight (determination of the position inside the zone, top view and the height graph for the whole flight).

All these function are useful not only for competition or show flights surveillance but also for flight training. Application of the ASSD PL system enables:

− keeping training flights under surveillance in real time:

− on the aerodrome circuit – usage of the plane graph function (top view of flight course) and 3D visualization (supervision of the aircraft position in space)

− to pilotage zone – usage of the height chart function (height chart) and the function for determining special zones (sonic and light signal indicating the break of a determined border),

− supervising flight parameters and the correctness of a flight performance; immediate communication between the instructor and the pilot and preventing hazardous situations; possibility to implement a sonic signal of breaking the zone into the module,

− supervising the flight on each stage and the possibility of on-ground instructor interference in the flight run due to direct radio communication with the pilot,

− flight reconstruction and printout of reports form the completed flight, what enables making a thorough flight analysis with the training participant as well as archiving the training / examination documentation,

− surveillance of up to 50 aircrafts at the same time and tracking of 10 of them (by highlighting parameters within the application),

− determination of special zones (so-called box), breaking of which is signalled by the sound and light within the application (even for the pilot – it is possible to program the module to give sonic signal when the determined height is broken),

− control of the training flight by the on-ground instructor, what should guarantee that the set task would be done and that the maximal safety level for pilots is maintain; development of safe separation zone between aircrafts; supervision over aircrafts being out of view,

− supervision of all flight parameters in terms of their correctness by the on-ground instructor.

The above description of functionalities and possible application of the ASSD system shows that this system not only contributes to improvement of performed operations safety in real time, but also results in the training level raise. Translating this information into safety models one can easily notice how great may be the influence of wide usage of the ASSD system in the general aviation. Individual system functions creates subsequent barriers what minimizes the possibility of irregularity occurrence.

6. CONCLUSION

Despite many navigation and collision avoidance systems used in the general aviation, there is still a need to implement a system enabling conduction of on-ground surveillance of the performed flight (mainly the training one, competition one and aerobatic one). Due to this technology it will be easier to detect hazardous situations. Moreover it will enable systematization of the assessment of flights performed within the frames of aerobatics championship. A system satisfying the discussed requirements is undoubtedly the ASSD PL system. Its wide application for the general aviation would significantly influence on the improvement of air operation safety. Research Consortium carried out the project of developing this technology plans to use the minimized version of mobile modules in other fields of aviation, such as parachute jumps, paragliders, balloons or gaining more and more popularity unmanned aircrafts flights. Due to this, the surveillance of all users of the determined air space will be possible.

Functionalities of the ASSD PL system enables it be categorized as the warning and collision avoidance system. Furthermore, mobile modules can be used as the flight parameters recorder for the general aviation (so-called *black box* for the General Aviation).

Analysis of safety models and the review of the state of this technology used worldwide allow to propose a thesis that nowadays there is no system controlling the flight on each stage. This situation may be changed if the ASSD PL system, being the response to the need of the general aviation, will be widely applied.

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BEZPIECZEŃSTWO OPERACJI LOTNICZYCH W TRAKCIE TRENINGU, ZAWODÓW ORAZ POKAZÓW AKROBACYJNYCH

Abstract

Kwestia dokładnego określenia pozycji samolotu (a/c) i jego podstawowych parametrów jest bardzo ważna dla procesu szkolenia pilotów i wykonywania akrobacji lotniczej. W związku z tym pojawiła się potrzeba wdrożenia inteligentnego i autonomicznego systemu umożliwiającego kontrolę lotu w czasie rzeczywistym. Metody kontroli kursu lotu i oceny lotu akrobacyjnego lub treningowego stosowane dotychczas nie są już wystarczające w XXI wieku. Perspektywa wdrożenia inteligentnego systemu czasu rzeczywistego dla bezpieczeństwa operacji lotniczych umożliwi analizę lotu na znacznie wyższym poziomie niż obecnie.

Słowa kluczowe: bezpieczeństwo lotów, modele bezpieczeństwa, zarządzanie bezpieczeństwem, systemy nawigacyjne