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Study of Unmanned Aerial Vehicle Flight Capabilities in the Aspect of Civil and Military Aviation Safety

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Abstract:

The article discusses the issues related to the adaptation of flights performed by military unmanned aerial vehicles in Poland (Unmanned Aerial Vehicle – UAV) to the civil aviation requirements. The unmanned aerial vehicles' flight capabilities were discussed from the perspective of using the automatic flight control system to minimise a threat to civil and military aviation. Owing to the growing interest of the European Union (EU) in unmanned systems, there are many threats related to the broadly understood traffic safety in the European airspace.

Keywords:

ERA, law, military aviation, UAV

1. Introduction

The aim of this paper is to present the results achieved in solving the problem of aviation safety of unmanned aerial vehicles (UAV) at the Air Force Institute of Technology. The unmanned aerial vehicle is a tool capable of performing air operations for military, commercial and recreational purposes [1]. The rapid development of computer technology, also in aerospace applications, allowed to develop equipment and software in the scope of using global satellite positioning systems (GPS), communications and a variety of sensors that a given type of the unmanned aerial vehicle can be equipped with [2]. A key challenge resulting from the lack of consistent traffic standards in the European airspace may be the possible violation of the sovereignty of areas with limited or legally prohibited airspace in a given altitude range and a real threat of close contact with other aircraft. The above issue concerns the safety analysis in the airspace of the European Union based on the performance of work in the international project "ERA" (Enhanced RPAS Automation). The "ERA" programme is an ad-hoc project of the European Defence

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Agency (EDA), in which 16 partners from the following five countries take part: Germany, France, Italy, Poland and Sweden. The main objective of the programme is to support the traffic regulation of unmanned aerial vehicles in the non-segregated European airspace [3]. The issues related to the observation and recognition are currently important both in peace and war conditions.

The unmanned aerial vehicle provide the opportunity to collect information using the “hover and stare” method, as well as the “perch and stare” method, which means that they can be operated in any convenient area, and they can send data in digital form with the use of optoelectronic heads, cameras, photo cameras or scanners with minimum energy consumption. A separate issue is the use of various classes of the unmanned aerial vehicles for civil tasks, among others, for patrolling and transport. The main role is played by rotorcraft, the features of which predispose to carry various types of loads (including weapons and ammunition). At the Air Force Institute of Technology, experimental constructions of the unmanned aerial vehicles were created in the structural form of a “flying wing” (“Falcon”, “Wampir”, “Chrabąszcz”), in the classic form (“MP45”, ”LUAV”, “HOB-bit”, recognition systems: “Rybak”, “Pszczoła”, “Nietoperz”, “Sarys”) and rotary observation platforms, such as “ILX-27” helicopter robot for special tasks, “Koliber” and the “Atrax” unmanned aerial vehicle of vertical take-off and landing [4].

1.1. Polish Law Regulations in the Aspect of Flight Safety

One of the main problems is to adapt the rules and conditions of the unmanned aerial vehicles’ flights to civil and military aviation in the airspace of Poland, which is a very important factor of national security. For example, for safe movement of the military unmanned aerial vehicle of the Male class in the territory of Poland, during the take-off, a selected zone is excluded from general use (civil aviation) to the moment of achieving the specified ceiling by the unmanned aerial vehicle [1]. In addition, special air routes in which the unmanned aerial vehicle has the right to perform its air missions are designated. To minimise the threat to civil aviation in the territory of Poland, the rules of performing flights in the VLOS (Visual Line of Sight) conditions were introduced. These conditions specify the operations within the operator’s sight, which were included in the regulation of the Minister of Transport, Construction and Maritime Economy of the Republic of Poland of 26 March 2013 on the exclusion of the application of some provisions of the Act of Aviation Law to some types of aircraft and the determination of conditions and requirements for the use of these aircraft. In accordance with the provisions applicable in Poland for small civil unmanned aerial vehicles, people performing sports or recreational flights are obliged to maintain a horizontal distance of not less than 100 m from the cities, housing developments or gatherings of people in the open air and 30 m from individuals, vehicles and civil structures that are not available for or under the control of the operator. These regulations apply to flying models weighing less than 0.6 kg.

The operators of the unmanned aerial vehicles used for purposes other than recreational or sports ones are required to have a qualification certificate (resulting from Article 95 paragraph 2 section 5a of the Act of 3 July 2002, Aviation Law, Journal of Laws of 2012 item 933, as amended), which can be obtained after passing the state examination in one of the two categories: UAVO VLOS (Visual Line of Sight) category. The certificate entitles them to fly within sight, provided that a safe distance and proper marking are maintained (the operator must have a vest, and the unmanned aerial vehicle must have an identification plate) and UAVO BVLOS Beyond Visual Line of Sight) category which entitles them to fly out of sight (control with the use of an image transmitted from the unmanned aerial vehicle). The flights must take place outside the controlled areas of airports, controlled areas of military airfields, and areas R – Restricted Area, D – Danger Area and P – Prohibited Area. The flights in the mentioned areas may be performed with the consent of a person responsible for and managing a given area [1].

1.2. Polish Unmanned Aerial Vehicles

At the Polish Air Force Institute of Technology, two types of the unmanned aerial vehicles are constructed: manoeuvring air targets (intended for fighter aviation or ground missile sets) and unmanned aerial vehicles (implementing the combat and reconnaissance missions).

A set of the controlled manoeuvring air targets allows for training and performance of artillery as well as artillery and missile shootings (Strzała-2M, Grom) and shootings from anti-aircraft missile sets (Osa, Kub, Newa) providing a practical range of targets up to 3 000 m at the target speed up to 160 km/h, at the altitudes of up to 600 m. An example of the military unmanned aerial vehicle with a jet propulsion is a system of air imitators for missile shootings under the name of “Jet” (Fig. 1). The fulfilment of the performance requirements (minimum flight speed of 100 m/s, ceiling 3 000 m) is currently possible only owing to the use of a jet propulsion, and the development and use of an automatic control system guarantees a practical range of operation above 20 km, and the possibility of using several air targets at the same time, which results in the approximation of training conditions to the actual conditions of the current battlefield [4].

Fig. 1 Jet air target “Jet”

The continuation of work on the jet air target with a programmed flight route is the "Jet-2" twin-engine aircraft (Fig. 2), which starts from the pneumatic launcher, and its maximum flight altitude is 6 000 m and the flight speed is over 160 m/s. This twin-engine jet is controlled with the use of an autopilot system, and its route is fully programmable, with the opportunity to change flight parameters already during the task performance. Landing is performed in a classical way or by parachuting.

Another example of polish UAV is a series of unmanned aerial vehicles of vertical take-off and landing "Atrax C". It is a modern construction made of glass-carbon composites built as a multi-rotor flying platform in the X4 (Fig. 3) and X8 (Fig. 4) systems. "Atrax C" is equipped with four arms, at the ends of which there are two electric motors driving the counter-rotating propellers. This allows the design for greater stability and safety of performed flights. The failure of one or even two motors allows for landing in a controlled way. The unmanned aerial vehicle is controlled from the ground station, which can control two "unmanned aerial vehicles" at the same time. The operator can determine the route and plan each of the flight parameters.

On the screen of the ground control station, the image from on-board cameras is displayed in real time, however, the basic flight parameters and the map are based on the data entered by the user. The "Atrax C" unmanned aerial vehicle is designed to perform reconnaissance tasks, such as the assessment of consequences of natural disasters, protection of persons and property and the support of SAR (Search and Rescue) action [4].

Fig. 2 Jet air target "Jet-2"

2. Unmanned Aerial Vehicles' Flight Capabilities for Automatic Flight Control

A typical automatic control system for the unmanned aerial vehicle using specific flight capabilities of the selected object in the form of combat aircraft [5, 6] may have the autonomous work ranges and navigational ranges that require cooperation, among others, with a navigation unit and an on-board computer.

Fig. 3 “Atrax C” in X4 configuration

Fig. 4 “Atrax C” in X8 configuration

The autonomous work ranges of such a system include, among others, attenuation of short-term oscillations of the aircraft in relation to the centre of gravity (with manual control from the ground, in a full range of the pitch, bank and course angles), course, pitch and bank stabilisation, stabilisation of the barometric flight altitude and leading the aircraft to a horizontal, linear flight at the fixed flight altitude from any pitch and bank angles with simultaneous stabilisation of the barometric flight altitude. The navigation ranges include automatic aircraft control at low altitudes using the radio altimeter, as well as automatic and directive side guiding. The automatic and directive control of the aircraft within the ranges includes tasks such as a flight along the route, return and descent to the area of the programmed landing airport, a landing approach to the programmed or non-programmed airport, leading the aircraft to the combat route line and the performance of a turn, the so-called “Immelman” (piloting figure aimed at a fast change of the flight altitude and direction) for bombing at climbing with leading to the straight horizontal flight and the barometric flight altitude stabilisation [7].

One of the unmanned aerial vehicle control ranges important for the civil aviation safety, in addition to ranges “Return and descent to the airport” and “Landing approach to the programmed airport”, is a range of “Flight along the route”. The flight control right of the selected unmanned aerial vehicle for this range, refers to the pitch channel [7]:

$$\delta_1 = \frac{T_{i3}s+1}{T_{i3}s}\left[\delta_{\text{ster}}(s)L51 + \mu_{\text{x1}}(q_{\text{d}})p(s)L42\frac{1}{T_F s+1}\right]L48\frac{1}{T_{\text{sn}}s+1}L1 \tag{1}$$

where s is the complex variable of the Laplace transform; T_{i3} – system feedback time constant; $\delta_{\text{ster}}(s)$ – the control signal Laplace transform; $L51$, $L42$, $L48$ – the logical conditions for the inclusion of the appropriate signals to the control system; $\mu_{\text{x1}}(q_{\text{d}})$ is the correction function depending on dynamic pressure (q_{d}); p – Laplace transform of an aircraft intercept angle; T_{F} – the correction filter time constant; T_{sn} – the time constant of the aileron propulsion drive.

The control signal δ_{ster} for the aileron tilt depends on a given angle Φ_z according to

$$\delta_{\text{ster}}(s) = i_{\Delta\Phi}\frac{2T_1 s+1}{T_1 s+1}(\Phi_z - \Phi) \tag{2}$$

$$\Phi_z = \left[i_y Y(s)L52 + i_{yp}Y(s)\right]\frac{1}{T_2 s+1}ogr12 + L53 \tag{3}$$

where i_{y} – the amplification of the aircraft deviation signal from a given course line; $Y(s)$ – Laplace transform of the lateral deviation of the aircraft from the set course; $L52$, $L53$ – the logical condition; i_{yp} – the amplification of the derivative of the lateral deviation of the aircraft from a given road line; T_2 – the low pass filter time constant; $ogr12$ – the signal amplitude limiter.

The simulation model for the automatic flight control system of the unmanned aerial vehicles of the “HOB-bit” class, including the implementation of the individual system controls, presented in the form of differential equations of motion of the aircraft control bodies, was built in the Matlab-Simulink programme. It allows for separate testing of the individual system control channels, among others, flight along the route (take-off, task execution, return and descent to the programmed airport area, landing) and autonomous control of the unmanned aerial vehicle at low altitudes [1].

3. Era Programme and ATOL and Auto-Taxi Systems

The national security problem in the context of using the unmanned aerial vehicles in the European Union airspace is still a very important security factor of every country, including the territory of Poland. The above issue is related to the analysis of safety in the EU airspace based on the international programme “ERA”, the objective of which is to allow the unmanned aerial vehicles of civil and military aviation to move in the non-segregate European airspace and to provide the safety levels of operation in emergency modes. The automation of take-offs, landings and taxiing of the remotely controlled aircraft will be required for operations at both civil and military airports [3]. The main objective of the "ERA" programme is to create legal regulations in the common airspace of the unmanned aerial vehicles and manned aircraft, to integrate the air operation in the airport space, and to create regulations for ATOL (Automatic Take-Off and Landing) and AUTO-TAXI – an automatic restart system for on-board systems of the aircraft after an emergency situation during the flight. It is also important to develop common standards of the unmanned aerial vehicle certification in the European Union [8]. The main tasks of the "ERA" programme will be achieved with support for the regulation and standardisation of these capabilities by providing safety assessment, procedures, simulations and demonstrations of flights. An example is the ATOL and AUTO-TAXI system demonstrator (Fig. 5) based on the MP-02 Czajka type aircraft equipped with a control and navigation system.

Element	Contributor
Platform	**MP-02 based dedicated platform**
Airfield	**Rzeszow**
Ground statnion/HSI interface	**Poland/Safran**
Remaining traffic	**Poland**

Fig. 5 View of ATOL and AUTO-TAXI systems

The demonstrator operation principle is based on the aircraft (Fig. 6) performance of automatic taxiing (AUTO-TAXI) before and after the flight, automatic take-off and landing (ATOL) and control over the control system's elements in case of emergency situations during the flight.

4. Example of Simulation Tests of the AUTO-TAXI System Demonstrator's Flight Capabilities

One of the elements of the conducted work for newly designed constructions of the AUTO-TAXI system demonstrator is to perform the numerical simulation of the flight [9, 10]. Main objective is to determine the MP-02 Czajka aircraft flight capabilities during autonomous work on the ground [11]. The demonstrator is an aircraft belonging to the Institute of Aviation equipped with a low-level control system which aims to perform automatic taxiing on the apron to the runway threshold, avoiding potential collisions with other vehicles and obstacles on the apron (Figs 7-10). The example test results were presented in the following graphs [11].

Fig. 6 View of the MP-02 Czajka aircraft with built-in control and measurement equipment

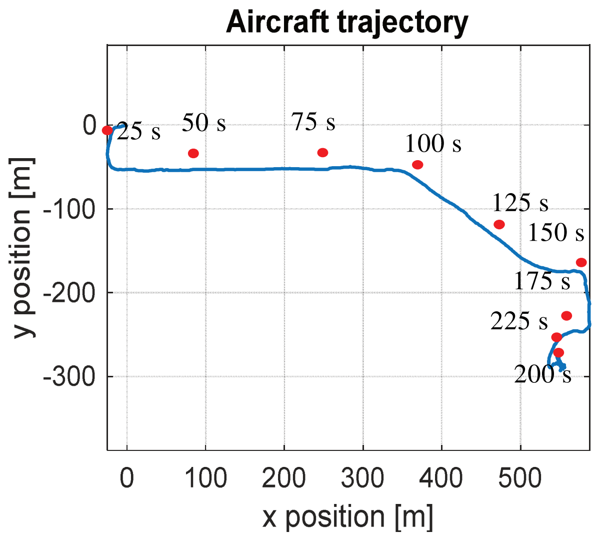

Fig. 7 MP-02 Czajka aircraft taxiing trajectory

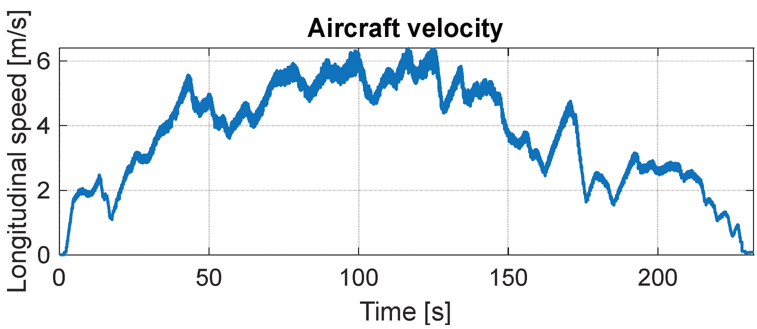

Fig. 8 MP-02 Czajka aircraft taxiing velocity

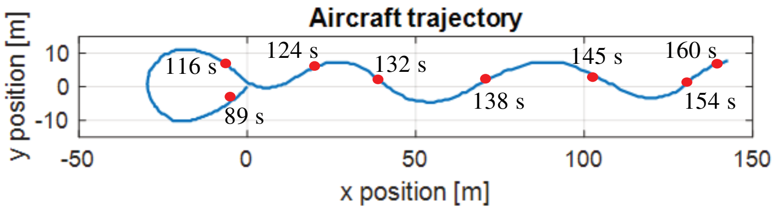

Fig. 9 MP-02 Czajka aircraft taxiing on the airport runway

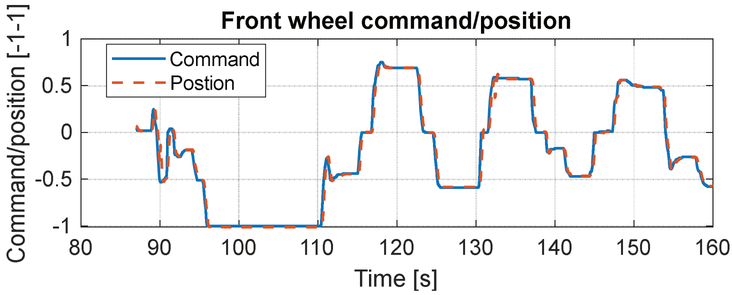

Fig. 10 Control of the position of the MP-02 Czajka aircraft front wheel during taxiing

Fig. 10 shows the position of the front wheel in the time domain. The graph contains information about the change of position of the front wheel from the centre point (in a flight direction) where 1 and –1 are the maximum values.

The obtained results allow for further analysis and work on the development of the AUTO-TAXI system demonstrator [11, 12].

5. Conclusions

In order to make it possible to apply, develop and conduct further studies in the field of unmanned civil and military aviation, it is necessary to create legal regulations defining safe adaptation of the unmanned aerial vehicles to the conditions prevailing in public airspace – both of the domestic and international airports – respecting the legal regulations in the European Union defined over the years. The main task of the “ERA” programme is to prepare technical and functional recommendations and operating procedures of the autonomous control system of unmanned aerial vehicles allowed to fly in the controlled civil airspace, with particular emphasis on autonomous take-off and landing, as well as to take action in emergency situations.

Ultimately, the final effect result of this project is the construction of three technology demonstrators presenting the autonomous operation of the RPAS system taking into account the developed procedures and standards that allow this system to move also in the airspace of the territory of Poland. The demand for the unmanned aerial vehicles, increasing in recent years, resulted in the creation of many structures with various geometric and mass parameters and aerodynamic systems, according to which they were built, and, above all, the range of possible applications. This trend of work includes the unmanned aerial vehicles, built at the AFIT, which are operated, among others, by the Polish army.

Numerical simulations of the UAV flight were an important element of the research, their objective was to determine the flight capabilities, and, first and foremost, to assess ability to perform automatic take-off, landing and taxiing. The objectives developed and built at the Air Force Institute of Technology ensure the automatic flight performance, the possibility of performing flights in difficult weather conditions, and the complexity of the performed tasks (e.g. several targets operating at the same time). The developed controls for the autonomous unmanned aerial vehicles constitute an important element in minimising the threat to civil and military aviation.

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