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# Introduction to Reliability Tests of Unmanned Aircraft Used in the Armed Forces of the Republic of Poland

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### Abstract

This paper is a theoretical introduction to the reliability tests of unmanned aerial vehicles used in the Polish armed forces. The purpose of this article is to determine the type / model of the unmanned aircraft used in the service of Polish Armed Forces, which results from the conducted reliability tests, will be the basis for generalizing them to the largest group for the subsequent research. In order to achieve the assumed goal, the author, firstly, reviews the terms and definitions describing the subject of the study. The trends occurring in the description of the examined subject-matter were recognized. Then, the typologies and classifications of unmanned aerial vehicles are analyzed on the basis of Polish and international sources, as well as normative documents. The last part of the paper comprises of a comparison of tactical and technical data of unmanned aerial vehicles used by the Polish Armed Forces.

**Key words:** reliability, safety, unmanned aerial vehicles

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### 1. Introduction

The broad spectrum of using unmanned aerial vehicles (UAVs) on the battlefield and their relatively low cost (several dozen times lower than it is the case of crewed machines) generate an increasing interest in this equipment, not only in developed, but also developing countries. This is reflected in both the unmanned fleet already owned by Poland, as well as in the Plan of Technical Modernization of the Polish Armed Forces [*Plan Modernizacji Technicznej Sił Zbrojnych RP*], where UAVs are the most frequently mentioned devices in three main operational priorities (OP): OP Image and satellite reconnaissance, OP Modernization of Artillery (as an accessory to the RAK system), and in the task Warmate circulating ammunition (Ocena astanu, 2019) (Dziennik Zbrojny, n.a.)

The growing interest in this equipment drives further dynamic technological and conceptual development. The artificial intelligence capabilities of UAVs are developed, the concepts for cooperation of these devices with crewed machines are created, as well as of their possible use in the swarm formation. Given the above, it can be unequivocally stated that the growing importance of unmanned aerial vehicles on the modern battlefield is unquestionable. This is the reason why it is so important for the Polish Armed Forces, which, in order to develop and maintain defense capabilities, should have devices of this sort. The purchases of new UAVs are carried out under individual operational programs stemming from the above-mentioned Technical Modernization Plan increase of the defense capabilities of the state. However, from the point

of view of maintaining these capabilities, it is equally important to increase the reliability parameters of devices already owned by the Polish Army. The constant need to carry out reliability tests is determined by the necessity to improve the UAVs' operation process, as well as by the need to enhance reliability allowing to complete the combat task.

Bearing in mind the fact that reliability determines the probability that an object will perform its function in a given time in certain conditions, one may even be tempted to state that possessing modern equipment, as UAVs undoubtedly are, and not carry out an analysis and evaluation of the possible improvement of their reliability parameters, is unacceptable. For, this can cause the failure of a potential mission, and in extreme cases, it may endanger the life and health of soldiers who operate a given device, or whose task depends on the success of the UAV's mission (e.g., reconnaissance).

Considering the above, it can be concluded that there is a justified need to perform reliability tests on unmanned aerial vehicles, and it is in the interest of the armed forces to perform such tests on the equipment used by the Polish Army. However, due to the existence of different types of UAVs, detailed testing of all unmanned aerial vehicles could prove too costly and time-consuming, and hence economically unjustified. The solution to this problem may be to find such an unmanned aircraft, whose examination results could be then extrapolated onto a larger group of aircraft (more types). Still, it is necessary to take into account the construction differences that occur in different types of UAVs. The analysis of the subject literature indicated shortcomings in the area of uniform studies related to this research area. Most of the researchers focus on one type of UAVs (e.g., MALE) (Goetzendorf-Grabowski, Frydrychewicz, 2006), or they are very general and do not analyze any specific aircraft (Petritoli, Leccese, 2017) (Caswell, Dodd, 2014).

Bearing in mind the lack of synthetic scientific studies on the reliability of UAVs and their ever-increasing impact on state security, the author decided to undertake research aimed at determining the type / model of the unmanned aircraft used by the Polish Armed Forces. The results of the conducted reliability tests will be methodologically generalized and will be referred to the largest possible group of UAVs. To achieve this adopted goal, it was decided to begin the research with analyzing the term 'unmanned aerial vehicle' that would include the criterion semantic features (Anusiewicz, 1994) of the examined subject. This was dictated by the results of the preliminary analysis indicating the interchangeable use of several concepts related to the subject of the study, i.e., an unmanned aerial vehicle. The results of the tests carried out at this stage are also an additional value consisting in an attempt to systematize the terminology associated with unmanned aerial vehicles. Then, the typology of unmanned aerial vehicles was analyzed to finally select one model. The most important research methods employed for this study include: analysis, synthesis, comparison, abstraction, and inductive and deductive inference.

It should be emphasized that this research is a basis for further work related to the enhancement of reliability of

unmanned aerial vehicles carried out by the author in her doctoral dissertation.

## 2. The Semantic Problem

An analysis of the subject literature showed the occurrence of various terms related to unmanned aerial vehicles. These terms, often used interchangeably, can cause cognitive problems related to semantics. Therefore, further research investigations were carried out to refine the scope of research, including reliability tests. In the analysis of the literature, five basic terms related to the subject of the study were distinguished:

1. Unmanned Air System (UAS);
2. Unmanned Aircraft;
3. Remotely Piloted Aircraft (South Africa);
4. Remotely Piloted Aircraft System (RPAS);
5. Radio-Controlled Aircraft (RC Aircraft);
6. Unmanned Aerial Vehicle;
7. Drone.

The analysis indicated that the term "unmanned aerial systems" belongs to the scope of a broad term defining the group of unmanned platforms "Unmanned Systems". It also took into account the center of operation of these systems. Currently, one can distinguish three basic types of Unmanned Systems: air, sea, and land (Cwojdzinski, 2014).

Due to the limited scope of the paper, the focus is solely put on unmanned aerial systems. In NATO, the term is defined as "a system whose components include the unmanned aircraft, the supporting network and all equipment and personnel necessary to control the unmanned aircraft" (AAP-6, 2011). Further analysis showed that unmanned aerial systems include (Adamski, Rajchel, 2013):

- flight ground control station (GCS – Ground Control Station) with an antenna system and a data transmission system;
- data transmission and exchange terminals and software;
- communication systems (ground / air; air / ground);
- a specified number of unmanned aircraft (including spare);
- UAVs take-off and landing (recovery) devices;
- means of communication (voice and data exchange) with air traffic management cells;
- devices (equipment) necessary for the operation, storage and transport of UAVs;
- all necessary documentation (technical, operational) regarding the abovementioned elements;
- additional devices necessary to carry out tasks (still camera, video camera, means of destruction).

When comparing the above with the term 'unmanned aerial vehicle', it should be noted that this term first appeared in military semantics in the 1990s (Gregorski, 2017). One of the first definitions of this term describes it as a reusable aerial apparatus (vehicle, ship, object) of any aerodynamic configuration, capable of carrying armament or other equipment, with no pilot-operator on board and capable of flying along a programmed route (Popularna Encyklopedia, 2002). This definition does not correspond to the current

reality, e.g., Polish Armed Forces are in possession of disposable UAVs that are intended for “kamikaze” attacks. Another definition was created in 2005 and defines UAVs as powered and unmanned apparatus. In order to stay in air, it can use the lift generated by the laws of aerodynamics on fixed (wings), movable support surfaces (rotor), or aerostatic buoyancy (aerostat). It can be controlled by autonomous systems or remotely by the operator (from the ground, air, or ship). It has been designed to return and be reused. It can be a single-use aircraft (Karpowicz, Kozłowski, 2003). The above definition seems to reflect the essence of the term in question. However, it is very complex. Therefore, in order to find an appropriate definition elucidating the subject of the study that would also take into account the environment in which the research is carried out, the author has adopted the NATO definition, which states that a UAV is: a power-driven aircraft, disposable or reusable that uses aerodynamic forces to provide force for a carrier that flies independently or is remotely piloted; capable of carrying deadly or incapacitating loads (AAP-6, 2011).

In 2011, ICAO introduced (ICAO, 2011) the concept of “remotely controlled aircraft,” which is part of the remotely controlled air system. Pursuant to air traffic regulations, the term “remotely controlled aircraft” includes an “unmanned aircraft which is piloted from a remote piloting station” (Załącznik do obwieszczenia, 2011). This means that a remote-controlled aircraft is a much narrower concept than an unmanned aerial vehicle, as it does not include autonomous systems. However, similarly to the previously considered unmanned air system, the remotely controlled air system includes all other devices (elements) necessary for the implementation of the flight. In this case, it will be a remote pilot station (ICAO RPAS, n.a.) (ICAO, n.a.). Similar to a remote-controlled aircraft, a radio-controlled aircraft is defined as a UAV subtype. The main difference resulting

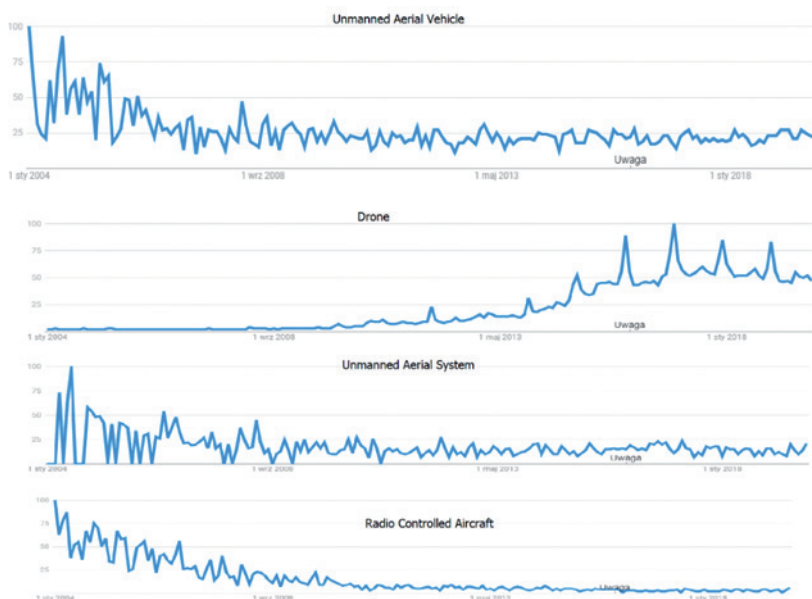
from semantics is the way aircraft is controlled. In the case of the previous term, the word “remotely” specifies how the aircraft is controlled and not the control method, while in the term radio-controlled aircraft the word “radio” limits the control method to radio control. In addition, other characteristics that distinguish a radio-controlled vessel can be found in the literature, such as limiting the number of operators – to one and the number of hours of work in the air – up to two hours (Ministerstwo Infrastruktury, 2019).

An analysis of the literature on the subject of research shows that the concept of “unmanned aerial vehicle” is synonymous with unmanned aircrafts. This is due to the fact that the term “unmanned aerial vehicle” defines the center in which the vessel operates – air. In contrast, the unmanned aerial vehicle determines the activity of a ship in the air, i.e. flight. According to the Aviation Law and accepted terminology by the scientific community, each flying apparatus (floating in the air) is an aircraft (Prawo lotnicze, 2002). The use of two terms to determine the same results from the previously misunderstood BSP characteristics, namely the use of the term “Unmanned Aerial Vehicles,” which due to the fact that the pilot always operates the aircraft, was a mistake.

The last term discussed is “drone,” and in the case of unmanned aerial vehicles, drone and BSP describe the same devices. The reason for the next term for the same device results from the interchangeable use of these terms by the media (in particular Western media) (BOTLINK, n.a.). It should be emphasized that the word drone is becoming more popular due to frequent use by the media as shown in the figure below.

The above charts illustrate the process of replacing all terms with the term drone. However, despite the growing popularity of the term “drone” due to the proliferation of unmanned systems themselves and the increasing use of the term by the media, it should be noted that it is slowly replacing the term “unmanned aerial vehicle” (Dougherty, 2016). Notwithstanding the above, analysis of the literature indicated that the most common term describing the subject of research in scientific literature is “unmanned aerial vehicle.”

Fig. 1. Trend of search terms in Google Trends



Source: <http://www.google.trends.com>, access 02/11/2019.

### 3. The Problem of Typology and Classification

Technical parameters and reliability parameters depend directly on the UAV type. Since the UAV type determines its construction, it thus also determines the structural elements used or tasks it will carry out, and in consequence, also the external factors to which it will be exposed during carrying out tasks. Given the above, it was considered important to analyze the UAV typology.

The typology of all aircrafts, including UAVs, may depend on many factors, the most common in the subject literature are typologies associated with aircraft attributes, i.e., their characteristics. The characteristics of aircrafts may be related to their flight or take-off and landing

characteristics (e.g., vertical take-off and landing). Other frequently used parameters describing aircrafts include: operating radius, flight time, equipment, load capacity, structure, aerodynamic system, etc. In addition, the division of aircraft may depend on their function and the scope and purpose of use. The generally accepted division concerns their use on the civil and military market. In relation to UAVs, other divisions can be found in the literature including e.g., the responsibility and risk associated with their use, or the business model where UAVs are divided into product and service. Keeping in mind the purpose of this paper, some of the most common UAV typologies are described below.

The first typology refers to functions that can be implemented by using UAVs. At the same time, the general division of the implemented functions can be categorized into civil functions and military functions. In the civilian area, UAVs functions are classified as follows (Ministerstwo Infrastruktury, 2019):

1. Monitoring-related functions – terrain or air imaging to obtain data for further analysis.
2. Functions related to transport – activities related to the movement of people and material goods.
3. Functions related to communication (telecommunications) – ensuring the safe use of airspace by many types of UAVs, especially autonomous unmanned aerial vehicles.

In the military area, the general division of UAVs divides them into reconnaissance, combat, and special ones.

However, it should be noted that the division both in the civil market and in the military area is directly related to the currently performed tasks (functions) of these devices. Therefore, it is not difficult to imagine that this typology will evolve as the concept of using UAVs in both areas develops further. This typology can also take various shapes, e.g., including equipment carried by UAVs. One such example is the following breakdown of military reconnaissance UAVs:

1. IMINT – optical recognition – equipment: infrared sensors, lasers, and radar sensors;
2. SIGINT – interception and recognition of electromagnetic waves;
3. MASINT – detection and tracking of ballistic missiles, tracking and detection of means of air attack with the possibility of determining their impact parameters, traces of submarines and aircraft using boosters;
4. OTHER – warning against: radiation, electromagnetic attack and others, especially used in combating systems intended for SEAD tasks.

Tab. 2. Aircraft classification according to the Polish Ministry of Transport

UMW Heavy unmanned aerial vehicle	K1. basic	Not applicable	MTOM > 150 kg
	K2. conventional		
	K3. special		
UML Light unmanned aerial vehicle	K3. special	UML-150 BSP	MTOM > 25 kg i <150 kg
	K5. unqualified	UML-25 BSP	MTOM < 25 kg

Source: Rozporządzenie Ministra Transportu, 2013.

However, in the subject literature, the most common classifications refer to UAVs. An example of such a classification is the distinguishability of these measures by the range of activity:

1. Close range up to 50 km;
2. Short range (performing reconnaissance and tracking operations) up to 150 km;
3. Medium range (carrying out complementary tasks for manned aircraft);
4. Long range (high altitude) – acquisition of information about the target;
5. UAVs of vertical take-off and landing used in the Navy. (Jane’s Airport Review, 2007)

Another characteristic feature of UAVs, and thus the most common division of this type of aircraft, is their weight. In the subject literature, the most common classification divides UAVs into five categories. This typology is presented in the table below.

Tab. 1. Classification of UAVs by mass

CLASS	CATEGORY	MASS	EXEMPLARY UAV
II / III	Very heavy	> 2000 kg	RQ-4 Global Hawk
	Heavy	200 – 2000 kg	A-160
I / II	Medium	50 – 200 kg	Raven
I	Light	5 – 50 kg	RPO Midget
	Very light	< 5 kg	Dragon Eye

Source: Mazir, n.d.

The mass division was adopted not only in the scientific and military environment, but it was also sanctioned by Polish legislation. For, the binding regulation also covers the classification of UAVs in Poland and divides them into two basic categories on the basis of their mass (Rozporządzenie Ministra Transportu, 2013).

It should be noted, however, that due to technological development, including the miniaturization of electronic systems, the typology based on the mass of the device is progressively less useful. Therefore, more and more often one can find “hybrids” of various UAVs’ attributes. Partial data resulting from the literature analysis are presented in the table below and include the classification taking into account four attributes:

Tab. 3. UAVs technical and tactical data

DESIGNATION	FLYING TIME	RANGE	ALTITUDE	LOAD CAPACITY
HIGH	> 24 h	> 1500 km	> 10000 m	> 100 kg
MEDIUM	5–24 h	100–400 km	1000–10000 m	50–100 kg
LOW	< 5 h	< 100 km	< 1000 m	< 50 kg

Source: Mazir, n.d.

A different division, which takes into account two UAVs attributes can be found in the classification proposed in the 2009 NATO documentation. UAVs there are divided into three main classes:

1. The first class – objects weighing less than 150 kg and with the flight time up to 6h;
2. The second class – objects in the range from 150 kg to 600 kg and with the flight time up to 24h;
3. The last class – objects weighing over 600 kg with the flight time of up to 40 h (Mazir, n.d.).

However, it should be noted that the above typologies have serious limitations. They make one attribute dependent on the second, which, due to the continuous miniaturization of aviation technology stemming from technological progress, prevents the proposed classification from reflecting real possibilities.

Given the above, it can be concluded that UAV typology that takes into account such attributes as unladen mass, or joints together two features (e.g., mass and operating radius) is not precise. Moreover, these typologies do not have significant cognitive value in determining UAV reliability. Therefore, guided by research inquisitiveness, a new division was made, which distinguishes UAVs according to their structural element, and in particular, their aerodynamic system, namely, a fixed-wing aircraft, rotorcraft, and aerostats (rotorcraft as well as balloons and airships):

It should be further noted that the aerodynamic system that includes all UAVs in its group is a system with fixed bearing surfaces i.e., fixed-wing vehicles. Therefore, it seems justified to carry out a reliability analysis taking into account the broadest UAV group. It should be emphasized that in the subject literature there are also other examples of typologies focusing on UAV constructions. One of them takes into account their propulsion systems: piston, jet, turbojet, and electric. Another one divides UAVs using the take-off and landing criterion: folding and retractable landing gear, fixed landing gear, UAVs fired from the launcher, carried by carriers, vertical take-off and landing, and multi-variant take-off systems that can also be equipped with classic landing systems, i.e., using a hook and airport braking ropes or a net or parachute (which is often treated as an emergency system). However, the analysis of the above classification has shown that it is impossible to unequivocally indicate the most common types of UAV structures in the above typologies.

#### 4. Comparison of Tactical And Technical Data of UAVs Used by the Polish Armed Forces

Practical and technical data are a source of information on the structural elements used and constitute necessary knowledge about the expected operational values of particular UAVs, including the values affecting their reliability.

Tab. 4. Divisions According to the Aerodynamic System

Aerodynamic system	Micro	Mini	Close Range	Short Range	Medium Range	Medium Range Endurance	Low Altitude Deep Penetration	Low Altitude Endurance	Medium Altitude Long Endurance	Hight Altitude Long Endurance	Unmanned Combat Aerial Vehicle	Lethal	Decoy
Fixed-wing aircraft	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rotorcraft	✓	✓	✓	✓	✓						✓		
Aerostats		✓	✓	✓									

Source: Adamski, Rajchel, 2013

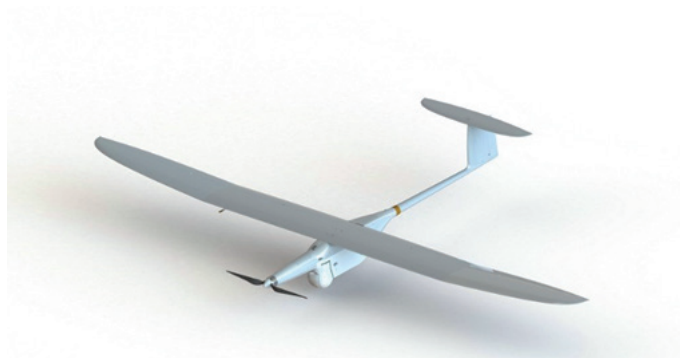


On the basis of the analysis and synthesis of the data on particular technical parameters, it is also possible to indicate differences and similarities in the UAV design, which will ultimately allow us to achieve the adopted goal. Taking into account the previous research results, an analysis has been carried out that focused on the fixed wing aircraft used by the Polish Armed Forces including: Warmate, FlyEye, Orbiter, RQ-21 Blackjack, and Scan Eagle. All of them belong to the Class 1 according to the NATO typology. Warmate belongs to the single use combat type, while the rest of the discussed UAVs are designed for reconnaissance missions. Due to the one-off nature of Warmate use, it was considered pointless to carry out a detailed analysis of this type of aircraft. Further research showed that the Polish Armed Forces have 15 sets of Orbiter and FlyEye, one set of Scan Eagle and one set of RQ-21A Blackjack. This fact determined the decision to conduct a detailed UAV analysis of only the largest group. Among the tactical and technical parameters that were analyzed there were: materials and construction, dimensions (wingspan, length) and weight, payload, maximum speed, and maximum altitude, operating range, maximum flight time. However, due to the similarities, the research results have led to the conclusion that it is impossible to unequivocally indicate one type of composites used in a particular UAV, because different elements are made of different materials. This means that, for example, a different composite was used to build the rotor blades and a different one for the cover construction.

### 5. FlyEye

The first example of a UAV introduced in the Polish Armed Forces was the FlyEye, produced by WB Electronics. Currently, the armed forces are equipped with 15 sets of this UAV model. This unmanned aerial vehicle is characterized by its composite structure and the possibility of taking-off in an almost vertical position, the so-called steep-angle. There is also the possibility of carrying out a two-stage steep-angle landing – it facilitates completion of tasks in adverse conditions. The UAV possesses fully automated flight control systems and the ability to coordinate and correct them (FLYEYE, n.d.).

Fig 1. FlyEye



Source: <http://www.reutechcomms.com/flyeye>, access 02/11/2019.

The mounted space recognition elements are equipped with specialized optical as well as thermal imaging cameras. The UAV can perform a flight with a radius of up to 30 km, and stay airborne up to three hours with constant data transmission in real time. After completing the task, it proceeds to perform a two-phase landing consisting in: in the first phase – dropping the container with the head and electronics on the parachute, and in the second – its own landing.

The FlyEye, thanks to its potential and modularity, can be transported by just one soldier, while the second soldier carries other pieces of equipment, such as ground flight control and data communication station (Brzezina, 2013).

Table 5. Tactical and Technical Data – FlyEye

Wingspan	3.6 m
Length	1.9 m
Maximum take-off mass	11 kg
Load mass	up to 4 kg
Speed of flight	from 50 to 170 km/h
Altitude	4000 m
Operation range	10/30/50 km
Time of flight	from 120 to 180 min

Source: WB GROUP, n.d.

### 6. Orbiter

Another discussed UAV, which is used by Polish Armed Forces is the Orbiter manufactured by the Israeli company Aeronautics Defense System Ltd. This aircraft was built in the arrangement of a flying wing with a single electric motor, which was mounted in the rear part of the fuselage, and the reconnaissance elements were installed in the forepart of the vehicle. The set includes: a portable launcher, one or more recognition cameras, and a communication console. The mounted reconnaissance elements are designed to operate in daytime and nighttime conditions. It also has a GPS receiver and inertial navigation systems (Brzezina, 2013).

Fig. 2. Orbiter



Source: <https://www.israeli-weapons.com/weapons/aircraft/uav/orbiter/Orbiter.html>, access 02/11/2019.

In order to perform a combat task, the above UAV should be placed on a small catapult or ejected by hand from a standing position into the air, after previous preparation. The main task of the service crew and the operator is to prepare the ground and flight control station for operations. Using the console components, one can plan the flight route and observe images in real time. If necessary, the control can be performed manually using the built-in joystick located next to the flight and mission console. The latest modernization of this weapon is the Orbiter-2B version, which is characterized by a range that is two times larger, duration of flight, and newer elements of the head with a built-in camera for HD reconnaissance (Modernization Plan, n.a.) (Aeronautics, n.a.)

Table 5. Tactical and Technical Data – Orbiter

Wingspan	2.2 m
Length	1m
Hight	0.3 m
Head mass for daytime missions	0.65 kg
Head mass for night-time missions	0.95 kg
Data transmission range	up to 15 km
Operational speed	46–120 km/h
Maximum speed	139 km/h
Maximum altitude	~ 5000 m
Maximum flight time	up to 1.5 h

Source: *Wydawnictwo Nowa, 2006; Wydawnictwo Nowa, 2007.*

Taking into account the development of unmanned aerial vehicles and the adopted methodological limitations, only the construction of the Orbiter-2B version was characterized.

The analysis of the tactical and technical data of the two discussed UAVs has shown that there are many similarities regarding their capabilities. The FlyEye has a longer operating range, can stay longer in the air, and is able to carry a heavier load than the Orbiter. On the other hand, Orbiter has a higher maximum speed and a higher altitude. Nevertheless, the differences are small and do not significantly affect their combat abilities.

## 7. Conclusions

Concluding the presented results of the theoretical research, it can be stated that despite the existence of several terms related to the subject of the study, the most suitable is “unmanned aerial vehicle”. It should be emphasized, however, that it is much narrower than the unmanned aerial system and wider than the controlled aircraft. Moreover, the research has shown that the variety of functions and equipment, as well as the dynamic development of these objects often makes the adopted typology obsolete, or it is impossible to assign a particular UAV to one class (one type), and in consequence, it is difficult to formulate a detailed, unambiguous description of

the UAVs types. The research has also shown that due to the large number of different types of UAVs, there is a justified need to limit reliability tests to a specific type of structure. Additionally, it has been demonstrated that despite the existence of numerous UAV classifications, it is the reliability tests that determine the usefulness of vehicles. The typologies focusing on tactical and technical data, although used in legislative documents, have little cognitive value from the point of view of the reliability of the objects. Therefore, in this particular case, the typologies based on structural elements seem to be most suitable for the research assumptions, and the typology based on the aerodynamic system showed unambiguously that the largest UAV group is the fixed-wing aircraft. Therefore, limiting the research group (which is justified from an economic point of view), it is expedient to carry out further research on the UAVs of the fixed-wing type.

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