AVIATION AND SECURITY ISSUES NO. 3(1/2023)
ISSN 2720-197X / eISSN 2956-3380

Anna MICHALSKA
Polish Air Force University
e-mail: a.michalska@law.mil.pl
ORCID: 0000-0002-9292-589X

Daniel MICHALSKI
Polish Air Force University
e-mail: d.michalski@law.mil.pl
ORCID: 0000-0001-8202-6738

Stepan SAVCHUK
Polish Air Force University
e-mail: s.savchuk@law.mil.pl
ORCID: 0000-0002-2475-9666

DOI: 10.55676/asi.v3i1.67

RELIABILITY OF UNMANNED AERIAL VEHICLES: WINGLETS' ISSUE

NIEZAWODNOŚĆ BEZZAŁOGOWYCH STATKÓW POWIETRZNYCH: ZAGADNIENIE WINGLETÓW

Abstract

The reliability of the military equipment determines the possibility of the success of the mission. This paper focuses on identifying damage to Unmanned Aerial Vehicles during their operation. The research problem was expressed by the question: which UAV elements are most often damaged, and what causes it? The research is based on the analysis of technical documents, an electronic damage archiving system, and manufacturer documentation. These studies were complemented by empirical research conducted at the 12th Unmanned Aerial Vehicles Base in Mirosławiec, Poland. The initial phase involved identifying damages affecting the operation of Unmanned Aerial Vehicles. Subsequently, the reliability measure was determined for the repairable two-state object, excluding repair time.

Keywords: Unmanned Aerial Vehicle; drone, reliability, exploitation

Streszczenie

Niezawodność sprzętu wojskowego decyduje o możliwości powodzenia misji. W artykule skupiono się na identyfikacji uszkodzeń bezzałogowych statków powietrznych podczas ich eksploatacji. Problem badawczy wyrażał się w pytaniu: które z elementów UAV ulegają najczęściej uszkodzeniom i co jest tego przyczyną? Badania opierają się na analizie dokumentacji technicznej elektronicznego systemu archiwizacji uszkodzeń oraz dokumentacji producenta. Uzupełnieniem tych badań były badania empiryczne prowadzone w 12. Bazie Bezzałogowych Statków Powietrznych w Mirosławcu. W początkowej fazie zidentyfikowano uszkodzenia mające wpływ na działanie bezzałogowych statków powietrznych. Następnie wyznaczono miarę niezawodności naprawialnego obiektu dwustanowego, z wyłączeniem czasu naprawy.

Słowa kluczowe: bezzałogowe statki powietrzne, drony, niezawodność, eksploatacja

Artykuł wpłynął do redakcji: 8.05.2023 / Zatwierdzono do publikacji: 25.06.2023

1. INTRODUCTION

Both the military and civilian sectors have recognized the potential of unmanned aerial vehicles (UAVs) or drones. This is evidenced by the growing interest of business and security leaders. In the civilian market, the estimated global value of UAVs from 2017 to 2026 exceeds $73.5 billion, equivalent to the annual GDP of Lithuania and Latvia combined[1]. The significant potential for their use in combat, their impact on operational military doctrine[2], coupled with their relatively low cost (many times less than manned aircraft), has aroused growing interest in developed and developing countries.

These trends are reflected in the Technical Modernization Plan of the Polish Armed Forces, where UAVs are prominently featured in three main operational priorities: Image and Satellite Reconnaissance, Missile and Artillery Forces Modernization (as additional equipment to the missile system), and the task of Circulating Ammunition of the Warmate type[3]. Undoubtedly, the role of UAVs in combat will continue to grow with technological advancements. Ongoing efforts aim to equip UAVs with artificial intelligence[4], develop concepts for their collaboration with crewed machines, and deploy them in swarm formations[5]. The increasing significance of Unmanned Aerial Vehicles (UAVs) and their proliferation[6] on the battlefield underscores the need for research on their operational aspects, with a particular focus on reliability[7] and faultlessness[8]. In this context, the presented article addresses the issue of identifying the most common damages to UAVs, which significantly impact their operational processes. The research was conducted using an unmanned aerial vehicle of the Orbiter 2B type. The study's results reflect existing documents and data from an electronic damage archiving system. Furthermore, empirical research was carried out at the 12th Unmanned Aerial Vehicles Base in Mirosławiec[9]. The identification of damages affecting the functioning of unmanned aerial vehicles and the monitoring of the structural condition (especially crucial for flight safety) are of paramount importance in the exploitation process.

---

[1] Ministerstwo Infrastruktury, Polski Instytut Ekonomiczny, Biała Księga Rynku Bezzałogowych Statków Powietrznych, Warszawa, luty 2019.

[2] P. Bernat, *Unmanned Aerial Vehicles and Their Growing Role in Shaping Military Doctrine*, "Security Forum" 2018, no. 2(1), pp. 77–90, DOI: 10.26410/SF_1/18/7.

[3] Ocena stanu realizacji Planu Modernizacji Technicznej Sił Zbrojnych RP na lata 2013–2022, 2017–2026 i 2021–2035 według stanu na dzień 13 października 2019.

[4] M.A. Lahmeri, M.A. Kishk, M.S. Alouini, *Artificial intelligence for UAV-enabled wireless networks: A survey*, "IEEE Open Journal of the Communications Society" 2021, no. 2, pp. 1015–1040.

[5] W. Chen, J. Liu, H. Guo, N. Kato, *Toward robust and intelligent drone swarm: Challenges and future directions*, "IEEE Network" 2020, no. 34(4), pp. 278–283.

[6] M. Fuhrmann, M.C. Horowitz, *Droning on: Explaining the proliferation of unmanned aerial vehicles*, "International Organization" 2017, no. 71(2), pp. 397–418.

[7] A. Michalska, *Introduction to Reliability Tests of Unmanned Aircraft Used in the Armed Forces of the Republic of Poland*, "Safety & Defense" 2019, no. 5(2), pp. 54–61.

[8] E. Petritoli, F. Leccese, L. Ciani, *Reliability and maintenance analysis of unmanned aerial vehicles*, "Sensors" 2018, no. 18(9), p. 3171, doi: 10.3390/s18093171, PMID: 30235897, PMCID: PMC6165073.

[9] D. Bogusz, *Porty lotnicze i morskie*, LAW, Dęblin 2023, doi: 10.55676/66514-68-3.

2. RESEARCH METHODS

The main objective of the research was to identify the most frequent critical damage to unmanned aerial vehicles during their operation. The research problem was expressed by the question: which of the UAV elements are most often damaged, and what are the causes of it? The research was conducted based on an analysis of technical documents, an electronic system for archiving damage, and manufacturer's documentation. These studies were supplemented by empirical research in the form of a diagnostic survey conducted at the 12th Unmanned Aerial Vehicle Base in Mirosławiec.

A collection of information and technical data gathered using the SAMANTA system supporting exploitation control allowed for the development of evidence and mathematical experience in calculating reliability – a measure of faultlessness – utilizing renewal theory. This system serves as an electronic data archiving and operational control support system[10]. The SAN/SAMANTA system aids the user in managing the operation of aviation technology, allowing for the recognition of signs indicating changes in the reliability, safety, and quality of the operation processes of aircraft[11]. It also determines recommended directions for preventive actions[12].

The SAN/SAMANTA BIS system consists, among other things, of local computerized databases installed in aviation units and repair facilities. These databases accumulate knowledge regarding the course of operation for each instance of an aircraft. The acquired data includes information about the registration and operational status of aircraft, their components, and subcomponents, along with details about their rotation and the functioning of individual instances of aircraft, components, and aggregates, among other things. The collected information is transmitted to collective databases at higher levels of aviation technology management and the central bank. Furthermore, after processing, the data is utilized according to the needs of direct users. Data emanating from each computer station is automatically compressed and encoded. Using the SAN/SAMANTA BIS system allows for assessing aircraft operation, considering the detectability of damages and the effectiveness of preventive measures, technical readiness of aircraft, flight safety levels in technical aspects, and support for the work of aviation incident investigation committees[13]. It facilitates estimating the actual workload (resources) and the processes of managing resource-related activities[14]. The reliability level and quality of the aircraft operation process are assessed using adopted indicators and characteristic analyses. During the

---

[10] R. Kaleta, J. Niczyj, A. Bryzek, *Zarządzanie procesami eksploatacyjnymi z wykorzystaniem systemów informatycznego wsparcia eksploatacji statków powietrznych*, “Autobusy” 2016

[11] R. Kaleta, M. Zieja, A. Bryzek, *Informatyczne wspomaganie procesu eksploatacji wojskowych statków powietrznych*, TRANSCOMP – XIV International Conference Computer Systems Aided Science. Industry and Transport, 6-9.12.2010 Zakopane, “Logistyka” 2010, no. 6, s. 1291–1300.

[12] R. Kaleta, M. Witoś, M. Zieja, *Systemy informatyczne wsparcia Lotnictwa Sił Zbrojnych RP*, “Logistyka” 2014, no. 6.

[13] M. Zieja, H. Smoliński, P. Gołda, *Information systems as a tool for supporting the management of aircraft flight safety*, “Archives of Transport” 2015, no. 36(4), pp. 67–76.

[14] A. Maziar, *Classification of unmanned aerial vehicles*, Mech Eng 2016.

compilation of operational data from the SAN/SAMANTA system, details regarding damages incurred by all Orbiter 2B devices were gathered over three years, spanning from the latter half of 2016 to the initial half of 2019. The dataset encompasses the following:

1. The count of damages recorded between 2016 and 2019.
2. Categorization into ground and air damage.
3. In-depth particulars concerning damages and the subsequent remediation procedures applied.
4. The overall count of flights.
5. The cumulative repair duration for specified components.
6. The count of take-offs and landings for the entire fleet within a specific year.
7. The total planned raid count for all UAVs.
8. The actual count of flights undertaken by all UAVs.
9. The nature of the service performed.

Following a comprehensive analysis of the amassed data and the cataloging of damages over the three-year period, specific insights were garnered regarding the frequency of damages for individual elements.

Empirical studies using a survey method were focused on individuals involved in the usage and operation issues. Thanks to these conducted studies, a realistic picture and qualitative reflection of UAV exploitation quality were obtained. The expert group participating in the survey comprised 30 individuals, with respondents being soldiers, including women and men. Responses were provided by experts serving in positions related to the operation and use of unmanned aerial vehicles. Additionally, six surveys were excluded from the study, including three due to respondents lacking involvement with the Orbiter 2B UAV and 3 for the unreliability of responses to the posed questions.

Research limitations concerned the diagnostic survey, including estimating the size of the research group, statistical error, and representativeness. This is due to the sensitive nature of information about the completion of the military unit where the research was conducted, affecting the safety and defense of the state. Furthermore, the study covered only one type of unmanned aerial vehicle, namely the Orbiter 2B. It is emphasized that the chosen type of UAV constitutes the vast majority used in the Polish Armed Forces. The decision was made to calculate exclusively for the reliability measure, which describes individual elements without considering the UAV as a complete structure. Exploitation data were entered into the SAMANTA system only from the second half of 2016 onwards, so the observation period was limited to that time.

3. MAIN CRITICAL DAMAGE OF UAVS

The analysis of the survey conducted with specialists in the field of unmanned aerial systems operations allowed, for the first time, the determination of which element of UAVs is the most unreliable. In the survey, it was established that the minimum

DOI: 10.55676/asi.v3i1.67

required experience in the field of UAVs operation is one year. The chart below illustrates the survey participants' responses, utilizing survey techniques for the first posed question regarding the most common primary cause of malfunction in unmanned aerial vehicles.

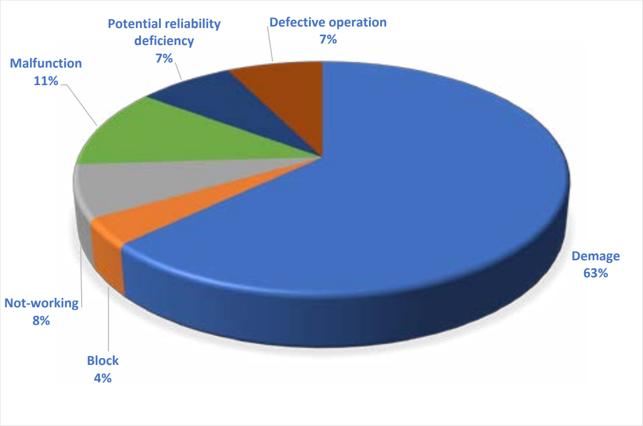

Figure 1. Percentage of the answer to the most common primary cause of malfunction in unmanned aerial vehicles

Source: own work.

This means that 63% of the surveyed individuals believe that the leading cause is damage, characterized by the loss of the object's fitness for further operation. Damage occurs when the parameters of the unmanned aerial vehicle are beyond the norm or exceed its critical strength values. The next question determined which structural elements, according to the respondents, are most commonly subject to damage.

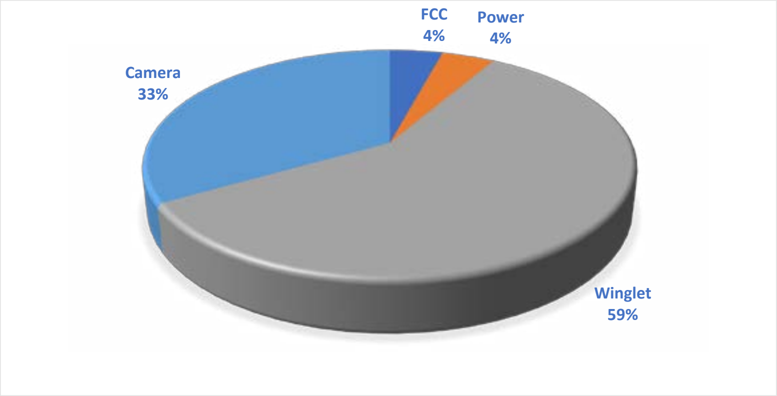

Figure 2. Percentage representation of the answer to which structural element of the UAV is most often damaged

Source: own work.

According to the data presented in Figure 2, it is evident that the most frequently damaged part is the winglet. It should be noted that the camera head response is 33%, the power supply is 4%, and FCC (Fly Control Computer) is 4%. These do not meet the criterion and are not part of the structure. Nevertheless, to highlight the differences and correctness, it was decided to present the included survey responses. The initial analysis of the research conducted based on the survey reveals that the main damages occurring in the unmanned aerial vehicle relate to damage to the skin elements. Studies on the most damaged element of the UAVs were conducted based on technical documentation analysis. The chart below presents the results regarding the quantity of damages and allows for identifying the most unreliable elements.

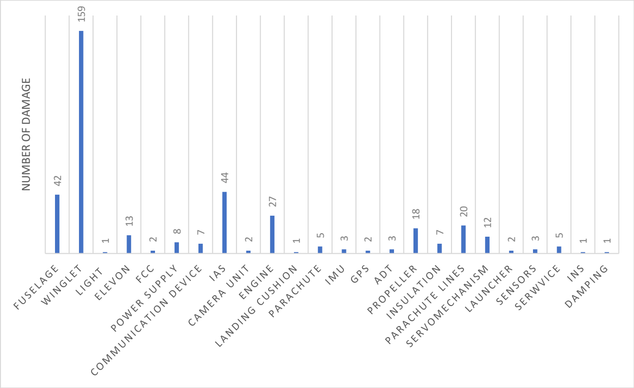

Figure 3. Analysis of SAMANTA system data, damage in the total observation time 2016–2019

Source: own work.

As a result of the conducted data analysis, it was decided to identify one element with the highest damage occurrence: Winglets in 37% of incidents.

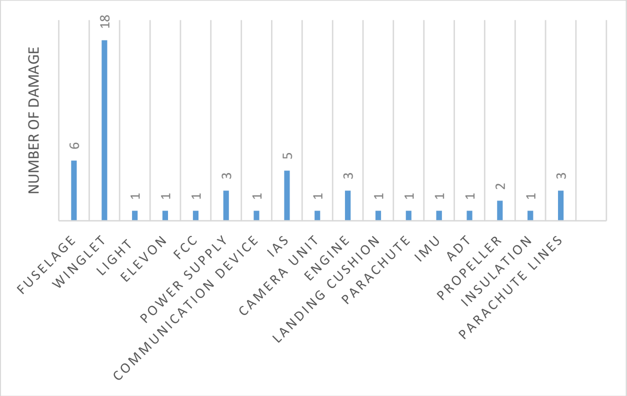

Figure 4. UAVs damage in 2016

Source: own work.

DOI: 10.55676/asi.v3i1.67

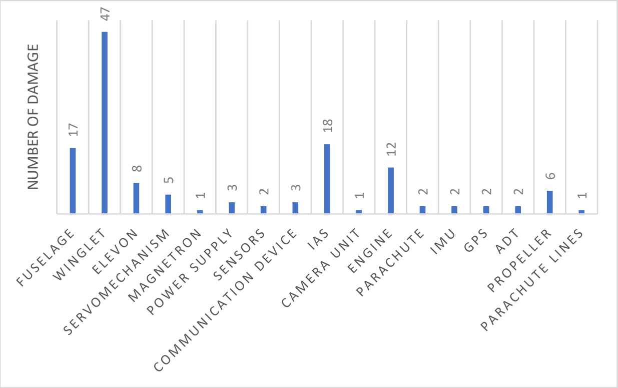

Figure 5. UAVs damage in 2017

Source: own work.

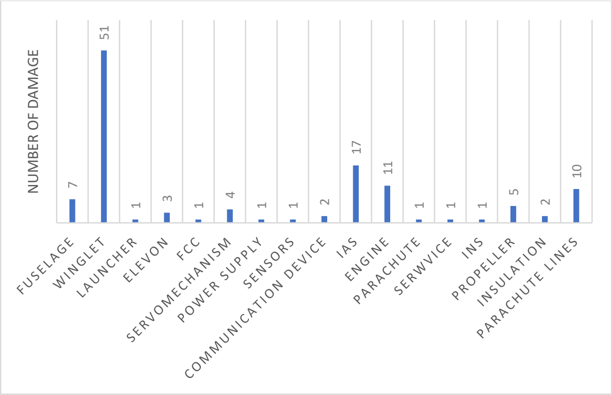

Figure 6. UAVs damage in 2018

Source: own work.

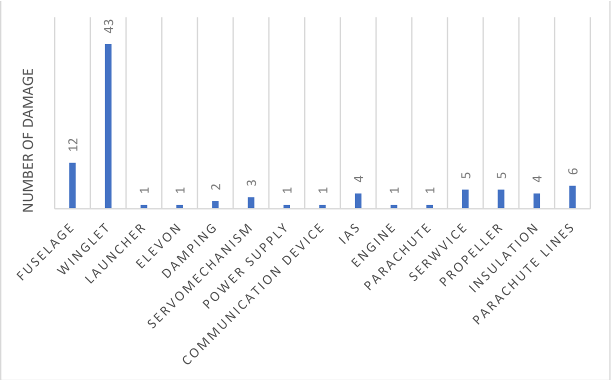

Figure 7. UAVs damage in 2019

Source: own work.

Based on the charts in Figure 4–7, it can be inferred that each year, regardless of internal and external factors, the most damage is associated with the skin (winglet). There was no observed situation in which there was an accumulation of damage instances (winglet) in one year. This means that the element was not deemed unfit multiple times, only within a specific period (one year), and did not exceed the damage to the elements chosen by the author. In another case, it would be challenging to determine whether such an element is the most reliable, and there is a need for reliability studies, or if there was only a problem, for example, with a defective batch of elements. Based on the presented research results, it was decided to analyze further that the most reliable elements of the unmanned aerial vehicle are the winglets. Further analysis was focused solely on studying the reliability of this element.

4. ANALYSIS OF UAV'S DAMAGE CAUSES

Analyzing the causes results in a targeted resolution of identification problems or events. The effectiveness of the analysis arises from eliminating the actual causes of the problems rather than conflating the causes with apparent symptoms. By directing corrective and preventive actions to the appropriate areas, one can expect the probability of problem recurrence to be minimized. However, it is recognized that preventing the causes from recurring entirely due to a single intervention is impossible. Hence, the repair process is often perceived as a tool for continuous analysis.

The following damage analysis was conducted during the observation period of the unmanned aerial vehicle type Orbiter. By pinpointing the most unreliable UAVs components and identifying their root causes, it is possible to influence the determination of problem resolution or defect elimination. This is considered absolutely necessary for enhancing reliability.

According to the classification established in the military unit, damages have been cataloged into two main categories. The first category includes ground damages resulting from the operational use of BSP (Base Station Processor) during maintenance activities (e.g., maintenance time, garage/hangar storage, downtime, etc.). In contrast, the second category consists of damages occurring during the aerial vehicle's operation, for example, during the flight phase. The percentage distribution of occurrence of these two categories are presented in Figure 8. Additionally, the documentation identifies 16 classifications of factors influencing BSP damages, out of which only four occurred during the observed 3-year period:

1. Technical wear and tear: The wear and tear of BSP components or subassemblies during its operation necessitates premature replacement.
2. Failure to maintain technical parameters: When the aircraft, its installations, or systems fail to maintain the required technical parameters, possibly due to misalignment or misconfiguration.
3. Adverse impact of weather conditions on aircraft operations: When unexpected entry into hazardous weather phenomena affects BSP operations.
4. Aviation incidents, such as platform disappearance.

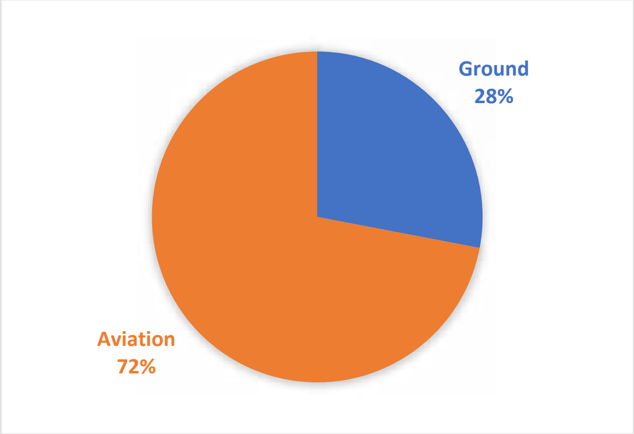

Figure 8. Classification of the damage on aviation and ground. SAMANTA data analysis over a three-year period

Source: own work.

During the survey, BSP Orbiter 2B operators provided the following responses to the same question: out of 24 individuals, 23 indicated the same phase – the flight phase (with a particular emphasis on landing). This implies that the majority of damages were classified as aviation-related.

In the conducted research, the flight time of BSP was identified as the period during which the highest number of damages occurred. The flight time of BSP encompasses all activities from takeoff to landing. Therefore, based on survey data, it was determined that damages most frequently occur during the landing phase.

In summary, the analysis of causes impacting the reliability of selected damages took into account the influence of the number of occurrences during the unmanned aerial vehicle's operational time (landing phase). According to literature others factors such as human[15] or weather conditions[16] can be taken into account as well but this is not a subject of this paper.

5. UNRELIABILITY MEASURES

During the operation, the reliability properties of unmanned aerial vehicles are initially mapped, and the assumed reliability measures are checked. As a result, this allows for quick modernization and the introduction of changes already at the design stage.

---

[15] D. Doroftei, G. De Cubber , H. De Smet, *Reducing drone incidents by incorporating human factors in the drone and drone pilot accreditation process*, [in:] Advances in Human Factors in Robots, Drones and Unmanned Systems: Proceedings of the AHFE 2020 Virtual Conference on Human Factors in Robots, Drones and Unmanned Systems, July 16-20, 2020, Springer International Publishing, USA 2021, pp. 71–77.

[16] M. Gao, C.H. Hugenholtz, T.A. Fox, M. Kucharczyk, T.E. Barchyn, P.R. Nesbit, *Weather constraints on global drone flyability*, "Scientific Reports" 2021, no. 11(1), p. 12092.

Empirical research was necessary to determine the reliability measures. Based on general knowledge derived from the operational information used, data acquisition was directed towards:

1. Diagnosing reliability state.
2. Predicting reliability states.
3. Operational effectiveness.

The decision was made to use the faultlessness measure to determine the considered objects' reliability. According to the Author, this measure is the best solution for the specific calculation of the reliability of selected elements of an unmanned aerial vehicle.

Reliability shaped during the operational stage manifests itself subjectively or objectively. The subjective way reflects assessments obtained through opinions or judgments, while the objective way does so using evaluations of obtained results as a result of active or passive experiments, descriptions, indicators. Taking the above into account, during the research conducted at the 12th Base of Unmanned Aerial Vehicles, both methods were used to acquire data through the SAN/SAMANTA (operating, failures, repairs, servicing) control assistance system, technical documentation and a survey was conducted.

The essence of the research is to determine the characteristics characterizing random properties. The randomness of features of an unmanned aerial vehicle is the result of unknown and uncontrollable factors. From many considered cases, a population group is derived without the ability to obtain data from all objects. The general population is determined randomly and is also a set of finite populations subject to investigation. Since each unmanned aerial vehicle participating in the study has an equal chance of being included in the sample, it was referred to as a simple random sample. As a result, the research results were presented as a set of feature values or events that occurred.

In the literature, the determination of reliability measures has been divided into two cases. The first one is the determination of reliability measures for non-repairable elements, and the second one is for repairable elements. In the research, only the method of calculating reliability for repairable objects was adopted because objects excluded from the study after repair were re-included in the research sample.

6. RELIABILITY CALCULATIONS OF SELECTED COMPONENTS OF UNMANNED AERIAL VEHICLE

The study involved estimating the leading distribution function, the instantaneous damage intensity function, and the instantaneous value of the reliability function using a non-parametric method. All results were subjected to non-parametric polynomial regression in specialized MATLAB software.

The study involved objects with a population of $n = 90$. Damages were repaired and reintroduced for further investigation. The repair time was not considered as the cumulative repair time exceeds the total operational time of the UAV.

Table 1. Repair and operational times of objects in years 2016–2019

ELEMENT	TYPE	TIME [h]
UAV	$T_{work\ BSP}$	2265h 16’
Winglets	$T_{fix\ WIN}$	255h 30’

Source: own work.

During the time interval [0, t_m], $m = 156$ failures were recorded. The estimation of the expected value of the reliability function $R(t_m)$ and confidence intervals where estimated $[\overline{R}(t_m), \underline{R}(t_m), \beta = 0{,}95]$. Based on the estimated values of the distribution of a continuous function which was constructed using MATLAB software, and its results were subjected to polynomial regression estimation. All confidence interval values for the reliability function, leading distribution function, and failure intensity were estimated using the chi-square quantiles distribution. Based on the estimates, a histogram was constructed using MATLAB software, and its results were subjected to polynomial regression estimation.

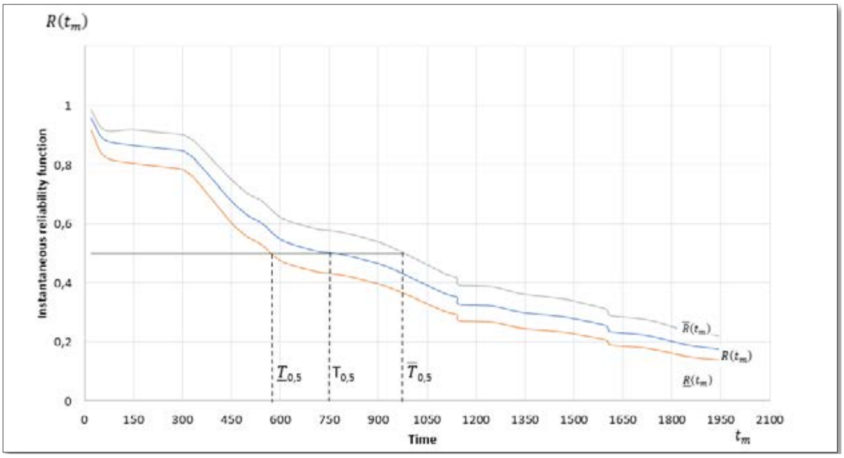

Figure 9. WINGLET Element Reliability Function

Source: own work.

The estimated quantile of order p = 0,5, representing the uninterrupted operation time of an object, is marked on the histogram. The benefits of the reliability function plot with $p = R = 0{,}5$, corresponding to the durability values $T_{0,5}$=750h, $\overline{T}_{0,5}$=980h, $\underline{T}_{0,5}$=583h, indicate that at a confidence level $\beta = 0{,}95$, the object’s reliability within the time interval [583, 980] will be $R(t_m) = 0{,}5$.

The next step involved estimating the expected value of the leading distribution function $\Lambda(t_m)$, and confidence intervals $[\overline{\Lambda}(t_m), \underline{\Lambda}(t_m)$, β=0,95], which were performed. Based on the estimated values, a histogram was created, and the results were subjected to polynomial regression in the MATLAB program.

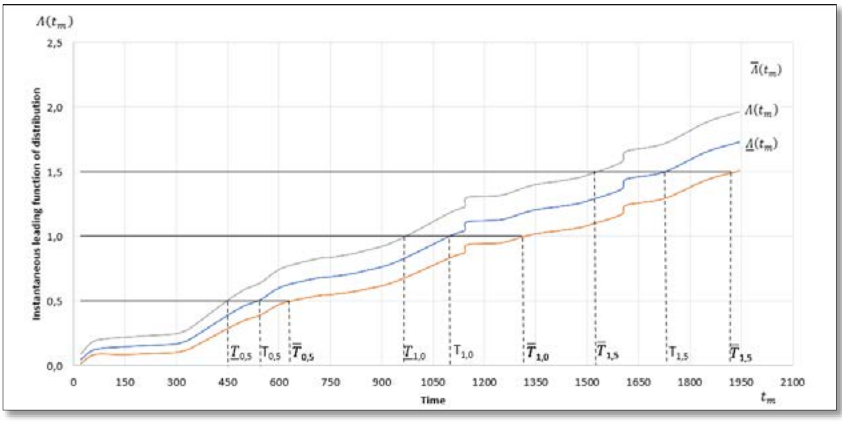

Figure 10. Leading function of the distribution of WINGLET elements
Source: own work.

Using graphical estimation based on figure 10, the expected value of the time to the m-failure and the value of the time between the (m-1) and m-failure (at 50% resource consumption) were determined as follows:

$$\begin{gathered} T_{0,5} = 545h\,,\ \underline{T}_{0,5} = 450h,\ \overline{T}_{0,5} = 630h \\ T_1 = \ 1098h,\ \underline{T}_1 = 966,\ \overline{T}_1 = 1308h, \\ T_{1,5} = \ 1729h, \qquad \underline{T}_{1,5} = 1517h, \overline{T}_{1,5} = 1920h. \end{gathered} \tag{1}$$

The obtained results present a numerical reflection of the initial assessment of the aging of objects by determining the time of failure-free operation.

$$\begin{gathered} T_{m-1,m} = T_m - T_{m-1} = T_1 - \ T_{0,5} = 553h \\ \overline{T}_{m-1,m} = \overline{T}_m - \overline{T}_{m-1} = \ \overline{T}_1 - \ \overline{T}_{0,5} = 673h \\ \underline{T}_{m-1,m} = \underline{T}_m - \underline{T}_{m-1} = \underline{T}_1 - \ \underline{T}_{0,5} = 516h \\ T_{m-1,m} = T_m - T_{m-1} = T_{1,5} - \ T_1 = 631h \\ \underline{T}_{m-1,m} = \underline{T}_m - \underline{T}_{m-1} = \underline{T}_{1,5} - \ \underline{T}_1 = 612h \\ \underline{T}_{m-1,m} = \underline{T}_m - \underline{T}_{m-1} = \underline{T}_{1,5} - \ \underline{T}_1 = 551h \end{gathered} \tag{2}$$

The obtained results present a numerical reflection of the initial assessment of object aging.

In subsequent calculations, the authors approximate the aging times of the objects. For this purpose, an estimation of the instantaneous average damage intensity function, $\lambda_w(t_m)$, as well as confidence intervals $\overline{\lambda_w}(t_m)$, $\underline{\lambda_w}(t_m)$, β=0,95] was performed and visualize on figure 11.

DOI: 10.55676/asi.v3i1.67

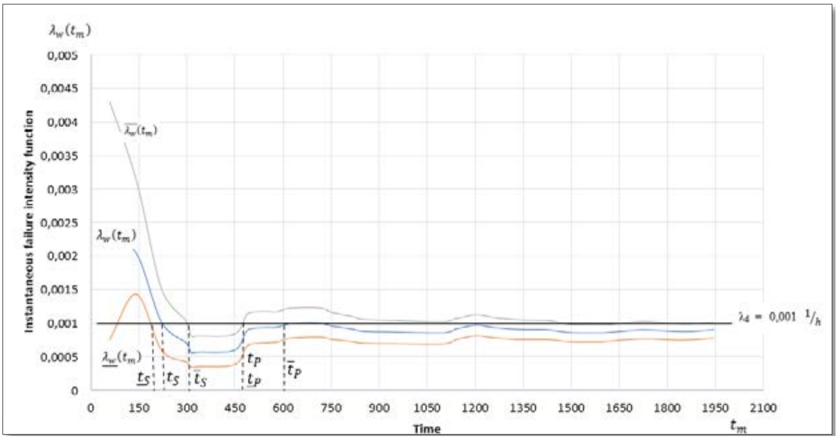

Figure 11. Value of Leading function of WINGLET elements

Source: own work.

The graphical method was used in the research, utilizing figure 11, to provide initial estimates of the aging time t_S of objects with confidence intervals, as well as the preventive action time t_P (after which preventive actions, such as component replacement, are performed) with confidence intervals, assuming an allowable intensity value of $\lambda_d = 0{,}001\ [^1/_h]$, The obtained values for $t_S = 222h,\ \overline{t}_S = 306h,\ \underline{t}_S = 187h$, respectively, with visible extremes on the graph. Since the BSP (object) is a composite entity, these extremes indicate the presence of weak elements in the object. Therefore, it is purposeful to estimate the time for preventive actions. On the graph above, the respective values for were found $t_P = \underline{t}_P = 474h, \overline{t}_P = 608h$.

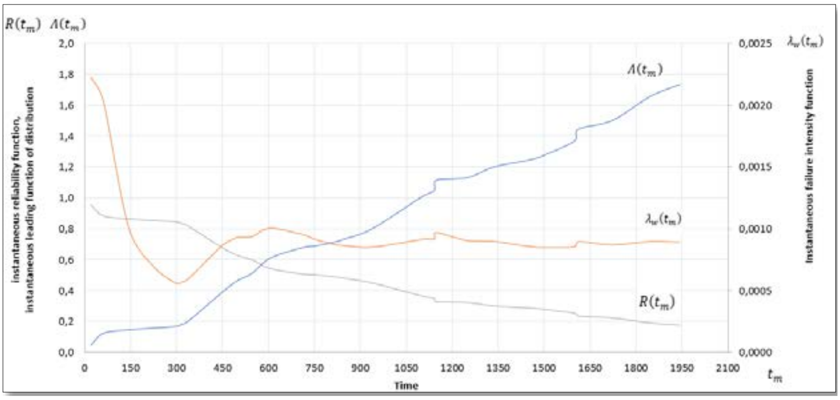

Figure 12. Comparison of instantaneous reliability function, instantaneous leading function of distribution, and instantaneous failure intensity function for winglet elements

Source: own work.

Considering the chosen winglet element as a whole and the graphical representation of the results, such as the instantaneous reliability function, the instantaneous damage intensity function, and the leading distribution function presented in figure 12, the characteristic can be divided into three parts. In the first part (up to approximately 150 flight hours), signals of a certain type try to stabilize, and it should be noted that at the beginning of the observation, there is always such a situation with a small amount of data. Furthermore, after this period, it can be preliminarily assessed that the aging process of the selected elements begins from the lower limit $\underline{t_s} = 187\ \mathrm{h}$ of flight time. In the next part, a noticeable smoothed extremum can be distinguished, which arises due to the increase in instantaneous damage intensity (during 300–600 flight hours), additionally causing a 27% decrease in the instantaneous reliability of the objects within 300 flight hours, and simultaneous 45% resource consumption within 600 flight hours. Therefore, it is reasonable to carry out preventive actions between 474 and 608 flight hours. In the last part, it can be observed that with 60% resource consumption in the time interval [600–1944], the characteristics tend to stabilize the damage process (instantaneous damage intensity, instantaneous reliability, and resource consumption). Additionally, it should be noted that resource consumption is proportionally much higher than the instantaneous reliability, which exhibits a constant distribution in damage intensity. Furthermore, the authors consider the correct estimation of the object's aging by determining the time between failures with a 50% resource consumption jump, which is equal to $T_{0,5} = 545h$, $T_1 = 1098h$, hours, and $T_{1,5} = 1729h$. The distribution of time between the specified intervals averages 592 flight hours.

7. CONCLUSION

This paper examines the reliability of unmanned aerial vehicles (UAVs) by identifying frequently damaged components and their causes. Conducted at a UAV base, the research combines analysis of technical documents, an electronic damage archiving system, and empirical studies. The results highlight the skin and winglets as the most frequently damaged UAV parts. Influencing factors include wear and tear, inadequate maintenance of technical parameters, weather conditions, and aviation incidents, with damage often occurring during flight, especially during landing.

The researchers used renewal theory and mathematical insights from the SAMANTA system, a data archiving, and operational control support system, to assess the reliability of the winglets. This system stored and analyzed operational data and revealed that winglets accounted for 37% of the damage. Further analysis categorized the damage into maintenance and flight phase damage, attributing the causes to wear, lack of maintenance, weather, and aviation incidents.

Interviews with Orbiter 2B UAV operators identified the landing phases as the most susceptible to damage. Overall, the study uses technical documentation and empirical data to increase understanding and provide critical insights to improve UAV reliability and operations.

BIBLIOGRAPHY

Bernat P., *Unmanned Aerial Vehicles and Their Growing Role in Shaping Military Doctrine*, “Security Forum” 2018, no. 2(1), p. 77–90, DOI: 10.26410/SF_1/18/7.

Bogusz D., *Porty lotnicze i morski*e, LAW, Dęblin 2023, DOI 10.55676/66514-68-3.

Chen W., Liu J., Guo H., Kato N., *Toward robust and intelligent drone swarm: Challenges and future directions*, “IEEE Network” 2020, no. 34(4), p. 278–283.

Doroftei D., De Cubber G., De Smet H., *Reducing drone incidents by incorporating human factors in the drone and drone pilot accreditation process*, [in:] Advances in Human Factors in Robots, Drones and Unmanned Systems: Proceedings of the AHFE 2020 Virtual Conference on Human Factors in Robots, Drones and Unmanned Systems, July 16-20, 2020, Springer International Publishing, USA 2021, pp. 71–77.

Fuhrmann M., Horowitz M.C., *Droning on: Explaining the proliferation of unmanned aerial vehicles*, “International Organization” 2017, no. 71(2), pp. 397–418.

Gao M., Hugenholtz C.H., Fox T.A., Kucharczyk M., Barchyn T.E., Nesbit P.R., *Weather constraints on global drone flyability*, “Scientific Reports” 2021, no. 11(1), 12092.

Kaleta R., Niczyj J., Bryzek A., *Zarządzanie procesami eksploatacyjnymi z wykorzystaniem systemów informatycznego wsparcia eksploatacji statków powietrznych*, “Autobusy” 2016.

Kaleta R., Witoś M., Zieja M., *Systemy informatyczne wsparcia Lotnictwa Sił Zbrojnych RP*, „Logistyka” 2014, no. 6.

Kaleta R., Zieja M., Bryzek A., *Informatyczne wspomaganie procesu eksploatacji wojskowych statków powietrznych,* TRANSCOMP – XIV International Conference Computer Systems Aided Science, Industry and Transport, 6-9.12.2010 Zakopane, s. 1291–1300, “Logistyka” 2010, no. 6.

Lahmeri M.A., Kishk M.A., Alouini M.S., (2021). *Artificial intelligence for UAV-enabled wireless networks: A survey*, “IEEE Open Journal of the Communications Society” 2021, no. 2, pp. 1015–1040.

Michalska A., *Introduction to Reliability Tests of Unmanned Aircraft Used in the Armed Forces of the Republic of Poland*, “Safety & Defense" 2019, no. 5(2), pp. 54–61.

Ministerstwo Infrastruktury, Polski Instytut Ekonomiczny, Biała Księga Rynku Bezzałogowych Statków Powietrznych, Warszawa, luty 2019.

Maziar A., *Classification of unmanned aerial vehicle*s, Mech Eng 2016.

Ocena stanu realizacji Planu Modernizacji Technicznej Sił Zbrojnych RP na lata 2013–2022, 2017–2026 i 2021–2035 według stanu na dzień 13 października 2019.

Petritoli E., Leccese F., Ciani L., *Reliability and maintenance analysis of unmanned aerial vehicles*, “Sensors” 2018, no. 18(9), 3171, doi: 10.3390/s18093171, PMID: 30235897, PMCID: PMC6165073.

Zieja M., Smoliński H., Gołda P., *Information systems as a tool for supporting the management of aircraft flight safety*, “Archives of Transport” 2015, no. 36(4), pp. 67–76.