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Summary of Failure Conditions Recorded in Selected Helicopters Operated by Army Air Corps

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Abstract. This paper has been drawn up for the Air Operations Group and the Technical Maintenance Group of the 56th Air Force Base in Inowrocław (Poland). Its primary purpose is to compare the frequency of failure conditions and their impact on the safety of flights performed on Mi-24 and W-3PL helicopters. Special attention has been paid to the values of flight parameters recorded and any anomalies identified. The data were analyzed using the "Objective Record Analysis" software, with two aspects taken into consideration. The first aspect – failure conditions which do not affect flight safety, i.e. when the crew exceeded the permissible flight parameters for a given exercise, an interference took place, a calculation error occurred in the system or the equipment became uncalibrated. A total of 534 failure states were singled out, with 18% of them caused by the human factor. The remaining 82% occurred due to interference and errors in the recording system or due to an incorrect flight parameter recording process (with this factor remaining beyond the control of the flight crew or maintenance personnel). The second aspect focused on failure conditions having an impact on flight safety, i.e. when the crew exceeded the aircraft's operating envelope or damage to the aircraft's systems and components occurred. 1,075 states have been recorded, with safety violations caused by exceeding the aircraft's operating limits accounting for 5% of them. Damage to aircraft systems and components was the root cause of the 95% of the failures (with emergency landings required in 6 cases). It was shown that 80% of the failure conditions studied occurred on the Mi-24, with the number of missions performed on this particular type being nearly twice as high as on the W-3PL. Analysis of the years to which the available data was related (2012-2016) has led to the conclusion that the number of flights performed and the number of failure conditions was on an increase. However, the share of failure conditions in the total number of flights decreased. Authors 1 and 2 serve in the 56th Air Force Base and were granted permission to access and publish the data presented in this paper.
Keywords: mechanical engineering, helicopters, failure conditions

1. INTRODUCTION AND PURPOSE OF THE PAPER

The safety of flight operations performed by the Polish Army Air Corps is based on materials drawn up at the Flight Control Laboratory [1-3]. The Laboratory is an organizational unit equipped with systems capable of processing data from on-board flight data recorders and translating such data into input materials that may be subjected to further analysis. The laboratory uses an objective flight control system relied upon to assess the quality of training, monitor the technical condition of aircraft, as well as detect and analyze threats encountered while performing flight missions.

The work was undertaken taking into account the needs of the Air Operations Group and the Technical Maintenance Group of the 56th Air Force Base in Inowrocław (Poland). The purpose is to compare the occurrence of failure conditions during the flights performed on Mi-24 and W-3PL helicopters [4], [5] (Fig. 1 a, b).

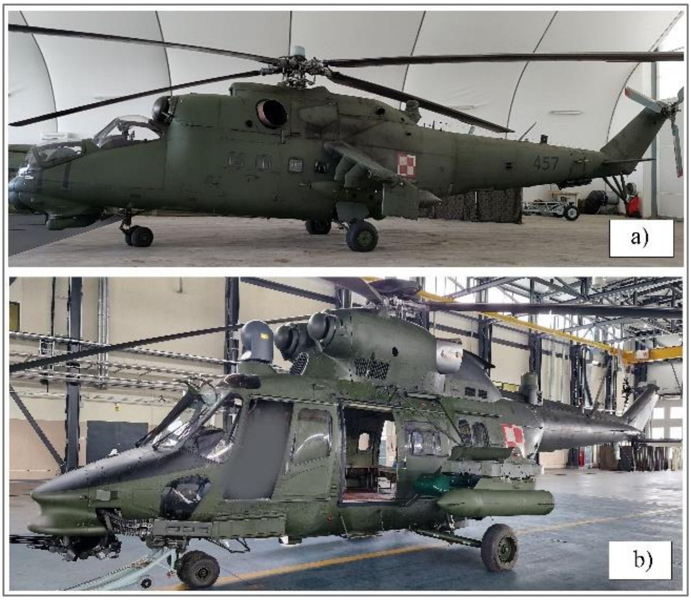

Fig. 1. Mi-24 (a) and W-3PL (b) helicopters

Special attention was paid to the types of parameters recorded and the occurrence of faults logged using the S2-3a flight data recorder [6].

The results of the authors' work, expanding the knowledge about failure conditions on different helicopter types, will be used at the 56th Air Force Base, inter alia to:

- develop a set of insights and recommendations for flight crews, to enhance flight safety,
- support decision-making for flight missions performed in specific conditions on individual helicopters types,
- conduct methodological training on maintenance procedures.

2. S2-3A RECORDER

The data analyzed was collected using the S2-3a recorder (Figure 2) offering the following characteristics:

a) operating and protection cassettes record data using Flash memory,
b) the pilot index dashboard allows to send the preset index number of the pilot performing the flight mission to the acquisition block,
c) measurement channels are checked by connecting the WTS4/AP702C tester; data is read by the S3-1c-O reader.

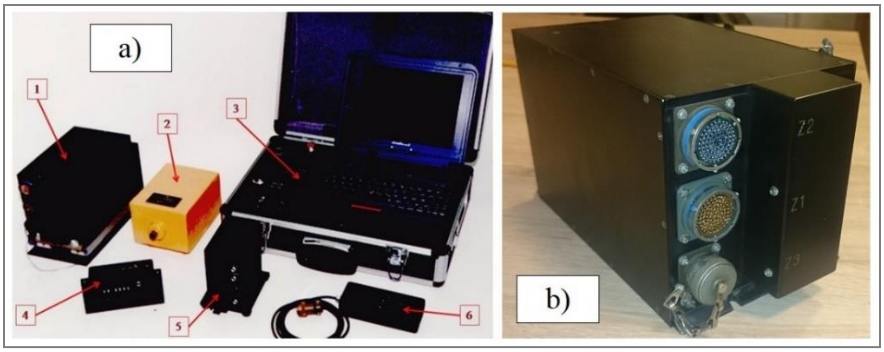

Fig. 2. S2-3a recording system: main components (a [6]) and recorder housing (b)

The S2-3a recorder is characterized, inter alia, by the following specifications:

- parameter recording duration: operating cassette ≥ 12h, protective cassette ≥ 6h.
- the number of recorded parameters depends on the type of the helicopter, and is not lower than
  - number of binary signals: 48, number of analog signals: 15.
  - number of rpm sensor signals: 3, GPS parameters: 3,
  - date/time, encoder/pilot index number and the system's diagnostic parameters are recorded.

3. "OAZ" FLIGHT PARAMETER DECRYPTION SOFTWARE

The *"OAZ" Objective Recording Analysis* software [7] is intended to decrypt data stored in the memory of the S2-3a recorder. Its main tasks include the following:

- transmission of data from the recorder, archiving it in the database and reading the data,
- graphically representing the waveforms of selected parameters in diagrams.

This allows to visually represent and analyze analog, computational and binary-state parameters (Figure 3). Parameters read from the recorder's cassette can be divided into specific time intervals. These intervals correspond to individual flights, with abnormal states recorded for each of them. The program's user interface is shown in Figure 3. The following data frames are available: *Filters*, *Recorder*, *Aircraft*, *Pilots*, *Records*, *Flights*, *Chart*, *Silhouette*, *Route*, *Parameters*, *Parameter scales*, *Exceeded limit*, *Archives* and *Description*.

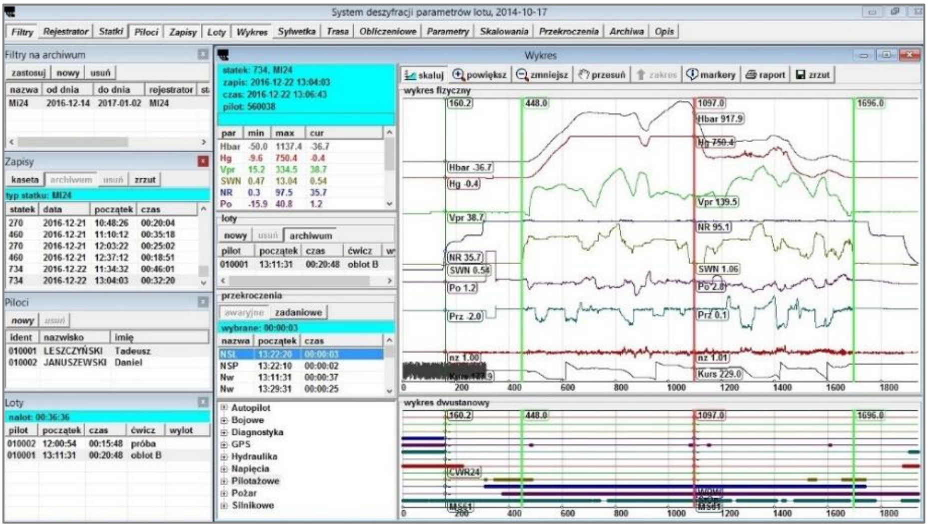

Fig. 3. View of the main bar, data sets and charts in the "OAZ" program

4. TYPES OF PROCESSES USED TO ANALYZE RECORDED DATA AND THEIR CHARACTERISTISCS

Data from flight data recorders is analyzed at 2 levels:

- general analysis; quantitative performance of the task at hand, performed to determine the course of the flight and compare the actual parameters against their preset values. Its purpose is to detect failure conditions and authorize the next flight of the aircraft/crew based on preventive recommendations,
- detailed (qualitative) analysis of the performance of the task at hand (the entire flight or a section thereof). It is conducted after a failure condition occurs (as identified during the general analysis stage), to determine its causes. It is also used to determine the correctness of actions undertaken by the crew, by maintenance personnel and the operator while executing the task at hand (according to the guidelines provided), and to determine correct operation of on-board systems.

Three types may be distinguished depending on their scope and frequency:

- ongoing, general analysis conducted after the task is completed. The data is analyzed to detect any irregularities / aircraft faults occurring during the mission. When flight envelope breaches, operational restriction violations or deviations from technical requirements are found, a specific analysis should be conducted,

- specific analysis is a detailed check performed if failure conditions occur, if a gross deviation from the flight parameters planned for the mission is detected or if flight safety threats are identified. It is performed to clarify any irregularities that have occurred,
- periodic analysis (detailed analysis performed once per month), based on the current and special analyses carried out. It should ensure the detection of any irregularities affecting the missions, simultaneously allowing to analyze the reliability of flight hardware and identify the presence of potential threats.

5. LIST OF OPERATING RESTRICTIONS

Knowledge of the operational limitations of a given aircraft type is crucial for proper interpretation of flight parameter values (analysis of the recorded data). The types of specific restrictions and their values were obtained from the relevant tables (e.g., Table 1 presents examples of analog parameter restrictions applicable to one of the helicopter types, i.e. the Mi-24) and were then entered into the "OAZ" software (Figure 4).

Table 1. Selected analog parameter restrictions for one of the helicopters

Parameter	Acronym	Sending unit	Range	Restrictions						
				Barometric altitude [m]	For all applications [kph]				For cruise and suspended load operations	
					Helicopter weight 11200 kg and below		Helicopter weight 11200÷11500 kg		Helicopter weight 11200÷12000 kg	
					V_{max}	V_{min}	V_{max}	V_{min}	V_{max}	V_{min}
Airspeed	Vpr	DWS-24	50 ÷ 400 kph	Near the ground	335	50	315	50	250	50
				500	320	50	305	50	250	50
				1,000	310	50	290	50	250	50
				2,000	285	50	265	50	200	70
				3,000	225	50	215	50	150	70
				4,000	180	70	140	70	-	-
				4,300	155	70	120	70	-	-
				4,500	120	70	-	-	-	-
Barometric altitude	Hbar	DW-15MW	0 ÷ 5000 m							
Geometric altitude	Hg	RW-5	0÷750m							
Emergency bus voltage 115 V	U_{115}	PO-750A	115 V ±3%							
Emergency bus voltage 3 x 36V	U_{36}	PT-125C	$36\ V^{+0.5}_{-1.5}V$							
Emergency bus voltage 27V – battery bus	U27		27V±10%							
Left engine compressor RPM Right engine compressor RPM	NSL NSP	D-2MT	20 ÷ 110%	Maximum permissible turbocharger speed for all speeds and altitudes: - start-up range - 101.15% - nominal range - 99.0% - cruise range I - 97.5% - cruise range II - 95.5%						
Left engine EGT Right engine EGT	Tgls Tgps	2-IA6	100 ÷ +1200 °C	Maximum permissible gas temperature measured before the turbine, at all speeds and altitudes: - start-up range - 990°C - nominal range - 955°C - cruise range I - 910°C - cruise range II - 870°C						
Rotor pitch	SWN	MU-615A	1 ÷ 15°							
Heading obtained from the “Grebień” gyroscopic system	Heading	GA-8	0 ÷ 360°							

Based on these, the flight parameters of the Mi-24 and W-3PL helicopters stored in the S2-3a recorder were checked and a comparative analysis of specific failure conditions was carried out.

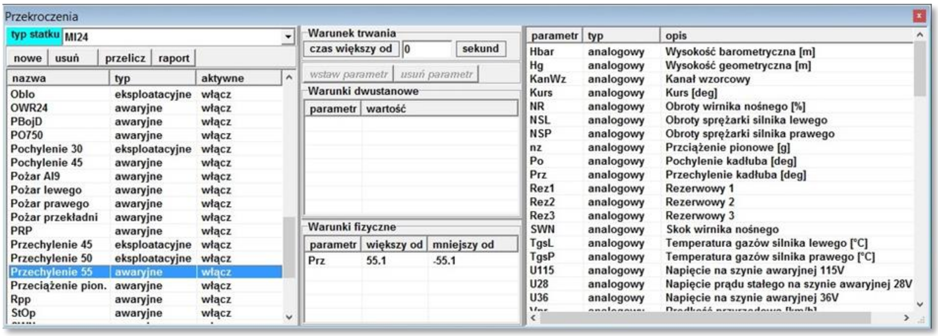

Fig. 4. Detailed operational restrictions introduced in the "OAZ" program

6. OCCURRENCE OF FAILURE CONDITIONS

A failure condition is a situation aboard the aircraft resulting from a crew fault or an aircraft fault. In order to identify the type of a given failure condition, current and detailed analyses are carried out in the presence of the flight crew and the maintenance personnel in charge of a given system, operating the aircraft. While analyzing the collected data, the following distinctions were made, inter alia:

- failure conditions caused by crew faults, such as:
  - bank angle intended for the mission exceeded – longitudinal axis (Figure 5 for the Mi-24),
  - excessive pitch,
  - excessive G (vertical axis),
  - failure to maintain constant speed (Figure 6 for W-3PL),
  - excessive rotor rpm,
- failure conditions caused by system faults, such as:
  - GPS signal interference affecting all channels (Figure 7 for Mi-24),
  - fuel pump 1 and 2 fault (Figure 8 for W-3PL),
  - AC/DC alternator fault,
  - no pressure in the main/backup hydraulic system,
  - main gearbox oil pressure drop,
  - presence of metal shavings in main gearbox oil,
  - excessive main gearbox oil temperature,
  - oil pressure drop in the left/right engine,
  - presence of metal shavings in left/right engine oil,

- dangerous left/right engine vibration levels,
- excessive left/right engine EGT,
- excessive left / right engine compressor rpm,
- difference between left and right engine compressor rpm.

Fig. 5. Exceeded bank angle permitted for the mission (Mi-24)

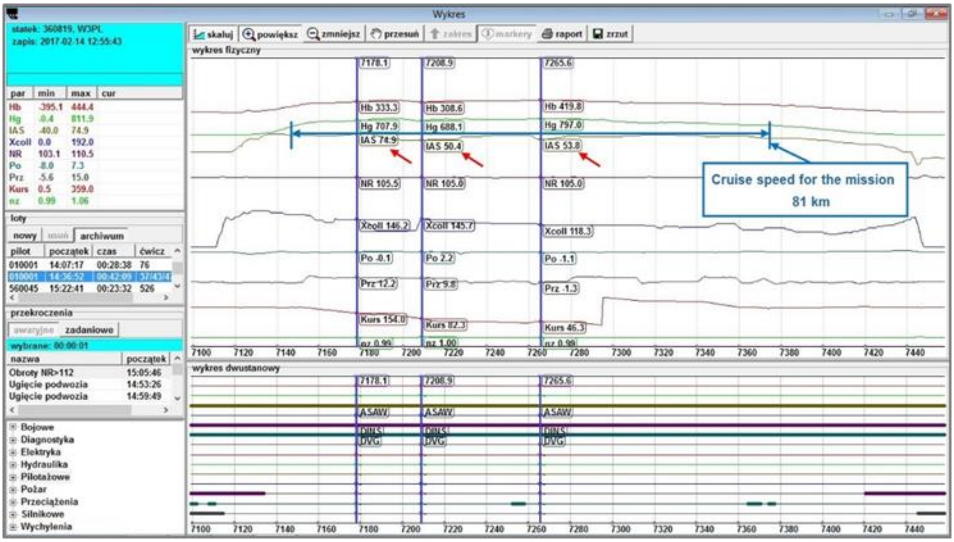

Figure 6. Failure to maintain the cruise speed planned for the mission (W-3PL)

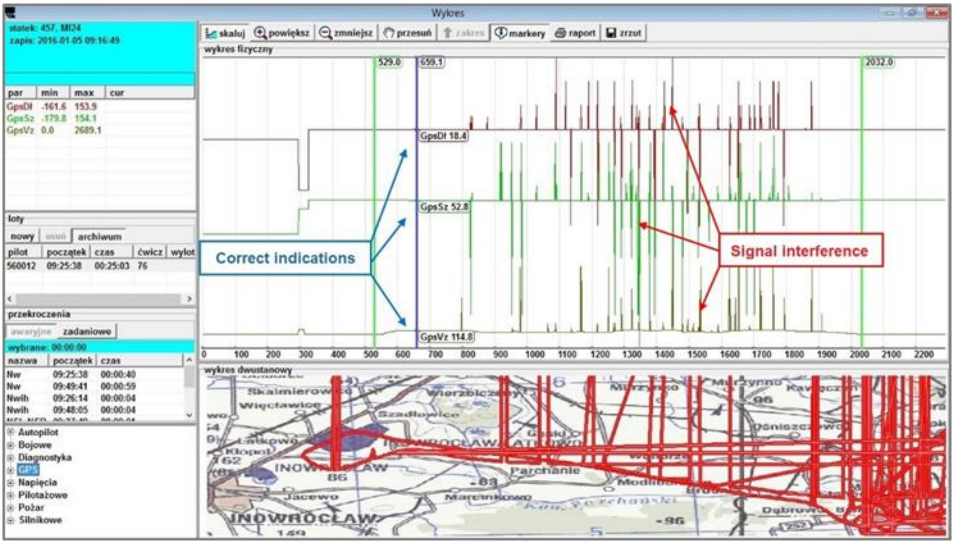

Fig. 7. GPS signal interference, affecting all channels (Mi-24)

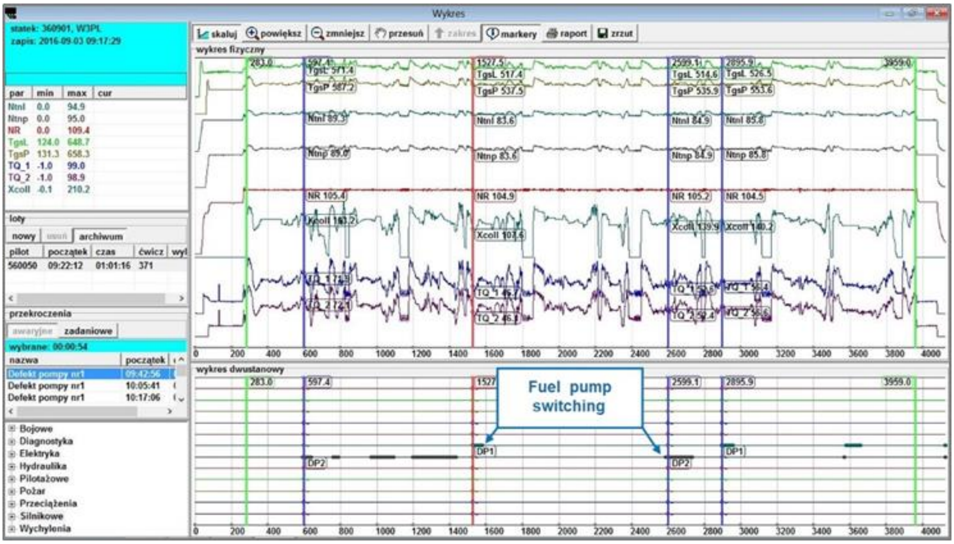

Fig. 8. Fuel pump 1 and 2 fault (W-3PL)

7. COMPARATIVE ANALYSIS OF FAILURE CONDITIONS

Data concerning the failure conditions was collected by analyzing records dating back to the period between 2012 to 2016. 12,776 records of various types were analyzed, i.e. engine start-ups, technical and preflight tests, test flights and other missions. The comparative analysis of the above-mentioned states was carried out at 2 levels:

a) failure conditions which do not affect flight safety,
b) failure conditions with direct impact on flight safety,

Then, a summary of the aforementioned failure conditions was drawn up, along with discussion points.

Re. a) failure conditions not affecting flight safety:

- the crew has exceeded the flight parameters permitted in a given mission;
- an interference or a computational error has occurred in the system or the transmitting equipment became uncalibrated.

534 such states have been identified. This figure covers both crew and aircraft faults. The comparison presented in Figure 9a shows that 18% of those cases (96 instances in which the parameters were exceed) were caused by the human factor. The remaining 82% instances were caused by interference and computational errors in the recording system and incorrect recording of the flight parameters (a factor remaining beyond the control of the flight crew or maintenance personnel).

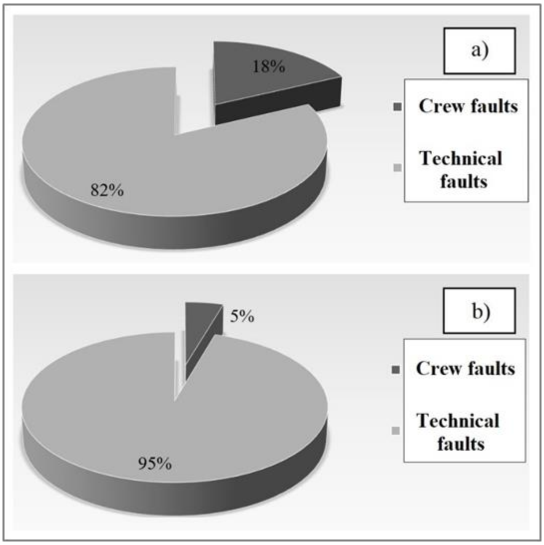

Fig. 9. Comparison of failure condition root causes: (a) with no impact - (b) with a direct impact on flight safety. The root causes identified include: crew actions, accounting for: 18% and 5% of the failure conditions, and aircraft faults - accounting for 82% and 95% of the failures, respectively

Re. b) failure conditions with direct impact on flight safety, where:
- the crew exceeded the aircraft's operating limitations,
- damage to the aircraft's systems and components occurred.

1,075 such failures have been identified. Their root causes (crew faults and aircraft faults) are compared in Fig. 9b. Safety breaches consisting in crews exceeding the helicopter's operating limitations account for 5% of all incidents (52 failures). Damage to aircraft's systems and components accounted for the remaining 95% of the faults, with 6 of them leading to emergency landings outside designated landing zones, without any negative consequences.
Discussion (summary of the above-mentioned failure conditions, with additional observations):
- after analyzing all the records, it appears that failure conditions have a direct impact on the safety of flights being performed (Fig. 10),

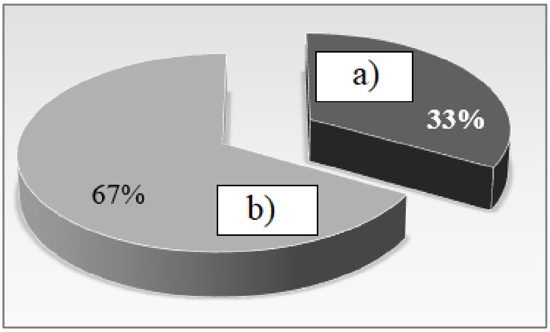

Fig. 10. Comparison of failure conditions in relation to their impact on flight safety: a) no impact – (33%), b) direct impact (67%)

- 80% of the failure conditions occurred on Mi-24 helicopters (Figure 11), and the related data may complement other studies concerned with their design,

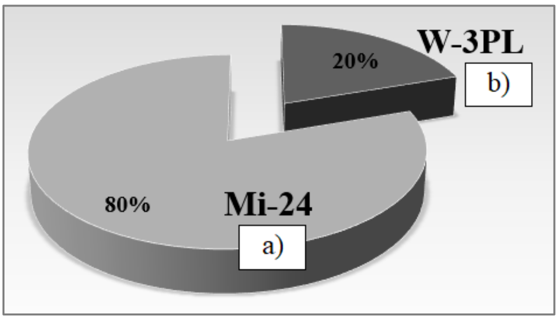

Fig. 11. Percentage share of failure conditions affecting specific aircraft types: a) Mi-24 (80%), b) W-3PL (20%)

- It should be noted that almost twice as many flight missions were performed on the Mi-24 than on the W-3PL (Fig. 12),

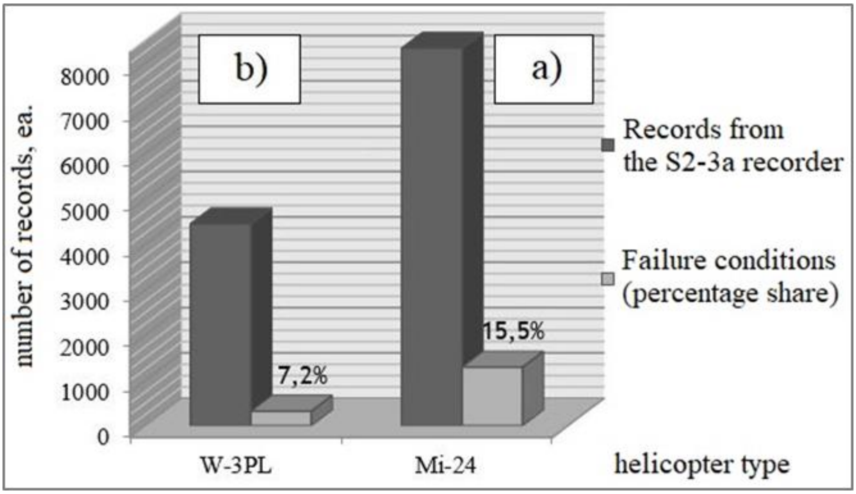

Fig. 12. Percentage of failure conditions in all missions performed by a given aircraft type: a) Mi-24 (15.5%), b) W-3PL (7.2%)

- between 2012 and 2016, both the number of flights performed and the number of failure conditions recorded were on an increase. However, the percentage share of all failure conditions in the total number of flights was decreasing (Fig. 13),

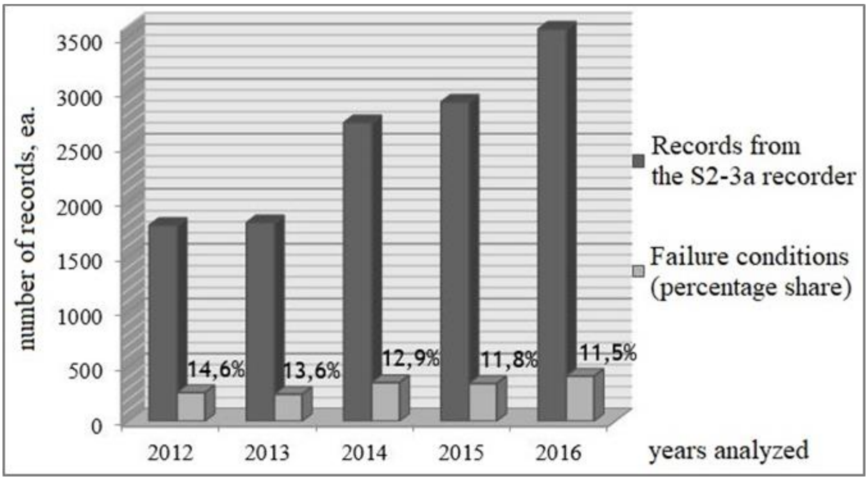

Fig. 13. The total number of flight missions performed during the period investigated vs. percentage share of failure conditions recorded

- while performing those missions on Mi-24 and W-3PL helicopters during the period identified above, 1,609 failure conditions were recorded, accounting for approximately 12% of all records generated (Fig. 14).
- the 12% rate referred to above is not low, but most of the faults were detected during routine preflight inspections or technical tests. During the period covered by the analysis, the 56th Air Force Base did not experience any aircraft accidents, and the failure condition-to-flights ratio was decreasing each year (Fig. 13).

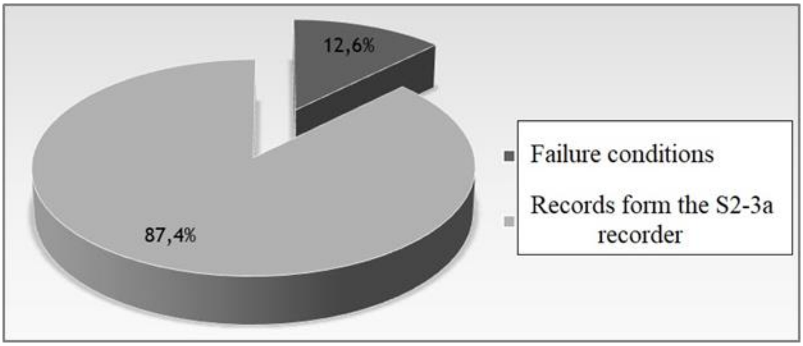

Fig. 14. Percentage share of failure conditions during all missions analyzed

Attention was paid to the most common crew errors and technical causes of the phenomena described. The most common crew errors

Re. a) resulting in failure conditions not affecting flight safety:

- exceeding the bank angle permitted for a given mission,
- failure to maintain constant speed assigned for the mission,

Re. b) resulting in failure conditions with a direct impact on flight safety:

- excessive rotor rpm,
- excessive G (vertical axis).

Most common technical root causes

Re. a) resulting in failure conditions not affecting flight safety:

- interference affecting the diagnostic channel and GPS signal,
- incorrectly recorded flight parameters, mainly vertical G-forces,

Re. b) resulting in failure conditions with a direct impact on flight safety:

- hydraulic system faults, including low pressure conditions,
- metal shavings in oil (main gearbox or one of the engines),
- AC or DC alternator failure,
- dangerous vibrations of one of the engines,
- excessive EGT on one of the engines.

3. CONCLUSIONS

The outcomes of the analysis allow to draw the following conclusions:

a) the majority of recorded failure conditions (67%) had a direct impact on flight safety,
b) the aforementioned failure conditions which affected flight safety were mostly caused by aircraft system faults (95%). The human factor contribution may be considered insignificant (5%),
c) 80% of all failure conditions affected the Mi-24 helicopter (with the remaining 20% identified on the W-3PL). It needs to be noted, however, that twice as many missions were performed on the Mi-24 than on the W-3PL,
d) during the period analyzed, the percentage share of failure conditions was decreasing, despite an increase in the total number of missions completed (year-on-year),
e) failure conditions were identified in approximately 12% of all flight missions performed,
f) despite the above mentioned 12% rate, no accidents occurred at the 56th Air Force Base at that time,
g) the percentage share of failure conditions was steadily decreasing during all those years,
h) in this publication, the number of failure conditions is related to the number of flights performed, rather than to the number of hours flown, as such an approach was considered to be more convenient for discussing and analyzing the data in the context of tasks performed by the Air Operations Group and the Technical Maintenance Group of the 56th Air force Base in Inowrocław.

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Zestawienie zarejestrowanych stanów awaryjnych wybranych śmigłowców Lotnictwa Wojsk Lądowych

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Streszczenie. Praca powstała na potrzeby Grup Działań Lotniczych i Obsługi Technicznej 56. Bazy Lotniczej w Inowrocławiu. Celem jest porównanie występowania stanów awaryjnych i ich wpływ na bezpieczeństwo lotów podczas zadań lotniczych na śmigłowcach Mi-24 i W-3PL. Zwrócono uwagę na wartości rejestrowanych parametrów lotu i zauważone nieprawidłowości. Dane analizowano z zastosowaniem programu „Obiektywna Analiza Zapisu" na dwóch poziomach. Pierwszy - stany awaryjne bez wpływu na bezpieczeństwo lotów, gdy załoga przekroczyła dopuszczalne parametry lotu zadane w ćwiczeniu lub wystąpiło zakłócenie, błąd obliczeniowy w systemie lub rozkalibrowanie urządzeń. Wyróżniono 534 stany, gdzie 18% spowodował czynnik ludzki. Pozostałe 82% to zakłócenia i błędy systemu rejestracji oraz nieprawidłowy zapis parametrów lotu (na co nie miała wpływu załoga wykonująca lot, ani personel obsługujący). Drugi poziom to stany awaryjne z wpływem na bezpieczeństwo lotów, gdy załoga dopuściła się przekroczenia ograniczeń eksploatacyjnych SP lub wystąpiło uszkodzenie urządzeń i agregatów SP. Wyróżniono 1 075 stanów, gdzie naruszenie bezpieczeństwa przez przekroczenie ograniczeń eksploatacyjnych SP to 5%. Uszkodzenia urządzeń i agregatów SP to pozostałe 95% (6 przypadków doprowadziło do lądowania awaryjnego). Wykazano, iż 80% przebadanych stanów awaryjnych cechuje Mi-24, na którym wykonano prawie 2x więcej zadań niż na W-3PL. Analizując lata skąd pochodzą udostępnione dane (2012–2016) zauważono, że rosła liczba wykonywanych lotów i liczba stanów awaryjnych, jednakże udział procentowy stanów awaryjnych w całości lotów malał. Autorzy 1 i 2 pełnią służbę w 56. Bazie Lotniczej i otrzymali zgody na dostęp do omawianych danych oraz ich publikację.

Słowa kluczowe: inżynieria mechaniczna, śmigłowce, stany awaryjne.