Pol J Aviat Med Bioeng Psychol 2021; 27(1): 7-19
DOI: 10.13174/pjambp.28.02.2024.02

ORIGINAL ARTICLE

REASONS FOR FAILED EJECTIONS IN THE POLISH AIR FORCE IN THE YEARS 1951-2021

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Source of support: Own sources

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Introduction: The primary task of an ejection seat is to help the pilot safely exit an inoperable aircraft. The factor that ejects the seat from the aircraft cockpit is a powder charge or rocket engine. Injuries sustained by the crew during catapulting depend on several factors, including, but not limited to, the sequence of ejection times and the speed of the decision. Most modern military jets are equipped with rocket ejection systems. The TS-11 "ISKRA" aircraft, equipped with a powder charge ejection seat, was in use by the Polish Air Force until 2022. The present study was undertaken by the author to analyze the causes of failed ejections in the Polish Air Force between 1951 and 2021.

Methods: The author created a medical form based on a serious airplane accident. He analyzed all the ejections, studying the minutes of the commissions investigating aviation accidents between 1951 and 2021. The data received were entered into a form and then statistically analyzed. The author set out to determine the relationship between the characteristics of the ejection process and the types of injuries sustained by ejecting pilots. The results were analyzed for various injuries with a special focus on fatal injury cases.

Results: Analysis included approval of 281 completed forms from severe aviation accidents between 1951 and 2021. The rate of failed ejections was 25.27% of the total. It ranks among the highest in military aviation compared to other such studies. The most important factor hindering safe ejecting was deciding to leave the aircraft cockpit too late.

Figures: 1 • **Tables:** 13 • **References:** 44 • **Full-text PDF:** http://www.pjambp.com • **Copyright** © 2021 Military Institute of Aviation Medicine, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

Discussion and Conclusion: The ejection seat has saved the lives of thousands of aircrews since its introduction in the 1940s. Using it is generally a safe life-saving measure. However, a number of factors may cause potential damage during ejection. These include the rapidity of the pilot's decisions, the task at hand, the aircraft's position, flight altitude or weather conditions.

Keywords: ejecting, military pilot, fatal injuries, late decisions

INTRODUCTION

The first ejection seats were introduced in the early 1940s in Germany [13,14]. The first successful ejection took place in January 1942. Currently, all military combat aircraft are equipped with ejection seats with a rocket launching system [42]. Thousands of pilots around the world owe their lives to these highly sophisticated systems for abandoning a damaged aircraft. Data from Martin Baker [20] shows that more than 7,000 pilots have ejected successfully. According to various reports, 80-90% of crews forced to abandon aircraft can be expected to survive ejection [28,39].

Survival rates and types of injuries caused by catapulting from modern jet aircraft have been studied by experts representing the air forces of various countries around the world. The findings, particularly mortality rates and injury patterns, are quite varied and have changed over the years [25,27,28,38]. These differences can be attributed to variations in aircraft, ejection seats and flight crew training in different countries over the years. In his paper, the author will present his findings on the ejections of all pilots who abandoned aircraft during their military missions between 1951 and 2021.

The author divided the obtained data into four groups based on the injuries suffered by pilots abandoned aircraft using the ejection seat in an extreme situation:

1. No injuries – the ejection was successful, without any injuries.
2. Light injuries – the ejection was successfully completed, but the pilot suffered injuries such as skin abrasions, petechiae, subcutaneous hemorrhages, dislocations, I° and II° burns.
3. Severe injuries – the ejection was successfully completed, but the pilot suffered serious injuries such as III° and IV° burns, fractures of the lower and upper limbs, severe spinal injuries including vertebral fractures, which required a long hospitalization and involved long-term inability to perform the profession of a military pilot.
4. Fatal injuries – the ejection resulted in the death of the pilot during the ejection or as its consequence.

In the current publication, the author will focus on ejections that ended with fatalities. Other ejections and the resulting physical and psychological injuries to pilots will be presented in the author's subsequent publications.

The first jet aircraft were introduced into Polish military aviation service in 1951. The aircraft were the Yak-17W and Yak-23. Both aircraft were equipped with an ejection seat. This seat was a developmental version of the seats used by German pilots during World War II. In 1951, the military aviation was updated with more modern aircraft, the MiG-15s, featuring upgraded KK-1 ejection seats. MiG-19P/PM jet aircraft, which break the sound barrier, were introduced into service in 1958. They were equipped with a KK-2 ejection seat. Typical MiG-21F13 supersonic aircraft with an SK-1 ejection seat were introduced in military aviation in 1961.

METHODS

All cases of ejection in the Polish Air Force (PAF) between 1951 and 2021 were analyzed. Only ejections made by military pilots in permanent service who performed combat or military training missions were eligible for analysis. The analysis omits cases of ejection of civilians and accidental activation of the ejection seat as part of technical inspections performed. Military pilots who performed demonstration ejections for television programs in the late 1950s and early 1960s were also excluded from the analysis. These were advertising materials promoting ejection seats as the safest form of exiting an aircraft in an extreme situation. Data collected included: type of aircraft, generation of ejection seat, age and experience of pilots, their anthropometric data, flight parameters, type of aviation mission performed and types of injuries. The author's study of ejections consisted of a post factum analysis of the material of individual pilots' aviation medicine files deposited at the Military Institute of Aviation Medicine, the protocols of the Commission for Investigation of National Aviation Accidents (KBWL LP) and the available specialized literature [4,5,10,19,44]. Each ejection case was analyzed by the author in terms of: the situation forcing the pilot to abandon the aircraft, the course of the ejection and the injuries sustained. The data was collected at the Air Accident Investigation Laboratory.

The PAF's sentencing regulations classify injuries into severe and light. The Medical Commission decides on the basis of the evaluation of injuries how long a pilot is unfit for duty on a particular type of aircraft. The commission does not consider the causes of their emergence, it only analyzes the actual state of the pilot's health. In his work, the author focused only on the analysis of ejections that ended in the death of the pilot.

The data obtained were subjected to statistical calculations using STATISTICA Version 12.5 (PL).

The study was approved by the Bioethics Committee of the Military Medical Academy in Łódź by Decision No. 32/02 dated 19.02.2002.

RESULTS

A detailed analysis of all severe accidents in the Polish Air Force showed that 281 pilots ejected from subsonic and supersonic aircraft with an ejection seat between 1951 and 2021. These results are shown in table 1.

Tab. 1. Division of ejections into successful and failed.

	Ejections	
Efficiency	**Number**	**Percentage**
Successful	210	74.73
Failed	71	25.27
Total	281	100.00

These results also show that as many as 25.27% of all ejections ended in the death of the pilot. This is one of the highest rates of failed ejections compared to foreign studies by other authors [1,3,11,27,29,38,40].

Tab. 2. Aircraft type and consequences of ejection.

	Ejections	
Aircraft type	**Number**	**Percentage**
Successful ejections, subsonic	129	45.91
Failed ejections, subsonic	49	17.43
Successful ejections, supersonic	81	28.83
Failed ejections, supersonic	22	7.83
Total	281	100.00

In table 2, the author presented a breakdown of all ejections into successful and unsuccessful, as well as those performed on subsonic and supersonic aircraft. These results are presented graphically in figure 1. They show that the most successful and unsuccessful ejections were on subsonic aircraft. The differences may be a result of the fact that, until 1958, Polish military aviation did not have aircraft capable of breaking the sound barrier, as these were the early days of the jet era. The second fact was that these planes were the primary aircraft for basic training of young pilots.

Nearly all studies that have examined ejection-related injuries and fatalities have found that the single most important factor increasing the risk of serious injury or death was the delay in deciding to exit the aircraft. This is the conclusion

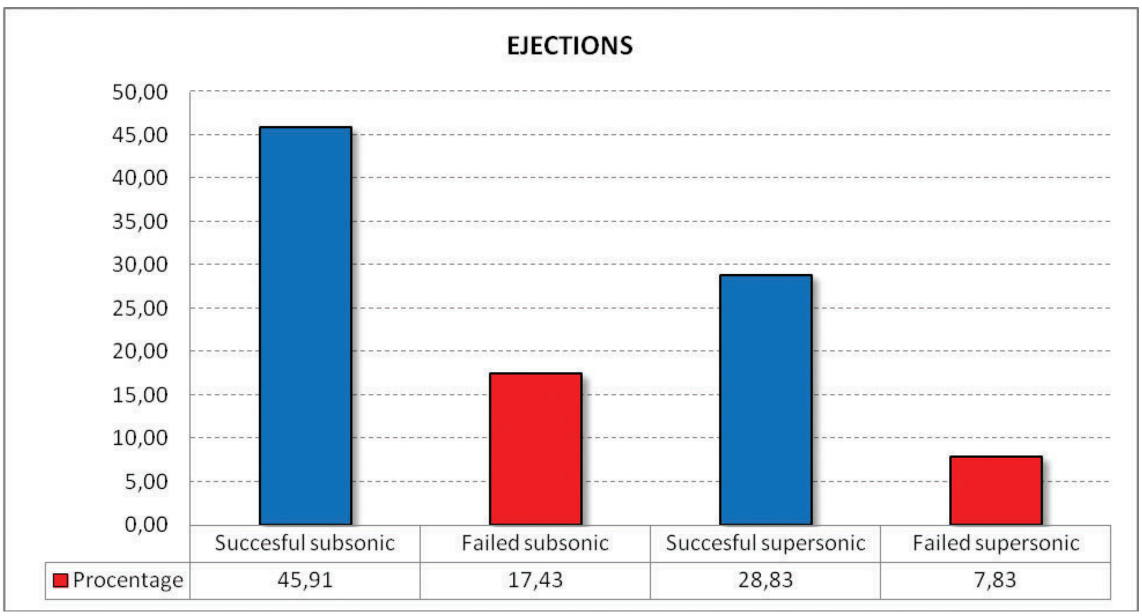

Fig. 1. Aircraft type and consequences of ejection.

presented by contemporary experts [8,12,16,24] dealing with this problem, as well as by their predecessors throughout the jet aircraft era. Making the right decision in an extreme situation is not an easy matter for pilots, as a decision made too hastily can result in many negative consequences for them.

Analyzing the age of the pilots who died, the author found that more than 50% of the pilots were younger than 30 years old (table 3). They were very young people with little soldier experience, as shown in table 4.

Tab. 3. Pilot's age at the time of ejection.

	Ejections	
Pilot's age	Number	Percentage
< 30	41	57.75
30- 39	26	36.62
40 >	4	5.63
Total	71	100.00

The analyzed pilots, despite their young age, had quite a lot of flying experience. Nearly 50% of them had a Class 1 military pilot rating (table 5). The fact that they died may indicate that they overestimated their flying skills.

Tab. 4. Military rank of the pilots at the time of the ejection.

	Ejections	
Military rank	Number	Percentage
Cadet	7	9.86
2nd Lt.	14	19.71
Lt.	26	36.62
Capt.	13	18.30
Maj.	8	11.26
Lt. Col.	3	4.25
Total	71	100.00

Tab. 5. Military pilot class.

	Ejections	
Pilot class	Number	Percentage
0	13	18.30
1	35	49.30
2	9	12.67
3	10	14.10
M	4	5.63
Total	71	100.00

A very important and relevant element in analyzing failed ejections is the flying experience of each pilot and especially their flying time, which indicates their overall flying experience and their flying time on the type of aircraft on which the failed ejection occurred. Experience on the type allows us to understand the mistakes made by the pilot and also allows to explain the behavior of the pilot and the other participants in an aviation accident in resolving a complex aviation situation.

Tab. 6. Total flight hours at the time of the crash.

	Ejections	
Total flight hours	Number	Percentage
0<x<500	27	38.01
501<x<1000	30	42.23
1001<x<1500	8	11.26
1501<x<2000	3	4.25
2001<x<2500	3	4.25
Total	71	100.00

Tab. 7. Hours on type on which there was a failed ejection.

	Ejections	
Hours on type	Number	Percentage
0<x<500	57	80.28
501<x<1000	12	16.90
1001<x<1500	2	2.82
Total	71	100.00

Tables 6 and 7 show the total flying time and flying time by type of pilots who had unsuccessful ejections during their flight mission.

The most important factor in the ejection process for most experts on the subject is making the right decision at the right time. Proper recognition of the threat in an already limited time frame (time deficit) will allow the crew to make a quick and appropriate decision to leave the damaged aircraft. As part of any preparation for an airborne mission, pilots should familiarize themselves with the operation of the ejection seat and study the limitations on its use. This knowledge will allow them to make the right decision. Such treatment was related to the use of subsonic combat-training aircraft (UTIMiG-15, SBLim-1, SBLim-2) for training flights for pilots of supersonic aircraft that did not have a combat-training version. This included MiG-19, MiG-21F13, MiG-21PF early versions of Su-7BM and Su-7BKŁ, Su-20 and early versions of MiG-23 aircraft [26].

In table 8, the author presented data on the altitude at which the ejection process was initiated. This situation refers to dropping the aircraft's cockpit fairing, pulling the seat headrest cover down over the face, or pulling the doubled handle of the ejection seat. More than 75% of pilots who had unsuccessful ejections abandoned their aircraft below 980 feet and 45% of them below 357 feet. The analysis of these results suggests that the pilots attempted to control the dangerous situation on board the aircraft until the end and were hesitant to eject due to a lack of knowledge and a general reluctance to use the ejection device.

Tab. 8. Altitude at which the ejection occurred.

	Ejections	
Altitude [feet]	**Number**	**Percentage**
0<=x<357	32	45.08
360<=x<660	15	21.14
690<=x<980	8	11.26
1020<=x<1600	8	11.26
1650<=x<2900	2	2.82
2950<=x<9800	1	1.40
9850<=x<26250	5	7.04
Total	71	100.00

One of the most important parameters a pilot must control during flight is the speed of the aircraft. The results in table 9 show that the pilots tried to maintain a safe speed to the end, as this guaranteed they would maintain control of the aircraft.

Tab. 9. Aircraft speed during ejection.

	Ejections	
Speed [knots]	**Number**	**Percentage**
81<=x<135	10	14.10
135<=x<190	12	16.90
190<=x<245	22	30.98
245<=x<300	11	15.50
300<=x<350	8	11.26
350<=x<405	1	1.40
405<=x<460	7	9.86
Total	71	100.00

Analyzing the type of aircraft on which the ejection occurred, we can see that the vast majority of failed ejections were made from subsonic aircraft. These amounted to 49, which is 69% of all failed attempts. The data shows that most failed ejections were performed by pilots on Lim-2, Lim-5 and TS-11 “ISKRA” aircraft [35,36]. These aircraft were the primary aircraft in both basic and advanced flight training [22]. These results are presented in detail in table 10.

The ejection seat is responsible for the safety of the pilot on board the aircraft. One of the main problems that arose before the designers was how to protect the pilot from injury if they had to abandon the aircraft in an extreme situation. In the early days, the inadequacy of ejection seats was quite high and with the increasing speed of aircraft there was an exponential increase in severe injuries including fatal injuries.

The designers had two major problems. The first was to give the pilot the opportunity to safely exit the aircraft and the second, even greater, is to convince the pilot to use the ejection seat. To support this suggestion, the author cites the history of service of the Yak-23 aircraft. This aircraft was equipped with an ejection seat. There were 8 disasters involving this aircraft.

Tab. 10. Type of aircraft on which the ejection took place.

	Ejections	
Type of aircraft	**Number**	**Percentage**
MiG-15	3	4.25
Lim-1	4	5.63
Lim-2	13	18.29
Lim-5	10	14.09
Ił-28	2	2.82
UMiG-15	1	1.40
SBLim-1	4	5.63
MiG-21 F-13	3	4.25
MiG-21 PF	5	7.03
MiG-21 PFM	3	4.25
TS-11 “ISKRA”	7	9.86
Su-7 BKŁ	1	1.40
Su-20	1	1.40
MiG-21 US	2	2.82
MiG-21 MF	2	2.82
Lim-6bis	1	1.40
MiG-21 U	1	1.40
MiG-21 Bis	2	2.82
SBLim-2	2	2.82
I-22"IRYDA"	2	2.82
Su-22UM3K	1	1.40
MiG-29	1	1.40
Total	71	100.00

None of these pilots even attempted to eject. In extreme situations, these pilots tried to land in randomly encountered terrain as they did when piloting piston-powered aircraft. A similar situation occurred with MiG-15 aircraft [17]. The aircraft was introduced into service in July 1951. The first failed ejection took place on June 12, 1953, in Słupsk. The first successful abandonment of a MiG-15 aircraft took place on April 9, 1953, in Słupsk. The pilot decided to leave the aircraft at NIMC after noticing malfunctions. They did not use the ejection seat, but jumped over the side of the plane. The first typical use of the ejection seat occurred on June 25, 1953 in Warsaw [15]. The entire ejection seat data is presented in table 11.

Tab. 11. Seat type on which the ejection was performed.

	Ejections	
Seat type	Number	Percentage
KK-1	28	39.44
KK-2	12	16.90
KM-1	5	7.04
SK-1	9	12.67
SK	7	9.86
KS-4	2	2.82
KM-1M	4	5.63
M-B	2	2.82
K-36	2	2.82
Total	71	100.00

A very important and relevant issue in the process of catapulting is the atmospheric conditions in which the pilot performs their flight mission. Data collected by the author shows that the more complicated the atmospheric conditions were, the fewer the situations in which pilots had unsuccessful ejections. Table 12 shows that 38 crashes occurred in daylight and good weather conditions, accounting for 53.53% of all failed ejections. The pilots delayed the decision to leave the cockpit of the aircraft until the very end. This was related to concerns about later professional consequences, they did not trust the ejection seat, and they were counting on assistance from Air Trafic Control.

Tab. 12. Weather conditions during ejection.

	Ejections	
Weather conditions	Number	Percentage
DVMC	38	53.53
DIMC	16	22.53
NVMC	12	16.90
NIMC	5	7.04
Total	71	100.00

Injuries sustained by pilots during failed ejections are the most significant issue the author wishes to present in his study. The unsuccessful ejection at a low altitude and high airspeed of the aircraft resulted in the fragmentation of the pilot's body upon impact with the ground. There were 37 such cases, accounting for 52.17% of all failed ejections.

Excessively low ejection altitude caused the parachute to fail to fully deploy and the pilot suffered internal injuries that resulted in immediate death or death from complications. There were as many as 21 such incidents. Which accounted for 29.61% of the tragically ended ejections. Two pilots suffered fatal head injuries during the ejection. These pilots did not follow safety rules when leaving the aircraft cockpit. The position they adopted in the ejection seat allowed the head to move freely, which led to damage to the base of the skull and cervical vertebrae during the high g-force phase. All injuries are illustrated in table 13.

Tab. 13. Type of injuries sustained by the pilots.

	Ejections	
Type of injury	Number	Percentage
Body fragmentation	37	52,17
Internal injuries	21	29,61
Drowned. Flight without training	1	1,40
He drowned in the sea	1	1,40
Tangled in the parachute canopy	1	1,40
He lost consciousness and dead	1	1.40
Internal injuries, death in hospital	1	1.40
Head injury during ejection	2	2.82
Drowned. Head injury during ejection	1	1.40
Internal injuries. Fell out of his parachute harness	1	1.40
Airborne seat crash with aircraft	1	1.40
He hit a tree with his seat	1	1.40
Internal injuries. He did not separate from his seat	1	1.40
Internal injuries. Hit a tree	1	1.40
Total	71	100.00

The author presented individual cases of failed ejections, which show how different situations lead to pilot tragedy:

1) The lieutenant made a solo flight in a duo above the clouds. An analysis of this flight showed that the pilot performed it without training on this type of aircraft. He never flew on the Lim-2 aircraft. In an extreme situation, the pilot made the decision to eject. He fell into a lake and drowned. The pilot, ejection seat and parachute were not found. The plane fell into Lake Łebsko 30 meters from the shore.
2) The lieutenant was performing a guided high altitude Night Instrument Meteorological Conditions (NIMC) flight along a set route in a duo. At an altitude of 9800 feet, he lost his leader and lost radio communication. The pilot made an attempt to find the leader. During the search, he lost his spatial orientation. After ejection, he fell into the sea and drowned. The plane collided with the water. A parachute and the remains of the plane were found in the course of the rescue operation. The pilot has not been found. The pilot was not trained for night flights over the sea in NIMC.
3) The lieutenant was performing a flight along a set route at night at high altitude. At an alti-

tude of 26200 feet, he lost spatial orientation. He ejected under unexplained circumstances. After separating from the seat, most likely under stress, the pilot became entangled in the wires and canopy of the parachute. Falling with an incompletely deployed parachute, he collided with the ground and died.

4) The cadet was performing an attack and photography operation, firing at ground targets. After completing the task, returning to the airport he had taken off from, he found an engine defect. Due to the low flight altitude, he did not eject. The moment the plane made contact with the ground, the ejection seat was activated. The seat threw the pilot outside the plane, which exploded in a moment. As a result of internal injuries, the pilot died on the way to the hospital.
5) The cadet was performing a flight to the zone for medium pilotage at high altitude. During the task, the aircraft began to descend rapidly. The pilot aborted the task and tried to inform ATC about it. The report was not received. According to the commission, at an altitude of about 2,600 feet, a detonation occurred in the aircraft. A moment later, the pilot dropped the cockpit canopy. The cause of the crash could not be explained.
6) The second lieutenant was performing a training flight in observance of the USL (simplified landing system) at NIMC. As it pierced the clouds going downward, the aircraft's longitudinal stability was disrupted. In such a situation, the instructor decided to abandon the aircraft. He made a mistake while using the ejection seat and exited the aircraft using the "over the side" method, hitting the left horizontal stabilizer with the right side of his body. The pilot fell to the ground after slipping out of the open parachute and died as a result. The commission determined that the pilot had an improperly attached parachute strap. The parachute was found 4.5 km from where the pilot fell.
7) The second lieutenant was performing a training flight in observance of the USL at NIMC. One minute after takeoff, the co-pilot reported that the landing gear had been retracted. At this point, communications were broken. Since the crew did not report again after another minute, it should, therefore, be assumed that the crash occurred in the second minute of the flight over Puck Bay. Initiated searches on land and on the water yielded no results. Four months later, the instructor's body was found and it was determined that he had ejected, but failed to separate from his seat. The wreckage of the plane and the body of the co-pilot have not been found.
8) The lieutenant was performing an interception flight in a duo. While performing the task, the aircraft flew into a storm cloud. Due to adverse weather conditions, the pilot lost spatial orientation. A search was launched. Based on the damage to the pilot's personal equipment, it was determined that he ejected at an altitude of 8200-11500 feet at 432 knots. During the ejection, the pilot failed to keep his head pressed against the headrest, causing it to hit the headrest and fatally injuring the pilot's head. The body of the pilot descending by parachute fell into a lake. It was not found until two weeks later.
9) The second lieutenant was performing a training flight. At an altitude of 490-650 feet, the pilot from the first cockpit heard a violent noise in the second cockpit. The instructor ejected himself through the cover of the second cockpit. The pilot was partially ejected outside the cockpit of the aircraft, resulting in damage to the parachute cover and its consequent opening. Only then did the pilot separate from the aircraft, but due to his injuries he slipped out of his parachute harness and fell to the ground. He died on the spot.
10) The second lieutenant as navigator was performing a flight in observance of the USL system at NIMC. The flight had gone well up to an altitude of 6,500 feet. In the fifth minute of the flight, the pilot reported that the engine shut down. ATC instructed the pilot to start the engine. The attempt proved unsuccessful. ATC instructed to prepare for catapulting. His further commands were to start the engine. This situation lasted up to the altitude of 2,000 feet. At an altitude of about 1,300 feet, the pilot ejected and landed safely by parachute. The navigator who was in the second cockpit ejected at an altitude of 80-100 feet. He crashed to the ground with his parachute unopened and suffered death.
11) The major was performing an interception flight as part of a duo formation. After takeoff at 490 feet, the pilot reported that he would attempt landing because he heard abnormal engine noise. After exchanging correspondence with the ATC, he passed the information into the ether: "watch out, I'm on fire, I'm going to eject myself." The ATC issued the command: "watch out, you're on fire, turn off the engine, eject 520," and 10 seconds later: "520 eject."

After a few seconds, the burning plane disappeared into the clouds, only to reappear a moment later with a variable gliding angle. The pilot ejected at an altitude of about 980 feet. The pilot fell with his parachute partially opened at a distance of about 426 feet before where the plane collided with the ground and within five meters of the ejection seat. The pilot died on the spot. According to the commission, the pilot had the right altitude to eject safely, but too little experience on the ejection seat training devices (his last training was in 1956) and the dangerous situation prevented him from safely exiting the aircraft.

12) The lieutenant was performing a training flight along a circle under Night Visual Meteorological Conditions (NVMC). After taking off, at an altitude of 660 feet, at a speed of 324 knots at a distance of about 3 km from the RW (runway), the instructor heard an explosion in the rear of the aircraft. He instructed the pilot to turn off the afterburner. After it was turned off, there was another, even stronger explosion. The instructor assessed these phenomena as a threat and gave the pilot the command to eject. The instructor ejected at an altitude of about 820 feet in ascending flight, at a speed of 324 knots. The trained pilot ejected from the first cockpit at an altitude of 1300-1500 feet 21 seconds after the instructor ejected. The pilot in the first cockpit failed to separate from his seat and died. The cause of the pilot's death was that the cable that disconnects the oxygen hose connectors at the ejection seat became stuck and broke off during the ejection. The cable was not replaced with a shorter one despite the order from 1971.

13) The second lieutenant was performing a flight in a duo to master group medium pilotage under Day Visual Meteorological Conditions (DIMC). During the flight task, the duo leader struck the left side of the fuselage and the rear lower tri-fuselage of the left wing against the upper right side of the fuselage and the cockpit canopy of the leading aircraft. As a result of the collision, the cover and right side of the cockpit of the guided aircraft were destroyed, and the ejection seat was set off when it was under the flap of the left wing of the guiding aircraft. The pilot died on the spot.

14) The lieutenant was performing a control flight at night in a covered cockpit under NIMC. After completing the flight task, the crew would return to the takeoff airport. At an altitude of about 2300 feet, the instructor reported to the ATC: "379, the engine is running poorly." The ATC did not hear this, so the instructor repeated it once more. The ATC ordered to pull back and then move forward the engine control lever. The instructor followed the command, but the engine rotation did not change. After an overly long exchange of words, the ATC gave the order to eject. As commanded, the pilot from the second cockpit ejected first at an altitude of 390-430 feet above a forest and landed safely. The instructor ejected after 2-3 seconds at an altitude of 360-390 feet. However, the altitude was too low. The pilot, along with his seat, hit a tree. He died on the spot.

15) The major was performing a training flight in observance of the USL system in the clouds under NIMC. During the flight task, when piercing clouds upwards at an altitude of 3280 feet, the crew found the engine rotation dropping to a level that did not guarantee the maintenance of level flight conditions. Although the ATC gave commands to eject, the crew commander, who was in the second cockpit, made attempts to start the damaged engine. Since these attempts failed, the pilot from the other cockpit ejected first, as per procedure, and landed unhindered. The pilot in the first cockpit ejected at an altitude of 460 feet. The altitude was too low for the parachute to fully inflate. The pilot died. The commission concluded that the cause of the crash was the pilot's late ejection out of the plane's 1st cockpit below the minimum permissible altitude, undertaken after the crew commander's delayed exit from the 2nd cockpit.

16) The major was performing an aerial weather reconnaissance flight under DVMC. In the 25th minute of the flight, at an altitude of 5100 feet, the engine spontaneously shut down during an attempt to increase engine rotations. Although the altitude was too low, the crew tried to start the engine three times, but without success. After the fact, the crew decided to eject. According to the rules, the pilot from the second cockpit ejected first. He abandoned the aircraft at an altitude of 950 feet, at a speed of 119 knots. And he fell to the ground with his parachute unopened, as he did not immediately separate from his seat. The pilot in the first cockpit ejected at an altitude of 790 feet and landed safely. Ironically, the pilot who died was a senior flight safety inspector in his military unit.

17) The major was performing a flight aimed at comprehensive use of aircraft armament and reconnaissance under DVMC. The pilot, in the

course of the flight task, while in the fourth turn, led the aircraft into a large tilt and increased the g-force. When the plane was at a speed below 270 knots, the pilot allowed the speed to decrease further and the g-force to increase. In this complex situation, the pilot brought the aircraft to beyond critical angles of attack, unintentionally causing the aircraft to stall. The pilot abandoned the aircraft, but due to the low altitude and high diving speed, the ejection was unsuccessful. After ejecting and separating from the seat, the pilot hit a tree. The parachute did not have time to inflate. Suffering internal injuries, the pilot died.

18) The major was performing a solo flight along a set route according to compass navigation and a flight to the zone under DVMC. After the flight along a set route, the pilot proceeded to complete the task in the zone. During the task, the pilot noticed the first symptoms of abnormal engine operation. The engine and flight parameters were clear evidence of engine shutdown and danger. The pilot, reporting the threat, informed of his decision to eject. At the time of the ejection, the aircraft's speed was 146 knots and the Barometric altitude relative to the airport and read by the pilot was 890 feet. However, the actual altitude, due to the elevation of the terrain in the ejection area, was about 790 feet. After 1.5 seconds, the straps securing the pilot to the seat were unfastened. After unfastening the belts, the pilot did not immediately separate from the seat, but kept felling with it for reasons the commission could not clearly explain. Separation of the pilot from the seat occurred at an altitude of no more than 450 feet. At this point, the parachute apparatus was activated, which initiated the process of opening the parachute. The parachute canopy did not inflate completely, as about 1.4 seconds later the pilot collided with the ground and died. He was about 100 feet short of parachuting safely.

19) The lieutenant was performing a flight involving combating air targets at night – intercepting one at a time under NVMC. After completing the flight task in the zone, the pilot directed the aircraft toward the airport. During the inbound flight, the aircraft was self-damaged. After diverting the aircraft to an uninhabited area, the pilot made the correct decision, which was to eject. Around 23:57, the pilot of the MiG-29 aircraft began the ejection process by pulling the doubled handle of the ejection seat at an altitude of about 300 feet. After a while, the moving part of the aircraft's cockpit canopy was tossed upward and separated from the airframe of the plane. The seat's electrical system was then disconnected from the aircraft's on-board network during the seat's upward movement along its guides. After the ejection seat left the cockpit, the parachute opening mechanism activated the lock that activates the primers of the pyro charge. The pressure of the pyro charge's powder gases was unable to shear the shear ring and thus trigger the parachute opening system and separate the pilot from the seat. The system for opening the parachute and separating the pilot from the seat did not work properly. The pilot remained strapped to the seat, which continued its descent along a ballistic track. The pilot collided with the ground at a distance of about 352 meters from where the cockpit canopy fell. He died on the spot. The plane went down at a distance of about 147 meters from the fall of the cockpit canopy and about 31 km from the beginning of the runway at Malbork airport.

DISCUSSION AND CONCLUSION

The author analyzed all ejections performed by military pilots between 1951 and 2021. The pilots abandoned the aircraft 281 times, but 71 of them suffered fatal injuries. The main reason for such a large number of deaths were delayed decisions to abandon the aircraft in an extreme situation. The late decision minimized the time needed to fully fill the parachute canopy. More than 66% of pilots who had unsuccessful ejections made decisions to abandon the aircraft below 200 meters above the ground. The author suggests that efforts should be made to improve pilots' awareness of the capabilities of current flight safety systems through training, in order to minimize the delay in making a decision to abandon a damaged aircraft.

Since the introduction of jet aircraft equipped with ejection seats, they have undergone significant improvement in terms of quality and reliability over the years. Presently, most of the highly maneuverable aircraft in the Polish Air Force are equipped with ejection seats [34,42], capable of rescuing the pilot from a minimum forward speed and zero altitude. Despite training all crew members on the importance of ejecting above the recommended minimum altitudes, over half of them delay the decision to make an emergency exit from the aircraft cockpit when faced with an extreme situation.

The problem of waiting too long before deciding to abandon the plane does not only affect Polish pilots. In 1968, Collins [9] checked all USAF aircraft accident reports involving ejections or attempts to exit an aircraft equipped with an ejection seat between 1962 and 1966. Of the 835 cases investigated, 135 ended in fatal injuries, and in 59% of the cases the pilot died. The reason was the lack of time to effectively deploy the parachute canopy resulting from the delayed decision to eject. Delayed ejection has always been associated with an increased risk of injury or death to the pilot. Experts investigating aviation accidents know how dangerous a late decision to ejection can be, but it is very difficult to clearly identify those factors that are particularly likely to be associated with the delayed abandonment of a damaged aircraft.

Of the many potential risk factors considered, only aircraft category, ejection seat, total flying time and flying time by type and the nature of the emergency situation showed some association with the likelihood of the pilot's decision to eject being delayed. The study indicated some correlation between the age of a flight crew member and the delayed decision to abandon the aircraft. Similar conclusions were reached by Milanov in his 1996 study [23], who analyzed the ejections of 60 Bulgarian pilots. Among the seven fatal ejections were no pilots from the oldest age category (40-49). According to Milanov, this has to do with flight experience in the air and continuity in theoretical training.

Many authors have analyzed the relationship between experience and risk of fatal injury in the process of ejection in their studies. As early as 1957, Zeller [43] included total pilot experience in his list of factors associated with ejection. In a 2001 study, Callaghan and Irwin [6,7] ranked pilots according to the total number of flight hours in the studied aircraft and found no relationship between experience and altitude of the ejection decision. The study also defined low experience as less than 500 hours, medium experience as 500 to 1,500 hours, and high experience as more than 1,500 hours, but the study's ability to detect significant differences was limited by the small numbers in each group. The author of this article proposed a similar division in his study. Out of the pilots who died, 57 had flown up to 500 hours, 12 had 500-1000 hours of flight time, and only two were the most experienced. In this study, the author analyzed military rank, as well as the class of military pilot associated with aviation experience. The relationship between military rank and pilot class and the chance of delaying the decision to eject was noted. They were significantly related to the timing of the decision to abandon the aircraft.

A very important factor affecting the timing of an aviator's decision to leave the aircraft is the subjective evaluation of himself as a master pilot. According to Miles [24], both novice and experienced aviators can be subject to overconfidence and complacency; these are among the few human factors that are often thought to increase with experience. Rieger [31] notes that the more experienced and skillful a pilot is, the more likely he is to fall victim to complacency. Wiener [41] notes that factors such as experience, training and knowledge contribute to complacency. If complacency and overconfidence do indeed increase with experience, then the results of this study suggest that these two human factors may be among those most likely to have an adverse effect on ejection time.

A number of reports [8,25,32] on accidents describe aviators deliberately delaying ejection to avoid crashing into populated areas. This reason for delay has also been noted in several previous studies [43] on ejections. While it seems reasonable to assume that pilots would be more likely to delay ejection when flying over populated land compared to open bodies of water (lake, sea), no such relationship was found in the current study. In several cases of failed ejections, the author analyzed ejections over bodies of water. In several cases, it was only weeks or months later that the ejected pilots were found. There were also accidents in which it was known that an ejection had occurred, but neither the pilot nor the aircraft were found.

The author and other experts [7,21,43] found that the number of crew members in an aircraft can affect the timing of these pilots' decisions to leave a damaged aircraft. In the current study, however, the author found that there is a relationship between the number of crew members and the likelihood of delaying the decision to eject. The author emphasizes the importance of communication and coordination among the crew. This has a huge impact on the decision to eject. Modern aircraft safety systems are designed to eject all crew members, if one pilot initiates the sequence of operation of the ejection seat, then as a result of this decision, both pilots in accordance with the procedure and sequence will be automatically ejected.

Both Miles [24] and the author found that the most important risk factor for delayed ejection identified in these studies was the overall nature of the emergency that ultimately led to abandonment of the aircraft. Compared to in-flight collisions with other aircraft or birds, delayed ejection was almost twice as common in mechanical emergencies and several times more common in emergencies caused through human action by aircrews. Many authors [6,23,37] have noted the relationship between the cause of the accident and the timing of the pilot's decision to eject. Nakamura [27] and Moreno Vázquez [25] found that delay was more common with mechanical failure events than with human error. Callaghan [7] and Taneja [37] suggested the opposite. Differing data between studies may reflect cultural issues. For the purposes of this study, unfortunate human factors included: physiological events such as gravitational induced loss of consciousness, in which the pilot was incapacitated, and spatial disorientation, in which the pilot was unaware that a malfunction had even occurred. In such situations, delayed ejections are common as long as the situation occurs at all, i.e. as long as the pilot has time to realize the danger.

The author realizes that there are several important limitations to this study. First, the study was retrospective. Second, a single researcher classified the participants and indicated whether the pilot was exposed to a potential risk factor. In analyzing each case, the author had to answer questions about the emergency situation that led to the ejection, when the pilot or crew lost control of the aircraft and when each crew member was ejected. The most difficult thing was to clearly determine the altitude at which control was lost and whether it was lost at all. Experts investigating aviation accidents in the 1950s, 1960s and 1970s did not always give this due diligence [33].

The severity of delayed ejection has been demonstrated in a number of studies [18] – delayed ejection is the most important contributor to serious injury or death during attempts to abandon the aircraft. The pilot's susceptibility to delaying the decision to eject has been suggested in expert studies and confirmed by the author's current study. More than half of pilots delay the decision to eject during an extreme situation on board during a flight, but those with less than 500 flight hours are particularly likely to do so. All flight crew training should be focused on flight safety. The author's study showed two important barriers to timely decisions to eject. Firstly, human factors [30] can overwhelm pilots and impede quick decision-making. Secondly, the guidelines for minimum conditions for ejection must be simple, clear, and unambiguously defined in order for pilots to effectively follow them in life- and health-threatening situations. Eliminating these obstacles can contribute to effective and safe ejection [2].

ACKNOWLEDGEMENTS

The author would especially like to thank Mr. Zbigniew Drozdowski, Marek Idzior and Radoslaw Szukała for their substantive support and assistance in creating the database.

AUTHORS' DECLARATION:

Study Design: Marian Macander. **Data Collection:** Marian Macander. **Manuscript Preparation:** Marian Macander. The Author declares that there is no conflict of interest.

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Cite this article as: Macander M. Reasons for Failed Ejections in the Polish Air Force in the Years 1951-2021. Pol J Aviat Med Bioeng Psychol 2021; 27(1): 7-19. DOI: 10.13174/pjambp.28.02.2024.02