ISSN PRINT 2319 1775 Online 2320 7876

Research Paper UGC CARE Listed (Group -I) Journal Volume 11, Issu 9,2022

FLIGHT RISKS: EXPLORING AIRCRAFT COLLISIONS WITH BIRDS OF PREY (ORDERS FALCONIFORMES AND ACCIPITRIFORMES)

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ABSTRACT
We examine statistical data on aircraft collisions with Accipitriformes and Falconiformes, two families of birds of prey. The analysis was based on research conducted at the Russian Academy of Sciences' Severtsov Institute of Ecology and Evolution (IPEE RAS). Predator birds' motivations and attractive elements to airfields are examined. Seven prey bird species involved in 29 airplane crashes between 2005 and 2022 were identified. The common buzzard, Buteo buteo, and the common kestrel, Falco tinnunculus, are the species with the highest frequency of bird attacks. The majority of crashes happen at the airport or close by; takeoff strikes happen 4.3 times more often than landing strikes. Crashing into raptors mostly damages the engine or the wing structure. Controlling bird behavior is advised in order to reduce the number of prey-bird collisions at the airport.

Keywords: birdstrike, birds of prey, identifying species after collision with aircraft, feather structure

I. INTRODUCTION:

Identification of the bird species involved in a collision with an aircraft is extremely important, as it allows one to determine the biological risks for a particular aerodrome and to take adequate measures to manage the behavior of the corresponding bird species to curb the increase in the number of collisions. Without species definition it is impossible to determine the location of the collision. Determining the species of birds that have not been involved in collisions or that were involved but did not cause damage to the aircraft is also useful for predicting the possible risks of collisions with aircraft (AC) in the future. It is quite fair that the act of having a particular species near an aerodrome is qualified in an ICAO document as a "dangerous approach" (Aerostandart…, 2022). The definition of species is also necessary for the design of protective devices for aircraft engines, which is especially important at the present time, when the creation of new domestic types of aviation equipment is becoming an urgent problem.

With the goal of solving problems of aerodrome ecology, namely the protection of aircraft from biodamage caused by birds and other animals, as well as development of joint proposals for the prevention of collisions between aircraft and animals at airports, in February 2020 a cooperation agreement between the Federal Air Transport Agency and the IPEE RAS was signed (Website of the Federal Agency…, 2022). Within the framework of this agreement, the employees of the Institute should conduct noncontractual identification studies based on feather material; in this case, the material and data of a collision that did not cause damage are analyzed.

As a result of many years of cooperation between IPEE RAS and PJSC Aeroflot Russian Airlines, the number of registered incidents with species identification has significantly increased, at least on the routes of this company. Comprehensive examinations are carried out in the case of biodamage to aircraft. The same studies are carried out for other Russian airlines and airports, but contracts with them are of a limited nature. Comprehensive studies of contract work include molecular genetic analysis and feather structure study to determine the species, the location of the incident, information on the biology of the species, and recommendations for managing the behavior of the species participating in the collision.

The purpose of this study is to analyze data on collisions with aircraft by birds from the orders Falconiformes and Accipitriformes.

II. MATERIALS AND METHODS

The source of information on the basis of which this study was carried out was the IPEE RAS data obtained as a result of contractual examinations, as well as performed in the framework of cooperation with the Federal Air Transport Agency on a noncontractual basis for the period from 2011 to 2022, inclu sive. To determine the species of birds of prey involved in collisions with aircraft, methods of molecular genetic analysis were used (Silaeva et al., 2020), as well as methods for determining the structure of the feather (macro- and ecological analysis, as well as methods of scanning electron and light-optical microscopy (Silaeva, 2019, Silaeva et al., 2020; Silaeva and Chernova, 2021). In cases of noncontractual work, the species is determined solely by the structure of the feather/feathers (Silaeva, 2019). The species in these cases can only be determined if there are indicative feathers; as a rule, these are wing or tail feathers or their fragments. By the down of the downy barbs, it is possible to determine an order or family.

III. RESULTS AND DISCUSSION

General statistics of bird collisions from the orders Falconiformes and Accipitriformes. The bird strike data for civil aviation flights of the Russian Federation are given in Table 1. Birds of prey are involved in many biodamaging situations; in particular, they actively encounter AC. According to statistics from the International Bird Strike Committee (Thorpe, 2012) from 1912 to 2002 47% of all incidents occurred with Accipitriformes. In the 1960s and 1970s, 112 collisions with birds of prey were recorded in the world out of the total number of incidents, 729 (Jacobi, 1974). Birds of prey have been known to attack aircraft. This occurs when the aircraft approaches the displaying pair, being at the same height or slightly lower (Bruderer, 1978). The territory of the airfield is very attractive for this group of birds in particular. From the heated runway, warm air currents rise, which birds of prey use to glide, conserving their energy. It is convenient to hunt in open uninhabited areas. Planes during take-off and landing knock down many large insects, which are eaten by small falcons. The foraging behavior of birds of prey is based on looking out for prey from a soaring flight, as well as gliding in place; the latter is especially characteristic of the kestrel Common Kestrel, the Red-footed Falcon, and the Common Buzzard. Looping or hovering raptors that stay in the air near a runway for long periods of time pose a significant threat to aircraft during taking off and landing. Small falcons also use the opportunity to catch lizards or shrews on the runway, which are clearly visible on a smooth surface. Black Kites, forming flocks on migration, sometimes numbering hundreds of birds, can soar for a long time in a common "carousel." Usually such accumulations occur near landfills and slaughterhouses, where birds linger. In India, aircraft collisions with the Black Kite Milvus migrans govinda make up 25%, and with the White-rumped Vulture Gyps bengalensis, 23% of the total number of incidents (Grubh and Satheesan, 1992). Migratory birds and, in

ISSN PRINT 2319 1775 Online 2320 7876

 UGC CARE Listed (Group -I) Journal Volume 11, Issu 9,2022

particular, birds of prey use the territory of the airport and its immediate surroundings for feeding or rest. At the same time, birds of prey like hawks and falcons are used at airfields as a repellent away small birds from the runway. An important component of this work, along with the identification of the species, is the establishment of the geographic location of the collision with the bird. This is necessary not only to determine the responsibility of the airport, but also for full accounting of data in the geo-information base and in the Unified database for registration and analysis of bird strike evidence. The geographic location of the collision is directly related to the biology of the species. By analyzing data on the biology of the species, as well as the circumstances of the collision, it is possible to determine the location of the incident. On the basis of biological data, we conduct ecological and geographical analysis, including data on the phenological zoning of the species, and combine these data with technical information obtained from the reports of the aircraft command (changes in technical parameters in engine operation, impact sound from a collision, smell, etc.) and messages from airport staff. On this basis, we draw a conclusion about the geographical location of the collision. When there is a lack of data on the circumstances of a collision, one has to resort to a ratio that indicates, in percentage terms, the probability of a collision at the airport of take-off, landing, or on the route. Below are a few examples from the Unified database for recording and analyzing data on bird strikes (Table 1). In case no. 2, after determining the species and subspecies, the Black-eared Kite Milvus migrans lineatus, it was concluded that the collision occurred presumably in the vicinity of the Irkutsk airport with two migratory specimens of the indicated subspecies. It was taken into account that in mid-September the species in the Moscow region occurs irregularly or in very small quantities. At the same time, the reports of the pilot and employees of airport services confirmed our conclusion. In case no. 6, the incident was found to have taken place at the airport in Alicante. In March, in the Moscow region, the occurrence of the Marsh Harrier is extremely low. In Spain, the Marsh Harrier population is a native resident. In addition, during seasonal migrations and in winter, individuals from more northerly regions of Europe are found here. During wintering and during migrations Marsh Harriers can be found in any open biotope, but they prefer to stick to wetlands with reed beds. The airport of Alicante is located just three kilometers from the Mediterranean coast. It is possible that the Marsh Harrier inhabited coastal wetlands. The conclusion was partially confirmed by the reports of the airport services of the city of Alicante.

Table 1. Collisions with Falconiformes and Accipitriformes on domestic and foreign civil aviation flights of the Russian Federation

No.	Species name	Date (dd.mm.yy)	Route	Flight stage	Aircraft damage
1	Brahminy Kite *Haliastur indus*	18.10.05	**Pune (India)**	Take-off	Engine no. 1
2	Black Kite *Milvus migrans*	18.09.19	**Irkutsk**—SVO	Take-off	Dent on left fender
3	"	26.07.21	**Orenburg**—Anapa	Take-off	Without damage
4	Marsh Harrier *Circus aeruginosus*	29.06.22	**St. Petersburg**—SVO	Take-off	RS Radardome
5	"	18.09.18	**Min. Water**—SVO	Take-off	Without damage
6	"	03.03.19	**Alicante**—SVO	Take-off	Horizontal Stabilizer
7	"	18.05.21	**Bukhara**—SVO	Take-off	Without damage
8	Goshawk *Accipiter gentilis*	12.08.15	**Irkutsk**—SVO	Take-off	Engine no. 2 and IGV panel
9	Rough-legged Buzzard *Buteo lagopus*	01.05.22	SVO—**Khrabrovo**	Landing	Engine no. 1
10	Long-legged Buzzard *Buteo rufinus*	13.06.19	SVO—**Bishkek**	Landing	Without damage
11	Common Buzzard *Buteo buteo*	25.04.18	**Stavropol**—SVO	Take-off	Without damage
12	"	04.05.21	Pulkovo—**SVO**	Landing	TPG on the fuselage, left fender liner, left flap and left MLG
13	"	01.11.19	**SVO**—Geneva	Take-off	Engine no. 1
14	"	20.10.21	**Vladivostok**—SVO	Take-off	Engine no. 1, IGV panel and port flap
15	"	18.10.19	**Lyon**—SVO	Take-off	Engine no. 1
16	"	31.07.19	**Dusseldorf**— SVO	Take-off	Engine no. 1
17	Peregrine Falcon *Falco peregrinus*	30.11.21	**Dusseldorf**—SVO	Take-off	Engine no. 2
18	Eurasian Hobby *Falco subbuteo*	18.08.17	**Rostov-on-Don**—SVO	Take-off	Without damage
19	"	15.08.16	**Khotilovo**—Vnukovo	Take-off	Engine no. 1
20	"	28.09.22	**Sochi**—SVO	Take-off	RS Radar dome
21	Red-footed Falcon *Falco vespertinus*	14.05.08	**Hannover**—SVO	Take-off	Left flap
22	Common Kestrel *Falco tinnunculus*	02.06.18	Yuzhno-Sakhalinsk—SVO	Not known	Without damage
23	"	08.08.19	SVO—Nizhnekamsk	Not known	Without damage
24	"	10.04.18	**SVO**—Sochi	Take-off	Engine no. 1
25	"	20.07.18	**Krasnoyarsk**—SVO	Take-off	Without damage
26	"	05.07.18	SVO—**Verona**	Landing	Engine no. 1
27	"	21.04.12	Ulaanbaatar—**SVO**	Landing	Left wing plane
28	"	21.08.09	Milan—SVO	Not known	Without damage
29	"	22.07.22	**Kaliningrad**—SVO	Take-off	Engine no. 2

The location of the collision is in bold; SVO, Sheremetyevo airport. RS, radar station; MLG, the main landing gear; IGV, input guide vanes of the engine; TPG, total pressure gauges.

In case no. 14, the encounter was with a migrant or nomadic subspecies of the Common Buzzard. The subspecies belongs to the eastern race of the Common Buzzard Buteo buteo japonicus, which breeds in Russia from the basin of the right tributaries of the Yenisei, Eastern Sayan, and Khangai east to the Pacific coast, so it was concluded that the incident could only have occurred at the airport of departure, that is, in Vladivostok.

In case no. 17, the Peregrine Falcon was a participant in the biodamaging situation. The Peregrine Falcon is a very rare nesting migratory species both in the Moscow region and Germany. But in Germany, programs have now been developed for breeding Peregrine Falcons in enclosures with the subsequent release of young animals into the wild, often the released birds gradually moving to cities. In the snowless and low-snow areas of Western Europe, which include Düsseldorf, the Peregrine Falcon also often winters. It winters very rarely in Moscow and Moscow region. The last migrating birds are recorded in October. In addition, the Peregrine Falcon is a daytime predator, and the landing at Sheremetyevo airport was at night. We took into account all these data and concluded that the incident took place at the airport of Düsseldorf, which German colleagues had to admit as well.

A similar incident (case no. 20) took place at Hannover airport. The Red-footed Falcon is quite common in Western and Eastern Europe; in the Moscow region, it is very rare, endangered, and listed in the Red Book of the Moscow region. Rarity and sporadic distribution was characteristic of the species in the past, but in the last quarter of the 20th century, the numbers of the population near Moscow have decreased even more; now the species is found singly in the region. Thus, according to the results of an ecological and ornithological survey of the territory of the airport and the 15 km zone adjacent to it, three years earlier, the Red-footed Falcon was not noted.

In case no. 23, the collision occurred on the airfield of Sheremetyevo airport with a migrating Common Kestrel. This conclusion was made based on of the report of the aircrew and biological data on the distribution of this species. During take-off at Sheremetyevo airport, the aircrew observed birds flying near the aircraft, and two seconds after take-off noted an increase in the vibration parameters. The Common Kestrel is a relatively rare nesting and migratory species of the Moscow region, most often found in open agricultural landscapes, where there are edges of tree plantations, as well as in the suburbs and outlying areas of various settlements, including Moscow. Birds often use the runway to look for prey, rest, and roost.

An incident with the Common Buzzard ended in serious consequences (case no. 13). During takeoff/separation from the runway on January 11, 2019, at Sheremetyevo airport, a bird attacked the plane. As a result, the buzzard was sucked into the left engine, two blades of the retaining stage of the internal contour of the engine guide vane were damaged. There was a smell of burning in the cabin; it was decided to return to the airport of departure (forced landing). At the same time, the species occurs sporadically in the Moscow region in winter, and its ecological niche is occupied by the Rough-legged Buzzard.

Collision analysis by type. Of the 29 collisions, the Common Kestrel accounted for ten; followed by buzzards with Common Buzzard in six and the Roughlegged Buzzard in one case. The Marsh Harrier was involved in four cases; there were three cases with a Eurasian Hobby, and three collisions with kites: two with Black Kites and one with a Brahminy Kite; and one each with a Goshawk, Peregrine Falcon, and Red-footed Falcon.

Collision analysis by stages of flight, the part of the aircraft affected by the impact, and the time of the year. The frequency of collisions is the greatest during ascent, which is fraught with the greatest consequences; the plane during take-off is heavy, and in this case, it is more vulnerable

ISSN PRINT 2319 1775 Online 2320 7876

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(Fig. 1a). The engine is the most vulnerable place, and the severity of biodamaging consequences depends on the mass of the bird. Representatives of all the orders studied belong to the second weight category. Almost half of the collisions occur on the engine, as it actively sucks in the birds (Fig. 1c). The engine can grind a small bird without loss of performance capabilities. An impact on the radar in the bow can threaten the loss of some radar functions. The largest number of collisions occurs in summer, and the number of events is approximately equal in autumn and spring; the time most free from incidents is winter. Analysis of Table 1 also showed that the ornithological safety of flights abroad is also not entirely in order. Out of ten foreign flights (cases 1, 6, 7, 10, 13, 17, 20, 25–27), eight had a collision abroad. Only in one case (no. 26) did it occur at Sheremetyevo, and the location of one incident has still not been identified.

Basic measures to avoid collisions with Falconiformes and Accipitriformes in the aerodrome environment. For the species of this group of birds, there are no special means of controlling behavior. Mainly environmental and sanitary measures are applied to eliminate the breeding factors of small mammals, which in turn attract birds of prey. But there are general measures to minimize collisions, more or less drastic, but without harming the birds.

Geomonitoring and Geo-Information Safety Systems for Flights in Aerodrome Ecology

To create geographic information systems for flight safety (GIS FS), employees of the IPEE RAS divided the airports of the Russian Federation into zones of the same type using physical-geographical and cli matic zoning. In this case, the data of the Federal Air Transport Agency on the degree of the absolute and/or relative number of collisions at airports and their environs are used (Fig. 2, according to Bukreev and Veprintseva, 2009).

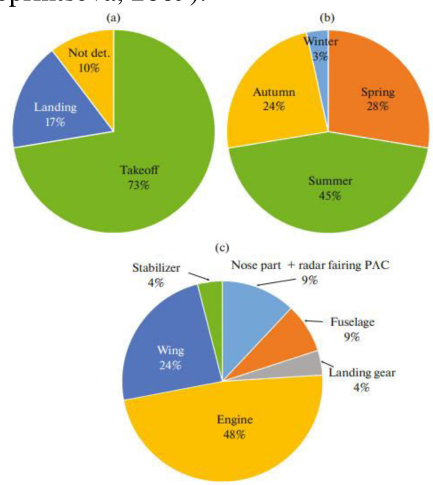

Fig. 1. Collision analysis by (a) stages of flight, (b) time of year, and (c) on the part of the aircraft affected by the impact.

For each airport, it is planned to assess the landscape and biotope features of the area and the ornithological load and its seasonal component and identify dangerous species. Not all most common species (species present in the zone at a given time, whether migratory, nomadic, or native resident) of the given study area are equally dangerous, as evidenced by the identification data obtained as a result of the abovementioned examinations. Information about the individual features of the airport is available in the reports of ecological and ornithological surveys, in field diaries, and in diagrams and maps of feeding and migratory movements of birds. In order to predict the danger of a collision with a particular bird species, an analysis and comparison of all available data on the airport and the 15-km zone around it is undertaken. In this way, databases on collisions and behavior of biodamaging bird species are created for each airport. These bases should be included in the GIS FS for Russia.

ISSN PRINT 2319 1775 Online 2320 7876

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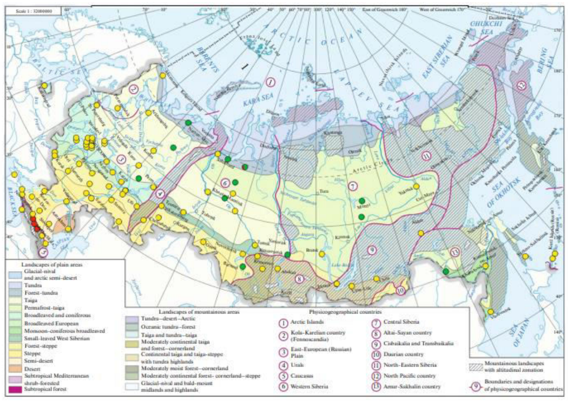

Fig. 2. Distribution of airports by physical-geographical regions and the number of collisions per 10000 take-offs and landings. Red circles, more than 10; yellow, from 1 to 9.9; green, less than 1 (Bukreev and Veprintseva, 2009, with changes).

plinary approach, in particular, of experience in field and radar ornithology, geostatistics, computer modeling, information management, remote sensing, and computer science. In addition, this work requires collaboration between academic, commercial, and conservation institutions, as well as birdwatching societies and airport aviation ornithologists. In the future, based on an in-depth study of longterm monitoring data, it is proposed to predict the species-specific behavior of birds in airport areas (Metz et al., 2021). The predictive life of bird strike avoidance models is on the order of 5–10 years (ShamounBaranes et al., 2007).

Bird Detection Systems for Flights in Real Time

Such systems are being created both here and abroad. In this case, radar or stereo systems are used (Gradolewski et al., 2021). At foreign airports, these systems calculate the strike risk for birds that are expected to cross the runway center line and cause damage to the aircraft. The rest birds, those on the ground, are subject to the attention of terrestrial ornithological services. As a result, birds are detected on the path of the aircraft, their speeds and trajectories of movement are predicted, and if there is a danger of collision, the ground services, having received information about the presence of birds on the path of the aircraft, give a command to the aircraft crew, and the flight is delayed or, in rare cases in case of large and long-term migrations, cancelled. Mainly the take-off is delayed, usually by no more than ten minutes. Such collision avoidance methods are proposed by international teams of authors from Germany, Holland, Israel, Denmark, and the United States (Metz et al., 2016, 2017, 2019, 2020, 2021a, 2021b; Van Gasteren et al., 2018).

At Pulkovo airport in St. Petersburg, the Volacom system developed in Bulgaria (Website Volacom, 2022) is used. At Sheremetyevo airport, a Merlin bird detection radar system developed in the United States was installed (AeroExpo website, 2022).

At the World Birdstrike Association Europe Conference March 7–8, 2022, a bird behavior monitoring radar system developed in Poland was presented (Advanced Protection Systems, 2022).

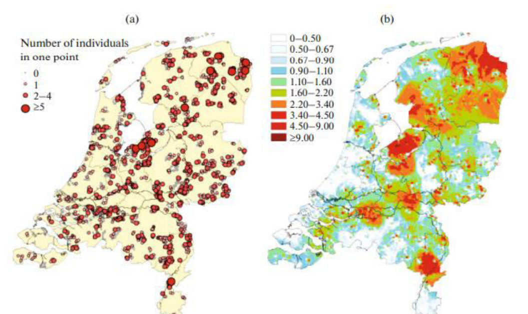

Fig. 3. (a) Number of Common Buzzards recorded at one survey site in December 2000. (b) Modeled buzzards's distribution map (Shamoun-Baraneset al., 2007).

In the Russian Federation, at the moment there are developments of JSC Research Institute Vector, the Orniornithological flight safety system for airports (Rostec website, 2022) and the radar-optical complex ROSK-1 of the Concern VPO Almaz-Antey (Official website of PJSC NPO Almaz-Antey, 2022). Both systems are in the testing phase. There is also a working system for detecting and tracking air objects by reflected radio signals from third-party sources in the passive-active radar systems “Enot”

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("Raccoon") (Batchev et al., 2016) with its own radiation pattern of an acoustic source of repellent signals, which is positioned in space depending on the position of the bird or birds the behavior of which is expected to be affected. A review of all the listed means for detecting and controlling the behavior of birds shows, firstly, their presence in the world and, secondly, the possibility of optical-electronic and radio-electronic means to detect birds at a distance of up to two kilometers. At the same time, a dense flock of birds comparable in size to an airplane can be detected even at a distance of 20 km. The main common drawbacks are the inability to determine the species from radar data; tracking exclusively single targets, that is, single birds, but not groups or flocks; and the absence of a directional pattern of acoustic signals, which automatically adjusts to the object being repelled. Such a diagram exists only in the "Enot" ("Raccoon") system. The main disadvantage is the lack of cognitive, fully automated systems for detecting and controlling animal behavior (Hoekstra and Ellerbroek, 2016). An automated and very effective means of detecting and controlling the behavior of birds without their elimination could be a complex cognitive system that would allow monitoring the airspace of the airfield zone using radar and optoelectronic means (Fig. 4).

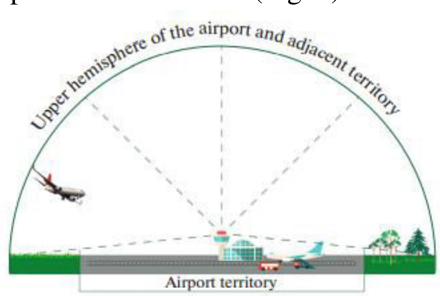

Fig. 4. Approximate scheme for control of zones dangerous for collisions with birds.

Removal of Part of the Bird Population and Removal from the Airport

Activities to capture birds of prey are held both at domestic airports and abroad. At O'Hare International Airport in Chicago (United States), experiments were carried out to capture and move the Redtailed Hawk Buteo jamaicensis outside the airport. At the same time, when catching and removing buzzards without their elimination, the relative number of collisions decreased by 47%, and movement with partial elimination reduced the number of cases by 67% (Washburn et al., 2021).

When using this method, care must be taken to ensure that only part of the bird population is taken and that the interests of the birds are also taken into account. Some "problem" species for aviation are rare or vulnerable, and most of the species, as links in the chain, constitute the biological diversity of our avifauna and represent valuable resources. Species that cause damage on the territory of the aerodrome, in a different ecological and economic situations, are indispensable. Birds of prey are consumers of the highest order, located at the top of the ecological pyramids, which is why they are especially sensitive to environmental changes. The main factors in the reduction of raptor populations are direct human persecution, deterioration of living conditions due to anthropogenic expansion, depletion of the food supply, the harmful effects of pesticides, death on man-made structures, and the impact of disturbances (Ilyukh and Khokhlov, 2010; Cleary and Dolbeer, 2005).

We do not suggest saving birds at the cost of the safety of aircraft and passengers, but other things being equal, we call on airfield services to avoid lethal measures for animals. Killing birds is not only inhumane, but also inappropriate. In this case, the ecological niche of the withdrawn population will be refilled by the another population, the less experienced members of which are unaware of the danger posed by an aircraft taking off or landing. As a result, the number of collisions with aircraft may increase. With proper management of ornithological resources in the aerodrome ecology, bird populations are formed that are adapted to local living conditions. Such individuals rarely encounter aircraft. At the same time, populations that include experienced individuals occupy part of the ecological capacity of the land and prevent the introduction of unadapted newcomers. But if such do appear, then the natives serve as a good example for newcomers, facilitating their adaptation.

IV. CONCLUSION

In conclusion, the study of aircraft collisions with birds, specifically those from the orders Falconiformes and Accipitriformes, reveals critical insights into the patterns and impacts of these incidents. Our analysis indicates that these bird orders, which include raptors and birds of prey, pose significant risks to aviation safety due to their size, flight behaviors, and habitats often intersecting with flight paths. The data underscores the need for enhanced bird strike prevention strategies, including improved radar detection, habitat management around airports, and the use of bird deterrents. Additionally, the development of more robust aircraft components and materials to withstand bird strikes could mitigate the damage and risks associated with such collisions. By implementing these measures, the aviation industry can enhance safety and reduce the economic and operational impacts of bird strikes involving Falconiformes and Accipitriformes

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