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An Analysis of Wildlife Strikes to Aircraft in Brazil: 2011-2018

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Abstract

Purpose: Aircraft accidents due to wildlife hazards have become a growing safety and economic problem to the Brazilian and international aviation industries. These safety occurrences have resulted in significant direct and indirect economic losses as well injuries and fatalities worldwide. The purpose of this study was to develop empirical information obtained from the analysis of wildlife strike and aircraft operations data in Brazil that could be used for accident prevention efforts.

Design/methodology: The research team collected and analyzed aircraft operations as well as wildlife strike data from the 32 busiest commercial airports in Brazil, from 2011 through 2018. Researchers obtained the number of aircraft operations at each of those 32 Brazilian airports from the Brazilian air traffic operations annual reports published by the Air Traffic Control Department. Wildlife strike data from the studied airports were obtained from the Brazilian national wildlife strike database. Descriptive data analysis was adopted to provide an intuitive and overall trend of wildlife strikes at and the 32 busiest commercial airports in Brazil.

Findings: Results indicate that the number of wildlife strikes at and around the investigated airports increased 70% even though the number of aircraft operations at these airports declined by 12% during the period studied. Birds were involved in 88% of the reported events. Most reported strikes (59%) and damaging strikes (39%) occurred during the arrival phases-of-flight. Most (33%) strikes were reported by airport personnel. A finding of concern was that the majority of wildlife strikes (97%) and damaging wildlife strikes (96%) occurred within the airport environment.

Practical implications: Findings of this study could be used as the groundwork during the development and assessment of wildlife hazard management programs and other aviation stakeholders' safety efforts to prevent aircraft accidents due to wildlife strikes.

Originality/value: The current project contributes to the safety management of wildlife hazards in Brazil by conducting a comprehensive analysis of wildlife strike and aircraft operations data (2011-2018) in the 32 busiest Brazilian commercial airports.

Keywords: Aviation safety, wildlife strikes in Brazil, wildlife hazard management program

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1. Introduction

The aviation industry provides vital economic contributions to Brazil. According to the National Civil Aviation Agency (ANAC), the number of air carrier operations at all commercial airports in Brazil declined by 11.6% from 2011 through 2018 (ANAC, 2019). Interestingly, the number of international commercial operations at these airports increased by approximately one percent during the same period. During 2017, the aviation industry, directly and indirectly, contributed approximately US$ 37.63 billion to the Brazilian gross domestic product (GDP) (Brazilian Airlines Union, 2018). Aviation generates more than 1.5 million jobs in Brazil, 65,000 of them are direct jobs. With demand slated to double until 2030, the economic contributions of aviation to the Brazilian GDP could increase to more than US$ 90 billion per year.

The COVID-19 pandemic has profoundly impacted the aviation industry. Border closures, the ensuing economic crisis, and travel restrictions are among the many factors that have caused a significant decline in air travels all over the world. The number of passengers using the Brazilian airports had a 57% decrease in 2020 if compared to 2019 (Garbuno, 2020). Many Brazilian aviation professionals have been furloughed since March 2020. Nonetheless, the long-term outlookfor the aviation industry remains strong and positive. Some of the "fundamental factors influencing pilot demand prior to the onset of the COVID-19 pandemic remain unchanged" (e.g., fleet growth) (Leontidis, 2020, p. 3). For example, there will be a need of around 16,000 pilots in South America until 2030, mostly in Brazil. Moreover, the recovery of Brazil's air traffic has been more pronounced than other countries in Latin America. The two largest Brazilian air carriers have been steadily increasing their capacity (Clark, Parker, Sims, Beltranena, Pasupathi, Pherous et al., 2020). The Brazilian air carriers have expressed confidence in the demand for air travel in early 2021 (Walker, 2020). According to the International Air Transport Association (2019), the number of direct aviation jobs in Brazil could be higher than 1.4 million in the next 20 years.

Wildlife strikes to aviation have become a serious safety and economic concern in Brazil. The Brazilian national wildlife strike database (NWSD) is managed by the Aeronautical Accident Investigation and Prevention Center (CENIPA) (Mendonca, Huang, Carney, & Johnson, 2018). A robust NWSD is vital for the evaluation of trends, the development and assessment of safety programs, and for providing the groundwork for national standards. Worldwide, mishaps due to wildlife strikes have resulted in the loss of 263 aircraft and more than 282 lives from 1998 through 2018 (Dolbeer, Begier, Miller, Weller & Anderson, 2019). In Brazil, two aircraft were damaged beyond repair, and at least five people killed as a result of wildlife strikes since 1962 (Oliveira, Silva, Santos & Novaes, 2017). Additionally, several pilots have been injured due to bird strikes.

Globally, the direct costs of aircraft accidents and incidents due to wildlife strikes have been estimated to range from US$1.2 to US$1.35 billion (Anderson, Carpenter, Begier, Blackwell, DeVault & Shwiff, 2015). In Brazil, aircraft collisions with wildlife are projected to cost a minimum of US$ 65 million in direct, ancillary, and other indirect costs (CENIPA, 2017a). Several factors have contributed to this increasing safety issue in Brazil, including increased air traffic (ANAC, 2019a), previous inadequate government regulations and policies preventing hazardous wildlife attractants near airports, and wildlife adapting to urban and suburban environments (Araujo, Peres, Baccaro & Guerta, 2018; Mendonca et al., 2018; Novaes & Alvarez, 2014).

Land use practices at (e.g., detention ponds) and around (e.g., solid waste landfills) the airport as well as habitats are fundamental factors determining the risk of wildlife strikes to aviation (Cleary & Dolbeer, 2005). The Federal Aviation Administration (FAA), for example, provides guidance materials regarding the construction or establishment of landfills (FAA, 2006) and on certain land uses (FAA, 2007) near public airports. Brazil has had an impressive population growth concentrated in few highly populated cities, such as Sao Paulo, Porto Alegre, and Recife (Eekeren, 2014). Due to inadequate and/or inexistent federal and state regulations and policies in the past (Oliveira, 2008; Mendonca, Keller & Schonhardt, 2019), there are still land-use practices (Bast, 2018; Bocchini, 2019) that sustain and/or attract hazardous wildlife to the airport environment. Nonetheless, operators of commercial airports are federally mandated and professionally obligated to take actions to prevent aircraft and wildlife collisions (ANAC, 2014).

Empirical data have indicated that safety strategies can significantly reduce the number and rate of strikes as well as damaging strikes (DeFusco & Unangst, 2013; Dolbeer et al., 2019). Brazilian-based air carriers authorized to operate under the Brazilian Federal Aviation Regulation (BFAR) 121 are generally regional and large airlines and cargo operators conducting regularly scheduled air transport operations. The air cariers operating in accordance with the BFAR 121 are required to comply with a number of safety requirements and standards in order to ensure safe, secure, and sustainable air operations. The BFAR 139 requires operators of airports hosting supplemental, flag, domestic, and international operations governed by the BFAR 121 to hold a BFAR 139 certificate. The BFAR 139 standard is also applicable to airports receiving international air carrier commercial operations (ANAC, 2009). The BFAR 139 certificated airports are mandated to develop and implement a wildlife hazard management program (WHMP) to minimize the risk to aviation operations posed by hazardous wildlife on and around the airport. Moreover, the BFAR 164 (ANAC, 2014) provides the standards for the aforementioned airports while developing their WHMP. Certificated airports are also required to conduct an annual assessment of their WHMP to identify possible new wildlife hazards and/or the effectiveness of the current safety strategies, and to update the program as needed. Thirty-one out of the 32 airports investigated in the present study are expected to have developed and implemented a WHMP (ANAC, 2015). It is important to note that one of the studied airports (SBMT) are not mandated to comply with the BFAR 139 nor the BFAR 164. Nevertheless, 20 of the studied airports hold valid BFAR 139 certificates (ANAC, 2018). However, only 14 out of those 20 airports have valid WHMP. Interestingly, five of the studied airports have valid WHMP even though they are not BFAR 139 certified (ANAC, 2020a).

A safety issue must be first defined so as to be effectively managed (Dolbeer et al., 2019). Developing effective WHMP relies heavily on empirical information obtained from the analysis of wildlife-strike data (MacKinnon, 2004). The analysis of the complex wildlife strike data provides the foundation for the safety efforts by aviation stakeholders, especially regulators and airport operators. Information obtained from such analysis is essential to determining "the economic cost of wildlife strikes, the magnitude of safety issues, and most importantly, the nature of the problem" (Dolbeer et al., 2019, p. 3). Additionally, this information is critical while assessing the effectiveness of safety programs. CENIPA has published special reports summarizing empirical information obtained from a scientific analysis of the Brazilian NWSD. However, the most recent report was published in 2016 (CENIPA, 2020). Most importantly, few research studies have been published addressing the safety management of wildlife hazards in Brazil.

This study is the second in a series whose general goals are to develop empirical data and information obtained from the scientific analysis of wildlife strike and aircraft operations data in Brazil. In the first report, Mendonca et al. (2018) investigated wildlife strike data from the three busiest airports in Brazil: São Paulo international airport (Guarulhos) (SBGR), Brasília international airport (SBBR), and Rio de Janeiro's Tom Jobim international airport (Galeão) (SBGL), from 2011 through 2016. Findings from this research project indicated that both the number and the rate (wildlife strikes per 100,000 aircraft operations) had steadily increased from 2011 through 2016 in SBGR, SBBR, and SBGL. Findings suggested that approximately 96% of the reported strikes involved commercial operators and that almost 52% of the damaging strikes occurred during the arrival phases of flight. The authors recommended outreach and education efforts by aviation stakeholders in order to increase the quantity and especially to enhance the quality of wildlife hazard reports. The authors concluded that future projects should extend to other commercial airports in Brazil.

The importance of wildlife strike data and information for accident prevention efforts warrant further scientific studies. The current project contributes to the safety management of wildlife hazards in Brazil by conducting a comprehensive analysis of wildlife strike and aircraft operations data in Brazil (2011-2018) in the 32 busiest Brazilian commercial airports.

2. Methodology

2.1. Data Collection

The Brazilian Air Traffic Control Department (DECEA) publishes air traffic operations annual reports with aircraft operations data and information from the 32 busiest airports hosting commercial operations in Brazil (Table 1). Researchers obtained the number of aircraft operations at each of those 32 Brazilian airports, from 2011 through 2018 (DECEA, 2014, 2017, 2019). DECEA (2019) defines an aircraft operation as "a landing, a takeoff, a touch-and-go, a missed approach, or an itinerant traffic" (p. 9). The 32 airports used in this study hosted approximately 85% of the aircraft operations in 2018. Moreover, these airports accounted for about 72% of all the wildlife strikes to aviation in Brazil from 2011 through 2018.

Identifier	Airport Name	City-Sate
SBGR	Sao Paulo / Guarulhos International Airport	Sao Paulo – Sao Paulo
SBSP	Congonhas International Airport	Sao Paulo – Sao Paulo
SBBR	Brasilia International Airport	Brasilia – Federal District
SBGL	Rio de Janeiro / Galeao International Airport	Rio de Janeiro - Rio de Janeiro
SBRJ	Santos Dumont Airport	Rio de Janeiro - Rio de Janeiro
SBKP	Viracopos / Campinas International Airport	Campinas – Sao Paulo
SBCF	Belo Horizonte / Confins International Airport	Belo Horizonte – Minas Gerais
SBPA	Porto Alegre International Airport	Porto Alegre – Rio Grande do Sul
SBMT	Campo de Marte Airport	Sao Paulo – Sao Paulo
SBSV	Salvador / Dois de Julho International Airport	Salvador - Bahia
SBRF	Recife / Guararapes International Airport	Recife - Pernambuco
SBJR	Jacarepagua Airport	Rio de Janeiro - Rio de Janeiro
SBCT	Curitiba / Afonso Pena International Airport	Curitiba - Parana
SBGO	Santa Genoveva Airport	Goiania - Goias
SBFZ	Fortaleza / Pinto Martins International Airport	Fortaleza - Ceara
SBFL	Florianopolis / Hercilio Cruz International Airport	Florianopolis – Santa Catarina
SBVT	Vitoria / Goiabeiras Airport	Vitoria - ES
SBBH	Belo Horizonte / Pampulha Airport	Belo Horizonte – Minas Gerais
SBBE	Belem / Val de Cans International Airport	Belem - Para
SBEG	Manaus / Brig. E. Gomes International Airport	Manaus - Amazonas
SBRP	Ribeirao Preto / Dr. Leite Lopes Airport	Ribeirao Preto – Sao Paulo
SBCG	Campo Grande International Airport	Campo Grande – Mato Grosso do Sul
SBNF	Navegantes International Airport	Navegantes – Santa Catarina
SBUL	Uberlandia International Airport	Uberlandia – Minas Gerais
SBLO	Londrina Airport	Londrina - Parana
SBSJ	Sao Jose dos Campos Airport	Sao Jose dos Campos – Sao Paulo
SBFI	Foz do Iguacu International Airport	Foz do Iguacu - Parana
SBSL	Sao Luis International Airport	Sao Luis - Maranhao
SBMO	Maceio International Airport	Maceio - Alagoas
SBPJ	Palmas International Airport	Palmas - Tocantins
SBJV	Joinville International Airport	Joinville – Santa Catarina
SBUR	Uberaba International Airport	Uberaba – Minas Gerais

Table 1. The 32 busiest commercial airports in Brazil: 2011-2018

Note: Source – DECEA (2014, 2017, 2019)

CENIPA has adopted a voluntary wildlife strike reporting system where aviation professionals are strongly encouraged to report wildlife strikes, sightings, and near-misses during flight operations (Mendonca et al., 2018). However, in accordance with the Brazilian national standards (CENIPA, 2017), aircraft accidents and incidents (e.g., damaging wildlife strike; strike causing injuries to crew members and/or passengers), as defined by the

International Civil Aviation Organization (2016), must be reported to CENIPA. Only data from wildlife strike reports that occurred at and around the 32 busiest airports hosting commercial operations in Brazil, from 2011 through 2018, were utilized in this project. Researchers also used data and information from CENIPA (2017) and Oliveira et al. (2017) to have a better picture of the economic magnitude of this safety issue. Data from the CENIPA NWSD (CENIPA, 2020), including all Brazilian airports, were also utilized so that we could better understand the risk wildlife hazards pose to aviation operations in Brazil. For the 32 investigated airports the dataset was sorted out to include: type of operator, phase of flight, partly struck, sources of the report, time of the day, weather conditions, damage to aircraft, damage to aircraft and phase of flight, damage to aircraft and altitude of the strike, damage to aircraft and time of the day, and wildlife species. For damaging strikes, we considered the reported strikes in which damage was reported as positive or undetermined.

2.2. Analytical Methods

The researchers summarized the data and calculated the wildlife strike index as the number of wildlife strikes per 100,000 aircraft operations per year, as suggested by Mendonca et al. (2018). The use of this wildlife-strike index is expected to include the possible influential factor of the number of aircraft movements in the risk of wildlife strikes to aviation (Dolbeer et al., 2019). We also adopted descriptive statistics in order to obtain an empirical estimate of the nature and magnitude of the wildlife hazard issue with respect to a variety of factors, for the Brazilian aviation industry.

3. Results

3.1. Wildlife strikes in Brazil: A brief overview

From 2011 through 2018, there were 15,142 reported aircraft incidents or accidents resulting from wildlife strikes in all Brazilian military, commercial, and private airports. Approximately 30.17% (n = 4,569) of those caused damage to aircraft. One general aviation (GA) aircraft was destroyed as a result of a bird strike(s). However, it is important to note that this accident did not occur at one of the 32 airports investigated in the current study. No fatalities were reported during the period studied. However, one GA (in 2011) and one military (in 2013) pilots were seriously injured as a result of bird strikes at the Salvador airport environment. In addition, one military pilot was injured after bird strikes in a military airfield, in Rio de Janeiro, in 2015. During the period studied, most reported strikes contained either no information or conflicting information regarding the costs and/or aircraft downtime time associated with those incidents. Nevertheless, considering only the 91 most significant strikes that occurred between 2011 and 2016 in which the direct costs and/or aircraft downtime were provided (Oliveira et al., 2017), the direct economic losses were approximately US$ 20,312,000, with an average of US$ 223,208.80 per damaging strike. Similarly, there were 103 wildlife strike reports that provided aircraft downtime, totaling 20,094 aircraft downtime hours, with an average of 195.09 hours per strike.

3.2. Wildlife strikes in the 32 busiest airports in Brazil (2011-2018)

Year	Wildlife Strike Reports	Total Movements at the 32 Busiest Brazilian Airports	Wildlife Strike Index
2011	1,067	2,576,722	41.41
2012	1,260	2,780,623	45.31
2013	1,333	2,707,609	49.23
2014	1,184	2,649,514	44.69
2015	1,456	2,507,777	58.06
2016	1,626	2,263,527	71.83
2017	1,630	2,198,761	74.13
2018	1,818	2,260,670	80.42
Total	**11,374**	**19,945,203**	**57.03**

Table 2. Wildlife strikes and aircraft operations at the 32 busiest airports in Brazil: 2011-2018

From 2011 through 2018 there were 11,374 reported wildlife strikes to aircraft at or around the 32 busiest commercial airports in Brazil. Considering the strike reports in which information about the species was provided (n = 6,296), 5,528 (87.81%) incidents involved birds, 108 strikes (1.71%) involved reptiles, and 660 (10.48%) strikes involved mammals. Among the 660 mammal strikes, 173 involved bats. The number of reported wildlife strikes increased by 70% from 2011 through 2018. Conversely, the number of aircraft operations decreased by approximately 12.27% during the same period. Thirty-two percent (n = 3,661) of the wildlife strikes caused damage to the aircraft (Table 2).

3.3. Type of operators

Type of Operator	Reported Strikes	Aircraft Movements	Wildlife Strike Index
Commercial	8,817	13,433,211	65.64
General Aviation	617	5,687,269	10.85
Military	227	824,723	27.63
Unknown	1,713	------------	------------
Total	11,374	19,945,203	57.03

Table 3. Wildlife strikes per type of operator at the 32 busiest airports in Brazil: 2011-2018

The majority (91.26%) of the reported wildlife-strike events in which the operator was identified involved commercial operators, followed by GA aircraft (6.39%). Fifteen percent of the reported strikes did not contain information about the type of operator (Table 3).

3.4. Strikes per phase of fight

Phase of Flight	Number of Strikes	Damaging Strikes
Taxi	135	32
Takeoff	2,537	655
Climb	285	112
Cruise	38	294
Descent	126	41
Approach	845	270
Landing	3,509	553
Low Altitude Navigation	25	6
Unknown	3,874	1,698
Total	11,374	3,661

Table 4. Number of wildlife strikes and damaging strikes per phase of flight at the 32 busiest airports in Brazil: 2011-2018

Note. Aircraft turnaround check involves aviation-related personnel who identify the wildlife strike anytime between after landing through departure, excluding the crew members who operated the aircraft at the time the strike probably occurred (the exact phase of flight where the strike occurred is generally not identifiable) (CENIPA, 2017).

Note 2. Runway check involves aviation professionals (generally airport personnel) finding wildlife remains, whole or in part, at the airport environment, in which they will have a reason to believe were the result of (a) wildlife strike(s) (the exact phase of flight where the strike occurred is generally not identifiable) (CENIPA, 2017).

Note 3. "Low-altitude navigation flight is a flight mission performed by the armed forces in Brazil in which aircraft fly at low altitudes outside the airport environment for different purposes" (Mendonca et al., 2018, p. 12).

During the period studied and considering only the reports in which the phase of flight was reported, most strikes (59.74%) occurred during the arrival phases of flight (descent; approach; landing). Similarly, the majority of damaging strikes (44.01%) happened during the arrival phases of flight. However, considering only specific phases of flight, most strikes (46.79%) happened during landing whereas the majority (33.37%) of the damaging strikes (aircraft serious incident or accident) occurred during takeoff. It is important to note that 669 strikes were identified during the runway check. In addition, 3,048 strikes and 263 damaging strikes were reported as occurring during the aircraft turnaround check. For the purpose of this study the researchers considered those strikes to have occurred during an unknown phase of flight (Table 4).

3.5. Part struck and sources of report

Considering only the reports in which information about the part of the aircraft struck was reported (n = 6,137), the aircraft parts most hit by animals at or around the 32 busiest Brazilian commercial airports was the engine (27.62%), followed by the landing gear (11.29%) (Figure 1). From 2011 through 2018, 33% of the wildlife strikes were reported by airport personnel (not including wildlife hazard management professionals), followed by safety professionals (25.07%) (Figure 2).

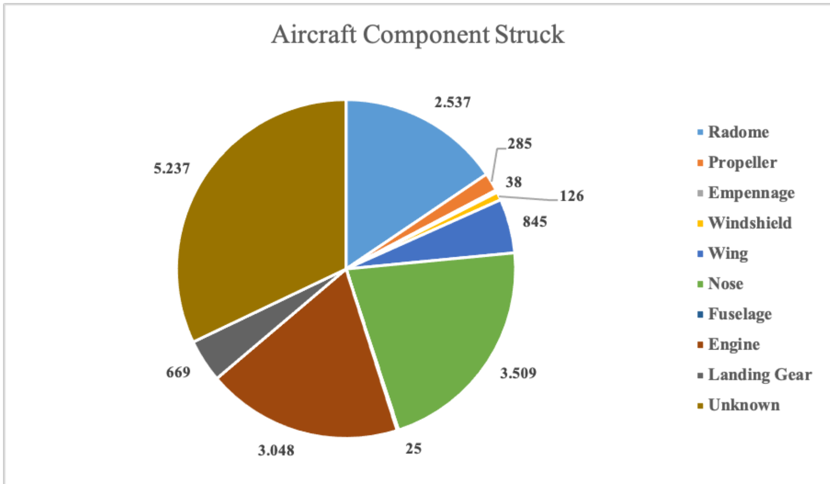

Figure 1. Aircraft components hit by wildlife

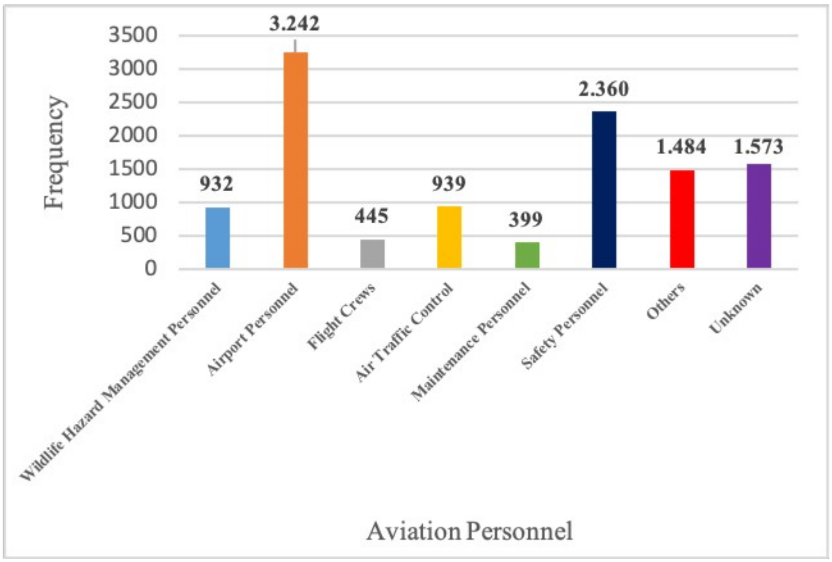

Figure 2. Aviation professional submitting the report

3.6. Time of occurrence of the safety event

The proportion of wildlife strikes and damaging wildlife strikes varied among times of the day. The great majority of strikes (62.08%) and of damaging strikes (66.21%) occurred during the day. Notably, 28.71% and 22.07% of the strikes and damaging strikes, respectively, occurred at night. Even though almost 10% of the total strikes happened during dawn and dusk, only 2.33% of those caused damage to aircraft (Table 5).

Time of the Day	Strikes	Damaging Strikes
Dawn	509	132
Day	7,061	2,424
Dusk	539	134
Night	3,265	808
Total	11,374	3,661

Table 5. Number of wildlife strike events per time of the occurrence at the 32 busiest airports in Brazil: 2011-2018

3.7. Altitude during the wildlife strike and of the damaging wildlife strike

From 2011 through 2018, approximately 93.45% and 90.63% of the strikes and damaging strikes, respectively, occurred at or below 500 feet above ground level (AGL). About 97% of the strikes and 96% of the damaging strikes happened within the airport environment (at ≤ 1,500 feet AGL) (Dolbeer et al., 2019). Considering only the strikes that occurred within the airport jurisdiction (n = 10,665), 30.23% of them (n = 3,223) caused damage to the aircraft. Yet, three percent (n = 372) and four percent (n = 139) of the strikes and damaging strikes, respectively, occurred outside the airport wildlife hazard management efforts (if any) effectiveness (at ≥ 1,500 feet AGL). Even though only one percent of the total strikes occurred between 5,001 and 5,500 feet AGL (n = 12), 75% of them caused damage to the aircraft (n = 9). Noteworthy to mention that during these analyses the researchers included only the strike reports in which the altitude of the event was reported.

Altitude in feet AGL	Number of Strikes	Number of Damaging Strikes
0-500	10,313	3,047
501-1,000	239	103
1,001-1,500	113	73
1,501-2,000	74	36
2,001-2,500	53	21
2,501-3,000	46	16
3,001-3,500	34	13
3,501-4,000	38	12
4,001-4,500	23	7
4,501-5,000	22	8
5,001-5,500	12	9
5,501-6,000	14	3
6,001-6,500	10	0
6,501-7,000	9	7
7,001-7,500	6	0
7,501-8,000	0	0
Above 8,000	31	7
Unknown	337	299
Total	11,374	3,661

Table 6. Number of wildlife strike events per altitude AGL

4. Discussion and Conclusions

The aviation industry has long recognized the financial and safety threat collisions between wildlife and aircraft pose to aircraft operations (DeFusco, Junior, Cooley, & Landry, 2015). According to Cleary and Dolbeer (2005), a first and mandatory step in the safety management of wildlife hazards to aviation is the collection and analysis of previous aircraft incidents and accidents due to wildlife strikes. Researchers analyzed wildlife strike and aircraft operations data from the 32 busiest Brazilian commercial airports (see Table 1), from 2011 through 2018. Results indicated that during the period studied the number (70%) and rate of wildlife strikes (94%) have increased in the 32 busiest commercial airports in Brazil, despite a decrease (12%) in the number of aircraft operations. As previously mentioned, during the period studied, 72% of all reported wildlife strikes in Brazil occurred at or around these 32 commercial airports. Possible explanations for the reported increase in aircraft-wildlife collisions in Brazil include, but are not limited to:

1. Lack of and/or inadequate national policies and standards addressing the safety management of wildlife hazards to aviation by aviation stakeholders, especially airport operators;

2. Successful aviation safety programs (e.g., WHMP) leading to more strikes being reported;

3. Increased wildlife activities at and/or around the studied airports;

4. Increased aircraft operations in some of the studied airports in which the probability of wildlife strikes for unidentified factors (e.g., wildlife hazard attractants near the airport) is high (Araujo et al., 2018; Bast, 2018);

5. Commercial airports that did not hold an airport BFAR 139 operating certificate (ANAC, 2018);

6. Airport operators that, despite holding an airport BFAR 139 operating certificate (ANAC, 2020a) have not yet developed and/or implemented a WHMP;

7. Ineffective WHMP by airport operators;

8. Inconsistent wildlife strike databases (e.g., by airport operators) that hinder the development of or the annual (and/or periodic) effectiveness assessment of the airport WHMP; and

9. Any combination thereof.

From 2001 through 2018, most aircraft-wildlife collisions at the 32 busiest commercial airports in Brazil involved commercial aircraft. GA aircraft accounted for less than four percent of the total strikes in which the type of operator was identified. However, the GA aircraft wildlife index was smaller than the commercial and military operators' indexes. A possible reason for this finding could be that the number of commercial aircraft operations, from 2011 through 2018 was 2.36 and 16.3 higher than the number of GA and military aircraft operations, respectively. Other conceivable explanation for this finding could be a higher safety awareness by commercial operator professionals who are more likely to report strikes than military and especially GA operators. Empirical data suggest that GA aircraft operators are less likely to report wildlife strikes (Dolbeer et al., 2019). Findings from previous studies indicate that GA operators report approximately five percent of the total strikes (Cleary & Dickey, 2010; Schwarz, Belant, Martin, DeVault & Wang, 2014). Nevertheless, airport and safety professionals reported almost 50% of the 11,374 strikes from 2011 through 2018. A finding of concern, which shed some light in Mendonca et al. (2018), was that flight crews reported less than four percent of the total strikes. Educational initiatives to encourage aviation professionals, especially pilots, to report strikes is imperative for safety enhancement. Nevertheless, aviation professionals should also be better educated in order to provide as much (accurate) information as possible whenever submitting a wildlife strike report. For example, few strike reports provided cost information associated with the occurrence.

Considering only wildlife strikes (n = 11,037) and damaging strikes (n = 3,362) in which the altitude of the event was reported, 97% and 96%, respectively, occurred at the airport wildlife hazard management jurisdiction (at ≤ 1,500 AGL). Similarly, considering the number of strikes (n = 6,466) and damaging strikes (n=1,963) in which the phase of flight was informed, 86% and 69%, respectively, occurred at the airport WHMP environment. Therefore, management efforts by airport operators supported by empirical wildlife strike data could significantly enhance the safety of aircraft operations at and around the Brazilian airports. In addition, as proposed by MacKinnon (2004), Mendonca, Carney, and Fanjoy (2018), and the National Transportation Safety Board (2009), it is recommended that pilots take actions while flying below 10,000 feet to reduce the risk of aircraft accidents due to wildlife strikes. Such efforts include reducing flight time and/or the aircraft airspeed while flying below this altitude, and the use of the external aircraft lights, if operationally possible.

Findings suggest that the risk of wildlife strikes and damaging strikes is the highest during the day. Nonetheless, the number of aircraft operations per time of the day was not available (DECEA, 2014, 2017, 2019). Assuming that the number of aircraft operations is significantly higher during the day, it is plausible to expect the number of strikes and damaging strikes to be also higher during the day. Nonetheless, airport operators could consider this finding while developing and/or assessing their WHMP. The aircraft component most reported as being struck was the engine. Current jet engines are "finely balanced precision machines" (MacKinnon, 2004, par. 10). A wildlife strike, even from a single small bird could result in some engine damage. According to Avrenli and Dempsey (2014), due to the higher rotation of the engine(s) in specific phases of flight (e.g., takeoff roll), bird ingestions to the engine could lead to complete engine failure and destruction. This is one of the reasons for the extremely high costs associated with wildlife strikes.

5. Further recommendations and future studies

According to Cleary and Dickey (2010), it is difficult to justify, fund, and defend some wildlife control airport strategies such as wildlife removal and/or lethal traps for mammals and birds without empirical wildlife strike data and information. Nevertheless, as cited by Dale (2009) and DeFusco & Unangst (2013), airport personnel must earnestly pursue their legal duties which include the safe operations of aircraft and the traveling public. Aircraft accidents frequently result in damage to property and /or loss of lives, public criticism, and adverse media attention (Mateou & Mateou, 2010; Solomon & Relles, 2011). In the U.S., criminal and civil lawsuits have been filed against airport operators and managers in the aftermath of aircraft mishaps due to wildlife strikes (Cleary & Dolbeer, 2005; Dale, 2009). In Brazil, aircraft accidents have also resulted in criminal and liability charges being filed citing the negligence, breach of duty, and/or intentional torts of aviation and other professionals (Cascione, 2007; Jardim, 2017; Werfelman, 2008). Therefore, airport operators should strive to develop, implement, and ensure the effectiveness of their WHMP not only for aviation safety assurance but also to legally protect the airport in case of a mishap resulting from wildlife strikes.

Empirical data (Hesse, Rea, & Booth, 2005; MacKinnon, 2004; Searing, 2019) clearly indicate that safety efforts by aviation stakeholders, especially airport operators (Cleary & Dolbeer, 2005; Dolbeer et al., 2019; Weller, 2019), could significantly enhance the safety of aircraft operations regarding wildlife hazards. The Brazilian aviation industry must balance the frequently constrained resources and aviation safety while developing strategies to manage the risk of wildlife strikes. Developing, assessing, and/or improving existing WHMP relies heavily on the analysis of wildlife strike data. According to Dolbeer et al. (2019), the information obtained from this analysis is vital for the "development and implementation of integrated research and management efforts to reduce wildlife strikes" (p. 3), significantly increasing the safety of aviation operations. Based on the findings of the current and the previous (Mendonca et al., 2018) studies, it is evident that outreach and education efforts are needed to enhance the reporting of strikes in Brazil. Some inconsistencies were found in the Brazilian wildlife strike database (e.g., a reported wildlife strike during takeoff roll at 3,000 feet AGL). Yet, several reports were missing information (e.g., costs; phase of flight). As previously mentioned, a robust wildlife strike database, which highly depends on the reporting of wildlife strikes (quantity and quality) by aviation professionals, is critical for management safety efforts, policy and regulatory decisions, and research initiatives. According to Cleary and Dickey (2010), "without consistently maintained records of wildlife activity, wildlife strikes, and wildlife management actions, the proper evaluation of a program is impossible. Without an evaluation, no assessment of the effectiveness of a program can be made" (p. 113). It is noteworthy to mention that the Brazilian wildlife strike reporting system needs to provide a mechanism to add information collected later. For example, a pilot can report a strike right after it happens but may not know the amount of damage and/or the direct and indirect costs associated with the strike until later. This information could be, if made available, later be provided by any aviation professional to CENIPA using the existing reporting system. At last, educational and promotional campaigns can assist in increasing the quantity and in enhancing the quality of wildlife strike reports by aviation professionals.

There are limitations to this study. The DECEA reports (DECEA, 2014, 2016, 2017) only had aircraft operations data from the 32 busiest airports in Brazil. Nevertheless, the 32 commercial airports investigated in this study hosted approximately 85% of the aircraft operations in 2018. Future studies should incorporate aircraft movement data from other Brazilian airports when these data become available. Moreover, the quality and quantity of the reported strikes limited the data analysis. For example, approximately 35% and 46% of the reported strikes did not contain information about the phase of flight and/or of the part struck, respectively. Yet, few reports contained information about the direct and indirect costs associated with the strike event. Such information is paramount while developing, implementing, and assessing the effectiveness of WHMP. Nonetheless, the researchers assumed that the reported wildlife strike data, as well as the aircraft operations data, was accurate

The researchers contend that a study to investigate the causes of the incompleteness of the reported strikes is imperative. Additionally, as suggested by Dolbeer et al. (2019) and Mendonca et al. (2018), a multifaceted educational outreach approach to improving the reporting of wildlife strikes to aircraft is recommended. We acknowledge that these limitations may constrain the generalizability of our findings. Nonetheless, findings of this study could be used as the groundwork during the development and assessment of WHMP and other aviation stakeholders' safety efforts to prevent aircraft accidents due to wildlife strikes. This study is the second in a series whose general goals are to investigate wildlife strike and aircraft operations data from Brazil, and to provide empirical data and information for accident prevention purposes. Based on the current and previous (Mendonca et al., 2018) projects, the next study will investigate wildlife strike data from the 20 busiest commercial airports in Brazil from 2011 through 2019, but providing empirical data and information for each specific airport.

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