OmniaScience

Journal of Airline and Airport Management

JAIRM, 2017 – 7(1), 43-64 Online ISSN: 2014-4806 – Print ISSN: 2014-4865

https://doi.org/10.3926/jairm.82

Managing the Risks: An Analysis of bird strike reporting at Part 139 Airports in Indiana 2001-2014

Flavio A. C. Mendonca, Julius Keller, Yu Wang

Purdue University (United States)

fmendonc@purdue.edu, keller64@purdue.edu, wang1505@purude.edu

Received June, 2016
Accepted April, 2017

Abstract

Purpose: The purpose of the current study was fourfold: to identify bird strike reporting trends at Part 139 airports in Indiana (2001-2014) for comparison to national data; to determine which quarter of the year yields the most bird strike data; to gain a clearer understanding of the relationship between altitude and bird strikes, and to develop information based upon the data analyzed that can be used for the safety management of birds including comparisons to national data.

Design/methodology: The researchers in this study answered the research questions by reviewing, sorting, and analyzing existing data. The data collection took place from March 01 to May 02, 2016. Two data sets were utilized for data collection. The National Wildlife Strike Database (NWSD) and the FAA Air Traffic Activity System (ATADS).

Findings: When compared to national data, Indiana Part 139 airports have seen a faster increase in bird strike reporting during 2012 and 2014. Aggregate data indicated June through September (Quarter 3) had a significantly higher frequency of bird strikes reported. When examining bird strikes and altitude of occurrences, the exponential equation explained 95 % of the variation in number of strikes by 1,000-foot intervals from 1000 to 10,000 feet. Not surprisingly, the risk of bird strikes appears to decrease as altitude increases.

Originality/value: This study adds to the body of knowledge by addressing the lack of published bird strike report analyses at a regional level. It also connects data analyses to safety management system

(SMS) concepts and Wildlife Hazards Management Programs (WHMP). The aviation community can use regional bird strike data and information to develop or enhance existing wildlife hazard management programs, increase pilot awareness, and for refinements in the development and implementation of integrated research and operational efforts to mitigate the risk of bird strikes.

Keywords: aviation safety, bird strikes, wildlife management, safety management systems.

---

1. Introduction

The world learned, in the aftermath of the miraculous accident involving US Airways Flight 1549, that birds pose a serious hazard to aviation safety and cause significant economic losses to the aviation industry (Dolbeer, 2009; Hardt, Colyer, & Allen, 2009). Additionally, bird strikes cause liability issues for airlines and airport operators (Dale, 2009; Juricic, Gaffney, Blackwell & Baumhardt, 2011). Globally, bird strikes, the most common wildlife encounter, and other wildlife strikes have killed more than 255 people and destroyed over 243 aircraft from 1988 to 2013 (Dolbeer, Wright, Weller, Anderson & Begier, 2015).

In the United States, bird strikes have resulted in, on annual average, 119,645 hours of aircraft downtime and $193 million in monetary losses (Dolbeer, Wright, Weller, Anderson & Begier., 2015). However, even though previous studies have indicated an increase in bird strike reporting, many bird strike reports do not provide accurate cost estimates, and many strikes go unreported. According to Dolbeer et al. (2015), from 1990 to 2014, reported monetary losses were approximately $643 million, including direct and indirect costs. However, only about 2% of the reports provided information about the financial losses related to the bird strike. Therefore, actual total costs in the U.S. may be significantly higher (Anderson, Carpenter, Begier, Blackwell, DeVault & Shwiff, 2015; DeFusco & Unangst, 2013).

The trend in under or inaccurate reporting is primarily attributed to several factors, including physical, which means the bird strike was not noticed by the pilots, during or post flight. Another example of physical is when a carcass is found but impossible to relate to an aircraft. Cultural, relates to when there is no active promotion of reporting of near-misses by crew members. Ignorance implies that an aviation professional does not believe in the importance of the reporting for reasons such as aversion to paperwork and or time pressure (Dekker & Buurma, 2005; Mendonca, 2008). Several strategies undertaken by the Federal Aviation Administration (FAA), in partnership with other aviation stakeholders from 2009 to 2013 have enhanced the quantity and quality of reporting (Dolbeer, 2015).

An estimated 91% of strikes with commercial aircraft at Part 139 airports are now reported (Dolbeer, 2015). The 14 Code of Federal Regulations (CFR) Part 139 applies to airports that serve any scheduled and unscheduled air carrier aircraft with more than 30 seats, and that serve scheduled air carrier operations in aircraft with more than 9 seats but less than 31 seats. Additionally, the FAA administrator may require other types of airports to be certified under 14 CFR Part 139 (FAA, 2017). Bird strikes are a significant liability and hazardous to aviation operations (Blackwell, DeVault, Seamans, Lima, Baumhardt & Juricic, 2012). Factors that have contributed to the increasing threat of birds to aviation include, successful environmental programs funded by conservation and governmental organizations, increased air traffic, and wildlife adaptation (Cleary & Dolbeer, 2005; Dolbeer, 2011; Dolbeer et al., 2015). Thus, recognizing that bird threats to aviation are of significance and increasing, aviation stakeholders have increased safety efforts to reduce the risk of aircraft accidents and incidents (DeFusco & Unangst, 2013). A primary way of understanding the significance of bird strikes is through data collection and analyses.

The purpose of the current study was fourfold: to identify bird strike reporting trends at Part 139 airports in Indiana (2001-2014) for comparison to national data; to determine which quarter of the year yields the most bird strike data; to gain a clearer understanding of the relationship between altitude and bird strikes, and to develop information based upon the data analyzed that can be used for the safety management of birds including comparisons to national data. This study adds to the body of knowledge by addressing the lack of published bird strike report analyses at a regional level. It also connects data analyses to safety management system (SMS) concepts and Wildlife Hazards Management Programs (WHMP). The aviation community can use regional bird strike data and information to develop or enhance existing wildlife hazard management programs, increase pilot awareness, and for refinements in the development and implementation of integrated research and operational efforts to mitigate the risk of bird strikes.

2. Literature Review

The risk of bird strikes is higher in and at the airport vicinity (Dolbeer, 2011; Dolbeer et al., 2015; Dolbeer & Begier, 2011; Dolbeer & Begier, 2012). The presence of wildlife within the airport vicinity poses a serious threat to aviation safety (Cleary & Dolbeer, 2005; Eschenfelder & DeFusco, 2010; ICAO, 2013a; Mendonca & Johnson, 2015). Therefore, adequate actions must be adopted to reduce the risk of aircraft accidents due to wildlife (FAA, 2007). Airport operators are legally and professionally obligated to reduce the risk of aircraft accidents due to wildlife (DeFusco & Unangst, 2013). Provisions in ICAO Annex 14 requires certified airports to develop and implement wildlife management programs to reduce the risk of wildlife strikes at the airport and vicinity (Cleary & Dolbeer, 2005; Dolbeer, 2006a; ICAO, 2012). A certificated airport operating under the 14 Code of Federal Regulations (CFR) Part 139 experiencing wildlife hazards is required to conduct a Wildlife Hazard Assessment (WHA). Based on the WHA, the airport movement, and other factors, the FAA will require the Part 139 airport operator to develop and implement a Wildlife Hazard Management Plan (WHMP) (Rillstone & Dineen, 2013). According to Dolbeer, Weller, Anderson and Begier (2016), all required Part 139 airports have completed an WHA or are a joint-use facility that maintains a Bird/Wildlife Aircraft Strike Hazard (BASH) Plan. The WHMP should be designed to address aviation safety threats caused by aircraft-wildlife collisions by establishing methods and procedures to manage and control wildlife (FAA, 2015; Rillstone & Dineen, 2013). The plan must be approved by the FAA and be included in the Airport Certification Manual (ACM). WHMPs will be a critical element when Safety Management Systems (SMS) are required for Part 139 airports.

The FAA (2015) defines SMS as "an organization-wide comprehensive and preventive approach to managing safety" (p. ii). Organizations with a functional SMS can proactively manage risks, detect and correct safety hazards before those problems contribute to an aircraft accident, and reduce the costs of mishaps (DeFusco, Junior, Cooley & Landry, 2015; ICAO, 2013b; Stolzer, Halford & Goglia, 2008). The most important benefit of an effective SMS is enhanced flight safety (Cardoso, Maurino & Fernandez, 2008; Gnehm, 2013; ICAO, 2013c; Ludwig, Andrews, Veen & Laqui, 2007; Mendonca & Johnson, 2015). Further benefits may include logical prioritization of safety needs, compliance with applicable regulatory standards, and continuous improvement of operational processes (Junior, Shirazi, Cardoso, Brown, Speir, Seleznev et al., 2009). Additionally, requirements for safety management systems (SMS) at Part 139 airports may be imposed in the near future. Data collection and analyses are a key element of an effective SMS program.

Following DeFusco et al., (2015), the safety management of wildlife fits perfectly with the SMS tenets. Data are normally collected as part of wildlife management programs. Safety risks are assessed and mitigated. Finally, "known risks are associated with hazardous wildlife; outcomes are measurable and empirical in nature; and wildlife management program goals such as continuous improvement through trending and data analysis can be incorporated directly into an airport's SMS" (DeFusco et al., 2015, p. 1).

According to Buurma and Dekker (2005), bird strike statistics are the main source of information for three processes. Bird strike reporting analyses will help stakeholders gain a clearer understanding of the problem. Data analyses are educational for employees and the general public. Furthermore, data is the primary determinant when measuring the effectiveness of preventive programs (e.g. WHMP) (Dekker & Buurma, 2005; Dolbeer, 2006b). Following Dolbeer et al., (2015), management strategies by airports operators should prioritize actions based upon data and information of previous strikes (e.g. altitude where most strikes occur). Additionally, the analysis of strike reports may provide information to the aviation industry to improve the resistance of bird impacts on aircrafts, and to establish standard operating procedures (SOPs) for pilots (MacKinnon, 2004). Several bird and other wildlife strike studies have analyzed data at a national level (Dolbeer et al., 2015).

The National Wildlife Strike Database (NWSD) became fully operational in 1995 (Cleary & Dolber, 2005; Dolber et al., 2015). This database contains more than 170,000 wildlife strikes reported to the FAA since 1990. The reporting of wildlife strikes is vital for accident prevention (Cleary & Dolbeer, 2005; Dekker & Buurma, 2005; Dolbeer & Wright, 2009; MacKinnon, 2004; Mendonca, 2011). Wildlife strike report data and information are vital to determining the nature of the safety hazard (e.g., costs of incidents, operators, altitude of the strikes, types of damage, and height and phase of flight during which strikes occur).

The FAA assisted by the U.S. Department of Agriculture (USDA), have produced annual and special reports from the NWSD (Dolbeer et al., 2015). The information obtained from these analyses provided a benchmark for aviation stakeholders, especially Part 139 operators, to develop, implement, evaluate, and improve required WHMPs. The last comprehensive review of wildlife strikes from the NWSD examined the time period from 1990-2014 and became available in August 2015.

The number of bird strikes reported to the FAA increased from 1,795 to 13,159 when comparing years 1990 and 2014 (Dolbeer et al., 2015).

Birds were involved in approximately 97% of all reported wildlife strikes. For both commercial and general aviation (GA), approximately 72% of bird strikes occurred within the vicinity of the airport (below 500 feet above ground level [AGL]). Over 91% of all reported bird strikes occurred below 3,500 feet AGL. Bird strikes occurring above 500 feet AGL were more likely to cause damage than strikes below 500 feet AGL for both GA and commercial aircraft. Additional research findings have added to the discussion of damage to aircraft by birds.

Previous studies (Avrenly & Dempsey, 2014; Dolbeer, 2007) purported the risk of substantial damage after a bird strike is higher during departure (takeoff run and climb) than arrival (descent, landing, landing roll). One factor that explains such difference is the faster rotation of the engine(s) during departure. Moreover, during the climb out phase of flight the aircraft usually moves faster than on final approach, thus increasing the severity of strikes. The equation KE = (½ mass) x (velocity squared), where KE stands for kinetic energy imparted on the airplane in foot per square inch, clearly reveals that the "engine speed" and the aircraft speed on departure increase the risk of substantial damage to the engine (Eschenfelder, 2005). A catastrophic bird strike (multiple engines) during departure creates a multitude of challenges, which explains the preponderance of hull losses following strikes during takeoff or climbout (Dolbeer, 2007).

Fifty-three percent of all reported bird strikes occurred between July and October. Majority of the incidents (61%) occurred when the aircraft was arriving (descent, approach, and landing roll) phase of flight compared to 35% during take-off roll and climb (departure). Sixty-three percent of the bird strikes occurred during the day, and 30% at night. Finally, Dolbeer et al., (2015) showed "that above 500 feet, the number of reported strikes declined consistently by 34% and 44% for each 1,000-foot gain in height for commercial and general aviation (GA) aircraft, respectively" (p. 72). Quality data and information undergird the integrated and efficient safety management of wildlife by airport operators. The NWSD provides a means to enhance aviation safety regarding the risk of aircraft accidents due to wildlife strikes. Moreover, the FAA annual and special reports provide information related to wildlife strikes in the U.S., but only in a national level. However, considering the highly variable and usually regional conditions that influence wildlife behavior (e.g., activities that attract birds to the airport environment; the behavior of migratory and non-migratory birds), there is a need to analyze regional data in order to develop specific information paramount for accident prevention. Experts assert there is room for improvement with regard to bird hazard and aviation safety (Belant & Ayres, 2014; Cleary & Dolbeer, 2005; DeFusco et al., 2015; DeFusco & Unangst, 2013). Currently, there is no information summarizing the results of analyses of the data from the NWSD related to Part 139 airports in the state of Indiana. Such analyses are critical to determining the economic cost of wildlife strikes, the magnitude of safety issues, and most important, the nature of the problems (e.g., wildlife species involved, level of damage, height and phase of flight during which strikes occur, and seasonal patterns). It is believed that information obtained from the analyses of the bird strikes in Indiana, using the NWSD, may provide information for national and local safety policies. Additionally, for refinements in the development of integrated research and safety efforts to mitigate bird strikes (Dolbeer et al., 2015). Moreover, it will generate information that could be used by pilots to reduce the risk of bird strikes (Dolbeer, 2015; MacKinnon, 2004; Mendonca, 2008). The concept of this research can also be useful for other Part 139 certificated airports across the U.S. At last, data and information on the number of accidents or incidents due to bird strikes may provide a benchmark for individual Indiana Part 139 airports to evaluate and improve Wildlife Hazard Management Plans (Dolbeer & Begier, 2011; ICAO, 2013a). To gain a clearer understanding of bird strike reporting at Part 139 airports in Indiana, the following research questions were addressed:

1. What is the number of bird strike reports per 100,000 movements for each year during 2001-2014 at Part 139 airports in the state of Indiana?
2. What are the differences in bird strike reports between each quarter of the year in during 2001-2014 at Part 139 airports in the state of Indiana?
3. What is the relationship between the altitude of flight (above ground level) and the number of bird strike reports during 2001-2014 at Part 139 airports in the state of Indiana?
4. What are the descriptive statistics for type of operator, time of day, level of damage to aircraft, cost of damage, and phase of flight when examining bird strike report data from Part 139 airports during 2001-2014?

3. Methodology

3.1 Data collection

The researchers in this study answered the research questions by reviewing, sorting, and analyzing existing data. The data collection took place from March 01 to May 02, 2016. Two data sets were utilized for data collection. The National Wildlife Strike Database (NWSD) and the FAA Air Traffic Activity System (ATADS). Both databases are publically available and accessible online. Researchers used the NWSD was to obtain the number of reported bird strikes that occurred within the vicinities of all 10 Part 139 airports in Indiana, shown in Table 1. The database output was filtered by Date Range, State, Airport, Operator (aviation sector), Phase of Flight, Altitude of Flight, Time of Day, Level of Damage, Cost of Repairs, Injuries, Fatalities, and Time of Year. The researchers selected the date range from January 1st, 2001 to December 31st, 2014. The final two quarters of 2015 was missing from the databases at the time of collection, therefore the data from 2015 was excluded from the study.

The ATADS database including air traffic operations was used to retrieve the number of aircraft movements. One aircraft movement refers to one takeoff, one landing or itinerant traffic. The database can be sorted by date and airport facilities. Similar to the FAA Wildlife Strike database, a 14-year data range from January 1st, 2001 to December 31st, 2014 was selected from ATADS.

Identifier	Airport Name	City
KBAK	Columbus Municipal Airport	Columbus, IN
KMIE	Delaware Country Regional Airport	Muncie, IN
KEVV	Evansville Regional Airport	Evansville, IN
KFWA	Fort Wayne International Airport	Fort Wayne, IN
KGYY	Gary International Airport	Gary, IN
KIND	Indianapolis International Airport	Indianapolis, IN
KBMG	Monroe Country Airpo	Bloomington, IN
KLAF	Purdue University Airport	Lafayette, IN
KSBN	South Bend International Airpo	South Bend, IN
KHUF	Terre Haute International Airport-Human Field	Terre Haute, IN

Table 1. Part 139 airports in the state of Indiana

3.2 Data analysis

Data collected from both datasets were exported to Microsoft Excel for data analysis. To ensure the validity of the study, three researchers checked data collected independently and discrepancies of the data were fixed. To answer research question 1, the numbers of bird strikes and aircraft movements at Part 139 airports in Indiana during 2001-2014 were obtained from the two databases. The researchers sorted the data and calculated the total number of bird strikes per 100,000 movements at the Part 139 airports by using Microsoft Excel. Regarding question 2, a Kruskal-Wallis test using SPSS 23® was conducted to determine if there were differences in the number of bird strikes per 100,000 movements between the four quarters of the year. Pairwise comparisons between the four quarters were provided and statistically significant differences were reported. To answer research question 3, the researcher examined an exponential equation to identify the relationship between the number of bird strikes and the altitude of flight above ground level by using Microsoft Excel. Regarding research question 4, additional data such as time of day, level of damage to aircraft, costs of damage, and type of operator were explored.

4. Results

The number of bird strike reports has increased steadily from 2001 to 2014 while the number of total movements at Indiana Part 139 airports has steadily declined. There was a 343.33% increase in bird strike reports when comparing years 2001 and 2014. The number of movements decreased 38.64%

between 2001-2014. Table 2 shows the year, number of bird strike reports, total movements, and bird strike reports per 100,000 movements. Figure 1 is a line graph representation of the same data.

Year	Bird Strike Reports	Total Movement at Indiana Part 139 Airports (2001-2014)	Bird Strike Reports per 100,000 Movements
2001	60	831,696	7.21
2002	55	850,203	6.47
2003	71	795,308	8.93
2004	106	791,288	13.40
2005	104	779,226	13.35
2006	131	739,583	17.71
2007	146	691,318	21.12
2008	116	661,459	17.54
2009	137	591,875	23.15
2010	113	569,111	19.86
2011	126	527,643	23.88
2012	166	527,703	31.46
2013	191	515,661	37.04
2014	266	510,323	52.12
Total	**1788**	**9,382,397**	**20.94 (Avg)**

Table 2. Total bird strike reports at Indiana Part 139 Airports (2001-2014). Note: Avg=average

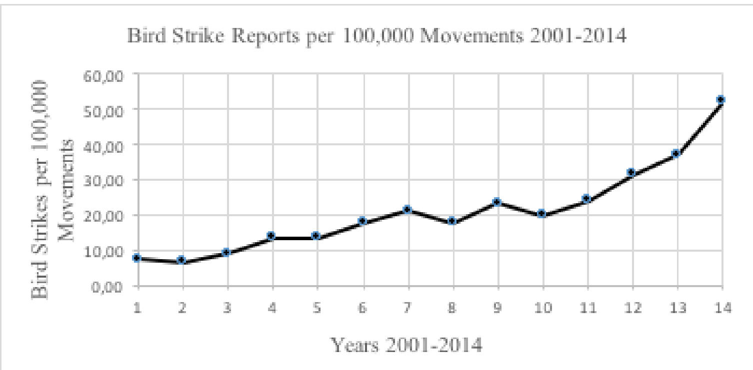

Figure 1. Bird strike reports per 100,000 movements at Indiana Part 139 airports 2001-2014

Researchers used the same databases to ascertain the number of bird strikes and total number of movements for each quarter between the years 2001 and 2014. The quarters were defined by the calendar year: January-March, April-June, July-September, and October-December. The average number of bird strike reports for Quarter 1 was 5.42. The average number of bird strike reports for

Quarter 2 was 16.17. The average number of bird strike reports for Quarter 3 was 35.97. Lastly, the average number of bird strike reports for Quarter 4 was 16.16. Tables 3 and 4 show the number of bird strike reports, total movements, and year broken down by quarter.

A Kruskal-Wallis test was conducted to determine if there were differences in reported bird strikes per 100,000 movements between the four quarters of the year: Quarter 1 ($n = 14$), Quarter 2 ($n = 14$), Quarter 3 ($n = 14$) and Quarter 4 ($n = 14$). The Kruskal-Wallis test was selected over an ANOVA because there was an outlier within quarter 3 (value 96.64 - Q3). Additionally, distributions of reported bird strikes per 100,000 movements were not similar for all groups, as assessed by visual inspection of a boxplot.

Year	Bird Strike Reports Q1	Movements	Strikes per 100,000 Movements	Bird Strike Reports Q2	Movements	Strikes per 100,000 Movements
2001	1	194,833	0.51	14	210,800	6.64
2002	3	192,633	1.56	10	219,467	4.56
2003	2	176,640	1.13	17	202,220	8.41
2004	5	185,339	2.70	25	201,827	12.39
2005	8	180,522	4.43	20	205,789	9.72
2006	9	178,142	5.05	23	189,948	12.11
2007	6	160,789	3.73	25	178,002	14.04
2008	3	149,537	2.01	23	175,704	13.09
2009	14	138,966	10.07	24	145,144	16.54
2010	6	129,097	4.65	31	150,542	20.59
2011	9	122,902	7.32	30	131,563	22.80
2012	17	123,958	13.71	49	135,821	36.08
2013	13	117,186	11.09	43	131,404	32.72
2014	21	108,191	19.41	56	133,404	41.99
Total	**117**	**2,158,735**	**5.42 (Avg)**	**390**	**2,411,601**	**16.17 (Avg)**

Table 3. Number of bird strike reports per 100,000 movements for Quarters 1 and 2 (2001-2014). Note. Avg=Average

Year	Bird Strike Reports Q1	Movements	Strikes per 100,000 Movements	Bird Strike Reports Q2	Movements	Strikes per 100,000 Movements
2001	33	220,945	14.94	12	205,118	5.85
2002	27	234,214	11.53	15	203,889	7.36
2003	31	219,462	14.13	21	196,986	10.66
2004	55	217,930	25.24	21	186,192	11.28
2005	59	205,901	28.65	17	187,014	9.09
2006	74	186,881	39.60	25	184,612	13.54
2007	81	188,852	42.89	34	163,675	20.77
2008	66	184,695	35.73	24	151,523	15.84
2009	82	159,495	51.41	18	148,270	12.14
2010	41	152,285	26.92	35	137,187	25.51
2011	56	143,857	38.93	31	129,321	13.91
2012	78	139,563	55.89	22	128,361	17.14
2013	91	141,731	64.21	44	125,340	35.10
2014	140	144,871	96.64	48	123,891	38.74
Total	**914**	**2,540,682**	**35.97 (Avg)**	**367**	**2,271,379**	**16.16 (Avg)**

Table 4. Number of bird strike reports per 100,000 movements per Quarters 3 and 4 (2001-2014) Note. Avg=Average

Quarter	n	Median	Avg Rank	Z
Q1	14	4540	11.50	-4.50
Q2	14	13565	28.90	0.09
Q3	14	37330	44.50	4.24
Q4	14	14690	29.10	0.17
Overall	**56**		**28.5**	

Table 5. Descriptive Statistics for Kruskal-Wallis test

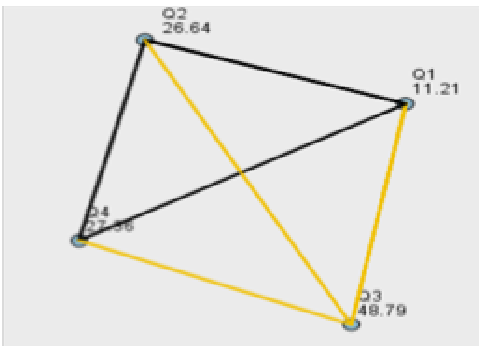

Figure 2. Pairwise comparisons of bird strikes per 100,000 movements.

Reported bird strikes per 100,000 movements were statistically significantly different between quarters of the year, $\chi2$ (3) = 37.635, p = .000. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure. A Bonferroni correction for multiple comparisons was made with statistical significance accepted at the adjusted $p < .0083$ level. The post-hoc analysis revealed statistically significant differences in reported bird strikes per 100,000 movements. Quarter 3 was significantly higher than Quarter 1 (p = .000), Quarter 2 (p = .002), and Quarter 4 (p = .003). Table 5 provides the medians for each quarter, average rank values, and z scores. Figure 2 indicates the mean rank and test statistics. The black lines represent non-significant differences. Table 6 shows the test statistics for the non-parametric Kruskal-Wallis test.

Each nodes shows the sample average rank of Quarter. Mean rank are indicated for each quarter. The black lines represent a non-significant comparison.

Quarters	Test Statistic	Std. Test Statistic	Sig.	Adjusted Sig.
Q1-Q2	-15.429	-2.503	.012	.074
Q1-Q4	-16.143	-2.619	.009	.053
Q1-Q3	-37.571	-6.095	.000*	.000
Q2-Q4	-.714	-.116	.908	1.000
Q2-Q3	-22.143	-3.592	.000*	.002
Q4-Q3	21.429	3.476	.001*	.003

Table 6. Test Statistics for Kruskal-Wallis Test. Note: Each row tests the null hypothesis that the sample 1 and sample 2 distributions are the same. Asymptotic significances 2-sided tests are displayed. The alpha level has been adjusted for the number of comparisons and is .0083, * denotes significance

In regards to the relationship between reported bird strike reports and attitude of flights, an exponential equation was utilized. The y axis represents the number of reported bird strikes. The x axis represents each 1000-foot height interval above ground level from 1000 to 10,000 feet. 1000-2,000 feet is considered interval 1 and 9,000-10,000 feet is considered interval 10. The graph excludes bird strikes below 1000 feet because this was where majority of strikes occurred. More specifically, for commercial and general aviation aircraft respectively, 69% and 95% of the bird strikes occurred below 1,000 feet AGL. Researchers desired to learn what happened after 1000 feet. The exponential equation explained 95% of the variation in number of strikes by 1,000-foot intervals from 1000 to 10,000 feet. The data combines commercial and general aviation data. The exponential equation is shown in figure 3.

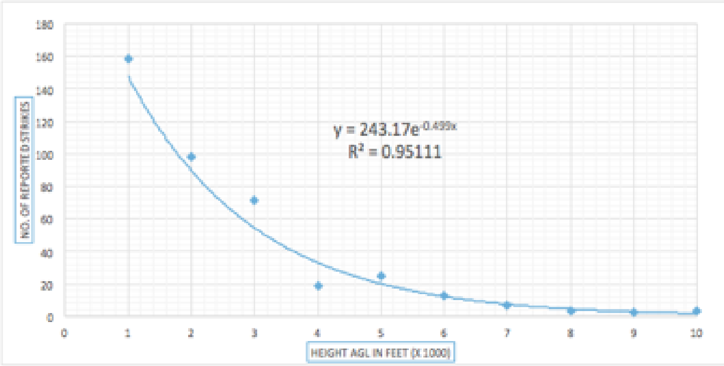

Figure 3. Number of bird strike reports commercial and general aviation aircraft combined by 1000 foot intervals. This graph excludes strikes ≤ 1000 feet above ground level

To provide additional findings, researchers further examined bird strike data (2001-2014) to extract type of operator, day/night, damage, and phase of flight. During the specified period, 1814 wildlife strikes within the vicinity of Part 139 airports in Indiana were reported. Birds accounted for 1788 (98.6%) of these strikes. There were 1038 (58%) bird strikes involving commercial aviation, 173 (9.6%), GA aircraft 49 (2.7%), military airplanes, 5 (<1%) government planes, and 523 (29%) strikes reported did not identify the operator. There were no injuries or fatalities reported from strikes during the period studied. These figures are shown in Table 7. In regards to time of day, reports from Indiana Part 139 airports indicated 557 strikes occurred during the day, 527 at night, 52 at dusk, 53 at dawn, while 599 were unknown. Frequencies are shown in Table 8.

Type of Operator	Number of Reported Bird Strikes
Commercial	1038
General Aviation	173
Military	49
Government	5
Unknown	523
Total	**1788**

Table 7. Type of operator and the frequency of bird strike reports (2001-2014)

Categories of Operator	Number of Reported Bird Strikes	Number of Movements	Strikes per 100,000 movements
Military	49	245,979	19.92
Civil	1,739	9,136,418	19.04

Table 8. Category of operator and the frequency of bird strike reports (2001-2014). Note 1: Reported strikes involving civil aviation include commercial, general aviation, government, and unknown (see Table 7). Note 2: Researchers incorporated the number of reported strikes to unknown type of operator to civil aviation because they most likely were. Note 3: The ATADS do not provide the number of local movements by type of operator

Dawn	Day	Dusk	Night	Unknown Time of Day	Total
53	557	52	527	599	1788

Table 9. Frequency of bird strikes and time of day

There were 19.92 reported strikes per 100,000 movements involving military aircraft. For civil aviation aircraft (commercial, general aviation, government, "unknown") there were 19.04 reported strikes per 100,000 movements. Researchers considered the reported strikes involving "unknown" type of operator to be civil aircraft since they most likely were. Out of the all the reports, 1163 reported level of damage, 1101 indicated no damage to the aircraft, 47 reported minor damage, six were uncertain, nine strikes caused substantial damage, and no aircraft were destroyed due to the bird strike. Thirty-six out of 62 damaging strikes occurred below 500 feet AGL. Only the reported strikes in which the operator, the type of damage, and the altitude of the strikes were identified were included in the analysis. Five hundred and forty-nine bird strike reports did not contain the phase of flight. However, 1229 reports provided the phase of flight. Reports indicated 51 bird strikes occurred during the descent phase, 567 happened during the approach phase, 7 strikes occurred during the landing phase, 191 while in the landing roll, 225 occurred during takeoff, and 188 during the climb. Regarding monetary losses of the specified data set, reported values indicated directed losses of $1,124,876 while other reported monetary losses totaled $24,794. Costs from years prior to 2014 were inflation-adjusted to 2014 U.S. dollars. It is important to highlight that 18 reports contained information about the costs of repairs, 33 provided an estimate of other monetary losses, and only 6 contained both pieces of information. Level of damage, phase of flight, and frequencies are shown in Tables 9 and 10.

Type of Operator	Number of Reported Bird Strikes
No Damage	1101
Minor	47
Substantial	9
Uncertain	6
Destroyed	0
Unreported	625
Total	**1788**

Table 10. Level of damage and frequency

Dawn	Day	Dusk	Night	Unknown Time of Day	Total
53	557	52	527	599	1788

Table 11. Phase of flight and frequency

For commercial aviation, from January 01, 2001 to December 31, 2014, about 60 % of bird strikes occurred when the aircraft was below 500 feet AGL, and 93 % occurred at or below 3,500 feet AGL. Strikes to commercial aviation aircraft in which the height of strike was not reported were excluded from analysis. During the same period, 90 % of bird strikes to GA aircraft occurred below 500 feet AGL, and practically 100 % of the strikes occurred at or below 3,500 feet AGL. Strikes to general aviation aircraft in which the height of strike was not reported were excluded from analysis. If we consider both commercial and GA, 65 % of the strikes occurred below 500 feet AGL, and 94% at or below 3,500 feet. Bird strikes in which the height of strike was not reported were excluded from analysis. Less than 3 % of the strikes occurred above 5,000 feet AGL for both commercial and GA aircraft. Almost twice as many strikes, 66 % of total, occurred during the arrival (descent, approach, landing, or landing roll) phase of flight compared to approximately 34 % during departure (take-off run and climb). Overall, 36 out of the 62 damaging strikes for commercial and GA aircraft occurred primarily in the airport environment (below 500 feet AGL). Seven strikes caused substantial damage to the aircraft. These occurred below 500 feet AGL and during the departure phase of flight.

5. Discussion

The researchers used data from the FAA NWSD and the FAA Air Traffic Activity System (ATADS). The last day of data collection from the FAA NWSD was May 02, 2016. The analysis of bird strikes data from January 1, 2001 to December 31, 2014 at Part 139 airports in Indiana reveals that bird strike reporting has steadily increased. During the examined time period the number of aircraft movements declined by 38.64%. However, the number of bird strike reports increased 4.4-fold from 60 in 2001 to a record 266 in 2014. The number of strikes per 100,000 movements increased 7 fold from 7.45 to 52.12. When comparing national results to the Indiana dataset, the average bird strikes per 100,000 movements was similar. Both datasets averaged approximately 20 bird strike reports per 100,000 movements for 2001-2014. However, during 2012 and 2014 the Indiana dataset indicates a steady and higher frequency of reporting. The Indiana dataset averaged 40 bird-strike reports per 100,000 movements while the national dataset averaged 29 reports per 100,000 movements. Bird activity may be increasing in Indiana and/or aviation professionals, who operate at these locations are becoming more proactive with bird strike reporting. Another plausible reason could be there may have been enhancements in wildlife management at the selected airports, thus increasing the reporting of wildlife strikes. Additional reasonable explanations could be that FAA programs directed to increase the number and quality of wildlife strike reports have been effective (Dolbeer et al., 2015). Additional research would need to be conducted to ascertain a more conclusive reason for this result.

Quarter three was identified as the time of year in which bird strike reporting was the highest. This follows similarly to the national trend suggesting Indiana Part 139 airports are also effected by the migratory season. Concentrated efforts by key stakeholders should be emphasized prior to the third quarter to mitigate risks. Airport operators should scale up wild life management efforts prior to quarter 3. An increase in awareness and communications between air traffic control (ATC) and pilots may be mitigating factors. Standard operating procedures can require pilots to reduce airspeed as much as possible when in the vicinity of the airport and spend as little time required below 3,500 feet (Dolbeer, 2006).

As aforementioned, almost 99% of the wildlife strikes involved birds. Furthermore, 58% of the strikes reported occurred in the commercial aviation sector. Only 9.6% of the reported strikes involved GA aircraft. Plausible explanations include the higher usage of Part 139 airports by commercial aircraft, and also enhanced reporting by airport operators and airliners. Considering only the reported strikes in which the time of day was informed, 46.8% of the strikes occurred during the day and 44.3% at night. Based on these numbers, the probability of a bird strike is practically the same regardless the time of the day.

For commercial and general aviation aircraft, 60% and 90% of the strikes occurred below 500 feet AGL respectively. Almost 4% of the bird strikes involving both commercial caused minor damage to aircraft, and 9 (< 1%) strikes led to substantial damage. The researchers considered only the reports in which the level of damage was reported. Almost 59% of the damaging strikes occurred below 500 feet AGL (airport environment). Differently from the national figures, in Indiana Part 139 airports the risk of a damaging strike is higher below 5oo feet AGL. Moreover, 78% of the substantial damaging strikes at or around Part 139 airports in Indiana occurred during the departure phase of flight and below 500 feet AGL, or in the airport jurisdiction. These findings are in agreement with the Avrenly and Dempsey (2014) and Dolbeer (2007) studies.

Regarding monetary losses, less than 1% of the reported strikes contained information about direct and indirect costs of the bird strikes. During the period of this study, bird strikes caused $1,149,670 in direct and other monetary costs to the aviation industry. Considering that only 1% of the reported strikes provided information about monetary losses associated with bird strikes, as cited by Anderson et al (2015) and Defusco and Unangst (2013), the projected total costs of the bird strikes in Part 139 airports in Indiana are most likely significantly higher.

The management of bird strikes based on SMS concepts offers a best-practice approach to a comprehensive safety system in which all hazards can be managed effectively, consistently, and comprehensively (DeFusco et al., 2015). The functional result of both an effective SMS and a WHMP is to proactively manage risks, detect and correct safety issues before those problems contribute to a mishap, and reduce the costs of incidents. Finally, data and information are vital to ensure that an SMS and a WHMP meet identified targets and goals. As mentioned by Cleary and Dolbeer (2005), "before a problem can be solved, the problem must first be understood. A necessary first step toward understanding the complex problem of aircraft collisions with wildlife is the collection and analysis of data from actual wildlife strike events" (p. 5). Despite an increase in bird strike reporting in Indiana Part 139 airports from 2001 to 2014, most reports lacked information (e.g., costs, phase of flight, level of damage). Moreover, based on previous studies, only 39% of the wildlife strikes are reported to the NWSD (Rillstone & Dineen, 2013). Therefore, further studies are recommended in order to increase the reporting of bird strikes as well as to enhance the quality of the strikes reported. MacKinnon (2004) suggest that information retrieved from current data should be utilized during initial and recurrent training of airlines' pilots. For example, understanding the relationship between airspeeds and the severity of a bird strike may provide guidance for mitigating strike hazards during high bird activity times such as the third quarter of the year.

6. Conclusion

The conflict between birds and aviation at and near Part 139 airports in Indiana is a safety issue and carries with it growing economic losses in the aviation industry. Though traffic has been declining at Part 139 airports in Indiana, commercial air traffic in the U.S. is predicted to grow at a rate of about 1.1 % per year from 24.5 million movements in 2014 to 30.3 million by 2030 (Dolbeer et al., 2015). Additionally, the active general aviation fleet is forecast to increase 0.2 percent a year between 2015 and 2036 (FAA, 2016). Therefore, the risk of bird strikes is also likely to increase. As demonstrated in this and previous studies, efforts to reduce the risk of bird strikes should be supported by current data and information.

The paramount step toward managing the risk of aircraft accidents due to birds is the collection and analysis of data from actual wildlife strike events. The FAA NWSD contains enough data to identify trends and highlight special considerations. However, as cited by Dolbeer and Wright (2009), improvements are needed in the quantity and quality of bird strikes reported. It is likely that the number of bird strikes as well as the direct and indirect costs are much higher. Despite the increase of reported strikes (Dolbeer et al., 2015), databases typically contain just a limited proportion of the real number of strikes that occurred (Buurma & Dekker, 2005). However, understanding the information retrieved from the bird strike data from Part 139 airports in Indiana can aid the development of strategies to reduce the risk of bird strikes to aviation.

The findings of this project reinforce the conclusions from previous studies that the airport environment is where bird hazard to aviation mitigation efforts should be focused. Special emphasis must be given to bird activity between July to September due to the higher risk of strikes during this period of the year. The findings of this study can also be incorporated into pilots' training programs. Additionally, data collection and analyses may be used during SMS processes. Limitations of this study include the fact that it is unknown how many bird strikes have truly occurred. Additionally, reporters may exclude information within the report making it difficult to ascertain the true outcome of the wildlife strike (e.g., level of damage, costs). Researchers assume the reported data, although incomplete, was accurate.

References

Anderson, A., Carpenter, D.S., Begier, M.J., Blackwell., B.F., DeVault, T.L., & Shwiff, S.A. (2015). Modeling the cost of bird strikes to US civil aircraft. J*ournal of Transportation Research*, 38, 49-58. https://doi.org/10.1016/j.trd.2015.04.027

Avrenli, K.A., & Dempsey, B.J. (2014). Statistical analysis of aircraft-bird strikes resulting in engine failure. *Journal of the Transportation Research Board*, 2449, 14-23. https://doi.org/10.3141/2449-02

Belant, J.L., & Ayres, C.R. (2014). *Habitat management to deter wildlife at airports: A synthesis of airport practice (ACRP Synthesis No. 52)*. Retrieved from the Transportation Research Board on the National Academies website: http://onlinepubs. trb.org/onlinepubs/acrp/acrp_syn_052.pdf https://doi.org/10.17226/22375

Blackwell, B.F., DeVault, T.L., Seamans, T.W., Lima, S.L., Baumhardt, P., & Juricic, E.F. (2012). Exploiting avian vision with aircraft lighting to reduce bird strikes. *Journal of Applied Ecology*, 49, 758-766. https://doi.org/10.1111/j.1365-2664.2012.02165.x

Cardoso, S.H., Maurino, D., & Fernandez, J. (2008, May). Lessons learnt from airport SMS implementation in South America. *Presented at the 10th International Conference on Applications of Advanced Technologies in Transportation (AATT)*, Athens, Greece.

Cleary, E.C., & Dolbeer, R.A. (2005). *Wildlife hazard management at airports: A manual for airport personnel.* Retrieved from http://www.faa.gov/airports/airport_safety/wildlife/resources/media/2005_faa_manual_complete.pdf

Dale, L.A. (2009). Personal and corporate liability in the aftermath of bird strikes: A costly consideration. *Journal of Human-Wildlife Conflicts*, 3(2), 216-215.

DeFusco, R.P., & Unangst, E.T. (2013). *Airport wildlife population management: A synthesis of airport practice (ACRP Synthesis No. 39)*. Retrieved from the Transportation Research Board on the National Academies website: http://www.trb.org/main/blurbs/169414.aspx https://doi.org/10.17226/22599

DeFusco, R.P., Junior, E.T.U., Cooley, T.R., & Landry, J.M. (2015). *Applying an SMS Approach to Wildlife Hazard Management (ACRP Report No. 145)*. Retrieved from the Transportation Research Board on the National Academies website: http://onlinepubs.trb. org/onlinepubs/acrp/acrp_rpt_145.pdf

Dekker, A., & Buurma, L. (2005, May). Mandatory reporting of bird strikes in Europe: Who will report what to who. *Paper presented at the 27th International Bird Strike Committee Meeting*, Athens, Greece. Abstract retrieved from http://www.int-birdstrike.org/Athens_Papers/IBSC27%20WPII-1.pdf

Dolbeer, R.A. (2006a). Birds and aircraft are competing for space in crowded skies. *International Civil Aviation Organization Journal,* 3, 21-24.

Dolbeer, R.A. (2006b). Height distributions of birds as recorded by collisions with civil aircraft. *Journal of Wildlife Management,* 70(5), 1345-1350. https://doi.org/10.2193/0022-541X(2006)70[1345:HDOBRB]2.0.CO;2

Dolbeer, R.A. (2007). Bird damage to turbofan and turbojet engines in relation to phase of flight: Why speed matters. B*ird and Aviation,* 2(7), 1-9. Retrieved from http://davvl.de/Voluenglisch/2007/Dolbeer.pdf

Dolbeer, R.A. (2009). Birds and aircraft: Fighting for airspace in ever more crowded skies. *Journal of Human-Wildlife Conflicts*, 3(2), 155-166.

Dolbeer, R.A. (2011). Increasing trend of damaging bird strikes with aircraft outside the airport boundary: implications for mitigation measures. *Journal of Human-Wildlife Conflicts*, 5(2), 235-248.

Dolbeer, R.A. (2015). *Trends in reporting of wildlife strikes with civil aircraft and in identification of species struck under a primarily voluntary reporting system - 1990-2013.* Retrieved from the Federal Aviation Administration website: https://www.faa.gov/airports/airport_safety/wildlife/media/trends-in-wildlife-strike-reporting-1990-2013.pdf

Dolbeer, R.A., & Begier, M.J. (2011, September). Why we need to compare wildlife strike data among airports to improve aviation safety. P*aper presented at the 13th North American Bird Strike Conference.* Niagara Falls, Canada. Abstract retrieved from http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1011&context=birdstrike2011

Dolbeer, R.A., & Begierm M. J. (2012, October). Comparison of wildlife strike data among airports to improve aviation safety. *Paper presented at the 10th CAR/SAM Regional Bird/Wildlife Hazard Prevention Committee Meeting and Conference (CARSAMPAF/10).* Montego Bay, Jamaica. Abstract retrieved from http://www.icao.int/NACC/Documents/Meetings /2012/CARSAMPAF10 /CARSAMPAF10Presentation11.pdf

Dolbeer, R.A., Weller, J.R., Anderson, A.M., & Begier, M.J. (2016). *Wildlife strikes to civil aircraft in the United States: 1990–2015 (Serial Report No. 22*). Retrieved from the Federal Aviation Administration website: https://www.faa.gov/airports/airport_safety/wildlife/media/Wildlife-Strike-Report-1990-2015.pdf

Dolbeer, R.A., & Wright, S.E. (2009). Safety management systems: How useful will the FAA national wildlife strike database be? *Journal of Human-Wildlife Conflicts*, 3(2), 167-178.

Dolbeer, R.A., Wright, S.E., Weller, J.R., Anderson, A.M., & Begier, M.J. (2015). *Wildlife Strikes to Civil Aircraft in the United States: 1990–2014 (Serial Report No. 21).* Retrieved from the Federal Aviation Administration website: http://www.faa.gov/airports /airport_safety/ wildlife/media/wildlife-strike-report-1990-2014.pdf

Eschenfelder, P. (2005, May). High speed flight at low altitude: Hazard to commercial aviation? Paper presented at the 7th Bird Strike Committee Meeting – USA/Canada, Vancouver, Canada. Abstract retrieved from http://digitalcommons.unl.edu/cgi/viewcontent.cgi? article=1003&context=birdstrike2005

Eschenfelder, P., & DeFusco, R. (2010, August). Bird strike mitigation beyond the airport. *AeroSafety World*, 5(7). Retrieved from http://flightsafety.org/aerosafety-world-magazine/august-2010/bird-strike-mitigation-beyond-the-airport

Federal Aviation Administration (FAA) (2007). *Hazardous Wildlife Attractants on or near Airports (Advisory Circular C 150/5200-33A).* Retrieved from http://www.faa.gov/ documentlibrary/media/advisory_circular/150-5200-33b/150_5200_33b.pdf

Federal Aviation Administration (FAA) (2015). *Safety Management Systems for Aviation Service Providers (Advisory Circular 120-92B).* Retrieved from http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1026670

Federal Aviation Administration (FAA) (2016). *FAA aerospace forecast: Fiscal years 2016-2036*. Retrieved from https://www.faa.gov/data_research/aviation/aerospace_forecasts/ media/FY2016-36_FAA_Aerospace_Forecast.pdf

Federal Aviation Administration (FAA) (2017). *Part 139 airport certification: What is a Part 139?* Retrieved from https://www.faa.gov/airports/airport_safety/part139_cert/what-is-part-139/

Gnehm, E. (2013, October). Annex 19: A key amendment to the Convention. *ICAO Journal*, 68(05). Retrieved from http://www.icao.int/publications/journalsreports/2013/ 6805_en.pdf

Hardt, J.D., Colyer, A., & Allen, J.R. (2009). Developing bird-strike risk assessment models for open-water restorations. *Journal of Wildlife Conflicts*, 3(2), 186-198.

International Civil Aviation Organization (ICAO) (2012). *Airport services manual. Part 3: Wildlife control and reduction (4th ed.).* Montreal, Canada: Author.

International Civil Aviation Organization (ICAO) (2013a). *Annex 19 to the Convention on International Civil Aviation, Safety Management (1st ed.).* Montreal, Canada: Author.

International Civil Aviation Organization (ICAO) (2013b). *ICAO safety management manual (3rd ed.).* Montreal, Canada: Author.

International Civil Aviation Organization (ICAO) (2013c). *Annex 14 to the Convention on International Civil Aviation, Aerodromes Volume 1 - Aerodrome Design and Operations (6th ed.).* Montreal, Canada: Author.

Junior, M.A., Shirazi, H., Cardoso, S., Brown, J., Speir, R., Seleznev, O., et al. (2009). *Safety management systems for airports (ACRP Report No. 01, volume 2).* Retrieved from the Transportation Research Board on the National Academies website: http://onlinepubs. trb.org/onlinepubs/acrp/acrp_rpt_001b.pdf

Juricic, E.F., Gaffney, J., Blackwell, B.F., & Baumhardt, P. (2011). Bird strikes and aircraft fuselage color: A correlational study. *Journal of Human–Wildlife Interactions*, 5(2), 224-234.

Ludwig, D.A., Andrews, C.R., Veen, N.R.J., & Laqui, C. (2007). Safety management systems for airports (ACRP Report No. 01, volume 1). Retrieved from the Transportation Research Board on the National Academies website: http://www.trb.org/Main/Blurbs/20159030.aspx

MacKinnon, B. (2004). *Sharing the skies manual – An aviation industry guide to the management of wildlife hazards.* Retrieved from the Government of Canada, Transport Canada website:

Mendonca, F.A.C. (2008). SMS for bird hazard: Assessing airlines pilots' perceptions (Unpublished master's thesis). University of Central Missouri, Warrensburg, MO.

Mendonca, F.A.C. (2011, September). Airlines' pilots' perceptions concerning recommended practices that reduce the risk of bird strikes. *Paper presented http://www.tc.gc.ca/eng/civilaviation/publications/tp13549-menu-2163.htmat the 11th meeting of the Bird Strike North America Conference,* Niagara Falls, Canada. Retrieved from http://digitalcommons.unl.edu/birdstrike2011/20/

Mendonca, F.A.C., & Johnson, M.E. (2015, October). Integrating sustainability and the safety management of wildlife in aviation. *Poster session presented at the University Aviation Association Fall Education Conference,* Salt Lake City, Utah.

Rillstone, D.J., & Dineen, C.M. (2013). *Airport responsibility for wildlife management (ACRP Legal Research Digest No. 20)*. Retrieved from the Transportation Research Board on the National Academies website: http://www.trb.org/main/ blurbs/169414.aspx

Stolzer, A.J., Halford, C.D., & Goglia, J.J. (2008). *Safety Management Systems in aviation.* Surrey, England: Ashgate.