COST BENEFIT ANALYSIS OF AVIAN RADAR SYSTEMS

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ABSTRACT

This research provides an initial analysis of the use of avian radar systems on bird strike occurrences on US Air Force installations. Collecting data at 5 major airfields, before and after installation comparisons are made of the costs and number of bird strikes on the airfields. Results indicate very little actual cost or bird strike improvement following installation using statistical t-tests. However, at Beale Air Force Base reductions of bird strikes to zero levels appear to indicate limited success for their avian radar system. Future research is needed to fully capture the true benefits of installing these systems.

INTRODUCTION

On 20 April 2012, the media was plastered with the heading, "Air Force 2 Strikes Bird Upon Landing, Biden Aboard"[11]. On the very same day, a bird flew into the engine of US Secretary of State Hillary Clinton's Air Force Presidential fleet aircraft and a third major strike led to the emergency landing of Delta Airlines Flight 1063 returning to John F. Kennedy Airport in New York [12]. This might seem like a busy day, but between the years 2006 and 2010, the Federal Aviation Administration (FAA) reported an average of 26 bird strikes per day for civilian airfields and the Air Force Safety Center logged an average of 13 strikes per day. As the media focus on 20 April 2012 illustrates, these bird strikes are not decreasing, but instead, aircraft bird strikes are an increasing problem. Recently, there have been many strong advances in avian research creating several new ways to mitigate this hazard including Bird Detection Radar (BDR) systems. While these systems have been tested and proven at locating birds, very little research exists to show whether or not an airfield actually benefits from reduced numbers of strikes or reduced costs of strikes after installation of a BDR. This study applies statistical analysis to quantify the economic justification of further purchases of these systems or to suggest that these dollars be spent on other more cost effective mitigation efforts.

Problem Statement and Research Objective

Should the Air Force fund BDR systems and will there be a resulting savings associated with reduced damage to aircraft from bird strikes if it does? Currently, there is limited quantitative research correlating the average quantity and average cost of bird strikes prior to BDR installation and the average quantity and average cost of bird strikes after BDR installation, on an airfield. This research focuses on whether or not BDRs are a cost effective method of bird strike mitigation. Overall, this research examines the value of installing additional BDR systems at AF installations, other military installations, or civil airfields worldwide.

LITERATURE

Two years after the first aircraft flight in 1903 Orville Wright struck a bird during a flight over a cornfield near Dayton, Ohio [3]. This first bird strike was the beginning of a long list of famous strikes with reported numbers of military strikes peaking in 2005 with 5,107 strikes [2]. Factors that contribute to this increasing threat are increasing populations of large birds and increasing air traffic by quieter, turbofan-powered aircraft [4]. Between 1990 and 2010, the FAA wildlife strike database received data for over 121,000 wildlife strikes with 17,605 of these strikes causing damage. For the Air Force, there have been more than 95,000 reported bird strikes since the Air Force Safety Center began tracking in 1985 with almost 4,500 strikes in 2011 alone [2]. According to the FAA, "Globally, wildlife strikes have killed more than 229 people and destroyed over 210 aircraft since 1988" [4]. In addition, the Air Force Safety Center reports 39 aircraft destroyed and 33 deaths on record since 1973 [2]. This loss of human life alone warrants the need for bird strike mitigation efforts, but in order to understand the full scope of this problem all costs must be considered.

Cost Considerations

Of the 17,605 damaging strikes recorded in the FAA database, only 30% provided estimates of aircraft downtime, 17% reported direct costs, and only 8% reported indirect costs. Previous FAA studies conclusively show that on average only 20% of the estimated total damaging strikes from 1990 to 2010 have been reported. By estimating to 100%, "the annual cost of wildlife strikes to the USA civil aviation industry is estimated to be 566,766 hours of aircraft downtime and $677 million in monetary losses" [4, p.11]. This total breaks down to $547 million per year in direct costs and $130 million per year in associated costs [5]. The Air Force simply reports direct total costs such as parts replaced which still totals approximately $821 million since 1985 [2]. Even when the total bill is available, it does not include many hidden costs such as lost revenue, costs for placing passengers in hotels, re-scheduling aircraft, flight cancellations, lost training, crew shuffling, passenger frustrations, and dumped fuel for emergency landings [3]. There are also many indirect costs including man-hours and equipment consumed through bird mitigation efforts already in place at airfields. Hill Air Force Base (AFB), Utah, recently reported a new United States Department of Agriculture (USDA) wildlife abatement contract costing $155,000 per year. These contracts are not inexpensive, but are one great way for airfields to ensure bird populations remain at a minimum. With the risk to human life and total costs reaching billions of dollars per year, implementing even extremely expensive solutions appears, on the surface, to make good economic sense.

Current Mitigation Efforts

Funding Bird/Wildlife Aircraft Strike Hazard (BASH) teams and USDA abatement contracts appears to be a great mitigation strategy, while not necessarily a complete solution. Civil recorded bird strike data shows that over 74% of collisions occur at or below 500 feet above ground level (AGL) and therefore within the airport environment. For every 1,000-foot gain in height above 500 feet AGL, the number of strikes declined by 33% for commercial aircraft [4]. Of the 19 civil and military large-transport aircraft destroyed by bird strikes from 1960 to 2004, airport environment strikes claimed 18. With the airport environment being suspect in the majority of wildlife strikes, this becomes the logical and easiest place to focus recently constrained resources [3].

The first and most important step to mitigation is thorough reporting. Pilots, airport operations personnel, maintainers, and anyone with specific knowledge of a wildlife strike should report. Previous strike data "provides a scientific basis for identifying risk factors; justifying, implementing and defending corrective actions at airports; and judging the effectiveness of those corrective actions"[3, p.6]. The next most important step is the FAA mandated wildlife hazard assessment at each individual airfield. In accordance with Title 14 Code of Federal Regulations, Part 139 Subpart D 139.337(b)(1-4), certified airports are required to complete wildlife hazard assessments when wildlife events occur [3, p.60]. The FAA administrator can then determine the wildlife hazard management plan for that particular airfield. These plans will typically include direction to utilize USDA biologists to provide training for airfield personnel in, "wildlife and hazard identification and the safe and proper use of wildlife control equipment and techniques" [3, p.27]. The Air Force has a Memorandum of Agreement with the FAA to manage wildlife and to collect strike information in a separate database. The Air Force also reduces aircraft strike hazards in accordance with the FAA four-part approach: Awareness, Control, Avoidance, and Aircraft Design [4].

While three of these: awareness of the problem, controlling populations of birds on the airfield, and aircraft design are critical, this research focuses specifically on methods of bird avoidance. Bird avoidance is a direct result of bird control, since the animals needing avoidance are the animals not controlled that are still located on the airfield. Both short-term active and long-term passive techniques are employed to control the airfield and rid the surrounding areas of potential hazards. If birds still exist after applying bird control methods, avoidance methods become critical since these birds left on the airfield remain potential bird strikes. This potential was evidenced in 1995 when 22 Americans and 2 Canadians were killed in a USAF E-3 Sentry crashed after it hit a flock of geese on take-off from Elmendorf AFB, Alaska. As a result, in 1996, an unnamed firm and the Air Force worked together to begin baseline testing and bird movement data collection to determine the feasibility of designing an avian radar system to avoid future bird strikes. With this focus on avoidance, the FAA and the Air Force began a collaborative effort to develop a radar system capable of detecting and tracking birds in 2001 [10]. The first Air Force BDR system was installed at Elmendorf AFB in 2002. However, this system is not currently used for airfield bird collision avoidance but only for migration tracking and is not considered in this study. After several Class A and B BASH mishaps, Dover AFB, Maryland, received a BDR in 2006 and has used the device to track bird activity. The base is awaiting official guidance from the anticipated Air Force Instruction 91-202, expected May 2012, authorizing tower controllers to use the bird location data in real time. Whiteman AFB, Missouri, received a BDR in 2007 with major upgrades to technology and improved placement location in 2011. Beale AFB, California, and Offutt AFB, Nebraska, both received BDRs in 2008 followed by a combat hardened system at Bagram AB, Afghanistan, in 2010.

Bird Detection Radar

Radar technology is not new but using the technology to locate and track wildlife is. In the developmental days of weather radar, birds were seen as unwanted clutter and a distraction for viewing the weather. With the new understanding that radar can purposely isolate wildlife, several companies have produced commercial systems utilizing combinations of X-band and S-band radar technology solely to identify bird populations on airfields [9]. Since the 5 Air Force airfields currently utilizing avian radar all employ variations of the MERLIN system, this research focuses solely on this system, maintained by DeTect, Inc.

The MERLIN radar system has an automatic and distinct advantage over other Air Force systems such as the Low-Level Bird Avoidance Model (BAM), which utilizes historic data to predict bird volume throughout a flight route or the Avian Hazard Advisory system (AHAS) which utilizes weather radar systems to piece together a near real-time image of bird activity [1]. Both BAM and AHAS draw information from systems not specifically designed to identify wildlife. BDRs, however, are designed to eventually provide aircraft controllers or pilots real-time information from a system located on the airfield property focused specifically on locating bird populations and therefore preventing risk at the approach and departure areas of the airfield [8]. This real-time picture of total bird volume in an area should not be confused with a sense-and-alert capability, which would allow controllers to vector aircraft around the real-time bird activity. Avian radar is not currently authorized for use as sense-and-alert since technology issues such as delayed reporting and antenna spin rates introduce an unknown volume of error. Real-time bird activity is, however, a huge benefit for USDA officials in locating activity on the airfield to focus immediate control and dispersal strategies [4].

During operation, these radar systems generate and transmit radio signals capturing the return echo in order to determine the locations of specific targets, in this case wildlife. Since radar provides very limited information such as range, direction, and velocity of target, the digital radar processer is critical in transforming the data into a usable visual display. The radar units are actually the small expense in the overall purchase cost of the radar system [7]. The total costs of all five systems are displayed in Table 1 below. The average maintenance and upkeep costs per year listed in Table 1 include the estimated electrical costs from Table 2 below.

Table 1. Cost Data by AFB [6]

<table>
<tr><th>Site</th><th>Date</th><th>Model/Upgrades</th><th>Base Cost</th><th>Total Equipment Cost</th><th>Average Equipment Cost Per Year (From Install)</th><th>Total Maintenance and Upkeep Costs (Estimated)</th><th>Average Maintenance and Upkeep Costs per Year (Estimated from Install)</th><th>Combined Average Cost Per Year (Estimated from Install)</th></tr>
<tr><td rowspan="3">Dover AFB</td><td>2006</td><td>XS2530i</td><td>$310,128</td><td rowspan="3">$424,162</td><td rowspan="3">$70,694</td><td rowspan="3">$144,850</td><td rowspan="3">$24,142</td><td rowspan="3">$94,835</td></tr>
<tr><td>2010</td><td>2nd VSR & Dual Range Processor</td><td>$114,034</td></tr>
<tr><td>2011</td><td>Extended Warranty (5yrs)</td><td>$127,500</td></tr>
<tr><td rowspan="2">Whiteman AFB</td><td>2006</td><td>XS5060i</td><td>$323,430</td><td rowspan="2">$411,470</td><td rowspan="2">$68,578</td><td rowspan="2">$17,350</td><td rowspan="2">$2,892</td><td rowspan="2">$71,470</td></tr>
<tr><td>2010</td><td>XS200i-Fixed</td><td>$88,040</td></tr>
<tr><td rowspan="2">Beale AFB</td><td>2008</td><td>XS2530i</td><td>$330,000</td><td rowspan="2">$330,000</td><td rowspan="2">$82,500</td><td rowspan="2">$139,067</td><td rowspan="2">$34,767</td><td rowspan="2">$117,267</td></tr>
<tr><td>2010</td><td>Extended Warranty (5yrs)</td><td>$127,500</td></tr>
<tr><td>Offutt AFB</td><td>2009</td><td>XS2530i</td><td>$318,000</td><td>$318,000</td><td>$106,000</td><td>$8,675</td><td>$2,892</td><td>$108,892</td></tr>
<tr><td>Bagram AB</td><td>2010</td><td>SS200m</td><td>$819,837</td><td>$819,837</td><td>$409,919</td><td>$5,783</td><td>$2,892</td><td>$412,811</td></tr>
</table>

METHODOLOGY

Research Design

This research focused on the following airfields, which utilize BDRs: Dover AFB, Whiteman AFB, Beale AFB, Offutt AFB, and Bagram AB. The researchers collected all bird strike data and cost data for these airfields from the Air Force Safety Automated System (AFSAS) database after receiving access from the Air Force Safety Center. All aircraft bird strikes at nearby airfields and not on the Air Force base, at altitudes over 3,000 feet, or more than 12 miles off the airfield were eliminated from the tables. This was done in order to isolate bird strikes in which the bird could potentially have been detected by the presence of a BDR system on the airfield under the given system altitude and range limitations advertised by DeTect Inc at http://www.detect-inc.com/. The researchers calculated, independently by airfield, the bird strike numbers by year using the years beginning 5 years before BDR installation up to 2011. The researchers used 5 years of data prior to installation, isolated by airfield, in order to limit location-based, seasonal, and anomalous variations as much as possible and to limit effects of such trends as increased strike reporting over time. The researcher also chose 5 years since this was the maximum expected data availability for Bagram AB, which eventually only provided data for 4 years prior to BDR installation. The researchers then collected tower operations data for each airfield from the annual USAF Air Traffic Activity Reports (ATARS) provided by the Air Force Flight Standards Agency (AFSA) located at Tinker AFB, Oklahoma. The bird strikes per tower operation and cost per tower operation were calculated in order to normalize these data sets for airfield usage across the years at each airfield. Tower operations were selected as the baseline since this number of operations coincides with the number of times an aircraft was in the BDR range. The tower controls the same airspace over the airfield that the BDR is expected to cover. Once an aircraft leaves this coverage, the pilot transfers away from tower control and over to departure control since the aircraft is no longer considered on or over the airfield.

Statistical Analysis

The study used a two sample t-test (unequal variances) to determine the significance of the differences in means, independently for four of the airfields (excluding Bagram AB), before and after BDR installation for both the number of bird strikes per tower operation and annual cost per tower operation. Since there is only one year of post installation data for Bagram AB, a two sample t-test (equal variances) was used. Each airfield had different sample sizes (n values) and different degrees of freedom, but all significance levels for testing were set to $\alpha = 0.05$. In this research, significant differences between the means, before and after BDR install, and trend direction were both considered critical. Next, a paired two sample t-test for means was used to determine the significance of the differences in means across the five airfields after BDR installation for both bird strikes per tower operation and cost per tower operation.

Assumptions and Limitations

The first and most important assumption in this research is that all bird strikes are being properly reported at all Air Force airfields. Input into the AFSAS database is limited by whether or not base personnel reported a strike and subsequently entered the data into the system. The study also assumed all airfields were at least compliant with the minimum FAA regulations and BASH programs throughout all years studied. The research also assumes that the 5-year data collection window prior to BDR installation averaged out anomalies. This timeframe was selected before the researchers performed any statistical analysis. For Offutt AFB, this time frame was inclusive of an $8 million incident, the most costly studied in this entire research effort, but it did not appear to skew the final results. Also, the study must acknowledge that the tower's area of operations and the BDR's range are both somewhat flexible and changing and not always identical, thereby creating a small amount of error, that is believed to be insignificant. Next, the small number and relative youth of BDR systems in the Air Force's inventory is another limitation (sample size).. More systems and more years of accumulated data may have provided slightly different results. Additionally, the researchers were unable to account for other changes to BASH programs which potentially occurred at the same time as BDR installation. Any airfield leadership willing to commit to the level of funding to purchase a BDR, might have also instituted other major bird strike corrective methods that impact the results. Finally, when calculating the cost of a bird strike, the USAF does not consider any indirect costs such as loss of training or dumped fuel, etc. The total costs used in this research are therefore much lower than the actual expected total costs reported by a civil airfield for the same strike with the same amount of damage.

RESULTS

The total bird strike data is contained in Tables 2-6. The researcher hypothesized that each airfield's average bird strikes per tower operation and average cost per tower operation would decrease after the installation of a BDR at an airfield.

Table 2. Dover AFB Bird Strike Data

Dover AFB	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
Number of Bird Strikes	54	19	36	21	28	34	57	51	49	45
Damaging Strikes	3	2	2	3	0	4	3	1	5	2
Annual Cost	$25,138	$9,830	$1,000,997	$2,418,797	$0	$3,648,013	$74,032	$992,679	$54,687	$394,990
Tower Operations	39,174	37,773	33,290	35,478	29,276	31,431	33,638	34,833	38,133	34,812
Strikes/Operation	0.0013785	0.000503	0.0010814	0.0005919	0.0009564	0.0010817	0.0016945	0.0014641	0.001285	0.0012927
Cost/Operation	$0.64	$0.26	$30.07	$68.18	$0.00	$116.06	$2.20	$28.50	$1.43	$11.35

Table 3. Whiteman AFB Bird Strike Data

Whiteman AFB	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
Number of Bird Strikes	41	17	14	56	88	92	85	63	87
Damaging Strikes	2	0	4	3	1	4	5	4	5
Annual Cost	$5,481	$0	$332,868	$86,002	$4,540	$20,473	$215,659	$39,926	$195,554
Tower Operations	20,785	22,753	25,249	28,406	34,954	35,218	29,528	31,241	21,638
Strikes/Operation	0.0019726	0.0007472	0.0005545	0.0019714	0.0025176	0.0026123	0.0028786	0.0020166	0.0040207
Cost/Operation	$0.26	$0.00	$13.18	$3.03	$0.13	$0.58	$7.30	$1.28	$9.04

Table 4. Beale AFB Bird Strike Data

Beale AFB	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
Number of Bird Strikes	15	20	25	28	10	9	21	20
Damaging Strikes	6	1	2	4	2	1	0	0
Annual Cost	$166,123	$3,410	$111,874	$130,440	$17,877	451	0	0
Tower Operations	41,012	32,590	43,468	40,667	34,892	32,483	34,348	37,002
Strikes/Operation	0.0003657	0.0006137	0.0005751	0.0006885	0.0002866	0.0002771	0.0006114	0.0005405
Cost/Operation	$4.05	$0.10	$2.57	$3.21	$0.51	$0.01	$0.00	$0.00

Table 5. Offutt AFB Bird Strike Data

Offutt AFB	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
Number of Bird Strikes	40	82	19	96	77	64	92	67
Damaging Strikes	1	2	1	7	5	3	2	0
Annual Cost	$10,000	$8,115,981	$83,330	$75,769	$73,148	$60,373	$236,646	$0
Tower Operations	32,409	32,226	21,314	28,104	28,425	25,897	23,492	23,779
Strikes/Operation	0.0012342	0.0025445	0.0008914	0.0034159	0.0027089	0.0024713	0.0039162	0.0028176
Cost/Operation	$0.31	$251.85	$3.91	$2.70	$2.57	$2.33	$10.07	$0.00

Table 6. Bagram AB Bird Strike Data

Bagram AB	FY06	FY07	FY08	FY09	FY10	FY11
Number of Bird Strikes	N/A	61	93	166	205	252
Damaging Strikes	N/A	4	4	7	4	17
Annual Cost	N/A	$1,438,354	$8,074	$692,293	$60,887	$434,440
Tower Operations	N/A	N/A	105,827	152,454	187,984	228,550
Strikes/Operation	N/A	N/A	0.0008788	0.0010889	0.0010905	0.0011026
Cost/Operation	N/A	N/A	$0.08	$4.54	$0.32	$1.90

All Part 1 t-test results are shown in Tables 7-16 in the Appendix. In observed data for Dover and Whiteman AFBs, the bird strike per tower operation mean after installation was significantly different than the bird strike per tower operation mean before installation, but in the wrong direction with bird strikes per tower operation increasing in Tables 7 and 9. The total cost per tower operation mean after installation was also not significantly different than the total cost per tower operation mean before installation so the average cost of bird strikes per tower operation at Dover and Whiteman AFBs remained statistically the same (Tables 8 and 10). There is no evidence to show that the BDR reduced bird strikes per tower operation or costs of damage per tower operation at Dover or Whiteman AFBs.

In observed data for Beale AFB, the bird strike per tower operation mean after installation was not significantly different than the bird strike per tower operation mean before installation (Table 11); however, the total cost per tower operation mean after installation was significantly different than the total cost per tower operation mean before (Table 12). In observed data for Offutt AFB, the bird strike per tower operation mean and total cost per tower operation were not significantly different than the means before installation (Tables 13 and 14). Therefore, there is no evidence to show that the BDR reduced bird strikes per tower operation or costs of damage per tower operation. In observed data for Bagram AB, the bird strike per tower operation mean after installation was not significantly different than the bird strike per tower operation mean before installation (Table 15) so the average number of bird strikes per tower operation remained statistically the same. The total cost per tower operation mean after installation was also not significantly different (Table 16).

Across Base Results

The study also averaged all airfield bird strike data across bases. It was hypothesized that across airfield average bird strikes per tower operation and across airfield average cost per tower operation would decrease after the installation of a BDR at an airfield. In observed data across the five bases, the bird strike per tower operation mean after installation was significantly different than the bird strike per tower operation mean before installation, but in the wrong direction with bird strikes per tower operation increasing as shown in Appendix A, Table 19. The total cost per tower operation mean after installation across the 5 bases was not significantly different than the total cost per tower operation mean before installation so the cost of bird strikes per tower operation across bases remained statistically the same, as shown in Appendix A, Table 20. There is no evidence to show that the BDR reduced bird strikes or costs of damage across the five bases and therefore the researchers failed to reject the null hypothesis.

Conclusions

Using cost data, the study found that only one airfield benefited from the installed BDR system. Beale AFB, the successful base, had the same average number of bird strikes per tower operation, but reduced average strike costs to almost zero over the 3-year period since installation. Barring other base related interventions that were not identified in this study, it appears that this system led to a reduction in cost per strike to almost zero. Across the years prior to install, Beale AFB averaged $85,945 per year spent on bird strike repairs. The BDR system cost over the time since installation, is estimated at $117,267 per year. Even with incredible mitigation results, the system at Beale is still losing $31,322 per year. From a purely financial perspective, looking at this data for Beale AFB during this time period, it would have been more cost effective to allow the bird strikes and pay the lower cost of repairs rather than spending the time and money installing and maintaining this BDR.

The total purchase cost of all 5 systems was $2,303,469. Total estimated maintenance and upkeep costs for the different years at the different bases totals $315,725. To date, the estimated total system cost is $2,619,194 with a current cost per year of $805,275. Again, looking at cost alone, four bases were a complete loss but Beale AFB had the estimated $85,945 in cost avoidance. In aggregate, the Air Force has already lost $2,533,249 and is losing approximately $719,330 per year on these existing systems Interestingly, Beale AFB has been recognized as a great example of how this system can be applied successfully and many important lessons have been learned. The most important lesson is that senior leadership support is essential at a base attempting this level of technological advancement. Placement of the system, communication methods, certificates of operation, and many other lessons were also learned. It is expected that future experimentation will follow this positive trend at Beale.

It is important to remember that the Air Force costing structure for bird strike damage only includes direct costs as mentioned earlier and these costs are often totaled during the initial estimation process and not after the repairs are completed. It is safe to say that the Air Force cost method significantly underestimates the total cost of bird strike damage including many hidden costs such as lost revenue, costs for placing aircrew and passengers in hotels, re-scheduling aircraft, flight cancellations, lost training, crew shuffling, passenger frustrations, and dumped fuel for emergency landings [3]. Also remember, the Air Force Safety Center reports 39 aircraft destroyed and 33 deaths on record since 1973 [2]. This research was solely focused on utilizing existing Air Force cost data to determine the cost efficiencies of these systems but future studies should consider such hidden costs as listed above and, more importantly, the potential loss of human life from allowing these strikes to continue. Although not cost effective, experimenting with these systems is providing critical information for the development of the future technology, which may one day eliminate damaging or lethal aircraft bird strikes.

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APENDIX A

Table 7. Dover AFB Strikes Per Operation t-Test Results

Dover AFB	Before	After
Mean	0.00090224	0.0013636
Variance	1.2938E-07	5.257E-08
Observations	5	5
df	7	
t Stat	-2.4185401	
P(T<=t) one-tail	0.02309554	
t Critical one-tail	1.89457861	

Table 8. Dover AFB Cost Per Operation t-Test Results

Dover AFB	Before	After
Mean	19.8296634	31.908748
Variance	896.675324	2331.9603
Observations	5	5
df	7	
t Stat	-0.4753456	
P(T<=t) one-tail	0.32450775	
t Critical one-tail	1.89457861	

Table 9. Whiteman AFB Strikes Per Operation t-Test Results

Whiteman AFB	Before	After
Mean	0.00155264	0.0028821
Variance	7.32E-07	7.061E-07
Observations	5	4
df	7	
t Stat	-2.3394048	
P(T<=t) one-tail	0.0259452	
t Critical one-tail	1.89457861	

Table 10. Whiteman AFB Cost Per Operation t-Test Results

Whiteman AFB	Before	After
Mean	3.32091956	4.5500978
Variance	31.9781546	18.05876
Observations	5	4
df	7	
t Stat	-0.3721312	
P(T<=t) one-tail	0.36040264	
t Critical one-tail	1.89457861	

Table 11. Beale AFB Strikes Per Operation t-Test Results

Beale AFB	Before	After
Mean	0.0005059	0.0004763
Variance	2.937E-08	3.103E-08
Observations	5	3
df	4	
t Stat	0.2325335	
P(T<=t) one-tail	0.4137685	
t Critical one-tail	2.1318468	

Table 12. Beale AFB Cost Per Operation t-Test Results

Beale AFB	Before	After
Mean	2.089761	0.0046281
Variance	2.9393497	6.426E-05
Observations	5	3
df	4	
t Stat	2.7194758	
P(T<=t) one-tail	0.0265078	
t Critical one-tail	2.1318468	

Table 13. Offutt AFB Strikes Per Operation t-Test Results

Offutt AFB	Before	After
Mean	0.00215899	0.0030684
Variance	1.1232E-06	5.691E-07
Observations	5	3
df	6	
t Stat	-1.4127931	
P(T<=t) one-tail	0.10371442	
t Critical one-tail	1.94318028	

Table 14. Offutt AFB Cost Per Operation t-Test Results

Offutt AFB	Before	After
Mean	52.266666	4.1349152
Variance	12449.132	27.80855
Observations	5	3
df	4	
t Stat	0.9628091	
P(T<=t) one-tail	0.1950831	
t Critical one-tail	2.1318468	

Table 15. Bagram AB Strikes Per Operation t-Test Results

Bagram AFB	Before	After
Mean	0.00101939	0.0011026
Variance	1.4826E-08	
Observations	3	1
df	2	
t Stat	-0.5918646	
P(T<=t) one-tail	0.30696751	
t Critical one-tail	2.91998558	

Table 16. Bagram AB Cost Per Operation t-Test Results

Bagram AFB	Before	After
Mean	1.64706163	1.9008532
Variance	6.29646846	
Observations	3	1
df	2	
t Stat	-0.087591	
P(T<=t) one-tail	0.46909114	
t Critical one-tail	2.91998558	

Table 17. Across Airfields Average Strikes Per Operation

Average Strikes/Operation	Before	After
Dover AFB	0.000902	0.001364
Whiteman AFB	0.001553	0.002882
Beale AFB	0.000506	0.000476
Offutt AFB	0.002159	0.003068
Bagram AB	0.001019	0.001103

Table 18. Across Airfields Average Cost Per Operation

Average Cost/Operation	Before	After
Dover AFB	$19.83	$31.91
Whiteman AFB	$3.32	$4.55
Beale AFB	$2.09	$0.00
Offutt AFB	$52.27	$4.13
Bagram AB	$1.65	$1.90

Table 19. Across Airfields Bird Strikes Per Operation t-Test Results

Across Bases	Before	After
Mean	0.00122784	0.0017786
Variance	4.1079E-07	1.302E-06
Observations	5	5
df	4	
t Stat	-2.1616147	
P(T<=t) one-tail	0.04835698	
t Critical one-tail	2.13184679	

Table 20. Across Airfields Cost Per Operation t-Test Results

Across Bases	Before	After
Mean	15.8308143	8.4998484
Variance	472.513731	174.58631
Observations	5	5
df	4	
t Stat	0.69901553	
P(T<=t) one-tail	0.26152674	
t Critical one-tail	2.13184679	