Woodhead Publishing in Mechanical Engineering

Bird Strike

An Experimental, Theoretical, and Numerical Investigation

Reza Hedayati and Mojtaba Sadighi

WP
Woodhead Publishing

Woodhead Publishing in Mechanical Engineering

Bird Strike

An Experimental, Theoretical, and Numerical Investigation

Written by

Reza Hedayati, Mojtaba Sadighi

ELSEVIER

AMSTERDAM • BOSTON • CAMBRIDGE • HEIDELBERG
LONDON • NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Woodhead Publishing is an imprint of Elsevier

WP
WOODHEAD PUBLISHING

Woodhead Publishing is an imprint of Elsevier
80 High Street, Sawston, Cambridge, CB22 3HJ, UK
225 Wyman Street, Waltham, MA 02451, USA
Langford Lane, Kidlington, OX5 1GB, UK

ISBN: 978-0-08-100093-9 (print)
ISBN: 978-0-08-100113-4 (online)

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2015942352

For information on all Woodhead Publishing publications visit our website at http://store.elsevier.com/

Printed in the United States of America

Bird Strike

Related title

Airport Bird Strike Scene Investigation and Emergency Rescue Airport Bird Strike Prevention Series
(ISBN 978-7-56501-939-5)

Contents

Introduction

1

1.1 Introduction

What is a bird strike? Any contact between a moving vehicle (usually an aircraft) and an airborne avian creature (usually a bird or bat) or a group of such avian creatures is called a bird strike. The term is usually expanded to include other wildlife species including terrestrial mammals. The result of such contact for a bird is, of course, usually fatal. For an aircraft, however, the result can vary from a blood smear, an indentation or small hole in the aircraft's frame, substantial damage to an aircraft component, or even complete aircraft destruction; this is usually caused by significant bird strikes that disable engines (Blokpoel, 1976).

A bird strike can, therefore, be a significant threat to the safety of aircraft travel. In fact, more than 90% of foreign object damages (FODs) can be attributed to avian creatures (Mao, Meguid, & Ng 2008). Consequently, bird strike is one of the most important safety concerns in the aviation industries (Hedayati, Sadighi, & Mohammadi-Aghdam 2014). Bird strikes have caused numerous accidents resulting in aircraft damage and human casualties. The risk of bird strike to the aviation industries is, however, within acceptable limits (it is estimated that bird strikes cause human death in only about 1 in every 10^9 flying hours (Thorpe, 2003)). Indeed, air travel is considered statistically to be one of the safest modes of travel (Blair, 2008).

However, bird strikes are an increasing problem for the aviation industries. It is thought that there are four main factors involved in the increasing number of reported bird strikes. First, successful wildlife protection programs have increased the number of birds, especially the more hazardous to aircraft migrant birds (that usually have larger body sizes and fly in large flocks). Second, the density of air traffic has increased (Blair, 2008) due to the advent of more low-cost airlines (that usually implement small and inexpensive aircraft) as well as the expanding demands of the emerging economies for faster modes of transport. Third, modern jet aircrafts have fewer, but more powerful engines that produce more thrust than ever; this increased thrust leads to increased bird ingestion. Fourth, more studies and investigations on bird strike have led to an increased awareness of the risks caused by bird strike. Today, the origin of several aircraft crashes is recognized by the aviation industry to be caused by bird strike, while in a few decades ago the cause was unknown in similar accidents.

Modern jet aircrafts are now carrying more and more passengers, and it is known that even a small amount of damage in the aircraft's windshield or engine can lead to a catastrophic chain of events (Meguid, Mao, & Ng 2008). As a result, it is critical to ensure that the different structural parts, e.g. the compressor blades, the windshield, the wings, and the tail's leading edges, are able to resist such high-energy impacts, and so guarantee a safe landing of the aircraft after bird strike (Hedayati & Ziaei-Rad, 2012a, 2012b). This is why an aircraft must show compliance with the "continued safe

Bird Strike. http://dx.doi.org/10.1016/B978-0-08-100093-9.00001-7

flight and landing" requirements following specified types of high-energy bird impact (Hedayati & Ziaei-Rad, 2013). The regulations regarding bird impact proofing for aircraft will be presented later in Chapter 3.

1.2 History of bird strike

Bird strikes have occurred throughout the history of aviation, with their increased frequency and consequences, mirroring the aviation industry's growth and global expansion. There have been a considerable number of bird-strike accidents; however, some are more prominent and well known. The first recorded bird-strike event was reported by Orville Wright in 1905. According to the Wright Brothers' diaries, "Orville ... flew 4,751 meters in 4 minutes 45 seconds, four complete circles. Twice passed over fence into Beard's cornfield. Chased flock of birds for two rounds and killed one which fell on top of the upper surface and after a time fell off when swinging a sharp curve".

Six years later, Eugene Gilbert, a French pilot, encountered an angry eagle while traveling from Paris to Madrid. Gilbert, flying an open cockpit Bleriot XI, was able to ward off the large bird by shooting it (Wikipedia, 2014). The other significant bird-strike event was recorded in 1912 by Calbraith P. Rodgers, who trained with the Wright brothers, and made the first transcontinental airplane flight by flying across the United States (Bilstein, 2001), which made him a national celebrity. A few months later, however, while performing in an exhibition flight over Long Beach, California, he flew into a flock of seagulls which subsequently became entangled in the control wires of his plane, causing the plane crash into the ocean (Post, 1912; Blair, 2008).

In the November 1925 issue of the *Royal Aeronautical Society Journal*, the then Director of Civil Aviation, Sir Sefton Brancker wrote the following in an article entitled "The Lessons of Six Years Experience in Air Transport" (Brancker, 1925; Thorpe, 2003):

> *There is one form of collision which must not be altogether forgotten; the possibility of colliding with birds in flight. We have had one mysterious incident in which the pilot lost control of his aircraft flying over the sea at a low height, the pilot's opinion was that he had been struck on the head by a sea bird, several were flying nearby, but nothing was ever clearly proved. In the East, propellers of aircraft taking-off have been broken by kites flying over the aerodrome. I have never heard of an aeroplane encountering a flock of ducks at night; such an eventuality might lead to danger of injury to the pilot, the propeller or wing structure. The best precaution to meet such a danger will be good screening for the pilot and robust metal construction.*

Due to a steady increase in the number of flights, passengers per plane, and flight speed, birds began to pose more threat to the aviation industries. However, the piston engines prevalent in the first half of twentieth century were more resistant against avian strikes compared to forthcoming engine types (Solman, 1973).

The bird strike with the greatest recorded human fatalities occurred on 4 October 1960 when a Lockheed Electra flew through several starlings, shortly after taking-off from Boston Logan International Airport. Due to the ingestion of the birds, two of the four turboprop engines lost power and one shut down, causing the plane to stall, and consequently crash into Boston Harbor. Of the 72 passengers, 62 lost their lives (Thorpe, 2003). Subsequently, the Federal Aviation Administration (FAA) developed a minimum bird collision standard for jet engines.

Although no single bird-strike event with fatalities as large as Boston's accident has since been recorded, the total number of people killed during the subsequent 60 years due to bird strikes exceeds five times of the fatality count in the 1960 Boston accident. The bird strike became a more common occurrence and attracted the concern of both the aviation industries and the authorities, as the commercial airline industry expanded and annual aircraft travel increased (Thorpe, 2003).

The next major bird-strike accident occurred in 1973, when a Learjet 24 flew through a flock of brown-headed cowbirds as it took off from Peachtree-Dekalb Airport in Georgia, USA. The aircraft crashed as a result of cowbird ingestion into both its engines and all seven people onboard were killed (Antonides, 2010).

On 15 September 1988, Ethiopian Airlines flight 737-200 ingested numerous pigeons into both engines during take-off. As a consequence, the engines lost thrust, resulting in a crash landing killing 31 of the 105 passengers on-board.

On 10 November 2008, a Boeing 737-8AS suffered multiple bird strikes (up to 90 strikes) in a flight from Frankfurt to Rome. The bird strikes caused both the engines to fail and the aircraft made an emergency landing. Passengers and crew were evacuated through the starboard emergency exits. Of the 172 people on-board, eight passengers and two crew received minor injuries (Milmo, 2008).

One of the recent famous examples of a catastrophe caused by bird strike is the bird impact on the aircraft engine of the US Airways, Airbus A320 in January 2009 (Fig. 1.1). The plane struck a flock of Canada geese shortly after take-off in a flight from LaGuardia Airport in New York City to Seattle–Tacoma International Airport in SeaTac; the bird strike caused power loss in both turbines and a subsequent ditching of the airplane into the Hudson River. When the aircraft's pilots realized that they were

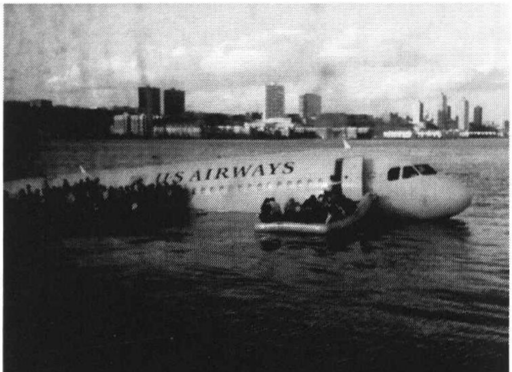

Figure 1.1 A US Airways Airbus A320 jet ditched in New York's Hudson River after hitting a flock of Canada geese. Photo by: Janis Krums. Some rights reserved. URL: https://flic.kr/p/5SHML6.

not able to reliably reach any airport, the pilots turned southbound and glided over the Hudson River and ditched the airliner some three minutes after power loss. All of the 155 occupants were safely evacuated from the airplane that was partly submerged and gradually sinking. The entire flight crew were subsequently awarded the Master's Medal of the Guild of Air Pilots and Air Navigators (Wikipedia, 2014).

1.3 Importance of bird strike

The aviation industry and its passengers suffer heavily from bird strike. According to the database provided by the International Bird Strike Committee, 55 fatal accidents have occurred between 1912 and 2009, in which 108 aircraft were damaged and 277 passengers were killed. Human fatalities and aircraft destruction during military flights are more difficult to estimate, but it is known that there has been at least 283 aircraft destructions, leading to 141 deaths between the years of 1959 and 1999 within a limited number of countries which provide regular bird-strike reports (Allan, 2000).

The majority of bird strikes do not cause aircraft crashes. According to the FAA database, in the year 2014, more than 93% of bird strikes caused no damage, about 4% caused minor damage, and some 2% caused substantial damage. In the same year, only five aircraft were destroyed. Those bird strikes with substantial damages are the main cause of economic losses due to the repair and/or delay costs. Some airlines collate bird-strike costs due to flight delays and cancellations (Allan, 2000). The determination of accurate costs is difficult, but it has been estimated that the annual economic losses within the USA alone are in the region of $614 million ($470 million in direct costs and $144 million in associated costs) (Grimaldi, 2011). Annual economic losses to commercial aircraft worldwide are more than $1.2 billion (Allan & Orosz, 2001).

Therefore, more and more aircraft manufacturers, aviation companies, and government authorities carry out advanced research and development (R&D) programs to reduce the annual costs, injuries, and fatalities that result from wildlife collisions. To mitigate the effects of bird strike, two main approaches are implemented: first, bird-strike prevention in which it is attempted to reduce the probability of such an incident occurring, and second, aircraft certification programs whereby different measures are employed to ensure the integrity of aircrafts against the high loads caused by high velocity impacts in accordance to international certification standards (Grimaldi, 2011).

1.4 Solutions to bird-strike problem

The potential damage tolerance of an aircraft should be investigated taking account the following matters (Guida, 2008):

- the residual strength and stiffness of the potentially damaged structure;
- the aerodynamic loading on the potentially damaged structure;
- the aerodynamic handling of the damaged aircraft;
- any changes in flutter characteristics;
- the effect of bird strike on the emergency systems; and
- the residual vision properties of any transparency component.

In the early days of designing bird-proof aircraft structures, experimental tests and theoretical calculations were used in order to predict the loads and the pressures imposed by the impact of bird strikes, and therefore, the potential damage incurred on the different types of aircraft structures (Hedayati & Ziaei-Rad, 2011a, 2011b). The high costs and the time-consuming practical procedures of experimental tests make them commercially unappealing to the industry. Many researchers tried to approach bird-strike problems theoretically, but due to its limitations for applicability in complex geometries and material models, theoretical solutions have been infrequently applied. However, the presence and development of powerful computers since the late 1990s has since made it possible to study numerous bird-strike problems much more efficiently (Hedayati, Ziaei-Rad, Eyvazian, & Hamouda 2014).

Bird strike is a high velocity impact in which materials with a huge difference in material property (bird as a soft impactor compared to aircraft body as a stiff target) come into contact with each other resulting in nonlinear material behavior, high strain rates, and extremely large deformations. Modern airframes are usually made of composite materials that have very complex damage-propagation modes. Nonlinear finite element (FE) codes have the capabilities of predicting the loads and deformations of both the birds and the complex aircraft components with acceptable levels of accuracy. In high velocity impacts, the pressure on bird tissues severely exceeds the tissues tolerable values, making the bird's material actually behave like a fluid. To discretize the bird model, there are generally three well-established approaches:

- Lagrangian;
- Arbitrary Lagrangian Eulerian (ALE); and
- Smoothed Particle Hydrodynamics (SPH).

Some explicit FE codes, such as LS-DYNA, have the capability of analyzing all the three above-mentioned approaches. The Lagrangian and SPH methods both use a Lagrangian framework, which means that the coordinates move with the material. Their only difference is exhibited in the way the bird material is presented. In the Lagrangian method, the bird body is divided into numerous continuously connected elements, whereas in the SPH method the bird material is presented by a set of discrete and mutually interacting mass nodes in space. In the ALE method, however, the coordinates system is not attached to the material. In fact, the bird material flows into an Eulerian mesh and its interacting forces are transferred to the target elements by means of an ALE coupling algorithm. Each of the three methods have their own advantages and disadvantages (which will be discussed later in Chapter 6 in greater depth) and choosing the correct method for each problem depends on many factors, such as the skillfulness of the user, the required outputs, and the specific conditions of the problem posed.

1.5 Outline of the book

In this book, the bird-strike problem for aircraft is introduced, the importance of its investigation is demonstrated by statistics (Chapter 2), and the methods to reduce the probability of a bird-strike event (Chapter 3), or its consequences are presented (Chapters 4–8).

In Chapter 2, the statistics of bird-strike events in the USA and around the world are presented, and the most important factors causing a catastrophic bird-strike event are highlighted. Risk assessment strategies for reducing the costs, injuries, and deaths caused by bird strike are also presented.

In order to decrease the number of bird strikes and/or alleviate the consequences of a bird strike, several solutions have been implemented by aircraft authorities worldwide, including enforcing strict regulations on the required safety characteristics of new aircraft and using bird harassment techniques to repel the birds away from aircraft. A complete list of currently implemented bird repelling techniques are presented in Chapter 3.

Chapters 4–6 are devoted to introducing the experimental, analytical, and finite element methods for investigating bird-strike problems, respectively. In Chapter 4, the setup of experimental bird-impact test facilities are described. These consist of a fire system, a support system, a measurement system, and a recording system. The steps required to prepare a real dead or a gelatin bird impactor are also described in detail. Finally, the results of the Hopkinson bar test, rigid target test, and deformable target test in perpendicular and inclined impacts are presented and discussed.

In Chapter 5, first, the 2D (two-dimensional) hydrodynamic theory that formulates bird strike against a rigid plate is introduced and explicit relationships for Hugoniot and steady pressures are given. Modifications to the results of this theory for yawed and inclined impacts are also presented. Non-rigid targets and porosity of the projectile are also discussed. Since the distribution of pressure in an oblique or right cylindrical impact is three-dimensional, a 3D (three-dimensional) fluid dynamic approach can be very useful. The dynamic forces being generated during a bird strike on an engine blade are highly nonlinear, and an awareness of these highly nonlinear dynamic forces is therefore very useful when designing bird-impact proof engines. This will be discussed in the final section of Chapter 5.

Chapter 6 provides an extensive description of the numerical methods of bird-strike modeling. This chapter presents a description of the basic theory of nonlinear analysis and a brief review of the following finite element modeling approaches: (a) pure Lagrangian, (b) Arbitrary Lagrangian Eulerian (ALE), and (c) Smoothed Particle Hydrodynamics (SPH).

Considerable research has been carried out on the resistance of different aircraft components, such as the fuselage, the wing's leading edges, the tailplane leading edge, the empennage, the transparent components, the fan blades, and the cockpit etc. against bird strike. A review of the relevant numerical and experimental researches is presented in Chapter 7.

Finally, in Chapter 8, the steps required to be taken to model a bird-strike phenomenon against a rigid target using Lagrangian, SPH, and ALE formulations are presented in detail. The effects of the different parameters involved in the different modeling techniques will be discussed, and the optimum parameters will be introduced. A detailed examination of the commercial explicit FE code LS-DYNA will be given which is more accurate and numerically stable than its other counterparts.

References

Allan, J. R. (2000). The costs of bird strikes and bird strike prevention. In *Human conflicts with wildlife: Economic considerations* (pp. 147–153). Lincoln, NE: USDA National Wildlife Research Center Symposia.

Allan, J. R., & Orosz, A. P. (2001). The costs of birdstrikes to commercial aviation. In *Bird Strike Committee – USA/Canada, third joint annual meeting* (p. 2). Calgary, AB.

Antonides, B. (2010). *Brookings regional airport 2010 wildlife hazard assessment*. Gander Island Consulting Service Inc.

Bilstein, R. E. (2001). *Flight in America – From the Wrights to the astronauts*. Baltimore, MD: Johns Hopkins University Press.

Blair, A. (2008). *Aeroengine fan blade design accounting for bird strike*. Dissertation, The University of Toronto.

Blokpoel, H. (1976). *Bird hazards to aircraft*. Clarke.

Brancker, M. G. S. S. (1925). The lessons of six years' experience in air transport. *Journal of the Royal Aeronautical Society*, *29*, 552.

Grimaldi, A. (2011). *SPH high velocity impact analysis – A birdstrike windshield application*. Dissertation, Department of Aerospace Engineering, University of Naples Federico II.

Guida, M. (2008). *Study design and testing of structural configurations for the bird-strike compliance of aeronautical components*. PhD Dissertation, Università degli Studi di Napoli Federico II.

Hedayati, R., Sadighi, M., & Mohammadi-Aghdam, M. (2014). On the difference of pressure readings from the numerical, experimental and theoretical results in different bird strike studies. *Aerospace Science and Technology*, *32*(1), 260–266.

Hedáyati, R., & Ziaei-Rad, S. (2011a). Effect of impact orientation on bird strike analysis. *International Journal of Vehicle Structures & Systems*, *3*(3).

Hedayati, R., & Ziaei-Rad, S. (2011b). Foam-core effect on the integrity of tailplane leading edge during bird-strike event. *Journal of Aircraft*, *48*(6), 2080–2089.

Hedayati, R., & Ziaei-Rad, S. (2012a). Effect of bird geometry and orientation on bird-target impact analysis using SPH method. *International Journal of Crashworthiness*, *17*(4), 445–459.

Hedayati, R., & Ziaei-Rad, S. (2012b). New bird model for simulation of bird strike on various layups used in transparent components of rotorcrafts. *Journal of Aerospace Engineering*, *27*(1), 76–85.

Hedayati, R., & Ziaei-Rad, S. (2013). A new bird model and the effect of bird geometry in impacts from various orientations. *Aerospace Science and Technology*, *28*(1), 9–20.

Hedayati, R., Ziaei-Rad, S., Eyvazian, A., & Hamouda, A. M. (2014). Bird strike analysis on a typical helicopter windshield with different lay-ups. *Journal of Mechanical Science and Technology*, *28*(4), 1381–1392.

Mao, R. H., Meguid, S. A., & Ng, T. Y. (2008). Transient three dimensional finite element analysis of a bird striking a fan blade. *International Journal of Mechanics and Materials in Design*, *4*(1), 79–96.

Meguid, S. A., Mao, R. H., & Ng, T. Y. (2008). FE analysis of geometry effects of an artificial bird striking an aeroengine fan blade. *International Journal of Impact Engineering*, *35*(6), 487–498.

Milmo, D. (2008). Bird strike forces Ryanair jet into emergency landing in Italy. *The Guardian*, http://www.theguardian.com/world/2008/nov/10/italy-ryanair-airline-accident.

Post, W. (1912). *Fall kills aviator.*

Solman, V. E. (1973). Birds and aircraft. *Biological Conservation*, *5*(2), 79–86.

Thorpe, J. (2003). Fatalities and destroyed civil aircraft due to bird strikes, 1912–2002. In: *International Bird Strike Committee, 26th Meeting, Warsaw, Poland.*

Wikipedia (2014). *Birdstrike.* Retrieved from, http://en.wikipedia.org/wiki/Bird_strike.

Statistics

2

2.1 Introduction

Since the very early days of manned flight, bird strike has been one the main issues regarding flight safety (Hedayati & Ziaei-Rad, 2012a). In the first years of aviation, bird strikes were rarely reported. When the number of bird strikes increased and more substantial damages were imposed on the aircrafts, some aviation companies and airliners began to collect statistics in order to determine the seriousness of the problem, as well as the main effective factors in the extent of the consequences of bird strikes. This would assist the aviation companies and airliners in researching the best solutions for approaching the problem (Blokpoel, 1976). Studies regarding the bird-strike statistics and the investigation of the mechanical responses of different aircraft components against bird strike date back to the 1940s. In those days, due to the increase in the number of flights as well as aircraft speeds, the damage caused by bird strikes sharply increased (Barber, Taylor & Wilbeck, 1978).

According to currently available data, it is estimated that a bird-strike event occurs once every 2000 flights (Khan, Kapania & Johnson, 2010). Further analyses of bird-strike statistics have shown that only 20% of bird strikes are actually reported by aviation staff. This means that the extent of economic and human losses resulting from bird strike could be much higher than what is currently presumed (Chuan, 2006). Consequently, this suggests that conducting further indepth studies on how to better capture reliable bird-strike event statistics and formulating strategies and solutions would be beneficial.

The International Civil Aviation Organization (ICAO) has established different regulations about bird strike in its publication *Annex 14* and states: "The bird-strike hazard on, or in the vicinity of, an aerodrome shall be assessed through: (a) the establishment of a national procedure for recording and reporting bird strikes to aircraft; and (b) the collection of information from aircraft operators, airport personnel, etc. on the presence of birds on or around the aerodrome constituting a potential hazard to aircraft operations."

2.2 Reporting a bird strike

All aviation personnel, including pilots, aircraft maintenance personnel, airport operators, etc., and all persons who are sufficiently informed about bird strike have a duty to report bird-strike incidents to the aviation authorities of the country/region concerned. In the USA, the reports must be submitted to the Federal Aviation Administration (FAA) using form number "5200-7", which can be electronically accessed at: http://wildlife-mitigation.tc.faa.gov. If the bird strike is reported by more

Bird Strike. http://dx.doi.org/10.1016/B978-0-08-100093-9.00002-9

than one person, more information about the event can be recorded. The several files, filled by various persons, are then collated and combined to provide a more complete report (Dolbeer & Seubert, 2009).

The precise identification of the bird species involved in an incident (e.g. Canada goose, Mourning dove, Red-tailed hawk, European starling, Snowy plover (as opposed to generic terms: e.g. goose, dove, hawk, starling, plover, or even worse goose, pigeon, birds of prey, passerine, shorebirds)) is of great importance. Knowing the exact species of the bird involved in a bird strike is critical in planning a successful wildlife risk management program at airports. A problem cannot be resolved, if it is not well understood or sufficiently well defined. If the aviation personnel are not able to identify the exact bird species, an ornithological biologist can identify the bird using the feathers or other remains. If there is no access to a trained, local ornithological biologists, the bird remains can be sent in a sealed plastic bag to bird identification laboratories (Dolbeer & Seubert, 2009).

2.3 Human losses and damages to aircraft

When a bird strikes an aircraft, damage is imposed on the aircraft, which can be as slight as a scratch or as vast as complete aircraft destruction. Injury or death of the aircraft passengers and staff can be the consequences of a substantial bird-strike event. In every form the staff complete for submission to the aviation authorities, there are fields regarding monetary and life losses. In addition to these recognizable direct losses, there are also indirect losses, such as long reparation times, a reduction in the number of customers using the airline or aircraft involved in a bird strike which has been widely reported and broadcast, or future legal cases brought by the passengers or their affiliates. After the occurrence, the liability is developed for which the claimant can request compensation or indemnity in cash for the damages sustained (Matijaca, 2005).

2.3.1 Annual increases

Presently, all the available evidence suggests that the bird-strike hazard is increasing year-by-year (Hedayati, Sadighi, & Mohammadi-Aghdam, 2014; Hedayati & Ziaei-Rad, 2012c; Hedayati & Ziaei-Rad, 2011). Many factors are causing this increasing trend. One of the significant factors is the general trend towards having fewer, more powerful engines per plane, rather than having several smaller ones due to economic considerations. While in 1960s, less than 25% of the planes were two-engine, they now constitute more than 90% of the operating airplanes in the USA (Blair, 2008). This reduction in the number of engines has made the robustness of individual engines against bird ingestion more important, because in a case whereby the thrust is lost by an engine, the proportion of remaining operating engines is obviously smaller in two-engine airplanes (Blair, 2008).

The more efficient reporting of bird strikes may also be the cause of the "increase" in the number of reported wildlife strikes. According to the data published by the