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BIRD-AIRCRAFT STRIKE HAZARDS:
AN OVERVIEW OF THE RISKS, COSTS AND MANAGEMENT

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By

Douglas N. Meeking
AGRA Earth & Environmental Limited

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16. Abstract

This report presents the results of research of available information on the nature of the bird strike hazard to aircraft. Most of that information is derived from United States and Canadian sources but published information from Europe and the United Kingdom is also incorporated. The scope of reference is civilian commercial aviation because that represents the greatest potential risk to the travelling public and is, coincidentally, the source of most systematically collected data. However, to the limited extent of the data available, military and general civilian aviation are also addressed.

The bird strike hazard is described in terms of those bird species and types of aircraft most commonly involved, as well as the operational, temporal, spatial and regulatory aspects of incidents recorded. A mean annual strike rate is estimated, as is the rate of damage to aircraft.

Costs related to aircraft-bird strikes are estimated on the basis of defined categories that include direct, indirect, ancillary, catastrophic and total.

Aspects of risk management are discussed in the context of the Canadian airport operational and regulatory environments.

Recommendations for future management direction and emphases in research and development are provided.

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16. Résumé

Ce rapport présente les résultats d'une recherche documentaire sur le péril aviaire dans l'aviation. La plupart des informations glanées proviennent de sources américaines et canadiennes, mais aussi de documents publiés en Europe et au Royaume-Uni. L'étude visait l'aviation civile commerciale, soit le secteur qui représente le plus grand risque pour le public voyageur, et qui procède à la collecte la plus systématique de données. L'aviation militaire et l'aviation générale ont quand même été prises en compte, dans la mesure où le permettaient le peu de données disponibles à leur sujet.

Le péril aviaire est décrit sous l'angle des espèces d'oiseaux et des types d'avions les plus souvent en cause dans les collisions, et des divers paramètres opérationnels, temporels, spatiaux et réglementaires se rapportant aux incidents documentés. Des estimations de la fréquence annuelle moyenne des collisions, de même que du pourcentage des incidents causant des dommages à l'avion, sont établies.

Les coûts engendrés par les collisions oiseaux-avions sont évalués et classés dans des catégories précises (coûts directs, coûts indirects, frais accessoires, coûts de catastrophes, coûts totaux).

Divers aspects de la lutte contre le péril aviaire sont abordés à la lumière des conditions d'exploitation et du cadre réglementaire qui caractérisent les aéroports canadiens.

Enfin, plusieurs recommandations sont formulées quant aux directions que devraient prendre dans l'avenir la lutte contre le péril aviaire et les travaux de R&D concernant ce problème.

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SUMMARY

This report presents the results of research and analysis of available information on various aspects of the hazard that birds pose to aircraft. The majority of information is derived from United States and Canadian sources but published information from Europe and the United Kingdom is also incorporated. The primary focus is civilian commercial aviation because that represents the greatest potential risk to the travelling public and is, coincidentally, the source of most systematically collected data. Emphasis is on data from the past decade but older information that remains relevant is reviewed. To the limited extent of the data available, military and general civilian aviation are also addressed.

All available evidence suggests that the bird strike hazard is increasing because of apparent increases in the populations of certain bird species and steadily increasing levels of air traffic. Also, the probability of a bird strike increases as the size and speed of aircraft increase. Thus, large, commercial jet transports are particularly vulnerable. Canadian records show that the Dash 8, Boeing 737, A320 and DC 9 are consistently noted as being among the most commonly involved in bird strikes.

The problem species of birds differ from one location to the next but overall, flocking species and larger size birds that congregate in flocks pose the greatest threat to aircraft. Records from across Canada show that gulls, geese, ducks, shorebirds, lapwings, passerines and birds of prey are most often involved. Recent, order of magnitude increases in urban, non-migratory populations of Canada geese across North America are an increasing concern.

Incident records show that more than 90% of aircraft collisions with birds take place at less than 1500 feet above ground level and about 50% of all incidents take place below 100 feet during take-offs or landings. Thus, most incidents occur on or near airport property. Land use practices on or near an airport can strongly influence local bird numbers by affecting the attractiveness of habitat, food supplies and level of harassment.

Seasonal patterns indicate that July-September accounts for about 50% of strikes, whereas December-March accounts for only 10%. Diurnal distribution shows the 09:00-15:00h period accounts for most strikes but incidents have been recorded at all hours of the day and night.

Transport Canada encourages reporting of bird strike incidents by pilots, airlines and airport operators but reporting is not legally required. Thus, the reporting rate varies and only an estimated 30% of all incidents are reported, although it is believed that there is a higher rate of reporting for damaging incidents (30-40% of all incidents).

From 1992-1997 the totals of bird strikes reported ranged from 622 (1992) to 795 (1995). The estimated average frequency of bird strike incidents was 10 per 10,000 aircraft movements for the top twenty (in terms of reported incidents) airports across Canada. The average rate for all airports would obviously be somewhat less.

Overall, recent models of high-bypass turbofan engines are damaged less frequently than older engine models because design standards have been progressively upgraded to increase engine resistance to damage from ingested objects such as birds.

Data on the costs of bird strike damage are fragmented and pertain mostly to direct costs of damage repair as reported by the civil aviation industry. Indirect costs and ancillary costs are rarely available. Catastrophic costs are estimated for a hypothetical civil aviation accident, based upon the insured value of an aircraft and recent awards for accidental fatalities in North America, without any consideration of secondary costs related to damage or fatalities at the crash site, or subsequent investigation and litigation expenses. This report has estimated that the total direct and indirect costs for bird strikes in Canada range between $247,900,000 and $613,290,000 ($Cdn 1997) for the estimated annual total of about 2,250 bird strike incidents.

Airline fleets are predicted to increase from about 11,000 aircraft in 1995 to about 12,500 in 2000 and to 21,000 by 2014. Worldwide passenger demand is expected to increase from 2.4 billion to 2.9 billion and 5 billion, respectively, for those same time periods. Clearly, the increasing number of large aircraft, increasing passenger capacities and increases in air traffic will progressively increase travellers' risk of exposure to bird strikes.

Of the 726 certified airports in Canada, 26 account for 94% of all passengers and cargo and these are able to cover operating expenses with earned revenue. Transport Canada owns, operates or subsidizes 150 airports. The National Airports Policy, 1994, is intended to commercialize airports while maintaining public safety and reducing Transport Canada's operating costs. The Policy could also provide the means for implementing a bird hazard risk management safety program at all airports in Canada. Other conventional risk management programs have focussed on advanced engineering to strengthen airframes and engines, airport habitat management and zoning regulations, research into methods of frightening birds from the path of an oncoming aircraft, computer models indicating risk levels based upon historic data about bird distribution and numbers, as well as the ongoing exchange of information among working groups such as the Bird Strike Committees in Canada, the United States and Europe.

The following recommendations for future management and research and development include:

- Transport Canada should regulate the mandatory reporting of damaging bird strikes, including strike damage evidence and itemized costs by airlines, airport operators and aircraft repair depots. Periodic audits of the three sources by Transport Canada would help to identify lapses in reporting rates where data gaps become apparent;

- A detailed risk analysis for bird-related catastrophic events in Canadian aviation should be undertaken by Transport Canada using an actuarial methodology to project the probability of a serious incident and the consequences to Canadian travellers. Such an analysis of this risk in the U.S. determined that there is a 25% probability of a major, bird-related catastrophe involving a large civil aviation aircraft in the U.S. within the next ten years;

- The primary focus for bird management should be on airport property where it appears the hazard is greatest;

- Transport Canada should develop and implement a requirement for at least the 20 highest bird-strike risk Canadian airports to develop and implement a bird hazard management plan, approved by Transport Canada, specifically designed to address the bird species and types of bird problems occurring there;

- Ongoing aircraft engineering research to reduce both the frequency and severity of bird strikes should be encouraged and funded by all stakeholders;

- The USAF Bird Avoidance Model (BAM) should be assessed, and refined if possible, for its applicability to Canadian civilian and military airports;

- The effectiveness of airport zoning regulations should be evaluated, with reference to managing bird hazards to aviation, and revised as necessary to make them an effective hazard management tool when used in concert with airport wildlife hazard management programs;

- Stakeholders should continue to fund ongoing research into the behaviour of birds with the objective of developing a better understanding of why and how they respond to stimuli that might be used to deter them from using airport property and also frighten them away from the path of oncoming aircraft;

- Research results should be shared internationally among regulators and industry to minimize duplication of effort and derive the maximum potential benefits from applying the results of such research to reducing bird hazards;

- Bird strike committees should broaden their scope to provide a critical review of ongoing research and safety programs to minimize the prospects of ineffective safety programs being undertaken;

- Bird strike committee members should co-operate to design, fund and implement focussed research programs that could lead to increased aviation safety improvements in terms of bird hazard management at and near airports; and,

- An effective process to improve information sharing would be the combining of U.S. and Canada (and possibly even Europe) Bird Strike Committee meetings once every few years, and alternating between venues in the U.S. and Canada to bring together those involved in the research and management of birds and other wildlife.

SOMMAIRE

Ce rapport expose les résultats de la recherche et de l'analyse de l'information disponible sur divers aspects du risque que représentent les oiseaux pour les avions. La plupart de l'information recueillie provient de sources américaines et canadiennes, mais aussi de documents publiés en Europe et au Royaume-Uni. L'accent a surtout porté sur l'aviation civile commerciale, soit le secteur où le public voyageur est exposé au plus grand risque, et où les données sont colligées le plus systématiquement. L'étude s'est limitée à l'information couvrant les dix dernières années, sans laisser de côté les informations moins récentes mais toujours pertinentes. L'aviation militaire et l'aviation générale sont également prises en compte, dans la mesure où le permet le peu d'information disponible à leur sujet.

Tous les documents recensés font état d'une progression du péril aviaire, imputable à l'accroissement apparent de la population de certaines espèces d'oiseaux, et de l'intensification du trafic aérien. De plus, la probabilité d'une collision oiseau-avion augmente en raison directe de l'augmentation de la taille et de la vitesse des avions. D'où la vulnérabilité particulière des gros avions à réaction aujourd'hui utilisés par l'aviation commerciale. Les rapports d'accidents compilés au Canada révèlent que le Dash 8, le Boeing 737, le A320 et le DC 9 sont les types d'appareils les plus souvent en cause dans des collisions avec des oiseaux.

Les espèces d'oiseaux dangereux varient d'un endroit à l'autre, mais règle générale, ce sont les espèces grégaires et les oiseaux de grande taille qui se rassemblent en bandes qui posent la plus grande menace aux avions. Selon des données provenant des quatre coins du Canada, les goélands, les oies, les bernaches, les canards, les oiseaux de rivage, les vanneaux, les passereaux et les oiseaux de proie sont les espèces à l'origine du plus grand nombre de collisions. L'accroissement exponentiel récent, en Amérique du Nord, de populations urbaines non migratrices de bernaches du Canada suscite de plus en plus d'inquiétudes.

Les rapports d'incidents indiquent que plus de 90 % des collisions oiseaux-avions se produisent à moins de 1 500 pieds du sol et qu'environ 50 % de tous les incidents ont lieu à moins de 100 pieds d'altitude, au décollage ou à l'atterrissage. Ainsi, la plupart des incidents se produisent à l'intérieur de l'enceinte aéroportuaire ou à proximité. L'utilisation des terrains de l'aéroport et des sols environnants peut avoir une influence marquante sur les populations locales, car elle détermine l'attrait de l'environnement pour les oiseaux, la quantité de nourriture mise à leur disposition, et le degré de harcèlement dont ils sont l'objet.

Les schémas saisonniers révèlent qu'environ 50 % des collisions ont lieu entre juillet et septembre, et seulement 10 % entre décembre et mars. Pour ce qui est de leur distribution journalière, la majorité se produisent entre 9 h et 15 h, mais des incidents ont été signalés à toute heure du jour et de la nuit.

Transports Canada encourage les pilotes, les compagnies aériennes et les administrations aéroportuaires à signaler les collisions avec des oiseaux, mais ceux-ci n'y sont pas tenus légalement. D'où le degré d'incertitude entourant les taux de déclaration. On estime à seulement 30 % le nombre de cas signalés, même si le taux de déclaration est supérieur, croit-on, pour les incidents ayant causé des dommages (de 30 % à 40 % de tous les incidents).

De 1992 à 1997, le nombre total des collisions oiseaux-avions signalées annuellement a varié de 622, en 1992, à 795, en 1995. La fréquence moyenne d'incidents mettant en cause une collision avec un oiseau a été évaluée à 10 pour 10 000 mouvements d'avions, si l'on ne tient compte que des vingt aéroports canadiens où ont été signalés le plus grand nombre d'incidents. Naturellement, la fréquence moyenne des incidents dans l'ensemble des aéroports serait quelque peu inférieure.

De façon générale, les turboréacteurs modernes à taux de dilution élevé sont moins souvent endommagés que les moteurs plus anciens, les normes de conception ayant été progressivement resserrées pour améliorer la résistance des moteurs à l'endommagement en cas d'absorption d'objets, tels des oiseaux.

L'information sur les coûts engendrés par les collisions oiseaux-avions est passablement morcelée et concerne surtout les coûts directs associés à la réparation des dommages déclarés par l'industrie de l'aviation civile. Rares sont les données sur les coûts indirects et frais accessoires afférents. Les coûts de catastrophes sont établis en posant l'hypothèse d'un accident d'avion civil, selon la valeur assurée de l'avion et les montants récemment accordés en Amérique du Nord pour l'indemnisation de pertes de vie accidentelles, et n'incluent pas les coûts secondaires reliés aux dommages ou aux victimes au sol, ni les frais d'enquête ou frais judiciaires engagés par suite de l'accident. Le rapport a établi entre 247 900 000 $ et 613 290 000 $ ($CAN de 1997) le total des coûts directs et indirects engendrés par les quelque 2 250 collisions oiseaux-avions survenant chaque année au Canada.

On s'attend que le parc aérien mondial, qui comptait quelque 11 000 avions en 1995, en comptera 12 500 en 2000, et 21 000 en 2014. Pendant ce temps, le nombre de passagers transportés dans le monde passera, estime-t-on, de 2,4 milliards à 2,9 milliards, puis à 5 milliards. En clair, la multiplication des gros porteurs, l'accroissement de la capacité des avions et l'intensification du trafic aérien sont autant de facteurs qui exposent les voyageurs aériens à un risque grandissant de collision oiseau-avion.

Vingt-six des 726 aéroports agréés du Canada traitent 94 % de tous les passagers et des marchandises transportés; dans ces grands aéroports, les revenus équilibrent les dépenses d'exploitation. Transports Canada est le propriétaire, le gestionnaire ou le bailleur de fonds de 150 aéroports. La Politique nationale des aéroports, rendue publique en 1994, a pour objectif de céder au secteur privé la responsabilité des aéroports, tout en garantissant au public le même degré de sécurité et en réduisant les coûts d'exploitation pour Transports Canada. Cette Politique pourrait constituer un cadre pour la mise en oeuvre de mesures de sécurité visant à lutter contre le péril aviaire dans tous les aéroports canadiens. Parmi les mesures classiques d'atténuation du risque prises à ce jour, on peut mentionner des techniques de pointe permettant le renforcement des cellules et des moteurs d'avions, des règlements touchant la gestion des habitats et l'utilisation des sols, la recherche de méthodes pour tenir les oiseaux à distance de la trajectoire des avions, des modèles informatiques servant à définir les niveaux de risque d'après les données historiques concernant les populations d'oiseaux et leur distribution, sans parler de l'échange constant d'information entre les groupes chargés de la question au Canada (le Comité du péril aviaire), aux États-Unis et en Europe.

Voici les recommandations formulées quant aux directions que devraient prendre dans l'avenir la lutte contre le péril aviaire et les travaux de R&D :

- Que Transports Canada oblige par règlement les lignes aériennes, les administrations aéroportuaires et les dépôts de réparation d'avions à déclarer les collisions oiseaux-avions ayant causé des dommages, y compris tout dommage semblant résulter d'une collision avec un oiseau, ainsi que les coûts afférents détaillés. Que Transports Canada effectue des vérifications périodiques auprès des trois instances visées, afin d'être en mesure de cerner, le cas échéant, l'origine de trous dans les données.

- Que Transports Canada lance une analyse détaillée, fondée sur une technique actuarielle, du risque de catastrophe reliée au péril aviaire dans l'aviation canadienne afin d'établir la probabilité d'accident grave, et de ses conséquences, à laquelle sont exposés les voyageurs canadiens. Une telle analyse de risque réalisée aux États-Unis a établi à 25 % la probabilité d'une catastrophe aérienne majeure causée par la collision d'oiseaux avec un gros porteur de l'aviation civile d'ici dix ans, aux États-Unis.

- Que les mesures de lutte contre le péril aviaire visent avant tout les aéroports, c'est-à-dire les zones apparemment les plus exposées au risque.

- Que Transports Canada formule et applique une exigence selon laquelle les 20 aéroports canadiens les plus vulnérables aux collisions oiseaux-avions seraient tenus d'élaborer et de mettre en oeuvre un plan de lutte contre le péril aviaire, préalablement approuvé par Transports Canada et expressément conçu en fonction des espèces d'oiseaux et des types de problèmes causés par les oiseaux à l'aéroport concerné.

- Que tous les intervenants appuient, financièrement et autrement, la recherche visant à réduire la fréquence et atténuer la gravité des collisions avec des oiseaux.

- Que l'on évalue la possibilité d'appliquer, en le peaufinant au besoin, le BAM (*Bird Avoidance Model*) de la USAF aux aéroports civils et militaires du Canada.

- Que l'on évalue l'efficacité des règles de zonage des aéroports sous l'angle de la lutte contre le péril aviaire, et que l'on revoie ces règles au besoin, de sorte que, conjuguées aux programmes de lutte contre la faune mis en place aux aéroports, elles contribuent à atténuer le péril aviaire.

- Que les parties intéressées continuent de financer la recherche en cours sur le comportement des oiseaux, dans le but de mieux comprendre les réactions de ceux-ci à certains stimuli qui pourraient être utilisés pour les effaroucher et ainsi les tenir à distance des terrains de l'aéroport et de la trajectoire des avions.

- Que les résultats des recherches soient diffusés auprès des organismes de réglementation et des milieux aéronautiques des autres pays, afin de réduire au minimum le double emploi et de tirer le maximum d'avantages de l'application des résultats de ces travaux à la lutte contre le péril aviaire.

- Que le mandat des comités chargés du péril aviaire soit élargi de façon qu'ils puissent exercer un jugement critique sur les programmes de recherche et de sécurité actuels, afin de parer à la mise en oeuvre de programmes qui s'avéreraient futiles.

- Que les membres des Comités du péril aviaire coopèrent à l'élaboration, au financement et à la mise en oeuvre de programmes de recherche bien ciblés, susceptibles de déboucher sur un accroissement de la sécurité aérienne, par la maîtrise du péril aviaire aux aéroports et dans les zones environnantes.

- Que des rencontres regroupant les Comités du péril aviaire du Canada, des États-Unis (voire d'Europe) soient organisées à intervalles pluriannuels, en alternance au Canada et aux États-Unis, pour favoriser l'échange d'information entre les groupes intéressés à la lutte contre les oiseaux et la faune, et aux travaux de recherche connexes.

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1.0 INTRODUCTION

1.1 THE NATURE OF BIRD STRIKES

In his classic 1976 book about the hazards of bird strikes on aircraft, Blokpoel defined a "bird strike" as "any contact between a moving aircraft and a bird or group of birds…"; however, the Bird Strike Committee Canada subsequently refined the definition to read as follows:

> A bird strike is deemed to have occurred whenever:
>
> - a pilot reports a bird strike;
> - aircraft maintenance personnel identify damage to an aircraft as having been caused by a bird strike;
> - personnel on the ground report seeing an aircraft strike one or more birds; and
> - bird remains, whether in whole or in part, are found on an air side pavement area or within 200 feet of a runway, unless another reason for the bird's death is identified (Transport Canada 1997).

Thorpe (1996) indicated that, since the first recorded fatality due to a bird strike in 1912, at least 52 civilian aircraft have been written off and 190 people killed in 30 fatal accidents, to the end of 1995. The probability of a bird strike increases as the size of aircraft, the number of aircraft, the speed of aircraft and the numbers of birds increase (Blokpoel 1976, Thorpe 1988, Milsom and Horton 1995, Donoghue 1996, MacKinnon 1997, Robinson 1997a). Incident records in Canada have documented that the vast majority (96-97%) of bird strikes take place at altitudes below 1500 feet (455 m) above ground level (AGL) and about 50% (17-59%) occur during take-off or landing procedures at altitudes below 100 feet (30 m) at ground level (Transport Canada 1993, 1994, 1995a, 1996, 1997, 1998). As such, the problem is greatest at or near airports, and the fact that airports tend to provide open field-like habitat that is attractive to certain species—particularly raptors, shorebirds, gulls, waterfowl, lapwings and passerines (starlings, blackbirds, cowbirds, etc.)—exacerbates the problem (Donoghue 1996). These species groups are consistently the most frequently cited as being responsible for bird strikes in North America and Europe (Blokpoel 1976, Thorpe 1988, Milsom and Horton 1995, Donoghue 1996, MacKinnon 1997, Robinson 1997, Transport Canada 1993, 1994, 1995a, 1996, 1997, 1998). Forbes (1996) stated that gulls, as a group, account for more than half of all bird strikes on a worldwide basis, but that Canada goose populations are increasing rapidly and they may soon become more of a hazard than the gulls.

Land use, such as landfills, wildlife refuges, wetlands, golf courses, parks and cultivated farmlands that provide avian feeding, resting, roosting or refuge near airports, can increase the potential numbers of birds flying near or over the airport each day. Situations that place the airport on the local travel routes of large numbers of birds making daily flights between such feeding, watering, roosting and rest areas can also place aircraft at higher risk of bird strikes. Finally, over the past several decades there has been an increasing trend in Canada and northern regions of the U.S. for ducks and geese to winter over in areas that provide winter refuge, with the result that these species now pose a year-round threat that in the past was, for the most part, seasonal (MacKinnon 1997, Thorpe 1997a, 1997b).

The frequency of bird strikes shows definite seasonal and diurnal patterns. July, August and September typically account for about 50% of the bird strike incidents, whereas December to March accounts for about 10% of the incidents. The diurnal distribution is also skewed, with the 09:00-15:00 h period accounting for the largest portion of strikes (Transport Canada 1993, 1994, 1995a, 1996, 1997, 1998). Thus, most strikes occur during the daylight period.

Furthermore, the potential for aircraft damage increases with higher aircraft speeds, large numbers of birds and larger birds (Blokpoel 1976, Thorpe 1988, Milsom and Horton 1995, MacKinnon 1997). Thus, large, jet-propelled passenger and transport aircraft are highly vulnerable to bird strikes and the consequences of a crash are particularly severe in terms of loss of human lives and property damage. Military aircraft, particularly fighters and other tactical aircraft that train in low-level combat maneuvers (<300 m AGL), appear to suffer a disproportionately higher rate of damaging bird strikes than do civilian aircraft, probably attributable to the amount of time military aircraft spend flying training missions at low altitudes and high speeds (Larose 1996).

Bird strike impacts can affect any component of the aircraft, but certain components are more often noted as having sustained bird strike damage. These include wings, engines and nose (Transport Canada 1993, 1994, 1995a, 1996, 1997, 1998). Birds that shatter windshields have injured or killed pilots; one or more birds being ingested into engines have caused damage ranging from inconsequential to catastrophic engine failure(s) that led to fatal crashes.

It is clear that a review of the nature of bird strikes must address both environmental and engineering considerations. There are several aspects to consider in assessing the environmental nature of bird strikes, ranging from land use around the airport and habitat control on the airport to the species of birds using the area, and the seasonal and diurnal patterns of use. Engineering aspects are also relevant, including the size and speed of the aircraft, and the design characteristics of the engines and hull to withstand foreign object damage (FOD).

2.0 THE RISK OF AIRCRAFT STRIKING BIRDS

Risk is typically assessed in terms of the probability of an event occurring and the consequences of that occurrence. The consequences of bird strikes are addressed in later sections of this report. This discussion will focus on the data that are available to quantify the probability of a bird strike and the probability of a damaging bird strike. In the landmark Canadian “Study of Bird Strikes at Canadian Airports - 1979”, Agar and Heybroek (1979) estimated that “…a bird strike will occur once in every 10,000 air movements and that once in every 50,000 movements serious damage will occur. Injuries from bird strikes may occur once in every 2 million movements and the probability of a fatality is once in every 5-7 million movements”. As will be shown in succeeding sections of this report, the probability of a strike and of strike damage would appear to have doubled or tripled in the interim, in Canada and internationally. Assessment of the probability of a fatality is beyond the scope of this report.

As referenced above, the probability of a bird strike increases with the increase in air traffic and numbers of birds in the vicinity of airports and aircraft flight corridors; increasing aircraft size and speed also increases the probability of a bird strike. The numbers and size of jet aircraft are increasing rapidly in North America, as are the numbers of gulls and waterfowl near heavily populated areas, where aircraft activity is concentrated.

Many organizations and jurisdictions in Canada and worldwide have incorporated reporting procedures for bird strike incidents, but the consistency of reporting has varied widely between airlines, airports, regulatory authorities, individual pilots and over time. Within these groups, at most, the summary figures can only be used to estimate minimum values. Unfortunately, it seems essentially impossible to differentiate between different databases because there is no way of knowing with confidence whether low values equate to low risk or low reporting rates and, conversely, whether high reported numbers of incidents equate to a high risk situation or apparently a very thorough, effective reporting system. In Canada, the four sources of reports are:

1) airports (both Transport Canada and non Transport Canada);
2) Transport Canada through the Bird/Wildlife Strike Report system and forms;
3) Department of National Defence (DND); and
4) individual pilots.

DND pilots and personnel at airports operated by Transport Canada are required to submit reports of bird strikes. Private and commercial pilots voluntarily submit reports on a form provided by Transport Canada; airlines voluntarily submit annual summary reports to Transport Canada. It is intuitively obvious that the level of detail and reliability of reporting will differ, particularly with airlines, pilots and airport personnel, and particularly so between those airports operated by Transport Canada and those that are not. At a Hawaiian airport in the U.S. (1990-1994), Linnel *et al.* (1997), reported that only 25% of bird strikes confirmed by airport maintenance staff were reported. As a Canadian example, Transport Canada identified that the number of airports reporting was 16, 25 and 25 for 1992, 1995 and 1996, respectively. The number of reported strikes from those same years for Vancouver was 7, 96 and 35, and for L.B. Pearson was 80, 45 and 74. During those same years the percent of strikes reported by airport personnel at Canadian airports ranged from 100% for some small airports to only 11% at Fredericton and 14% at L.B. Pearson. Thus, even within the six years for which recent data summaries are available, there appears to have been an inconsistency in data recording and reporting (Transport Canada 1993, 1994, 1995a, 1996, 1997, 1998). Transport Canada reported that pilot reports of bird strikes increased from 132 in 1994 to 319 in 1995, an increase of 141% (MacKinnon 1997). This probably does not accurately reflect an equal increase in the actual number of incidents from one year to the next. Similarly, Canada reported 28.5% as many strikes as the U.S. in 1994; and in 1993 Canada accounted for 21.3% of the world's strikes reported to International Civil Aviation Organization (ICAO). Both figures are likely disproportionately high, given the relatively lower rates of aircraft activity in Canada and the fact that many birds migrate out of Canada for the winter months. Furthermore, Transport Canada estimates that only 30% of Canadian bird strikes are reported.

Regardless, Transport Canada's data on recorded bird strikes in Canada for the period of 1992-1997 show a clear upward trend in frequency, as shown in Figure 1.

In an attempt to draw conclusions from the Transport Canada data presented for 1994, 1995, 1996 and 1997 (Transport Canada 1993, 1994, 1995a, 1996, 1997) for comparison with other sources, the listings of the top 20 airports in numbers of bird strikes were compared; 17 airports appeared in at least 4 of the 5 annual lists (Table 3.1b in each case). For those 17 airports, the strike rates were reviewed (Table 3.1c in each case); 23 examples provided overlap from the two tables over the four years of records (1997 strike rates were not yet available). The range of rates for the n=23 examples was 1.5-4.8 strikes per 10,000 movements. The arithmetic mean of the 23 values is 2.88 and a frequency histogram indicates that 13 of the 23 values lie between 2.5-3.3. Thus it would seem reasonable to approximate the average rate of bird strikes, from recorded data, at the top 20 Canadian airports is 2.9 (or at least within the range of 2.5-3.3) per 10,000 air movements to provide a basis for comparison with similar statistics from other sources. If, as stated by Transport Canada, the reported rate is only 30% of the actual, then a closer estimate of the true rate of bird strikes at the top 20 airports in Canada is closer to 10 per 10,000 air movements (0.1%). Intuitively, the mean strike rate for all Canadian airports combined would be lower but cannot be defined with any confidence from the data available.

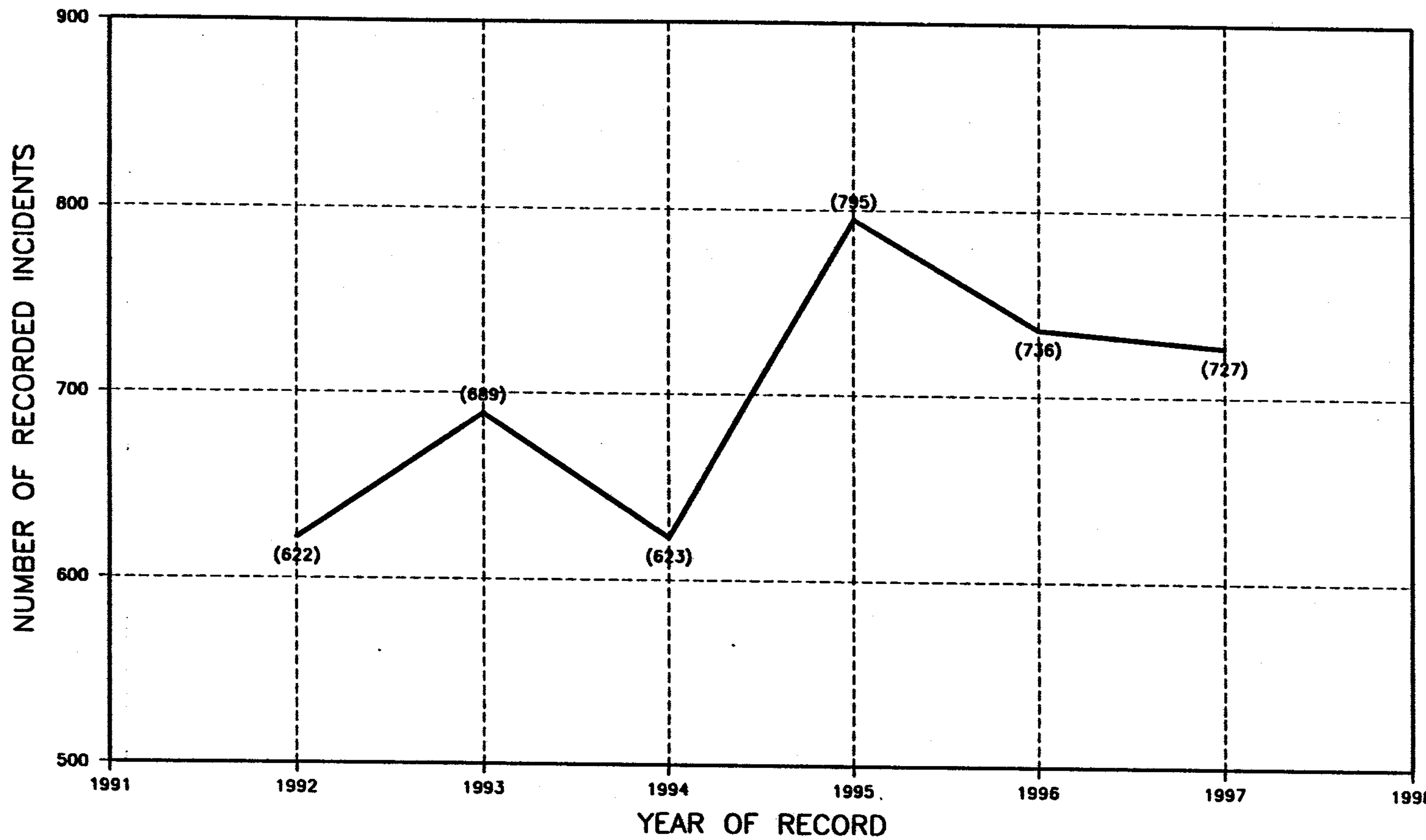

FIGURE 1
TRENDS IN REPORTED BIRD STRIKES AT MAJOR AIRPORTS IN CANADA: 1992-1997

Larose (1996) reported that the bird strike rates at CF (Canadian Forces) aerodromes ranged from 0.82-0.87 per 10,000 movements during the period 1994-1996; of the 105 strikes recorded in 1995, 17 (16.2%) caused some degree of damage. Thus, for 1995, the rate of damaging strikes was 0.17 per 10,000 air movements at CF aerodromes. Unfortunately, the total numbers of air movements were not reported each year so the annual rates per 10,000 movements could not be shown on a year-by-year basis. Although the CF reporting system should be highly reliable, the strike and damage rates stated are about one order of magnitude lower than those shown for civilian commercial aircraft; this discrepancy could relate to better bird hazard management practices, the inclusion of less vulnerable aircraft such as helicopters, the propeller-driven C130 or louder but slower jet trainer aircraft in the totals. Also, except for the large propeller-driven C130 transports, CF aircraft tend to be small jets and therefore less likely to be hit than a larger, civilian jet transport when confronted with a similar group of birds.

Thorpe (1997a) indicated that International Bird Strike Committee (IBSC) data showed that for U.K. airlines during the period of 1976-1995, the rate of bird strikes per 10,000 movements was lowest in 1991 (3.1) and had risen to 4.4 by 1995. He did not comment on the frequency of damaging strikes during that period. These data compare reasonably well with the range of strike rates determined above for Canada from the 1992, 1993, 1995, 1996 and 1997 Transport Canada Summary Reports (range of 1.5-4.9). Milsom and Horton (1995) reported Thorpe's 1988 data, suggesting a bird strike rate of 5.7 per 10,000 movements by European carriers.

Among those who track such information, there seems to be a higher degree of confidence in the figures reported for bird strikes that caused damage because a damage incident seems more likely to be reported. Even so, there is a wide range of opinion on the level of confidence that should be placed in these data. Donoghue (1996) reported that E. Cleary of the Federal Aviation Administration (FAA) believes only 15-20% of all strikes are reported (Cleary *et al.* 1997a); Boeing, in a 1996 study, recorded 175 incidents, of which 100 caused damage (a rate of 57%, at face value); and Lesham, of Tel Aviv University, cited reports that civil operators report only 15-20% of their damage (does not specify number of incidents or value of the damage), probably because of the insurance deductibles that can be as high as US $1.2 million per incident. Dimoustikos (1997) reported that American Airlines estimates that 60-70% of bird strikes do not cause damage (30-40% do cause damage). Thorpe (1997b) commented that, "Damaging strikes are much more likely to be reported, those countries where damage is over 4-5% of incidents either have poor reporting or a lot of heavy birds."

MacKinnon (1997) and Lehmkuhl (1997) reported that Lufthansa data from 1982-1995 showed a general upward trend in the number of reported strikes causing damage, whereas the overall number of strikes had declined until 1993 but was now projected to gradually increase. The frequency of damaging strikes per 10,000 air movements during the period of record had ranged from a low of 0.68 in 1982 to a high of about 3.6 in 1993, with trend data predicting 3.0 by 1996 and 3.5 by the end of the century. He also asserted that, as shown by his data, the ratio of total reported strikes to damaging strikes per 10,000 air movements is changing from year to year so an average rate or ratio may well result in misleading conclusions. Obviously these damaging strikes were “reported”, so they can be translated to 0.68 (1982), 3.6 (1993), 3.0 (1996) and 3.5 (projected forward to the year 2000) for comparison with the rates reported above from other sources.

Thorpe (1997c), in a review of 1986-1995 records of engine damage from bird strikes on multiple engine (2, 3 or 4 engines) registered aircraft over 5,700 kg (12,500 lb) reported in the U.K., indicated a total of 74 events where one or more engines were hit but only 22 incidents were recorded as having resulted in engine damage for the 10.26 million air movements on record. The 22 incidents equate to a rate of 0.021 damaging incidents per 10,000 air movements. This rate must be considered a minimal value for damage rates because data were not reported for bird strikes that caused damage other than to the engine(s). However, by comparison, the FAA study of engine ingestion events during the 1989-91 period (Banilower and Goodall 1995) identified a engine ingestion rate of 2.04 and a damage rate of 0.96 events per 10,000 air operations for wide-body jets having high-ratio bypass engines; damage resulted from about 47% of the ingestion events. During the same period of record, Thorpe (1997c) reported 4,268 bird strike incidents so the 22 incidents of damage to one or more engines, as reported above, constitute 0.52% of the total bird strikes recorded. The rate of bird strikes then was 4.2 and the overall rate of engine-damaging incidents was 0.021 per 10,000 movements. However, European airlines recorded that, during 1981-1985, only 17% of bird strikes hit engines (Martin 1995). This information can be extrapolated to the entire aircraft by increasing the rate by a factor of 6; i.e., 6 X 0.042% = 0.252%. This factor cannot reasonably be applied to the overall rate of damaging strikes to all parts of the aircraft because available evidence suggests engines are damaged disproportionately more often than most other parts of an aircraft (Transport Canada 1993, 1996, 1997).

Thus, to estimate the rate of damaging bird strikes, two approaches are available, based on the methods in which damage data are reported in the literature. In some cases, the ratio of reported strikes to damaging strikes is given; in other cases, the frequency of damaging strikes per 10,000 air movements is stated. Given that we have calculated an approximation of the bird strike rate at the top Canadian airports, and the results lie within the range of rates from other sources, this value will provide a basis for extrapolating to a rate for damaging bird strikes in Canada. The results of the damaging strike rate comparison should show similar values, if the data are reasonably reliable.

In terms of an absolute rate of damaging strikes per 10,000 air movements, Thorpe (1997a, b) estimated a rate of 0.021 for engine damage; the overall rate of damaging strikes would obviously be higher (6 times higher = 0.126 according to data from Martin (1995)) if all aircraft damage was included. He also provided data indicating an overall damaging strike rate of 0.15%. If, as proposed by Lesham, only 15-20% of damage incidents are reported, then the above two estimates of the overall damage rates should be 5-7 times higher, i.e., 0.63-0.88 and 0.75-1.0. Note that the upper extreme of these two ranges approximates 10% of the estimated rate for all bird strikes at the top Canadian airports. By comparison, Lehmkuhl's (1997) 1991-1995 Lufthansa data (per 10,000 air movements) showed a mean bird strike rate of 6.59 and a damaging strike rate of 2.74; as these data were systematically collected by one airline and based on its own experience with a range of jet transports, the data are probably more accurate than those compiled or extrapolated from a variety of unrelated sources. It would seem reasonable to assume that Lufthansa's data are representative of the civilian aviation industry in Europe as a whole.

In an exhaustive review of bird strikes on turbofan engines (Banilower and Goodall 1995), the FAA reported on data from over 3 million operations flown by more than 1,500 aircraft during the period January 1989 to August 1991. These data were collected from engine manufacturers; unfortunately, there were no data referenced for CF6-powered DC-10s in U.S. operations. Data are compared to those from a similar study conducted by the FAA during 1981-83 involving a similar number of aircraft (about 1,500), air operations (about 3 million), total ingestion events (about 660), but different generations of engines. Most of the engines in the early study predated 1974; as well, the 1984 FAA regulations required engine designs to be more resistant to FOD and particularly bird strike damage. The earlier study was based on information from the DC-8-70, DC-10, B-747, B-757, A-300, A-310 and L-1011 (Frings 1984). Aircraft models in the recent study included the A-300, A-310, A-320, B-747, B-757, B-767, DC-10 and MD-11. Most of the aircraft and engines were common to both studies; however, it was not made clear in the latter study that many of the engines from the first study may have been included in the second study (Curtis, pers. com.). Comparative data presented in Table 1 show that although there are some minor differences in the ingestion and multiple-engine ingestion rates, the rate of damaging strikes was 50% higher for the older generation of engines, suggesting that the design improvements are having the intended beneficial effect on repair frequency and costs, as well as, coincidentally, flight safety.

Table 1
Comparison of Damage Rates for Old and New High Bypass Ratio Turbofan Engines

Parameter	1989-1991	1981-1983
Number of aircraft	1,556	1,513
Number of operations	3,163,000	2,738,320
Number of ingestions	65/561/644*	97/484/638*
Ingestion rate (x 10^{-4})	0.70/2.52/2.04*	0.99/2.80/2.33*
Number of multiple engine events	31	25
Multiple engine ingestion rate (x 10^{-6})	9.8	9.86
Total number of engine events	675	663
Number of engine damage events	316	416
% of engine damage events	47	62
Rate of engine damage events (x 10^{-4})	0.96	1.45

Source: Banilower and Goodall (1995).

* U.S./FOREIGN/WORLDWIDE.

In terms of expressing the rate of damaging strikes as a ratio or fraction of total bird strikes, the above review of literature provides several clues. In his review of only those strikes causing engine damage, Thorpe's (1997a) data suggested a rate of 0.48%, a lower rate than would be expected for all damaging strikes. However, when factored up six-fold as per the information from Martin (1995), the ratio increases to 2.88%. Larose reported that 17 cases of damage resulted from 105 reported bird strikes to CF aircraft in 1995, a rate of 16.2%. Lehmkuhl's (1997) 1991-1995 Lufthansa data (per 10,000 air movements) showed a mean bird strike rate of 6.59 and a damaging strike rate of 2.74, indicating that on average 41.6% of strikes caused damage.

Tables 2 and 3 summarize the data and sources used to compile the estimated rates for bird strikes and the rate of damaging air strikes, respectively.

A comparison of the damaging strike rate data in Table 3 shows a range of about 1.5 for DND to 2.74-3.6 for Lufthansa's fleet per 10,000 air movements. Much of the other damage rate data cannot be directly compared for our purposes. The data also suggest that, of the strikes that occur, about 40% result in some damage to the aircraft. If this damage rate is applied to the Canadian and U.S. civil aircraft strike rates estimated in Table 2, then the overall damage rates for Canadian and U.S. civil aviation are similar to or slightly lower than those estimated by Lufthansa for their own fleet and 2.5 to 25 times higher than the rates estimated by Thorpe for the U.K. and Europe, supporting his contention that the latter rates are under-reported.

Table 2
Bird-Aircraft Strike Rates

Source	Location	Rate per 10,000 Air Movements	Comments
Transport Canada (1993, 1996, 1997)	Canada	mean = 2.9 10	Top 10 airports across Canada. Accounts for estimated 30% reporting rate.
Larose (1996)	Canadian Forces Aerodomes - Canada	0.82 - 0.87	1994 - 1996.
Thorpe (1997c)	U.K.	3.1 - 4.4	Data from 1976-1995. Values from 1991 and 1995, respectively.
Thorpe (1988)	Europe	5.7	IBSC data from European Airlines.
Banilower and Goodall (1995)	U.S. Foreign (all locations except U.S.) Worldwide	0.70 2.52 2.04	Engine ingestion rate only. Modern high bypass turbo fan engines.
Thorpe (1997c)	U.K.	4.27	From 10.26×10^6 air movements.
Martin (1995)	U.S. Foreign Worldwide	4.20 15.12 12.24	Banilower and Goodall rate extrapolated by 6 times (17% of bird strikes hit engines only).
Lehmkuhl (1997)	Lufthansa - Europe	6.59	1991-1995 data from Lufthansa operations in Europe.

Table 3
Bird-Aircraft Damaging Strike Rates

Source	Location	Rate	Comments
Larose (1996)	Canadian Forces Aerodomes - Canada	• 16.2% of 105 strikes recorded. • 0.00148% of all air movements-1995.	• 1995 data.
Boeing (1996)	U.S.	• 57% of total strikes.	• Small sample of 175 incidents.
Dimoustikos (1997)	United Airlines - U.S.	• 30-40% of incidents cause damage.	• No data presented to support estimate.
Lehmkuhl (1997)	Lufthansa Airlines (worldwide)	• 0.68×10^{-4} (1982). • 3.6×10^{-4} (1993). • 3.0×10^{-4} (1996 prediction). • 3.5×10^{-4} (predicted by 2000).	• Probably under-reported. • 1982-1995 data and trends.
Thorpe (1997c)	U.K.	• 0.021×10^{-4}.	• Based on 4,268 bird strikes. • Based on 74 engine strikes, of which 22 resulted in damage from 10.26×10^6 air movements of large aircraft (>12,500 lbs (5,700 kg)).
Banilower and Goodall (1995)	U.S.	• 0.96×10^{-4}. • 47% of engine strike incidents.	• Engine ingestion damage rate only. • Damage rate per 100 ingestions.
Martin (1995), Thorpe (1997a, b)	U.K., Europe	• 0.126×10^{-4}. • 0.15×10^{-4}.	• Extrapolated for overall aircraft from engine damage rate. • Overall rate from Thorpe.
Lesham (1996)	Europe	• $0.63\text{-}0.88 \times 10^{-4}$. • $0.75\text{-}1.0 \times 10^{-4}$.	• 5-7x the Martin rate above. • 5-7x the Thorpe rate above.
Lehmkuhl (1997)	Lufthansa - Europe	• 2.74×10^{-4}.	• Mean rate from 1991-1995 Lufthansa Airlines data.

The lower DND rate cannot be readily explained but may relate to the likelihood that military aircraft tend to be more damage resistant than civilian aircraft.

A brief comparison of damaging strike rates, as estimated by the procedures in Table 2, shows that the true bird strike rate for Canada probably lies between the extremes of the DND rate, at slightly less than 1.0, and the rate of 10×10^{-4} for the top 16 airports in Canada. This seems reasonable, given that bird strike rates at Canadian airports other than the top ten are lower but not definable from the smaller amount of data, and that the estimate for the U.S. is 4.2×10^{-4}. Overall, it would be reasonable to conclude that the rates for Canada and the U.S. are similar, given the general similarities of geography, air fleets and airport operations. The range of rates for the U.K. and Europe is 3.1-6.59 and, given the comparative data of Banilower and Goodall (1995) presented in Table 1 and the Lufthansa data provided by Lehmkuhl (1997), at face value, we would tend to have greater confidence in comparative data from the same source/set (such as Lufthansa Airlines), even if systematically under-reported, than data from a variety of sources that are suspected of under reporting but with no sense of any degree of consistency across the range of sources. By comparison with the range of rates shown for the U.K. and Europe above, the Banilower and Goodall (1995) data allow an extrapolation (6 times, to account for only a 16% reporting rate) to bird strike rates of 15.12×10^{-4} for “foreign” sources and 12.24×10^{-4} worldwide. Again, given that bird management efforts worldwide are less than in North America and the U.K., these rates would appear to be reasonable, on a comparative basis.

3.0 COSTS OF BIRD-AIRCRAFT COLLISIONS

3.1 METHODOLOGY

The primary sources of information for assessing costs of bird strike damage are available from published sources; Transport Canada and other regulatory agencies; aviation industry associations; proceedings from meetings of Bird Strike Committee Canada, Bird Strike Committee USA and Bird Strike Committee Europe; as well as solicited information from airline operators such as United Airlines, Lufthansa Airlines and Air Canada; aircraft manufacturer and repair firms such as Boeing; and other companies providing services to the aviation industry. Also, to develop the most recent data, a number of Canadians, as well as internationally recognized experts in bird strike hazards and related costs, have reviewed this report and provided additional information from published, unpublished or otherwise obscure sources in order that this report can stand as a comprehensive and current summary of the state of knowledge on the subject of bird strikes to aircraft.

The challenge in developing meaningful estimates of costs related to bird strike damage to aircraft relates to the reality that the database is derived from a variety of sources that have recorded incidents for a variety of purposes, to an inconsistent level of detail, format and priority. There is also the potential for discrepancies between the primary data collected and the summary reports provided by airlines, military sources, airport operators, aircraft repair and maintenance firms, and air industry regulators. As detailed in Section 2, the reporting rate for bird strike incidents is believed to be only 15-30% of the actual rate and the frequency of damaging strikes is also under reported, but probably to a lesser extent.

Much of the cost information presented in this report is comparative in nature. In order to facilitate direct comparisons between sources, the author has converted all references, unless otherwise indicated, to 1997 Canadian dollars (Cdn $), using Canadian Consumer Price Index data from the Statistics Canada website, an exchange rate of Cdn $1.30 per $1.0 U.S. (US$), Cdn $0.80 per German Mark (DEM) and Cdn $2.25 per British Pound Sterling (£). These exchange rates were selected to provide a reasonable approximation of average exchange rates over the past two decades.

In the competitive environment of commercial travel, an airline might be unwilling to publicize its bird strike rate if such information would lead to the public perception that the airline was in any way less safe to fly with than a competitor. However, experience in the U.S. to date indicates that airlines have not been exposed to public criticism as a result of a serious bird strike incident. Similarly, an airport operator might not willingly divulge bird strike information if such data could lead to the imposition of an expensive wildlife control program, invite future legal liabilities for an aircraft damage incident allegedly due to inadequate bird control measures or the public perception that the airport was not operated in a manner that protected public safety. Regardless, in the event of a serious U.S. incident, lawsuits naming the airport operators would likely follow, and the media and public would focus on any obvious bird management problem that the operators were not actively trying to eliminate. As a co-operative service to civil aviation authorities and in the interests of public safety, both the Canadian and U.S. military divulge the incidence rates and costs of bird strikes on military tactical, training and transport aircraft. The United States Air Force (USAF) provides such information through a number of its websites, in the interest of reducing bird hazards to its own operating units and the general public.

Data from the variety of sources may understate costs and not be directly comparable for use in developing averages or trends. Many sources of data are unclear as to whether the cost of a repair includes parts only, parts and labor, or parts, labor and associated costs such as sending a repair crew with parts to a location away from a main repair depot to restore an aircraft to service. The costs associated with loss-of-use are rarely considered but could be substantial for a large commercial aircraft. Lehmkuhl (1996) made the point that with an insurance deductible typically in the range of $1.3-1.56 million (US $1.0-1.2 million) per claim, the cost of repairs is likely to be under-reported, with only costs in excess of the deductibles being reported to insurers. Curtis 1998 (pers. com.) advised that generally insurance on the hull excludes engines. Also, deductibles on the hull depend on the aircraft size and range from about $650,000-1,300,000 (US $500,000-1,000,000). Thus, it is rare that hull damage from a bird strike would lead to an insurance claim. The review of available information for this report also demonstrated that peripheral costs related to search and rescue, aircraft salvage, crash site cleanup, subsequent investigations and on-the-ground property damage or personal injuries are rarely, if ever, included. Such peripheral costs would rarely apply to bird strike incidents, except for major accidents involving large transport-type aircraft.

Mean costs and cost trends may also be exaggerated because the majority of bird strike reports are provided by commercial pilots, scheduled airlines and the military. These entities tend to operate larger, more expensive aircraft than the larger number of owners of typically smaller, private and executive general aviation aircraft, so any attempt to derive average cost data for aircraft damage will be skewed towards the more expensive repairs to large, multi-engined aircraft. With the inconsistent reporting rate for bird strikes and strike damage, it is next to impossible to estimate a correction factor for such a bias. While some evidence suggests that small, executive jets suffer a disproportionately large rate of damaging bird strike incidents, probably because of the high frequency of shorter flights and use of small airports, the majority of available data comes from the airline industry and military sectors, which account for a majority of the costs associated with bird strike damage to aircraft.

By way of demonstrating some of the issues identified above, and to put Canadian carriers' costs into perspective with some of the costs documented or calculated in the following sections of this report, data from eight recent bird strike incidents in Canada and one from the U.S. are presented in Table 4.

When compared to the accident rates and related cost database for automobiles, data on the various costs related to bird-aircraft collisions are few. Thorpe (1997c) detailed 55 serious incidents due to bird strikes, during the period 1912-1995, where the aircraft was destroyed and/or one or more fatalities may have occurred. Of these, 4 occurred in Canada and 27 in the U.S. Compared to the frequency of vehicle damage, injuries and death on roads of the world, the frequency of aircraft incidents due to bird strikes is extremely low and provides a small sample size from which to derive conventional statistical summaries such as average costs. Furthermore, because aircraft and aviation operations are much more expensive than cars, trucks and their operations, there is a very wide range of potential costs such that mean values from a relatively small number of samples cannot be expected to reflect meaningful averages. A specific example would involve an "engine repair" that could range from the cost of a few minutes of a technician's time to dress a few slightly damaged turbofan blades so the aircraft can continue its flight without delay, to the other extreme where an aircraft is grounded for several days or weeks while the damaged engine is replaced at a repair depot and at a cost of several millions of dollars. For example, an engine is damaged by a bird strike and must be repaired before returning to service. If the aircraft was from a large airline and happened to be at one of its maintenance bases, the repair or even an engine replacement might be accomplished quickly and the aircraft returned to service within a day or so. If the same damage were to occur at a more remote location, costs would likely escalate sharply since the resources to deal with the situation may have to be flown in or contracted out, and the crew and passengers from the disabled aircraft may have to be accommodated at local hotels or provided with alternate transportation. Garber (1996b) reported that the cost of damage to two engines of a Concorde that ingested Canada geese was US $6 million, whereas the minor repair by the technician would not likely accrue any reportable costs and any replacement of parts at a later date would be recorded as regular maintenance.

Although the first documented crash and fatality due to a bird strike was in 1912, this review and assessment will concentrate on records since 1990 but will make reference to earlier data to put current information into perspective for long-term trends and comparative purposes. Aircraft costs and insurance settlements for personal injuries and accidental deaths have escalated sharply since 1990, but older data are still valuable to this study because many of the aircraft in service before 1990 are still in operation and the types of damage they might have sustained could recur. Aircraft repair costs and insurance may have changed significantly but aircraft have not; therefore, information from past incidents can help predict future costs. Cost data from earlier years has been extrapolated to 1997 Cdn $ where possible.

Table 4
A Summary of Costs Related to Recent Bird-Aircraft Strike Incidents in Canada

Date	Location	Airline	Aircraft	Bird Species	Description of Incident and Damage	Estimated Costs
Jul-97	Edmonton, AB	WestJet	Boeing 737	Not known	Bird strike occurred while plane was taking off, at about 90 knots. #1 engine was lost. Internal damage to the engine. More than 2 hours in delays.	>$600 000
Jul-97	Nanaimo, BC	Central Mountain Air	Beechcraft 1900	2-10 geese	On departure from runway at about 600 ft (182 m) the aircraft was struck on nose, denting skin. Tail section and windshield also struck, but not damaged. Landed without incident.	Direct Costs: >$20,000
Jul-97	Fort Severn, ON	Bearskin Airlines	Beechcraft	Gull	Damage to left wing and landing light. Aircraft out of service for 3 weeks.	$100,000
Jun-97	Vancouver, BC	Greyhound Airlines			Dent in leading edge of wing.	
Aug-97	Thunder Bay, ON	Air Canada	DC-9	Gulls	During take-off the plane was struck by numerous gulls. Plane returned to airport after vibrations forced a shut-down of the left engine. Damage to left engine fan stages 1 and 2, numerous torn blades, blade and stator damage in core gas path, core damage to engine.	Direct Costs: $717,000
Aug-97	Charlottetown, PEI	Air Atlantic	DeHavilland Dash 8	Duck	Damage to leading edges of wings.	Direct Costs: $10,000
Nov-97	Santa Ana, CA	Northwest Airlines	A320 Airbus	Maybe pelican or large bird; not a goose	Damage to the #2 engine included engine core, reverser and cowling.	$2,000,000
Oct-97	Vancouver, BC	Canadian Airlines Int.	DC-10	Snow goose	On approach into airport. Damage to #1 engine, 1 ft x 1.5 ft (0.3 m x 0.45 m) wrinkle dent on engine nose cowling. Aircraft landed without incident.	Direct Costs: $1,000
Mar-98	Vancouver, BC	Canadian Airlines Int.	747	Waterfowl	Damage to #2 engine included bent blades, tears and shingled mid-span beyond limits. Engine replaced. Engine failure may have been due to a previous, unknown bird strike.	$500,000

3.2 COST ESTIMATES

Costs related to bird-aircraft collisions can accrue in several ways and are organized into five categories to facilitate presentation and discussion in subsequent sections of this report. *Direct costs* include the costs incurred by the aircraft owner/operator for repair or replacement of a damaged aircraft or aircraft parts as a result of a bird strike. For the purpose of this study, *indirect costs* include those “hidden costs” (Robinson 1997b) incurred by the aircraft owner/operator. *Ancillary costs* are those incurred by the airport owners/operators, regulatory authorities or emergency response agencies to deal with the bird strike hazard threat in Canada. *Catastrophic costs* the destruction of an aircraft, with or without fatalities. Finally, for the purpose of this review, *total costs* are intended to represent estimates that would include all of the above components except catastrophic costs, because the those are not regular, recurring costs of operations.

3.2.1 Direct Costs

Direct costs include the costs incurred by the aircraft owner/operator for repair or replacement of a damaged aircraft or aircraft parts as a result of a bird strike. Thus, direct costs include those for both parts and labor but are not intended to include replacement of an aircraft as would happen with a catastrophic accident (see Section 3.2.4). Lehmkuhl (1996) provides data from Lufthansa Airlines that represents more than 50% of the civil aviation activity in Germany. He stated that the 1990-1994 annual “total costs of hull damage”, which we interpret to include engines but not any secondary costs, ranged from $666,000-2,945,000 (DEM 867,908-3,421,880) when selected extreme events were deleted (these were crashes that he apparently believed would skew the cost data significantly higher). About 80% of the events cost less than $8,650 (DEM 10,000), whereas on an annual basis, 0-3% of the incidents cost more than $430,000 (DEM 500,00); a very high percentage of bird strike incident costs are less than insurance deductibles and therefore would not result in insurance claims but would be borne entirely by the aircraft owner. Furthermore, the same data showed an average cost per 10,000 movements ranging from $16,500-44,300 (DEM 19,259-51,440) during the same period. Because these data were collected to comply with an aviation regulation, they would seem to be at least as credible as any other data collected elsewhere and dependent on voluntary submissions.

The FAA summarizes bird strike incident data for the U.S. civil aviation industry. Cleary *et al.* (1996, 1997b) reported that of the 6,519 bird strikes reported to the FAA during 1993-1995, there were 1,507 (23%) reports indicating that the strike damaged the aircraft and/or had a negative effect on the flight (i.e., precautionary landing, aborted take-off, fuel dump, etc.). The 979 (15%) damaging bird strikes were estimated to have incurred more than $35.5 million (US $26 million) of aircraft damage and related costs that included 30,000 hours of aircraft down time. The report apparently did not identify the number of bird strikes for which there was an estimate of the time out of service. The available data do not permit differentiating between the proportions of direct versus indirect costs and have been developed from the 25% of damaging incidents for which cost data were reported. Cleary *et al.* also proposed that, because of the low reporting rates and other undefined factors, the actual losses due to all wildlife are probably closer to 374,000 hours per year of aircraft down time and US $155 million per year of monetary losses. Given that he reported 97% of all wildlife strike damage (but only 44% of aircraft down time) was due to bird strikes, the above figures translate to about 363,000 hours of aircraft down time and $203 million (US $148 million) for damages from bird strikes alone during the three years of record. Based on an estimated overall reporting rate of 20% in the U.S., he estimated the annual cost of bird strikes would approximate $336 million (US $245 million) in monetary costs and 280,000 hours of aircraft down time.

By way of comparison, Wong (Larose and MacKinnon 1996) extrapolated an estimate of annual costs of bird strike damage to U.S. civil aviation of $154 million (US $117 million) per year, based solely on United Airlines records of FOD costs. Conover *et al.* (1995) estimated the costs of wildlife strikes to the USAF of more than $147 million (US $112 million), so total costs almost certainly exceed $264 million (US $200 million) per year.

In a discussion of engine maintenance costs due to erosive sand particles passing through turbofan engines, Air Algeria (El Hadi *et al.* 1996) estimated the costs of an unscheduled removal and repair of a Pratt & Whitney JT8D engine was in the order of $675,000-1,000,000 (US $500,000-750,000).

Pratt & Whitney, GE Aircraft Engines and Rolls Royce have indicated that the cost of a new turbofan engine for the B747, B777 generation of aircraft can range from $6.6-13.25 million (US $5-10 million) (Air Transport World 1996).

3.2.2 Indirect Costs

The extent of such costs can be determined by such factors as the extent of aircraft damage, operator's fleet size, type of operation (cargo or passenger) and proximity to a repair facility. Factors contributing to the hidden costs could include costs of re-routing passengers; passenger and crew accommodation and meals during delays; replacement of on-board food during a delay; jettisoned or wasted fuel; substituting an aircraft or parts; contractual penalties for late deliveries; loss of income from an aircraft undergoing unscheduled maintenance, repairs or inspections; and air traffic control, crew relocation or replacement and aircraft storage associated with delayed take-offs or landings. Also included could be losses of bookings and costs to restore public confidence after an incident, the "ripple effects" of any of the foregoing factors that could increase costs or reduce revenues, and any hidden costs in hull insurance rates that might have been inflated because of previous bird strike damage claims. Although there are few references providing the documented costs from specific incidents, some examples are to be found in the literature. Lehmkuhl (1996) noted that:

> … in addition to the costs of hull damages the costs of consequential damage have also an important influence on the cost situation of airlines. Although it is possible to buy insurance … I do not know of any airline having done so. As airlines have (in general) no coverage for such costs, no permanent data collection is done in respect to such costs.

Lehmkuhl offered some additional observations related to costs of consequential damage; they depend on the extent of damage, the distance between the place of the incident and where a repair can be done, the size of the airline fleet, and whether cargo or passengers are being carried. He also estimated that the cost of a block hour for an aircraft could range from $8,000-20,000 (DEM 10,000-25,000) per hour, hotel accommodation can be $160 (DEM 200) per passenger per night and replacement engines can cost as much as $6.5 million (DEM 8 million). Finally, he speculated that in the absence of hard statistics, it seems realistic to assume that consequential damage costs are "considerably" higher than those for hull damage.

3.2.3 Ancillary Costs

Ancillary costs are those incurred by the airport owner/operator regulatory authorities or emergency response agencies to deal with the bird strike hazard threat in Canada. Delays in airport operations due to disabled aircraft, emergency responses for damaged aircraft and bird-repelling activities can cost operators significant time and money each year. Transport Canada and the various airport operators co-operate to develop and implement bird hazard management programs, such as those for the Vancouver International Airport and the Lester B. Pearson Airport at Toronto, in order to reduce the chances of incurring larger ancillary costs related to a bird strike accident. Transport Canada and DND collect records and prepare annual summaries of bird strike incidents, but without cost data. Both agencies co-chair Bird Strike Committee Canada and have staff dedicated to management of the bird strike threat. Emergency response agencies train for aircraft crash search and rescue response, although not necessarily related to a bird strike. Neither Transport Canada nor DND have published information related to the costs of preparing the annual summaries, maintaining staff committed to addressing the bird strike hazard, maintaining participation in Bird Strike Committee Canada, and attending meetings of the counterpart committees in the U.S. and Europe or the U.K., although such a figure could be estimated from general labor, travel and overhead costs for the Government of Canada. It would be difficult, if not meaningless, to arbitrarily apportion the annual costs of emergency crash response and search and rescue (SAR) training for bird strike incidents as a fraction of all emergency response and SAR training; it would be much more appropriate and relevant to review actual emergency response and SAR records from recent, specific incidents considered representative of the types of situations that might occur in Canada as a result of bird strikes.

Ball (1996) noted that the Vancouver International Airport 1997 Wildlife Control Program would operate on a 24-and-7 basis and require 11 wildlife officers. Cost was estimated at more than $200,000 for labor and $60,000 for equipment, exclusive of new test equipment or vehicles. Ball (pers. comm.) indicated that 1997 costs were approximately $500,000 for the comprehensive bird management program.

Garber (1996a) has reported extensively on the ongoing wildlife management programs at John F. Kennedy and La Guardia Airports near New York City to reduce risks from gulls, geese, raptors, pigeons and shorebirds. The Port Authority of New York and New Jersey has a wildlife management staff of 30 and an annual budget of US $1 million to try to manage one of the highest rates of bird strikes in the U.S.

Regrettably, the apparently successful USAF Bird Avoidance Model (BAM) program costs have not been published in the literature reviewed for this report.

Order-of-magnitude costs estimated for airport delays during 1988 at Chicago O'Hare Airport (Chicago Delay Task Force 1991) were extrapolated to Toronto's Lester B. Pearson Airport. Bird hazards were not specifically cited as delay factors, but these costs can reasonably be applied toward cost estimates of delays to a large Canadian airport's operations due to bird hazards. Direct operating costs (aircraft fuel and oil, crew salaries, and other direct costs) were added to indirect costs such as passenger delay time costs and missed connection costs. A Canadian operator's cost estimates for delays to various types of large aircraft and Transport Canada's estimates for costs per unit of time for various types of aircraft in holding situations were all factored into the estimated total cost of delays for a 1996 typical planning day at the Lester B. Pearson Airport of $154 million per year and as much as $228 million per year based on an annual peak planning day ratio of 320.

3.2.4 Catastrophic Costs

A catastrophic incident involves destruction of an aircraft, with or without fatalities. Given the small database (55 incidents and 190 fatalities, 1912-1995 worldwide, according to Thorpe, 1996) for accidents known to have been caused by bird strikes, a more meaningful assessment can be developed around estimates of potential costs related to an incident as might be done by the insurance industry such that the total cost would be the cost of the aircraft plus a cost per fatality or injury based on recent litigated/negotiated industry settlements. Robinson (1997b) identified that in the worldwide civil aviation fleet, there were in excess of at least 1,000 aircraft in service, or on order to airlines, valued at $130 million (US $100 million) or more and several valued at more than $260 million (US $200 million). Currently, there are more than 1,200 aircraft insured for $100 million or more (Robinson pers. comm.). Furthermore, of the estimated worldwide fleet of 270,000 general aviation aircraft (those not including large commercial aircraft), 63% are based in the U.S. and only 5.5% are based in Canada; this places a large percentage of the world's smaller aircraft in North America. Although the potential for a major legal liability is much less than for civil aviation, it should not be disregarded. Recent court settlements in the U.S. have established a value of about $3.25 million (US $2.5 million) for an insurance settlement for an accidental death (Garber 1996b, Robinson 1997b). For example, the hypothetical cost for a total loss of a fairly new B747 with 300 passengers plus the crew would be upwards of $195 million (US $150 million) for the aircraft (less than $130 million (US $100 million) for older B-747s) and in the vicinity of $3.25 million (US $2.5 million) per passenger fatality (U.S. laws related to workplace injuries and fatalities would reduce this for flight and cabin crews), for a total nearing $1,170 million (US $900 million). Obviously, actual costs would relate to the model and vintage of the aircraft as well as the total of passengers and crew aboard. Thus, the potential direct-cost exposure for a catastrophic accident can readily be estimated by assuming the passenger and crew capacity as well as the replacement cost of the aircraft. The estimate might also include a provision for substantial third-party liability losses for crash site damage in addition to the aircraft and passengers, on the assumption that the crash is most likely to occur near an airport and could involve a residential, commercial or industrial area. Obviously, crashes due to bird strikes will occur almost every year and costs can be assigned for each specific incident, based on costs assigned when the type of aircraft, and the numbers of injuries and fatalities are known. If an assessment of general costs and an order-of-magnitude total cost is sufficient detail, then a better procedure might be to go to the larger database for aircraft crashes from all causes and extrapolate costs from that larger data pool to the smaller number of incidents due to bird strikes. Similarly, where data on additional costs such as search and rescue, salvage and accident investigations were available, these could be added to provide a cumulative total. With the steadily increasing costs of large civilian transport aircraft and increasing seating capacity of such aircraft, the potential for a major accident, huge legal liabilities and costs is of increasing concern to airlines, airport operators, air transport regulators and the aviation insurance industry.

With specific reference to Canada, the four incidents recorded by Thorpe (1996) showed one helicopter and three small, conventional aircraft involving seven injured and seven fatalities (1971, 1981, 1994 and 1994); only one of these (1981) happened at or near an airport. Thus, this small sample gives no indication of the potential liabilities and costs that would accrue to an incident involving a large commercial carrier, so if the costs of an accident are to be used to justify intensive bird hazard management programs at Canadian airports, then the approach of using documented Canadian accidents would provide less convincing justification than would a projection of potential costs associated with the loss of a single, large, commercial carrier. Ideally, such a projection could be linked to an estimate of the probability of such an occurrence in Canada (over the next decade, for example) to justify the creation and implementation of a bird hazard management program, prioritized for the major airports in Canada on the basis of air traffic volumes, type of air traffic and bird hazard records. Such a projection of potential costs or estimation of the probability of a catastrophic incident is beyond the scope of this review.

3.2.5 Total Costs

For the purpose of this review, total costs are intended to represent estimates that would include all of the above components. The challenge in presenting this information from literature sources is to clearly understand which components are actually factored into an author's estimate. Too often an estimate of "total cost" is stated without a clear statement of what costs are included.

Transport Canada (Kieran *et al.* 1981) undertook to calculate the costs of aircraft accidents in Canada using an "accounting approach", as often used in the automobile industry, that assigned estimated costs to various accident loss components such as fatalities and injuries, hull damage, search and rescue, investigations by government and non-government agencies, insurance administration, financial impact on the operator and property damage. The first three factors were found to account for about 90% of the costs. Data from 1976-1979 were used. In 1980 dollars, the cost of a single fatality was estimated at $298,000, far below the more recent estimate of $2.5 million, even when 1980 dollars are escalated to 1997 equivalent. Finally, total annual costs were estimated to range from $210-285 million ($103-138 million in 1980 dollars).

Wong (1996) advised that one-third of the FOD to United Airlines aircraft was due to bird strikes, and FOD in the U.S. is estimated to cost "FOD committee members" (term not defined), including airlines and airports, approximately $423 million (US $320 million) a year. Wong also stressed that not all FOD incidents are reported but reporting is more likely when the aircraft is delayed or damaged. If it can be assumed that United Airlines experience is representative, then bird strike damage in the U.S. amounts to a minimum of about $141 million (US $107 million). Given that replacement of a single turbofan engine could exceed $3.25 million (Garber 1996c) and Wong also advised that of the 177 bird strikes to United Airlines aircraft in 1995, the cost of the 31 damaging strikes was at least $660,000 to repair aircraft and engines, Wong's estimate for all FOD seems low and probably did not include indirect or ancillary costs.

Donoghue (1996) stated that MacKinnon reported on a conservative Canadian study that concluded bird strikes in North America annually incur costs of approximately $508 million; given that about 12% of aircraft in North America are Canadian, the Canadian costs would approach $42.25 million (Canadian dollars assumed). This value seems unrealistically low for Canada, especially in light of the Transport Canada (1981) estimates of $211-284 million ($103-138 million in 1980 dollars) per year.

The USAF (1993) reported an annual total of 3,000-3,500 bird strikes per year at an annual cost of more than $89 million (US $65 million), and seven fatalities between 1987 and 1992. It was not likely that the costs included secondary costs and/or a provision for the "costs" of the fatalities, so these cost estimates are most certainly understated, at least by civil aviation standards.

Cleary *et al.* (1997b) summarized reported monetary costs of bird strikes to U.S. civil aviation totaling $49,972,000 (US $38,439,270) for the period 1992-1996 and averaging $9,994,000 (US $7,687,855). These estimates apparently included only reported costs of aircraft damage and reflect only direct costs. Given the above values for comparison and the $5 million cost of a single turbofan engine replacement, this estimate seems unrealistically low by at least one order of magnitude.

Individual incident reports offer a glimpse of the range of costs that can be incurred, but only if the various costs from a large number of bird strike damage incidents of all sizes are thoroughly itemized will the industry costs become clear. This would be an arduous and costly undertaking.

Data from the past three years suggest that, in Canada, civil aviation experiences about 2,250 (750 x 3) bird strikes and CF may experience upwards of 125, for a Canadian total of about 2,400 incidents. The adjustment factor of 3 for civilian incidents is intended to account for the estimated under-reporting rate. Similar estimates for the U.S. would be about 16,700 (2,200 x 6 + 3,500), which seems reasonable in terms of order-of-magnitude given that Canadian civil aviation accounts for about 8% of the aircraft registered in the U.S. but the U.S. military aircraft vastly outnumber the Canadian counterpart. Any such estimate is necessarily crude and inherently vulnerable to criticism because of the acknowledged, but unsubstantiated, reporting biases.

In terms of bracketing a range of "total cost" for the U.S., based on primarily United Airlines, Lufthansa and FAA data, Cleary's 1997 estimate of US $245 million and Wong's estimate of US $117 million for direct costs provide a starting range. If we then consider Cleary's estimate of 280,000 aircraft hours lost to delays of various sorts and apply the range of values of US $6000-15,400 per hour for aircraft downtime (as estimated by Lehmkuhl), then we can add a range of US $1.723-4.307 billion for indirect costs to the above values, for a range of US $1.840-4.552 billion representing the total of direct and indirect costs to civil aviation in the U.S. in a recent year, without factoring in any costs as calculated for delays at airports such as O'Hare. The addition of US $112 million for total, undefined USAF costs (assuming a 100% reporting rate and all costs direct and indirect costs accounted for) is probably low but not unreasonable by comparison for our purpose. Thus, the estimated range of direct plus indirect costs to U.S. civil aviation is US $1.840-$4.552 billion; to that range add estimated USAF direct costs of $112 million, for a total range of US $1.952-$4.531 billion. This total must be viewed as a minimum, based on the premise that ancillary and other potentially significant indirect costs have not been included, nor have the costs to general aviation.

To translate the above costs proportionately to Canada's situation, while accounting for the dollar exchange rate difference, the U.S. civil costs can be factored down in proportion (2,250/16,700) to the probable numbers of total bird strikes, as estimated above. Thus the annual sum of direct and indirect costs to civil aviation for bird strikes in Canada are estimated to be in the range of $247.9-613.29 million for the estimated 2,250 incidents in a recent year. If the same approach is taken for Canadian military costs, then an estimate of $5.6 million is derived for the estimated 125 annual bird strikes. The latter figure assumes a 100% military reporting rate so, in reality, must be considered a minimum value. Thus, total costs to Canadian civil and military aviation— exclusive of any ancillary costs, potentially significant indirect costs or any consideration of general aviation—are estimated to be within the range of $253.5-618.9 million when expressed in 1997 Canadian dollars.

4.0 RECENT TRENDS IN BIRD-AIRCRAFT COLLISIONS

The 1979 study by Agar and Heybroeks provided a reference for Canada's bird strike problem, based on data from the period of 1976-1978. The following discussion of more recent trends in bird strikes will focus on the Canadian aviation environment since 1990 and, where possible, both civilian and military because that is the primary emphasis of this review. However, data from the U.S. and Europe, particularly the U.K., will be noted by way of putting the Canadian experience into perspective with other jurisdictions having high levels of aviation activities and a similar, if not identical, bird strike reporting system that can provide comparable data.

4.1 BIRD TYPES AND SPECIES

Data compiled by Transport Canada and DND (Hounsell 1994; Transport Canada 1993a, 1996; MacKinnon 1997; Larose 1996) indicate that there has been a generally upward trend in the total number of bird strikes recorded at Canadian airports since 1992, as shown in Figure 1. Data also show that the problem species vary from one airport to the next and sometimes seasonally at any particular airport. There are several common factors evident from the Canadian records in terms of species or groups of species involved. Gulls, as a group, are consistently recorded as being involved with the largest number of incidents each year; i.e., 17% in 1992, 28% in 1995 and 25% in 1996. Sparrows, swallows, starlings and snow buntings, the next four species groups most often encountered, together do not account for the number of incidents attributed to gulls. It should also be noted that the annual frequency of bird strikes attributed to "unidentified" species ranges from 30-50% but the relative proportions of the top five species probably does not change in this grouping. Other species/groups commonly in the top 10 list and accounting for more than 1% of incidents include: plovers, owls, hawks, larks, sandpipers and ducks (1992); hawks, crows, larks and plovers (1995); and ducks and hawks (1996).

Virtually all reports relating bird strike hazards to bird populations assert that bird populations are increasing, often dramatically, as documented for Canada geese, snow geese, gulls and a few other species (Donoghue 1996, MacKinnon 1996) in Canada. Curtis (pers. comm.) reported that at the National Aerospace FOD Prevention Conference in June 1997 at Seattle, Dr. Richard Dolbeer of the USDA stated that the non-migratory goose population tripled in North America between 1985 and 1995. Canada geese have not only increased in numbers in the urban environment of Canadian cities such as Toronto, Calgary and Vancouver, but have largely become non-migratory so that the risk of these large birds to aircraft has become a year-round concern where not long ago the birds were absent from November to April. Populations of starlings, pigeons and sparrows (mostly house sparrows) are resident in every Canadian city, and have been common in the urban and suburban environments for more than a century (Quammen 1996). They can be extremely numerous and are known to sometimes gather in large wintering flocks in wooded or wetland areas near airports where they can collectively pose a hazard to aircraft (Ball 1996, Transport Canada 1995a).

International reports corroborate concerns about goose and gull population increases in the eastern U.S. (Kemper 1995; Garber 1996a, b; Phillips 1996; Preusser and Forbes 1996). Seubert (1996) reported that Canada goose populations have increased exponentially in all North American flyways during the period 1970-1995. Goose populations are reportedly increasing in the U.K. and Europe (Thorpe 1997c, Milsom and Horton 1995). These and other adaptable species expand their populations as they exploit changes in urban, suburban and rural landscapes, including airports. Increasingly effective conservation efforts, a prevailing social attitude toward protection of all wildlife (even species that should no longer be considered "wild"; i.e., non-migratory urban ducks and geese, feral pigeons, starlings and house sparrows in cities), and the gradual cleansing of DDT and its residues from the world's environment have resulted in increased bird populations.

4.2 FLEET AND TRAFFIC GROWTH

Reports from Europe and North America unanimously project steady increases in the civil aviation fleet and in aviation traffic throughout the world until at least the middle of the next decade. Robinson (1997b) showed ICAO figures forecasting worldwide passenger levels to increase from about 2.4 billion in 1994 to about 2.9 billion by 2000 and 5 billion by the year 2014. An estimated 72-76% would be domestic travel, with the remainder being international. To accommodate this traffic demand, air fleets were projected to increase from about 11,000 aircraft in 1995 to about 12,500 by the end of this century and to 21,000 by the year 2014. At any given time, about 15% of the fleet would be cargo aircraft. This rate of growth could require upwards of U.S. $50 billion of investment annually, reflecting that since 1986, the estimated value of the civil aviation fleet has at least doubled; at this time there are more than 1,000 aircraft valued at more than US $100 million each and airlines are currently operating several aircraft valued at more than twice that. Clearly, the number of large, wide-body aircraft with high seating capacity is increasing. Lehmkuhl (1997), from International Air Transportation Association (IATA) statistics, showed that from 1990-1994 there was a 10% increase in the total number of starts by the top 20 airlines from 7.049 million to over 7.717 million. Transport Canada's records and projections for 1991-1998 indicate that the overall total number of aircraft movements is expected to rise only slightly but the total number of passenger movements will rise from about 60 million to 74 million; clearly, the mean seating capacity of aircraft is increasing. Robinson also estimated that about 68.5% of the active world fleet of about 270,000 aircraft are operating in North America, of which 63% are in the U.S. and the remaining 5.5% are in Canada. Virtually all of the large-capacity passenger aircraft are jet- or turboprop-powered.

Seubert (1996) also presented figures indicating increases in aircraft numbers worldwide and in North America during the 1985-1995 period of 68% and 51%, respectively. IATA figures for 1985-1994 showed that in the U.S. departures by scheduled airlines increased by 29%.

Clearly, the worldwide, North American and Canadian trends are consistently towards more and larger aircraft, increased activity levels and larger passenger loads. Since the exposure to risk for the world's airline fleet is in direct proportion to the number of air movements, the trend in the number of movements in a country is a better measure of risk exposure than is the population of aircraft there.

4.3 AIRCRAFT TYPE AND SIZE

Records show clearly that the probability of a bird strike increases as the size and speed of aircraft increases (Blokpoel 1976, Thorpe 1988, Milsom and Horton 1995, Donoghue 1996, MacKinnon 1997, Robinson 1997a). Thorpe (1997c) also showed that the rate at which birds are ingested into engines is proportionately higher for aircraft with multiple engines (3, 8 and 5 per million flights for twin-, three- and four-engined aircraft, respectively). Thus, amongst civilian aircraft, large, multiple-engined jet aircraft appear to be the most commonly involved in bird strikes. Military reports consistently show fighter aircraft as frequently involved in bird strikes; this is not unreasonable, given that fighters are the fastest aircraft, fly under virtually all weather conditions throughout the country and fly relatively often at low altitudes where the aircraft are more likely to experience bird strikes. In Canada, DND records from 1992-1996 consistently showed that CF-18 fighter aircraft, Tutor jet trainers, C130 Hercules and C140 Aurora aircraft experienced the highest frequencies of bird strikes (Larose 1996; Transport Canada 1993, 1996, 1997) but the data do not relate the strike rates of the four aircraft types to any common denominator such as number of flying hours or number of air movements so these data cannot necessarily be compared at face value for bird strike rates. USAF records are not expected to differ significantly in this regard, given that the USAF operates many more aircraft all over the world and reports in excess of 2,500-3,500 bird strikes each year (Chamberlain, no date).

Although records show that any type of aircraft engine can be damaged by a bird strike, certain types seem to be more vulnerable than others. Engine design influences the extent of damage that can be expected to be sustained from a bird strike, on average. Turboprop and older-style turbine engines are more prone to extensive damage than the newer designs that have incorporated a higher resistance to FOD and high bypass turbofans. However, the high bypass turbofans typically have a proportionately larger diameter air intake frontal area that increases the probability of ingesting a foreign object such as a bird. Transport Canada annual summary reports (Transport Canada 1993, 1994, 1995a, 1996, 1997, 1998) showed that 46-52% of strikes reported involved turbofan-powered aircraft; of those, 9-13% involved hits to an engine and of those, 14-26% resulted in engine damage. Second to turbofans were the turboprop engined aircraft involved in 32-35% of reported incidents, resulting in 13-16% engine hits and 4-15% engine damage. Aircraft powered by piston, turbojet and turboshaft engines were far less likely to report an incident; in no year did the three types combined account for more than 19% of reported incidents and engine damage was rare but not unknown. Interestingly, the B-737 aircraft is reported as having suffered engine damage more often than almost any other jet aircraft. Cleary *et al.* (1996) suggested that the reason aircraft such as the B-727, B-737, B-757, MD-80/DC-9 and Fokker FK-100 were involved in more than 50% of the bird strikes reported to the FAA during 1993-1995 was that these are short-haul aircraft that spend proportionately more time operating at low altitudes (take-offs and landings) compared to larger, long-haul aircraft, and short-haul aircraft are more likely to operate at smaller airports that do not operate a comprehensive bird hazard management program. Cleary's hypothesis might well explain why, in Canada, the twin turboprop Dash 8 is also commonly involved in bird strikes. Phillips (1996) speculated that the engines in many B-737 and DC-9 aircraft are older model turbofan engines such as the Pratt & Whitney JT-8-series that were certified before the FAA adopted standards (U.S. Federal Aviation Regulations, 1974 and 1984) for bird ingestion tests; current standards require that an engine be able to withstand multiple ingestions of small- to medium-sized birds (such as 1 kg gulls or ducks) and at least one large bird (such as a 3.64 kg goose), and maintain its power for a specified period of time. The upgraded JT8D-200 used on the MD-80, GE90, Pratt & Whitney PW4084 and Rolls Royce Trent 800 engines used on the B-777 all meet the more stringent standards.

Certain models of aircraft are reported, in Canada, to be involved in bird strikes more often than others but this record could reflect the locations and operating modes of these aircraft rather than a crude comparison of their probability of a strike. Of the top 10 aircraft involved in bird strikes between 1992 and 1996, the Dash 8, B-737 and A-320 appear in the top five each year. Other aircraft noted each year include DC-9, Hercules C-130, Tutor CT-114, B-767 and Aurora CP-140 (Transport Canada 1993, 1996, 1997). Data are not available to relate strike rates to numbers of air movements or hours flown, so these data are only relative to one another.

4.4 LOCATION

Transport Canada annual summaries for 1992, 1993, 1995 and 1996 were reviewed to determine whether the data indicate that trends are evident in the annual totals of bird strikes at the top 12 airports (data available for all four years), the total number of bird strikes at all (n=75) Canadian airports and the percentage totals by region. The 1994 and 1997 reports were not available at the time this information was compiled.

With a few notable exceptions, the annual totals for the top 12 airports were consistent over the four years for which the data were available. For example, Vancouver reported totals of 21, 34, **98** and 27; Pearson reported 80, 85, **45**, and 62; and Winnipeg reported **58**, 23, 38 and **13** for the same four years of record. Given the inconsistent reporting as discussed in Section 2, the figures highlighted in bold font may simply represent inconsistent reporting during that year or may be an indicator that from year to year there may be unpredictable extremes, as can be found in meteorological records. Regardless, it is probably safe to accept these annual totals as minimal values, for bird strike management purposes. When the 1992 and 1993 two-year totals are calculated for each airport and compared to those from 1995 and 1996, seven airports (Pearson, Dorval, Calgary, Thunder Bay, Moncton, Winnipeg and Victoria) show a declining rate and five (Halifax, Vancouver, Ottawa, Quebec City and Edmonton International) show an increasing rate. Given the lack of long-term, reliable data, more rigorous statistical analyses are not likely to yield any better trend indicators.

Over four years of records, the annual totals for all Canadian airports were 622, 679, 795 and 736. When consideration of the extreme data point for the 98 bird strikes at Vancouver is factored into a comparison of the annual totals, a consistent upward trend becomes evident. While it is useful to compare bird strike rates per number of flights or air movements or hours flown, from a pure aviation safety viewpoint the success of future airport bird hazard management would best be measured by the rate at which the absolute number of bird strikes is reduced from year to year. Transport Canada and airport managers will have to be prepared to accept that in some years there will be extremes of data for individual airports, but should strive to attain an annual bird strike rate that demonstrates due diligence in the face of some yet-to-be-determined point of acceptable risk level versus diminishing returns on effort and expenses. The dream of zero risk is simply not attainable at any price. Consistent data collecting over a number of years will yield a database that should indicate such a practical limit for each airport.

When the various Transport Canada administrative regions were compared for annual bird strike totals as a percentage of the national total, Ontario and the combined Central/Northern regions were consistently high with mean rates of 26%, compared to 16% for each of the Atlantic, Quebec and Pacific Regions. There did not appear to be any meaningful regional trends evident from these data.

4.5 OTHER FACTORS

There are 726 certified airports in Canada—Transport Canada owns, operates or subsidizes 150 of these. Ninety-four percent (94%) of all air passengers and cargo use only 26 airports; those are the airports that cover their operating expenses with earned revenue. Because the costs to taxpayers to subsidize the operation of most other airports were considered too high, the National Airports Policy (NAP) in 1994 began the process of commercialization of airports and the creation of Canadian Airport Authorities (CAAs). Before the NAP there was no statutory, regulatory or policy framework that defined a clear role for the federal government in the operation of airports in Canada. An important aspect of the NAP, as quoted from the Transport Canada website in April 1998 is that "… commercialization will not dilute Transport Canada's highest priority; ensuring and, where possible, enhancing the safety and security of Canadians." Through existing and future regulations and certification requirements, Transport Canada intends to maintain its role as regulator but will change its role from airport owner and operator to that of owner and landlord. It will ensure that Canadian air travelers continue to be protected by appropriate federal safety and security standards. In fact, under the new the policy "the department's role and responsibilities as landlord and lease administrator will increase proportionately."

This report has assessed the nature and cost of bird hazards to aviation, which are at least equivalent to the other types of aviation hazards for which standards exist (e.g., de-icing). Yet at this time there exist no minimum legal requirements for an airport to manage hazards posed by birds. "Future regulation and public policy development relating to airports in Canada will be considered on the basis that they contribute to a safe, secure and viable system of airports." With airport operations increasingly in private hands, access to Transport Canada's experienced staff and knowledge base seems less likely to be used by operators. Furthermore, in an effort to control costs, operators may be tempted to freeze or reduce bird management programs and thereby increase the potential for bird strikes and serious accidents, not to mention higher potential direct and indirect operating costs for the airlines. There is also the possibility that an airport faced with a serious bird problem may waste resources and try an ineffective mitigation measure. Either way, the end result is a mismanagement of this safety risk. Given the hazards posed to aircraft by birds and other wildlife, and the potential for a catastrophic event, it would seem prudent on the part of the regulator, Transport Canada, to establish and monitor airport compliance with a minimum standard for wildlife hazard prevention. Only by a constant reminder of the operators' liabilities (Lehmkuhl 1996, Robinson 1997b) and enforcement, by Transport Canada, of a minimum standard of bird control will the number of bird strikes to aircraft be maintained or reduced in the face of increasing populations of problem bird species such as gulls and geese, and steadily increasing aircraft activity in Canada. In this context, airport operators should be able to demonstrate to Transport Canada that the airport liability insurance is adequate to cover claims that might arise from bird-aircraft collisions in the airport environment.

It is therefore suggested that minimum risk management standards be established for bird control, and that the certification and authority for an airport to operate be contingent upon this component of its overall safety management plan being in place. As in some countries (e.g., the U.K.), the authority to operate can also be revoked (by the Civil Aviation Authority) should the minimum standards relating to bird risk management not be met. This would be the most direct and cost-effective strategy for Transport Canada to achieve its highest priority—safety of the travelling public in Canada.

5.0 RISK MANAGEMENT

Curtis (1997) conducted a risk assessment of a fatal, large-jet transport bird strike in the U.S. or Canada and determined that there is a 25% probability of such an incident in the next 10 years.

The traditional approach to bird hazard management has focussed on bird harassment and minimizing the attractiveness of the airport property and environs for birds, particularly flocking species such as gulls, waterfowl, blackbirds and lapwings. Direct harassment by vehicles, trained falcons, radio-controlled model aircraft, shooting, conspecific distress calls, noise makers and pyrotechnics have all been used with varied success. Habitat management to make airport properties unattractive is a common practice. Grass length is controlled and standing water eliminated in order to discourage birds from feeding and loafing on airport air-side areas. Potential food, water and shelter/security sources have thereby been eliminated. Experiments have been conducted with aircraft markings, aircraft-mounted strobe lights and aircraft acoustics analyses to determine whether the aircraft themselves can function to frighten away birds early enough to preclude strikes during take-offs and landings. A detailed review of the subject of bird strike prevention techniques is beyond the scope of this study; further information will become available in fall or winter 1998 from a separate study being completed for Transport Canada.

Birds have highly developed senses of sight and hearing, and most bird-scaring techniques rely on providing a stimulus to either or both of these senses. This begs the obvious question of why, given birds' keen senses and mobility, can they not more consistently avoid collisions with large, easily seen and noisy aircraft? Additional coordinated research on this issue would seem to be a worthwhile long-term investment in risk management.

Aircraft designers have progressively strengthened airframes and engines to reduce the potential damage from bird strikes. Under 1974 and 1984 provisions of the U.S. Federal Aviation Regulations, current models of high bypass ratio turbofan engines are required to withstand the impacts from one 3.64 kg bird or four 1.0 kg birds while maintaining power. Older models of turbofan or turboprop engines do not meet such stringent requirements for resistance to FOD. Regardless, and particularly for those engines with the largest inlets, performance is almost certain to be impaired if multiple ingestions of large birds such as geese (up to 5.9 kg), a very large bird such as a 9.1 kg swan or pelican, or a large number of smaller birds such as gulls, ducks, starlings or lapwings were to occur. All of these species groups are found in Canada and some are very numerous in certain areas at certain times.

One aspect that may be worth further assessment relates to the actions of flight crews to bird strikes or the threat of an imminent strike and whether their actions contributed to undesirable or unexpected results. In several of the major bird strike-related accidents, the aircraft was either able to reject the take-off or continue the take-off safely, but one or more crew decisions (and in one case certification and procedure development decisions) resulted in a hull loss or serious aircraft damage. Curtis (1996) has examined a number of recent incidents to determine whether there were common factors that led to the accidents, or that could have prevented the accidents or at least resulted in less damage to the aircraft.

Airport zoning regulations were invoked as deemed necessary by Transport Canada, when it owned and operated airports, under the authority of the *Aeronautics Act*, to control developments that could compromise aircraft safety within specified distances of airports. Creation of open landfills, composting sites, wetlands and any other types of facilities that could attract large numbers of birds can be prohibited or special operating conditions imposed to limit bird numbers. There are, however, numerous exemptions to these regulations so their potential effectiveness is reduced. In the evolving role as air transportation regulator, Transport Canada would be well advised to review the record of the effectiveness of the zoning regulations and their implementation to determine whether the regulations have achieved their intended purpose, and how the regulatory process and its implementation might be improved.

Recently, the USAF developed an IBSC Bird Avoidance Model (BAM) to predict the risk of bird strikes for aircraft flying in high-risk areas from air bases in North America. The model also highlights areas of high risk for pilots flying low-level training missions in particular areas at specific periods of the year. Initial results indicate some reduction in the frequency of bird-aircraft strikes for military tactical aircraft (Arrington 1994). No equivalent system of risk assessment and management has been developed for civil aviation in North America or Europe. With the automated information systems now available, such a system might be cost effectively implemented for Canadian airports so pilots could receive real-time pre-flight bird hazard information at the same time they receive weather information. The bird hazard database could include long-term seasonal information with updates based on recent incidents, airport bird control staff reports, local meteorological conditions that influence bird activities, etc.

In Europe and North America, interested representatives from regulatory agencies, airport operators, airlines, aircraft manufacturers, the military and a host of industry-related associations, consultants, and service/supply companies have formed committees to provide regional and international forums for the collection, distribution and comparison of data on bird strikes to aircraft (Bird Strike Committee Europe, Bird Strike Committee U.S., Bird Strike Committee Canada). Meetings are held annually or more often to present new data, review ongoing research programs and recent incident reports, and introduce new products. These committees do not have authority to implement regulations or other changes; such initiatives must come from the individual regulatory agencies, airport operators, aircraft manufacturers, military organizations or the airlines themselves. It would also seem, from reviewing minutes of several meetings, that while there is a general exchange of information, there is little critical assessment of the information or products presented. In this regard, it is very important to understand the limitations of the data presented and the effectiveness or lack of it for products in actual use, rather than only as reported from the manufacturers' field trials. Without the critical assessment, new safety programs and research could be based on erroneous or incomplete information, leading to compromised public safety as well as a waste of time and money.

6.0 RECOMMENDATIONS FOR FUTURE MANAGEMENT AND RESEARCH AND DEVELOPMENT

Populations of large- and medium-sized birds that travel in flocks are increasing in North America, as is the volume of aviation activity, so the potential for serious, costly and potentially deadly bird-aircraft collisions is increasing accordingly. With the clear evidence for the ongoing high annual costs of bird strikes and the potential for very high costs as well as human injuries and fatalities from a catastrophic accident, the bird strike hazard cannot be ignored by airlines, airport operators or aviation industry regulators such as Transport Canada. Recommendations, supported by rationale, are provided to address the major issues demonstrated in this overview.

a) The true extent of the bird strike hazard risks and costs cannot be quantified without accurate bird strike records, but enough data have been compiled to establish, with a high degree of confidence, that a significant risk does indeed exist.

- Transport Canada should regulate the mandatory reporting of bird strike damage evidence by airlines, airport operators and aircraft repair depots. Periodic audits of the three sources would help to identify lapses in reporting rates where data gaps become apparent.

- Transport Canada should undertake a systematic accounting of the reported Canadian bird strikes for each of the past three years, using assumed estimates of appropriate direct and indirect costs for each incident, and an escalation factor to account for under-reporting in order to develop a detailed and more defensible estimate of total costs to civil and military aviation in Canada. DND should be encouraged to track typical indirect costs related to damaging bird strike incidents, for the same reasons.

b) Cost data and appropriate risk analyses should provide justification for an intensified approach to bird hazard management at Canadian airports.

- A risk analysis for bird strike-related fatalities in Canada should be undertaken by Transport Canada using an actuarial methodology to project the probability of a serious incident and the consequences to Canadian travelers. An example of such a risk assessment for projected hull losses and fatalities involving large jet transport in the U.S. or Canada has been prepared by Todd Curtis and can be found on the "Airsafe" website: http://www.airsafe.com.

c) The research and data gathering to date is wasted unless applied toward reducing the risk of bird strikes to aircraft.

- The primary focus for bird management should be on airport property where records show that the greatest hazard exists.

- Transport Canada should develop and implement a requirement for Canadian airports to develop and implement a bird hazard management plan specifically designed to address the types of bird problems occurring there.

- Ongoing aircraft engineering research to reduce both the frequency and severity of bird strikes should be encouraged and funded by all stakeholders.

- The USAF BAM should be assessed, and refined if possible, for its applicability to Canadian civilian and military airports.

- The effectiveness of airport zoning regulations should be evaluated, with reference to managing bird hazards to aviation, and revised as necessary to make them an effective hazard management tool when used in concert with airport wildlife hazard management programs.

- Stakeholders should continue to fund ongoing research into the behavior and physiology of birds, with the objective of developing a better understanding of why and how they respond to stimuli that might be used to deter them from using airport property and also frighten them away from the path of oncoming aircraft.

- Research results should be shared among regulators and industry to minimize duplication of effort and derive the maximum potential benefits from applying the results of such research to reducing bird hazards.

d) Bird strike committees provide an international forum for the exchange of information.

- Bird strike committees should broaden their scopes to provide a critical review of ongoing research and safety programs to minimize the prospects of ineffective safety programs being undertaken.

- Bird strike committees should expand their use of websites and other electronic media to communicate with industry, regulatory agencies and the pubic.

- Bird strike committee members should cooperate to design, fund and implement focused research programs that could lead to increased aviation safety improvements in terms of bird hazard management at and near airports.

- An effective process to improve information sharing would be the combining of U.S. and Canada Bird Strike Committee meetings once every few years, and alternating between venues in the U.S. and Canada to bring together a larger proportion of the active bird hazard management practitioners.

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