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Risk Analysis of High-speed Aircraft Departures Below 10,000 Feet

Bruce MacKinnon
Wildlife Control Specialist; Aerodrome Safety Branch, Transport Canada

Richard Sowden (Capt.)
President; Avian Aviation Consultants, Guelph, Ontario, Canada

Terry Kelly
SMS Aviation Safety Inc., Ottawa, Ontario

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Capt. Richard Sowden, President; Avian Aviation Consultants, Guelph, Ontario, Canada
Terry Kelly, M.A., President; SMS Aviation Safety Inc., Ottawa, Ontario, Canada

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Abstract

This paper abridges a Canadian study that examined bird-related safety risks to aircraft climbing to 10,000 feet MSL (mean sea level) at speeds in excess of 250 kias (knots indicated airspeed). The study employed a risk-based framework to examine ornithological information, bird strike data, aircraft-certification standards, aircraft climb performance and aircraft flight profiles.

Foremost among its findings, the study determined that populations of high-risk bird species are increasing, that many of these species flock at the altitudes in question, and that aircraft exposure to risk will increase in part because of projected increases in aircraft movements.

Examining the appropriateness of current and proposed mitigation, the study determined that current airframe and engine certification standards do not reduce risks associated with strikes by high-risk bird species. The study also found that any potential operating-cost savings that might be achieved through increased flight speeds would be more than offset by losses incurred through bird strikes.

The study predicted that higher flight speeds would increase the total number of bird strike events involving high-risk species, the number of occurrences involving major damage, and the potential for catastrophic losses.

Accordingly, the study concluded that aircraft should remain restricted to speeds of 250 knots or slower below 10,000 feet MSL.

Introduction

Background: Nearly half of the world's aircraft activity occurs in the United States, where aircraft speeds below 10,000 feet MSL are governed by FAR 91.117(a). The regulation states: "Unless otherwise authorized by the Administrator, no person may operate an aircraft below 10,000 feet MSL at an indicated airspeed of more than 250 knots (288 mph)." The rule evolved as a means to augment see-and-avoid VFR practices following several mid-air collisions in the early 1960s. Although difficult to confirm, the rule also appears to provide the baseline for a number of speed-related, bird strike-tolerance test conditions related to engine and airframe design and certification. For the most part, aircraft operating in Canada conform to FAA certification rules; however, Canada is not currently in harmony with FAR 91.117(a) respecting aircraft speed on departures from Canadian airports.

Nonetheless, populations of large flocking-bird species—which tend to migrate at relatively high altitudes—are increasing in Canada, as are damaging bird strike events at higher altitudes. In response, Transport Canada (TC) presented a Notice of Proposed Amendment (NPA) 2002-022 to

CAR 602.32 on February 26, 2002. The NPA proposed to eliminate the Canadian ATC practice of allowing aircraft departing from Canadian airports to exceed 250 kias below 10,000 feet MSL.

To provide additional data in support of the amendment, TC contracted a risk analysis of the practice. The resulting study, *Risk Analysis of High Speed Aircraft Departures Below 10,000 Feet* (ref. 1), was presented to the TC Canadian Aviation Regulatory Committee. The committee concluded that there was a requirement to manage risks associated with collisions between large flocking birds and aircraft operating at the altitudes in question, and decided to enact NPA 2002-022.

In the past, the development of air regulations has been reactive; most aviation-industry rules have been drafted in response to accidents. NPA 2002-022, however, marked a turning point for TC. The amendment was among the department's first attempts to apply data-driven risk-management procedures to develop air-safety regulations proactively. The study was also the world's first holistic, system-safety examination of risks associated with high-speed departures. As such, this work may influence other nations to consider enacting similar—or revising existing—regulations.

<u>Objective and Method</u>: The TC study examined safety risks related to high-speed departures at altitudes below 10,000 feet. The analysis was conducted using accepted industry techniques—by identifying hazards and determining related-risk probability and severity with respect to current and proposed mitigation.

For the purposes of TC's analysis, the specific hazards were birds. Safety risks associated with this hazard range from minor aircraft damage to an aircraft impact with the ground.

Strike probability is proportional to exposure to a hazard, and therefore is determined by the presence of species types (e.g., population numbers), as well as the characteristics of those species. Five gradient classes are employed to predict probability, of which Class One predicts frequent likelihood of a bird strike and Class Five predicts a rare probability.

Strike severity indicates the potential consequences of bird strike events, and includes injury or loss of human life as well as economic losses associated with aircraft damage. Category-A events indicate catastrophic loss, measured as either the complete loss of an aircraft or the loss of more than one human life as a consequence of a bird strike event. Category-B events indicate major damage, measured as either significant damage to airframes, failure of one or more engines, failure of one or more aircraft systems, serious injury to one or more aircraft occupants, or the loss of life of no more than one aircraft occupant. Finally, Category-C events indicate minor damage to airframes, engines or aircraft systems.

The degree of severity is influenced by a variety of factors, including bird mass, the number of birds involved in a strike, aircraft speed, and the point of impact on an aircraft.

Probability and severity of damaging bird strikes are influenced by the nature of mitigation. For example, the use of landing lights reduces the probability of strikes by making aircraft more conspicuous to birds; windshield heaters diminish severity of bird impacts by making these surfaces more pliable.

Information sources include the bird and wildlife strike databases of Transport Canada, the FAA and ICAO, as well as aircraft and engine certification standards published in Part V of the Canadian Air Regulations.

Scope: The proposed amendment addresses only those aspects of CAR 602.32 that restrict departures between 3,000 feet AGL (above ground level) and 10,000 feet MSL at maximum speeds of 250 knots. Thus, the analysis focused on aircraft types and operations that have normal operating envelopes above 10,000 feet and at speeds greater than 250 knots.

Limitations: Data related to the risk analysis was limited in a number of ways. With regard to bird strike data, experts suggest that only 20 to 30 percent of bird strike events are actually reported. As a result, the probability of bird strike events is likely higher than the data suggest. Furthermore, data elements of bird strike occurrences are inconsistently reported, leading to incomplete records. Since no single repository of bird species data exists, estimates were produced from data collated from a variety of sources.

As tracking mechanisms to attribute aircraft repair and aircraft time out of service costs to particular bird strike events are either poor or non-existent, it was difficult to determine precise costs of aircraft damage caused by bird strike events.

With respect to industry operational data—much of which is protected as proprietary business information—airlines neither consistently nor accurately report flying hours, nor do they report flying hours that aircraft spend between the altitudes of 3,000 and 10,000 feet. Such limitations impeded an accurate determination of potential operational efficiencies and cost savings that might be realized through high-speed departures.

High-risk Bird Species

The study examined in detail the bird species that pose greater risks to flight above 3,000 feet AGL. Analysis exposed critical information concerning species population trends and bird movements.

As greater risks are presented by medium-sized and large birds, the study paid particular attention to bird species—namely, migratory waterfowl, gulls and raptors—with mean weights (1.5, 4 and 8 lbs.) that are near, at, and above those referenced in aircraft and engine certification standards.

A review of literature on bird populations (ref. 2 and 3) revealed that populations of North American high-risk bird species are subject to an overall increasing trend, partly due to habitat and species conservation measures. For example, during the 10-year period between 1990 and 1999, the North American Canada Goose population tripled from 2 million to 6 million. The US Fish and Wildlife Service's waterfowl-population status report for 2000 indicates that the population of geese in North America is growing at approximately 10 percent each year, and will nearly double to reach some 11.7 million birds by 2005.

The study also focused on bird flocking behaviour, as the potential number of strikes in a single bird strike occurrence—as well as potential for damage—increases with the number of birds involved. Of the 36 North American species whose mean weight is 4 lbs. or greater, 24 (67 percent) exhibit strong flocking behaviour, 9 (25 percent) exhibit limited flocking behaviour, and 3 (8 percent) exhibit solitary behaviour.

The study included an examination of migratory activity, revealing that as many as 80 percent of North American bird species migrate. While altitudes vary, certain radar data indicate that the majority of migratory birds fly between 5,000 and 7,000 feet AGL.

Bird Strike Data Analysis

The study’s examination of various bird and wildlife strike databases revealed a number of compelling findings. For example, the top three bird species struck between altitudes of 3,000 and 10,000 feet were also among the largest: waterfowl (50.6 percent), gulls (19.7 percent) and raptors (9.7 percent). Of note, 50 percent of the strikes that involve waterfowl also account for 90 percent of all damage costs.

The data also show that the likelihood of striking waterfowl increases with altitude. As waterfowl are also flocking species, the probability of multiple-strike events may also increase. In fact, 30 percent of strikes in which birds were heavier than 4 lbs. involved more than one bird; 39 percent of multiple-bird strikes involved birds heavier than 8 lbs.

As the most severe consequences would likely occur if an event involved multiple strikes of large flocking birds ingested by aircraft engines, it follows that aircraft with at least two engines—and preferably more—are more likely to survive an event. However, current aircraft design trends appear relatively uninfluenced by the threat of multiple-strike events. In 1969, 75 percent of the commercial airline fleet was composed of aircraft with more than two engines each. This number will have decreased to 10 percent by 2008.

Findings related to strike distribution by altitude (figure 1) were of particular interest. Of significance is the inverse relationship between numbers of reported strikes and actual strike damage as altitude increases. Although the number of reported strikes decreases as altitudes become greater, damage resulting from strikes is increasingly likely above 7,000 feet. This trend is due to the species struck at these altitudes (noted above), as well as the relative increase in true air speed at higher altitudes.

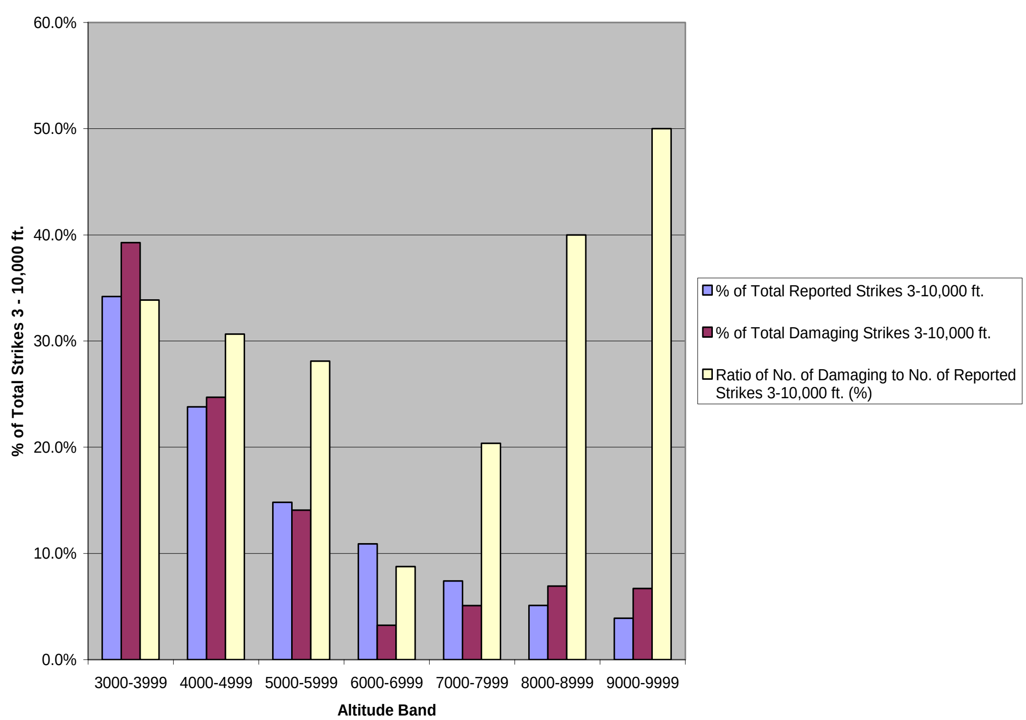

Figure 1 – Bird strikes versus altitude

Not surprisingly, seasonal data indicate that, while strikes occurred year round, they peaked during spring and fall migratory periods. On the other hand, night and day strikes were rather evenly distributed—51.1 percent to 48.8, respectively. This suggests that pilots are no more able to detect and avoid birds during daylight conditions than during periods of darkness.

The study's analysis of aircraft damage costs faced a considerable challenge. Estimates suggest that only 20 percent of reports involving damaging strikes actually include any damage costs. In light of limited reporting—as well as a lack of indirect cost data—any estimates of damage cost per strike event and annual strike costs are significantly less than actual values.

Using available data, the study calculated the average per-strike damage cost to be US$71,413. By extrapolation, a highly conservative average damage-cost projection of strikes between 3,000 and 10,000 feet is US$2.05 million annually in North America; the same average cost in Canada is an equally conservative CDN$434,000.

While indirect cost estimates are even less reliable, current information (ref. 4) enabled basic calculations. Damage from bird strikes leads, at best, to flight delays and, at worst, to flight cancellations. Industry information indicates that a single delay or cancellation leads to four secondary delays or cancellations. Based on estimated costs for flight delays and cancellations, the study determined North American indirect bird strike damage costs to be as high as US$16.2/CDN$24.7 million per year—CDN$2.7 million of this total in Canada.

It is important to note that these indirect figures do not consider any costs associated with loss of passenger goodwill resulting from delays and cancellations, or legal fees and damage settlements resulting from associated civil litigation.

Aircraft and Engine Certification Standards

The study found that aircraft and engine certification standards, like many in the aviation industry, do not mirror conditions encountered during actual operations. With regard to bird-impact forces, certification standards assume the compromise of only one system or component per event. In other words, standards do not require manufacturers to demonstrate safe flight after bird strike events that damage multiple aircraft components—such as a strike event that damages the airframe and one or more engines.

Certification standards have numerous other limitations. Standards are designed principally to address the critical take-off phase of flight. Tests are not conducted to address engine ingestion of birds at speeds higher than those referenced in the standards, nor are tests conducted with bird species having mean weights that exceed the standards. Furthermore, the standards require no examination of uncontained engine failures that lead to damage to other aircraft systems, such as hydraulics and flight controls. Consequently, the standards take no account of numerous circumstances that are predictable in normal operating conditions. This paucity of data hinders risk analysis.

The study noted that FAR 33 standards were revised in September 2000 to address increased bird weights; however, no plan exists to make retroactive any regulatory amendments. Only newly developed engines will be required to meet enhanced standards.

Airframe-certification standards focus on four areas: air-speed indicating systems, airframes, windshields and empennage. No plans have been developed in the United States or Canada to extend these standards, which are based solely on the likelihood of single bird impacts.

The study went on to examine in detail the complexities of both air speed and bird-impact force, calculated by determining change in a bird's kinetic energy:

A mid-sized Canada Goose (10 lbs.) that strikes an aircraft at 250 kias at 9,000 feet MSL generates an impact force of 72,617 lbs. An impact at the same altitude with a goose of the same weight at 300 knots—a speed increase of only 20 percent—results in a 44 percent increase in impact force, or 104,500 lbs.

The study found that, even at 250 kias, birds of 8 lbs. and greater exceed FAR certification impact standards between altitudes of approximately 8,000 and 10,000 feet. When IAS is increased to 300 knots, the results change dramatically. Even 4-lb. birds exceed strike-impact standards above approximately 4,300 feet MSL; 8 lb. birds exceed impact standards at all elevations.

<u>Stakeholder Liability</u>

The issue of liability for injury, death and damage resulting from bird strikes is complex and varies according to the circumstances of each event. The study undertook a brief examination of potential-stakeholder liability to provide context for the safety-risk evaluation process.

The principal aim with respect to liability is to establish proof of negligent conduct by one or more stakeholders. In the event of litigation, stakeholder actions would be judged by determining whether they had demonstrated due diligence in exercising appropriate duties of care and warning with respect to bird strike hazards. Particular attention would focus on the probability of bird strikes resulting from Transport Canada regulations, and the adequacy of aircraft-certification standards to mitigate risks. An air operator's policy would be judged on whether it was reasonable and proactive in mitigating bird strike risk during the departure phase of flight. As the air-navigation service provider, NAV CANADA would be judged on the adequacy of its communication of high-speed flight hazards below 10,000 feet, and on the tools provided to controllers to assess related risks. An aircraft manufacturer would be scrutinized to determine whether it clearly communicated information to air operators and flight crews regarding bird strike impact certification speeds for each aircraft and model. Finally, pilots-in-command would be judged on their assessment of bird strike risk for a flight, and their application of company policy and aircraft-operating techniques to minimize related risks.

The TC study, however, found that the current level of stakeholder knowledge is poor and inconsistent with respect to safety-risks associated with high-speed flight below 10,000 feet MSL. As there are numerous examples of successful litigious actions in which bird strike damage cases have resulted in multi-million dollar judgments, the study observed that all stakeholders would be well advised to embark on education and awareness programs to ensure that appropriate standards of care are met.

<u>Potential Operating Efficiencies</u>

Although risk analysis seeks to mitigate occurrence probability or severity, mitigation must be assessed in the context of associated economic costs. The study determined that theoretical efficiencies achievable by improving a single aviation-system component are almost always reduced and sometimes nullified by other constraints experienced during normal operating conditions. Net operating costs, in fact, balance fuel efficiency and aircraft-operating time—the most fuel-efficient flight is not necessarily the most cost-efficient flight, nor is the most time-efficient flight necessarily the most cost efficient. For example, an aircraft operating at 325 knots, but with a manufacturer's economical speed of 285 knots, will incur a fuel-burn penalty that may offset any efficiency accrued through increased operating speed.

The study investigated numerous factors related to potential operating efficiencies, including aircraft performance during climb phase, efficiencies in high-speed climbs, speed limitations, aviation-system constraints to high-speed flight, and altitude and temperature effects on performance.

Relationships differ between aircraft speed and exposure, speed and probability, and speed and severity. Exposure increases linearly with speed; a 20 percent increase in speed leads to a 20 percent increase in exposure. Probability is an inverse function of rate of climb; a 20 percent increase in rate of climb reduces probability by 20 percent. Severity, however, increases as the square of speed, so that a 20 percent increase in speed increases impact forces by 44 percent ($1.2^2 = 1.44$).

A review of performance data shows that rate of climb in constant indicated-airspeed climbs changes by only +/- 3 to 5 percent as indicated airspeeds increase in the altitude range considered in the study, and therefore has no significant effect on bird strike probability. In accelerating speed climbs, however, rate of climb is reduced approximately 50 percent, thereby doubling the probability of occurrence while the aircraft is accelerating. Therefore, during normal climb and acceleration maneuvers to speeds above 250 knots, exposure, probability and severity of bird strike risk are higher than those in a constant 250-knot climb. Exposure and probability will increase proportionately, and severity will increase as a square function.

As it is proprietary information of manufacturers and airlines, aircraft performance data was, for the most part, unavailable. However, the aviation industry reports average aircraft-operating costs to be $60 per minute. According to industry calculations (ref. 5), the greatest savings in operating expenses are $19 for a 300-knot climb and $23 for a 330-knot climb. When compounded over a large number of flights, these savings can be considerable. For an airline that operates 750 flights per day, a savings of $630,000 could be achieved every year.

These figures, however, are theoretical and do not take into account real-world operational constraints experienced during most flights. For example, more than 400,000 movements take place each year at Toronto's Lester B. Pearson International Airport. The facility often operates at maximum capacity, requiring ground-delay programs, airborne holding of aircraft, and flow control to manage traffic movement. Under these conditions, high-speed flight below 10,000 feet MSL will not increase air-navigation service capacity, reducing the ability to achieve the theoretically calculated savings.

Safety-risk Analysis

Exposure and probability: The study noted that the principal variables affecting exposure to risk, and therefore occurrence probability, are aircraft-traffic movements, bird-species population trends, flight distance, and time spent in bird-rich altitudes. In the absence of mitigation, an increase in one or all risk factors can be expected to result in a higher frequency of bird strike events.

Canadian air traffic continues to increase, influenced only occasionally by such short-term anomalies as the temporary downswing experienced after the events of September 11, 2001. Growing demands for air travel will drive the search for increased airspace capacity. Consequently, the number of aircraft operating through altitudes of 3,000 to 10,000 feet is expected to increase. Meanwhile, populations of high-risk bird species are also increasing. The result will likely be a corresponding increase in the probability of bird strike events between 3,000 and 10,000 feet.

Severity: The study observed that strike severity fluctuates with changes both to populations of large flocking species and to aircraft operating speeds. Increases in flocking species will lead not just to increased occurrence probability, as demonstrated earlier, but also to increases in occurrences that result in more severe Category-A and B damages.

Of particular concern is the previously reported increase in populations of large flocking waterfowl species, particularly Canada Geese. In a UK study (ref. 2), modeling of aircraft encounters with Canada Geese predicted that 18 percent of occurrences would involve impact to both aircraft engines.

With respect to changes in aircraft operating speeds, the study demonstrated that strike-impact force increases as a function of the square of impact speed; therefore, higher air speeds will result in increasingly severe strike events that occur at the altitudes in question.

Risk analysis: The study found no evidence to indicate that safety-risks to aircraft operating between 3,000 and 10,000 feet will diminish. Furthermore, the study found increasing evidence that population growths of high-risk species will continue to increase in the short- and middle-term.

Accordingly, the increased safety risks will likely result in increases to the total number of bird strike events involving high-risk species, the proportion of occurrences at migratory altitudes, the number of Category-B occurrences, and the potential for a Category-A occurrence.

Mitigation: The study asserted that mitigation should reasonably be expected to reduce exposure, probability, or severity—or combinations thereof; be intuitive and easy to enact by operational staff such as pilots and air-traffic controllers; and not place undue financial hardship on aircraft operators.

Mitigation regarding exposure: As both air-traffic movements and populations of high-risk bird species are expected to increase in North America for the foreseeable future, the study found that aircraft exposure to these species is increasing unmitigated.

Mitigation regarding probability: The study observed no new activities that in the short- or middle-term will mitigate the increasing probability of an occurrence between 3,000 and 10,000 feet. While progress has been made in macro forecasting of large, seasonal movements of high-risk species, this practice remains an inadequate means of informing aircraft operations. Enhanced detection methods offer some promise for the future. For example, real-time radar systems are being developed to detect bird movements in aircraft flight paths; however, this technical capability is at least a decade away.

Mitigation regarding severity: The study determined that the only appropriate and effective mitigation currently available is reducing the speed of aircraft operating in high-risk altitudes of 3,000 to 10,000 feet. In light of forecasts predicting increased probability and severity of bird strike events below 10,000 feet, the ineffectiveness of other possible mitigation activities, and the significant relationship of aircraft velocity on impact forces, speed reduction would reduce exposure, probability and severity of Category-A and, to a slightly lesser degree, Category-B damage in a bird strike event.

The study also noted other measures to mitigate severity of bird strike events between 3,000 and 10,000 feet; however, these measures are not likely to be proactively implemented. For example, as discussed earlier, increasing the number of engines on passenger-carrying aircraft would reduce the probability of Category-A occurrences in the event of multiple strikes to more than one power plant; however, the risk of such an occurrence remains unmitigated—not only are aircraft and aero-engine designers and manufacturers reducing the number of aircraft engines, but the number of two-engine aircraft is also projected to increase.

Similarly, changes to airframe- and engine-certification standards fail to mitigate anticipated increases in the frequency of Category-A and B losses. Current engine models will be grandfathered under revised FAA engine-certification standards. Meanwhile, no known work is underway to revise airframe-certification standards, and any such changes would likely take at least a decade to enact.

Conclusion

The Transport Canada study applied a rigorous data-driven, risk-analysis process to determine that high-speed departures are not safe, and that NPA 2002–022—which restricts aircraft operations to speeds of 250 knots or slower below 10,000 feet MSL—is appropriate and effective risk mitigation.

The study acknowledged that potential operating-cost savings could be achieved with high-speed flight below 10,000 feet MSL; however, the study also showed that many interrelated operational constraints would normally impede the realization of these highly theoretical savings. In fact, the direct damage cost of a single, major Category-B occurrence, or two to three minor Category-B occurrences, could easily exceed the industry-quoted theoretical annual operational cost savings of high-speed flight.

Furthermore, the study demonstrated that any organization that would endorse high-speed air operations below 10,000 feet MSL, which would subject airframes and engines to conditions that exceed certification standards, faces potential liability.

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Biographies

Bruce MacKinnon, Wildlife Control Specialist, Transport Canada Aerodrome Safety Branch, 300 Sparks Street, Ottawa, Ontario, Canada, K1A 0N8, telephone - (613) 990-0515, facsimile - (613) 990-0508, e-mail - mackinb@tc.gc.ca

Bruce MacKinnon is a graduate of the University of Calgary, where he specialized in large-mammal behaviour. He is currently Wildlife Control Specialist for Transport Canada, Civil Aviation. Bruce has chaired Bird Strike Committee Canada since 1993, and is Vice-chair, Outreach, for the International Bird Strike Committee. He has written extensively on wildlife-hazard issues, and has been involved as an advisor and expert witness in the management of bird strike issues and land-use conflicts around the world.

Captain Richard Sowden, President, Avian Aviation Consultants, 14 Hilldale Crescent, Guelph, Ontario, Canada, N1G 4C4, telephone - (519)-763-1299, facsimile - (519) 836-7935, e-mail- richard.sowden@sympatico.ca

Richard Sowden has been involved in flight safety since 1991, working with both the Canadian Airline Pilots Association and Air Canada Pilots Association. As an Air Canada pilot for more than 24 years, Richard is thoroughly familiar with bird-related aircraft-safety issues. Richard currently evaluates bird- and wildlife-strike hazards, develops risk-management strategies and provides airport wildlife-management training.

T.F. Kelly, M.A., President, SMS Aviation Safety Inc., 275 Slater Street, Suite 900, Ottawa, Ontario, Canada, K1P 5H9, telephone - (613) 238-3232, facsimile - (613) 236-3754, e-mail - sms@magma.ca

Terry Kelly has worked in safety for over 25 years. He has been a professional pilot, aviation-accident investigator, safety analyst, safety-program evaluator, and safety-policy advisor. Much of his current work focuses on the proactive safety management of change, and on conducting safety-risk assessments.