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Factors Influencing the Incidence of Bird-strikes at Melbourne Airport, 1986-2000

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Abstract

The results of 149 surveys of bird species' distribution and abundance at Melbourne Airport between January 1997 and June 2000, together with local weather information and bird-strike data were used to assess the comparative importance of a number of variables affecting the incidence of bird-strikes at the airport.

At least 36 bird and bat species were involved in 'bird-strikes' at Melbourne Airport between 1986 and 2000, although only 11 species were involved in 10 or more incidents. The Australian Magpie (*Gymnorhina tibicen*) presents the greatest threat of bird-strikes at Melbourne.

Bird abundance and activity are important factors in determining the incidence of bird-strikes. The greatest frequency of bird-strikes occurred during autumn (April–May), which is the season when the greatest numbers of birds are at the airport. The incidence of bird-strike is greatest between 08:00 and 12:00, apparently reflecting bird activity levels rather than aircraft traffic volume. The majority of bird-strikes occurred at 'zero feet' altitude and within a comparatively small area of the airport, which has important implications for the management of bird hazards. An unexpected finding was that the incidence of bird-strikes increased during days with strong winds (50–60 km/h). Local weather conditions play an important role in determining the risk of bird-strike, and this relationship needs further investigation.

Introduction

Although bird-strikes are not common events—an investigation of bird-strikes in Europe between 1981 and 1985 found there was an average of 5.7 bird-strikes per 10 000 aircraft movements (Thorpe 1990)—they do present a real hazard to aircraft and exact a significant cost in terms of both human lives and money. In one recent estimate, the US Federal Aviation Administration assessed that birds and other animals cause US $35 million worth of damage to aircraft every year, with US $5 million additional costs due to dumped fuel, flight delays, aircraft schedule changes and loss of revenue (Porter 1994). The worst bird-strike incident to have occurred in Australia took place on 29 September 1977, when a Royal Australian Air Force F-111 struck several Australian Pelicans (*Pelecanus conspicillatus*) whilst flying off Evans Head, New South Wales; resulting in the deaths of both crew members and the loss of the aircraft (Directorate of Flying Safety 1997).

The problem of bird-strikes is likely to become greater in the future as the volume of air traffic increases. Between 1964 and 1974, bird-strikes cost the US Air Force over US $10 million, together with the loss of 11 pilots and 19 aircraft (Burger 1983). By 1993 the annual cost of bird-strike damage to the US Air Force was US $15 million (E&SS 1994). Furthermore, it has been suggested that modern aircraft, which are generally quieter and have larger engine air-intakes than older models, are involved in proportionately more bird-strikes than older aircraft because birds are less able to detect them in time to avoid collisions (e.g. Chilvers *et al*. 1997).

While commercial aircraft generally fly too high to be at risk of colliding with birds, many military and light aircraft utilise the same air space as birds, and all aircraft are exposed to the risk of a bird-strike when landing or taking off at airports. The threat of bird-strikes in the vicinity of an airport is increased because

several bird species congregate at these sites (e.g. Blokpoel 1976; Burger 1983). Between 75% and 90% of all bird-strikes in the United States and Western Europe have occurred at airports (Burger 1983; E&SS 1994), while up to 98% of bird-strikes in Canada occur at airports (E&SS 1994). Thus the management of bird populations at airports and reduction of the risk of a bird-strike are becoming increasingly important to airport operators.

There were 43 recorded bird and bat strikes (hereafter referred to simply as 'bird-strikes') at Melbourne Airport during 1993, and 34 during 1994, giving Melbourne the third highest incidence among Australian airports. During 1995 the number of bird-strikes fell significantly to 19, but Melbourne was still rated as the airport with the seventh highest incidence of bird-strikes in Australia (BASI 1996). Consequently, in 1997, Melbourne Airport authorities initiated an active, multi-faceted programme to reduce the site's attractiveness to birds and so reduce the risk of a bird-strike on aircraft using the airport. As part of this wider management plan, this study set out to ascertain the occurrence and abundance of bird species at this airport, and to investigate some of the factors likely to effect the incidence of bird-strikes there.

Study Site and Methods

Melbourne Airport is Australia's second largest in terms of aircraft and passenger movements. The airport operates two major runways: a north–south runway 3657 m long and an east–west runway 2286 m in length; with an airside manoeuvring area of some 750 ha. The airport lies on the flat Newer Volcanic Plains which extend to the west of Melbourne, between 100 and 120 m above sea level (Duncan 1982). It is bounded by Moonee Ponds Creek to the east and Deep Creek, which runs through a deeply incised valley some 40 to 50 m below the level of the plain, to the west. To the northwest of the airport lies a small remnant woodland dominated by Grey Box (*Eucalyptus microcarpa*) trees, while the banks of Deep Creek support River Red Gums (*Eucalyptus camaldulensis*) with an understorey of both native and exotic shrubs (Peake *et al*. 1995). Much of the remaining surrounding area is pasture, with predominantly exotic grasses, although there are rows of trees alongside most of the northern half of the airport's perimeter fence (Keith Turnbull Research Institute 1995). Within 1.5 km of the airport's eastern border there is a large refuse tip which, although ostensibly accepting only non-putrescible waste, attracted several hundred gulls, ravens and ibises until 1993, when operating procedures were improved considerably and there were changes in the nature of refuse accepted (A. Rohead pers. comm.).

A total of 149 surveys of the numbers and species of birds using the airport grounds were conducted between 08:30 and 12:30 from January 1997 to June 2000. Security and safety considerations largely restricted access to the airport's perimeter road. During bird counts, this 14 km road was traversed by car at a very slow speed, using the vehicle as a mobile hide from which to count birds, with frequent stops to scan surrounding areas and to listen for bird calls. Ground not visible from the perimeter road, such as inside drainage ditches, was observed from vantage points or investigated on foot. Results of these bird counts were recorded on a map of the airport overlaid with a 200-m grid (Fig. 1).

Details of 446 bird-strikes at Melbourne Airport between January 1986 and December 2000 were obtained from Bureau of Air Safety Investigation records (199 records between 1986 and 1992), Ansett Australia records (35 records between 1993 and 1996) (Operational Safety Department 1997) and bird-strike reports submitted by Operations Staff at the airport (253 records between 1986 and 2000). Following the International Bird Strike Committee's recommended criteria of 'on airport' (see Manktelow 2000), only bird-strikes occurring below 500 ft for aircraft taking off and below 200 ft for approaching aircraft were considered to have occurred at Melbourne Airport.

A record of the number of aircraft movements per month at the airport between November 1988 and December 2000 was obtained from Melbourne Airport, as was a record of the number of aircraft movements per hour during a typical week in 1997. These data were analysed to assess variation in the incidence of bird-strikes with time of day, season, bird species, altitude and air traffic volume at the airport.

In addition, a daily record of weather conditions at the airport between January 1989 and October 1997, purchased from the Australian Bureau of Meteorology, was compared with bird-strike data to investigate the influence of weather variables on the incidence of bird-strikes.

Results

Bird Numbers and Distribution

Sixty-five species of bird were recorded within the airport's grounds during surveys (Table 1), with an average bird count of 494.1. The Common Starling (*Sturnus vulgaris*) was by far the most numerous species recorded at the airport, comprising 39.7% of average bird numbers. The second most numerous species, the Australian Magpie, was significantly less abundant, making up 15.9% of average bird numbers. The majority of bird species recorded, typically native woodland species associated with the remnant Grey Box woodland to the northwest of the airport, occurred in very low numbers on the airport and the eight most numerous species made up 87.8% of average bird numbers (Table 1).

Birds were distributed unevenly across the airport grounds and there was a clear relationship between bird distribution and the presence of trees and buildings (Fig. 1); those birds recorded in the middle of the airport were mostly transitory individuals moving across the airport. Those areas of the airport with the greatest concentration of birds were the western 'arm'; the air traffic control tower with its associated buildings and trees; and the concentration of large hangers at the southern end of the airport. A radar tower with associated buildings, and Sugar Gums (*Eucalyptus cladocalyx*) lining part of the airport perimeter created other foci for birds at the airport. The number of birds at the airport varied with season, and numbers increased during the autumn (March–May) and winter (June–August) months (Fig. 2).

Bird Species and Bird-strikes

The animal species involved in bird-strikes at Melbourne Airport was recorded for 318 of the 446 incidents that took place between 1986 and 2000. However, some 80 bird carcasses which had been retrieved and stored at Melbourne Airport were examined during the course of this study and *c*. 15% of these were found to have been identified incorrectly in official reports. Therefore, there must be some doubt over many of the other bird identifications.

The available data reveal that 40 taxa, representing a minimum of 36 bird and bat species, have been involved in bird-strikes at Melbourne Airport; although 22 of these taxa have been struck by aircraft three times or less during the 15-year period under review. Only 11 taxa have been involved in 10 or more bird-strikes: Australian Magpie—28.0% of bird-strikes where the species involved was identified; unidentified raptors—6.9%; Feral Pigeon (*Columba livia*)—6.6%; Masked Lapwing (*Vanellus miles*)—6.3%; Skylark (*Alauda arvensis*)—5.0%; ravens (*Corvus* spp.)—5.0%; Brown Falcon (*Falco berigora*)—4.4%; Richard's Pipit (*Anthus novaeseelandiae*)—4.1%; Black-shouldered Kite (*Elanus axillaris*)—3.8%; Nankeen Kestrel (*Falco cenchroides*)—3.1%; and Barn Owl (*Tyto alba*)—3.1% (Table 2). Thus Australian Magpies represent the greatest threat of bird-strikes at the airport.

A number of bird species, mostly nocturnal, known to have been struck by aircraft at Melbourne Airport between 1997 and 2000 were not recorded at the airport during bird surveys over that period, namely: Barn Owl, Southern Boobook (*Ninox novaeseelandiae*), and Pacific Golden Plover (*Pluvialis fulva*).

There were 22 multiple bird-strikes between 1986 and 2000, involving eight different bird species (Table 2). The only two bird-strikes to have involved more than two birds include an incident when three Welcome Swallows (*Hirundo neoxena*) were reported to have struck an aircraft, and one involving three unidentified birds.

Only 10 bird-strikes (2.2%) were reported to have caused significant damage to the aircraft involved and in three of these cases the identity of the animal species responsible was never established. The size of the bird involved in a bird-strike was not directly related to the amount of structural damage caused to the

aircraft, with a House Sparrow (*Passer domesticus*) reportedly causing significant damage to an aircraft's engine. However, species known to have caused significant damage to aircraft were generally large and included Wedge-tailed Eagle (*Aquila audax*), Australian Magpie, Brown Falcon, Nankeen Kestrel, Feral Pigeon and an unidentified duck.

Temporal Variation of Bird-strikes

The annual frequency of bird-strikes at Melbourne Airport between 1989 and 2000, in terms of the number of bird-strikes per 10 000 aircraft movements, is shown in Fig. 3.

Fig. 1 The average density of all bird species across Melbourne Airport during 149 surveys, 1997 to 2000.

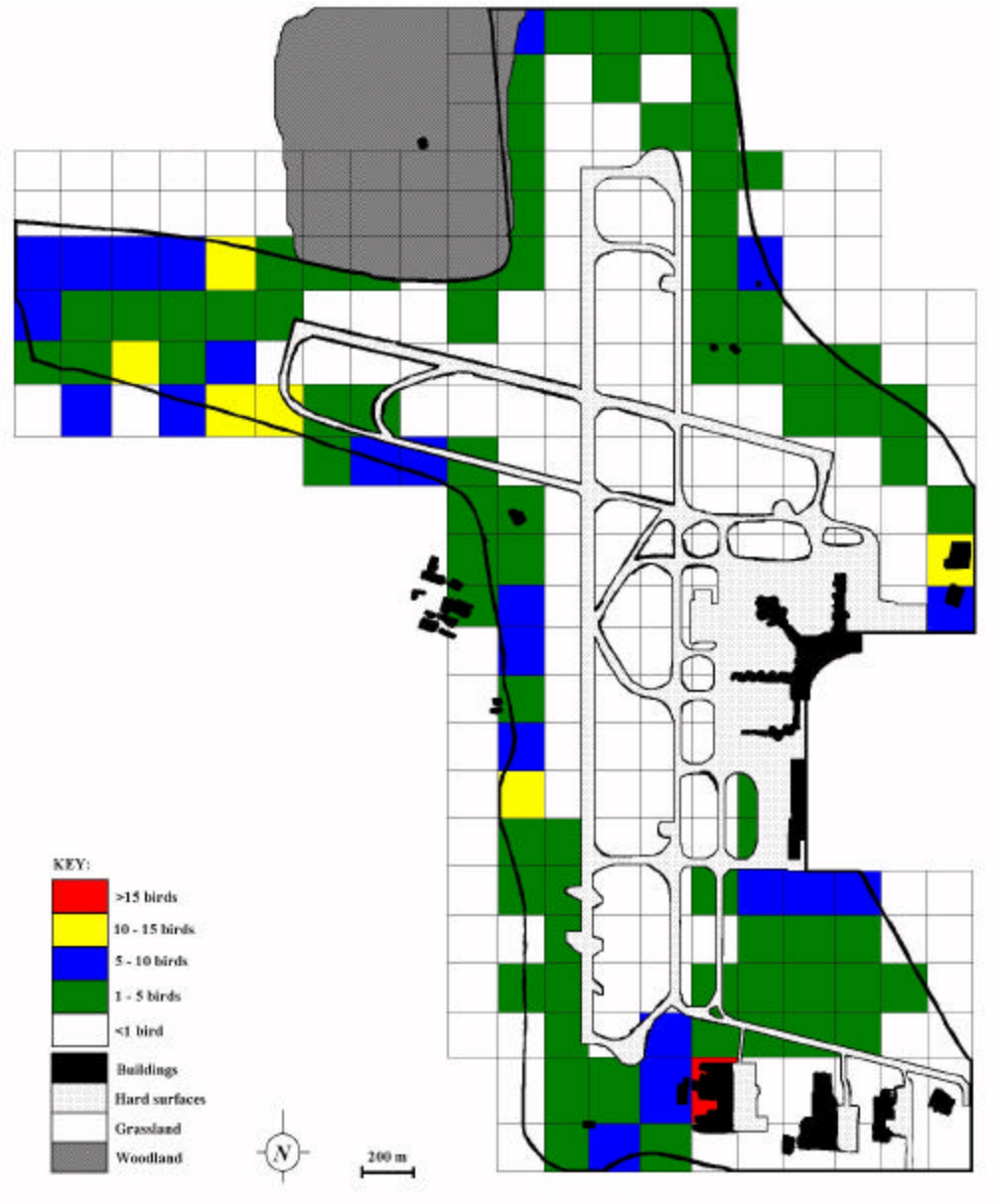


Table 1 The average and maximum number of each bird species recorded at Melbourne Airport during 149 surveys, 1997–2000.

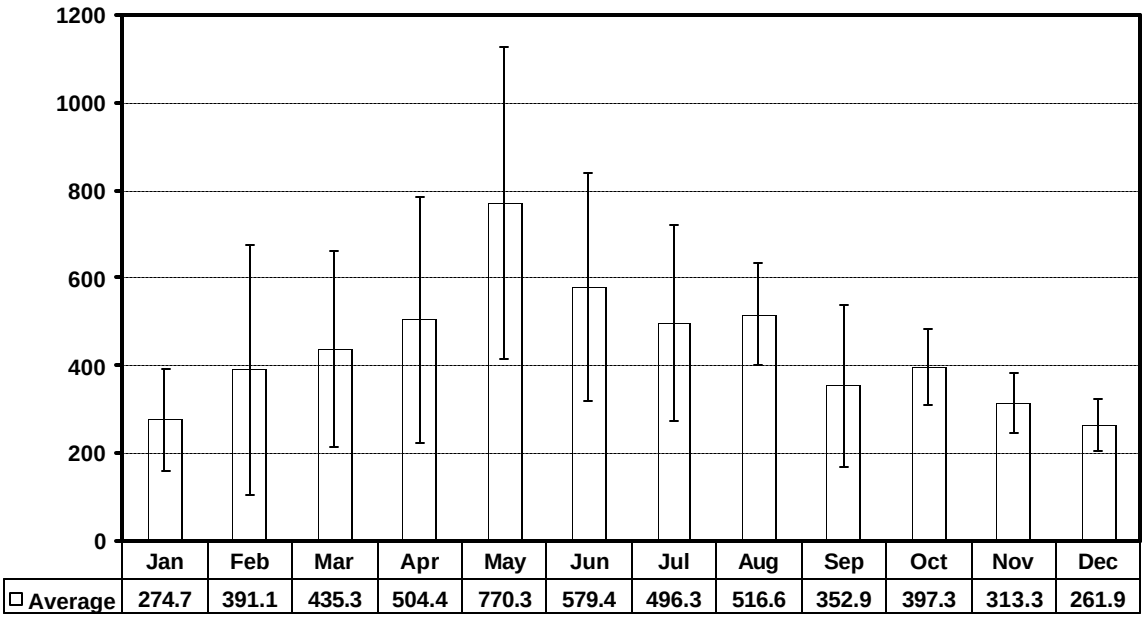
Bird Species	Average Count	Maximum Count
Common Starling (*Sturnus vulgaris*)	196.21	802
Australian Magpie (*Gymnorhina tibicen*)	78.71	291
Little Raven/Australian Raven (*Corvus mellori/C. coronoides*)	46.47	283
House Sparrow (*Passer domesticus*)	35.13	163
Skylark (*Alauda arvensis*)	25.42	118
Feral Pigeon (*Columba livia*)	17.52	145
Richard's Pipit (*Anthus novaeseelandiae*)	17.32	65
Welcome Swallow (*Hirundo neoxena*)	17.15	315
Yellow-rumped Thornbill (*Acanthiza chrysorrhoa*)	6.95	75
Magpie-lark (*Grallina cyanoleuca*)	6.58	65
Straw-necked Ibis (*Threskiornis spinicollis*)	6.40	115
Sulphur-crested Cockatoo (*Cacatua galerita*)	4.99	76
Silver Gull (*Larus novaehollandiae*)	4.42	500
Common Myna (*Acridotheres tristis*)	4.30	22
European Goldfinch (*Carduelis carduelis*)	3.13	37
Willie Wagtail (*Rhipidura leucophrys*)	2.77	20
Nankeen Kestrel (*Falco cenchroides*)	1.60	7
White-faced Heron (*Egretta novaehollandiae*)	1.54	50
Red-rumped Parrot (*Psephotus haematonotus*)	1.48	33
Masked Lapwing (*Vanellus miles*)	1.29	9
Eastern Rosella (*Platycercus eximius*)	1.14	13
Red Wattlebird (*Anthochaera carunculata*)	1.13	41
Brown Falcon (*Falco berigora*)	1.01	7
Superb Fairy-wren (*Malurus cyaneus*)	0.82	8
White-plumed Honeyeater (*Lichenostomus penicillatus*)	0.71	10
Crimson Rosella (*Platycercus elegans*)	0.47	7
Red-browed Finch (*Neochmia temporalis*)	0.42	20
Galah (*Cacatua roseicapilla*)	0.42	6
Tree Martin (*Hirundo nigricans*)	0.38	16
Australian White Ibis (*Threskiornis molucca*)	0.32	20
Wedge-tailed Eagle (*Aquila audax*)	0.30	5
Black Kite (*Milvus migrans*)	0.30	4
Australian Wood Duck (*Chenonetta jubata*)	0.29	16
Fairy Martin (*Hirundo ariel*)	0.25	8
Laughing Kookaburra (*Dacelo novaeguineae*)	0.24	3
White-fronted Chat (*Ephthianura albifrons*)	0.22	7
Black-faced Cuckoo-shrike (*Coracina novaehollandiae*)	0.19	11
Dusky Woodswallow (*Artamus cyanopterus*)	0.17	5
Whistling Kite (*Haliastur sphenurus*)	0.15	2
Musk Lorikeet (*Glossopsitta concinna*)	0.10	6
Pacific Black Duck (*Anas superciliosa*)	0.08	3
Little Eagle (*Hieraaetus morphnoides*)	0.08	2
Black-shouldered Kite (*Elanus axillaris*)	0.08	2
European Greenfinch (*Cardeulis chloris*)	0.07	6
Australian Hobby (*Falco longipennis*)	0.07	1
Flame Robin (*Petroica phoenicea*)	0.07	1
Pallid Cuckoo (*Cuculus pallidus*)	0.06	4
Spotted Turtle-dove (*Streptopelia chinensis*)	0.06	2
Grey Fantail (*Rhipidura fuliginosa*)	0.05	3
White-necked Heron (*Ardea pacifica*)	0.05	2
Silvereye (*Zosterops lateralis*)	0.04	5
Peregrine Falcon (*Falco peregrinus*)	0.04	1

Brown Thornbill (*Acanthiza pusilla*)	0.04	1

Table 1 (cont.) The average and maximum number of each bird species recorded at Melbourne Airport during 149 surveys, 1997–2000.

Bird Species	Average Count	Maximum Count
Common Blackbird (*Turdus merula*)	0.04	1
Zebra Finch (*Taeniopygia guttata*)	0.03	2
Swamp Harrier (*Circus approximans*)	0.02	2
Masked Woodswallow (*Artamus personatus*)	0.02	2
Restless Flycatcher (*Myiagra inquieta*)	0.02	2
Varied Sitella (*Daphoenositta chrysoptera*)	0.01	2
Cattle Egret (*Ardea ibis*)	0.01	1
Brown Goshawk (*Accipiter fasciatus*)	0.01	1
Fan-tailed Cuckoo (*Cuculus flabelliformis*)	0.01	1
Little Corella (*Cacatua sanguinea*)	0.01	1
Brown-headed Honeyeater (*Melithreptus brevirostris*)	0.01	1

Fig. 2 Average bird numbers (with standard deviation) at Melbourne Airport, 1997 to 2000.



There was little monthly variation in the number of aircraft movements at Melbourne Airport, with the average monthly movements between November 1988 and December 2000 being: January—11 632; February—11 138; March—12 312; April—11 765; May—11 775; June—11 368; July—12 064; August—11 949; September—11 618; October—12 125; November—11 425; December—11 724. In contrast, there are clear seasonal variations in the incidence of bird-strikes (Fig. 4). The greatest frequency of bird-strikes occurs during April, with the lowest frequency over winter (June–August) and early spring (September–October).

As might be expected, there was marked variation in the incidence of bird-strikes over 24 hours (Fig. 5). The greatest number of bird-strikes occurred between 08:00 and 10:00, with a second, smaller, peak around noon. While these morning peaks in bird-strikes correspond to high volumes of air traffic over those periods, there is no similar correlation between bird-strikes and increased air traffic volume during the evening (Fig. 5)

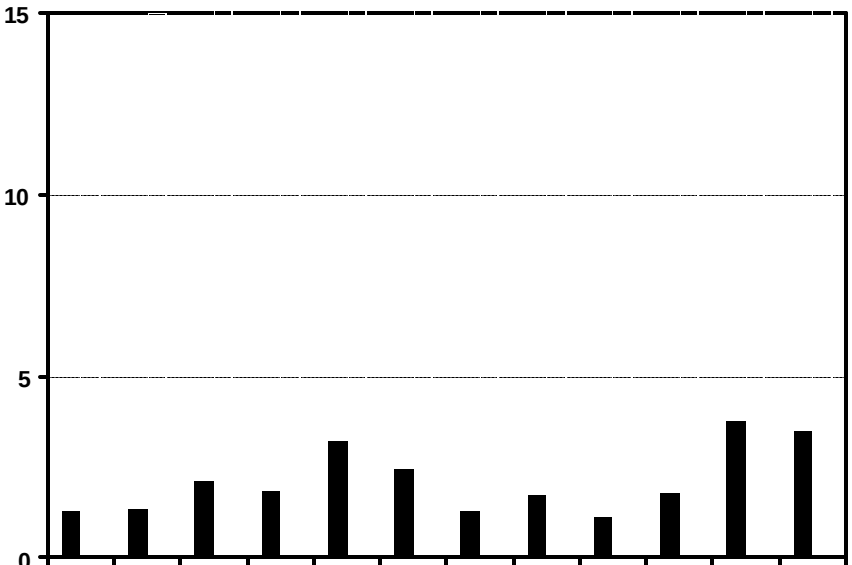
and the diel variation in the frequency of bird-strikes differed significantly from the expected frequency based upon the number of aircraft movements per hour (χ^2 = 100.58, d.f. = 22, P<0.01).

Table 2 Bird and bat taxa involved in bird-strikes at Melbourne Airport, 1986 to 2001.

Bird Species	No. of Bird-strikes	No. of Birds Involved
Australian Magpie (*Gymnorhina tibicen*)	89	*92
"Hawk"/"Eagle"/Unidentified raptor	22	22
Feral Pigeon (*Columba livia*)	21	*25
Masked Lapwing (*Vanellus miles*)	20	20
Skylark (*Alauda arvensis*)	16	16
Raven (*Corvus* spp.)	16	*18
Brown Falcon (*Falco berigora*)	14	14
Richard's Pipit (*Anthus novaeseelandiae*)	13	14
Black-shouldered Kite (*Elanus axillaris*)/"Kite"	12	*14
Nankeen Kestrel (*Falco cenchroides*)	10	10
Barn Owl (*Tyto alba*)	10	10
Silver Gull (*Larus novaehollandiae*)	9	*11
House Sparrow (*Passer domesticus*)	9	9
Unidentified bat species	7	7
Common Starling (*Sturnus vulgaris*)	5	5
Welcome Swallow (*Hirundo neoxena*)	4	*6
White-faced Heron (*Egretta novaehollandiae*)	4	4
Australian White Ibis (*Threskiornis molucca*)	4	4
Sulphur-crested Cockatoo (*Cacatua galerita*)	3	3
Magpie-lark (*Grallina cyanoleuca*)	3	*4
Banded Lapwing (*Vanellus tricolor*)	2	*3
"Duck"	2	2
Australian Wood Duck (*Chenonetta jubata*)	2	2
Grey-headed Flying-Fox (*Pteropus poliocephalus*)	2	2
Peregrine Falcon (*Falco peregrinus*)	2	2
Spotted Turtle-dove (*Streptopelia chinensis*)	2	2
"Owl"	2	2
Pacific Black Duck (*Anas superciliosa*)	1	1
Latham's Snipe (*Gallinago hardwickii*)	1	1
Pacific Golden Plover (*Pluvialis fulva*)	1	1
Black Kite (*Milvus migrans*)	1	1
Wedge-tailed Eagle (*Aquila audax*)	1	1
Australian Hobby (*Falco longipennis*)	1	1
Galah (*Cacatua roseicapilla*)	1	1
Barking Owl (*Ninox connivens*)	1	1
Southern Boobook (*Ninox novaeseelandiae*)	1	1
"Swift"	1	1
Superb Fairy-Wren (*Malurus cyaneus*)	1	1
Tree Martin (*Hirundo nigricans*)	1	1
European Greenfinch (*Cardeulis chloris*)	1	1
Not recorded	128	–

* denotes multiple bird-strikes were recorded

Fig. 3 Long-term trends in bird-strike rate at Melbourne Airport, 1989 to 2000



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bird-strike/10 000 aircraft movements	1.29	1.34	2.11	1.82	3.21	2.46	1.29	1.70	1.11	1.80	3.76	3.49
No. Bird-strikes	13	15	26	24	43	34	19	26	17	27	60	61

Fig. 4 Mean bird-strike rate per month at Melbourne Airport, Nov. 1988 to Dec. 2000

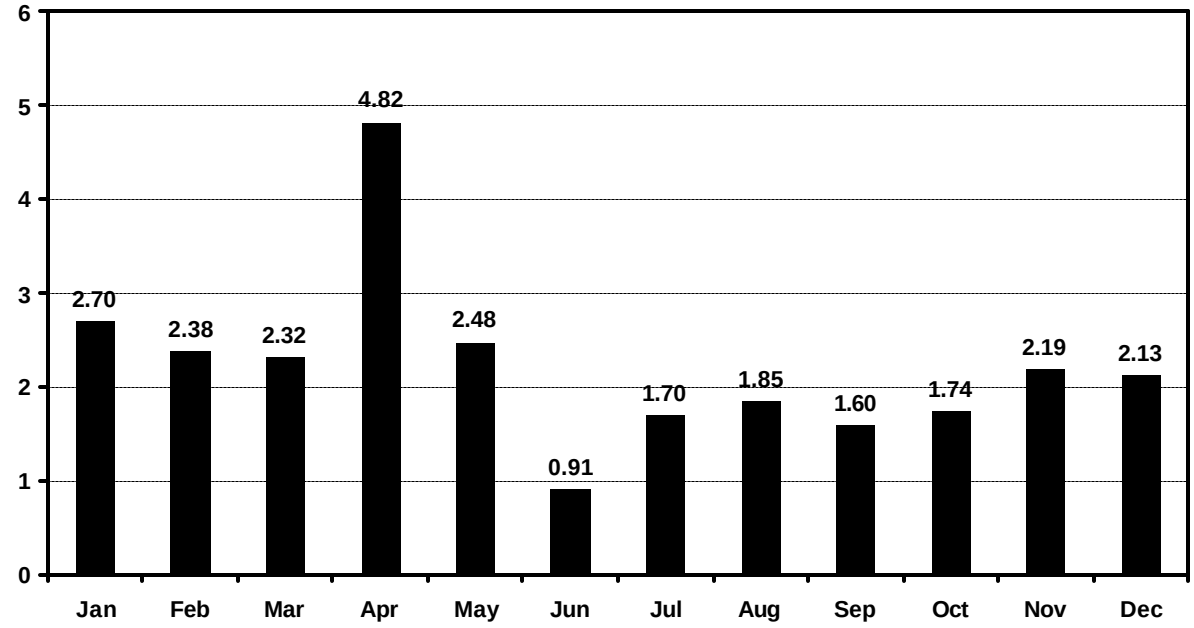


Fig. 5 Hourly variation in aircraft traffic (from a typical week during 1997) and the incidence of bird-strikes at Melbourne Airport, 1986 to 2000.

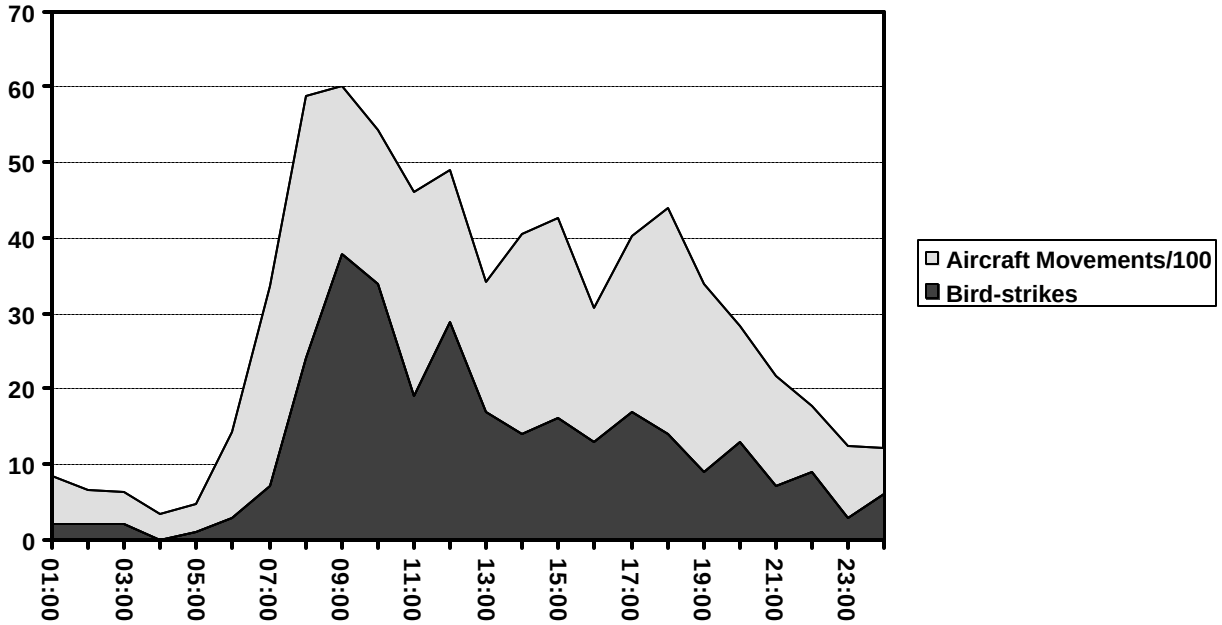
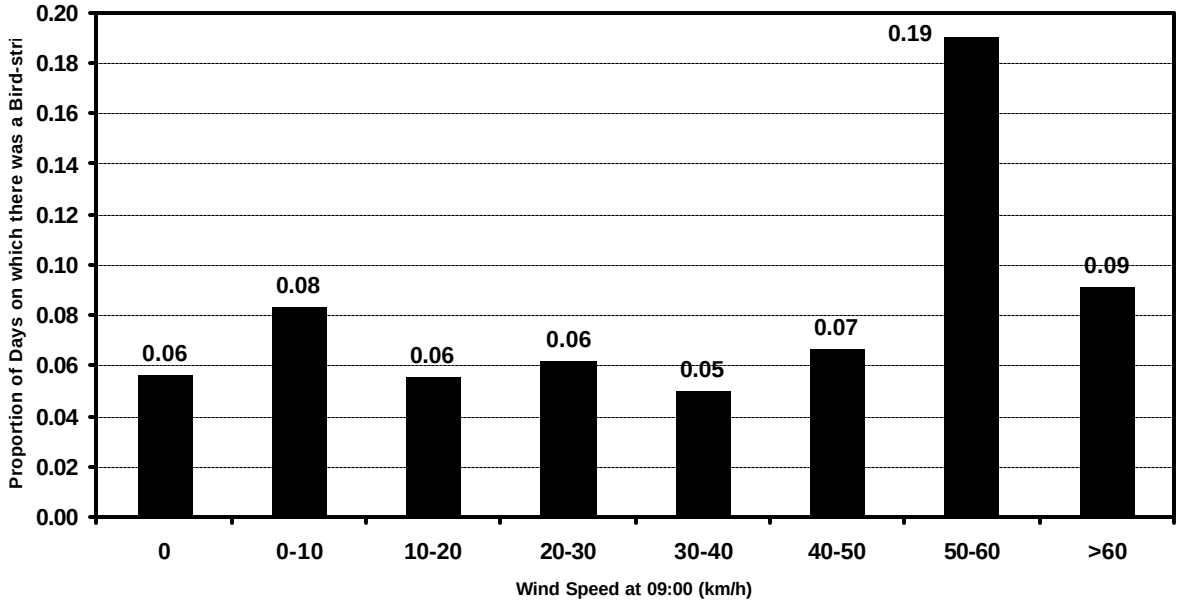


Fig. 6 The relationship between wind speed at 09:00 and the incidence of bird-strikes at Melbourne Airport, Jan. 1988 to Oct. 1997.



Spatial Variation of Bird-strikes

The phase of flight during which an aircraft struck a bird was recorded in 299 cases. Of these, the great majority—261 instances (87.2%)—occurred at 'zero feet' altitude, when the aircraft was on the ground: 135 (45.1%) during the landing roll; 109 (36.4%) during the take-off run; and 17 (5.7%) during taxiing. Bird-strikes on aircraft off the ground occurred in 38 (12.8%) instances: 25 (8.4%) during the approach; eight (2.7%) during the climb to altitude; and five (1.7%) during the descent. The altitude at which bird-strikes occurred conforms closely to the phase of flight, and in many cases the altitude recorded for an incident was possibly derived from the known phase of flight, with the majority of recorded altitudes being 'zero feet'. The altitude criteria for 'on airport' bird-strikes excluded all bird-strikes at any great altitude from this analysis, and the greatest recorded altitude was one incident at 100 feet.

Weather and Bird-strikes

Only three weather variables were analysed in this initial study. There was a significant association between the occurrence of a bird-strike and rainfall during that day ($\chi^2 = 58.4$, d.f. = 3, $P<0.01$, Table 3), with the incidence of bird-strikes on days when up to 10 mm of rain fell higher than expected.

Table 3 Observed and expected bird-strikes by rainfall category at Melbourne Airport, 1989–97.

Rainfall (mm)	Days overall	% of days	Obs. days with bird-strikes	Exp. days with bird-strikes
0	1 883	58.17	132	130.89
<1	945	29.19	36	65.69
1–10	280	8.65	49	19.46
10.1–20	129	3.99	8	8.97
Total	3 237	100	225	225

There was no significant association between the occurrence of a bird-strike and the wind direction ($\chi^2 = 15.66$, d.f. = 15). However, there was a statistically significant association between the occurrence of a bird-strike and wind speed ($\chi^2 = 16.70$, d.f. = 7, $P<0.05$). Figure 6 indicates that the incidence of bird-strikes increased during days of strong winds, of 50 to 60 km/h.

Discussion

The most abundant bird species at Melbourne Airport are open grassland species, such as the Australian Magpie, Welcome Swallow and Richard's Pipit, and those generalist species which are suited to urban landscapes, such as Common Starlings, Feral Pigeons, House Sparrows, ravens and gulls (Table 1). Melbourne Airport authorities maintain an active, multi-faceted programme to reduce this site's attractiveness to birds and so reduce the risk of a bird-strike on aircraft using the airport. Measures include strict control of waste material which might provide food for birds, regular patrols during the day to assess bird hazards, the use of fixed 'scares' and "Bird-frite" crackers fired from shotguns to disperse bird flocks from the airport's grounds, bird population monitoring, and habitat management. The comparatively low numbers and diversity of birds at the airport are an indication of the success of this integrated management programme.

With the exception of the western 'arm' of the airport, it is apparent that most birds occur in the vicinity of buildings or tree-lines, where they may take shelter (Fig. 1). The western arm is attractive to birds for a number of other reasons. It is the most secluded and undisturbed area of the airport and, perhaps more importantly, it lies between a piggery which attracts large numbers of birds and the remnant Grey Box woodland which provides shelter for these and other birds. The area also supports large numbers of invertebrates (W.K. Steele unpubl. data) which provide food for several bird species.

The initial decline in the incidence of bird-strikes at Melbourne Airport from 1993 is likely to be due to changes in the nature of refuse accepted by the adjacent tip from that date, which saw a marked reduction in the number of Silver Gulls and other birds frequenting the site (A. Rohead pers. comm.). There have been no Silver Gulls involved in bird-strikes at the airport since 1993. Implementation of a multi-faceted bird hazards management programme has not prevented an increase in the bird-strike rate at the airport in recent years. Although Melbourne Airport has a bird-strike rate considerably lower than the European average of 5.7 strikes per 10 000 aircraft movements (Thorpe 1990), the increase in bird-strike rate over the past two years is of some concern and the reasons for this increase need to be identified.

The greatest frequency of bird-strikes at Melbourne Airport occurred during autumn, with the lowest frequency over winter and early spring (Fig. 4). This pattern does not mirror exactly the seasonal variation in bird numbers at the airport, although bird numbers also increased during autumn (Fig. 2). With the onset of rains during Melbourne's wet autumn months additional food resources become available to several bird species, attracting many birds to the airport at that time of year: Sulphur-crested Cockatoos (*Cacatua galerita*) feed on Onion Grass (*Romulea rosea*) bulbs during late autumn, and White-faced Herons (*Egretta novaehollandiae*) and ibises forage for frogs and invertebrates wherever standing water forms after rain. The most striking example of seasonal variation in the incidence of bird-strikes is provided by the White-faced Heron, with all bird-strikes involving this species taking place during May. Flocks of Silver Gulls frequently move inland during periods when storms affect coastal areas. At such times the airport provides a suitable roost site, with spacious open areas which deny potential predators a concealed approach. Prior to the reduction in activity at the adjacent refuse tip, up to 2 000 Silver Gulls foraged at this site, and during late autumn many of these birds used Melbourne Airport's grounds as a roosting site.

The seasonal pattern to bird-strikes at Melbourne Airport is similar to that at Christchurch Airport, New Zealand, which has a peak in the incidence of bird-strike during April and the lowest incidence during June (Chilvers *et al*. 1997). In contrast, the seasonal pattern at Melbourne Airport was very different to that in Lithuania in the Northern Hemisphere. Most bird-strikes in Lithuania occur during summer, and at night, because that is the period when most migratory birds are in flight and at high altitudes (Zalakevicus 1994).

The results presented here support the findings of Lavery (1969) at Townsville Airport, Queensland, and indicate that the great majority of bird-strikes occur when aircraft are still on the ground. This is related to the behaviour of the most commonly struck species, the Australian Magpie, which generally flies close to the ground and which frequently undertakes rapid pursuit flights of other birds, during which the birds can cross runways and taxiways whilst concentrating on their quarry and ignoring approaching aircraft. This has implications for bird hazard management at Melbourne Airport since, as the majority of bird-strikes occur actually on the runways and taxiways, it should be possible to reduce bird-strikes by deterring birds from this relatively small area through habitat management, active deterrence, and the judicious use of insecticides and acoustic deterrents.

While bird abundance and activity may be important factors in determining the incidence of bird-strikes the volume of aircraft traffic apparently is of little consequence. There is a marked seasonal influence on the incidence of bird-strikes at Melbourne Airport while there is no real variation in the number of aircraft movements each month. Furthermore, the marked variation in the incidence of bird-strikes over 24 hours (Fig. 5), with most bird-strikes occurring during the morning, would seem to be related to the fact that this is the period when birds are most active, rather than being a function of aircraft traffic (Lavery 1969, this study). A similar pattern was found at both Christchurch, where the highest occurrence of bird-strikes is between 08:00 and 10:00 (Chilvers *et al*. 1997), and Townsville Airports (Lavery 1969).

At Melbourne Airport, local weather conditions, particularly rainfall, have the greatest influence on the incidence of bird-strikes of the three factors assessed here: aircraft traffic volume, bird numbers, and weather. The observation that there is a greater chance of a bird-strike at an airport following rainfall is not new and it has been reported from previous studies of airports in both the USA and Britain (Gabrey & Dolbeer 1996; Manktelow 2000). Although the onset of autumn rains causes large numbers of birds to move onto the grounds of Melbourne Airport in search of food, the overall number of birds at the airport does not

appear to determine the incidence of bird-strikes there (Figs 2 and 4). It is possible that rain may cause an increased risk of bird-strike not only through attracting birds to the airport but also by reducing a bird's ability to avoid an aircraft through reduced visibility and increased ambient noise. However, the relationship between rainfall, bird numbers and bird-strike frequency deserves more detailed investigation than the brief study presented here.

The incidence of bird-strikes at Melbourne Airport increased during periods of strong winds, of over 50 km/h, which may be due to the birds' lessened ability to control their flight and react quickly in strong winds, or to wind noise concealing the sound of an approaching aircraft until it is too late for a bird to avoid a collision. Nonetheless this is a somewhat surprising finding because birds at the airport were less active during periods of strong winds than during calmer periods, and the birds generally flew very close to the ground when there was a strong wind. Manktelow (2000) investigated the possible influence of wind speed on the incidence of bird-strikes at nine British airports but found no statistically significant correlation between the two. However, Manktelow (2000) did find a significant relationship between wind direction and the occurrence of bird-strikes at two of the nine British airports she studied. Although the prevailing wind direction largely determines the likelihood of rainfall at Melbourne Airport, with southwesterly winds bringing rain, in this brief study wind direction was found to play no part in determining the incidence of bird-strikes at Melbourne Airport.

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