

FLIGHT SPEED AND DIRECTIONAL RESPONSES TO WIND BY MIGRATING CANADA GEESE

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ABSTRACT.—We monitored headings, flight speeds, and time of flight of nine transmitter-tagged giant Canada geese (*Branta canadensis maxima*) during 10 different autumn migration flights during which data on wind directions and speeds were also available. Destination of these individuals was known because of previous observations of the same birds. This enabled us to evaluate their headings with respect to wind drift. As the magnitude of the following component of the wind increased, air speeds of migrating geese declined while ground speeds were not significantly changed. Therefore, the cost of transport over the ground, and probably metabolic rate, were minimized. Headings of migrant geese varied systematically and significantly with wind direction, but track directions did not deviate significantly from the goal direction. Thus, the geese compensated for wind drift. Visual reference to landmarks may have been the cue used to correct for drift, as weather conditions were such that geese could see the ground. *Received 1 March 1983, accepted 5 December 1983.*

THE ability of migrating birds to detect and adjust to winds is variable; migrants either maintain a constant air speed (Blokpoel 1974; Alerstam 1978a, b) or vary it in relation to wind conditions (Bellrose 1967, Bruderer and Steidinger 1972, Pennycuik 1975, Able 1977, Larkin 1980, Larkin and Thompson 1980, Bellrose and Crompton 1981, Block and Bruderer 1982). Relying on assumed migration routes and destinations based on the knowledge of a species' distribution, researchers have documented apparent compensation (partial or complete) or the lack of it for lateral displacement caused by cross winds (Drury and Nisbet 1964; Lack 1969; Parslow 1969; Bergman and Donner 1971; Evans 1972; Gauthreaux 1972; Williams et al. 1972, 1977; Alerstam 1975a, b, 1976; Richardson 1976; Bingman et al. 1982). In our study, the destination of individual, migrating Canada Geese (*Branta canadensis*) tagged with transmitters was known because of previous observations of the same marked birds. This allowed us to monitor headings of experienced migrants with respect to wind drift because of our precise knowledge of their migratory destination.

METHODS

We collected data during the autumn 1973 and 1974 migrations of individuals from a population that nests

between Lakes Manitoba and Winnipeg in Manitoba and migrates (865 km) to Silver Lake, Rochester, Minnesota (Raveling 1976a, b, 1978). Migration flight paths and speeds of transmitter-tagged geese were monitored with the use of a ground vehicle, airplane, ground observers, and a base station, as described by Cochran et al. (1967). The transmitter design was similar to that described by Raveling (1969), except that a whip antenna was used to maximize signal-reception range. As a result, a package containing either the transmitter or both the transmitter and batteries was positioned on the back of the bird. The total weight of transmitters (including harness) varied between 50 and 75 g (1–3% of adult body weight), depending on size and number of batteries used. Before each migration season, 17–29 geese were outfitted with transmitters. Geese used in this study had been previously marked between 1968 and 1970 with individually identifiable, plastic neck-bands at the Marshy Point Goose Sanctuary (50°32'N, 98°7'W), located on the southeast shore of Lake Manitoba about 105 km northwest of Winnipeg, Manitoba, and identified as having regularly migrated to Rochester, Minnesota (43°55'N, 92°30'W; Raveling 1978). The direct-line following direction (direction from which birds were coming) for migration between Marshy Point and Rochester is 325°.

Migrations of transmitter-tagged geese occurred between 14 October and 18 November. Data on headings, times, and winds for the present analysis were obtained for nine birds during 10 migration flights. Three geese flew nonstop, whereas six geese (including one bird for which the migration was tracked in both 1973 and 1974) interrupted their migration in western or northwestern Minnesota. While tracking the migration flight, we observed a flock containing a transmitter-tagged goose on seven occasions. We

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TABLE 1. Wind characteristics and flight speeds of Canada Geese during autumn migration.^a

Level	Direction ^c	Wind characteristics ^b				Flight speed ^b	
		Speed (km/h)	Magnitude of following/opposing component ^d (km/h)	Cross component ^d (km/h)	Angle of incidence ^e	Ground (km/h)	Air (km/h)
Surface	315° ± 5° (270°-10°)	23 ± 1 (11-40)	17 ± 3 (0-37)	13 ± 2 (0-28)	40° ± 5° (0°-90°)	83 ± 4 (49-110)	65 ± 4 (32-101)
Geostrophic	355° ± 5° (308°-48°)	50 ± 3 (24-87)	18 ± 4 (-16-56)	40 ± 5 (2-80)	60° ± 5° (5°-89°)	83 ± 4 (49-110)	60 ± 5 (16-100)

^a Values presented are the mean ± SE with the range in parentheses.

^b Sample sizes for surface-wind direction and speed correspond to the number of weather stations supplying appropriate information during 10 migration flights ($n = 44$). Sample sizes ($n = 20$) for flight speeds and for following component, cross component, and angle of incidence correspond to the total number of surface-wind determinations made during 10 migration flights (measurements were made on one occasion each for 6 migration flights and on 2, 4, and 6 occasions during the other 4 flights). Sample sizes were reduced by one for each geostrophic wind category due to an inappropriate heading that could have resulted from an error in estimation of wind during one migration flight ($P < 0.01$ that the aberrant heading is part of the population of calculated headings, Snedecor and Cochran 1967: 157).

^c Direction from which wind was blowing.

^d Wind direction and speed were resolved trigonometrically along axes parallel and perpendicular to the headings of the goose to yield following/opposing and cross components. Headings were the direction toward which the bird oriented; track directions were those flown relative to the ground (Lack and Williamson 1959). The heading direction and speed were determined by subtracting the wind direction and speed vector from the track direction and speed vector.

^e Angle between wind direction and a bird's heading.

visually estimated these flocks to be flying 100-600 m above the ground ($\bar{x} = 330$ m).

We obtained weather and wind conditions from weather stations located along the migration route: Winnipeg, Manitoba; Grand Forks and Fargo, North Dakota; and Thief River Falls, Detroit Lakes, Alexandria, St. Cloud, Minneapolis, Redwood Falls, and Rochester, Minnesota. Surface-wind data were available for all migrations. Upper level wind may vary from surface wind. A measurement of upper wind (600 m) was available on only eight occasions during the migration season (only two of which corresponded to a time when a transmitter-tagged goose was migrating). Therefore, we used both surface wind data (as have others, e.g. Alerstam 1978a) and estimates of the geostrophic wind (prevailing between 500-1,500 m, Godske et al. 1957) to assess the effects of wind on migration speeds and directions.

RESULTS AND DISCUSSION

There were no significant differences between nonstop and interrupted migration flights for surface and estimated geostrophic wind characteristics or for the birds' ground and air speeds ($t < 0.57$, $P > 0.50$ for all comparisons); therefore, the data for all migrating

geese monitored were combined (Table 1). Regardless of whether surface or estimated geostrophic wind data were used, regression analyses (Bartlett's 3-group test, Sokal and Rohlf 1969) indicated that, as the magnitude of the following component increased, air speeds of migrating Canada Geese declined, whereas ground speeds were not significantly altered (Fig. 1).

A migrating bird may minimize energy use by: (a) maintaining the minimum metabolic rate for flight, (b) minimizing the cost of transport through the air (flying at a constant air speed), or (c) minimizing the cost of transport over the ground (air speed varies with wind speed and the bird's heading) (Schnell and Hellack 1979). Assuming a goose has 20% mechanical efficiency (Tucker 1973) and flies at 330 m, the following equation, modified from Tucker [1974, equation (2)] estimates power requirements during flight:

$$P_i = 1.11[5(73.42m^2b^{-2}V^{-1} + 6.6 \times 10^{-3}m^{0.66}V^{2.5}) \times (1 + 1.81m^{-0.167}V^{-0.5}) + 3.7m^{0.723}]$$

where P_i is power input in watts, m is body

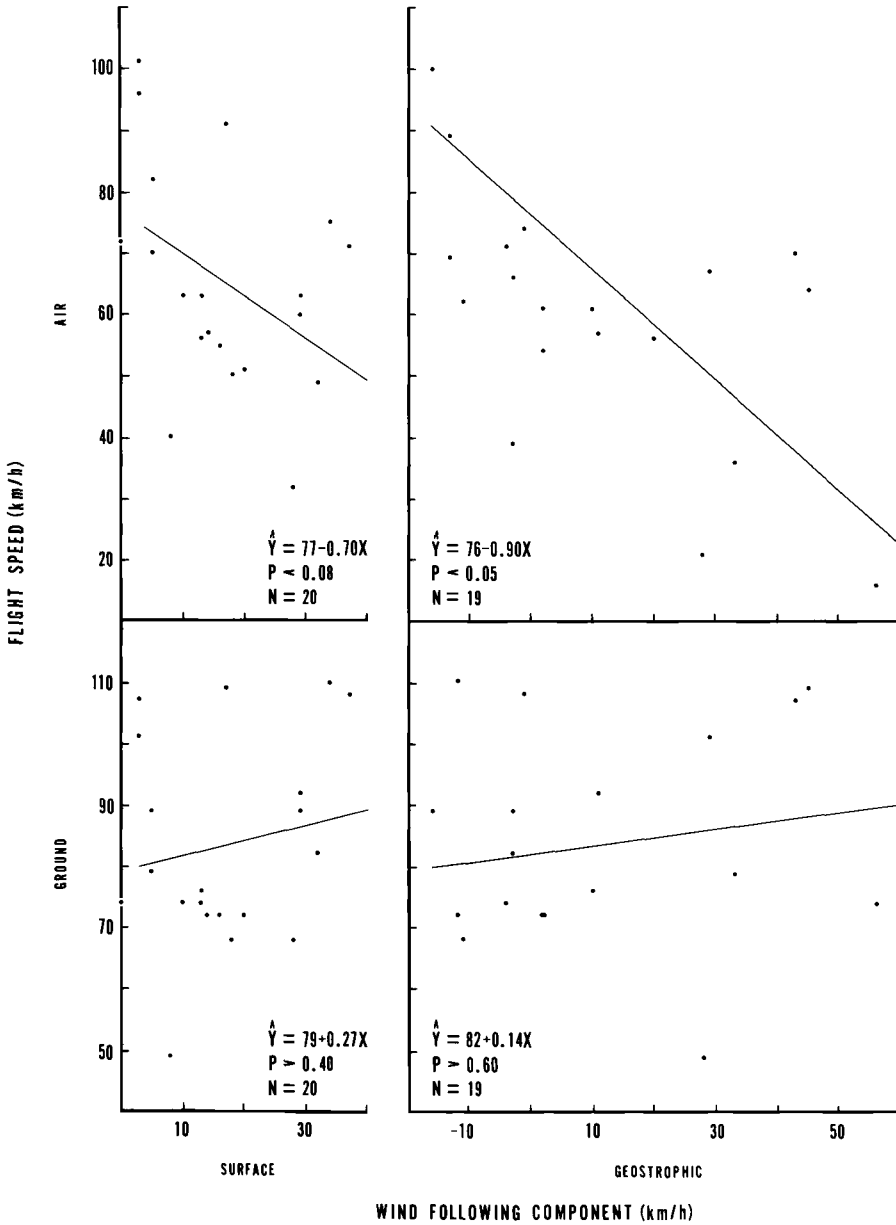


Fig. 1. Influence of wind speed on flight speed of migrating Canada Geese.

mass in kilograms, b is wing span in meters, and V is air speed in meters per second. Wing span was estimated from the formula $b = 1.1m^{0.33}$ [Tucker 1974, equation (4)]. This power estimate was then divided by weight (in newtons) to obtain metabolic rate and weight (in newtons), which multiplied by ground speed of the bird in meters per second yielded cost of trans-

port over the ground (Tucker 1974). Predicted air speeds for the minimum metabolic rate for flight and the minimum energy cost of transport over the ground were then calculated (Table 2).

The decrease in air speed as the following wind increased (Fig. 1) indicated that the birds did not minimize the cost of transport through

TABLE 2. Predicted air speeds for minimum metabolic rate for flight and minimum energy cost of transport over the ground.

Wind level	Predicted air speed (km/h) for minimum cost of transport ^a ($\bar{x} \pm SE$)	Compared to observed air speed ^b		Predicted air speed (km/h) for minimum metabolic rate ($\bar{x} \pm SE$)	Compared to observed air speed ^b	
		<i>t</i>	<i>P</i>		<i>t</i>	<i>P</i>
Surface ^c	69 ± 1	1.13	>0.20	52 ± 0 ^d	3.20	<0.005
Geostrophic ^c	72 ± 1	2.89	<0.01	52 ± 0 ^d	1.54	>0.20

^a Calculated using monthly average body weight in kg (4.01, 4.14, 4.82, 4.92, and 5.02) corresponding to the month and year of migration departure and sex of the goose.

^b Contained in Table 1.

^c The range in speed for surface wind was 0-37 km/h and -16-56 km/h for geostrophic wind.

^d Values are the same because metabolic rate is independent of wind conditions.

the air (see b above). They did appear to minimize the cost of transport over the ground (see c above), because there was no significant difference between predicted and measured air speeds for surface-wind conditions (Table 2).

Similarly, there was no significant difference between predicted and measured air speeds required to minimize metabolic rate (see a above) for flights in geostrophic wind conditions (Table 2). Because the wind conditions in which

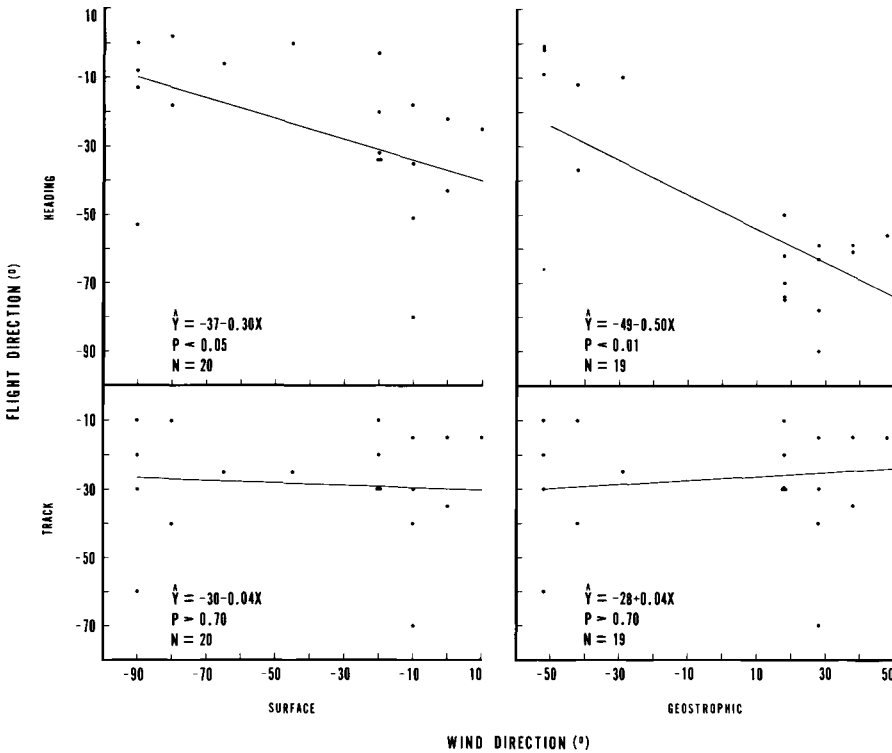


Fig. 2. Influence of wind direction (direction from which wind was blowing) on flight direction (direction from which bird was flying) of migrating Canada Geese. Directions are measured relative to north (360°). Directions west of north are negative; those east of north are positive.

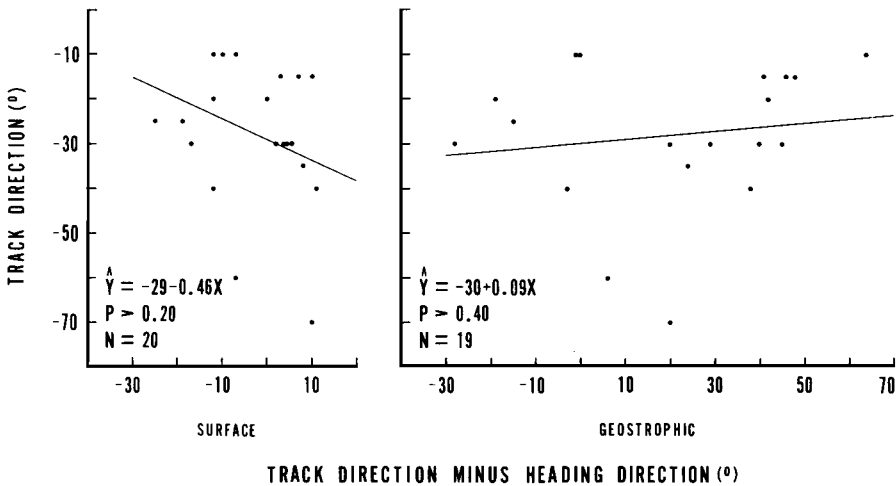


Fig. 3. Influence of the angle between track and heading directions on the track direction of migrating Canada Geese for surface and geostrophic wind conditions. Track directions (direction from which bird was flying) are measured relative to north (360°). Directions west of north are negative; those east of north are positive.

the bird was flying were not accurately known, actual air speeds may represent a compromise between these two types of optimization (see also Schnell and Hellack 1979). With a goal in mind, a bird may conserve energy in response to strong winds by flying longer at a slower speed. In moderate or light winds, flying faster and at a speed that maximizes the distance traveled per unit of time will minimize the migration time.

While headings varied systematically and significantly, track directions did not vary significantly with wind direction (Fig. 2). Regressions of the track direction on the angle between the heading and track directions were performed to determine the magnitude of compensation for wind drift. With drift compensation, the regression coefficient will be 0. A value of 1 indicates complete drift from a constant heading. These analyses indicated that the birds compensated for wind drift during all migration flights, whether nonstop or interrupted, and therefore only the combined data are presented (Fig. 3). As weather conditions allowed these geese to see the ground during all flights reported on here, visual reference to landmarks may have been the cue used to detect their departure from their goal track.

In autumn, this population of Canada Geese tends to migrate between wildlife refuges,

which provide protection from hunters, and to minimize the number of migration stopover locations (Raveling 1978). Migrations documented during this study tended to be characterized by direct flight paths, nonstop flights when departure time and weather conditions permitted, and the resumption of interrupted migrations as soon as weather conditions permitted (Wege and Raveling 1983). Flight paths of individual geese whose migration origin and destination were known revealed that the direct nature of autumn migrations was accomplished with the use of minimal energy (reducing air speed with increasing following wind) and by the correction for drift from the goal track.

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Report of Meeting of the Committee on Classification and Nomenclature
Louisville, Kentucky, 24-26 February 1984

The Committee on Classification and Nomenclature takes the opportunity of reporting on its annual winter meeting to note several taxonomic changes that have an immediate effect, and to solicit information from the ornithological community.

The scientific name of the Crissal Thrasher (p. 573, A.O.U. Check-list, 6th edition) is now *Toxostoma crissale* Henry, which replaces *T. dorsale*, suppressed by the International Commission on Zoological Nomenclature (1983, Opinion No. 1249). The names of the tribe Gallinagoini (p. 204) and Subfamily Cyclarhinae (p. 600) become Gallinaginini and Cyclarhininae, respectively, because incorrect roots have been used in the past for formation of these names. American Black Oystercatcher (p. 173) reverts to Black Oystercatcher; an extralimital (African) species with the same color modifier and group name is now considered to have a different, nonconflicting English name (Blackish Oystercatcher), and the additional modifier "American" is no longer necessary. Fernandina's Woodpecker (p. 396) is changed to Fernandina's Flicker to promote uniformity with closely related species; Bare-eyed Thrush (p. 561) becomes Bare-eyed Robin, to avoid confusion with the English name of an extralimital thrush. Note also the correction of "Turquoise-browed Motmot" (p. 371, typographical error) to "Turquoise-browed Motmot."

The preferred citation for the 6th edition (p. ii) is incomplete for bibliographic purposes; it should also list as publisher "American Ornithologists' Union, Washington, D.C." (Allen Press, Lawrence, Kansas, is the printer).

Recently published papers proposing taxonomic changes (e.g. recognition of *Pluvialis fulva*; recognition of *Sphyrapicus nuchalis*; merging of *Phaeornis* in *Myadestes* and splitting of "*Phaeornis*" *obscurus* into several species; splitting of *Microcerculus marginatus* into several species) as well as other taxonomic issues will be deliberated at Committee meetings in August 1984 and February 1985, with decisions to be published in the next supplement to the A.O.U. Check-list (scheduled for July 1985). Additional data affecting these decisions, as well as other data that are pertinent to potential taxonomic changes, are solicited by the Committee (please send to **Burt L. Monroe, Jr., Chairman, Department of Biology, University of Louisville, Louisville, Kentucky 40292**).

Preparation of a companion volume to the 6th edition dealing with geographic variation and subspecies is well underway, with a schedule for publication in about 5 years. The Committee is seeking data on geographic variation (especially data that may not be published in the near future) and volunteers for review of accounts of various taxonomic groups.

It has been pointed out that ornithology seems to be the only discipline in which English names of species are capitalized. The Committee strongly supports continuation of this policy. The advantages in the designation of a bird species by capitalization greatly outweigh the disadvantages, particularly with the large number of descriptive modifiers that form part of the English names. Confusion is easily avoided; e.g. the phrases "a White Tern" and "a white tern" have distinctly discrete meanings. The use of lower case initial letters in English names in other disciplines seems to be a matter of tradition, but we encourage capitalization for English names of species not only in birds but in other groups as well.

As of the end of the February 1984 meeting, Committee membership consists of Chairman Monroe, Secretary Richard C. Banks, John W. Fitzpatrick, Thomas R. Howell, Ned K. Johnson, Henri Ouellet, James V. Remsen, Jr., and Robert W. Storer.