Supplementary Information Methods.

GPS, IMU and anemometer processing

GPS data were post-processed differentially over the short baseline between base station and pigeons using Waypoint GrafNav 8.10. L1 C/A code pseudorange measurements were used to calculate the position of each GPS logger, with velocity determined from L1 Doppler measurements. This approach can deliver position accuracy to 0.5m and speed accuracy better than 0.1m/s. Accuracy in relative position between receivers is likely to be considerably better due to cancellation of offsets arising from common local error sources. Wind speeds varied from very light ((0.04-0.80m/s) to moderate (maximally 4.77m/s) over the two days of measurement covering seven bouts of flying. From these measurements, we determined horizontal and vertical groundspeed, V_{GPS} and V_z respectively (from GPS alone), relative airspeed V_{air} (GPS speeds combined with anemometer measurements) and flap timing (from dorsal acceleration). For each flap, we calculated the mean dorsal acceleration $\overline{a_{dorsal}}$ and mean rostral acceleration $\overline{a_{rostral}}$ from accelerometers. Average whole-flight rostral accelerations were subtracted from $\overline{a_{rostral}}$ to remove effect of cross-talk from dorsal acceleration. Gyroscope measurements were integrated over each flap, providing net pitch $\Delta\theta_{flap}$ and yaw $\Delta\phi_{flap}$ angular displacements. Also, for every pigeon for every flap, the location of all other pigeons relative to the instantaneous direction of travel was calculated and used to determine two 'Flock Factors' *FF*: FF_{ahead} represents the proportion of the forward hemisphere view covered by other pigeons (assuming every pigeon to have a representative span of 0.5m); FF_{behind} the proportion of the trailing hemisphere view.

Turning and banking calculations

Average centripetal accelerations $a_{centrip}$ over five wingbeats were calculated from GPS velocity measurements. In order to avoid sideslip during a

turn, thereby both loading the wings evenly and minimising induced power, the pigeon should roll and maintain a bank angle ψ :

$$\psi = \tan^{-1}\left(\frac{a_{centrip}}{g}\right).$$

If this is achieved, the net acceleration should act dorsally:

$$a_{dorsal} = \sqrt{g^2 + a_{centrip}^2}.$$

The pigeon, flying with an angular turn rate Ω, would pitch and yaw every flap over each flap period *T*:

$$\Delta\theta_{flap} = \Omega T \sin(\psi)$$

$$\Delta\phi_{flap} = \Omega T \cos(\psi)$$

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Table SI 1. Partial regression coefficients and statistical parameters for frequency (in Hz).

	Estimate	SE	DF	SS	F statistic	p value
Partial regression coefficient						
Constant	11.46	0.580				
K_1	-1.16	0.122	1	15.7	95.8	<0.0001
K_2	0.0783	0.00846	1	99.6	606	<0.0001
K_3	-0.00168	0.000195	1	5.27	32.0	<0.0001
K_4	0.201	0.00411	1	12400	75500	<0.0001
K_5	-6.71×10^{-3}	0.000303	1	1320	8010	<0.0001
K_6	0.0000746	6.83×10^{-6}	1	40.5	247	<0.0001
K_7	0.0235	0.00121	1	95.5	581	<0.0001
K_8	0.00973	0.000341	1	67.9	413	<0.0001
K_9	-0.000589	0.000158	1	0.676	4.11	0.043
K_{10}	0.0119	0.000158	1	1780	10800	<0.0001
K_{11}	-0.000150	6.02×10^{-6}	1	8.54	52.0	<0.0001
K_{12}	-4.21×10^{-6}	2.63×10^{-7}	1	37.4	227	<0.0001
K_{13}	7.44	0.281	1	75.4	459	<0.0001
K_{14}	-164	9.29	1	29.8	181	<0.0001
K_{15}	1060	78.1	1	19.6	119	<0.0001
K_{16}	2.81	0.278	1	47.8	291	<0.0001
K_{17}	-33.4	9.14	1	4.02	24.4	<0.0001
K_{17}	135	76.21	1	0.0843	0.513	0.47
Pigeon 1	-0.227	0.00536				
Pigeon 2	0.500	0.00766				
Pigeon 3	-0.0413	0.00692				
Pigeon 4	-0.0703	0.00569				
Pigeon 5	0.598	0.00576				
Pigeon 6	-0.017	0.00543				
Pigeon 7	-0.189	0.00493				
Pigeon 8	0.289	0.00504				
Pigeon 9	0.289	0.00530				
Pigeon 10	0.297	0.00530				
Pigeon 11	0.462	0.00783				
Pigeon 12	0.0548	0.00570				
Pigeon 13	0.110	0.00665				
Pigeon 14	0.438	0.00616				
Pigeon 15	0.123	0.00524				
Pigeon 16	-0.0287	0.00496				
Pigeon 17	0.275	0.00541				
Pigeon 18	0.474	0.00541				
Pigeons			18	9980	3370	<0.0001

Table SI 2. Partial regression coefficients and statistical parameters for dorsal body-motion amplitude (in meters).

	Estimate	SE	DF	SS	F statistic	p value
Partial regression coefficient						
Constant	0.0109	0.00209				
K_1	0.00161	0.000440	1	0.000290	135	<0.0001
K_2	-0.000142	0.0000306	1	0.0000417	19.5	<0.0001
K_3	3.84×10^{-6}	7.03×10^{-7}	1	4.28×10^{-6}	2.00	0.16
K_4	-0.000524	0.0000148	1	0.0226	10500	<0.0001
K_5	0.0000213	1.09×10^{-6}	1	9.227×10^{-6}	4.30	0.038
K_6	-3.70×10^{-7}	2.47×10^{-8}	1	7.65×10^{-6}	3.57	0.059
K_7	0.0000119	4.38×10^{-6}	1	0.0000205	9.57	0.002
K_8	0.0000210	1.23×10^{-6}	1	0.0000980	45.7	<0.0001
K_9	1.41×10^{-6}	5.72×10^{-7}	1	8.69×10^{-6}	4.05	0.044
K_{10}	0.0000667	5.69×10^{-7}	1	0.0289	13500	<0.0001
K_{11}	-1.02×10^{-7}	2.18×10^{-8}	1	0.00888	4140	<0.0001
K_{12}	-3.43×10^{-8}	9.50×10^{-10}	1	0.00187	871	<0.0001
K_{13}	-0.0418	0.00101	1	0.00117	545	<0.0001
K_{14}	1.07	0.0336	1	0.00126	587	<0.0001
K_{15}	-7.42	0.282	1	0.00119	555	<0.0001
K_{16}	-0.0349	0.00101	1	0.00121	565	<0.0001
K_{17}	0.872	0.0330	1	0.00130	606	<0.0001
K_{17}	-5.84	0.275	1	0.000857	399	<0.0001
Pigeon 1	0.000693	0.0000193				
Pigeon 2	0.000811	0.0000277				
Pigeon 3	0.00114	0.0000250				
Pigeon 4	0.000152	0.0000205				
Pigeon 5	-0.000908	0.0000208				
Pigeon 6	-0.00185	0.0000196				
Pigeon 7	-0.000736	0.0000178				
Pigeon 8	-0.000924	0.0000182				
Pigeon 9	-0.00124	0.0000191				
Pigeon 10	0.00105	0.0000192				
Pigeon 11	-0.000914	0.0000283				
Pigeon 12	0.000560	0.0000206				
Pigeon 13	-0.000792	0.0000240				
Pigeon 14	-0.00217	0.0000222				
Pigeon 15	0.000185	0.0000189				
Pigeon 16	0.000244	0.0000179				
Pigeon 17	-0.00191	0.0000196				
Pigeon 18	-0.000513	0.0000195				
Pigeons			18	0.143	3710	<0.0001