

Protocol S1

Supplementary list of flight speeds and biometry of bird species

The table gives flight speeds and biometry for 138 species of birds in continuous flapping flight tracked by radar. Tracking details are only given for the novel data collected by the T.A. group at Lund University (102 species). Data from Bruderer and Boldt (2001, 64 species, indicated by •) are presented for their subset of birds in continuous flapping flight.

The following data referring to speeds are listed: mean equivalent airspeed (U_e), standard deviation of U_e , mean vertical speed (U_z), number of tracks (n) and total track time for the radar recordings. For the data from Bruderer and Boldt (2001) only mean U_e and number of tracks, included into the present analysis, are given (for further details see Bruderer & Boldt 2001).

Data on biometry is based on a review of 33610 measurements of body mass, wingspan or wing area, where all measurements of a given parameter refer to unique birds. The contribution of each source on the species level was: Dunning (1993, 135 species), Magnan (1922, 87), Bruderer and Boldt (2001, 82), Pennycuick (1999, 57), Greenewalt (1962, 55), Hedenström, A. (unpubl., 31), Hedenström (1994, 14), Strandberg, R. (unpubl., 6), Cramp et al. (1977-94, 2), Hedenström (1999, 1), Hedenström (1992, 1) and Rosén, M. (unpubl., 1). Weighted averages are given in the table and the total mean is the mean of all species.

The following information referring to biometry are listed: Number of body mass measurements, mean total body mass of a fresh killed or live bird (kg), number of wing span measurements, mean wing span (b ; maximum wingtip to wingtip distance on a bird in the hand, in metres), number of wing area measurements, wing area (S ; projected area of both wings when fully stretched including the area of the body between the wings, m^2). Data was selected to compare with the methods of measuring birds by Pennycuick (1999) and was used as is from all authors except from Greenewalt (1962: Table 8). Here, the wing area was corrected (increased) by using 'wing spread' instead of 'length of both wings' given a constant aspect ratio (b^2/S), and only 'wing spread' was used as a measure of wingspan (cf.

Greenewalt, 1962). Species are arranged into six main phylogenetic groups according to the phylogeny of Ericson et al. (2006).

References in this protocol:

- Bruderer, B. & Boldt, A. (2001) Flight characteristics of birds: 1. radar measurements of speeds. *Ibis* **143**:178-204.
- Cramp, S., Simmons, K.E.L & Perrins, C.M. , eds. (1977-94) *The Birds of the Western Palearctic*, vol 1-9 (Oxford University Press).
- Ericson, P.G.P., Anderson, C.L., Britton, T., Elzanowski, A., Johansson, U.S., Källersjö, M., Ohlson, J.I., Parsons, T.J., Zuccon, D. & Mayr, G. (2006) Diversification of Neoaves: integration of molecular sequence data and fossils. *Biol. Lett.* **2**: 543-547.
- Dunning, J.B. (1993) *CRC Handbook of Avian Bodymasses* (CRC Press, Boca Raton).
- Greenewalt, C.H. (1962) Dimensional relationships for flying animals. *Smithsonian miscellaneous collections* **144**(2): 1-46.
- Hedenström, A. & Ålerstam, T. (1992) Climbing performance of migrating birds as a basis for estimating limits for fuel-carrying capacity and muscle work. *J. exp. Biol.* **164**: 19-38.
- Hedenström, A. (1994) Flight strategies in Arctic Birds. In *Tundra Ecology 1994: A Cruise Report* (Swedish Polar Research Secretariat, Stockholm).
- Hedenström, A., Rosén, M., Åkesson, S. & Spina, F. (1999) Flight performance during hunting excursions in the Eleonora's falcon *Falco eleonora*. *J. exp. Biol.* **202**: 2029-2039.
- Magnan, A. (1922) Les caractéristiques des oiseaux suivant le mode de vol. *Ann. Sci. Nat.* **10**(5): 125-134.
- Pennycuick, C.J. (1999) *Measuring birds' wings for flight performance calculations*, 2nd edition (Boundary Layer Publications, Bristol).

Taxon	Species	U ₀ (m/s)	sd (m/s)	U _z (m/s)	N (tracks)	Track- time (s)	N (mass)	Mass (kg)	N (b)	b (m)	N (S)	S (m ²)
Swans, geese & ducks	<i>Cygnus olor</i>	16.2	1.6	0.1	24	8540	115	10.597	21	2.30	9	0.6504
	<i>Cygnus columbianus</i>	18.5		0.4	1	440	167	6.637	12	1.98	11	0.4608
	<i>Cygnus cygnus</i>	17.3	2.0	-0.1	10	3969	25	8.689	19	2.29	18	0.6045
	<i>Anser fabalis</i>	17.3	2.7	0.0	44	14600	127	3.035	1	1.62	1	0.2675
	<i>Anser albifrons</i>	16.1	2.0	0.1	5	1255	169	2.582	1	1.41	1	0.1835
	<i>Anser anser</i>	17.1	2.6	0.0	21	10100	176	3.326	7	1.55	6	0.3079
	<i>Branta canadensis</i>	16.7		0.2	1	180	395	3.628	4	1.69	4	0.3717
	<i>Branta leucopsis</i>	17.0	2.2	0.0	22	10740	620	1.705	1	1.08	1	0.1150
	<i>Branta bernicla</i>	17.7	2.8	0.1	97	45450	792	1.306	3	1.01	3	0.1129
	<i>Tadorna tadorna</i>	15.4		0.0	1	120	16	1.193				
	<i>Anas penelope</i>	20.6	2.1	0.1	36	15300	77	0.783	11	0.82	11	0.0814
	<i>Anas crecca</i>	19.7	4.0	0.2	9	3050	281	0.348	6	0.59	5	0.0428
	<i>Anas platyrhynchos</i>	18.5	2.3	0.3	22	7470	5871	1.082	24	0.88	24	0.1062
	<i>Anas acuta</i>	20.6	2.6	0.4	6	1920	294	1.024	2	0.90	2	0.0879
	<i>Aythya ferina</i>	23.6		0.7	1	190	322	0.823	1	0.77	1	0.0615
	<i>Aythya fuligula</i>	21.1	1.1	0.7	3	670	1044	0.694	1	0.71	1	0.0474
	<i>Aythya marila</i>	21.3		1.1	1	150	27	0.931	1	0.82	1	0.0621
	<i>Somateria mollissima</i>	17.9	2.4	0.0	240	79218	56	2.015	2	0.98	2	0.1310
	<i>Somateria spectabilis</i>	16.0	0.3	-0.2	2	740	183	1.591	1	0.93	1	0.1080
	<i>Polysticta stelleri</i>	21.9		-0.1	1	310	90	0.805				
	<i>Clangula hyemalis</i>	22.0	1.4	0.1	3	510	1299	0.874	2	0.71	2	0.0669
	<i>Melanitta nigra</i>	22.1	4.0	-0.1	14	5220	13	0.990	1	0.85	1	0.0679
	<i>Melanitta fusca</i>	20.1	4.7	0.0	32	10760	13	1.743	1	0.97	1	0.1010
<i>Bucephala clangula</i>	20.3	3.8	0.3	10	4560	113	0.901	2	0.70	2	0.0598	
<i>Mergus serrator</i>	20.0	2.9	0.2	33	13430	37	1.004	2	0.87	2	0.0678	
<i>Mergus merganser</i>	19.7	1.1	0.1	2	420	26	1.489	2	0.93	2	0.0767	
Flamingo, pigeons & swifts	<i>Phoenicopterus ruber</i> •	15.2			3		26	3.053	1	1.53	1	0.2715
	<i>Columba oenas</i>	15.8	2.0	0.1	8	1830	20	0.295	1	0.75	1	0.0532
	<i>Columba palumbus</i>	16.3	2.3	0.3	87	45920	522	0.490	3	0.75	3	0.0842
	<i>Columba palumbus</i> •	17.6			11							
	<i>Apus apus</i>	9.7	2.0	0.4	34	18570	230	0.038	14	0.40	13	0.0168
	<i>Apus apus</i> •	10.6			163							
	<i>Apus pallidus</i> •	10.5			33		661	0.042	1	0.44	1	0.0263
<i>Apus melba</i> •	12.6			36		13	0.078	1	0.57	1	0.0304	
Waders, gulls & terns	<i>Haematopus ostralegus</i>	13.0	2.5	0.2	19	9930	293	0.523	6	0.82	4	0.0810
	<i>Charadrius hiaticula</i>	19.5		0.4	1	130	84	0.064	9	0.41	9	0.0179
	<i>Pluvialis dominica</i>	13.7		0.2	1	790	60	0.145				
	<i>Pluvialis squatarola</i>	17.9	3.9	0.1	14	4870	37	0.219	6	0.62	6	0.0420
	<i>Vanellus vanellus</i>	12.8	1.3	0.0	14	3380	79	0.219	4	0.75	2	0.0744
	<i>Vanellus vanellus</i> •	11.9			2							
	<i>Calidris canutus</i>	20.1	1.9	-0.2	7	2990	42	0.128	20	0.50	19	0.0286
	<i>Calidris alpina</i>	15.3	1.9	0.5	36	13578	652	0.054	23	0.36	23	0.0156
	<i>Philomachus pugnax</i>	17.4	1.0	-0.1	3	1120	270	0.114	9	0.55	9	0.0388
	<i>Philomachus pugnax</i> •	13.6			3							
	<i>Gallinago gallinago</i>	17.1	2.7	0.0	22	5660	37	0.132	7	0.52	6	0.0476
	<i>Limosa lapponica</i>	18.3	2.1	0.2	15	7710	94	0.318	1	0.73	1	0.0520
	<i>Numerius phaeopus</i>	16.3	0.9	0.2	4	1260	66	0.383	1	1.07	1	0.1365
	<i>Numerius arquata</i>	16.3	2.3	0.3	16	7040	231	0.794	6	0.97	2	0.1182
	<i>Tringa nebularia</i>	12.3	3.3	0.1	5	1290	52	0.174	1	0.61	1	0.0406
	<i>Tringa glareola</i>	9.6	1.7	1.1	3	980	31	0.066	4	0.40	4	0.0203
	<i>Arenaria interpres</i>	14.9	0.7	0.7	2	630	35	0.111	11	0.47	11	0.0252
	<i>Phalaropus lobatus</i>	13.1		0.2	1	230	61	0.033	4	0.34	4	0.0146
	<i>Phalaropus fulicarius</i>	12.4	2.3	-0.1	6	1000	216	0.054	6	0.42	6	0.0196
	<i>Stercorarius pomarinus</i>	15.2	2.3	0.2	16	5320	128	0.688	3	1.18		
	<i>Stercorarius parasiticus</i>	13.8	2.2	-0.2	7	1500	45	0.438	17	1.06	16	0.1175
	<i>Stercorarius longicaudus</i>	13.6	1.9	0.6	3	1550	48	0.297	4	1.00	4	0.0891
	<i>Larus minutus</i>	11.5	0.1	0.2	2	610	87	0.118				
	<i>Larus ridibundus</i>	11.9	1.6	0.0	19	6190	352	0.283	28	0.97	28	0.0976
	<i>Larus canus</i>	13.4	2.9	0.1	36	14050	176	0.411	5	1.11	3	0.1246
	<i>Larus fuscus</i>	13.1	1.9	-0.2	11	3150	130	0.719	14	1.34	14	0.1934
	<i>Larus fuscus</i> •	11.9			11							
	<i>Larus argentatus</i>	12.8	1.8	0.0	18	7210	374	1.142	11	1.34	11	0.1968
	<i>Larus glaucooides</i>	15.9		-0.2	1	140	3	0.819				
	<i>Larus hyperboreus</i>	13.4	0.8	0.1	3	530	65	1.445				
	<i>Larus marinus</i>	13.7	1.2	-0.2	4	700	219	1.669	10	1.67	10	0.2881
	<i>Rissa tridactyla</i>	13.1	0.4	-0.1	2	660	411	0.408	6	0.96	6	0.0953
	<i>Sterna caspia</i>	12.1		0.6	1	210	84	0.655				
<i>Sterna paradisaea</i>	10.9	0.9	0.4	2	500	262	0.110	1	0.80	1	0.0571	
<i>Chlidonias leucopterus</i> •	12.0			1	111	111	0.054	1	0.65	1	0.0545	
Divers, cormorants, pelican, herons, storks & crane	<i>Gavia stellata</i>	18.6	3.9	0.0	7	3660	13	1.505	1	1.04	1	0.0890
	<i>Gavia arctica</i>	19.3	2.1	0.1	13	3710	5	2.543	1	1.20	1	0.1196
	<i>Gavia adamsii</i>	18.7	0.5	0.4	2	220	7	5.500				
	<i>Phalacrocorax carbo</i>	15.2	3.0	0.1	35	13410	62	2.227	9	1.40	9	0.2240
	<i>Pelecanus onocrotalus</i> •	15.6			1		7	8.504	5	2.91	4	0.9554
	<i>Botaurus stellaris</i>	8.8		1.0	1	340	4	1.133	2	1.26	2	0.2727
	<i>Nycticorax nycticorax</i> •	11.2			4		8	0.763	3	1.06	2	0.1589
	<i>Ardeola ralloides</i> •	11.7			1		24	0.287	1	0.86	1	0.1114
	<i>Egretta alba</i> •	10.2			2		27	0.888	6	1.44	4	0.2443
	<i>Ardea cinerea</i>	12.5	2.2	0.1	14	4840	34	1.439	3	1.73	3	0.3716
	<i>Ardea cinerea</i> •	11.2			49							
	<i>Ardea purpurea</i> •	10.8			12		3	0.906	1	1.35	1	0.2488
	<i>Ciconia nigra</i> •	16.0			6		2	3.000	1	1.50	1	0.2842
	<i>Ciconia ciconia</i> •	16.0			6		72	3.432	4	1.91	3	0.5326
	<i>Plegadis falcinellus</i> •	12.6			5		4	0.566	2	0.89	1	0.0986
	<i>Platalea leucorodia</i> •	14.1			7		9	1.857	2	1.30	2	0.2415
	<i>Porzana porzana</i>	13.9		-0.1	1	100	18	0.078	2	0.38	2	0.0236
	<i>Grus grus</i>	15.0	2.7	-0.2	12	6010	19	5.614	2	2.22	2	0.5855
	<i>Grus grus</i> •	13.6			1							

Falcons, crows & songbirds	<i>Falco naumanni</i> •	11.3			12		60	0.151	1	0.65	1	0.0611
	<i>Falco tinnunculus</i>	10.1	0.2		1	120	105	0.203	7	0.73	5	0.0708
	<i>Falco vespertinus</i> •	12.8			4		11	0.165	1	0.72	1	0.0728
	<i>Falco subbuteo</i> •	11.3			20		14	0.238	6	0.74	6	0.0667
	<i>Falco eleonorae</i> •	12.8			2		22	0.387	2	0.95	2	0.1041
	<i>Falco peregrinus</i> •	12.1			13		51	0.789	20	1.02	19	0.1257
	<i>Lullula arborea</i> •	9.8			1		962	0.027	1	0.29	1	0.0164
	<i>Alauda arvensis</i>	15.1	2.1	-0.4	15	2880	393	0.039	5	0.35	5	0.0207
	<i>Alauda arvensis</i> •	12.7			20							
	<i>Riparia riparia</i>	14.3		0.6	1	140	250	0.015	4	0.27	4	0.0096
	<i>Riparia riparia</i> •	11.3			9							
	<i>Hirundo rupestris</i> •	9.9			1		10	0.019	3	0.32	2	0.0116
	<i>Hirundo rustica</i>	10.0	2.0	-0.4	2	700	2343	0.016	6	0.32	6	0.0136
	<i>Hirundo rustica</i> •	11.3			108							
	<i>Delichon urbica</i>	9.7	0.5	-0.1	2	390	256	0.015	3	0.29	3	0.0104
	<i>Delichon urbica</i> •	11.0			76							
	<i>Anthus trivialis</i>	12.7	2.2	0.2	4	1170	438	0.022	2	0.27	2	0.0126
	<i>Anthus trivialis</i> •	12.0			4							
	<i>Anthus pratensis</i> •	10.5			6		232	0.018	4	0.26	4	0.0123
	<i>Motacilla flava</i> •	12.7			7		164	0.018	2	0.26	1	0.0103
	<i>Motacilla alba</i>	14.1	1.9	-0.3	5	610	101	0.021	8	0.26	8	0.0119
	<i>Motacilla alba</i> •	13.0			13							
	<i>Prunella modularis</i> •	12.2			1		541	0.020	14	0.21	14	0.0090
	<i>Oenanthe oenanthe</i> •	12.8			1		73	0.023	6	0.28	6	0.0143
	<i>Turdus pilaris</i>	13.0	2.9	0.2	15	6970	76	0.105	7	0.42	7	0.0299
	<i>Turdus pilaris</i> •	12.4			6							
	<i>Turdus philomelos</i>	11.0	2.1	0.4	6	2490	290	0.068	21	0.36	21	0.0218
	<i>Turdus philomelos</i> •	11.7			8							
	<i>Turdus iliacus</i>	13.8	1.8	0.3	6	1450	317	0.061	35	0.36	35	0.0223
	<i>Turdus viscivorus</i>	11.9	3.3	-0.4	3	600	21	0.114	2	0.44	2	0.0333
	<i>Turdus viscivorus</i> •	12.4			2							
	<i>Parus ater</i>	10.6	2.3	0.1	2	160	51	0.009	1	0.18	1	0.0073
	<i>Parus major</i> •	13.6			1		63	0.019	13	0.23	13	0.0109
	<i>Garrulus glandarius</i>	6.7	1.0	0.2	2	310	60	0.162	5	0.54	5	0.0644
	<i>Garrulus glandarius</i> •	12.9			2							
	<i>Nucifraga caryocatactes</i>	13.4	2.8	-0.1	2	370	72	0.173	2	0.58	2	0.0584
	<i>Corvus monedula</i>	12.5	2.6	0.0	13	3260	202	0.245	5	0.65	3	0.0684
	<i>Corvus monedula</i> •	14.7			3							
	<i>Corvus frugilegus</i>	11.5	1.2	0.1	16	4870	79	0.488	3	0.93	2	0.1380
	<i>Corvus frugilegus</i> •	13.0			8							
	<i>Corvus corone</i>	13.5	2.6	0.0	5	1260	147	0.566	6	0.91	5	0.1378
	<i>Corvus corax</i>	14.3	0.9	-0.1	5	1325	10	1.149	2	1.21	1	0.2472
	<i>Stumus vulgaris</i>	16.2	4.3	-0.5	4	1360	2875	0.083	17	0.38	14	0.0244
	<i>Stumus vulgaris</i> •	12.4			9							
	<i>Fringilla coelebs</i>	12.8	1.9	0.2	23	8410	169	0.022	18	0.26	18	0.0132
	<i>Fringilla coelebs</i> •	12.8			52							
	<i>Fringilla montifringilla</i>	15.0	2.9	-0.9	4	1110	63	0.024	13	0.27	13	0.0126
<i>Fringilla montifringilla</i> •	11.6			2								
<i>Carduelis chloris</i> •	12.2			1		25	0.028	6	0.25	6	0.0123	
<i>Carduelis carduelis</i> •	12.8			3		53	0.016	3	0.24	3	0.0093	
<i>Carduelis spinus</i>	14.5	1.6	-0.3	60	20150	59	0.014	9	0.21	9	0.0076	
<i>Carduelis spinus</i> •	12.4			2								
<i>Carduelis cannabina</i>	14.8	4.5	-0.2	2	800	53	0.015	2	0.24	2	0.0095	
<i>Pyrrhula pyrrhula</i>	13.4		0.9	1	300	39	0.022	5	0.27	5	0.0136	
<i>Pernis apivorus</i>	12.5	2.3	-0.3	13	1860	28	0.778	10	1.26	10	0.2471	
<i>Pernis apivorus</i> •	10.1			16								
<i>Milvus migrans</i> •	11.7			7		33	0.815	2	1.52	1	0.2805	
<i>Milvus milvus</i>	12.0	0.3	-0.5	2	400	17	1.012	3	1.66	3	0.3248	
<i>Haliaeetus albicilla</i>	13.6	0.9	-0.2	2	200	34	4.967	4	2.18	4	0.8824	
<i>Neophron percnopterus</i> •	12.6			3		11	2.062	2	1.65	1	0.3555	
<i>Circus aeruginosus</i>	11.2	1.6	-0.5	2	200	56	0.653	11	1.16	11	0.2040	
<i>Circus aeruginosus</i> •	10.1			22								
<i>Circus cyaneus</i>	9.1	0.7	-0.2	2	180	363	0.433	3	1.10	3	0.1568	
<i>Circus macrourus</i> •	9.6			3		23	0.420	2	1.09	2	0.1483	
<i>Circus pygargus</i> •	8.4			1		22	0.291	3	1.09	3	0.1350	
<i>Accipiter nisus</i>	11.3	1.9	-0.1	12	3040	361	0.277	46	0.67	43	0.0768	
<i>Accipiter nisus</i> •	10.0			64								
<i>Accipiter brevipes</i> •	11.1			57		10	0.195	1	0.70	1	0.0739	
<i>Buteo buteo</i>	11.6	2.7	-0.1	10	4200	491	0.885	15	1.24	14	0.2689	
<i>Buteo buteo</i> •	13.3			13								
<i>Buteo lagopus</i>	10.5	0.0	-0.2	2	1120	279	0.943	8	1.35	7	0.3324	
<i>Aquila pomarina</i> •	11.7			2		38	1.391	1	1.47	1	0.5153	
<i>Aquila nipalensis</i> •	7.7			1		1	2.900	1	2.03	1	0.4853	
<i>Aquila chrysaetos</i>	11.9		-0.5	1	40	61	4.069	13	2.03	11	0.5970	
<i>Hieraetus pennatus</i> •	11.3			2		24	0.828	1	1.11	1	0.2004	
<i>Pandion haliaetus</i>	13.3	2.7	0.0	5	1030	49	1.578	23	1.60	22	0.3201	
<i>Pandion haliaetus</i> •	11.4			10								
<i>Merops apiaster</i> •	12.2			28		384	0.057	1	0.47	1	0.0273	
Mean (species)	14.1			17		232	1.065	6	0.91	6	0.1442	