Journal of Avian Biology

JAV-01298
Vansteelant W. M. G., Shamoun-Baranes, J., McLaren, J., van Diermen, J. and Bouten, W. 2017. Soaring across continents: decision-making of a soaring migrant under changing atmos-pheric conditions along an entire flyway. – J. Avian Biol. doi: 10.1111/jav.01298

Supplementary material

Soaring across continents: decision- making of a soaring migrant under changing atmospheric conditions along an entire flyway

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Appendix 1

Content

Appendix 2

Content

Appendix 1

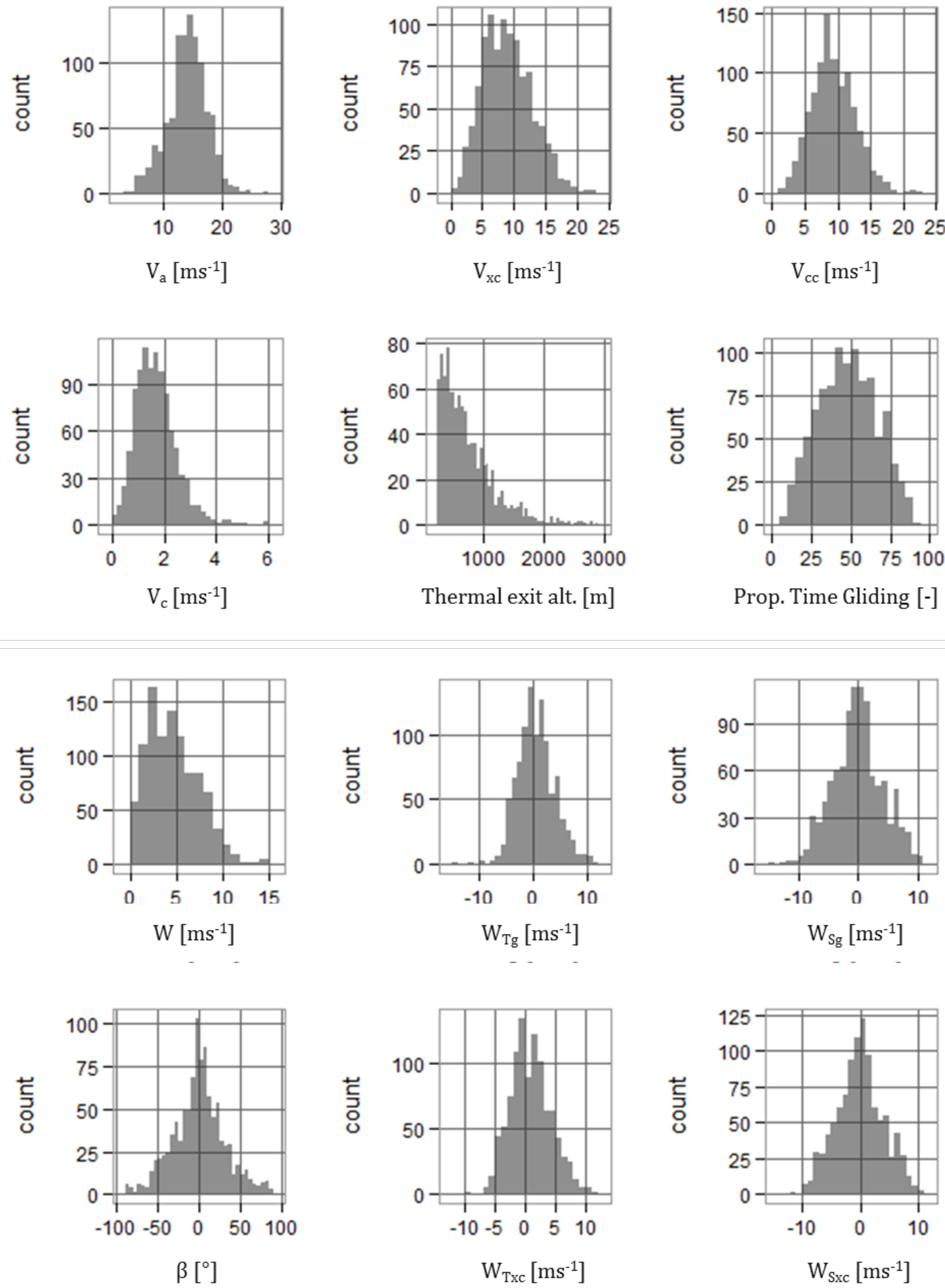

Fig. A1. Frequency distributions of flight parameters derived from GPS-tracking and wind data from a mesoscale global weather model. See glossary for description of abbreviations.

		V_a [ms^{-1}]		V_{cc} [ms^{-1}]		V_{xc} [ms^{-1}]		V_c [ms^{-1}]		TEA [m]		Prop. Time Gliding [%]		W [ms^{-1}]		W_{Tg} [ms^{-1}]		W_{Sg} [ms^{-1}]		W_{Txc} [ms^{-1}]		W_{Sxc} [ms^{-1}]	
Bird	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
599	250	15.3	3.3	9.71	3.2	9.11	3.6	1.85	0.8	837.7	498.1	48.5	19.4	4.52	2.5	0.14	3.3	0.11	4.3	0.58	3.2	0.33	4
600	259	14.1	3.9	9.34	3.7	9.31	4.0	1.68	0.7	734.2	431.2	47.8	17.3	4.6	2.5	0.91	3.5	-0.73	4.2	1.15	3.5	-0.5	3.7
856	193	13.5	3.3	9.12	3.5	8.62	3.7	1.54	0.7	728.5	386.0	48.7	19.8	4.5	2.6	0.44	3.1	0.21	4.2	0.77	3.1	-0.38	4.1
857	148	13.0	3.0	8.61	2.9	9.17	4.1	1.67	0.7	740.2	371.5	48.9	18.2	5.52	2.6	1.82	3.8	1.32	4.6	1.55	3.8	1.00	4.4
859	156	14.3	2.8	9.37	3.1	8.5	3.8	1.73	0.8	864.8	646.5	48.5	16.6	4.61	3.2	0.19	3.4	-0.36	4.5	0.33	3.6	-0.21	4.3

Table A1. Summary statistics of flight parameters and indicators of soaring conditions. Bird speed variables were calculated from GPS observations and wind speeds were interpolated from a mesoscale atmospheric model. See glossary for description of abbreviations.

	$\lvert W_{Tg}\rvert$ [ms^{-1}]					$\lvert W_{Sg}\rvert$ [ms^{-1}]					$\lvert W_{Txc}\rvert$ [ms^{-1}]					$\lvert W_{Sxc}\rvert$ [ms^{-1}]					W [ms^{-1}]				
	Intercept		Coeff.		R^2	Intercept		Coeff.		R^2	Intercept		Coeff.		R^2	Intercept		Coeff.		R^2	Intercept		Coeff.		R^2
	value	P	value	P		value	P	value	P		value	P	value	P		value	P	value	P		value	P	value	P	
V_c [ms^{-1}]	1.82	<2E-16	-0.04	1E-04	< 0.02	1.67	<2E-16	0.01	0.33	<0.01	1.84	<2E-16	-0.05	2E-05	<0.02	1.66	<2E-16	0.01	0.15	<0.01	1.77	<2E-16	-0.01	0.14	<0.01
TEA [m]	817.96	<2E-16	-19.03	4E-03	<0.01	805.75	<2E-16	-12.06	0.03	<0.01	836.78	<2E-16	-25.19	0.00	<0.02	797.05	<2E-16	-9.56	0.10	<0.01	844.21	<2E-16	-16.57	0.00	<0.01

Table A2. Correlations between thermal soaring conditions and wind conditions. We fit single-effect linear regression models to investigate the relationship between each thermal climb variable (rows) and each of the wind variables (columns). Estimates and p-values for intercepts and regression coefficients as well are given for each model respectively.

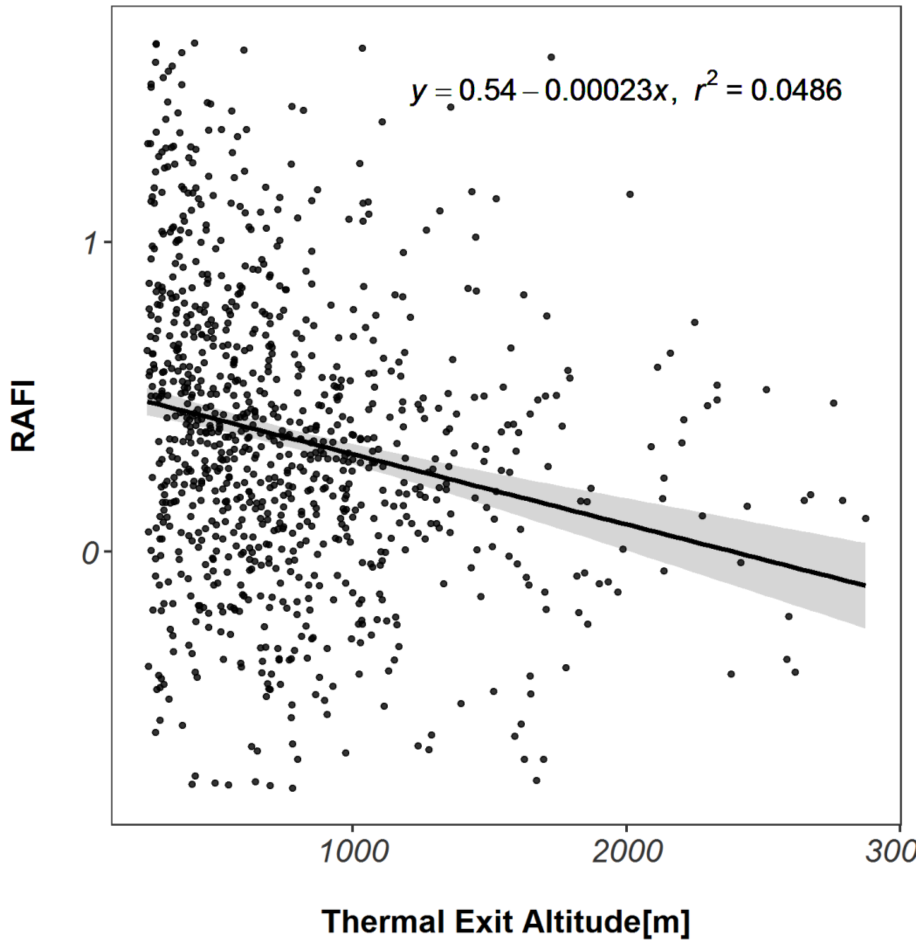

Fig. A2. RAFI in relation to thermal exit altitude.

Appendix 2

We conducted a sensitivity analysis for the parametrization of body mass (0.6 – 1.4 kg), wing span (1.1 – 1.5 m), wing area (0.23 – 0.26 m^2), the body drag coefficient (0.10 – 0.40) and combinations of mass and body drag. We used exaggerated values of wing size, wing area and body mass compared to real Honey Buzzards (www.vogelwarte.ch) for our sensitivity analysis. As such we get an impression for how large or heavy a Honey Buzzard should be in order for the observed air speeds to be time-optimal. We did not use body mass measurements of the individuals we tracked because they were only measured in the breeding season.

Body drag coefficients of a large bird like the Honey Buzzard are currently assumed to have a value of approximately 0.10 (Pennycuick et al. 1988, Hedenström and Liechti 2001, Pennycuick 2008). However, some studies have shown that an external device can increase body drag by up to 50%, and the presence of an antenna can even double total body drag (Bowlin et al. 2010, Pennycuick et al. 2012). UvA-BiTS loggers are not cubic in shape, but rather rounded, and have a very short antenna (3 cm). That should result in less added drag than suggested in earlier studies (Bowlin et al. 2010, Pennycuick et al. 2012). We tested body drag coefficient of 0.10, assuming no increase in drag due to loggers, to 0.40, which is slightly higher than the value of 0.30 that was used in optimal soaring studies until the 1990's (Pennycuick et al. 1988, Spaar and Bruderer 1997).

The sensitivity analysis revealed that a body drag coefficient of 0.40 would nearly account for the relationship between measured gliding air speeds and climb rates (Fig A1.D). However, it is unlikely that Honey Buzzards would actually have such a high body drag coefficient (Pennycuick et al. 1988, Pennycuick 1997). Additional sensitivity analysis for variation in mass, wing length, wing area and air density yielded no indications that the mismatch between observed and predicted gliding air speeds can be accounted for by these model uncertainties (Fig A1). The average relation between climb rates and gliding air speeds would be optimal if birds had a mass below 0.6 kg (and then simulation only worked in the lower range of observed climb rates because light-weight birds could not overcome high drag at medium to high air speeds).

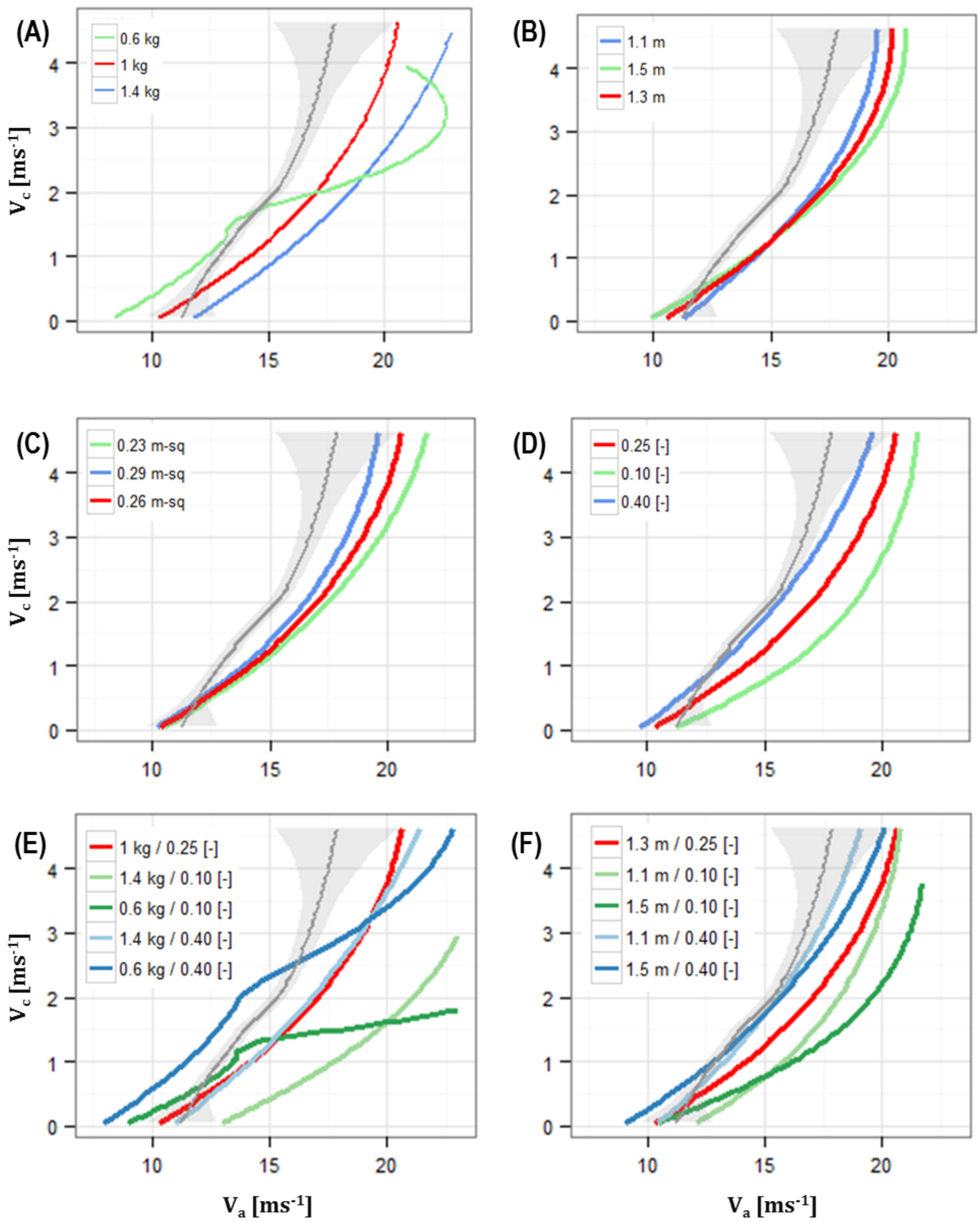

Fig. A1. Model sensitivity analysis. Plots show predicted V_{opt} (colours) for varying combinations of morphological parameters in an aerodynamic model of a soaring Honey Buzzard. Red lines indicate parameter combinations which we used in the reference model for this paper. We also plot the average gliding airspeeds as a function of climb rates (grey line and s.e.-intervals). We tested sensitivity of model predictions for (A) body mass, (B) wing length, (C) wing surface area, (D) body drag coefficient, (E) combined body mass and drag coefficients and (F) combined wing length and body drag coefficient.