

Electronic supplementary material for the article
“Flight behaviours and energy savings in adult and juvenile house
martins (*Delichon urbicum*) foraging near their breeding colony”

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Figure S1: RSV device in the field, in front of the wide lawn and urban gardens where house martins were recorded.



Figure S2: RSV device.

Rigid assembly of a camera and a set of mirrors rotating on a tripod with a fluid video head equipped with angular encoders. A second camera is visible on the right side, and was used to take pictures of the filmed birds with a greater magnification.

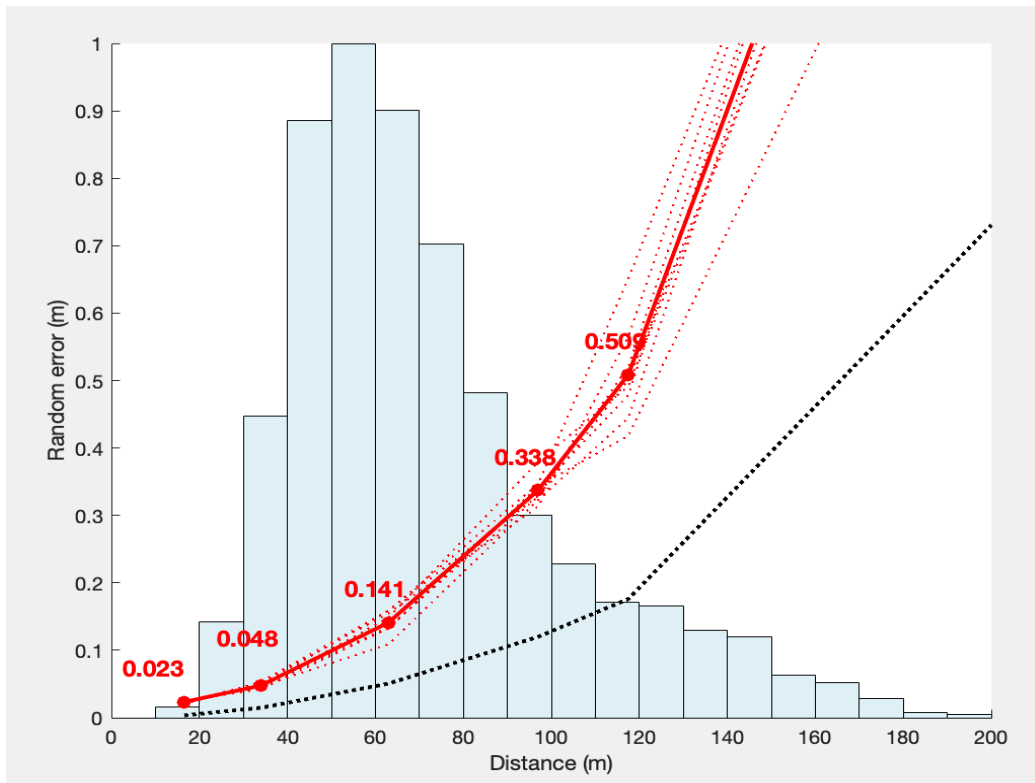


Figure S3: Random error in 3D location reconstruction, as a function of distance from the RSV device.

Red dots: mean error for calibration points. Red dotted lines: error for individual calibrations. Black dotted line: theoretical random error (from 3D space quantization only – see Methods section and de Margerie et al. (2015) for additional sources of error). The background histogram shows the distance distribution for all sampled bird locations.

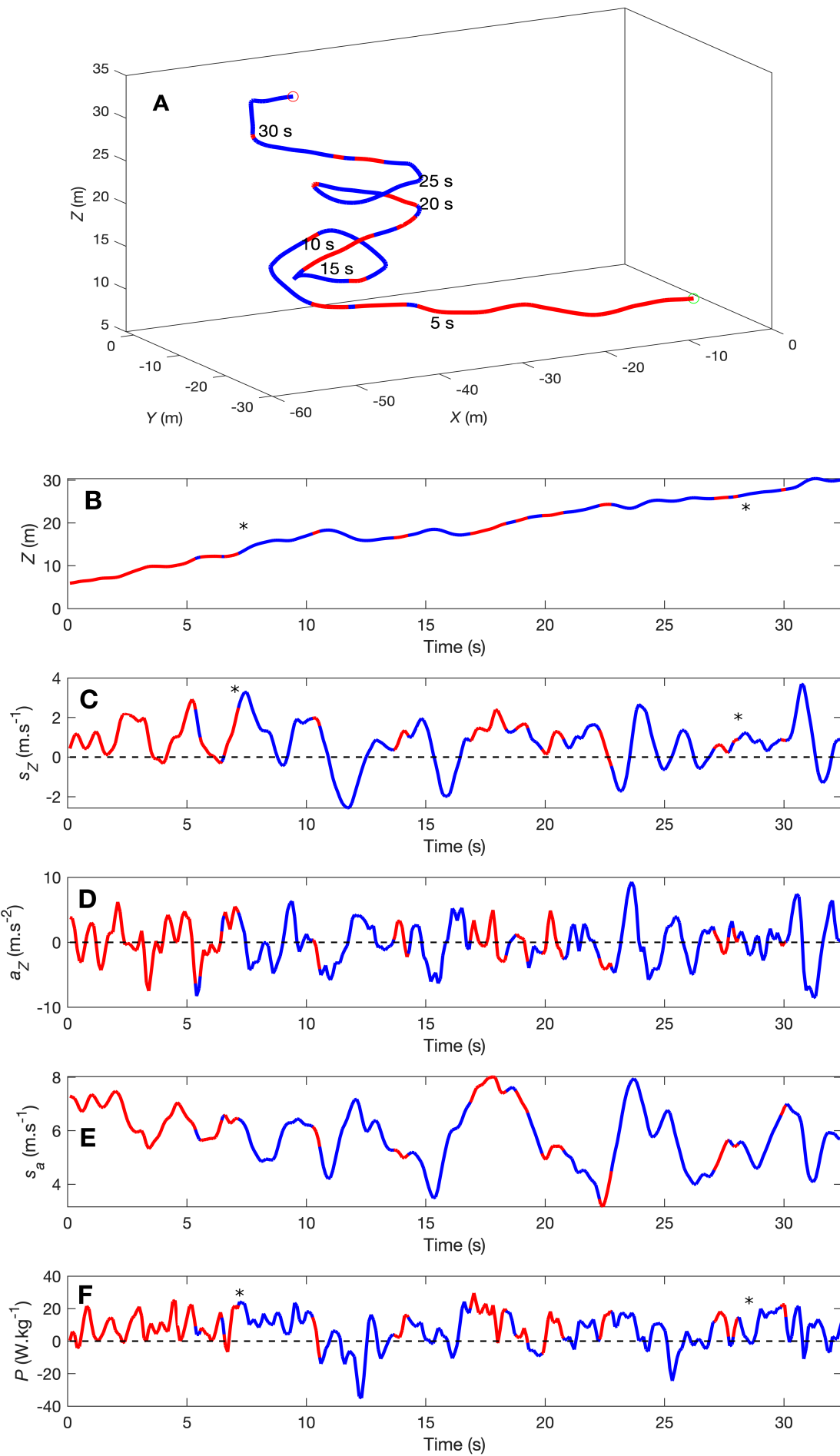


Figure S4: 3D view of a house martin's trajectory exhibiting thermal soaring, along with several biomechanical variables versus time. On all panels, gliding is represented by blue segments, flapping by red segments, and undetermined behaviours by black thin segments (wing movement not visible on video record). (A) 3D view of the trajectory with temporal indications every 5 s. (B) Height (Z) versus time. (C) Vertical speed (s_z) versus time. (D) Vertical acceleration (a_z) versus time. (E) Airspeed (s_a) versus time. (F) Mass-specific power (P) versus time. Asterisks indicate specific moments described in the text.

Figure S4 shows the 3D view of a trajectory where thermal soaring is apparent. Indeed, several sequences show positive vertical speeds (Fig. S4C) with positive powers (Fig. S4F) while the bird is gliding, for example between 7 and 10 s, or between 28 and 30 s. Each time, the gliding bird is gaining a few meters in altitude (Fig. S4B).

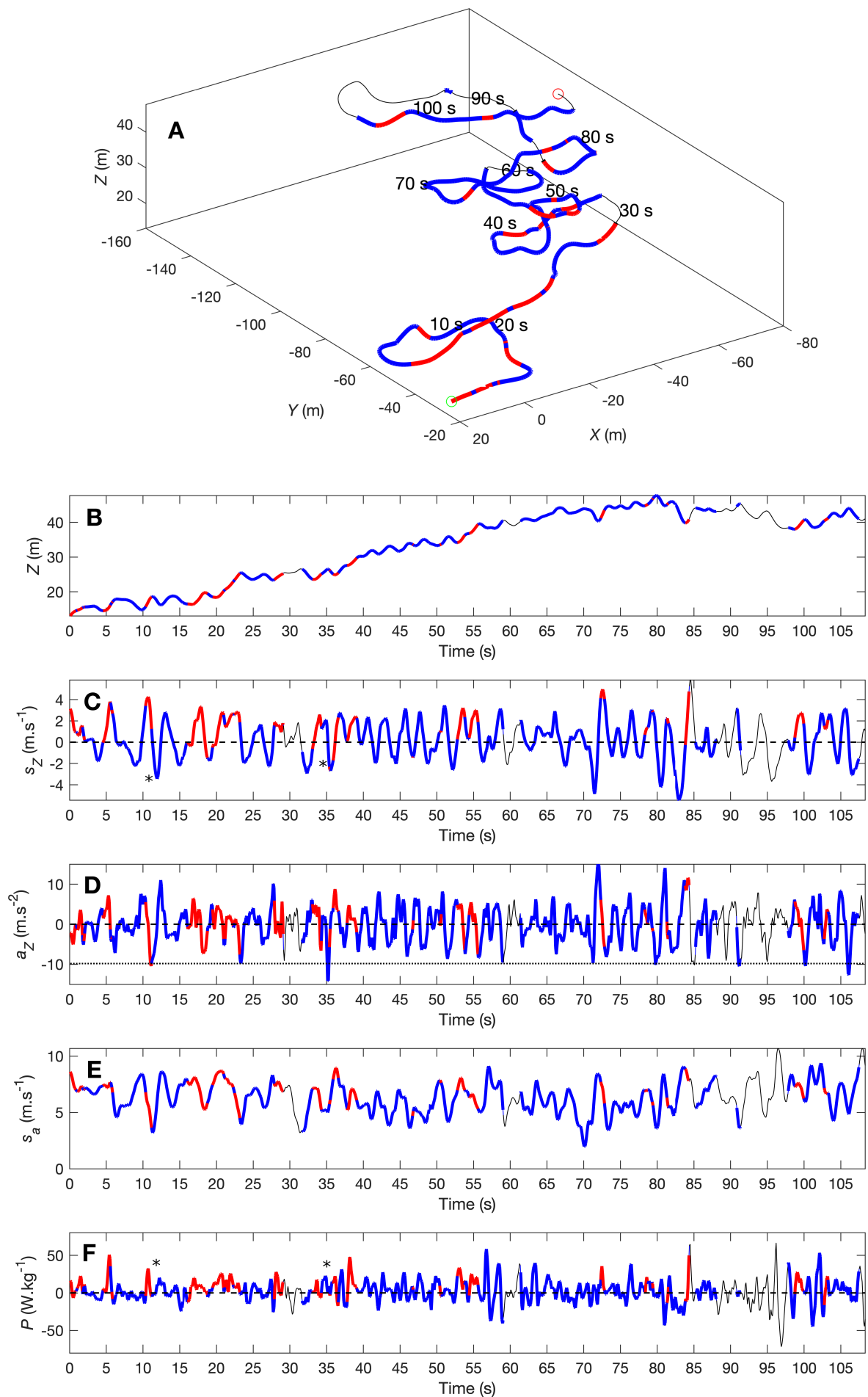


Figure S5: 3D view of a house martin's trajectory exhibiting temporal oscillations in vertical speed and gliding descents with positive power values, along with several biomechanical variables versus time. On all panels, gliding is represented by blue segments, flapping by red segments, and undetermined behaviours by black thin segments (wing movement not visible on video record). (A) 3D view of the trajectory with temporal indications every 5 s. (B) Height (Z) versus time. (C) Vertical speed (s_z) versus time. (D) Vertical acceleration (a_z) versus time. (E) Airspeed (s_a) versus time. (F) Mass-specific power (P) versus time. Asterisks indicate specific moments described in the text.

Figure S5 shows the 3D view of a trajectory where several phenomena are visible. Firstly, vertical speed (Fig S5C) shows temporal oscillations, mostly between -2 and $2 \text{ m}\cdot\text{s}^{-1}$. While the bird is mostly gliding, it is alternatively ascending and descending, again probably using external energy sources as $P > 0$ during gliding is often observed (Fig. S5F). Vertical acceleration (Fig. S5D) shows negative values that are regularly close to -1 g ($-9.81 \text{ m}\cdot\text{s}^{-2}$) which is observed for an object in free fall. Thus, this suggests that the bird is alternating sequences of ascensions and free falls while gliding. Besides, another phenomenon is visible on this trajectory: some birds have a positive power during gliding descents (e.g. at 11 s or at 35 s), which means that it is accelerating more than what its altitude loss would imply. This could be due to downward wind gusts.

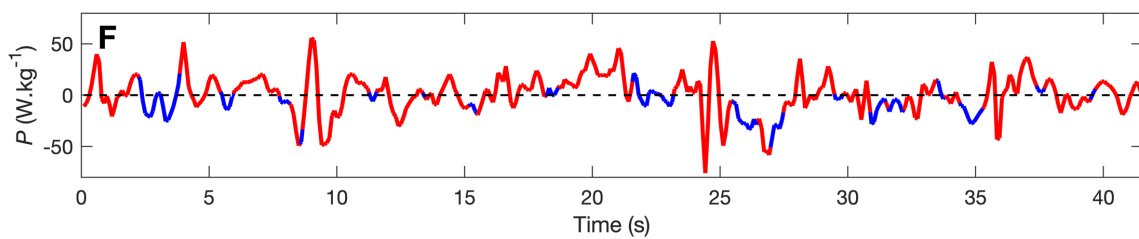
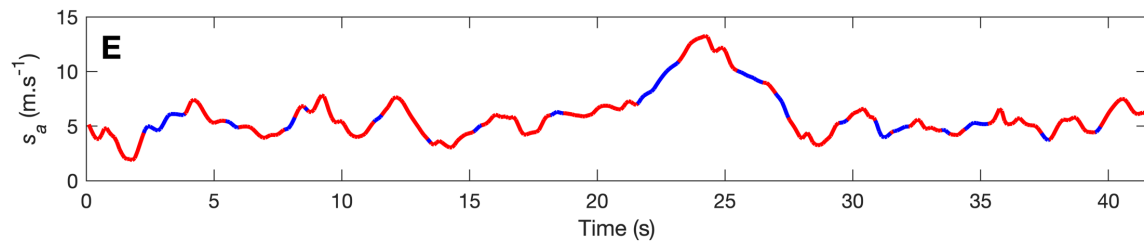
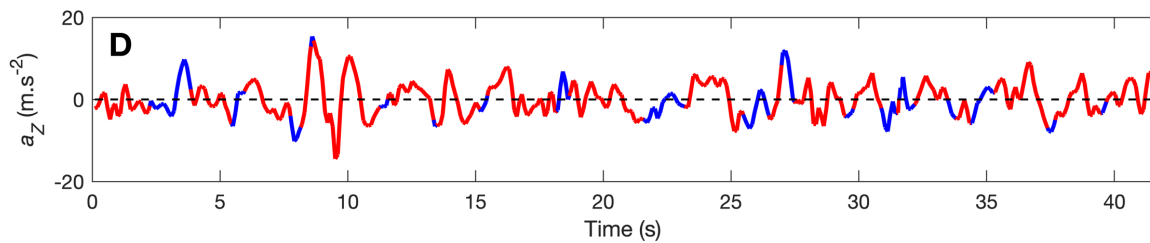
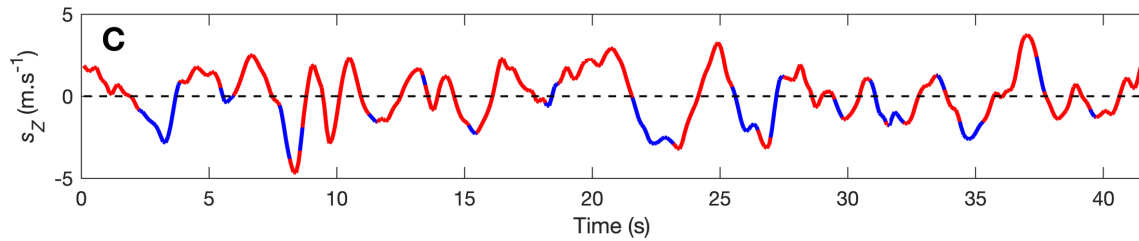
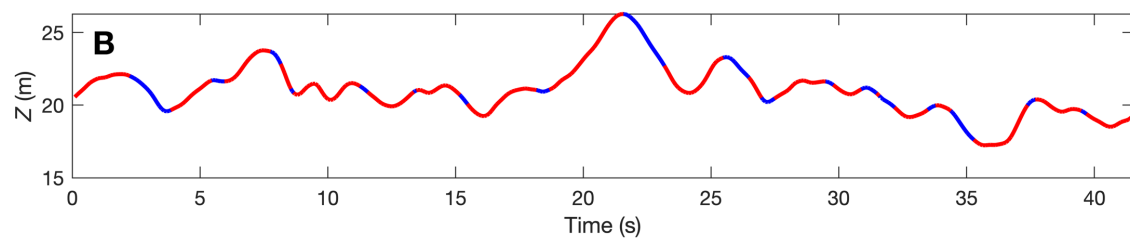
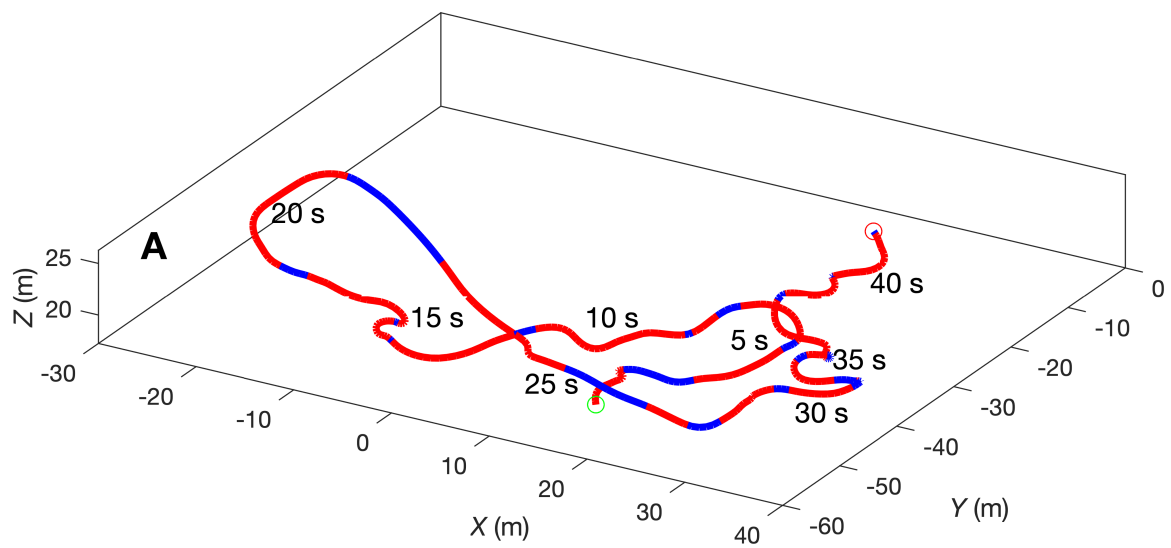


Figure S6: 3D view of a house martin's trajectory exhibiting flapping descents negative power values, along with several biomechanical variables versus time. On all panels, gliding is represented by blue segments, flapping by red segments, and undetermined behaviours by black thin segments (wing movement not visible on video record). (A) 3D view of the trajectory with temporal indications every 5 s. (B) Height (Z) versus time. (C) Vertical speed (s_z) versus time. (D) Vertical acceleration (a_z) versus time. (E) Airspeed (s_a) versus time. (F) Mass-specific power (P) versus time.

Figure S6 shows the 3D view of a trajectory where the bird, contrary to previous examples, does not seem to use thermal updrafts, performs most ascents with active flapping, and gliding is limited to descent (Fig. S6B). In fact, this bird shows a peculiar behaviour: mechanically efficient flapping should be associated with positive mechanical power (as is the case in previous examples, see Fig. S4F and Fig. S5F where red bouts are mostly above zero power), but here the bird often used flapping flight during descents (red bouts below 0 in Fig. S6C), sometimes resulting in negative power (fig. S6F). Although surprising, it is possible that house martins can use active flapping to generate adverse forces used for braking or to perform a sharp turn (e.g. for prey capture), or even for a purpose other than transport (e.g. in-flight preening).

Table S1: Sensitivity analysis for smoothing tolerance.

The results of the main statistical tests carried out in our analyses are presented for the three values of smoothing tolerance considered. The value of 1.2 was used in our final analyses. Overall, the significance of results is not influenced by smoothing tolerance.

Statistical test	Statistical test	Smoothing tolerance		
		1.0	1.2	1.4
s_z glide vs flap	t-test	$t(9561) = -37.09$ p < 0.001 ***	$t(9561) = -37.22$ p < 0.001 ***	$t(9561) = -37.33$ p < 0.001 ***
s_{ha} glide vs flap	t-test	$t(9561) = -12.79$ p < 0.001 ***	$t(9561) = -12.94$ p < 0.001 ***	$t(9561) = -12.95$ p < 0.001 ***
P_{p1s} glide vs flap	t-test	$t(2703) = -34.40$ p < 0.001 ***	$t(2703) = -34.43$ p < 0.001 ***	$t(2703) = -34.48$ p < 0.001 ***
P_{k1s} glide vs flap	t-test	$t(2703) = 2.07$ p = 0.039 *	$t(2703) = 2.38$ p = 0.018 *	$t(2703) = 2.61$ p = 0.009 **
s_a glide vs flap	t-test	$t(9561) = -13.08$ p < 0.001 ***	$t(9561) = -13.25$ p < 0.001 ***	$t(9561) = -13.27$ p < 0.001 ***
$\log_{10}(R)$ glide vs flap	t-test	$t(9561) = -12.89$ p < 0.001 ***	$t(9561) = -13.19$ p < 0.001 ***	$t(9561) = -13.24$ p < 0.001 ***
F glide vs flap	t-test	$t(9561) = 4.87$ p < 0.001 ***	$t(9561) = 5.70$ p < 0.001 ***	$t(9561) = 6.17$ p < 0.001 ***
Gliding s_a , downwind (DW) vs crosswind (CW) vs upwind (UW)	ANOVA	p = 0.499 NS	p = 0.872 NS	p = 0.529 NS
Flapping s_a , DW vs CW vs UW	ANOVA	p < 0.001 ***	p < 0.001 ***	p < 0.001 ***
Flapping s_a , Pairwise comparisons	Tukey post-hoc test	DW vs CW: p = 0.2239 NS DW vs UW: p < 0.001 *** CW vs UW: p = 0.0365 *	DW vs CW: p = 0.2622 NS DW vs UW: p < 0.001 *** CW vs UW: p = 0.0355 *	DW vs CW: p = 0.2766 NS DW vs UW: p < 0.001 *** CW vs UW: p = 0.0317 *
s_a vs s_w , gliding	linear model	DW: y = -0.534x p = 0.014 * CW: y = 0.005x p = 0.982 NS UW: y = 0.830x p < 0.001 ***	DW: y = -0.540x p = 0.014 * CW: y = 0.002x p = 0.991 NS UW: y = 0.827x p < 0.001 ***	DW: y = -0.542x p = 0.014 * CW: y = -0.004x p = 0.985 NS UW: y = 0.817x p < 0.001 ***
s_a vs s_w , flapping	linear model	DW: y = -0.410x p = 0.078 NS CW: y = -0.310x p = 0.149 NS UW: y = 0.672x p = 0.003 **	DW: y = -0.410x p = 0.072 NS CW: y = -0.312x p = 0.139 NS UW: y = 0.682x p = 0.003 **	DW: y = -0.411x p = 0.070 NS CW: y = -0.316x p = 0.138 NS UW: y = 0.699x p = 0.002 **
s_z vs weather variables, gliding	linear model	Temperature: y = 0.027x p = 0.001 ** Solar rad.: y = 0.001x p < 0.001 *** Humidity: y = -0.008x p = 0.002 **	Temperature: y = 0.027x p = 0.001 ** Solar rad.: y = 0.001x p < 0.001 *** Humidity: y = -0.008x p = 0.002 **	Temperature: y = 0.027x p = 0.001 ** Solar rad.: y = 0.001x p < 0.001 *** Humidity: y = -0.008x p = 0.002 **
s_z vs weather variables, flapping	linear model	Temperature: y = -0.013x p = 0.155 NS Solar rad.: y = -0.000x p = 0.818 NS Humidity: y = -0.001x p = 0.711 NS	Temperature: y = -0.013x p = 0.150 NS Solar rad.: y = -0.000x p = 0.842 NS Humidity: y = -0.001x p = 0.691 NS	Temperature: y = -0.013x p = 0.159 NS Solar rad.: y = -0.000x p = 0.855 NS Humidity: y = -0.001x p = 0.685 NS

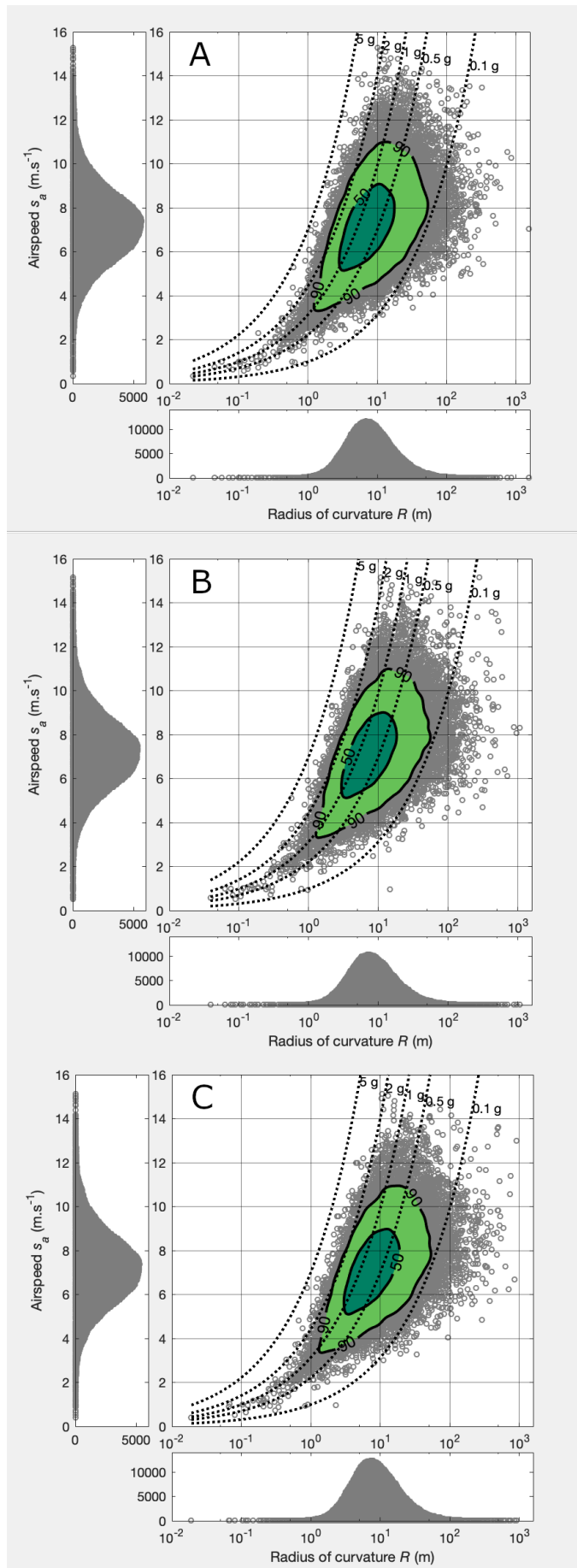


Figure S7: Example of the minor influence of smoothing tolerance on the graphical results: distribution of airspeed (s_a) versus instantaneous radius of curvature (R). Three values of smoothing tolerance were tested: (A) 1.0, (B) 1.2 and (C) 1.4.