Advanced Grant

Gliding
Stability and manoeuvrability

Authors:
Ernesto Sánchez-Laulhé
José Ángel Acosta
Ramón Fernández Feria

ICUAS 2020

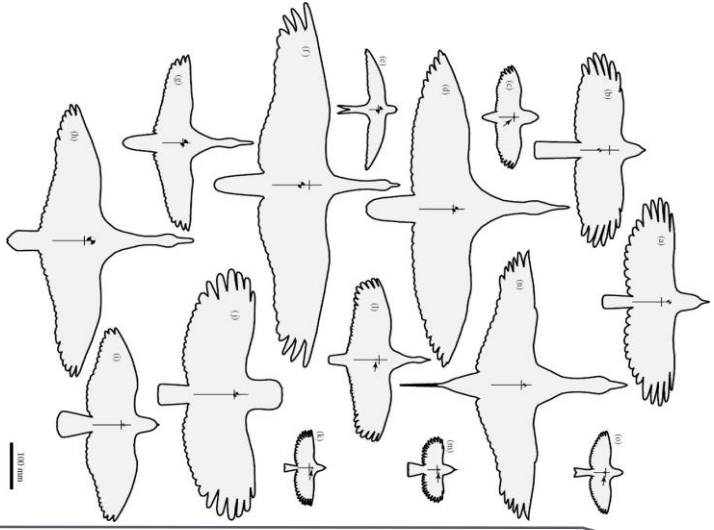
- Updated non-linear model
- Gliding linearization
- Free-response of the ornithopter
- Stability modes

Additional work presented in February

- Transference function for the trajectory angle from the tail deflection
- Simplification of phugoid mode
- Simplification of short period modes
- Simplification of the zeros of the system

Work in progress

- Analysis of birds: extend the study to biological data in order to apply it for ornithopter design
- Thomas & Taylor, 2001, *Animal Flight Dynamics I. Stability in Gliding Flight*



Data collection

- Geometrics from the article of Thomas and Taylor: Aspect ratio, surface relation, centre of gravity and aerodynamics centres
- Sizing: mass of the specimens unknown
- Contact with Mr. Graham Taylor: Information of mass and size of specimens of diverse species. Also other information (wingbeat frequency, flight speed,…)
- Solution: platform of the specimens in the article, scaled with the data provided by Mr. Taylor
- Inertia: difficulties to obtain real data. Assumed by simplifications of wing, body and tail mass distributions
- Some extra assumptions: Dihedral angle, wing aerodynamic centre above the centre of gravity. It has effects on stability

Birds information used

	General		Wing						Tail					
species	m(kg)	Iy (Kg/m^2)	b(m)	AR	c(m)	S(m^2)	lw(m)	hw(m)	Lambda	AR	S(m^2)	b(m)	c(m)	lt(m)
jackdaw Corvus monedula	0,245	0,003378	0,65	4,92	0,132	0,0859	-0,0270	0,0268	0,0382	0,4787	0,0033	0,0396	0,0828	-0,2012
sparrowhawk Accipiter nisus	0,277	0,003188	0,67	4,36	0,153	0,1028	0,0370	0,0276	0,0822	0,512	0,0085	0,0658	0,1285	-0,2121
quail Coturnix coturnix	0,096	0,000106	0,37	4,20	0,088	0,0326	0,0011	0,0152	0,0366	1,7391	0,0012	0,0456	0,0262	-0,1258
eider Somateria mollissima	2,015	0,010344	0,98	6,54	0,149	0,1468	-0,0086	0,0404	0,0726	0,7005	0,0107	0,0864	0,1233	-0,2492
swift Apus apus	0,038	8,744E-05	0,4	7,91	0,051	0,0202	-0,0042	0,0165	0,0948	0,3912	0,0019	0,0274	0,0700	-0,1199
red-breasted-Goose Branta ruficollis	1	0,007334	1,17	6,88	0,170	0,1991	0,0288	0,0482	0,0465	0,6447	0,0093	0,0773	0,1199	-0,2565
hooded merganser Mergus cucullatus	0,61	0,001796	0,56	5,55	0,101	0,0571	-0,0057	0,0232	0,0832	0,8288	0,0048	0,0628	0,0757	-0,1935
mallard Anas platyrhynchos	1,082	0,011992	0,88	5,79	0,152	0,1337	-0,0239	0,0362	0,0430	0,8043	0,0057	0,0680	0,0845	-0,2640
stock dove Columba oenas	0,295	0,001754	0,75	4,75	0,158	0,1183	-0,0109	0,0309	0,0906	1,0757	0,0107	0,1074	0,0998	-0,2428
tawny owl Strix aluco	0,418	0,003414	0,95	4,26	0,223	0,2117	-0,0064	0,0391	0,0408	0,8511	0,0086	0,0857	0,1007	-0,2836
chaffinch Fringilla coelebs	0,022	0,000238	0,26	3,44	0,075	0,0196	-0,0154	0,0107	0,0479	1,3803	0,0009	0,0360	0,0261	-0,1250
moorhen Gallinula chloropus	0,265	0,000799	0,559	4,39	0,127	0,0712	0,0119	0,0230	0,0275	1,2626	0,0020	0,0497	0,0394	-0,1778
robin Erithacus rubecula	0,017	6,476E-05	0,21	4,27	0,049	0,0103	-0,0058	0,0087	0,1707	1,4444	0,0018	0,0505	0,0350	-0,1009
pintail Anas acuta	1,024	0,006673	0,9	6,16	0,146	0,1314	-0,0132	0,0370	0,0456	1,3157	0,0060	0,0888	0,0675	-0,2721
greenfinch Carduelis chloris	0,028	8,832E-05	0,25	3,97	0,063	0,0157	-0,0061	0,0103	0,0714	0,8427	0,0011	0,0308	0,0365	-0,1007

Model Assumptions

- Very thin airfoil theory
- Prandtl's lifting line theory
- Induced drag from elliptical wing
- Tail: low aspect ratio wing
- Friction drag similar for all specimens
- Same Lighthill number for all the specimens
- Same downwash for all the specimens

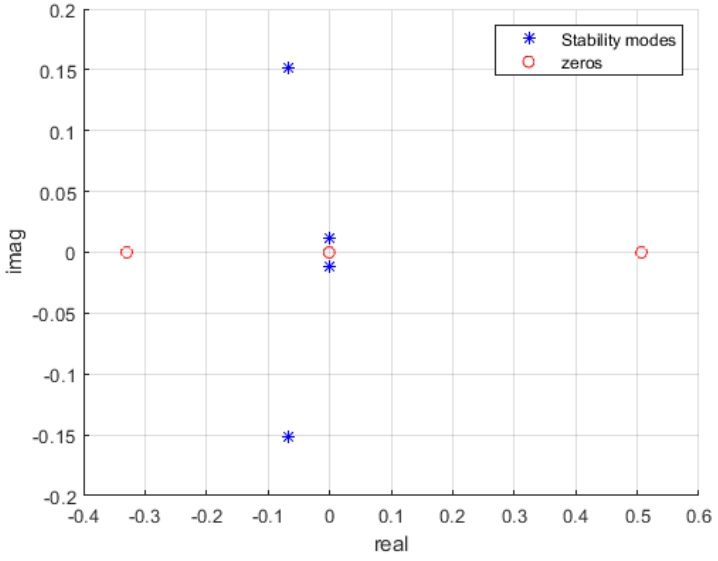
Trimming condition

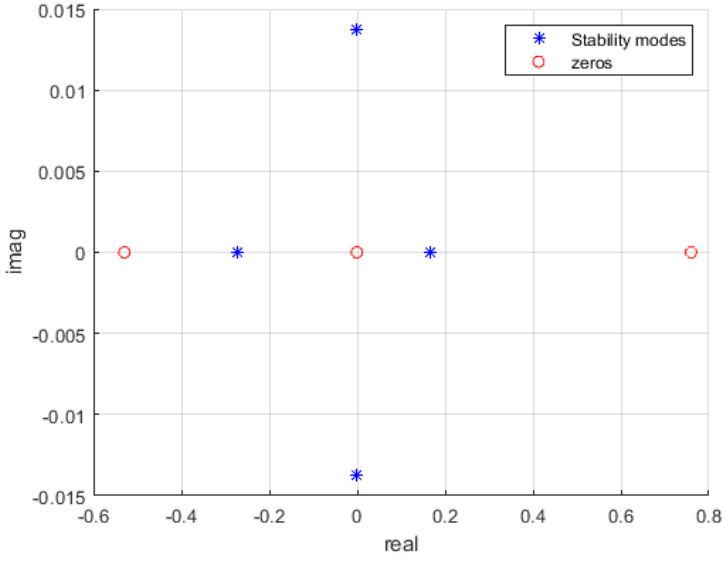
- Similar condition for all the birds
- Angle of attack around 4^o for all the specimens
- Not necessarily the optimum gliding condition
  - This optimum would be different for each specimen
  - Different conditions between birds difficult the comparision
- Control variables in order to trim:
  - Tail deflection
  - C_{M_0}: Control by twisting in the wings
- Ideally, tail deflection would be the only control variable
- Lack of control by the tail. Necessary to use the other condition. Does not affect the linearization, just the steady condition

Linearization coefficients

species	CXVP	CZGP	CZTP	CMGP	CMQP	CXV	CXG	CXT	CZV	CZG	CZQ	CZT	CMG	CMQ	CXDT	CZDT	CMDT
jackdaw Corvus monedula	70,506	138,756	-12,113	-0,0246	1	-0,1082	-0,4204	-0,5749	1,1082	-14,5747	3,4397	14,4775	0,0300	-0,0086	0,0036	0,0927	-0,0013
sparrowhawk Accipiter nisus	57,297	114,871	-11,805	0,0430	1	-0,1149	-0,3675	-0,6272	1,1059	-14,1951	-3,4084	14,0918	-0,0520	-0,0233	-0,0290	0,2139	-0,0053
quail Coturnix coturnix	109,046	213,624	-12,076	-0,0124	1	-0,1119	-0,3526	-0,6420	1,0763	-14,8807	0,3246	14,7773	0,0126	-0,0243	-0,0014	0,3420	-0,0158
eider Somateria mollissima	299,385	531,272	-12,711	-0,0095	1	-0,1044	-0,5318	-0,4641	1,1499	-14,6961	1,4223	14,6057	0,0112	-0,0061	0,0092	0,2397	-0,0029
swift Apus apus	121,350	217,761	-12,851	-0,0078	1	-0,1017	-0,5961	-0,4002	1,1801	-14,5024	1,8781	14,4165	0,0092	-0,0057	0,0063	0,1661	-0,0018
red-breasted-Goose Branta ruficollis	96,390	176,685	-12,555	0,0342	1	-0,1008	-0,5445	-0,4518	1,1702	-14,2969	-2,5603	14,2111	-0,0369	-0,0160	-0,0126	0,1365	-0,0042
hooded merganser Mergus cucullatus	343,662	625,908	-12,655	-0,0073	1	-0,1095	-0,4705	-0,5247	1,1154	-15,0493	1,6645	14,9516	0,0083	-0,0075	0,0135	0,3448	-0,0033
mallard Anas platyrhynchos	173,975	318,653	-12,473	-0,0143	1	-0,1049	-0,4858	-0,5099	1,1316	-14,6763	2,9176	14,5840	0,0170	-0,0061	0,0065	0,1682	-0,0017
stock dove Columba oenas	51,605	106,450	-12,496	-0,0666	1	-0,1143	-0,4077	-0,5869	1,0926	-15,1190	1,9760	15,0149	0,0753	-0,0572	0,0197	0,5073	-0,0315
tawny owl Strix aluco	28,931	64,743	-11,873	-0,0705	1	-0,1123	-0,3599	-0,6349	1,0886	-14,5125	0,7044	14,4099	0,0860	-0,0358	0,0069	0,1820	-0,0242
chaffinch Fringilla coelebs	48,565	103,131	-11,542	-0,0157	1	-0,1191	-0,2635	-0,7302	1,0538	-14,5128	3,7166	14,4005	0,0190	-0,0094	0,0138	0,3692	-0,0033
moorhen Gallinula chloropus	95,539	185,425	-11,910	0,0210	1	-0,1100	-0,3711	-0,6239	1,0957	-14,4658	-1,1932	14,3659	-0,0257	-0,0142	-0,0165	0,1800	-0,0071
robin Erithacus rubecula	109,336	216,110	-13,003	-0,0109	1	-0,1255	-0,3628	-0,6304	1,0693	-15,8193	4,8371	15,7027	0,0115	-0,0183	0,0505	1,3368	-0,0079
pintail Anas acuta	174,180	318,801	-12,751	-0,0170	1	-0,1041	-0,5102	-0,4856	1,1335	-14,9404	2,1254	14,8489	0,0197	-0,0123	0,0114	0,2907	-0,0051
greenfinch Carduelis chloris	92,394	183,062	-11,878	-0,0115	1	-0,1169	-0,3288	-0,6653	1,0731	-14,6828	2,0758	14,5745	0,0136	-0,0072	0,0124	0,3247	-0,0035
PowerBird	13,699	34,848	-12,887	-0,2108	1	-0,1261	-0,2980	-0,6968	1,2412	-13,0829	2,0927	12,9818	0,0840	-1,0462	-0,1352	2,6364	-0,5020

Stability modes and Zeros





Stability modes and Zeros

	Phugoid		Short Period				Zeros		
Species	Real	Imag	Real	Imag	q	Alpha	Fast Possitive	Fast Negative	Slow
jackdaw Corvus monedula	-0,00091	0,01112	-0,0676	0,1513	0	0	0,5067	-0,3298	-0,00069
sparrowhawk Accipiter nisus	-0,00179	0,01376	0	0	-0,2728	0,16737	0,7597	-0,5298	-0,00092
quail Coturnix coturnix	-0,00061	0,00655	-0,0527	0,1037	0	0	1,1272	-0,5930	-0,00059
eider Somateria mollissima	-0,00025	0,0027	-0,0214	0,103	0	0	0,4912	-0,3364	-0,00021
swift Apus apus	-0,00044	0,00678	-0,0398	0,0856	0	0	0,4621	-0,3172	-0,00053
red-breasted-Goose Branta ruficollis	-0,00089	0,00866	0	0	-0,2181	0,1542	0,8746	-0,5459	-0,0006
hooded merganser Mergus cucullatus	-0,00023	0,00227	-0,0193	0,0891	0	0	0,4354	-0,3123	-0,00019
mallard Anas platyrhynchos	-0,00042	0,00459	-0,0328	0,124	0	0	0,4416	-0,3033	-0,00031
stock dove Columba oenas	-0,00138	0,0143	-0,1281	0,2378	0	0	1,3904	-0,6171	-0,00124
tawny owl Strix aluco	-0,00181	0,02547	-0,1585	0,2279	0	0	2,3454	-0,7818	-0,00207
chaffinch Fringilla coelebs	-0,00085	0,01515	-0,0821	0,1037	0	0	0,3901	-0,2812	-0,00102
moorhen Gallinula chloropus	-0,001	0,00823	0	0	-0,1924	0,12078	1,0142	-0,5842	-0,00063
robin Erithacus rubecula	-0,00068	0,00661	-0,0506	0,0961	0	0	0,3260	-0,2504	-0,00065
pintail Anas acuta	-0,00042	0,00455	-0,0376	0,1339	0	0	0,6168	-0,3875	-0,00035
greenfinch Carduelis chloris	-0,00073	0,00811	-0,0489	0,1033	0	0	0,4507	-0,3196	-0,00064
Powerbird	-0,00558	0,02167	0	0	-1,1626	-0,3773	2,5402	-0,9453	-0,00431

Conclusions

- 2 cases:
  - 3 unstable specimens. Expected as they were statically unstable. Two real modes (short period), one of them unstable. Complex mode (phugoid) stable
  - Other specimens: two complex modes, phugoid and short period, both stable.
- Zeros: Two fast, one stable and the other unstable. One slow and stable
- Phugoid and short period less separated than they are in the ornithopter
- Theoretical approximations:
  - Excellent results for the short period, allows to study it without considering the complete system
  - The damping of the phugoid has a certain error. Also the zeros
  - However, main trends are always considered

Differences with the ornithopter

- Weight: wing load of the birds considered is far superior to that of our ornithopter
- Inertia: Similar to the weight. Even though inertia from birds is estimated by certain approximations and is not necessarily accurate, for sure it is bigger than the inertia of the ornithopter due to the increasement of the weight
- Relative size: Different point of view, our ornithopter is much bigger than the birds for the same weight
- Aerodynamic damping, which affects mainly to the short period mode, are much bigger in the ornithopter
- This is amplified by size of the tail, much bigger than all the birds
- Tail size is justified by the lack of other control variables (twist of the wings)

Future work

- Conclusions of the analysis
- Experimental approach:
  - In order to complete the article
  - Yet to be defined
  - Variation of the centre of gravity, dihedral angle, position of the tail,…
  - Use of information from other experiments in order to adjust some coefficients to reality.
- Final structure of the article