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N.P.L. Aerofoil Catalogue and Bibliography

By

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N.P.L. Aerofoil Catalogue and Bibliography

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14th July, 1951

This report catalogues aerofoils which have been designed (or substantially modified) at the N.P.L. and which have been the subject of theoretical investigations, aircraft design studies or wind-tunnel tests. Within these limits it is intended to be complete, except that it excludes a number of wing sections designed expressly to the requirements of aircraft firms. A full Bibliography is appended. Detailed numerical data have been collected together elsewhere+.

The opportunity has been taken to assign to each aerofoil an NPL number which it is hoped will be quoted in any future reference to it. It is intended to continue this numbering with aerofoils designed subsequently.

The arrangement of the lists of aerofoils follows broadly the successive stages in the development of the design theory. Each list is prefaced with a brief indication of the family character of the aerofoils it contains.

Abbreviations

CAT	:	Compressed Air Tunnel, N.P.L.
Froude Tank	:	(Ship Division, N.P.L.)
HST	:	High Speed Tunnels, N.P.L.
Theor.	:	Theoretical results
4 ft. 7 ft. 9 x 7 13 x 9	}	Wind-tunnels, N.P.L.

LIST 1/

+N.P.L. Aerofoil Sections: Tabulated Details. N.P.L. Aero/211, (July 1951). Copies can be obtained on application to the Superintendent, Aerodynamics Division, National Physical Laboratory, Teddington.

LIST 1 - Existing Aerofoils to which Equations have been Fitted

These include approximations to P2040 (a 20 per cent thick Piercy aerofoil with its maximum thickness at 40 per cent chord from the leading edge), RAF 6, Clark Y, NACA 16 and a de Havilland high-speed propeller section.

NPL No.	Aerofoil	Thickness	Design C_L	References (A.R.C. Report numbers)
41	P2040	0.20	Symmetrical	Aircraft Engineering 11, 151 (1939) (Theor.); 4800, 8718 and 11084 (HST)
51	RAF 6 approx.	0.10	-	7780 (Theor.)
52		0.15	-	7780 (Theor.)
53	Clark Y approx.	0.06	-	6028 (Theor.); 9756 and R. & M.2058 (HST)
54		0.07	-	6028 and 6897 (Theor.); 7308, 9756 and 11191 (HST)
55		0.10	-	6028 (Theor.)
56		0.12	-	5804, 6028 and 6156 (Theor.)
57		0.15	-	6028 (Theor.); 11191 (HST)
58		0.25	-	6028 (Theor.)
59,60	de Havilland	0.07	-	6132 and 6897 (Theor.)
61,62	approx.	0.10	-	6132 (Theor.)
63	NACA 16 approx.	0.12	0	5804 (Theor.) } See 8863 (Theor.) for range of thickness and camber
64		0.07	0.3	6897 (Theor.)
65		0.07	0.5	6897 (Theor.)
66		0.07	0.6	6897 (Theor.)
67	NACA 16 approx.	0.04	0.35	7308 and 9756 (HST)
68		0.05	0.30	Tests in hand (HST)
69		0.06	0.22	9756 and 11191 (HST)
70	Propeller	0.06	0.55	10551 (HST): no results available
71	sections+	0.06	0.88	10551 (HST): no results available
72		0.065	0.30	Tests in hand (HST)
73		0.07	0.55	9756 and 11191 (HST)
74		0.10	0.22	9756 and 11084 (HST)
75		0.10	0.30	11114 and 13238 (HST)
76		0.10	0.55	9756 and 11084 (HST)
77		0.10	0.88	9756 and 11084 (HST)
78		0.15	0.22	11084 (HST)
79		0.15	0.55	11084 (HST)
80		0.15	0.88	11191 (HST)

LIST 2/

+These "NACA 16 propeller sections" comprise an approximation to the NACA 16 fairing, superposed on a logarithmic camber-line. In the notation used in the reports on these sections the third digit signifies the camber, and the fourth the thickness, according to the following arbitrary scheme:-

Code	:	1	2	3	4	5	6
Design C_L	:	0.22	0.55	0.88	0.35	-	-
Thickness (per cent)	:	7	10	14	4	6	15

For instance, NACA 16/15 is cambered to a design C_L of 0.22 and is 6 per cent thick.

NOTE: R. & M.2058 = ARC 6062 + 6528 + 7216 (HST: some CAT results are also included).

LIST 2 - EC, EQ, ECH and EQH Aerofoils

The shapes of these aerofoils were actually defined by algebraic formulae. In each case the fairing (half-thickness) comprises an elliptic forward portion and a cubic or quartic rear portion which, in the case of ECH and EQH, is replaced by a hyperbolic curve very near the trailing edge. The numbers following the letters indicate the maximum thickness and its chordwise position, followed by the value and position of the maximum camber (if any). For instance, the aerofoil EC 1250/0640 comprises a fairing with an elliptic nose and cubic rear portion, with maximum thickness 12 per cent of the chord occurring at 50 per cent chord from the leading edge; this fairing is superposed on a camber-line with maximum camber 0.6 per cent, occurring at 40 per cent chord.

NPL No.	Aerofoil	References
101	EC 1240	4726, 5272, 5862, 6532, 7026, 7615, 8041, 8682, 11084 and R. & M.2058 (HST)
102	EC 1240/0640	4708 (HST)*; 5035 and 5255 (CAT); 5862, 8682, 11084 and R. & M.2058 (HST)*
103	EC 1240/0658	8682, 11084 and R. & M.2058 (HST)
104	EC 1250	4978 (CAT); 5622, 6130, 6146, 6378, 6662, 6999, 7067, 7176, 7278, 7308, 7448, 8395, 8682, 10729, 11084 and R. & M.2058 (HST); 13906 (Flight)
105	EC 1250 with concave control	11933 and 12284 (HST). Further work in hand.
106	EC 1250 with wedge tail	10551 (HST): no results available. Trailing-edge angle 10.8°
107	EC 1250/0640	10551 (HST): no results available
108	EC 1250/1050	10551 (HST): no results available
'09	EC 1550	4978 (CAT); R. & M.2058 (HST); 8725 (Derivative measurements)
116	EQ 1550, hollow ground	8725 (Derivative measurements)
117	EQ 1550/1050	4978 (CAT)
121	E76CH 0747	7669 (Theor.)
122	E81CH 0748	7669 (Theor.)

126/

*More precisely, EC 1240/05_8 40

NOTE: R. & M.2058 = ARC 6062 + 6528 + 7216 (HST; some CAT results are also included).

NPL No.	Aerofoil	References
126	EQH 1240	5804 (Theor.)
127	EQH 0950/1050	5547+ (CAT)
128	EQH 1250	5804 (Theor.)
129	EQH 1250/0640	11084 and R. & M.2058 (HST)
130	EQH 1250/1050	5517* (CAT); 11084 and R. & M.2058 (HST)
131	EQH 1250/1550/	6676, 6785 and 6998 (13 x 9)
132	EQH 1250/4050	6156 (Theor.)
133	EQH 1260	5804 (Theor.); 5592 (Froude tank, 13 x 9 and 9 x 7)
134	EQH 1550	8682, 11084 and R. & M.2058 (HST)
135	EQH 1550/1058	4978≠ (CAT); 11084 and R. & M.2058 (HST)

+There mis-named EQ 0950/1050

*There mis-named EQ 1250/1050

/More precisely, EQH 12*50/1550 (i.e., t = 0.118)

≠There mis-named EQ 1550/1058

NOTE: R. & M.2058 = ARC 6062 + 6528 + 7216 (HST; some CAT results are also included)

LIST 3/

LIST 3 - "Roof-top" Aerofoils and Simple Camber-lines designed Aerodynamically

These include the first aerofoils designed, by Goldstein's approximate method, to have prescribed velocity distributions.

(a) Symmetrical "Roof-top" Aerofoils

Ref.: 6225 (Theor.)

Aerofoil	A	B	C	D	E	F	G	H
NPL No.	141	142	143	144	145	146	147	148

Ref.	J. Williams (Theor.)	8877 (Theor.) / 9748 (13 x 9)	7814 (Theor.)	7814 (Theor.)	13446 (13 x 9)
Aerofoil	8%	15%	18%	24%	33%*
NPL No.	149	150	151	152	153

See also NPL 282 (LIST 4)

(b) Camber-lines with g_i constant when $0 \leqslant x \leqslant X_1'$ and decreasing linearly thence to zero at the trailing edge+.

Report 8548 (Theor.) gives the relevant data for $X_1' = 0.25$, 0.30, 0.35, - - - - 0.95, 1. The camber-lines of the following two "roof-top" aerofoils are of this type:-

Aerofoil NPL 177 : "Roof-top" 1442/1547** of Reports 8682, 9585 and 13531 (HST)

Aerofoil NPL 178 : R 537 - 1515 of Report 10620 (Theor.)

(c)/

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*Tested with distributed suction over the region of adverse gradient.

+g_i denotes the first approximation to the super-velocity when $C_L = C_{Lopt}$, excluding the contribution due to the finite thickness of the aerofoil (C_{Lopt} being the lift coefficient at which the velocity over the camber-line alone is finite at the leading edge).

**Designated "H.S.4" at R.A.E. (Not to be confused with the HSA series of LIST 5.)

(c) Camber-lines for which g_i is constant (k) when $0 \leqslant x \leqslant X_1'$, then varies linearly to sk at X_2' and then linearly again to zero at the trailing edge.

Ref.: 8277 (Theor.). The following table numbers these camber-lines, regarded as aerofoils of zero thickness.

X_1'	X_2' \ s	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4
0.4	0.8	180	181	182	183	184	185	186	187	188
	0.9	189	190	191	192	193	194	195	196	197
	1.0	198	199	200	201	202	203	204	205	206
0.5	0.8	207	208	209	210	211	212	213	214	215
	0.9	216	217	218	219	220	221	222	223	224
	1.0	225	226	227	228	229	230	231	232	233
0.6	0.8	234	235	236	237	238	239	240	241	242
	0.9	243	244	245	246	247	248	249	250	251
	1.0	252	253	254	255	256	257	258	259	260

The camber-line of the following "roof-top" aerofoil is of this type:-

Aerofoil NPL 261 : Goldstein Reflex GR 1540/2037 of Reports 7209 and 11084 (HST)

LIST 4/

LIST 4 - Modified "Roof-top" Aerofoils

In the "MR" series, the figures following indicate (a) X_q, the designed chordwise position of peak velocity at zero lift, (b) the upper limit of the C_L-range of favourable gradients on both surfaces, (c) the value of C_{Lopt} (defining the camber), and (d) the aerofoil thickness. For example, MR 640-018 has the following properties: $X_q = 0.6$; upper limit of C_L-range = 0.40; $C_{Lopt} = 0$ (zero camber); 18 per cent thick.

NPL No.	Aerofoil	Reference
269	14.7% Goldstein	8140 (13 x 9)
270	MR 413-010	8532 (Theor.)
271	MR 424-015	
272	MR 450-020	
273	MR 513-010	
274	MR 523-015	
275	MR 525-015	
276	MR 546-020	
277	MR 613-010	
278	MR 622-015	
279	MR 645-021	
280	14.7% Watson	8941 (Theor.)
281	1541a	13039 (7 ft. No. 2)
282	1541*	
283	1541b	
284	1541c	
285	1541d	
290	RAE 102+, cusped	H. C. Garner
291	Cambered RAE 102+	-

LIST 5/

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*This was the basic ("Roof-top") section.

+See C.P. No. 80 for details of the RAE 102 aerofoil.

LIST 5 - Aerofoils designed by Approximate Method using Numerical Conjugation

"AN" signifies an aerofoil designed by approximate methods using numerical conjugation; "NAN" indicates that the aerofoil also employs a new stock camber-line. The numbers following these letters have the same significance as for the "MR" series. For instance, AN 420-109 has the following properties: $X_q = 0.4$; upper limit of C_L-range $= 0.20$; $C_{Lopt} = 0.1$; 9 per cent thick. Similarly, NAN 532-1415 has $X_q = 0.5$, upper limit of C_L-range $= 0.32$; $C_{Lopt} = 0.14$; 15 per cent thick. "HSA" signifies "high-speed aerofoil".

NPL No.	Aerofoil	Reference
301	AN 414-011	8659 (Theor.)
302	AN 528-015	8659 (Theor.)
303	AN 420-109	8942 (Theor.)
304	HSA I	9076 (Theor.)
305	HSA II	9076 (Theor.)
306	HSA III	9076 (Theor.)
308	HSA V*	9809 (Theor.); 11496 (4 ft. No. 2); 11560; 11758
309	HSA VI*	9809 (Theor.)
310	HSA VII	B. Thwaites (Theor.)
311	NAN 530-117	10620 (Theor.)
312	NAN 524-0412	10620 (Theor.)
313	NAN 532-1415	10620 (Theor.)
314	NAN 530-1413	10620 (Theor.)
315	NAN 540-1513	10620 (Theor.)
316	NAN 522-112	10620 (Theor.)
317	NAN 525-110	10620 (Theor.)
318	NAN 521-0411	10620 (Theor.)
319	NAN 545-1515	10620 (Theor.)
320	NPL 320	12154 (Theor.)
321	NPL 321	Forthcoming report on tunnel tests with distributed suction

LIST 6 - Low-drag Aerofoils designed by Lighthill's Exact Method

NPL No.	Aerofoil	Reference
331	19.6% Symmetrical	8597, Appendix I (Theor.)
332	13 % Symmetrical	8597, Appendix VI (Theor.) See also 8658
333	19.2% Symmetrical	8597, Appendix VII (Theor.)
334	14.1% Symmetrical	8597, Appendix X (Theor.)
335	13 % Symmetrical	13003 (13 x 9)
336	15 % Symmetrical	A. R. Curtis (Theor.)
337	15 % Symmetrical	A. R. Curtis (Theor.)

LIST 7/

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*Designed for use with distributed suction over the nose.

LIST 7 - Low-drag Slot-suction Aerofoils

(a) Designed by Goldstein's approximate method

NPL No.	Section	References
351	16%, cambered	8877 (Theor.)
352	A preliminary design	6784 (Shape only)
353	16% symmetrical Griffith	6784, 7178 and 7463 (4 ft. tunnel); 7561, 7464, 8054, 8055 and 9320 (13 x 9)
354	21% symmetrical Griffith	A. R. Curtis (Theor.)
355	22% symmetrical Griffith	10096 (HST)
356	30% symmetrical Griffith	8864, 9810, 10097, 10630 and 11599 (13 x 9); 11610 (Theor.)
357	30% symmetrical, multi-slot	11796, Aerofoil XIII (Theor.)
358	30%, cambered	J. Williams (Theor.)
359	33% symmetrical, multi-slot	11796, Aerofoil IX (Theor.)

(b) Designed by Lighthill's exact method

NPL No.	Section	References
361	70% symmetrical (Modified Joukowski)	8597, Appendix II (Theor.)
362	34% symmetrical	8597, Appendix IV (Theor.)
363	40% symmetrical	8719, Fig. 1 (Theor.)
364	48% symmetrical	8597, Appendix V (Theor.)
365	31% symmetrical (GLAT III)*	10933 (Theor.)
366	GLAT III with spread velocity drop	12999 (Theor.)
367	Stagnation-streamline modification of GLAT III	12999 (Theor.)
371	Bulrush I	A. R. Curtis (Theor.)
372	Bulrush II	A. R. Curtis (Theor.)
373	Bulrush III	A. R. Curtis (Theor.)
374	Bulrush IV	A. R. Curtis (Theor.)
375	Bulrush V	A. R. Curtis (Theor.)
376	Bulrush VI	A. R. Curtis (Theor.)
377	25% "Lobster-pot"	M. B. Glauert (Theor.); D. H. Heughan (Expt.)
379	30%, cambered	8597, Appendix XI (Theor.)
380	41%, cambered	8597, Appendix XIII (Theor.)
381	GLAS I*	9180 (Theor.)
382	GLAS II	9180, 10933 and 11610 (Theor.); 10854 and 11797 (13 x 9); 11269 (CAT)
383	GLAS III	9180 (Theor.)
384	GLAS IV	9180 (Theor.)
385	38%, cambered	12999 (Theor.)
386	Sink-slot modification of GLAS II	12999 (Theor.)
387	Sink-slot modification of NPL 385	12999 (Theor.)

LIST 8/

*"GLAS" indicates an aerofoil designed by Glauert using Lighthill's method, for use with suction at a single slot; a "GLAT" aerofoil employs two slots. GLAS III is an exception to this rule.

LIST 8 - Nose-slot Suction Aerofoils

These are thin aerofoils designed for high maximum lift.

NPL No.	Section	References
401	11 % symmetrical	8597, Appendix VIII (Theor.)
402	5.4%, bi-convex	8658 (Theor.)
403	8.6%, cambered	8658 (Theor.); 10506 (4 ft. No. 2); 11560
404	8.6%, round-nosed	10507 (4 ft. No. 2); 11560
405	13 %, cambered	8658 (Theor.)
406	14.2%, cambered	8658 (Theor.)
	8% symmetrical sections:-	
407	A1	12144 (Theor.)
408	A2	
409	A3	
410	A4	
411	A5	
412	A6	
413	B1	
414	C1	
415	D1	
416	D2	
417	E1	
	8% sections, cambered:-	
418	A2	12144 (Theor.)
419	A5	
420	D2	
421	E1	
431	D2/1	13090 (Theor.)
432	D2/2	
433	D2/3	
434	D2/4	

LIST 9 - Aerofoils designed for obtaining Lift Independently of Incidence

Ref.: 10294 (Theor.)

NPL No.	Section
451	34.23% (TFA III)*
452	20 % TFA
453	14.65% (TFA V)
454	CVA I+
455	CVA II

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*"TFA" denotes "Thwaites Flap Aerofoil".

+"CVA" denotes "Constant-velocity Aerofoil".

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[+]Actually EQH 1250/1050

[x]Actually EQH 0950/1050

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