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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 640

INTERFERENCE OF WING AND FUSELAGE FROM TESTS OF 18 COMBINATIONS IN THE N.A.C.A. VARIABLE-DENSITY TUNNEL

COMBINATIONS WITH SPLIT FLAPS

By Albert Sherman
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SUMMARY

As part of the wing-fuselage interference investigation in progress in the N.A.C.A. variable-density wind tunnel, the effects of various split-flap arrangements applied to wing-fuselage combinations were determined. Split flaps were found to exert their influence independently of the interference, and their effects on the aerodynamic characteristics of rectangular-airfoil combinations appeared to be more or less proportional to their exposed span lengths. The interference, moreover, showed the same character with the split flaps as without them.

INTRODUCTION

An extensive program of research is being conducted in the N.A.C.A. variable-density wind tunnel on the interference between wing and fuselage at large values of the Reynolds Number (references 1, 2, and 3). Reference 1 outlined the wing-fuselage interference program and presented the initial and basic parts thereof, comprising test results for 209 combinations that represented, to the widest practical extent, the most important parameters of combination, such as: wing position relative to the fuselage, wing shape, juncture shape, and fuselage shape. The investigation was subsequently continued mainly with regard to fuselage shape and comprised combinations with round, rectangular, triangular, elliptical, and airfoil-type fuselages.

The wide employment of split flaps in design indicated that information would be desirable concerning the interferences associated with wing-fuselage combinations having split flaps. Medium-camber or thick wing sections are known to be less affected by the interference of a fuselage than small-camber or moderately thick profiles (e.g., the N.A.C.A. 0012). In reference 3, moreover, it appeared that the effects of adding a split flap to a tapered wing having a thick section at the root were little influenced by the presence of a fuselage. In the phase of the investigation reported herein, therefore, various split-flap arrangements were added to wing-fuselage combinations having rectangular N.A.C.A. 0012 airfoils, and their effects, mainly with regard to the maximum lift, were determined. The descriptions in table V of the combinations tested indicate the scope of the experimental investigation.

MODELS AND TESTS

The wing models employed were rectangular 5- by 30-inch duralumin airfoils of N.A.C.A. 0012 (see reference 1), and N.A.C.A. 23012 (reference 4) profiles. The N.A.C.A. 0012 airfoil is "standard" as a critical airfoil for the wing-fuselage interference investigation. The N.A.C.A. 23012 was included to show the effect on the interference associated with the use of a more recent profile. These wings were combined only with the round fuselage (reference 1), which is an airship form of polished duralumin, 20.156 inches in length, having a fineness ratio of 5.86. The various flap arrangements were made of brass plate and had sharpened trailing edges. They were all 20 percent of the wing chord in width and had the deflections, span lengths, and span positions indicated in table V. The fillets were formed of smoothly finished plaster of paris as indicated in the third column of table V. Photographs of representative combinations are shown in figures 1 and 2.

The tests were performed in the variable-density wind tunnel (reference 5) at a test Reynolds Number of approximately 3,100,000 (effective R = 8,200,000). In addition, values of the maximum lift coefficient were obtained at a reduced speed corresponding to a test Reynolds Number of approximately 1,400,000 (effective R = 3,700,000). The testing procedure and test precision, which are practically the same as for an airfoil alone, are fully described in reference 1. Since the tests of reference 1 were made, a small additional correction of less than -1 percent has been applied to the measurement of the dynamic pressure q to improve the precision of the results.

RESULTS

The test data are given in the same manner as in reference 1, in which the methods of analysis and of presentation of the results are fully discussed.

As in the preceding reports of the interference program (references 1, 2, and 3), the test results are given in tables supplemented by figures. Table I contains the characteristics of the wings alone and table II, those of the fuselage. Table III presents the sums of the fuselage characteristics and the interferences at various angles of attack for each of the combinations tested. The values given represent the differences between the characteristics of each combination and those of the wing alone or of the wing with a full-span split flap. Thus, for convenience, the effects of reductions in the flap span or of changes in the flap shape are included in the interference of the fuselage. Obviously, the characteristics of the combinations themselves can, if desired, be obtained by adding corresponding items in tables I and III. Table IV of the program (see reference 1), which presents interference data for disconnected combinations, is not continued herein because no additional combinations of this character were investigated.

Table V contains the combination diagrams and descriptions in addition to the principal aerodynamic characteristics of the combinations. The values d/c and k/c represent the longitudinal and vertical displacements, respectively, of the wing quarter-chord axis measured (in chord lengths) positive ahead of and above the quarter-length point of the fuselage axis; i_w is the angle of wing setting.

The last nine columns of the table present the following important characteristics as standard nondimensional coefficients based on the original wing areas of 150 square inches:

a, lift-curve slope (in degree measure) as determined in the low-coefficient range for an effective aspect ratio of 6.86. This value of the aspect ratio differs from the actual value for the models because the lift results are not otherwise corrected for tunnel-wall interference. For most of the combinations with split flaps, values averaged over the useful range of lift coefficient are given.

e, Oswald's airplane, or span, efficiency factor. (See reference 1.)

$C_{D_{e_{min}}}$, minimum effective profile-drag coefficient $\left(C_D - \frac{C_L{}^2}{\pi A}\right)_{min}$. For most of the combinations with split flaps, average values of the drag taken over the useful range of lift coefficient and accurate to within about 5 percent are given instead.

$C_{L_{opt}}$, optimum lift coefficient, i.e., the lift coefficient corresponding to $C_{D_{e_{min}}}$.

n_o, aerodynamic-center position indicating approximately the location of the aerodynamic center ahead of the wing quarter-chord axis as a fraction of the wing chord. Numerically n_o equals $\frac{dC_{m_{c/4}}}{dC_L}$ at zero lift.

C_{m_o}, pitching-moment coefficient at zero lift about the wing quarter-chord axis. For most of the combinations with split flaps, average values of the moment taken over the useful range of lift coefficient and accurate to within about 5 percent are given instead.

$C_{L_{ib}}$, lift coefficient at the interference burble, i.e., the value of the lift coefficient beyond which the air flow has a tendency to break down as indicated by an abnormal increase in the drag.

$C_{L_{max}}$, maximum lift coefficient given for two different values of the effective Reynolds Number. (See reference 1.) The turbulence factor employed in this report to obtain the effective R from the test R is 2.64.

As in reference 2, the values of the effective Reynolds Number differ somewhat from those given in reference 1 because of a later more accurate determination of the turbulence factor for the tunnel. The values of the effective Reynolds Number given in reference 1 are subject to correction by a factor of 1.1.

Figures 3 to 5 present the variation with angle of attack of the aerodynamic characteristics for certain combinations, grouped so as to illustrate the effects of variations in the interesting parameters of combination. Angle-of-attack plots are more effective than polars for showing the character of the lift-curve peaks and the lift-curve displacements produced by split flaps.

DISCUSSION

Full-span flaps.- The main effects upon the aerodynamic characteristics of an airfoil due to deflecting a split flap are: An increment is added to the maximum lift, the lift curve is displaced toward the negative angles, and large drag and negative pitching-moment increments are applied. When a deflected full-span split flap is added to a combination of a rectangular airfoil and a round fuselage, these results are apparently but little modified. The flaps act more or less independently of the interference, which shows a similar character for combinations with or without split flaps. The effects of the interference are most noticeable with respect to the interference burble and the maximum lift, because the action of the flap generally overshadows the effects on the other characteristics. Figure 3 illustrates the effect of the vertical position (with respect to the fuselage) of a flapped wing upon the interference. Definite interference effects on the drag, the pitching moment, and the lift-curve displacement can be seen that vary with wing position, but they are small compared with the results of adding a split flap and with the interference on the lift-curve peaks. It is interesting to note that the maximum lifts are affected in their absolute magnitude just as for combinations without split flaps (compare table V) and, moreover, that the interference burble for the midwing combinations with and without flaps occurs at approximately the same angle of attack. (See reference 1.) Likewise, different airfoil profiles show the same relative susceptibility to the interference burble when combined in the midwing position with flaps or without flaps. (Compare combinations with N.A.C.A. 0012 and N.A.C.A. 23012 rectangular airfoils in table V; and, also, compare combinations with tapered N.A.C.A. 0018-09 wing and elliptical fuselage in reference 3.) The N.A.C.A. 23012 profile (1.8 percent maximum camber, 15 percent back of the leading edge) was somewhat less susceptible than the N.A.C.A. 0012 (zero camber) as regards the interference burble. This result was to be expected from consideration of its mean-line shape. The addition of split flaps produced little change in this relationship.

Reduced-span flaps.- In practical applications, flaps of only partial span are often used to accommodate ordinary ailerons. The cost in maximum-lift increment for the rectangular wings is approximately proportional to the reduction in flap span, being more than proportional to the span reduction where the flap goes through the fuselage and less where it goes under the fuselage (table V). As shown in figure 4, the characteristics other than the maximum lift are similarly affected.

Cut-outs in flaps.- Also for practical reasons, gaps are often left in split flaps at the inner ends near the fuselage. Such cut-outs of fairly large size were investigated (table V). Figure 5 shows that the cost in maximum lift, although appreciable, may not be serious. (See also table V.)

The opposite of a flap cut-out, that is, a flap addition such as employed for an air brake on a low-wing combination (fig. 2), showed very little effect except on the drag (table V, combination 283).

Drag and pitching moment.- The split flaps had very large effects on both the effective profile drag and the pitching moment. These characteristics for the large-span flaps exhibited, however, a negligible variation with angle of attack over the useful range of lift. In table V, therefore, it was possible to give for this range average values that are accurate enough for most engineering uses. Further, drag and pitching-moment increments for various flap spans on rectangular wings could be taken as approximately proportional to the exposed span length of the flaps.

It may be concluded that split flaps on rectangular wings behave predictably and do not materially alter the wing-fuselage interference, particularly as regards the burble.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 9, 1938.

REFERENCES

1. Jacobs, Eastman N., and Ward, Kenneth E.: Interference of Wing and Fuselage from Tests of 209 Combinations in the N.A.C.A. Variable-Density Tunnel. T.R. No. 540, N.A.C.A., 1935.

2. Sherman, Albert: Interference of Wing and Fuselage from Tests of 28 Combinations in the N.A.C.A. Variable-Density Tunnel. T.R. No. 575, N.A.C.A., 1936.

3. Sherman, Albert: Interference of Wing and Fuselage from Tests of 30 Combinations in the N.A.C.A. Variable-Density Tunnel. Combinations with Triangular and Elliptical Fuselages. T.R. No. (to be published), N.A.C.A., 1938.

4. Jacobs, Eastman N., and Clay, William C.: Characteristics of the N.A.C.A. 23012 Airfoil from Tests in the Full-Scale and Variable-Density Tunnels. T.R. No. 530, N.A.C.A., 1935.

5. Jacobs, Eastman N., and Abbott, Ira H.: The N.A.C.A. Variable-Density Wind Tunnel. T.R. No. 416, N.A.C.A., 1932.

TABLE I - AIRFOIL CHARACTERISTICS

Airfoil	C_L	C_{D_e}	$C_{m_{c/4}}$	C_L	C_{D_e}	$C_{m_{c/4}}$	C_L	C_{D_e}	$C_{m_{c/4}}$
	$\alpha = 0^\circ$			$\alpha = 4^\circ$			$\alpha = 12^\circ$		
Rectangular N.A.C.A. 0012	0.000	0.0080	0.000	0.307	0.0087	0.003	0.920	0.0150	0.004
Rectangular N.A.C.A. 23012	.090	.0085	-.006	.400	.0095	-.004	1.025	.0161	-.007
Rectangular N.A.C.A. 0012 with 0.2c split flap deflected 60°	.975	.1718	-.204	1.268	.1736	-.207	1.819	.1755	-.213
Rectangular N.A.C.A. 23012 with 0.2c split flap deflected 60°	1.049	.1726	-.207	1.341	.1738	-.211	1.895	.1754	-.218
Rectangular N.A.C.A. 23012 with 0.2c split flap deflected 75°	1.109	.2093	-.199	1.389	.2095	-.201	1.909	.2095	-.205

TABLE II - FUSELAGE CHARACTERISTICS

Fuselage	Engine	C_L	C_D	[1]C_{m_F}	C_L	C_D	[1]C_{m_F}	C_L	C_D	[1]C_{m_F}	C_L	C_D	C_{m_F}	C_L	C_D	[1]C_{m_F}
		$\alpha = 0^\circ$			$\alpha = 4^\circ$			$\alpha = 8^\circ$			$\alpha = 12^\circ$			$\alpha = 16^\circ$		
Round	None	0.000	.0041	.000	.001	.0042	.016	.005	.0049	.028	.011	.0062	.035	.019	.0085	.038

[1] Pitching-moment coefficient about the quarter-chord point of the fuselage.

TABLE III - LIFT AND INTERFERENCE, DRAG AND INTERFERENCE, AND PITCHING MOMENT AND INTERFERENCE OF FUSELAGE IN WING-FUSELAGE COMBINATIONS

Combination	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$
	$\alpha = 0°$			$\alpha = 4°$			$\alpha = 12°$		
271	0.035	0.0045	-0.001	0.056	0.0048	0.000	0.096	0.0058	0.010
[1]272	-.024	-.0113	-.009	-.012	-.0102	-.006	.014	-.0070	.012
[1]273	-.121	-.0243	.019	-.106	-.0246	.023	-.073	-.0217	.040
[1]274	-.564	-.1077	.113	-.545	-.1100	.118	-.470	-.1105	.131
[1]275	-.655	-.1229	.144	-.626	-.1267	.153	-.540	-.1272	.168
[1]276	-.080	-.0105	.014	-.068	-.0102	.014	-.056	.0245	-.006
[1]277	-.100	-.0070	.033	-.083	-.0069	.039	-.051	.0209	.016
[1]278	-.633	-.1097	.146	-.602	-.1133	.154	-.519	-.1141	.165
279	-.037	.0046	-.001	-.015	.0049	.000	.013	.0059	-.005
[1]280	-.060	-.0017	.018	-.051	-.0013	.022	-.043	.0030	.025
[1]281	-.139	.0021	.034	-.130	.0035	.035	-.113	.0027	.037
[1]282	-.591	-.0954	.147	-.570	-.1007	.148	-.518	-.1046	.146
[1]283	-.474	-.0588	.134	-.457	-.0659	.133	-.406	-.0748	.120
284	-.015	.0031	-.004	.006	.0029	.003	.039	.0033	.014
[1]285	-.101	-.0079	.031	-.086	-.0073	.035	-.060	-.0055	.049
286	.010	.0032	-.002	.027	.0031	.002	.061	.0044	.013
[1]287	-.072	-.0110	.014	-.059	-.0114	.015	-.033	-.0055	.024
[1]288	-.089	-.0129	.020	-.081	-.0113	.020	-.051	-.0082	.026

[1] The values given represent the differences between the characteristics of each combination and those of the corresponding airfoil with full-span split flap.

TABLE V. - PRINCIPAL AERODYNAMIC CHARACTERISTICS OF WING-FUSELAGE COMBINATIONS

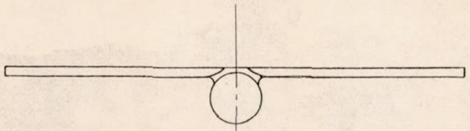
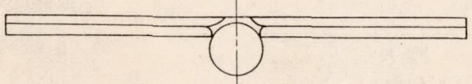
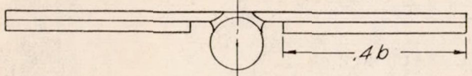
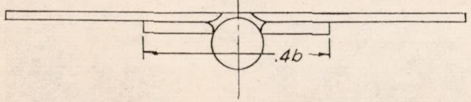
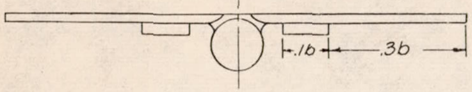
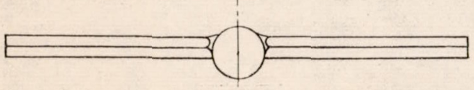
Diagrams representing combinations	Combination	Remarks	Longitudinal position d/c	Vertical position k/c	Angle of wing setting i_w (deg.)	Lift-curve slope (per degree) a $A=6.86$	Span efficiency factor e	$C_{D_{e_{min}}}$	$C_{L_{opt}}$	Aerodynamic-center position n_o	C_{m_o}	Lift coefficient at interference burble [1]$C_{L_{ib}}$	[2]$C_{L_{max}}$	
													Effective R = 8.2 x 10^6	Effective R = 3.7 x 10^6
Rectangular N.A.C.A. 0012 airfoil with round fuselage														
	-	Wing alone	-	-	-	0.077	0.85	0.0080	0.00	0.010	0.000	[A]1.5	[c]1.54	[c]1.39
	-	Wing alone with full-span split flap deflected 60°	-	-	-	.074	-	[7].17	-	-	[7]-.21	-	[c]2.20	[c]2.15
	271	With ordinary tapered fillets and plaster finish at junctures	0	0.34	0	.082	[4].85	.0125	.00	.015	-.001	[A]1.7	[c]1.71	[c]1.54
	272	Tapered fillets; plaster finish: 60° split flap	0	.34	0	[7].077	-	[7].16	-	-	[7]-.20	-	[c]2.33	[c]2.21
 .4b	273	Tapered fillets; plaster finish: 60° split flaps	0	.34	0	[7].078	-	[7].15	-	-	[7]-.18	-	[c]2.17	[c]2.13
 .4b	274	Tapered fillets; plaster finish: 60° split flap	0	.34	0	[7].078	-	.0632	.85	-	[7]-.09	[A]1.8	[c]1.87	[c]1.79
 .1b .3b	275	Tapered fillets; plaster finish: 60° split flaps	0	.34	0	.081	-	.0465	.85	.014	-.063	[A]1.8	[c]1.80	[c]1.77
	276	Tapered fillets; plaster finish: 60° split flap	0	.16	0	[7].079	-	[7].16	-	-	[7]-.19	-	[a]1.80	[b]1.83

TABLE V. (Cont.)

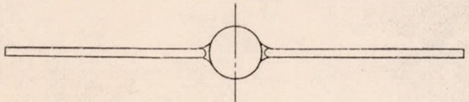
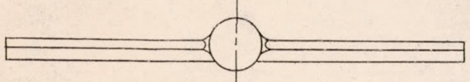
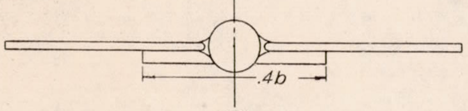
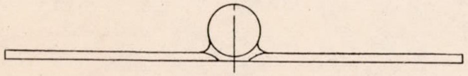
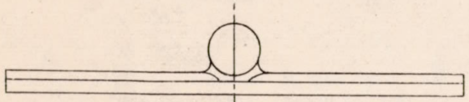
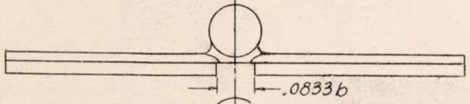
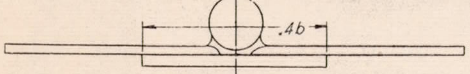
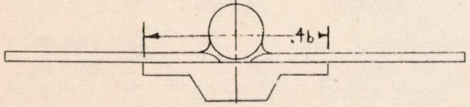
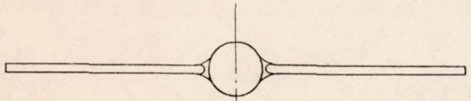
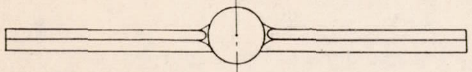
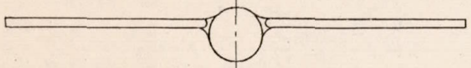
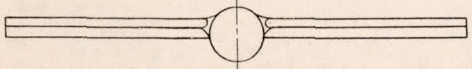
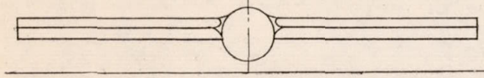
Diagrams representing combinations	Combination	Remarks	Longitudinal position d/c	Vertical position k/c	Angle of wing setting i_w (deg.)	Lift-curve slope (per degree) a $A = 6,86$	Span efficiency factor e	$C_{D_{e_{min}}}$	$C_{L_{opt}}$	Aerodynamic-center position n_o	C_{m_o}	Lift coefficient at interference burble $^1C_{L_{ib}}$	$^2C_{L_{max}}$ Effective $R = 8.2 \times 10^6$	$^2C_{L_{max}}$ Effective $R = 3.7 \times 10^6$
Rectangular N.A.C.A. 0012 airfoil with round fuselage														
	137	(From reference 1) Tapered fillets; plaster finish	0	0	0	.081	.85	.0115	.00	.030	.000	$^B1.0$	$^a1.23$	$^a1.22$
	277	Tapered fillets; plaster finish: 60° split flap	0	0	0	$^7.078$	-	$^7.17$	-	-	$^7-.17$	-	$^a1.80$	$^a1.80$
	278	Tapered fillets; plaster finish: 60° split flap	0	0	0	.081	-	.0590	1.02	.014	-.062	$^B1.3$	$^a1.40$	$^a1.40$
	279	Tapered fillets; plaster finish	0	-.34	0	.082	$^5.85$	.0126	.00	.018	-.001	$^A1.6$	$^c1.60$	$^c1.50$
	280	Tapered fillets; plaster finish: 60° split flap	0	-.34	0	$^7.076$	-	$^7.17$	-	-	$^7-.18$	-	$^c2.26$	$^c2.13$
	281	Tapered fillets: plaster finish: 60° split flap	0	-.34	0	$^7.077$	-	$^7.18$	-	-	$^7-.17$	-	$^c2.20$	$^c2.07$
	282	Tapered fillets plaster finish: 60° split flap	0	-.34	0	$^7.077$	-	.0706	1.20	-.004	-.056	$^A1.9$	$^c1.92$	$^c1.79$
	283	Tapered fillets; plaster finish: 60° split flap with addition to flap	0	-.34	0	$^7.078$	-	.1004	1.50	-.018	-.061	$^A1.9$	$^c1.96$	$^c1.83$

TABLE V. (Concl.)

Diagrams representing combinations	Combination	Remarks	Longitudinal position d/c	Vertical position k/c	Angle of wing setting i_w (deg.)	Lift curve slope (per degree) a $A = 6.86$	Span efficiency factor e	$C_{D_{e_{min}}}$	$C_{L_{opt}}$	Aerodynamic-center position n_o	C_{m_o}	Lift coefficient at interference burble $^{1}C_{L_{ib}}$	$^{2}C_{L_{max}}$ Effective $R = 8.2 \times 10^6$	$^{2}C_{L_{max}}$ Effective $R = 3.7 \times 10^6$
Rectangular N.A.C.A. 23012 airfoil with round fuselage														
	–	Wing alone	–	–	–	.078	$^{4}.85$	.0085	.12	.007	–.007	$^{A}1.6$	$^{c}1.61$	$^{c}1.43$
	–	Wing alone with full-span split flap deflected 60°	–	–	–	.074	–	$^{7}.17$	–	–	$^{7}-.21$	–	$^{c}2.32$	$^{c}2.24$
	–	Wing alone with full-span split flap deflected 75°	–	–	–	.068	–	$^{7}.21$	–	–	$^{7}-.20$	–	$^{c}2.37$	$^{c}2.25$
	284	Tapered fillets; plaster finish	0	0	0	.082	$^{5}.85$	.0117	.08	.024	–.011	$^{6}{}^{A}1.4$	$^{b}1.47$	$^{b}1.41$
	285	Tapered fillets; plaster finish: 60° split flap	0	0	0	$^{7}.079$	–	$^{7}.17$	–	–	$^{7}-.17$	–	$^{b}2.03$	$^{b}2.04$
	286	Tapered fillets plaster finish	0	.16	0	.082	$^{4}.85$	.0117	.14	.016	–.010	$^{A}1.5$	$^{b}1.56$	$^{b}1.48$
	287	Tapered fillets plaster finish: 60° split flap	0	.16	0	$^{7}.077$	–	$^{7}.16$	–	–	$^{7}-.19$	–	$^{c}2.10$	$^{c}2.11$
	288	Tapered fillets; plaster finish: 75° split flap	0	.16	0	$^{7}.076$	–	$^{7}.20$	–	–	$^{7}-.17$	–	$^{c}2.10$	$^{c}2.08$

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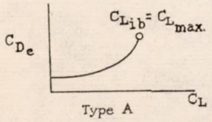
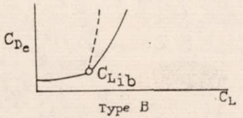
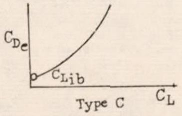
[1] Letters refer to types of drag curves associated with the interference burble as follows



Type A



Type B



Type C

[2] Letters refer to condition at maximum lift as follows: ^{a}reasonably steady at $C_{L_{max}}$; ^{b}small loss of lift beyond $C_{L_{max}}$; ^{c}large loss of lift beyond $C_{L_{max}}$ and uncertain value of $C_{L_{max}}$.

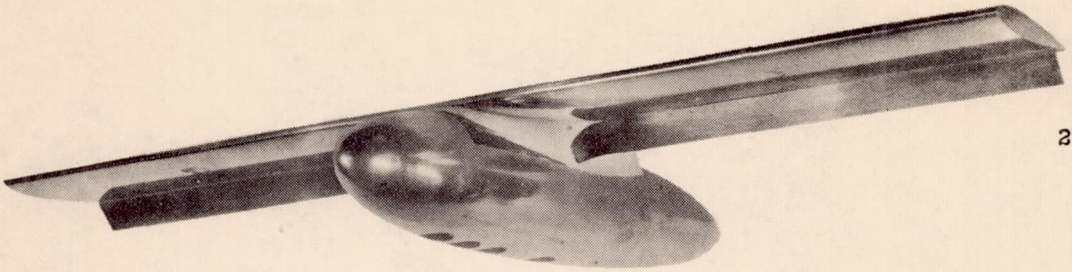
[3] Poor agreement in high-speed range.

[4] Poor agreement over whole range.

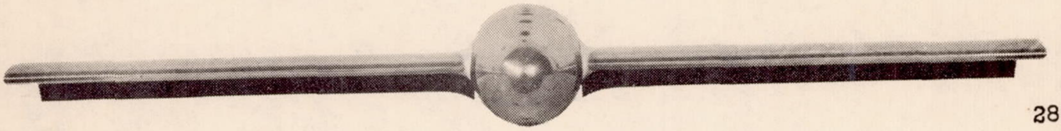
[5] Poor agreement in high-lift range.

[6] Rapid increase in drag preceding definite breakdown.

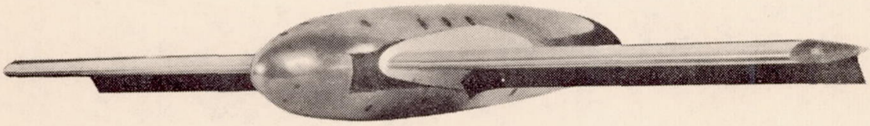
[7] Value that is averaged over useful range.



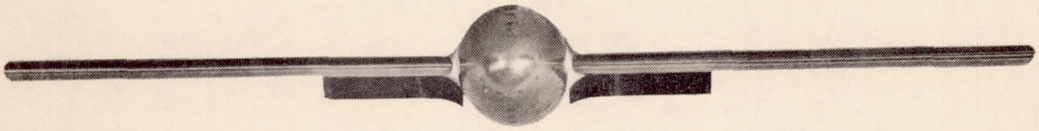
272



285



285



278

Figure 1.- Combinations 272, 285, and 278, showing split flaps.

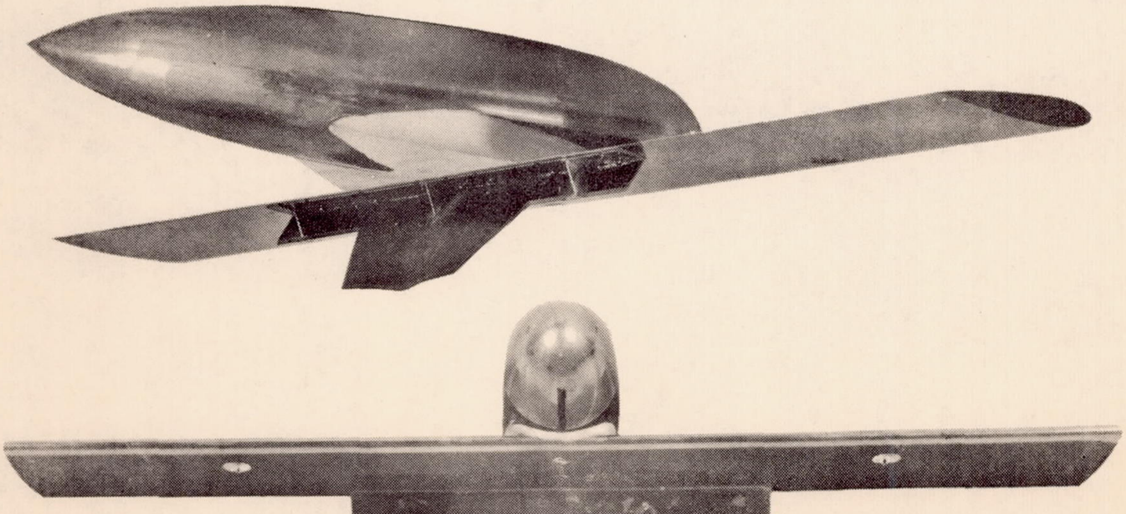


Figure 2. - Combination 283, showing air brake.

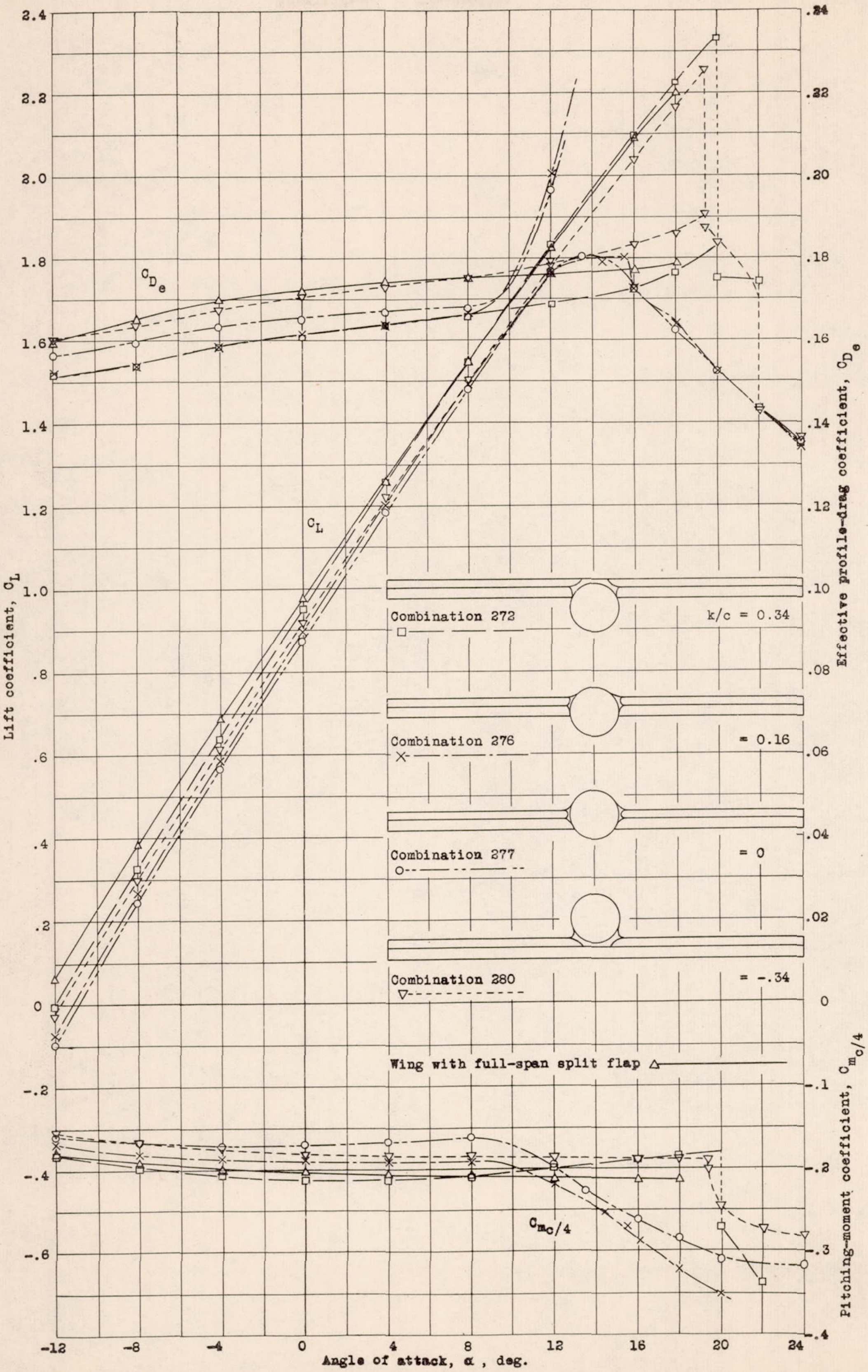


Figure 3. - Characteristics for various vertical wing positions. Rectangular N.A.C.A. 0012 airfoil with full-span split flap deflected 60° and round fuselage with tapered fillets.

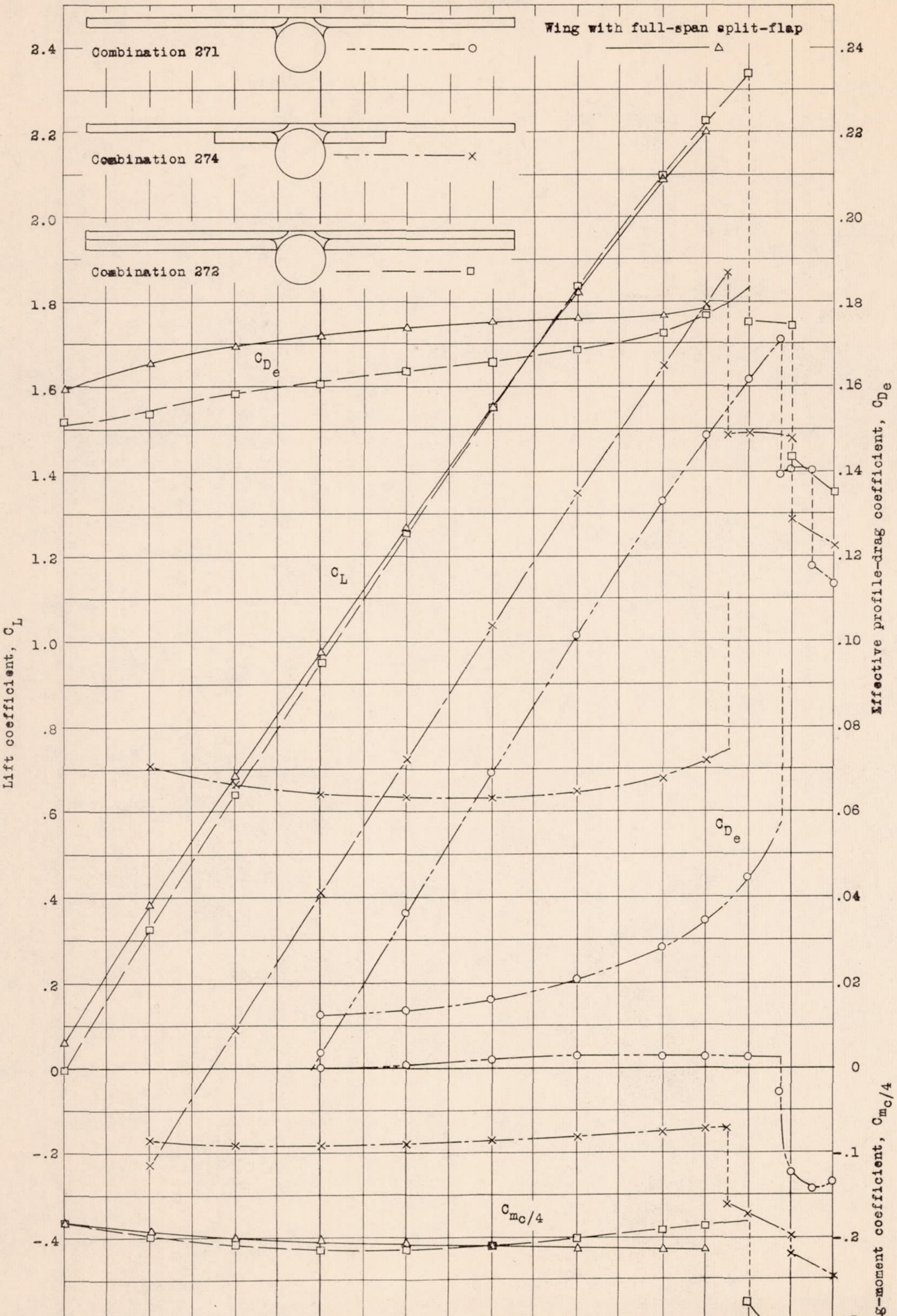


Figure 4. - Effect of reducing the flap span. Rectangular N.A.C.A. 0012 airfoil with split flap deflected 60° and round fuselage with tapered fillets. k/c = 0.34

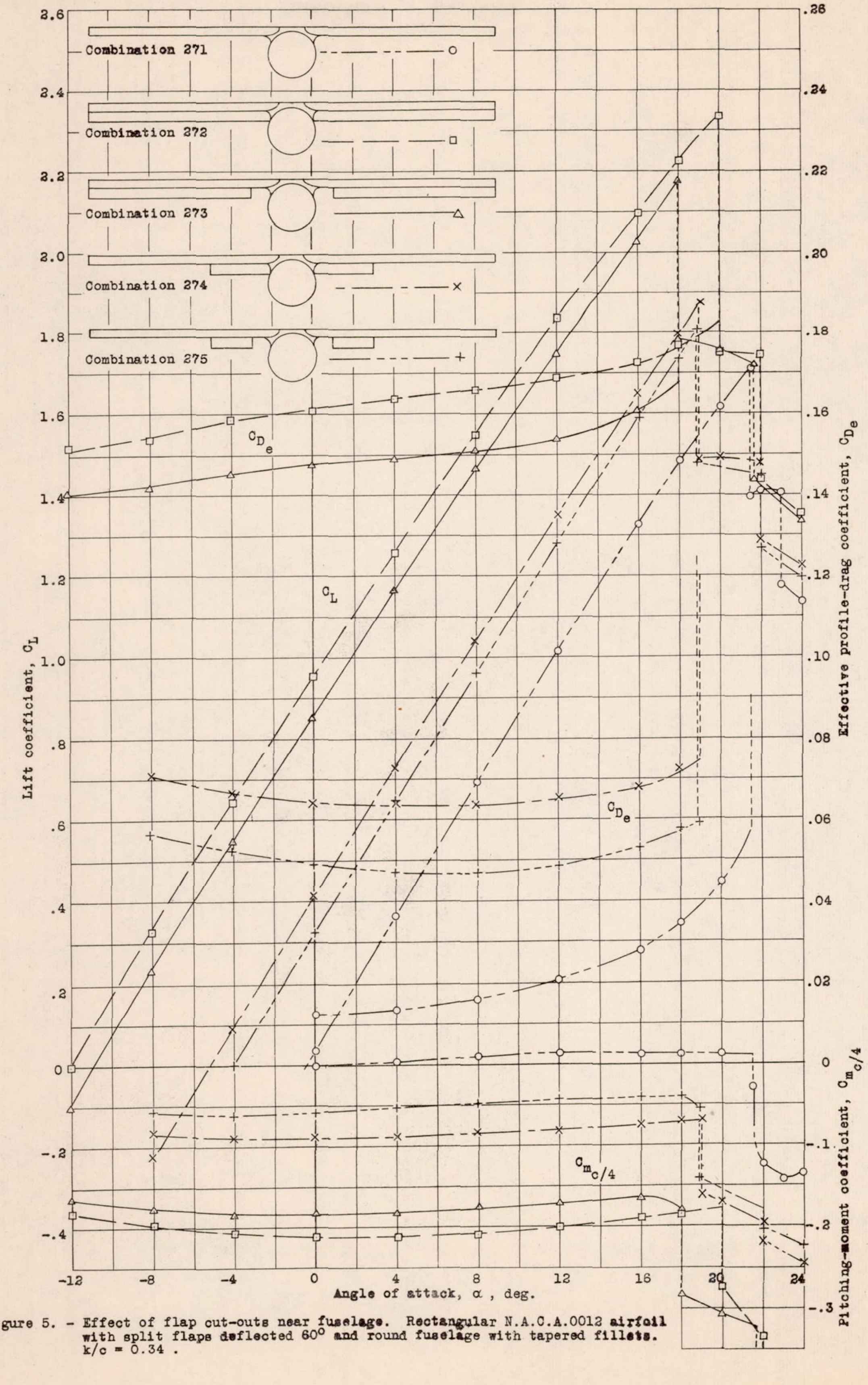


Figure 5. - Effect of flap cut-outs near fuselage. Rectangular N.A.C.A.0012 airfoil with split flaps deflected 60° and round fuselage with tapered fillets. k/c = 0.34 .