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RESEARCH MEMORANDUM

STATIC STABILITY AND CONTROL OF CANARD CONFIGURATIONS AT MACH NUMBERS FROM 0.70 TO 2.22 - LONGITUDINAL CHARACTERISTICS OF AN UNSWEPT WING AND CANARD

By Victor L. Peterson and John W. Boyd

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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STATIC STABILITY AND CONTROL OF CANARD CONFIGURATIONS AT MACH NUMBERS FROM 0.70 TO 2.22 - LONGITUDINAL CHARACTERISTICS OF AN UNSWEPT WING AND CANARD

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SUMMARY

The results of an investigation of the static longitudinal stability and control characteristics of a canard airplane configuration are presented without analysis for the Mach number range from 0.70 to 2.22. The configuration consisted of an aspect ratio 3.1 unswept wing, an aspect ratio 3.0 unswept canard, a low aspect ratio vertical tail, and a Sears-Haack body. The hinge line of the canard was in the extended chord plane of the wing, 1.33 wing mean aerodynamic chords ahead of the reference center of moments. The ratio of the area of the exposed canard panels to the total area of the wing was 8.1 percent. Data are presented for various combinations of the canard, wing, and vertical tail for an angle-of-attack range from -6° to +18°. The canard deflection angles ranged from 0° to +20°.

INTRODUCTION

The possible gains to be realized at supersonic speeds in the form of reduced trim drag and increased maneuverability by the use of canards rather than conventional tail-aft controls have resulted in increased interest in these arrangements. Therefore, an extensive research program aimed at determining the static longitudinal and directional characteristics of a number of canard configurations has been undertaken by the NACA.

This report is one of a series pertaining to the Ames Aeronautical Laboratory program and presents without analysis the longitudinal characteristics of one complete configuration and its component parts. The configuration consisted of an unswept wing of aspect ratio 3.1, an unswept canard of aspect ratio 3.0, a low aspect ratio vertical tail, and a Sears-Haack body.

[redacted]

Results of other phases of the investigation directed at determining the effects of canard plan form and location are reported in references 1 through 3.

NOTATION

a.c.	aerodynamic center determined at $C_L = 0$, percent $\bar{c}$
$\bar{c}$	mean aerodynamic chord of wing, ft
c_c	canard root chord, ft
C_D	drag coefficient, $\frac{\text{drag}}{qS}$
C_{D_o}	drag coefficient at zero lift
C_L	lift coefficient, $\frac{\text{lift}}{qS}$
C_{L_α}	lift-curve slope taken through zero angle of attack, per deg
C_m	pitching-moment coefficient, $\frac{\text{pitching moment}}{qS\bar{c}}$, referred to the projection of the $0.035\bar{c}$ point on the fuselage reference line
C_{h_c}	canard hinge-moment coefficient, $\frac{\text{canard hinge moment}}{qS_c\left(c_c/2\right)}$, referred to the projection of $0.50c_c$ point on the fuselage reference line
C_{Z_c}	force coefficient normal to canard, $\frac{\text{canard normal force}}{qS}$
$\left(\frac{L}{D}\right)_{max}$	maximum lift-drag ratio
M	free-stream Mach number
q	free-stream dynamic pressure, lb/sq ft
S	wing area formed by extending the leading and trailing edges to the plane of symmetry, sq ft

S_C canard exposed area, sq ft

α angle of attack of wing root chord, deg

δ angle of deflection of the canard with respect to the extended wing chord plane, positive when trailing edge is down, deg

Configurations are denoted by the following letters used in combination:

B body

C canard

V vertical tail

W wing

APPARATUS AND MODEL

Test Facility

The experimental data were obtained in the Ames 6- by 6-foot supersonic wind tunnel which is a closed-circuit variable-pressure type with a Mach number range continuous from 0.70 to 2.22. A recent modification involved perforating the test-section floor and ceiling and adding a boundary-layer removal system to enable uniform flow to be maintained at transonic and low supersonic speeds. At the same time injector flaps were installed downstream of the test section to extend the upper Mach number limit by reducing the required compression ratio across the nozzle and by better matching the weight flow characteristics of the nozzle with those of the compressor.

Analysis of the results of an extensive survey of the modified wind-tunnel characteristics, although incomplete, is sufficiently complete to establish the validity of the results of the present investigation.

Description of Model and Balances

The sting-mounted model consisted of an unswept wing of aspect ratio 3.1, an unswept canard of aspect ratio 3.0, and a low aspect ratio vertical tail, all mounted on a fineness ratio 12.5 Sears-Haack body. A dimensional sketch of the model is shown in figure 1(a). The wing had 3-percent-thick biconvex sections and the vertical tail had NACA 0003-63 sections streamwise. The constant thickness canard, detailed in figure 1(b), had beveled leading and trailing edges. The canard which was pivoted about the 0.50 canard root chord was mounted in the extended wing chord plane 1.33 wing mean aerodynamic chords ahead of the reference center of moments ($0.035\bar{c}$). The ratio of the area of the exposed canard panels to the total area of the wing was 8.1 percent and the ratio of the total areas was 11.5 percent. The wing, canard, and vertical tail were of solid steel construction to minimize aeroelastic effects. The surfaces were polished to give a smooth surface and further treated to prevent corrosion.

The fuselage was cut off as shown in figure 1(a) to accommodate the sting and the six-component strain-gage balance which measured forces and moments on the entire configuration. Canard normal forces and hinge moments were obtained from a two-component strain-gage balance mounted in the nose of the fuselage. The canard, wing, and vertical tail were removable, enabling data to be taken which would permit an evaluation of the contribution of each of the component parts of the model and the interference between parts.

TEST AND PROCEDURES

Range of Test Variables

Mach numbers of 0.70, 0.90, 1.00, 1.10, 1.30, 1.70, and 2.22 were covered in the investigation. The test Reynolds number based on the wing mean aerodynamic chord was 1.84 million at Mach numbers of 1.00 and 1.10, and 3.68 million at all other Mach numbers. The smaller Reynolds number at transonic speeds was necessary because of model structural limitations.

At the relatively low Reynolds numbers at which most wind tunnels operate, extensive regions of laminar flow can exist on models at zero lift. At lifting conditions the transition points on the model surfaces usually move forward, thus causing a change in friction drag with changing lift coefficient which is difficult to evaluate and, moreover, not necessarily representative of full scale. In order to induce transition at fixed locations on the component parts, a 0.010-inch-diameter wire was placed on the wing and 0.005-inch-diameter wires were affixed to the canard and vertical tail in the locations shown in figure 1(a). When the model was tested with the canard off, a 0.010-inch-diameter wire was located on the body 4 inches from the nose. The wire sizes were selected on the basis of reference 4. Although there is no conclusive evidence as to the magnitude of the form drag increment contributed by the transition wires, previous studies have indicated this increment to be not more than 0.0010. All of the data presented herein are for transition-fixed conditions.

Reduction of Data

The data presented herein have been reduced to standard NACA coefficient form. The moment center for the data presented herein was chosen so that the minimum static margin in the range of trim lift coefficients between 0 and 0.5 throughout the Mach number range investigated was $0.03\bar{c}$; the resulting moment center was at the 0.035 point of the wing mean aerodynamic chord.[1] The canard hinge moments were computed about a hinge line located at the 0.50 point of the canard root chord. Factors which affect the accuracy of the results are discussed in the following paragraphs.

Stream variations.- Surveys of the stream characteristics of the Ames 6- by 6-foot supersonic wind tunnel showed that in the region of the test section, essentially no stream curvature existed in the pitch plane of the model and that axial static-pressure variations were usually less than ±1 percent of the dynamic pressure. This static-pressure variation resulted in negligible longitudinal-buoyancy corrections to the drag of this model; therefore, no corrections for stream curvature or static-pressure variation were made in the present investigation.

From tests of the model in the normal and inverted attitudes, a stream angle, which was less than $\pm 0.30^\circ$ throughout the Mach number range, was found to exist in the pitch plane. The data presented herein have been corrected for these stream angles which correlated closely with those obtained from a cone survey.

Support interference.- The effects of model support interference on the aerodynamic characteristics were considered to consist primarily of a change in the pressure at the base of the model. However, the drag data presented herein contain no base drag component since the base pressure was measured and the drag was adjusted to correspond to that in which the base pressure is equal to the free-stream static pressure; therefore, no corrections were made to take into account support interference.

Tunnel-wall interference.- The effectiveness of the perforations in the wind-tunnel test section in preventing choking and absorbing reflected disturbances at transonic and low supersonic speeds has been established experimentally. Unpublished data from the wind-tunnel calibration indicate that reliable data can be obtained throughout the Mach number range if certain restrictions are imposed on the model size

[1]A similar stability criterion was used to select the center of moments for the data presented in reference 1; the resulting center of moments was, however, at the 0.21 point of the wing mean aerodynamic chord.

and attitude. The configurations and methods of testing used in the present investigation conform to these restrictions so that data at transonic and low supersonic speeds are reasonably free of interference effects. Thus, no corrections for wall interference have been made.

RESULTS

The data are presented in this report without analysis in order to expedite publication. All of the experimental data are tabulated in tables I and II. Selected portions of the data are presented in figures 2 through 4. Lift, drag, and pitching-moment characteristics are presented in figure 2 for several test Mach numbers for the canard on and off. Figure 3 shows the variations of canard normal forces and hinge moments as a function of angle of attack at constant canard deflection angles. Summarized in figure 4 are the lift-curve slopes, maximum lift-drag ratios, minimum drag coefficients, and aerodynamic centers as a function of Mach number for the canard on at zero deflection and for the canard off. It should be pointed out that data were not available to cross-plot the parameters shown in figure 4 between the Mach numbers of 0.90 and 1.00 and the Mach numbers 1.00 and 1.10. Previous data on this type of wing have shown that results at intermediate Mach numbers are necessary in order to make accurate cross plots.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Nov. 27, 1957

REFERENCES

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4. Winter, K. G., Scott-Wilson, J. B., and Davies, F. V.: Methods of Determination and of Fixing Boundary-Layer Transition on Wind Tunnel Models at Supersonic Speeds. R.A.E. TN Aero. 2341, British, Sept. 1954.

TABLE I.- AERODYNAMIC CHARACTERISTICS WITH THE WING ON

(a) BVW

M	α, deg	C_L	C_D	C_m
0.70	-6.2	-0.464	0.0561	0.0863
	-4.1	-.308	.0305	.0504
	-2.0	-.156	.0173	.0282
	-1.6	-.127	.0160	.0242
	-.1	-.011	.0132	.0025
	.4	.023	.0130	.0013
	1.9	.126	.0157	-.0146
	3.9	.281	.0278	-.0403
	6.0	.439	.0518	-.0754
	7.9	.586	.0857	-.1295
	9.9	.705	.1313	-.1930
0.90	-5.9	-.578	.0716	.1649
	-3.9	-.381	.0364	.0883
	-1.9	-.169	.0181	.0318
	-1.5	-.135	.0166	.0280
	.1	-.002	.0135	.0062
	.6	.046	.0141	-.0024
	2.1	.175	.0180	-.0213
	4.1	.395	.0388	-.0866
	6.1	.583	.0713	-.1527
	8.1	.740	.1173	-.2138
	10.1	.879	.1686	-.2673
	12.1	1.034	.2339	-.3383

M	α, deg	C_L	C_D	C_m
1.00	-5.8	-0.528	0.0790	0.1744
	-3.7	-.352	.0456	.1061
	-1.7	-.157	.0297	.0403
	-1.2	-.120	.0259	.0324
	.3	.020	.0258	-.0041
	.8	.072	.0243	-.0180
	2.3	.212	.0320	-.0567
	4.3	.404	.0542	-.1262
	6.3	.583	.0901	-.1969
	8.3	.742	.1346	-.2635
	10.2	.886	.1847	-.3241
	12.3	1.028	.2494	-.3862
	14.3	1.147	.3175	-.4386
	16.3	1.253	.3919	-.4868
	18.3	1.343	.4682	-.5298
1.10	-5.8	-.501	.0775	.1676
	-3.8	-.340	.0490	.1051
	-1.7	-.165	.0302	.0430
	-1.3	-.128	.0284	.0349
	.2	.006	.0222	-.0075
	.8	.052	.0218	-.0188
	2.3	.196	.0319	-.0557
	4.2	.361	.0518	-.1153
	6.2	.522	.0822	-.1779
	8.2	.673	.1251	-.2388
	10.2	.812	.1742	-.2974
	14.3	1.058	.2967	-.4057
	16.2	1.155	.3635	-.4500
	18.2	1.248	.4366	-.4940

M	α, deg	C_L	C_D	C_m
1.30	-6.0	-0.424	0.0654	0.1623
	-4.0	-.290	.0410	.1094
	-1.9	-.145	.0254	.0529
	-1.5	-.115	.0227	.0412
	0	.002	.0198	-.0015
	.5	.035	.0206	-.0120
	2.0	.142	.0253	-.0519
	4.1	.288	.0407	-.1066
	6.0	.417	.0631	-.1581
	8.1	.561	.0988	-.2141
	10.0	.686	.1400	-.2635
	11.9	.795	.1871	-.3064
	14.0	.917	.2447	-.3567
	16.1	1.022	.3085	-.3973
	18.0	1.153	.3856	-.4506
1.70	-6.2	-.309	.0509	.1309
	-4.2	-.212	.0331	.0905
	-2.1	-.116	.0219	.0500
	-1.6	-.086	.0199	.0367
	-.2	-.005	.0171	.0030
	.4	.018	.0171	-.0052
	1.8	.092	.0199	-.0362
	3.9	.195	.0301	-.0789
	5.9	.292	.0462	-.1194
	7.9	.394	.0709	-.1626
	9.9	.496	.1027	-.2060
	11.8	.588	.1396	-.2452
	13.9	.680	.1841	-.2867
	15.9	.769	.2354	-.3257
	17.9	.852	.2912	-.3613

M	α, deg	C_L	C_D	C_m
2.22	-5.7	-0.215	0.0351	0.0941
	-3.6	-.139	.0221	.0604
	-1.6	-.062	.0151	.0277
	-1.2	-.044	.0139	.0197
	.4	.014	.0128	-.0036
	.8	.027	.0134	-.0086
	2.4	.086	.0167	-.0340
	4.3	.159	.0253	-.0653
	6.4	.235	.0392	-.0982
	8.4	.310	.0585	-.1318
	10.3	.385	.0830	-.1645
	12.4	.463	.1144	-.1990
	14.4	.543	.1523	-.2344
	16.4	.622	.1968	-.2703
	18.4	.694	.2449	-.3040

TABLE I.- AERODYNAMIC CHARACTERISTICS WITH THE WING ON - Continued

(b) BVWC; $\delta = 0^{\circ}$

M	α, deg	C_L	C_D	C_m	C_{Z_c}	C_{h_c}
0.70	-6.1	-0.484	0.0592	0.0322	-0.0405	-0.1725
	-4.1	-.320	.0324	.0164	-.0263	-.1345
	-2.1	-.170	.0189	.0142	-.0135	-.0633
	-.6	-.048	.0144	.0112	-.0036	-.0107
	-.1	-.016	.0132	.0099	-.0008	.0019
	.3	.018	.0141	.0021	.0020	.0025
	1.9	.133	.0169	.0004	.0122	.0488
	3.9	.290	.0291	-.0048	.0246	.1215
	6.0	.463	.0554	-.0199	.0395	.1708
	7.9	.616	.0926	-.0487	.0522	.1645
	9.9	.753	.1402	-.0845	.0606	.1228
	12.0	.839	.1901	-.1260	.0607	.0886
	14.0	.870	.2331	-.1484	.0601	.0769
0.90	-5.9	-.587	.0742	.0924	-.0451	-.1951
	-4.0	-.394	.0388	.0509	-.0287	-.1542
	-1.9	-.171	.0192	.0139	-.0126	-.0589
	-.2	-.023	.0147	.0099	-.0008	-.0048
	.1	.009	.0144	.0033	.0010	-.0015
	.6	.053	.0154	.0010	.0041	.0178
	2.1	.183	.0200	-.0048	.0137	.0662
	4.1	.392	.0387	-.0372	.0293	.1528
	6.1	.593	.0737	-.0753	.0465	.1980
	8.1	.768	.1228	-.1162	.0612	.2037
	9.9	.925	.1765	-.1596	.0713	.2171
	12.2	1.112	.2573	-.2610	.0622	.0918
	14.0	1.246	.3273	-.3202	.0629	.0675
1.00	-5.6	-.523	.0773	.0961	-.0439	-.1224
	-3.7	-.350	.0483	.0580	-.0296	-.1014
	-1.7	-.159	.0314	.0247	-.0126	-.0476
	0	-.003	.0259	.0028	-.0010	-.0006
	.4	.038	.0271	-.0075	.0018	.0023
	.8	.074	.0274	-.0133	.0047	.0107
	2.3	.212	.0342	-.0341	.0148	.0545
	4.4	.414	.0571	-.0755	.0318	.1037
	6.1	.576	.0881	-.1124	.0458	.1171
	8.2	.750	.1369	-.1545	.0602	.1278
	10.3	.917	.1943	-.1976	.0739	.1236
	12.2	1.070	.2588	-.2423	.0844	.1337
1.10	-5.8	-.505	.0804	.0912	-.0445	-.1099
	-3.7	-.332	.0497	.0537	-.0288	-.0861
	-1.8	-.175	.0319	.0364	-.0142	-.0513
	-.2	-.028	.0266	.0147	-.0024	-.0063
	.2	.027	.0269	-.0078	0	.0027
	.8	.063	.0272	-.0066	.0045	.0107
	2.2	.204	.0337	-.0361	.0147	.0503
	4.3	.377	.0545	-.0694	.0286	.0880
	6.1	.533	.0854	-.1066	.0424	.0924
	8.2	.694	.1302	-.1458	.0549	.1142
	10.2	.840	.1821	-.1829	.0673	.1129
	12.3	.983	.2437	-.2194	.0797	.1062
1.30	-5.9	-0.426	0.0671	0.0935	-0.0370	-0.0562
	-4.0	-.294	.0431	.0637	-.0257	-.0411
	-1.9	-.141	.0272	.0288	-.0124	-.0254
	-.3	-.020	.0225	.0046	-.0024	-.0027
	0	.004	.0223	-.0009	0	-.0019
	.6	.044	.0228	-.0084	.0032	.0034
	2.0	.142	.0271	-.0282	.0119	.0199
	4.0	.291	.0427	-.0631	.0243	.0427
	6.1	.441	.0687	-.0979	.0374	.0549
	8.0	.574	.1020	-.1270	.0489	.0654
	10.0	.716	.1473	-.1610	.0600	.0763
	12.1	.846	.2025	-.1886	.0704	.0842
	14.0	.957	.2578	-.2156	.0792	.0847
1.70	-6.2	-.327	.0553	.0809	-.0286	-.0258
	-4.1	-.221	.0351	.0565	-.0188	-.0174
	-2.0	-.111	.0227	.0305	-.0093	-.0078
	-.4	-.021	.0186	.0083	-.0017	-.0013
	-.2	-.007	.0186	.0042	-.0004	-.0006
	.5	.025	.0187	-.0023	.0025	.0023
	1.9	.104	.0213	-.0213	.0094	.0069
	3.9	.209	.0324	-.0466	.0185	.0163
	5.9	.321	.0518	-.0744	.0288	.0207
	7.9	.431	.0791	-.1016	.0379	.0316
	9.8	.523	.1101	-.1244	.0463	.0383
	11.9	.627	.1519	-.1511	.0548	.0457
	13.9	.724	.1980	-.1781	.0629	.0505
	15.9	.821	.2539	-.2068	.0706	.0513
	17.9	.900	.3095	-.2217	.0776	.0488
2.22	-5.6	-.233	.0384	.0618	-.0195	-.0080
	-3.6	-.153	.0246	.0403	-.0128	-.0082
	-1.6	-.068	.0165	.0181	-.0062	-.0017
	-.2	-.008	.0144	.0030	-.0012	-.0021
	.4	.011	.0144	-.0006	.0002	.0013
	.9	.032	.0148	-.0052	.0025	-.0025
	2.4	.092	.0180	-.0210	.0072	.0004
	4.3	.170	.0271	-.0408	.0138	.0042
	6.4	.256	.0432	-.0636	.0211	.0046
	8.4	.338	.0648	-.0845	.0282	.0084
	10.3	.418	.0916	-.1050	.0349	.0168
	12.4	.505	.1269	-.1286	.0425	.0155
	14.4	.583	.1663	-.1485	.0496	.0205
	16.5	.664	.2130	-.1694	.0572	.0245
	18.4	.739	.2627	-.1909	.0633	.0304

TABLE I.- AERODYNAMIC CHARACTERISTICS WITH THE WING ON - Continued

(c) BVWC; $\delta = 5.1^\circ$

M	α, deg	C_L	C_D	C_m	C_{Z_c}	C_{h_c}
0.70	-6.1	-0.467	0.0551	0.0622	-0.0146	-0.0692
	-2.1	-.158	.0193	.0414	.0089	.0507
	-.2	-.016	.0159	.0438	.0223	.1188
	1.9	.143	.0209	.0397	.0370	.1660
	5.8	.453	.0607	.0179	.0596	.1456
	9.9	.743	.1443	-.0827	.0579	.0884
	13.9	.882	.2386	-.1380	.0635	.0897
0.90	-6.0	-.586	.0720	.1337	-.0146	-.0564
	-2.0	-.173	.0198	.0472	.0108	.0708
	0	.002	.0167	.0468	.0268	.1595
	2.1	.189	.0234	.0465	.0454	.2014
	6.1	.602	.0833	-.0396	.0678	.2140
	10.0	.947	.1450	-.1780	.0647	.0851
	14.1	1.256	.3373	-.3134	.0677	.0756
1.00	-5.7	-.525	.0804	.1497	-.0125	-.0415
	-1.6	-.157	.0309	.0614	.0138	.0648
	.3	.030	.0313	.0416	.0312	.1127
	2.3	.211	.0380	.0206	.0465	.1299
	6.3	.592	.0974	-.0686	.0689	.1207
	10.2	.920	.2027	-.1583	.0829	.0893
	14.2	1.190	.3340	-.3045	.0735	.0495
1.10	-5.7	-.495	.0785	.1394	-.0138	-.0469
	-1.7	-.177	.0337	.0732	.0136	.0599
	.1	-.013	.0280	.0605	.0280	.0918
	2.2	.192	.0367	.0185	.0434	.1031
	6.2	.542	.0926	-.0630	.0635	.1099
	10.2	.846	.1888	-.1437	.0778	.0836
	14.1	1.108	.3154	-.2510	.0811	.0369
1.30	-5.9	-0.426	0.0661	0.1419	-0.0113	-0.0117
	-2.1	-.163	.0297	.0804	.0105	.0291
	0	.004	.0244	.0456	.0246	.0503
	2.1	.155	.0313	.0130	.0373	.0648
	6.0	.438	.0734	-.0551	.0564	.0746
	10.0	.720	.1557	-.1287	.0685	.0689
	13.9	.965	.2673	-.1888	.0792	.0375
1.70	-6.2	-.317	.0528	.1182	-.0080	0
	-2.1	-.097	.0232	.0610	.0100	.0174
	-.1	.007	.0207	.0378	.0197	.0241
	1.9	.118	.0252	.0109	.0292	.0337
	5.9	.334	.0575	-.0443	.0454	.0436
	9.9	.537	.1188	-.0979	.0563	.0430
	13.9	.735	.2094	-.1558	.0662	.0272
	17.9	.915	.3228	-.2133	.0766	.0163
2.22	-5.8	-.221	.0370	.0882	-.0039	.0017
	-1.6	-.052	.0164	.0421	.0084	.0090
	.4	.029	.0156	.0216	.0153	.0128
	2.3	.105	.0208	.0034	.0223	.0138
	6.4	.266	.0478	-.0369	.0359	.0207
	10.4	.428	.0987	-.0790	.0486	.0189
	14.4	.587	.1735	-.1229	.0584	.0243
	18.4	.740	.2708	-.1703	.0665	.0220

TABLE I.- AERODYNAMIC CHARACTERISTICS WITH THE WING ON - Continued

(d) BVWC; $\delta = 10.4^{\circ}$

M	α, deg	C_L	C_D	C_m	C_{Z_c}	C_{h_c}
0.70	-6.2	-0.468	0.0588	0.1013	0.0086	0.0486
	-2.1	-.133	.0228	.0798	.0363	.1590
	-.1	.008	.0221	.0792	.0488	.1584
	1.9	.147	.0278	.0717	.0569	.1465
	5.9	.458	.0669	.0148	.0587	.0912
	9.9	.740	.1491	-.0721	.0626	.0847
	13.8	.895	.2453	-.1278	.0693	.0935
0.90	-6.0	-.581	.0754	.1830	.0118	.0838
	-1.9	-.155	.0249	.0978	.0458	.2049
	0	.011	.0242	.0962	.0596	.2112
	2.0	.186	.0304	.0725	.0624	.1544
	6.1	.602	.0884	-.0508	.0662	.0828
	10.0	.933	.1916	-.1625	.0704	.0727
	14.0	1.266	.3457	-.3062	.0758	.0721
1.00	-5.8	-.526	.0823	.2003	.0155	.0748
	-1.7	-.159	.0373	.1232	.0489	.1236
	.3	.032	.0366	.0870	.0632	.1230
	2.3	.216	.0442	.0635	.0746	.1243
	6.2	.596	.1072	-.0261	.0981	.1140
	10.2	.925	.2123	-.1546	.1004	.0608
	14.1	1.192	.3385	-.2908	.0821	.0574
1.10	-5.9	-.508	.0841	.1934	.0124	.0648
	-1.8	-.188	.0402	.1364	.0446	.1054
	.3	.004	.0354	.1062	.0577	.1085
	2.2	.206	.0449	.0508	.0687	.1134
	6.2	.565	.1031	-.0310	.0897	.1079
	10.2	.854	.1988	-.1337	.0960	.0648
	14.2	1.116	.3264	-.2517	.0913	.0434

M	α, deg	C_L	C_D	C_m	C_{Z_c}	C_{h_c}
1.30	-6.1	-0.425	0.0705	0.1891	0.0137	0.0453
	-2.0	-.134	.0343	.1235	.0387	.0662
	-.1	.001	.0313	.0951	.0496	.0744
	2.0	.152	.0385	.0578	.0612	.0792
	6.0	.448	.0830	-.0232	.0790	.0922
	10.0	.729	.1664	-.1014	.0963	.0746
	14.1	.972	.2830	-.1734	.1064	.0532
1.70	-6.3	-.308	.0543	.1563	.0120	.0279
	-2.1	-.079	.0279	.0973	.0322	.0360
	-.2	.025	.0266	.0708	.0405	.0465
	1.9	.132	.0323	.0431	.0489	.0541
	5.9	.349	.0673	-.0144	.0652	.0650
	9.9	.547	.1297	-.0694	.0797	.0606
	13.9	.737	.2187	-.1273	.0932	.0507
	18.0	.922	.3383	-.1914	.1055	.0239
2.22	-5.7	-.205	.0376	.1149	.0116	.0145
	-1.6	-.040	.0204	.0715	.0254	.0174
	.4	.043	.0210	.0499	.0323	.0199
	2.5	.129	.0280	.0278	.0399	.0233
	6.5	.290	.0586	-.0116	.0549	.0344
	10.3	.443	.1095	-.0539	.0681	.0436
	14.4	.598	.1852	-.0992	.0799	.0478
	18.4	.747	.2832	-.1484	.0901	.0465

TABLE I.- AERODYNAMIC CHARACTERISTICS WITH THE WING ON - Concluded

(e) BVWC; $\delta = 19.9^{\circ}$

M	α, deg	C_L	C_D	C_m	C_{Z_c}	C_{h_c}
0.70	-6.2	-0.445	0.0706	0.1644	0.0478	0.1660
	-2.0	-.135	.0365	.1195	.0553	.1150
	-.1	.009	.0340	.0938	.0556	.1018
	1.9	.147	.0382	.0739	.0577	.1039
	5.9	.452	.0777	.0275	.0653	.0981
	9.8	.731	.1594	-.0489	.0711	.1018
	14.0	.901	.2653	-.1105	.0790	.0932
0.90	-6.0	-.565	.0893	.2430	.0508	.1622
	-1.9	-.148	.0397	.1240	.0638	.0977
	.1	.019	.0376	.1055	.0670	.0899
	2.0	.186	.0445	.0875	.0721	.0863
	6.1	.583	.1004	-.0194	.0759	.0809
	10.1	.906	.2011	-.1259	.0792	.0754
	14.1	1.194	.3438	-.2522	.0839	.0662
1.00	-5.7	-.505	.1007	.2916	.0676	.1316
	-1.8	-.169	.0604	.2026	.0903	.1148
	.3	.003	.0557	.1600	.0968	.1037
	2.3	.208	.0609	.1083	.0961	.0740
	6.3	.593	.1243	-.0092	.1065	.0446
	10.3	.924	.2283	-.1416	.1033	.0413
	13.7	1.162	.3370	-.2532	.0883	.0528
1.10	-5.8	-.487	.1001	.2763	.0610	.1243
	-1.7	-.176	.0605	.2100	.0844	.1054
	.2	.021	.0570	.1496	.0891	.0977
	2.2	.210	.0645	.0808	.0887	.0698
	6.2	.555	.1198	-.0236	.0985	.0432
	10.2	.867	.2175	-.1162	.1066	.0293
	13.8	1.090	.3271	-.2276	.0952	.0323
1.30	-6.0	-0.403	0.0848	0.2589	0.0542	0.0918
	-2.0	-.120	.0520	.1840	.0730	.0945
	0	.016	.0502	.1473	.0809	.0928
	2.0	.157	.0577	.1084	.0888	.0828
	6.0	.441	.1015	.0143	.0986	.0564
	10.0	.726	.1864	-.0834	.1068	.0207
	14.0	.965	.3011	-.1629	.1135	.0073
1.70	-6.2	-.271	.0652	.2089	.0453	.0752
	-2.1	-.053	.0431	.1436	.0607	.0838
	-.1	.051	.0427	.1135	.0678	.0836
	1.9	.151	.0508	.0858	.0744	.0805
	5.8	.357	.0865	.0253	.0875	.0641
	9.9	.552	.1509	-.0396	.0988	.0423
	13.8	.741	.2405	-.1099	.1072	.0113
	17.9	.916	.3581	-.1791	.1143	-.0075
2.22	-5.7	-.170	.0463	.1584	.0398	.0438
	-1.6	-.009	.0335	.1124	.0526	.0503
	.4	.067	.0366	.0924	.0586	.0606
	2.4	.146	.0448	.0703	.0646	.0666
	6.4	.303	.0772	.0233	.0762	.0694
	10.3	.447	.1288	-.0206	.0861	.0629
	14.4	.595	.2044	-.0698	.0960	.0457
	18.4	.734	.3000	-.1211	.1046	.0189

TABLE II.- AERODYNAMIC CHARACTERISTICS WITH THE WING OFF

(a) BV

M	α, deg	C_L	C_D	C_m
0.70	-6.3	-0.004	0.0058	-0.0187
	-4.1	0	.0058	-.0148
	-2.0	.003	.0060	-.0110
	-.6	.003	.0058	-.0055
	-.1	.004	.0061	-.0044
	.4	.005	.0049	-.0033
	1.9	.007	.0060	.0015
	3.9	.008	.0056	.0086
	5.9	.010	.0062	.0133
	8.0	.013	.0071	.0174
	9.9	.017	.0079	.0206
	11.9	.020	.0093	.0245
	13.9	.027	.0112	.0273
	16.0	.033	.0137	.0301
	17.9	.039	.0161	.0339
0.90	-5.9	-.004	.0063	-.0174
	-3.9	-.001	.0060	-.0139
	-1.8	.002	.0058	-.0094
	-.4	.004	.0061	-.0057
	.1	.005	.0063	-.0045
	.6	.006	.0062	-.0036
	2.1	.004	.0064	.0041
	4.0	.006	.0059	.0099
	6.0	.010	.0066	.0131
	8.1	.013	.0079	.0175
	10.0	.018	.0086	.0198
	12.1	.024	.0099	.0234
	14.1	.030	.0125	.0258
	16.1	.036	.0151	.0295
	18.1	.043	.0180	.0328

M	α, deg	C_L	C_D	C_m
1.00	-5.8	-0.005	0.0084	-0.0176
	-3.8	-.001	.0087	-.0143
	-1.8	.003	.0072	-.0104
	-.2	.004	.0068	-.0057
	.3	.005	.0073	-.0042
	.8	.002	.0069	.0001
	2.2	.005	.0067	.0044
	4.3	.007	.0074	.0110
	6.3	.009	.0074	.0160
	8.3	.015	.0078	.0188
	10.3	.019	.0097	.0212
	12.2	.023	.0106	.0242
	14.3	.032	.0141	.0262
	16.4	.039	.0158	.0310
	18.3	.048	.0208	.0330
1.10	-5.8	-.007	.0107	-.0149
	-3.8	-.001	.0110	-.0126
	-1.7	.002	.0104	-.0083
	-.3	.003	.0097	-.0044
	.2	.005	.0094	-.0010
	2.1	.006	.0093	.0031
	4.2	.008	.0111	.0079
	6.2	.012	.0107	.0118
	8.2	.015	.0117	.0159
	10.1	.020	.0126	.0176
	12.2	.026	.0149	.0200
	14.2	.032	.0170	.0226
	16.2	.040	.0199	.0251
	18.3	.049	.0247	.0262

M	α, deg	C_L	C_D	C_m
1.30	-6.0	-0.008	0.0092	-0.0148
	-4.0	-.003	.0087	-.0122
	-1.9	0	.0085	-.0071
	-.4	.002	.0084	-.0034
	0	.002	.0084	-.0021
	.6	.003	.0084	-.0008
	2.0	.005	.0084	.0029
	4.1	.008	.0086	.0080
	6.0	.011	.0092	.0124
	7.9	.016	.0104	.0152
	10.0	.021	.0117	.0182
	12.0	.028	.0138	.0205
	14.1	.036	.0167	.0225
	16.1	.045	.0203	.0250
	18.0	.055	.0253	.0265
1.70	-6.2	-.011	.0095	-.0125
	-4.1	-.006	.0088	-.0098
	-2.1	-.002	.0084	-.0062
	-.6	0	.0084	-.0021
	-.2	.001	.0083	-.0008
	.4	.002	.0081	.0001
	1.8	.004	.0082	.0036
	3.9	.007	.0082	.0090
	5.9	.012	.0093	.0129
	7.8	.016	.0103	.0160
	9.9	.022	.0120	.0189
	11.8	.031	.0145	.0200
	13.8	.041	.0183	.0210
	15.9	.056	.0241	.0196
	18.0	.075	.0322	.0181

M	α, deg	C_L	C_D	C_m
2.22	-5.7	-0.011	0.0088	-0.0115
	-3.6	-.006	.0073	-.0077
	-1.6	-.001	.0068	-.0047
	.2	.002	.0058	.0001
	.4	.002	.0067	.0013
	.8	.003	.0068	.0021
	2.4	.006	.0069	.0044
	4.4	.010	.0067	.0093
	6.3	.015	.0085	.0114
	8.3	.022	.0097	.0140
	10.4	.031	.0128	.0143
	12.4	.045	.0170	.0118
	14.5	.062	.0232	.0079
	16.4	.079	.0306	.0059
	18.4	.093	.0385	.0045

TABLE II.- AERODYNAMIC CHARACTERISTICS WITH THE WING OFF - Continued

(b) BVC; δ = 0°

M	α, deg	C_L	C_D	C_m
0.70	-6.1	-0.053	0.0117	-0.0679
	-4.0	-.035	.0087	-.0410
	-3.1	-.019	.0054	-.0174
	-.6	-.010	.0070	.0013
	-.2	-.004	.0053	.0044
	.4	.006	.0066	.0027
	1.9	.019	.0068	.0202
	3.9	.034	.0092	.0452
	5.9	.053	.0115	.0698
	7.9	.071	.0152	.0938
	9.9	.087	.0207	.1120
	11.9	.094	.0258	.1193
	13.9	.102	.0312	.1215
	15.9	.108	.0363	.1283
	18.0	.123	.0446	.1349
0.90	-6.0	-.060	.0129	-.0807
	-4.0	-.038	.0092	-.0509
	-1.8	-.019	.0081	-.0172
	-.4	-.006	.0071	-.0004
	.1	-.002	.0074	.0048
	.5	.008	.0075	.0024
	2.1	.020	.0076	.0232
	4.1	.042	.0090	.0524
	6.0	.062	.0125	.0847
	8.2	.085	.0181	.1116
	10.0	.102	.0235	.1325
	12.0	.120	.0307	.1532
	14.2	.116	.0353	.1465
	16.1	.126	.0421	.1521
	18.1	.144	.0518	.1638
1.00	-5.5	-0.057	0.0152	-0.0764
	-3.7	-.039	.0113	-.0491
	-1.7	-.019	.0099	-.0190
	-.2	-.005	.0095	-.0001
	.3	.003	.0086	-.0009
	.8	.010	.0099	.0043
	2.2	.022	.0095	.0257
	4.2	.042	.0119	.0571
	6.2	.065	.0164	.0873
	8.3	.085	.0195	.1128
	10.3	.103	.0258	.1363
	12.2	.122	.0338	.1579
	14.3	.141	.0422	.1795
	16.3	.158	.0513	.1975
	18.3	.173	.0625	.2114
1.10	-5.8	-.056	.0188	-.0770
	-3.8	-.039	.0151	-.0500
	-4.0	-.017	.0102	-.0217
	-.2	-.004	.0123	-.0023
	.3	.005	.0114	-.0027
	.8	.008	.0128	.0047
	2.3	.024	.0128	.0255
	4.2	.042	.0139	.0506
	6.3	.064	.0186	.0783
	8.2	.081	.0229	.1021
	10.2	.097	.0296	.1250
	12.2	.114	.0363	.1450
	14.2	.131	.0457	.1646
	16.3	.150	.0566	.1842
	18.3	.165	.0671	.1973
1.30	-6.0	-0.051	0.0160	-0.0692
	-4.0	-.036	.0131	-.0458
	-1.9	-.019	.0112	-.0203
	-.5	-.008	.0105	-.0017
	0	-.002	.0104	.0037
	.5	.005	.0104	.0043
	2.0	.019	.0108	.0207
	3.9	.036	.0124	.0441
	6.0	.054	.0156	.0690
	8.0	.071	.0200	.0920
	10.0	.089	.0259	.1137
	12.0	.104	.0327	.1323
	14.0	.120	.0410	.1492
	16.0	.136	.0497	.1626
	18.1	.153	.0607	.1749
1.70	-6.1	-.044	.0151	-.0540
	-4.1	-.031	.0124	-.0339
	-2.0	-.017	.0105	-.0146
	-.7	-.008	.0098	-.0001
	-.2	0	.0095	-.0010
	.4	.005	.0097	.0041
	1.8	.013	.0102	.0184
	3.8	.029	.0114	.0378
	5.9	.044	.0143	.0573
	7.9	.059	.0184	.0765
	9.9	.074	.0234	.0939
	11.9	.090	.0296	.1082
	13.9	.108	.0380	.1216
	15.9	.128	.0482	.1306
	18.0	.154	.0620	.1346
2.22	-5.5	-0.034	0.0115	-0.0385
	-3.7	-.024	.0095	-.0242
	-1.5	-.012	.0082	-.0078
	-.1	-.005	.0074	.0037
	.4	.004	.0077	.0011
	.9	.006	.0078	.0057
	2.3	.014	.0088	.0167
	4.4	.026	.0117	.0328
	6.4	.040	.0117	.0468
	8.4	.053	.0161	.0609
	10.4	.070	.0217	.0723
	12.4	.090	.0290	.0802
	14.4	.112	.0389	.0861
	16.4	.136	.0505	.0931
	18.4	.160	.0638	.1006

TABLE II.- AERODYNAMIC CHARACTERISTICS WITH THE WING OFF - Continued

(c) BVC; δ = 5.2°

M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m
0.70	-6.2	-0.019	0.0073	-0.0334	1.00	-5.8	-0.018	0.0107	-0.0354	1.30	-6.0	-0.021	0.0118	-0.0309	2.22	-1.7	0.005	0.0084	0.0142
	-2.1	.007	.0075	.0152		-1.7	.015	.0103	.0191		-2.0	.012	.0111	.0156		.3	.017	.0093	.0297
	-.1	.026	.0084	.0378		.3	.035	.0111	.0513		0	.028	.0128	.0409		2.3	.030	.0111	.0443
	1.9	.043	.0109	.0641		2.3	.058	.0164	.0801		2.0	.046	.0152	.0649		6.4	.055	.0179	.0775
	5.9	.077	.0190	.1071		6.2	.096	.0244	.1315		6.0	.079	.0233	.1108		10.4	.083	.0294	.1052
	9.9	.087	.0271	.1191		10.2	.131	.0381	.1754		10.0	.106	.0361	.1506		14.3	.121	.0473	.1190
	13.9	.103	.0365	.1330		14.3	.158	.0553	.2135		14.0	.136	.0532	.1833		18.4	.165	.0739	.1300
	17.9	.126	.0513	.1509		18.3	.171	.0719	.2189		18.1	.165	.0743	.2033					
0.90	-5.9	-.020	.0083	-.0342	1.10	-5.9	-.021	.0130	-.0338	1.70	-6.1	-.021	.0116	-.0224					
	-1.9	.012	.0079	.0150		-1.7	.015	.0141	.0185		-2.1	.008	.0110	.0149					
	.1	.031	.0090	.0467		.2	.033	.0151	.0465		-.1	.023	.0121	.0350					
	2.1	.053	.0124	.0779		2.2	.053	.0184	.0737		1.9	.036	.0140	.0545					
	6.0	.092	.0222	.1270		6.2	.090	.0287	.1204		5.8	.064	.0212	.0928					
	10.0	.099	.0301	.1355		10.2	.121	.0419	.1649		9.8	.090	.0324	.1271					
	14.1	.120	.0419	.1539		14.2	.147	.0597	.2058		13.8	.120	.0485	.1539					
	18.1	.148	.0606	.1806		18.3	.161	.0756	.2060		17.9	.159	.0720	.1664					

TABLE II.- AERODYNAMIC CHARACTERISTICS WITH THE WING OFF - Continued

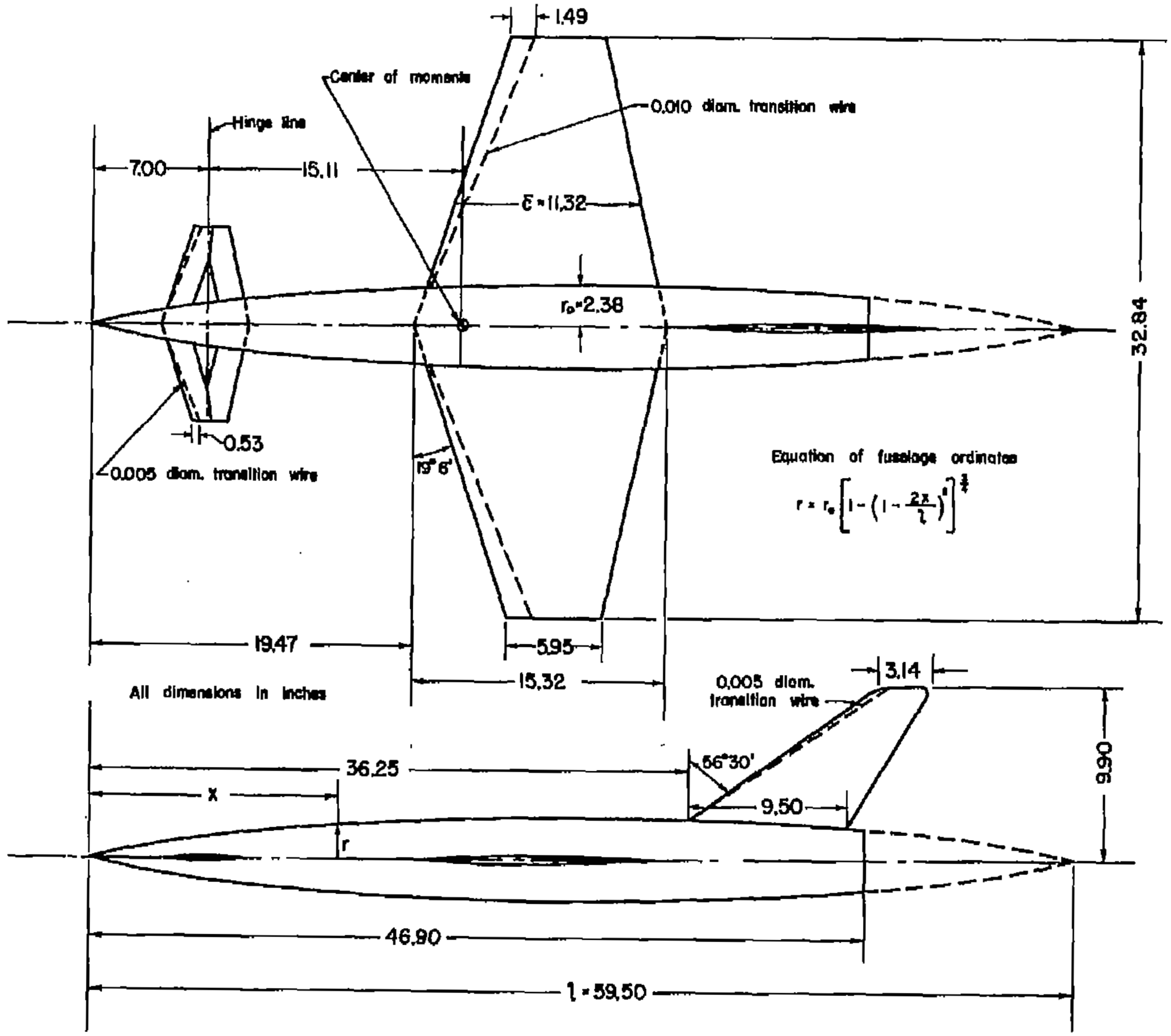
(d) BVC; $\delta = 10.2^{\circ}$

M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m
0.70	-6.2	0.003	0.0086	0.0020	1.00	-5.8	0.010	0.0110	0.0070	1.30	-6.1	0.005	0.0123	0.0075	2.22	-5.7	0.001	0.0100	0.0087
	-2.1	.038	.0113	.0487		-1.7	.053	.0151	.0647		-2.0	.041	.0157	.0514		-1.6	.026	.0118	.0366
	0	.057	.0147	.0717		.3	.072	.0198	.0922		0	.059	.0193	.0748		.4	.039	.0139	.0498
	1.9	.069	.0193	.0899		2.3	.090	.0250	.1167		2.0	.073	.0238	.0962		2.3	.052	.0167	.0652
	5.9	.079	.0254	.1015		6.3	.126	.0386	.1614		6.1	.104	.0356	.1327		6.3	.075	.0265	.0963
	9.9	.092	.0333	.1167		10.2	.138	.0488	.1817		9.9	.127	.0497	.1721		10.3	.099	.0394	.1241
	14.0	.110	.0451	.1371		14.2	.154	.0643	.2071		14.0	.146	.0664	.1992		14.4	.129	.0582	.1394
	18.0	.128	.0592	.1583		18.2	.169	.0809	.2244		18.0	.160	.0830	.2095		18.4	.168	.0839	.1475
0.90	-6.0	.006	.0087	.0048	1.10	-5.9	.007	.0135	.0058	1.70	-6.2	.002	.0121	.0086					
	-1.8	.050	.0127	.0636		-1.7	.050	.0195	.0603		-2.1	.033	.0145	.0428					
	.1	.069	.0172	.0892		.3	.066	.0229	.0863		-.2	.046	.0175	.0620					
	2.1	.086	.0223	.1132		2.2	.083	.0285	.1080		1.8	.061	.0211	.0785					
	6.1	.090	.0287	.1171		6.2	.115	.0414	.1487		5.9	.088	.0313	.1128					
	10.1	.111	.0395	.1421		10.3	.128	.0529	.1745		9.8	.108	.0439	.1461					
	14.1	.130	.0524	.1640		14.1	.143	.0686	.1984		13.8	.132	.0613	.1734					
	18.1	.147	.0682	.1825		18.3	.162	.0870	.2094		17.9	.166	.0854	.1826					

TABLE II.- AERODYNAMIC CHARACTERISTICS WITH THE WING OFF - Concluded

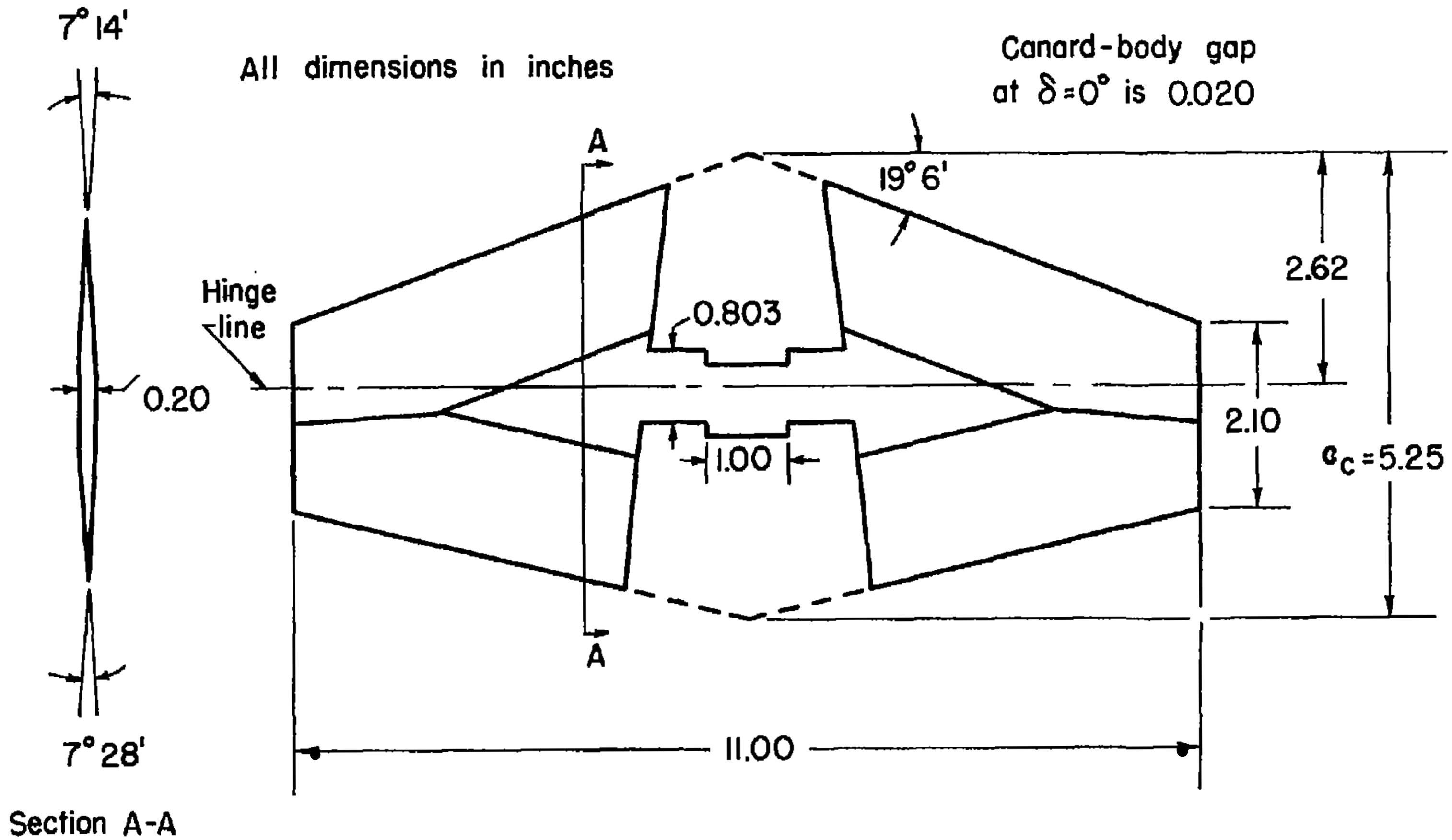
(e) BVC; $\delta = 19.9^{\circ}$

M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m	M	α, deg	C_L	C_D	C_m
0.70	-6.1	0.046	0.0212	0.0692	1.00	-5.7	0.069	0.0242	0.0967	1.30	-5.9	0.055	0.0254	0.0776	2.22	-5.7	0.035	0.0199	0.0558
	-2.1	.057	.0256	.0808		-1.7	.098	.0362	.1419		-1.9	.081	.0344	.1140		-1.6	.059	.0267	.0811
	-.1	.061	.0284	.0884		.2	.105	.0426	.1537		.1	.091	.0396	.1292		.4	.069	.0304	.0950
	1.9	.066	.0315	.0978		2.2	.108	.0452	.1567		2.1	.102	.0461	.1462		2.3	.079	.0359	.1077
	5.8	.075	.0379	.1160		6.2	.132	.0587	.1758		6.1	.120	.0583	.1657		6.4	.097	.0483	.1324
	9.9	.097	.0486	.1271		10.2	.148	.0728	.1962		10.0	.136	.0727	.1888		10.3	.114	.0624	.1550
	13.9	.119	.0627	.1458		14.3	.152	.0862	.2122		14.0	.145	.0873	.2069		14.4	.140	.0823	.1659
	18.0	.134	.0796	.1692		18.2	.162	.1022	.2280		18.1	.157	.1056	.2217		18.4	.170	.1074	.1697
0.90	-5.9	.053	.0219	.0760	1.10	-5.7	.064	.0304	.0893	1.70	-6.0	.042	.0236	.0662					
	-1.9	.068	.0288	.0956		-1.7	.091	.0414	.1302		-2.0	.066	.0308	.0963					
	.1	.074	.0320	.1072		.3	.097	.0465	.1438		-.1	.078	.0355	.1109					
	2.1	.082	.0366	.1206		2.2	.099	.0492	.1474		1.9	.088	.0413	.1254					
	5.9	.093	.0443	.1368		6.3	.123	.0622	.1682		5.8	.109	.0541	.1508					
	10.1	.115	.0563	.1505		10.2	.137	.0771	.1880		9.8	.126	.0692	.1752					
	14.2	.136	.0717	.1685		14.3	.144	.0904	.2018		13.9	.139	.0855	.1908					
	18.1	.149	.0885	.1905		18.3	.155	.1071	.2117		17.9	.162	.1075	.1991					



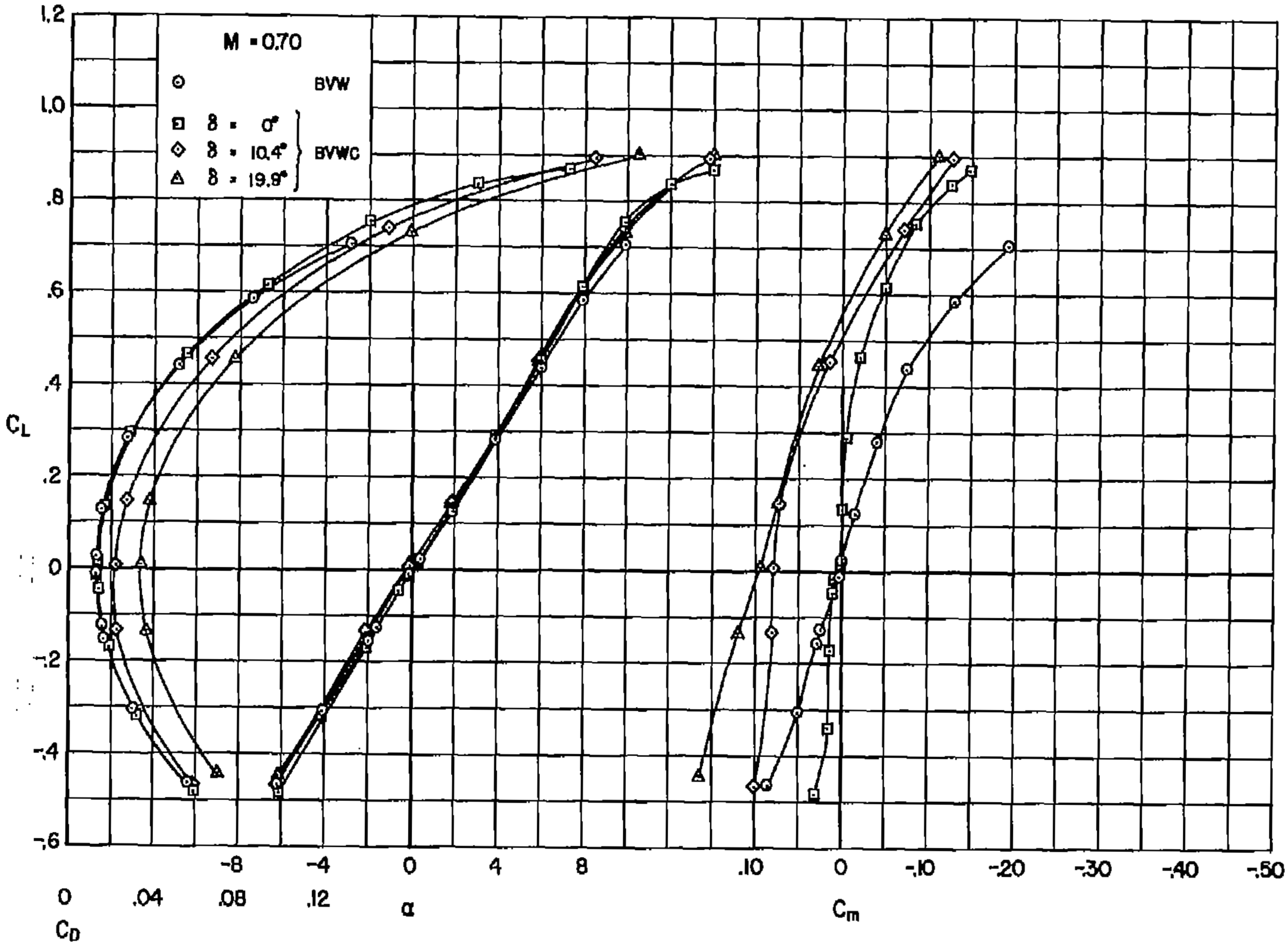
(a) Dimensional sketch of complete model.

Figure 1.- Model details and dimensions.



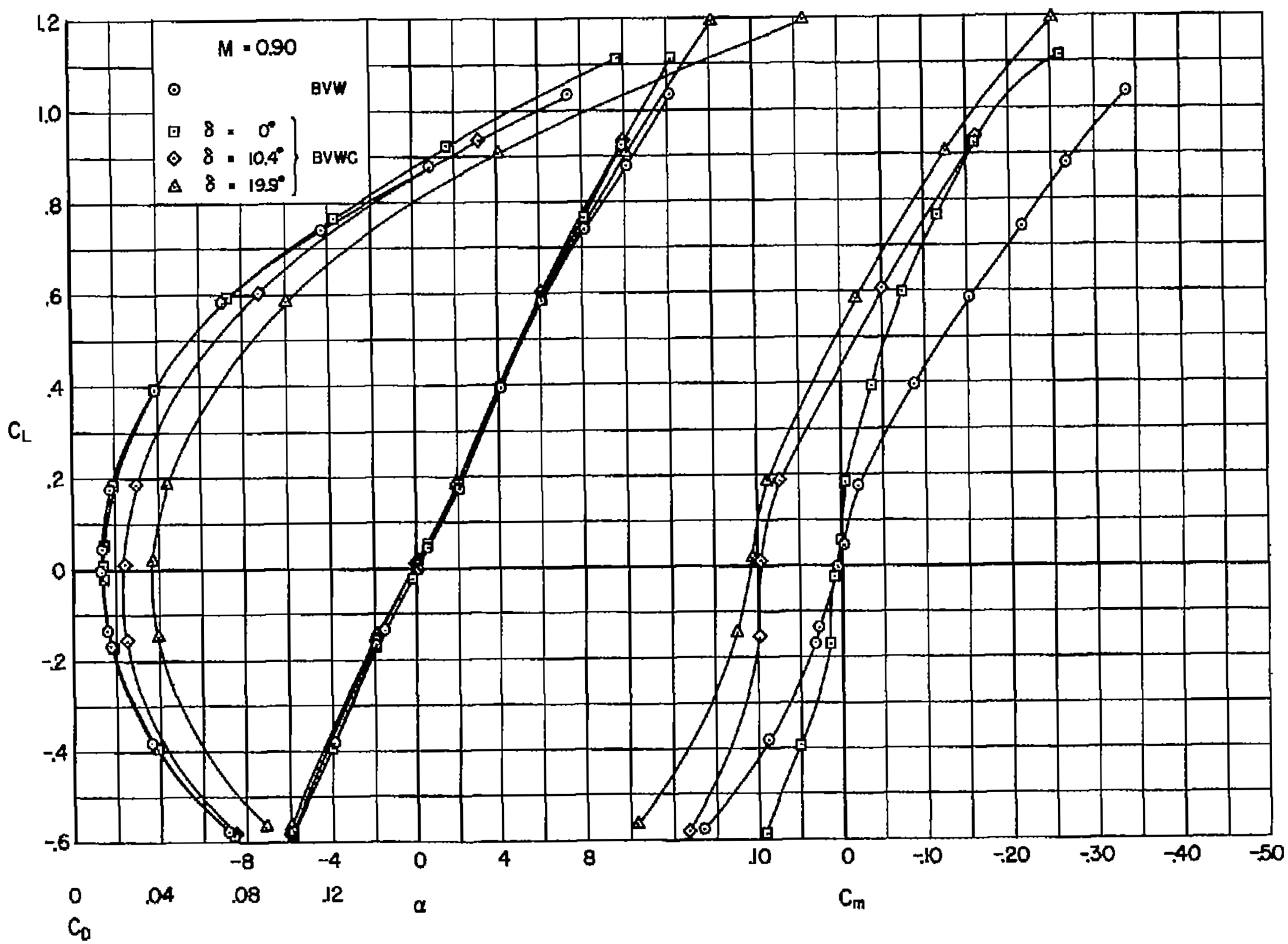
(b) Details of canard surface.

Figure 1.- Concluded.



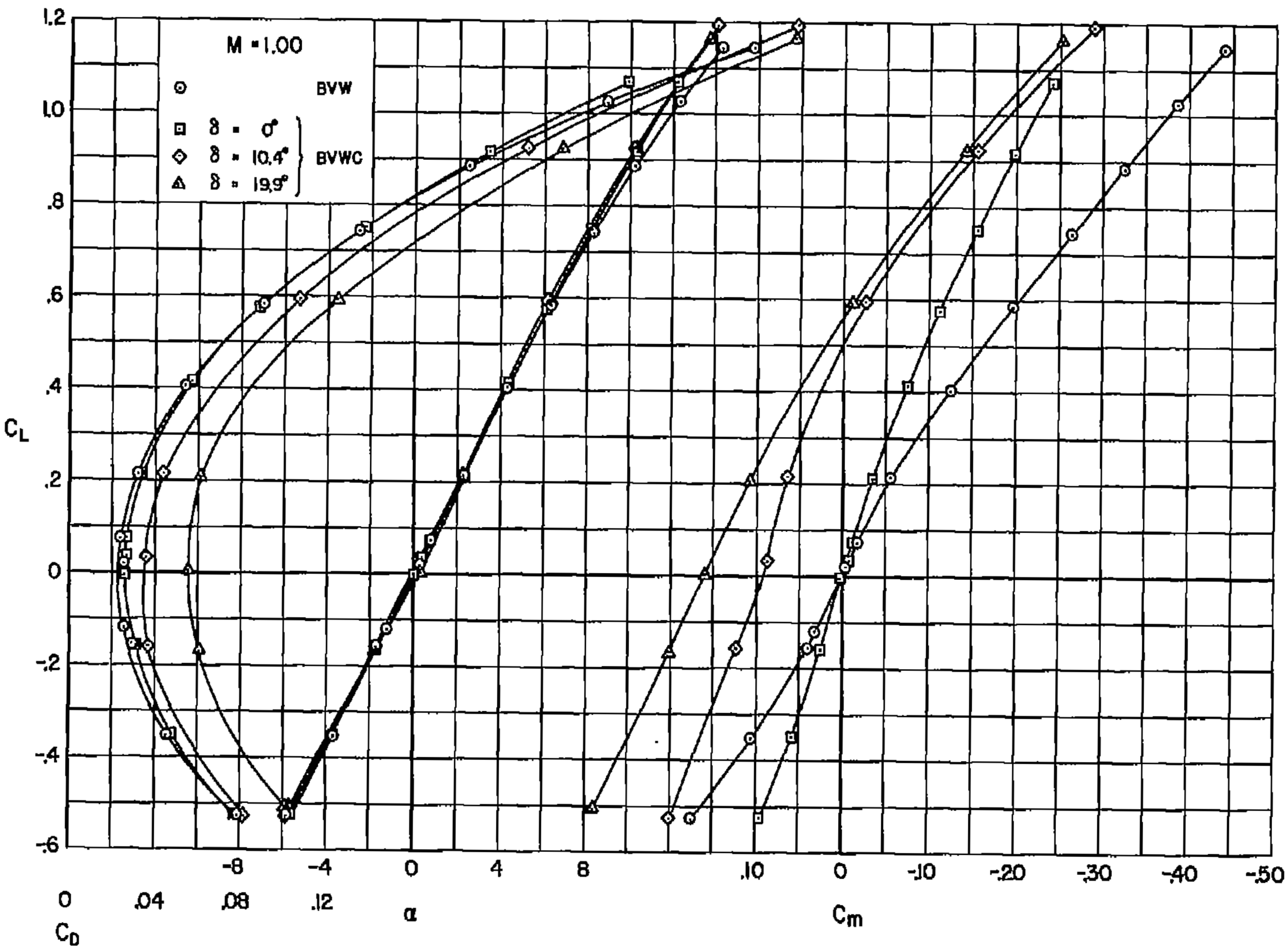
(a) M = 0.70

Figure 2.- Lift, drag, and pitching-moment characteristics for the canard on and deflected and the canard off.



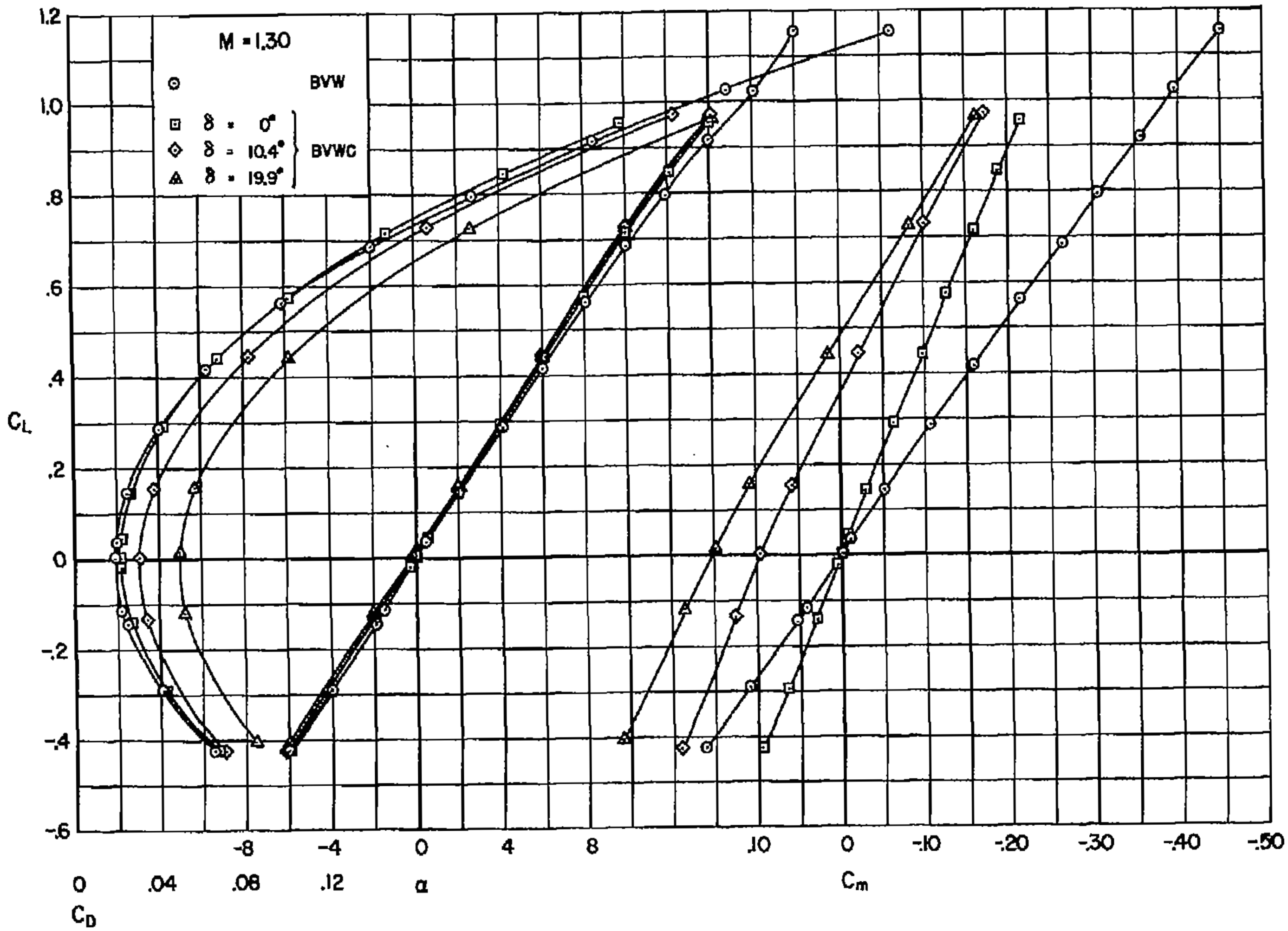
(b) M = 0.90

Figure 2.- Continued.



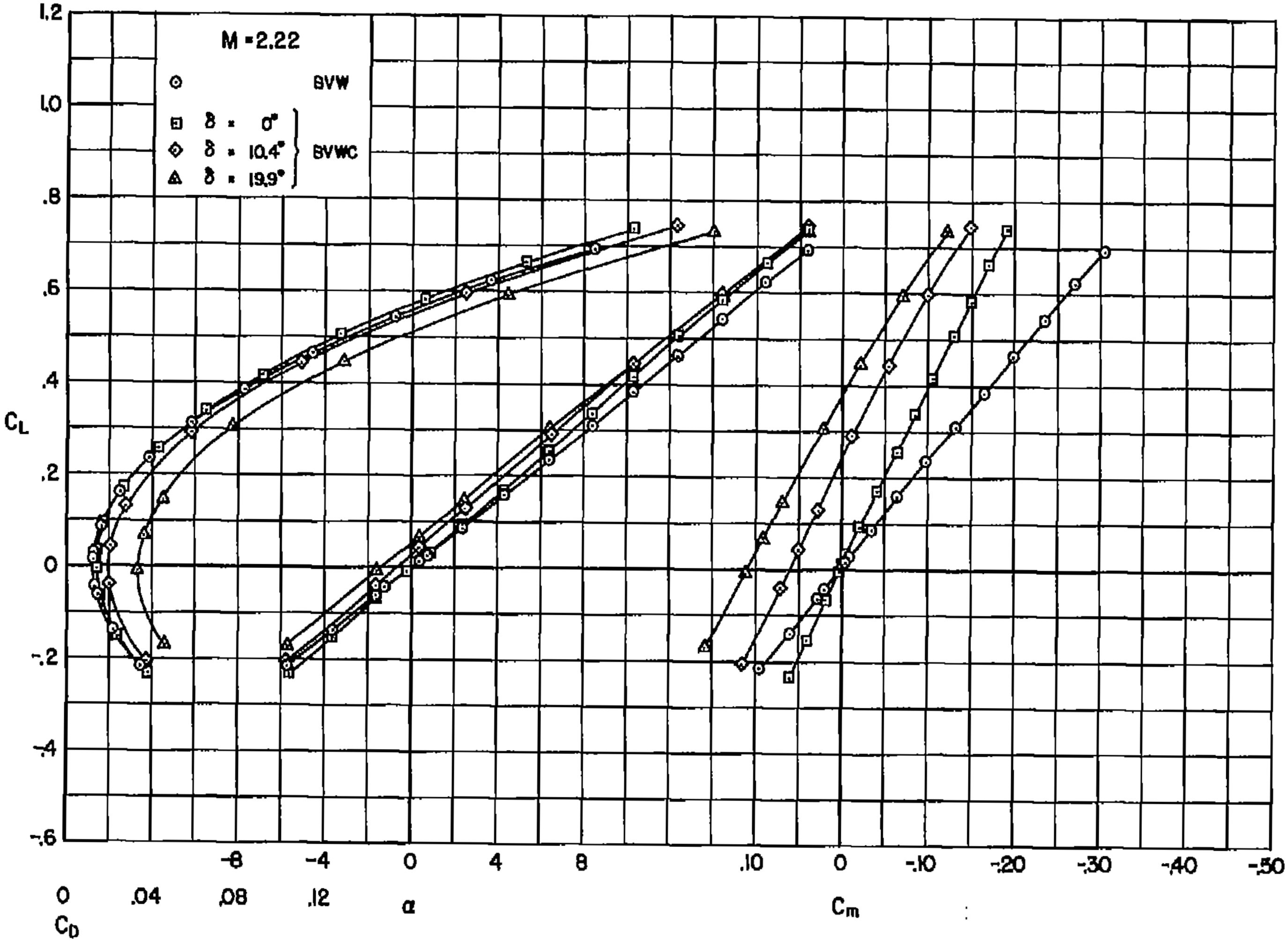
(c) M = 1.00

Figure 2.- Continued.



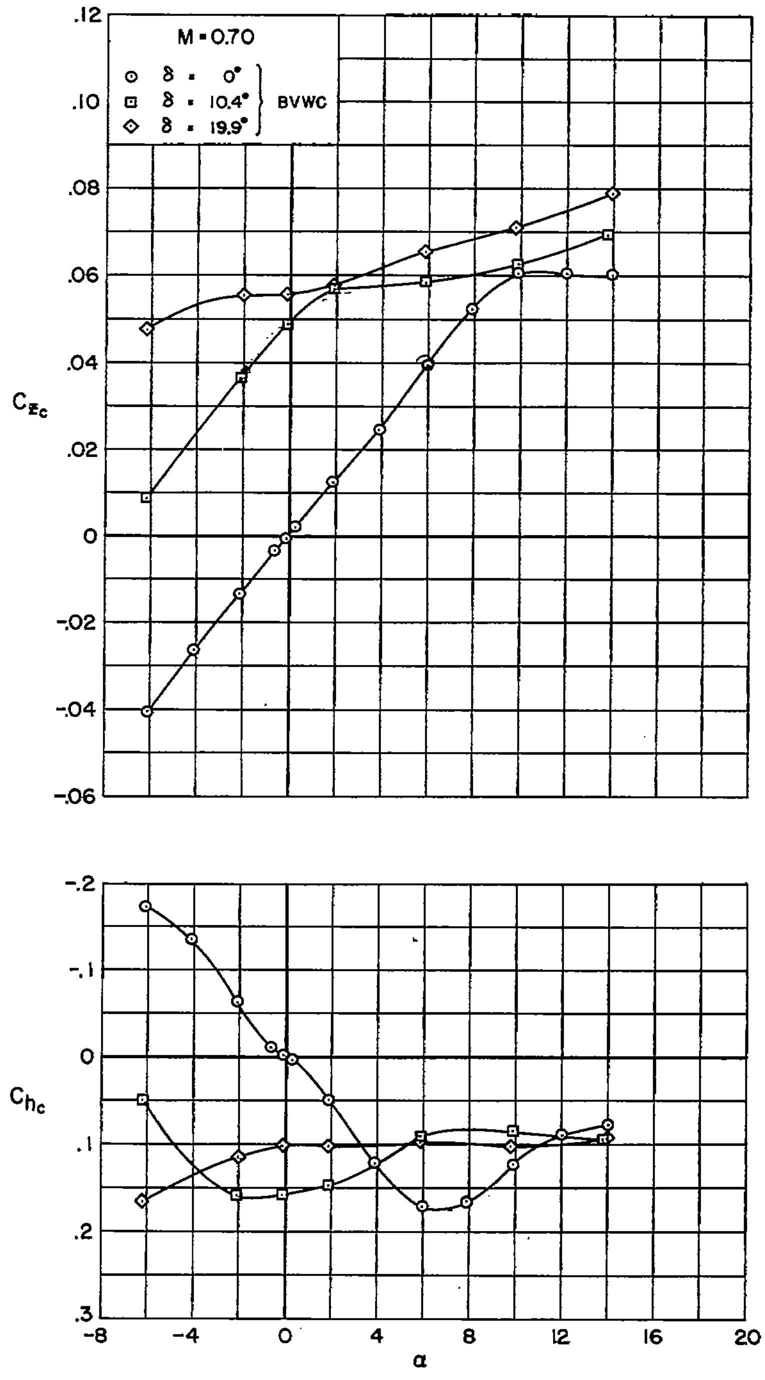
(d) M = 1.30

Figure 2.- Continued.



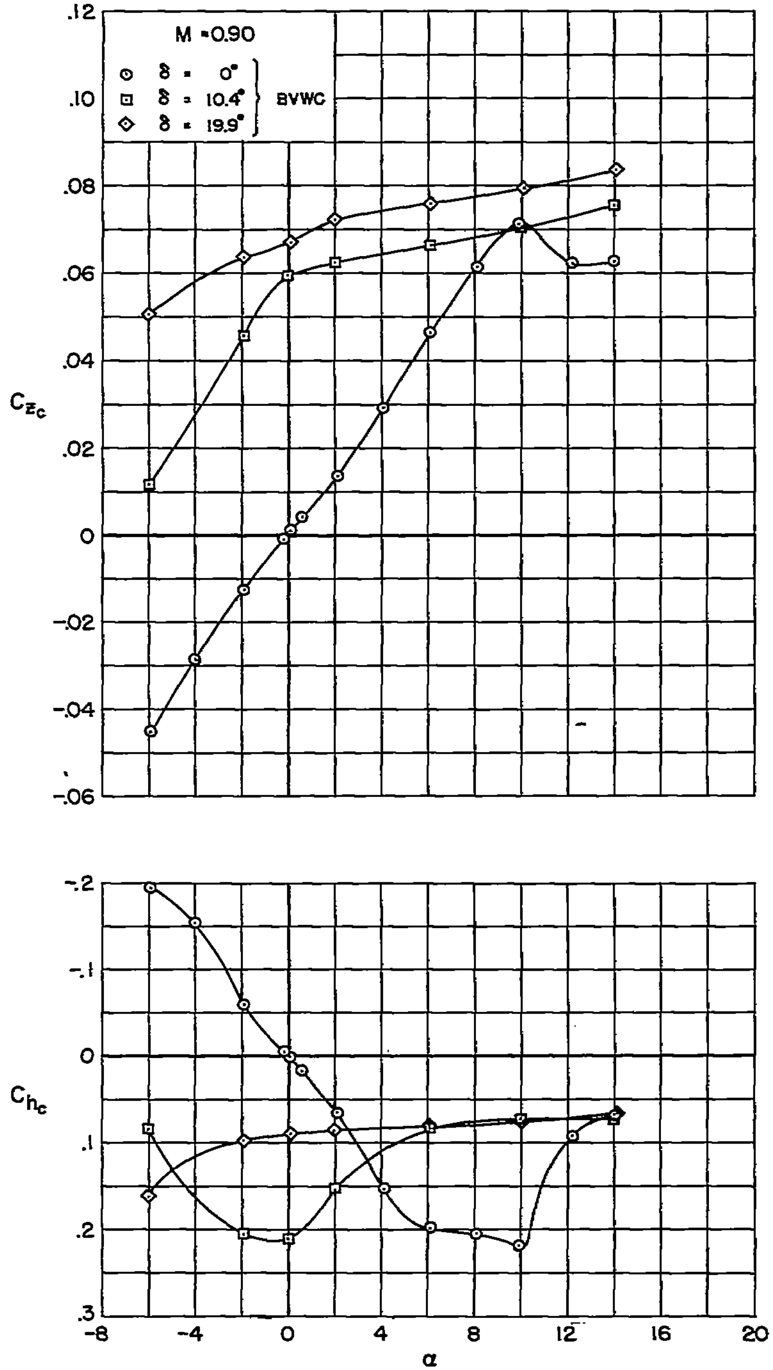
(e) M = 2.22

Figure 2.- Concluded.



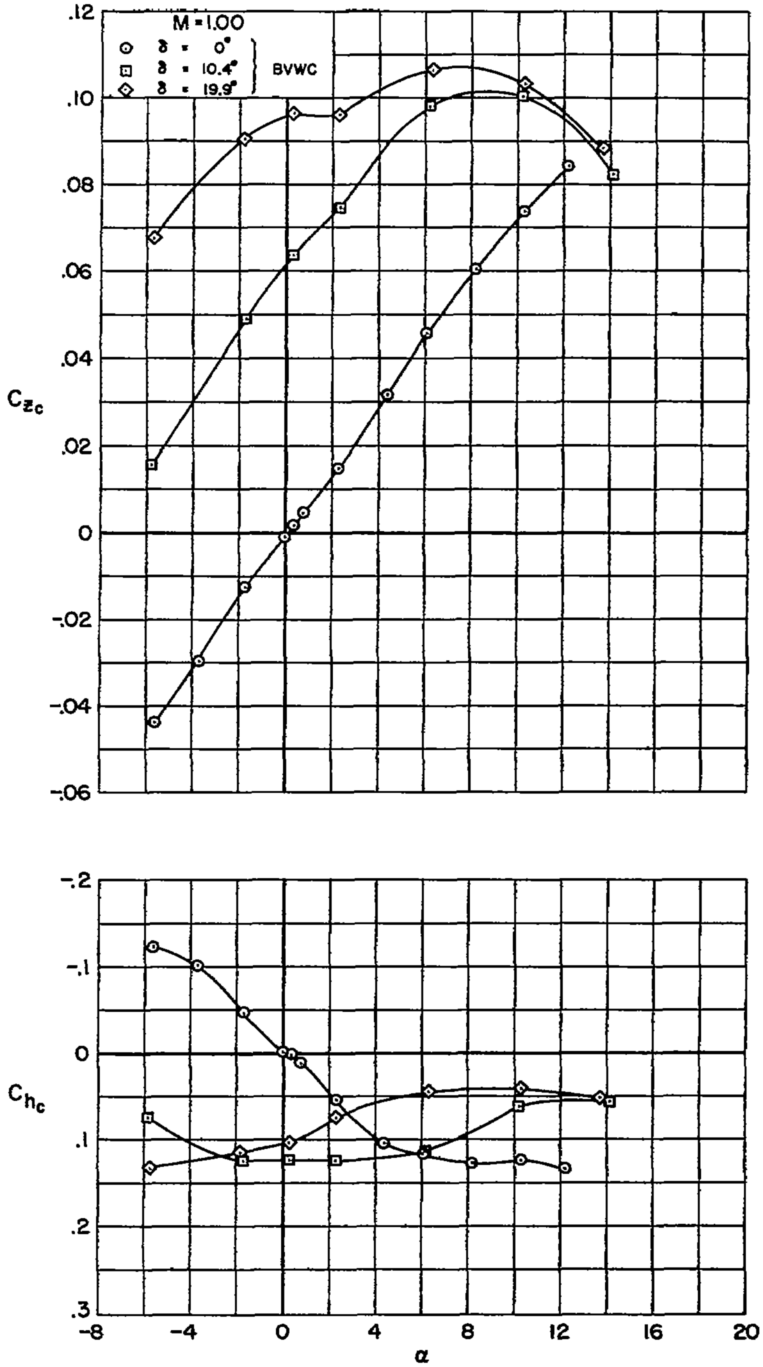
(a) M = 0.70

Figure 3.- Variation of canard normal-force and hinge-moment coefficients as a function of angle of attack at constant canard deflection angles.



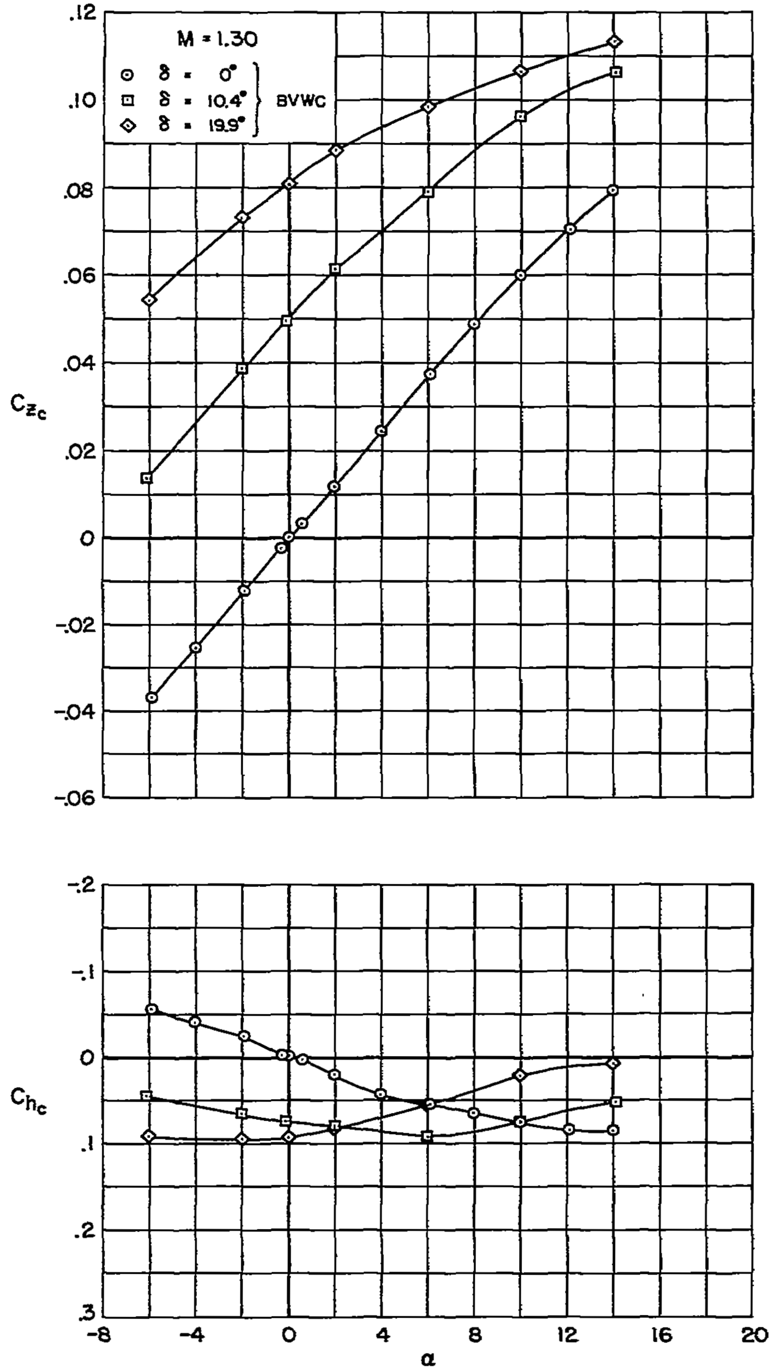
(b) M = 0.90

Figure 3.- Continued.



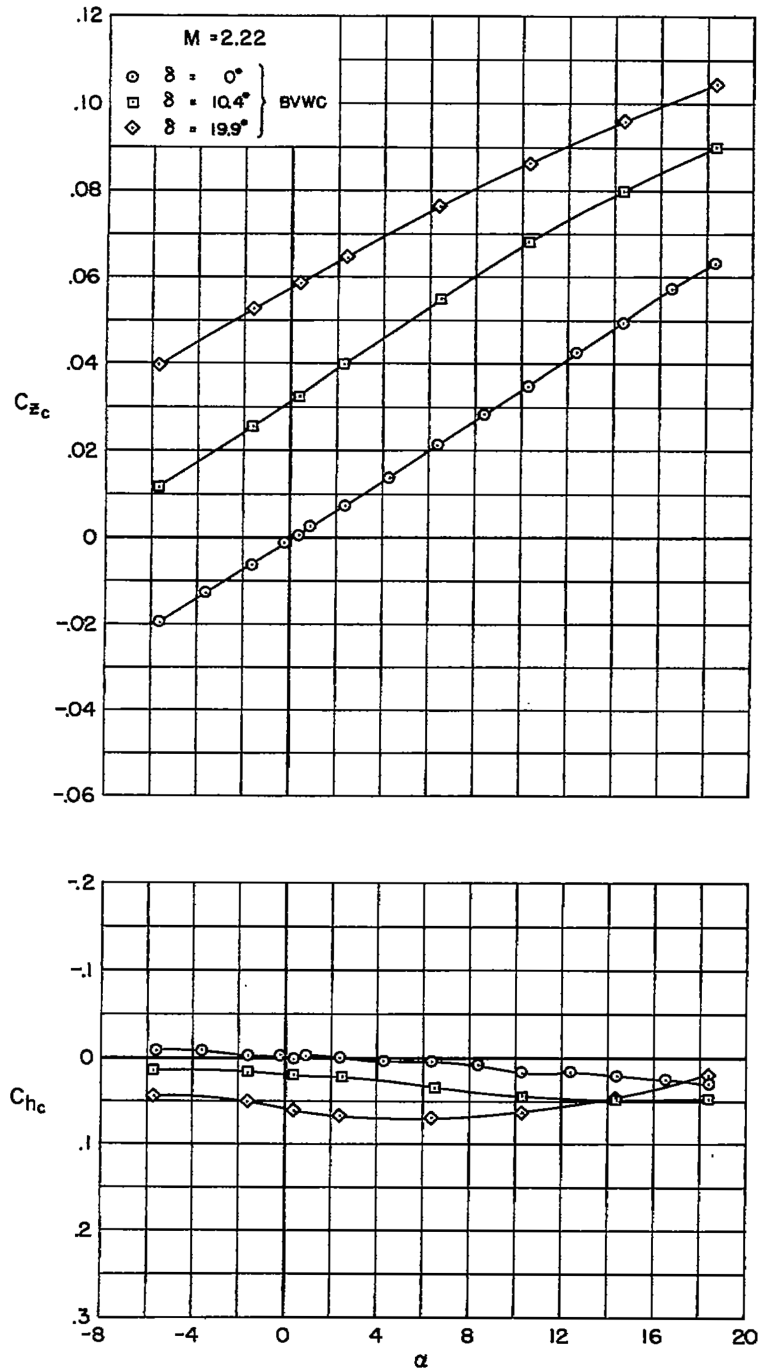
(c) M = 1.00

Figure 3.- Continued.



(d) M = 1.30

Figure 3.- Continued.



(e) M = 2.22

Figure 3.- Concluded.

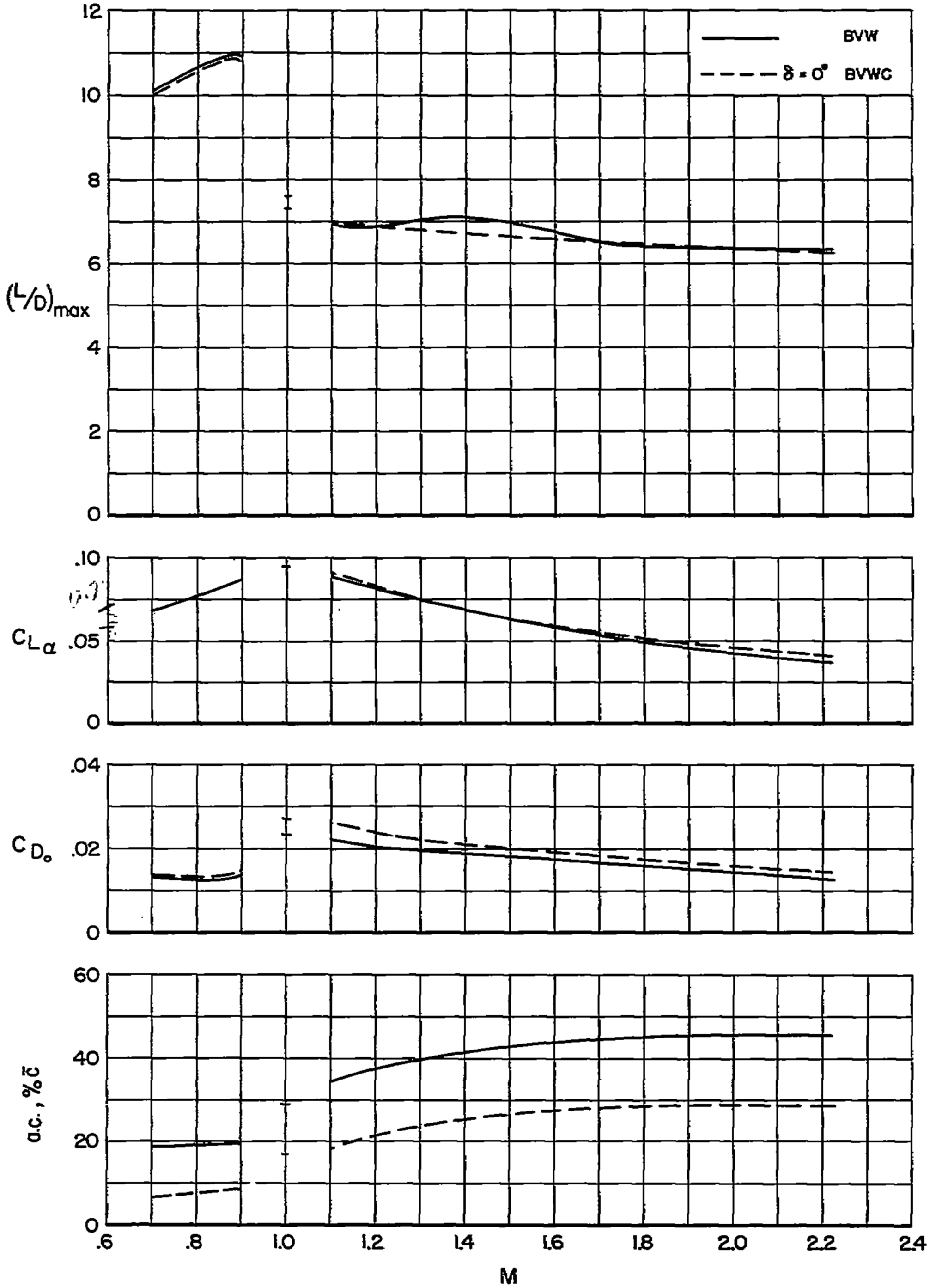


Figure 4.- Variation of maximum lift-drag ratios, lift-curve slopes, minimum drag coefficients, and aerodynamic centers as a function of Mach number for the canard on and off.

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