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AERODYNAMIC CHARACTERISTICS OF A TANDEM WING CONFIGURATION AT A MACH NUMBER OF 0.30

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SUMMARY

An investigation has been conducted to determine the aerodynamic characteristics of a tandem wing configuration. The configuration had a low forward mounted sweptback wing and a high rear mounted sweptforward wing joined at the wing tip by an end plate. The investigation was conducted at a Mach number of 0.30 at angles of attack up to 20°. A comparison of the experimentally determined drag due to lift characteristics with theoretical estimates is also included.

The results of this study indicate that the complete configuration first exhibits wing flow separation at a fairly low angle of attack, about 6°, and complete wing stall at about 12°. The complete configuration exhibits a linear pitching moment coefficient up to wing stall above which a sharp nose down pitching moment occurs. The wing camber surface, which was designed to produce a zero pitching-moment coefficient at the design lift coefficient, resulted in a complete configuration with a small positive pitch. The tandem wing configuration did produce a lower drag due to lift than a single element wing having the same span and area. The complete configuration exhibits directional stability and positive dihedral effect throughout the test angle-of-attack range.

INTRODUCTION

The National Aeronautics and Space Administration is currently conducting wind tunnel studies to provide information for use in developing airplane concepts which possess desirable stability, control, and performance characteristics over a wide range of flight conditions. The present paper discusses a tandem wing concept, which was first studied at the Langley Research Center in the 1950's as a means of achieving good stability and control characteristics. (See ref. 1.) The results of that study were not promising, primarily because of the interference effects between the wing tips. Recently interest has been renewed in this wing concept as a result of the increased performance potential (suggested by the Lockheed Corporation) that may be realized from its application to either fighter-or transport-type aircraft. It can be demonstrated theoretically that the drag due to lift of a wing with a fixed span requirement can be decreased by splitting the wing into a tandem wing arrangement. There are also indications that the tandem wing concept may offer some structural advantages when the wings are joined at the tip by forming a box-type structure, as well as offering possible control advantages. There are, obviously, many unknowns in a design of this type which are beyond the scope of this paper and will not be discussed. A discussion of the application of this wing to transonic transport concept is presented in reference 2.

The purpose of this paper was to study the tandem wing configuration to ascertain if the reduction in drag due to lift suggested by theory could indeed be obtained. A second purpose was to validate a recently developed computer program which described the camber lines of the multiple lifting surfaces.

The study was conducted in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.30 and at angles of attack up to 20°.

SYMBOLS

The results as presented are referred to the stability axis system with the exception of the lift and drag coefficients, which are referred to the wind axis system. The moment reference center was located at a point 40.022 inches rearward of the nose along the model reference lines (see figure 1).

A	wing aspect ratio
b	wing reference span, 12.0 inches
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_m	pitching moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
C_{ℓ_β}	effective dihedral parameter, $\frac{\partial C_\ell}{\partial \beta}$, per deg.
C_{n_β}	directional stability parameter, $\frac{\partial C_n}{\partial \beta}$, per deg.
C_{y_β}	side force parameter, $\frac{\partial C_y}{\partial \beta}$, per deg.
c	local wing chord, inches
$\bar{c}$	wing mean geometric chord, 6.96 inches

L/D   lift-drag ratio, $\frac{C_L}{C_D}$

q   free-stream dynamic pressure, lbs/ft^2

S   wing reference area, 1.14 ft.^{2}

x   distance behind leading edge of wing, inches

y   distance from fuselage center line (measured spanwise), inches

Z   wing airfoil ordinate, inches

α angle of attack, deg.

β angle of sideslip, deg.

n   nondimensionalized spanwise station, $\frac{y}{b/2}$

Subscripts

l   lower

u   upper

MODEL DESCRIPTION

A three-view drawing of the model studied is presented in figure 1 and a photograph of the model in figure 2. The model as illustrated in figure 1 consists of a simple fuselage with two swept wings joined at the wing tip by an end plate. The tandem wing planform was formed by splitting an aspect ratio 3.50 wing in half (down the 50 percent chord line) to form two wing planforms and staggering the wings such that the low forward wing is swept back and the rear high wing is swept forward. The wings were cambered and twisted, (design lift coefficient of 0.35) with a thickness ratio of 6 percent. Ordinates for the cambered airfoils are presented in Tables I and II. The wing panels were jointed at the tip by a flat end plate, having beveled leading and trailing edges. A leading edge maneuvering device was simulated by attaching a thin piece of metal to the wing, as shown in figure 1. The simulated flap was deflected 20° with respect to the wing chord plane.

WING DESIGN PROCEDURE

The main camber surface of the wings was designed by using procedures of reference 3 for a design point corresponding to a lift coefficient of 0.35 at a Mach number of 0.30. The following items were a part of the design considerations.

1. Pitching moment is zero at the design lift coefficient.
2. The vortex drag was minimized for the tandem wing combination at the design lift coefficient.
3. Span loadings on each wing were specified to be composed of the following forms:

$$\sqrt{1 - n^2}, \quad n^2 \sqrt{1 - n^2} \quad \text{and} \quad n^4 \sqrt{1 - n^2}$$

The coefficients were set to match the pitching moment coefficient and lift coefficient constraints and drag minimization.

4. The chord loadings remained unchanged in shape over the wings and were of constant amplitude over the first 50 percent of the chord. The loadings varied linearly over the remainder of the chord to zero at the trailing edge.

TEST AND CORRECTIONS

The investigation was conducted in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.30 corresponding to a Reynolds number per foot of 1.94×10^6. The angle of attack varied from -2° to 20° at sideslip angles of 0° and ±4°. Transition strips 1/8 inches wide of No. 100 carborundum grains were placed at 0.45 inch streamwise from the leading edge of the wings, end plates and vertical tail, and 1.0 inch behind the nose of the fuselage.

Corrections to the model angle of attack have been made for deflections of the balance and sting support system due to aerodynamic load. Pressure measurements obtained from orifices located within the fuselage base cavity were used to adjust the drag coefficient to a condition of free-stream static pressure at the model base.

Jet boundary and blockage corrections were found to be negligible and were not applied to the data.

PRESENTATION OF RESULTS

The basic longitudinal aerodynamic characteristics are presented in figures 3 through 6, the major results summarized in figure 7, and three lateral-directional characteristics in figure 8. As an aid in locating a particular part of the data, the following list of figures is presented:

RESULTS AND DISCUSSION

The effects of the various model components on the longitudinal aerodynamic characteristics of the configuration are presented in figures 3 (forward wing removed first) and 4 (rear wing removed first). The data for the complete configuration illustrates that flow separation first occurs on the wing at a fairly low angle of attack, about 6°, with complete wing stall occurring at approximately 12°. The complete configuration exhibits a linear pitching moment coefficient up to wing stall above which a sharp nose down pitching moment occurs. It should be noted that the configuration with the rear wing only (forward wing removed) exhibits a pitch-up (see figure 3) at wing stall as does the configuration with the forward wing only (see figure 4). The tandem wing combination, however, illustrates a nose down pitching moment.

The tandem wing combination was designed and constructed without any consideration given to the design or integration of the end plates with the wings. The primary effects of these end plates, as would be expected (see figure 5), is to increase the drag over the entire lift coefficient range and reduce the stability level slightly. With proper integration (that is, cambering and twisting the end plates considering the interference effects of the wing on the end plates and the end plates on the wing), the end plates should provide a reduction in the drag due to lift of the configuration.

The tandem wing combination (without end plates) was designed to produce zero pitching moment coefficient at the design lift coefficient. As illustrated by the data of figure 5, zero pitching moment coefficient occurred at a lift coefficient of about 0.30. The fuselage used during this study was considerably longer than the fuselage used in the design of the configuration. The longer fuselage accounts for about half the positive pitching moment that is seen to exist at the design lift coefficient.

Leading-edge flap deflection by delaying flow separation over the wing, resulted in an increase in lift at the higher angles of attack accompanied by the expected decrease in drag due to lift. Even though the drag due to lift was decreased, the maximum lift drag ratio remained approximately the same.

A properly designed tandem wing configuration should exhibit lower drag due to lift than a single element wing having the same span or area. The theoretical estimates (made using procedures of reference 3 and presented in figure 7) illustrate the magnitude of the expected reduction. The solid line is the estimate for the tandem wing configuration and the dashed line for the configuration with the aspect ratio 3.5 wing (wing with same span and area as the tandem wings). The drag at zero lift, in these estimates, was obtained by using the experimental drag data for the fuselage and vertical tail and an estimate of the friction plus form drag for the wings.

The experimental data agrees extremely well with the estimated data up to lift coefficient slightly above the design lift coefficient. Above the design lift coefficient flow separation occurs on the wings and the drag increases drastically. The implication of these data is that the computer program is indeed a viable tool to use in the design of optimum wing shapes for specific aircraft concepts. These data also illustrate the potential reduction in drag which is obtained, for wings with a fixed span, by utilizing the tandem wing concept.

The complete configuration exhibits directional stability and positive dihedral effect throughout the test angle of attack range. Removing the end plates results in a positive increment in C_{n_β} through out the test angle-of-attack range. It is not particularly surprising that the end plates contribute a destabilizing moment since the surfaces are located relatively far forward on the fuselage.

CONCLUSIONS

A wind tunnel study has been made to determine the aerodynamic characteristics of a tandem wing configuration. As a result of this program, several conclusions can be made:

1. The complete configuration first exhibits wing flow separation at a fairly low angle of attack, about 6°, and complete wing stall at about 12°. The complete configuration exhibits a linear pitching-moment coefficient up to wing stall above which a sharp nose down pitching moment occurs.
2. The wing camber surface, which was designed to produce a zero pitching-moment coefficient at the design lift coefficient, resulted in a complete configuration with a small positive pitch.
3. The tandem wing configuration did produce a lower drag due to lift than a single element wing having the same span and area, and the experimental data agreed extremely well with the theoretical estimate.
4. The complete configuration exhibits directional stability and positive dihedral effect throughout the test angle-of-attack range.

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3. Lamar, John E.: Application of Vortex Lattice Methodology for Predicting Mean Camber Shapes of Two-Trimmed-Non Coplanar-Complex Planforms with Minimum Induced Drag at Design Lift. NASA TN D-3090

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Table I. - Ordinates of Forward Wing

x/c	y/b/2 = 0.156, $c/\bar{c}$ = 0.573		y/b/2 = 0.253, $c/\bar{c}$ = 0.554		y/b/2 = 0.300, $c/\bar{c}$ = 0.538		y/b/2 = 0.367, $c/\bar{c}$ = 0.522		y/b/2 = 0.433, $c/\bar{c}$ = 0.506		y/b/2 = 0.500, $c/\bar{c}$ = 0.490		y/b/2 = 0.567, $c/\bar{c}$ = 0.474	
	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c
0.000	0.0867	0.0867	0.0506	0.0506	0.0434	0.0434	0.0381	0.0381	0.0339	0.0339	0.0302	0.0302	0.0266	0.0266
.005	.0917	.0824	.0553	.0461	.0482	.0389	.0429	.0337	.0387	.0294	.0350	.0257	.0313	.0221
.008	.0929	.0817	.0564	.0452	.0493	.0381	.0441	.0329	.0397	.0285	.0360	.0248	.0324	.0212
.013	.0945	.0802	.0580	.0437	.0509	.0367	.0456	.0314	.0413	.0271	.0377	.0234	.0342	.0199
.025	.0973	.0777	.0608	.0413	.0538	.0342	.0486	.0290	.0446	.0249	.0409	.0213	.0373	.0177
.050	.1013	.0751	.0647	.0384	.0577	.0315	.0526	.0264	.0486	.0224	.0450	.0188	.0416	.0154
.075	.1046	.0728	.0678	.0359	.0610	.0292	.0560	.0242	.0521	.0203	.0486	.0168	.0452	.0134
.100	.1073	.0709	.0705	.0340	.0637	.0273	.0589	.0224	.0551	.0187	.0518	.0153	.0483	.0119
.150	.1112	.0674	.0745	.0307	.0681	.0243	.0635	.0197	.0600	.0162	.0568	.0130	.0535	.0097
.200	.1137	.0643	.0774	.0280	.0714	.0220	.0671	.0177	.0637	.0143	.0607	.0113	.0576	.0082
.250	.1147	.0610	.0809	.0273	.0737	.0201	.0696	.0160	.0664	.0128	.0636	.0100	.0607	.0071
.300	.1144	.0576	.0817	.0249	.0749	.0181	.0711	.0143	.0682	.0114	.0655	.0087	.0628	.0060
.350	.1126	.0538	.0814	.0226	.0750	.0162	.0715	.0127	.0688	.0100	.0664	.0075	.0638	.0050
.400	.1096	.0496	.0800	.0200	.0741	.0141	.0709	.0109	.0685	.0085	.0662	.0062	.0638	.0038
.450	.1051	.0453	.0775	.0176	.0720	.0122	.0691	.0093	.0668	.0070	.0648	.0050	.0626	.0028
.500	.0993	.0407	.0737	.0151	.0688	.0102	.0662	.0076	.0642	.0056	.0623	.0037	.0604	.0018
.550	.0921	.0361	.0688	.0128	.0644	.0084	.0621	.0061	.0603	.0043	.0587	.0027	.0569	.0009
.600	.0838	.0316	.0629	.0107	.0590	.0068	.0570	.0048	.0554	.0032	.0540	.0018	.0525	.0003
.650	.0745	.0271	.0561	.0087	.0530	.0054	.0510	.0036	.0497	.0023	.0485	.0011	.0471	-.0003
.700	.0644	.0225	.0487	.0068	.0460	.0041	.0444	.0026	.0434	.0014	.0424	.0004	.0413	-.0006
.750	.0539	.0183	.0409	.0053	.0386	.0030	.0374	.0018	.0364	.0008	.0356	.0000	.0347	-.0009
.800	.0430	.0141	.0327	.0039	.0309	.0021	.0299	.0010	.0292	.0003	.0285	-.0003	.0278	-.0010
.850	.0321	.0103	.0244	.0026	.0231	.0013	.0224	.0006	.0219	.0001	.0214	-.0004	.0209	-.0009
.900	.0212	.0066	.0162	.0016	.0153	.0007	.0148	.0002	.0145	.0000	.0142	-.0004	.0138	-.0008
.950	.0105	.0031	.0080	.0006	.0076	.0002	.0074	.0000	.0072	-.0002	.0071	-.0003	.0069	-.0005
1.000	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001

Table I. - Concluded

x/c	y/b/2 = 0.633, $\frac{c}{\bar{c}}$ = 0.458		y/b/2 = 0.700, $\frac{c}{\bar{c}}$ = 0.442		y/b/2 = 0.767, $\frac{c}{\bar{c}}$ = 0.426		y/b/2 = 0.833, $\frac{c}{\bar{c}}$ = 0.410		y/b/2 = 0.900, $\frac{c}{\bar{c}}$ = 0.394		y/b/2 = 0.967, $\frac{c}{\bar{c}}$ = 0.378	
	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c
0.000	0.0227	0.0227	0.0182	0.0182	0.0130	0.0130	0.0067	0.0067	-0.0027	-0.0027	-0.0584	-0.0584
.005	.0278	.0186	.0233	.0141	.0178	.0085	.0116	.0023	.0022	-.0072	-.0534	-.0626
.008	.0288	.0177	.0244	.0132	.0189	.0077	.0126	.0014	.0033	-.0078	-.0523	-.0635
.013	.0306	.0163	.0261	.0118	.0206	.0063	.0144	.0001	.0050	-.0093	-.0505	-.0648
.025	.0336	.0140	.0291	.0095	.0239	.0043	.0177	-.0019	.0083	-.0113	-.0472	-.0668
.050	.0378	.0116	.0334	.0072	.0283	.0021	.0221	-.0041	.0130	-.0133	-.0424	-.0686
.075	.0416	.0098	.0372	.0054	.0321	.0003	.0260	-.0058	.0168	-.0168	-.0382	-.0700
.100	.0447	.0083	.0406	.0041	.0354	-.0010	.0294	-.0071	.0203	-.0161	-.0344	-.0708
.150	.0501	.0063	.0459	.0021	.0410	-.0028	.0351	-.0087	.0262	-.0176	-.0277	-.0715
.200	.0543	.0049	.0503	.0009	.0455	-.0039	.0397	-.0097	.0311	-.0183	-.0219	-.0713
.250	.0575	.0039	.0537	.0000	.0491	-.0045	.0435	-.0101	.0351	-.0185	-.0166	-.0702
.300	.0598	.0030	.0561	-.0007	.0517	-.0051	.0464	-.0104	.0383	-.0185	-.0119	-.0687
.350	.0610	.0022	.0575	-.0013	.0533	-.0055	.0482	-.0106	.0407	-.0183	-.0076	-.0666
.400	.0612	.0012	.0580	-.0020	.0541	-.0059	.0493	-.0107	.0421	-.0179	-.0040	-.0640
.450	.0602	.0004	.0572	-.0026	.0536	-.0062	.0492	-.0106	.0425	-.0173	-.0010	-.0608
.500	.0582	-.0004	.0555	-.0031	.0544	-.0065	.0481	-.0105	.0420	-.0166	.0014	-.0571
.550	.0549	-.0010	.0525	-.0035	.0496	-.0064	.0459	-.0101	.0404	-.0155	.0031	-.0529
.600	.0507	-.0015	.0486	-.0036	.0460	-.0062	.0428	-.0073	.0380	-.0142	.0041	-.0480
.650	.0457	-.0017	.0438	-.0036	.0416	-.0058	.0388	-.0086	.0347	-.0127	.0046	-.0428
.700	.0400	-.0019	.0384	-.0034	.0365	-.0054	.0342	-.0076	.0307	-.0112	.0047	-.0373
.750	.0337	-.0019	.0324	-.0032	.0309	-.0047	.0291	-.0065	.0263	-.0093	.0043	-.0313
.800	.0271	-.0017	.0261	-.0027	.0249	-.0039	.0235	-.0054	.0214	-.0076	.0037	-.0253
.850	.0203	-.0015	.0196	-.0022	.0187	-.0031	.0177	-.0041	.0162	-.0056	.0029	-.0189
.900	.0135	-.0011	.0130	-.0016	.0125	-.0021	.0118	-.0028	.0108	-.0038	.0019	-.0127
.950	.0067	-.0007	.0065	-.0009	.0063	-.0011	.0060	-.0014	.0055	-.0019	.0010	-.0064
1.000	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001

Table III. - Ordinates of Rear Wing

x/c	y/b/2 = 0.024, $c/\bar{c}$ = 0.605		y/b/2 = 0.065, $c/\bar{c}$ = 0.595		y/b/2 = 0.087, $c/\bar{c}$ = 0.590		y/b/2 = 0.102, $c/\bar{c}$ = 0.586		y/b/2 = 0.156, $c/\bar{c}$ = 0.573		y/b/2 = 0.233, $c/\bar{c}$ = 0.554	
	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c
0.000	0.0003	0.0003	0.0277	0.0277	0.0361	0.0361	0.0425	0.0425	0.0500	0.0500	0.0583	0.0583
.005	.0052	-.0040	.0325	.0233	.0408	.0316	.0472	.0380	.0546	.0454	.0629	.0537
.008	.0064	-.0048	.0336	.0224	.0419	.0307	.0483	.0371	.0557	.0445	.0640	.0528
.013	.0082	-.0061	.0353	.0210	.0435	.0292	.0499	.0357	.0573	.0430	.0656	.0513
.025	.0117	-.0079	.0384	.0188	.0465	.0269	.0528	.0332	.0602	.0406	.0683	.0487
.050	.0168	-.0095	.0425	.0163	.0504	.0242	.0567	.0305	.0639	.0377	.0719	.0456
.075	.0211	-.0107	.0462	.0144	.0538	.0220	.0600	.0282	.0670	.0352	.0749	.0431
.100	.0251	-.0113	.0493	.0129	.0567	.0203	.0627	.0263	.0696	.0332	.0773	.0409
.150	.0320	-.0118	.0546	.0108	.0616	.0178	.0673	.0235	.0738	.0330	.0812	.0374
.200	.0379	-.0115	.0589	.0095	.0654	.0160	.0709	.0215	.0769	.0275	.0839	.0345
.250	.0431	-.0106	.0622	.0086	.0683	.0147	.0734	.0198	.0790	.0254	.0857	.0321
.300	.0472	-.0096	.0647	.0079	.0702	.0134	.0751	.0183	.0802	.0234	.0865	.0297
.350	.0503	-.0085	.0661	.0073	.0711	.0123	.0756	.0168	.0802	.0213	.0861	.0272
.400	.0524	-.0076	.0665	.0065	.0710	.0110	.0751	.0151	.0793	.0193	.0847	.0247
.450	.0533	-.0065	.0656	.0058	.0696	.0098	.0734	.0136	.0070	.0172	.0819	.0221
.500	.0530	-.0056	.0636	.0050	.0671	.0085	.0705	.0119	.0737	.0151	.0781	.0195
.550	.0514	-.0046	.0604	.0044	.0634	.0074	.0664	.0104	.0691	.0131	.0731	.0171
.600	.0486	-.0036	.0560	.0038	.0586	.0064	.0612	.0090	.0635	.0113	.0669	.0147
.650	.0447	-.0027	.0507	.0033	.0528	.0054	.0551	.0077	.0569	.0095	.0598	.0124
.700	.0400	-.0019	.0446	.0028	.0463	.0044	.0482	.0064	.0496	.0078	.0522	.0103
.750	.0344	-.0012	.0379	.0023	.0391	.0035	.0407	.0051	.0418	.0062	.0438	.0082
.800	.0282	-.0007	.0306	.0018	.0316	.0027	.0328	.0039	.0335	.0046	.0352	.0063
.850	.0214	-.0004	.0231	.0013	.0237	.0019	.0246	.0028	.0251	.0033	.0262	.0044
.900	.0145	-.0001	.0154	.0008	.0158	.0012	.0164	.0018	.0167	.0021	.0174	.0028
.950	.0073	-.0001	.0077	.0003	.0079	.0005	.0082	.0076	.0083	.0009	.0086	.0012
1.000	.0001	-.0001	.0001	-.0001	.0001	.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001

Table II. - Continued

x/c	y/b/2 = 0.300 $\frac{c}{\bar{c}}$ = 0.538		y/b/2 = 0.367 $\frac{c}{\bar{c}}$ = 0.522		y/b/2 = 0.433 $\frac{c}{\bar{c}}$ = 0.506		y/b/2 = 0.500 $\frac{c}{\bar{c}}$ = 0.490		y/b/2 = 0.567 $\frac{c}{\bar{c}}$ = 0.474		y/b/2 = 0.633 $\frac{c}{\bar{c}}$ = 0.458	
	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c
0.000	0.0630	0.0630	0.0664	0.0664	0.0688	0.0688	0.0705	0.0705	0.0716	0.0716	0.0723	0.0723
.005	.0676	.0584	.0710	.0618	.0734	.0642	.0751	.0659	.0762	.0670	.0769	.0677
.008	.0687	.0574	.0720	.0608	.0755	.0632	.0761	.0649	.0772	.0660	.0778	.0667
.013	.0702	.0560	.0736	.0593	.0759	.0617	.0776	.0633	.0788	.0644	.0794	.0651
.025	.0730	.0534	.0763	.0567	.0786	.0590	.0803	.0607	.0814	.0618	.0820	.0624
.050	.0765	.0503	.0797	.0535	.0820	.0558	.0836	.0574	.0847	.0585	.0852	.0592
.075	.0794	.0476	.0826	.0508	.0848	.0530	.0864	.0546	.0874	.0556	.0879	.0561
.100	.0818	.0454	.0849	.0485	.0870	.0506	.0886	.0522	.0895	.0531	.0900	.0536
.150	.0855	.0417	.0885	.0447	.0905	.0467	.0919	.0481	.0928	.0490	.0931	.0493
.200	.0881	.0387	.0909	.0415	.0929	.0435	.0942	.0448	.0950	.0456	.0952	.0458
.250	.0896	.0360	.0923	.0387	.0942	.0406	.0954	.0418	.0960	.0424	.0961	.0426
.300	.0902	.0334	.0927	.0359	.0944	.0376	.0956	.0388	.0961	.0393	.0961	.0393
.350	.0949	.0306	.0919	.0330	.0935	.0347	.0945	.0357	.0950	.0362	.0950	.0362
.400	.0879	.0279	.0901	.0301	.0916	.0316	.0925	.0325	.0929	.0329	.0928	.0328
.450	.0849	.0251	.0870	.0272	.0883	.0285	.0891	.0293	.0894	.0296	.0893	.0295
.500	.0808	.0222	.0827	.0241	.0839	.0253	.0846	.0260	.0849	.0263	.0847	.0261
.550	.0755	.0195	.0772	.0212	.0783	.0223	.0789	.0229	.0791	.0231	.0788	.0228
.600	.0690	.0168	.0705	.0183	.0715	.0193	.0720	.0198	.0722	.0200	.0719	.0197
.650	.0617	.0143	.0630	.0156	.0638	.0164	.0643	.0169	.0644	.0170	.0641	.0167
.700	.0537	.0117	.0547	.0129	.0554	.0135	.0558	.0140	.0560	.0141	.0558	.0138
.750	.0451	.0095	.0460	.0104	.0465	.0109	.0469	.0113	.0469	.0113	.0467	.0111
.800	.0361	.0073	.0368	.0080	.0372	.0083	.0375	.0087	.0375	.0057	.0374	.0086
.850	.0270	.0052	.0275	.0057	.0278	.0060	.0280	.0062	.0280	.0062	.0279	.0061
.900	.0179	.0033	.0182	.0036	.0184	.0036	.0185	.0039	.0186	.0040	.0185	.0039
.950	.0089	.0015	.0091	.0017	.0092	.0018	.0092	.0012	.0092	.0018	.0092	.0018
1.000	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001

Table II. - Concluded

x/c	y/b/2 = 0.700 $\frac{c}{\bar{c}}$ = 0.442		y/b/2 = 0.767 $\frac{c}{\bar{c}}$ = 0.426		y/b/2 = 0.833 $\frac{c}{\bar{c}}$ = 0.410		y/b/2 = 0.900 $\frac{c}{\bar{c}}$ = 0.394		y/b/2 = 0.967 $\frac{c}{\bar{c}}$ = 0.378	
	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c	Z_u/c	Z_L/c
0.000	0.0721	0.0721	0.0715	0.0715	0.0704	0.0704	0.0689	0.0689	0.0420	0.0420
.005	.0767	.0674	.0761	.0669	.0749	.0657	.0734	.0642	.0465	.0373
.008	.0776	.0664	.0770	.0658	.0759	.0647	.0743	.0631	.0475	.0363
.013	.0792	.0649	.0785	.0642	.0774	.0631	.0758	.0615	.0490	.0347
.025	.0818	.0622	.0811	.0615	.0800	.0604	.0783	.0587	.0515	.0319
.050	.0850	.0588	.0842	.0580	.0830	.0568	.0812	.0550	.0545	.0283
.075	.0876	.0558	.0867	.0546	.0854	.0536	.0835	.0517	.0569	.0251
.100	.0897	.0532	.0887	.0523	.0873	.0509	.0853	.0489	.0588	.0224
.150	.0927	.0489	.0916	.0478	.0901	.0463	.0878	.0440	.0615	.0177
.200	.0946	.0452	.0934	.0440	.0917	.0423	.0892	.0398	.0632	.0138
.250	.0955	.0419	.0942	.0406	.0922	.0386	.0895	.0359	.0640	.0104
.300	.0954	.0386	.0940	.0372	.0919	.0351	.0890	.0322	.0640	.0072
.350	.0941	.0353	.0926	.0338	.0905	.0317	.0875	.0285	.0632	.0043
.400	.0919	.0319	.0903	.0303	.0881	.0281	.0850	.0250	.0618	.0018
.450	.0884	.0286	.0868	.0270	.0846	.0248	.0814	.0216	.0594	-.0005
.500	.0838	.0252	.0822	.0236	.0800	.0214	.0770	.0184	.0563	-.0022
.550	.0779	.0219	.0765	.0205	.0744	.0184	.0714	.0154	.0523	-.0037
.600	.0711	.0189	.069.	.0175	.0678	.0156	.0650	.0128	.0476	-.0046
.650	.0634	.0161	.0621	.0147	.0603	.0129	.0578	.0104	.0424	-.0050
.700	.0551	.0132	.0513	.0120	.0523	.0105	.0502	.0082	.0367	-.0053
.750	.0461	.0105	.0452	.0096	.0439	.0083	.0420	.0064	.0306	-.0050
.800	.0369	.0080	.0361	.0073	.0351	.0062	.0335	.0046	.0244	-.0044
.850	.0276	.0058	.0270	.0052	.0262	.0044	.0250	.0032	.0182	-.0036
.900	.0182	.0036	.0179	.0033	.0173	.0027	.0166	.0020	.0120	-.0025
.950	.0091	.0017	.0089	.0015	.0086	.0012	.0082	.0008	.0060	-.0014
1.000	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001	.0001	-.0001

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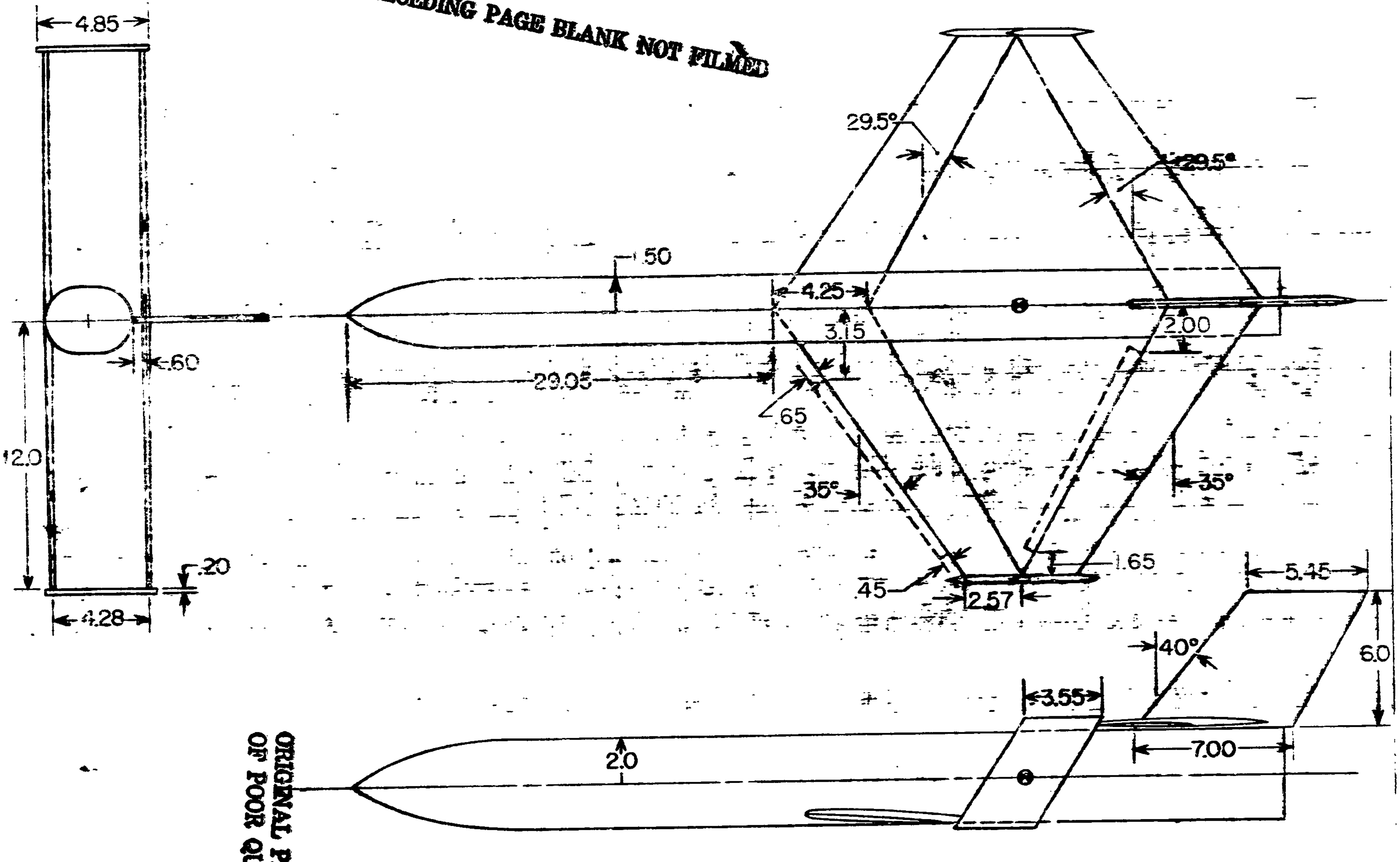

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Figure 1. Drawing of model studied (all dimensions in inches).

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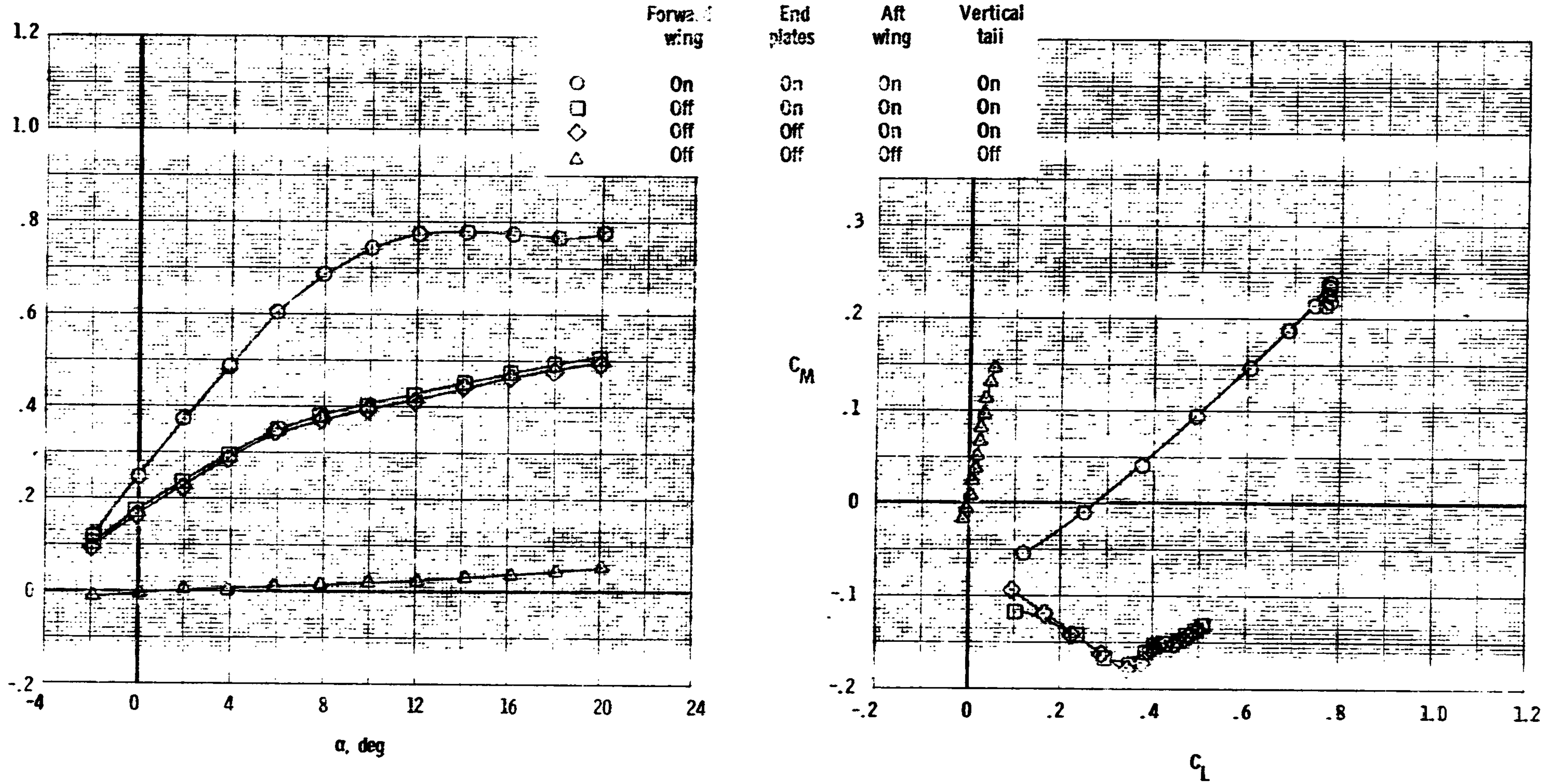

Figure 3. Effect of model components on longitudinal aerodynamic characteristics.

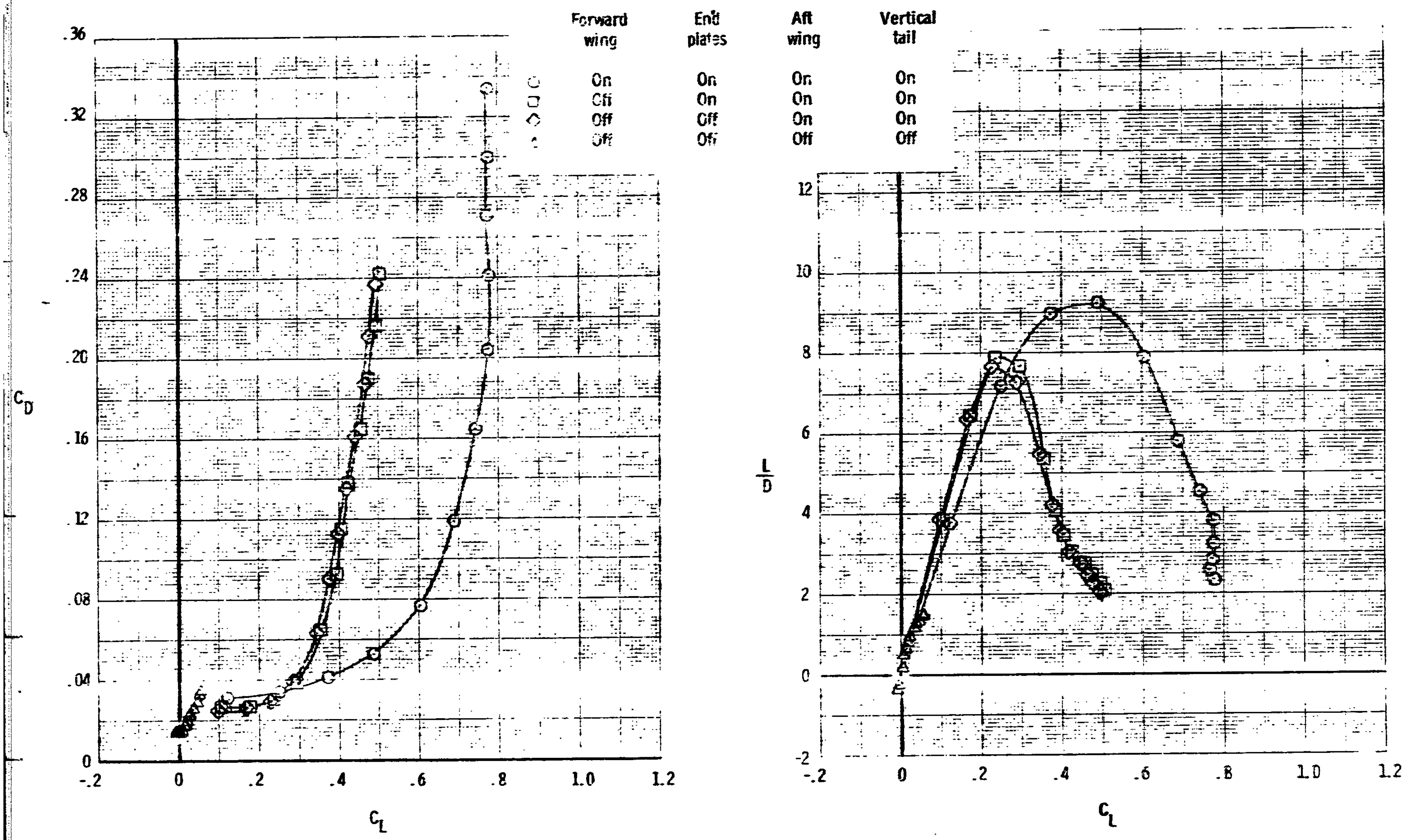

Figure 3. Concluded.

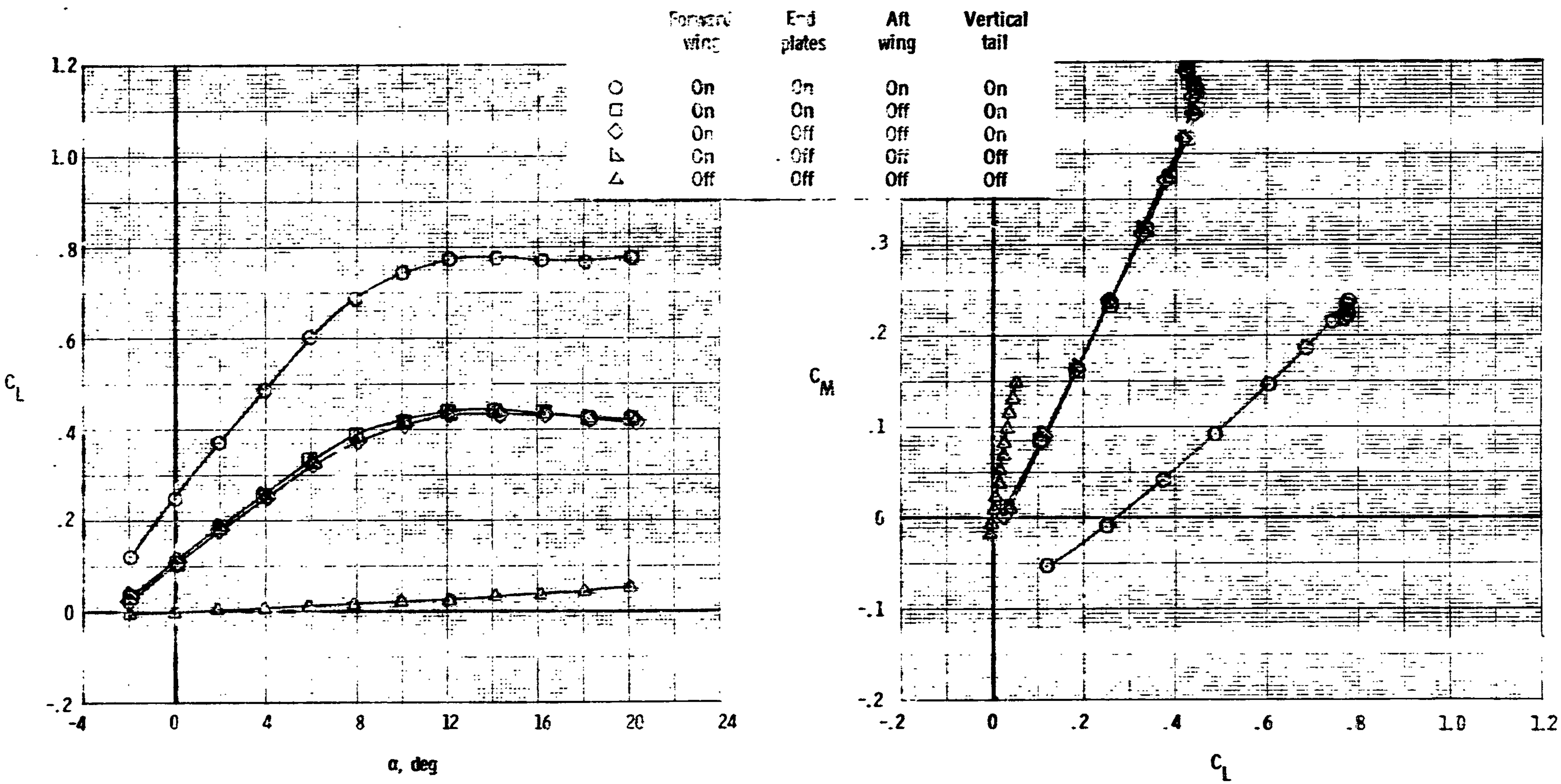

Figure 4. Effect of model modification on the longitudinal aerodynamics characteristics.

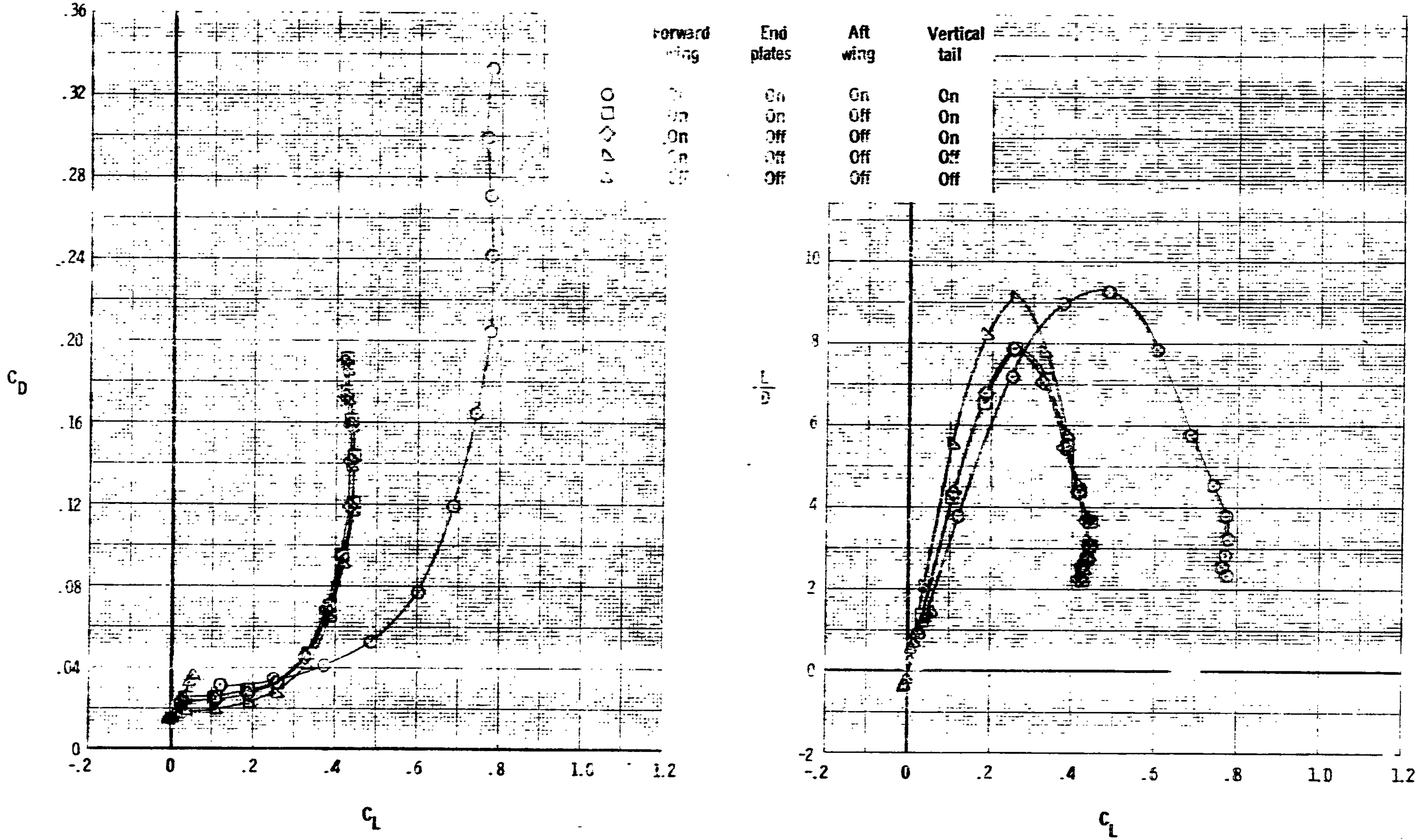

Figure 4. Concluded.

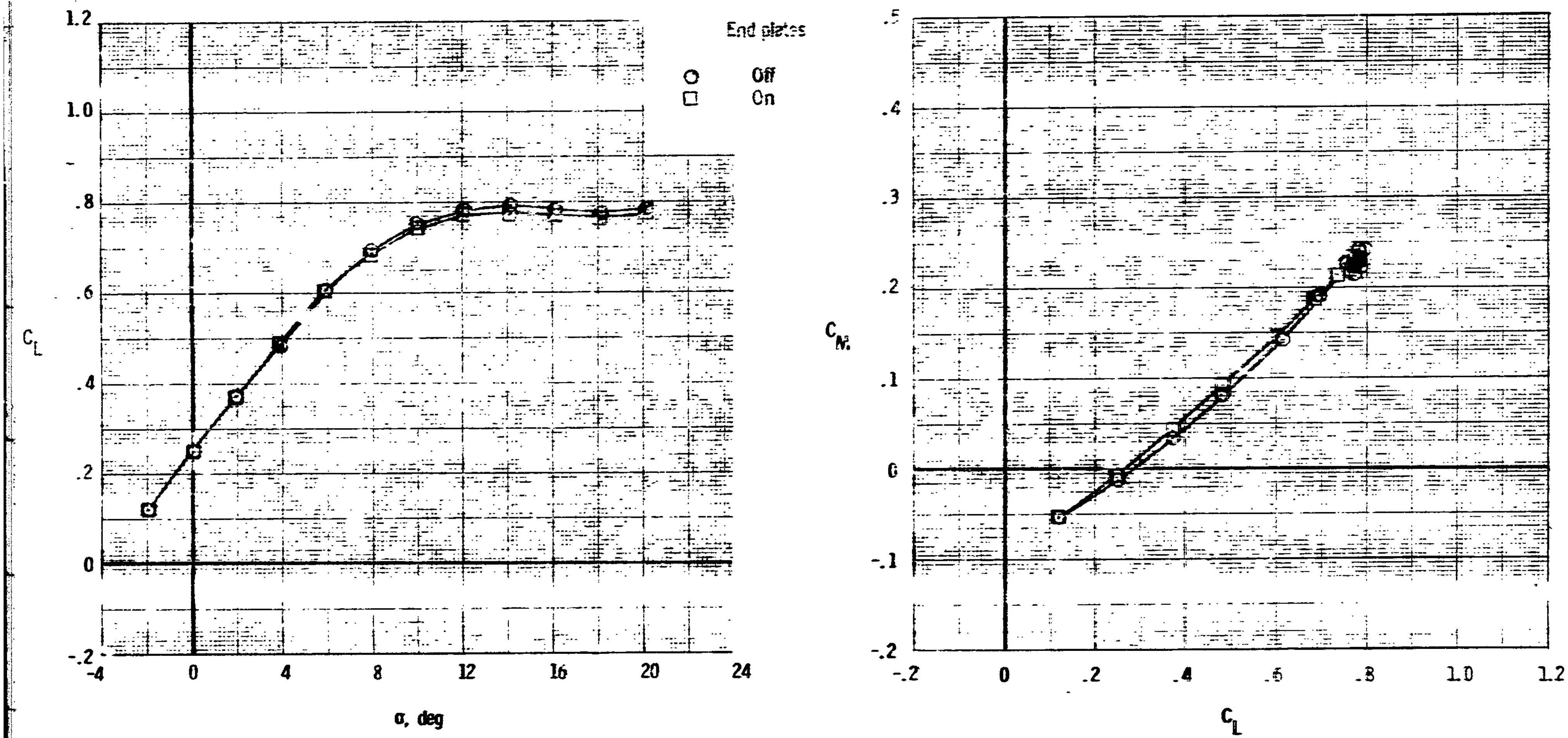

Figure 5. Effect of wing end plates on the longitudinal aerodynamics characteristic.

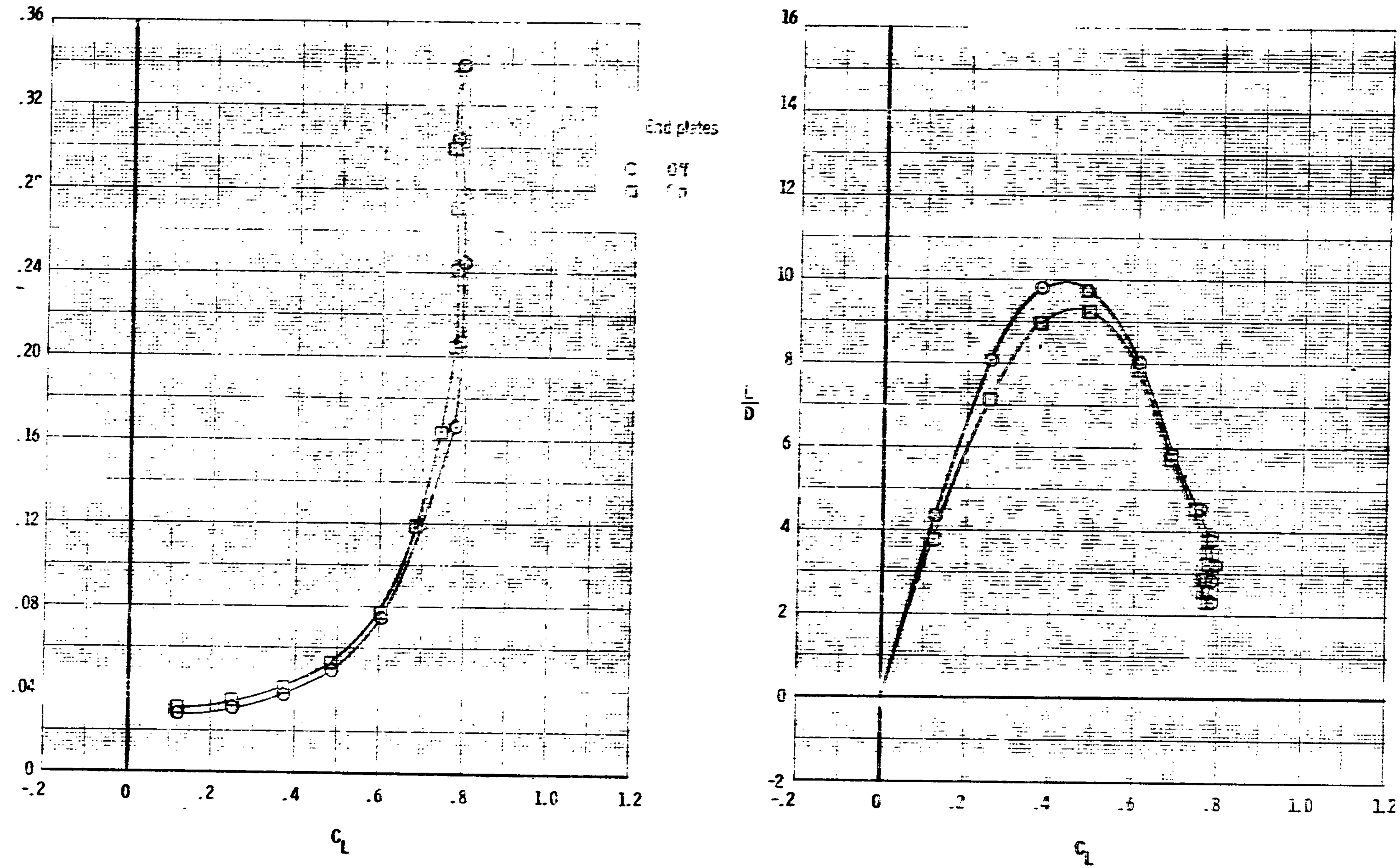

Figure 5. Concluded.

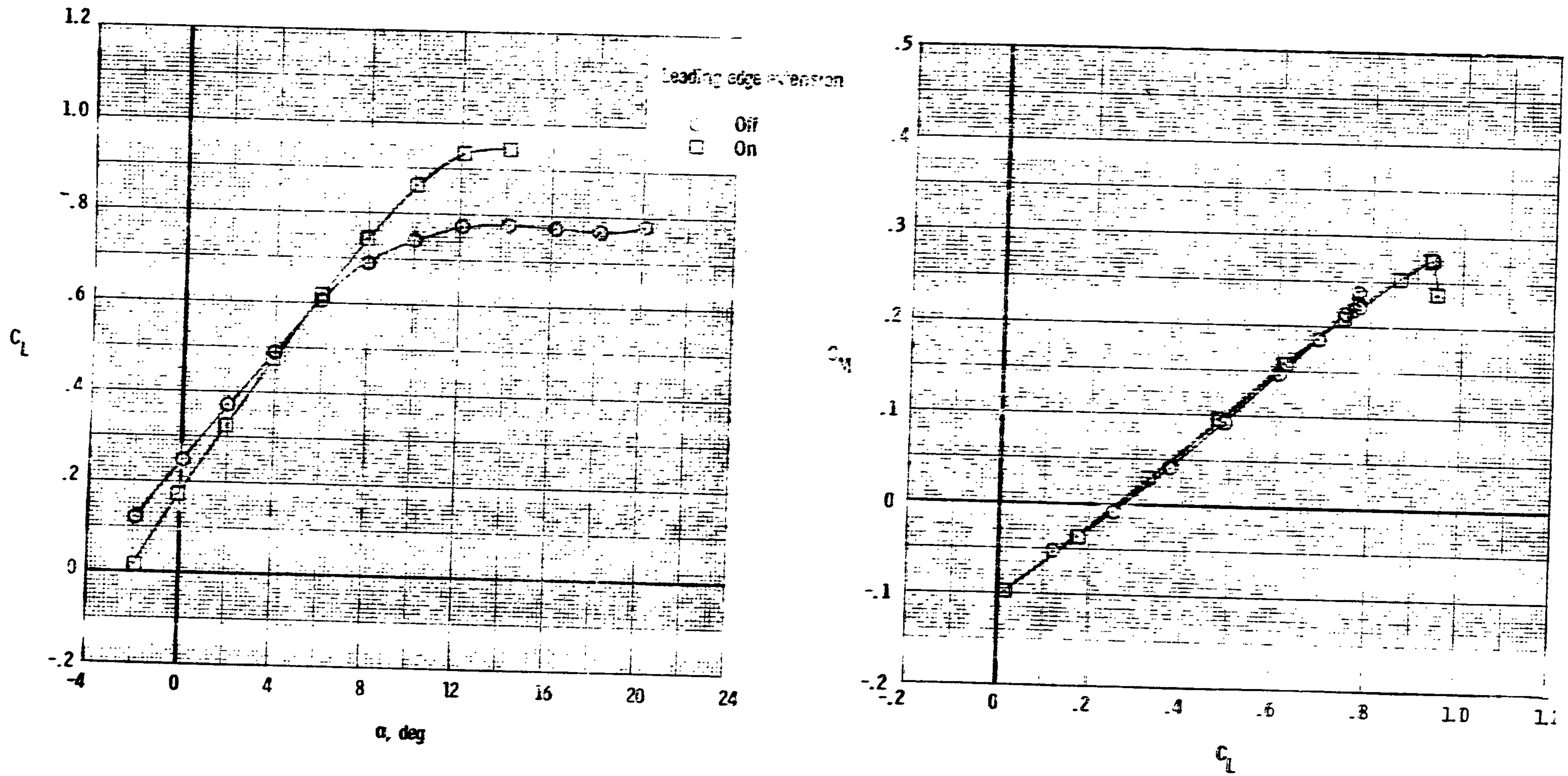

Figure 6. Effect of wing leading edge flaps on the longitudinal aerodynamic characteristics.

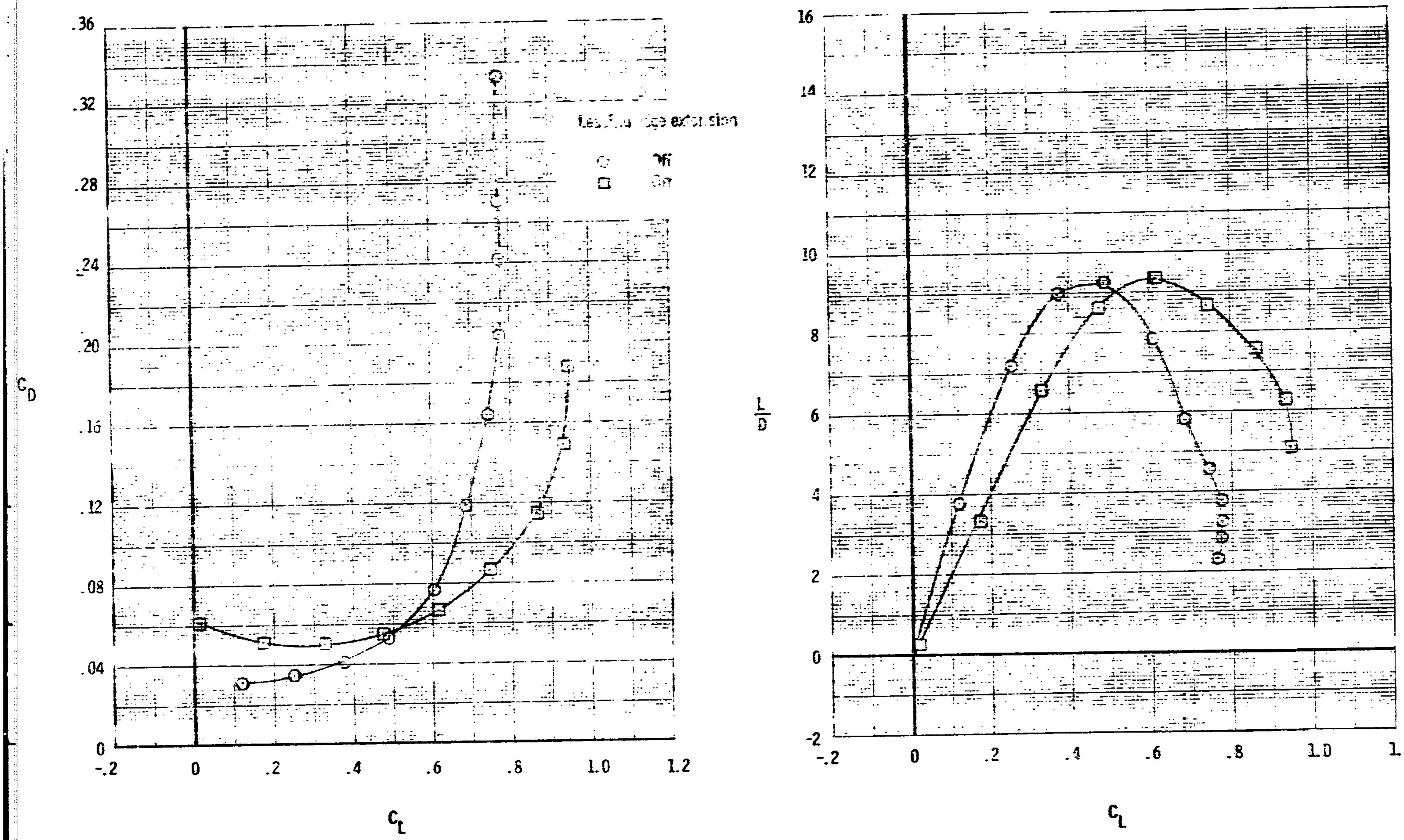

Figure 6. Concluded.

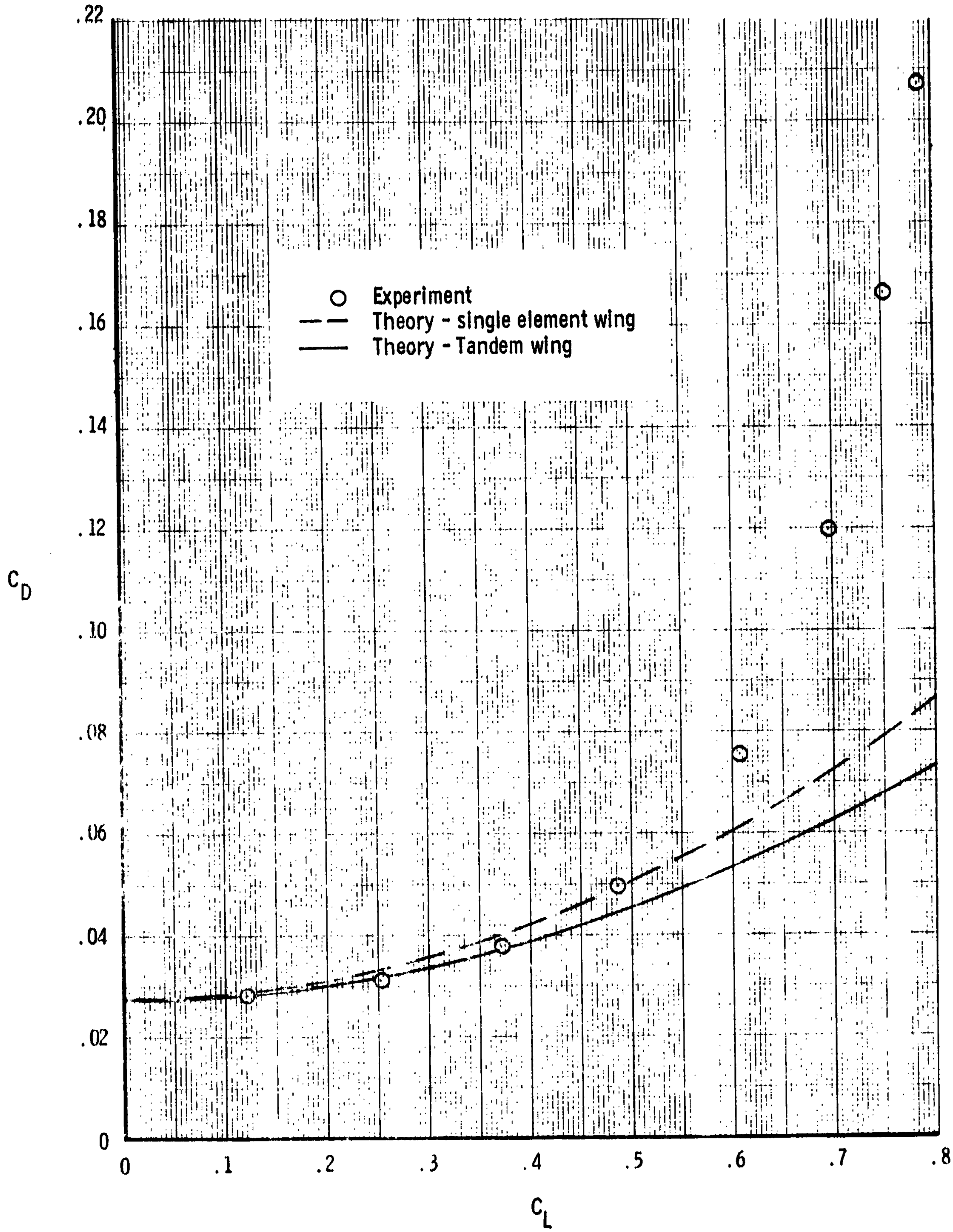

Figure 7. Comparison of experimental data with estimates. End plates off.

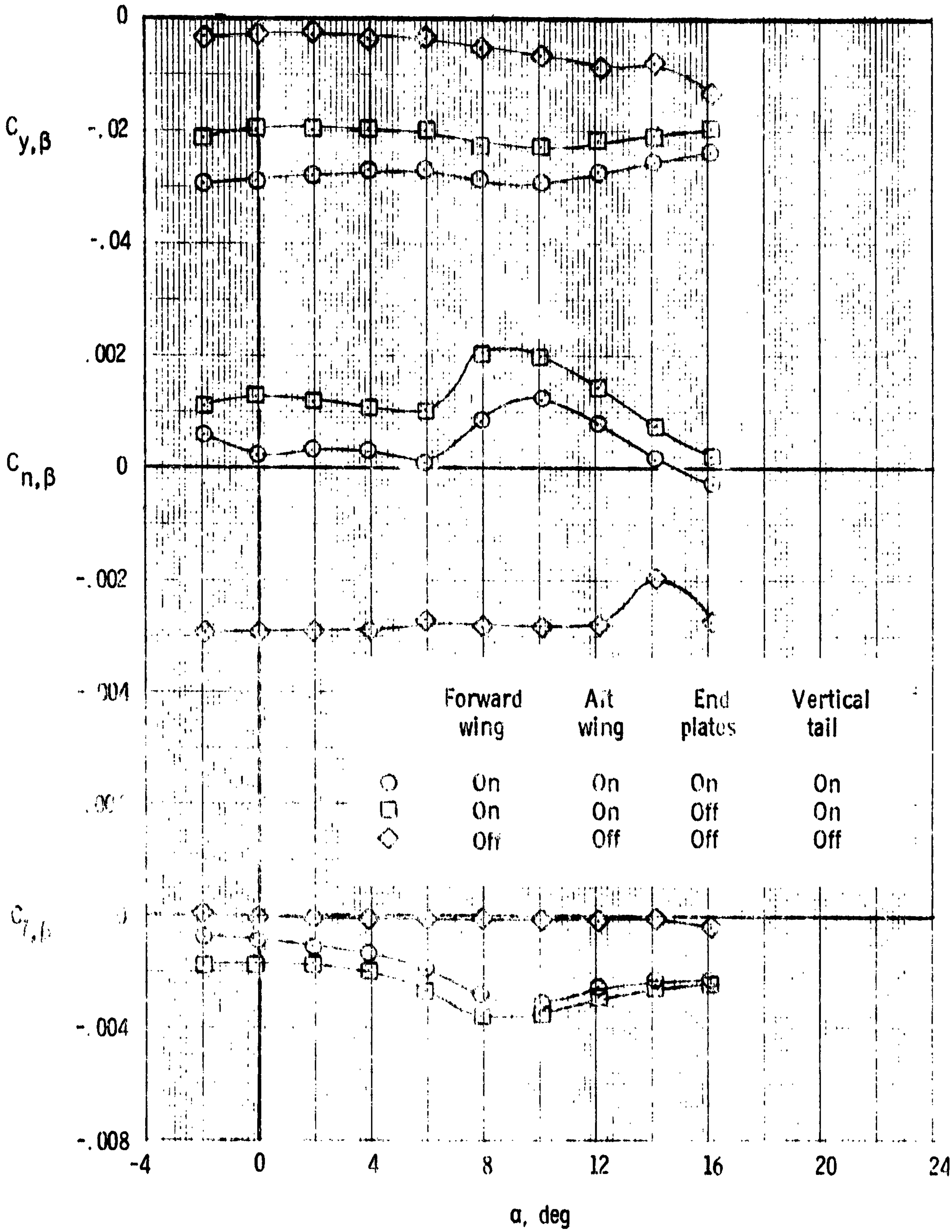

Figure 8. Effect of model modification on lateral directional characteristics.