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RESEARCH MEMORANDUM

for

U. S. Army Chemical Corps

WIND-TUNNEL INVESTIGATION AT LOW SPEED OF AERODYNAMIC CHARACTERISTICS OF ARMY CHEMICAL CORPS MODEL E-112 BOMBLETS WITH SPAN-CHORD RATIO OF 2:1

By William Letko

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

An experimental investigation has been made in the Langley stability tunnel to determine the aerodynamic characteristics of the Army Chemical Corps model E-112 bomblets with span-chord ratio of 2:1. A detailed analysis has not been made; however, the results showed that all the models were spirally unstable and that a large gap between the model tips and end plates tended to reduce the instability.

INTRODUCTION

At the request of the U. S. Army Chemical Corps, low-speed tests of the Cook Research Laboratories vortex gliders (designated as the Army Chemical Corps model E-112 bomblets) were made in the Langley stability tunnel. The vortex gliders were designed for use in certain military applications where dispersal of small units over very large areas is desirable. The vortex gliders under consideration were designed to rotate rapidly about the spanwise axis while falling. This rotation induces a circulation about the gliders, and consequently, produces a lift. Lift-drag ratios from 1.0 to 2.0 are practically achievable and are high enough to be of military value. The advantage of these gliders over conventional wing-alone or wing-body gliders arises as a result of the rapid lift-producing rotation which introduces a gyroscopic stiffness that assists in preserving the initial heading.

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Drop tests by Cook Research Laboratories of the original configurations of the vortex gliders showed the gliders to be spirally unstable. Wind-tunnel tests reported in reference 1 showed that a gap between model tips and end plates resulted in spirally stable configurations. Reference 1 also showed that use of large area end plates would also result in spiral stability even for a solid model.

The model with different gaps discussed in reference 1 had a span-chord ratio of 3:1 (model 3). The present tests were made to determine the characteristics of a model with span-chord ratio of 2:1. A few additional tests were also made with the model having a span-chord ratio of 3:1.

SYMBOLS

The data are presented about the stability axes and positive directions of forces and moments are shown in figure 1.

C_L	lift coefficient, F_L/qS
C_D'	drag coefficient, F_D'/qS
C_Y	lateral-force coefficient, F_Y/qS
C_l	rolling-moment coefficient, M_X/qSb
C_n	yawing-moment coefficient, M_Z/qSb
F_L	lift
F_D'	drag (approximate)
F_Y	lateral force
M_X	rolling moment
M_Z	yawing moment
q	dynamic pressure, $\frac{1}{2}\rho V^2$
ρ	mass density of air
b	span

c	chord
S	area
n	rotational speed, rps
V	free-stream velocity
r	yawing angular velocity
p	rolling angular velocity
$\frac{rb}{2V}$	yawing-velocity parameter
$\frac{pb}{2V}$	rolling-velocity parameter
β	angle of sideslip
ψ	azimuth angle
γ	glide path angle, positive in climb

$$C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$$

$$C_{l_\beta} = \frac{\partial C_l}{\partial \beta}$$

$$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$$

$$C_{Y_r} = \frac{\partial C_Y}{\partial \frac{rb}{2V}}$$

$$C_{l_r} = \frac{\partial C_l}{\partial \frac{rb}{2V}}$$

$$C_{n_r} = \frac{\partial C_n}{\partial \frac{rb}{2V}}$$

$$C_{Y_p} = \frac{\partial C_Y}{\partial \frac{pb}{2V}}$$

$$C_{l_p} = \frac{\partial C_l}{\partial \frac{pb}{2V}}$$

$$C_{n_p} = \frac{\partial C_n}{\partial \frac{pb}{2V}}$$

APPARATUS AND MODELS

All tests were made in the Langley stability tunnel. The static and yawing stability derivatives were obtained in the 6- by 6-foot curved-flow test section in which curved flight is simulated by causing air to flow in a curved path about a fixed model. The rolling derivatives were obtained in the 6-foot-diameter rolling-flow test section in which rolling flight is simulated by twisting the air about a fixed model.

The models were supplied by Cook Research Laboratories and were made of magnesium. Removable tip blocks were supplied so that tests could be made with different gaps between end plates and model tips. The driving vanes were also removable and provision was made to allow changing the span of the driving vanes. The geometric characteristics of the model with span-chord ratio of 2:1 are given in figure 2, and the geometric characteristics of the model with span-chord ratio of 3:1 are given in reference 1. Photographs of both models are given in figure 3. A shaft mounted in ball bearings passed through each model and was fastened to a yoke support (fig. 3(a)) which, in turn, was mounted on a six-component mechanical balance system. During the tests the models were free to rotate about the shaft and the rotational speed was measured with a Strobotac. As a matter of interest, it should be pointed out that the tunnel models were about three times the size of a practical flight model.

TESTS AND CORRECTIONS

Tests of the models were made at a dynamic pressure of 8 pounds per square foot. The airspeeds and Reynolds number (based on chord) for the models are given in the following table:

Model span-chord ratio	q	V,ft/sec	Reynolds number
3:1 (model 3 of ref. 1)	8	84	436,000
2:1	8	84	620,000

Tests of the model with span-chord ratio of 2:1 were made with driving vanes off, with driving vanes of span equal to 86 percent of full model span, and with vanes which had a span equal to the full model span less the total span of the particular gap being tested. For each of these conditions, this model was tested with gaps between the model and end plates equal to 0, 3, 6, 9, 12, and 15 percent of the model chord.

Tests of the model with span-chord ratio of 3:1 were made with driving vanes of 98 percent and 83.6 percent of full model span with a gap between the model and end plates of 3 percent of the model chord.

No jet-boundary corrections were applied to the data. Support-strut tare corrections, however, have been applied, and the lateral-force coefficient has been corrected for the buoyancy effect of the static pressure gradient associated with curved flow.

PRESENTATION OF RESULTS

The results of the investigation are presented in figures 4 to 7. All data presented for the models are based on the following geometric characteristics:

Model span-chord ratio	Chord, ft	Span, ft	Area, sq ft
3:1	0.817	2.492	2.036
2:1	1.167	2.500	2.916

The values of C_{n_β}, C_{l_β}, and C_{Y_β} presented in table 1 are the slopes of the coefficient against β (in degrees) obtained near $\beta = 0^{\circ}$.

The derivatives C_{n_r}, C_{l_r}, C_{Y_r}, C_{n_p}, C_{l_p}, and C_{Y_p} were obtained from plots of coefficients against $rb/2V$ and $pb/2V$ similar to those presented for $\beta = 0^{\circ}$ in reference 1. Table 2 is provided as an index to the figures.

DISCUSSION

As was pointed out in reference 1, the slope of the spiral stability boundary for the vortex gliders is determined very closely by the negative reciprocal of the lift-drag ratio, that is, $\frac{C_{n_\beta}}{C_{l_\beta}} = \tan \gamma = \frac{F_D'}{F_L}$ and the boundary provides a simple criterion for determining whether a configuration is spirally stable or unstable. This criterion indicated that all the configurations with span-chord ratios of 2:1 tested in the present investigation would be spirally unstable although some of the configurations were close to their spiral-stability boundary. (See fig. 7.) The model configurations with span-chord ratios of 3:1 tested in this investigation were also unstable but are not shown in the figure. Figures 7(a) and 7(b) indicate that introducing a gap between the model and end plates tends to move the model closer to the spiral-stability boundary for the model with span-chord ratio of 2:1, both with driving vanes of constant span (86.0 percent of the model span) and for the model with driving vanes off.

For the model with the driving vanes of a span equal to the model span minus the gap span, introducing a small gap tended to be destabilizing, whereas increasing the gap size tended to be stabilizing. (See fig. 7(c).) Reference 1 showed that some of the models having span-chord ratios of 3:1 with a constant-span driving vane equal to 83.6 percent of model span were spirally stable for a large gap size.

It should be pointed out that an examination of the equations of motion for the vortex gliders indicates that low rotational speeds (that is, before model reaches its full rotation) may result in an oscillatory instability sufficient to cause the model to tumble endwise. The equations of motion for the vortex gliders are presented in an unpublished report by R. A. Fredette of Cook Laboratories entitled "Dynamic Stability of Vortex Gliders."

CONCLUDING REMARKS

The results of the investigation show that all the models tested were spirally unstable but that a large gap between the model tips and end plates tends to reduce the spiral instability for all models. Analysis of the equations of motion for the gliders indicated that at low rotational speeds the model might also have oscillatory instability.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 3, 1956.

William Letko
William Letko
Aeronautical Research Engineer

Approved: George F MacDougall
for Thomas A. Harris
Chief of Stability Research Division

mhg

REFERENCE

1. Letko, William, and Williams, James L.: Wind-Tunnel Investigation at Low Speed of the Aerodynamic Characteristics of the Army Chemical Corps Model E-112 Bomblets. NACA RM SL55J26, U. S. Army Chemical Corps, 1955.

TABLE 1.- GEOMETRIC AND AERODYNAMIC CHARACTERISTICS OF MODELS

Model span-chord ratio	Span of driving vane	Ratio of gap size to chord	$\frac{2\pi nc}{V}$	$\frac{F_L}{F_D'}$	C_L	C_D'	C_{n_β}, per deg	C_{l_β}, per deg	C_{Y_β}, per deg	C_{n_r}	C_{l_r}	C_{Y_r}	C_{n_p}	C_{l_p}	C_{Y_p}
3:1	0.9806	0.03	1.86	1.45	2.07	1.43	0.0046	-0.0006	-0.0210						
3:1	.836b	.03	1.72	1.37	1.85	1.35	.0044	-.0009	-.0245						
2:1	Off	.0	2.21	1.60	2.51	1.57	.0003	.0034	-.0285						
2:1	Off	.03	1.51	1.29	1.48	1.15	.0	.0012	-.0380						
2:1	Off	.06	1.37	1.10	1.20	1.09	-.0002	.0012	-.0370	-0.430	0.050	0.313	-0.115	-0.179	0.422
2:1	Off	.09	1.29	1.01	1.05	1.04	-.0006	.0015	-.0380						
2:1	Off	.12	1.29	.95	.96	1.01	-.0006	.0017	-.0390						
2:1	Off	.15	1.24	.88	.86	.98	-.0007	.0011	-.0390						
2:1	.860b	0	2.28	1.43	2.33	1.63	.0007	.0028	-.0275						
2:1	.860b	.03	1.71	1.06	1.50	1.42	.0013	.0003	-.0360						
2:1	.860b	.06	1.55	1.02	1.21	1.19	.0006	.0005	-.0370						
2:1	.860b	.09	1.46	.91	1.07	1.17	-.0001	.0006	-.0380						
2:1	.860b	.12	1.45	.87	.98	1.13	-.0005	.0009	-.0390						
2:1	.860b	.15	1.40	.81	.88	1.08	-.0007	.0010	-.0390	-.390	-.128	.188	-.059	-.162	.336
2:1	1.000b	0	2.46	1.40	2.36	1.68	.0010	-.0006	-.0275						
2:1	.972b	.03	1.73	1.15	1.53	1.33	.0017	.0003	-.0340	-.542	.174	.103	-.155	-.200	.492
2:1	.944b	.06	1.58	1.02	1.26	1.23	.0005	.0007	-.0370	-.457	.099	.144	-.112	-.192	.456
2:1	.921b	.09	1.49	.92	1.10	1.19	-.0001	.0012	-.0380	-.441	.045	.147	-.074	-.180	.383
2:1	.915b	.12	1.45	.86	.98	1.14	-.0008	.0012	-.0390	-.472	.008	.147	-.055	-.175	.372

TABLE 2.- INDEX OF DATA

Figure	Model span-chord ratio	Gap size	Span of driving vane	Data presented
4	3:1	0.03c	0.980b .836b	C_L, C_D', C_n, C_l, C_Y, and n against β
5(a)	2:1	0	1.000b .860b Off	C_L, C_D', C_n, C_l, C_Y, and n against β
5(b)	2:1	.03c	.972b .860b Off	
5(c)	2:1	.06c	.944b .860b Off	
5(d)	2:1	.09c	.921b .860b Off	
5(e)	2:1	.12c	.915b .860b Off	
5(f)	2:1	.15c	.860b Off	
6(a)	2:1	.03c	.972b	C_{n_p}, C_{l_p}, C_{Y_p}, C_{n_r}, C_{l_r}, and C_{Y_r} against β
6(b)	2:1	.06c	.944b Off	
6(c)	2:1	.09c	.921b	
6(d)	2:1	.12c	.915b	
6(e)	2:1	.15c	.860b	
7(a)	2:1	Varies	Off	Spiral stability boundaries
7(b)	2:1	Varies	.860b	
7(c)	2:1	Varies	Varies	

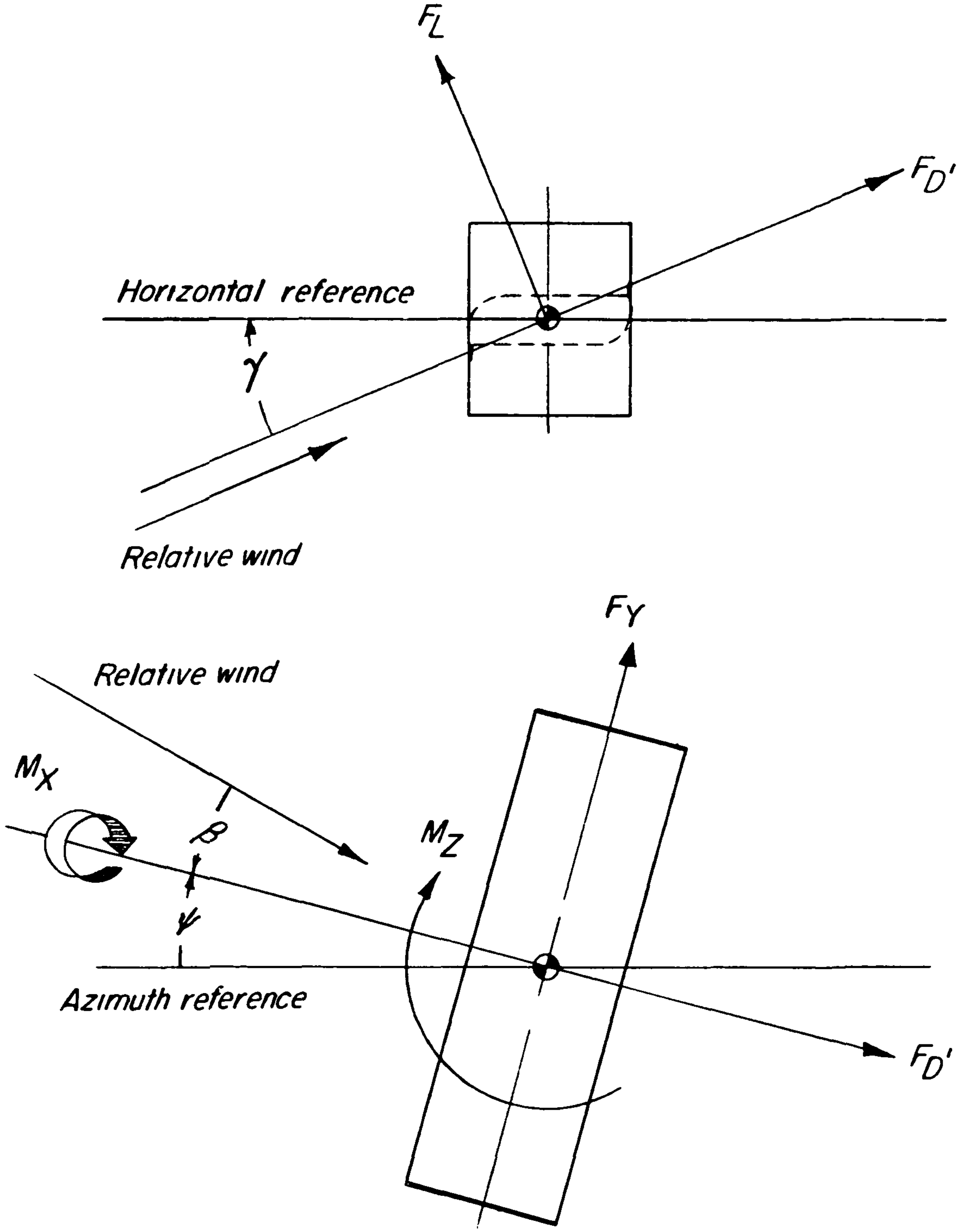

Figure 1.- System of axes used. Arrows indicate positive direction of angles, forces, and moments.

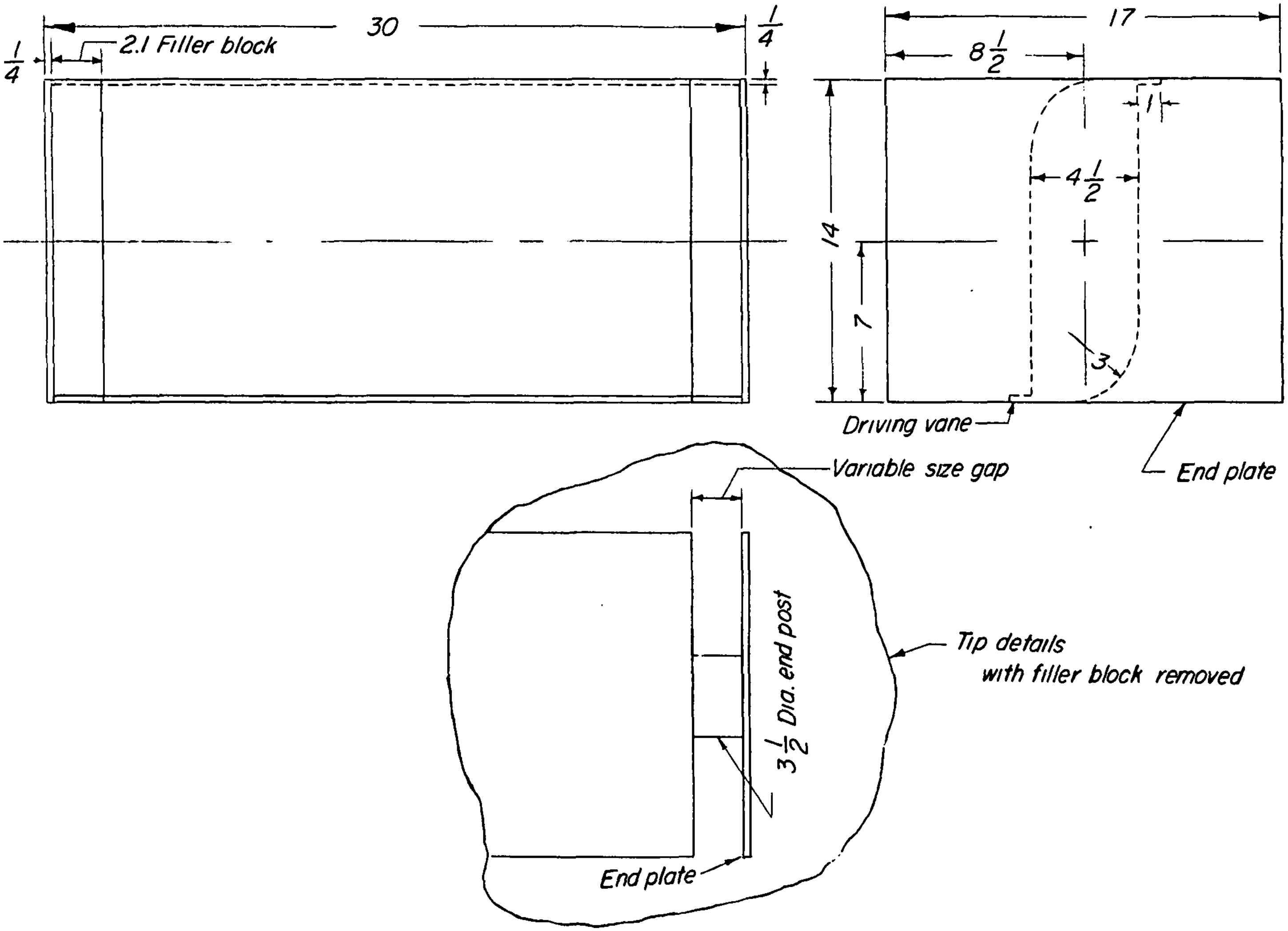

Figure 2.- Geometric characteristics of model with span-chord ratio of 2:1. (All dimensions are in inches unless otherwise stated.)

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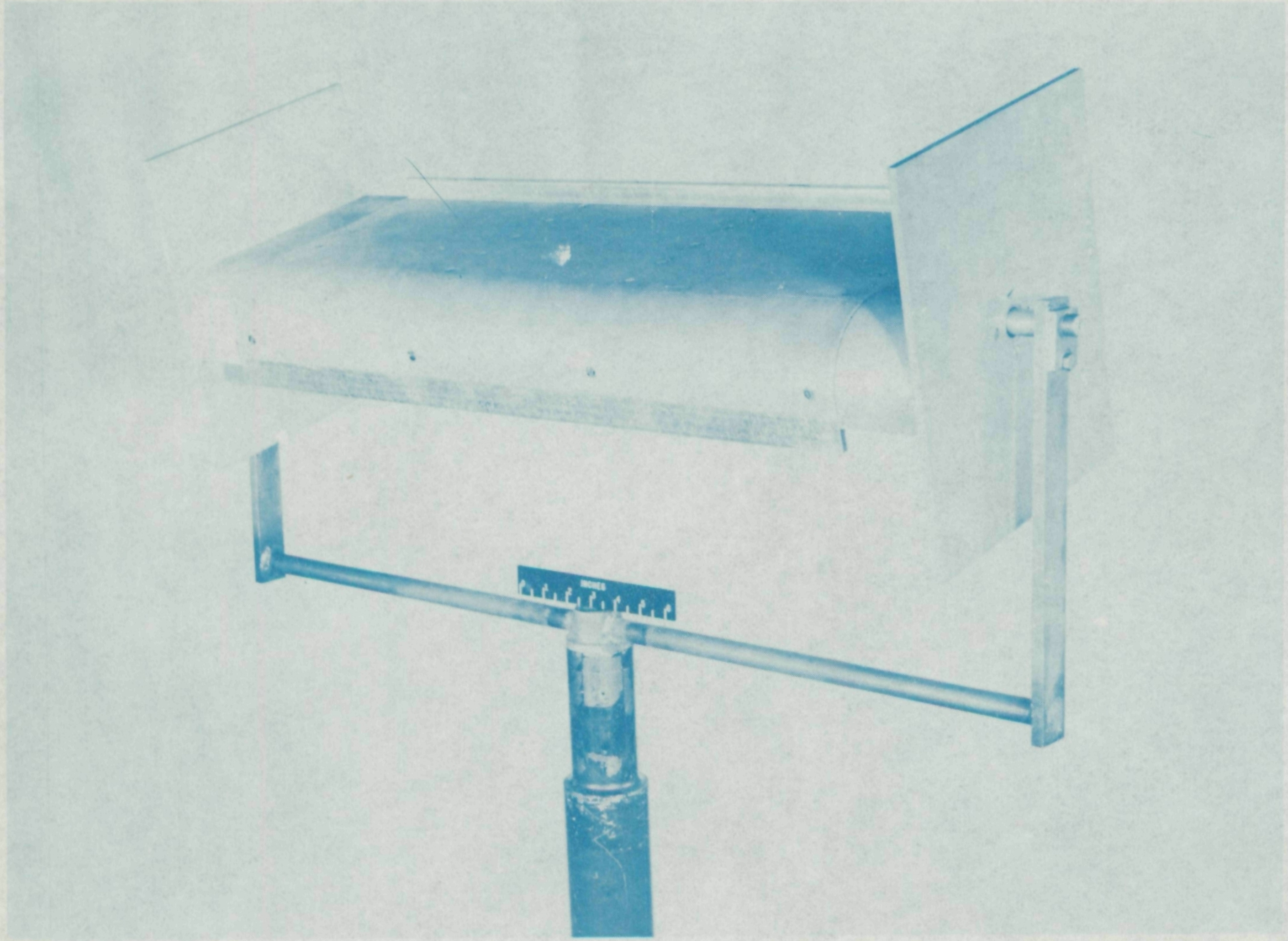

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(a) Model with span-chord ratio of 3:1.

Figure 3.- Photographs of models.

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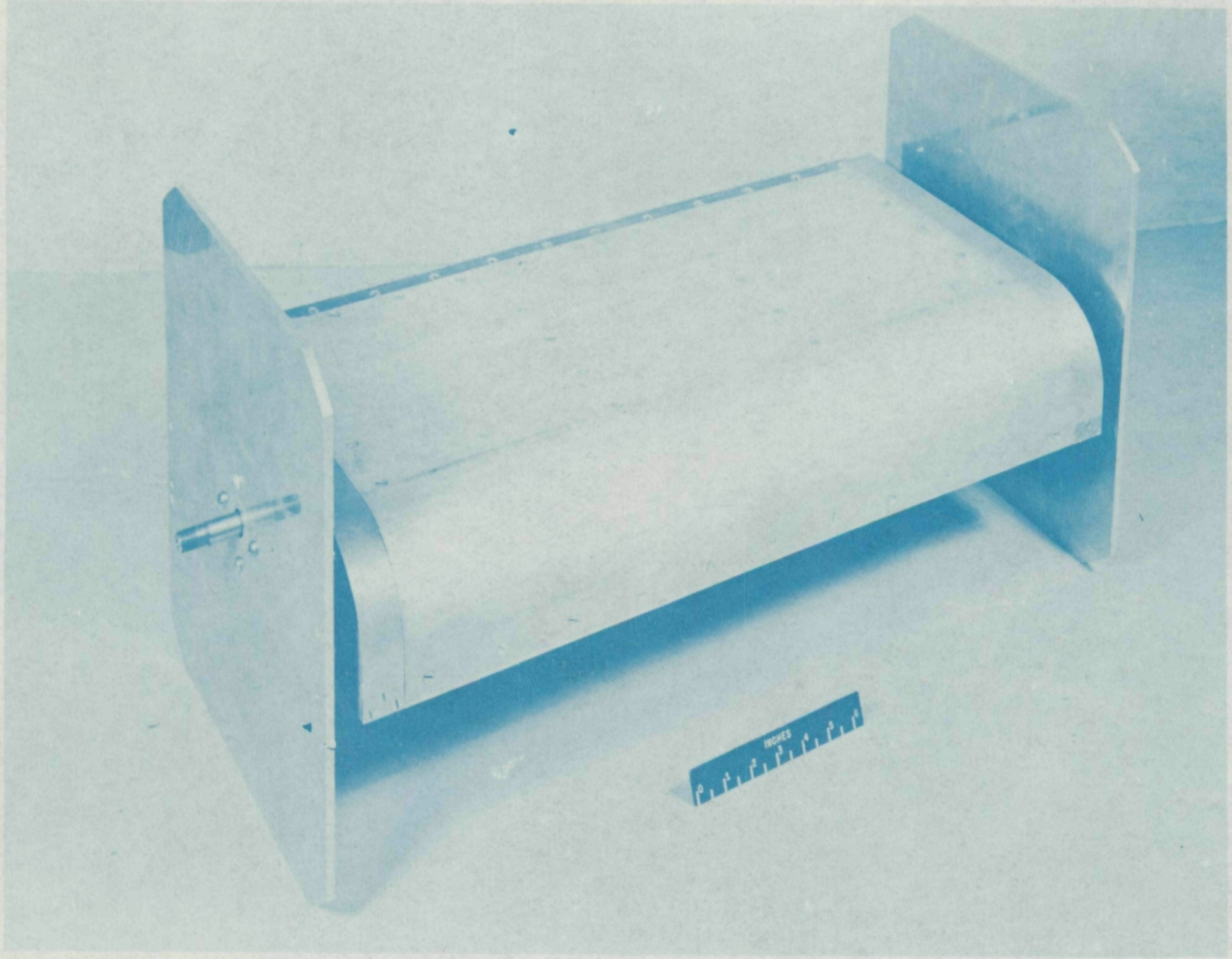


(b) Model with span-chord ratio of 2:1. L-92851

Figure 3.- Concluded.

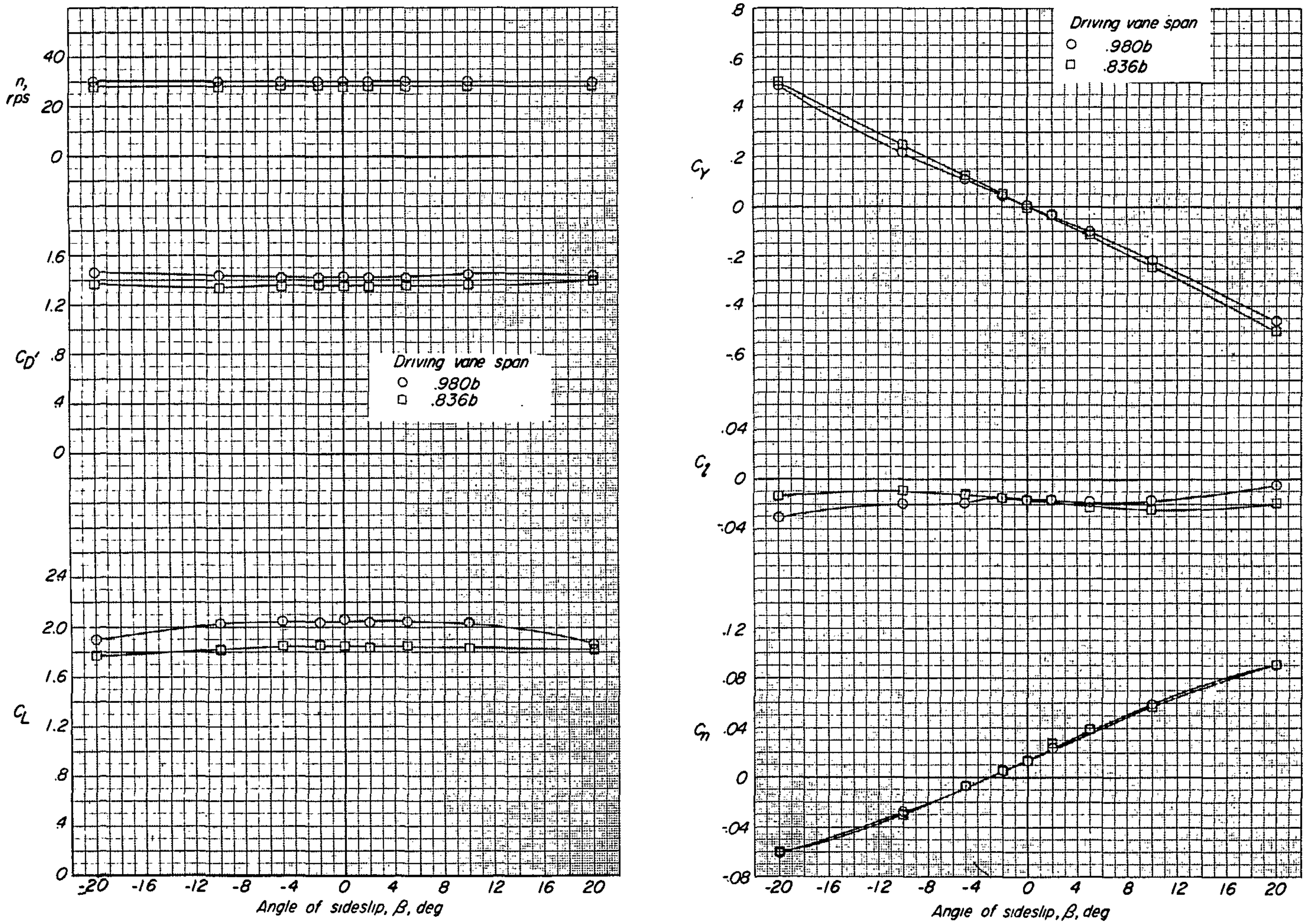
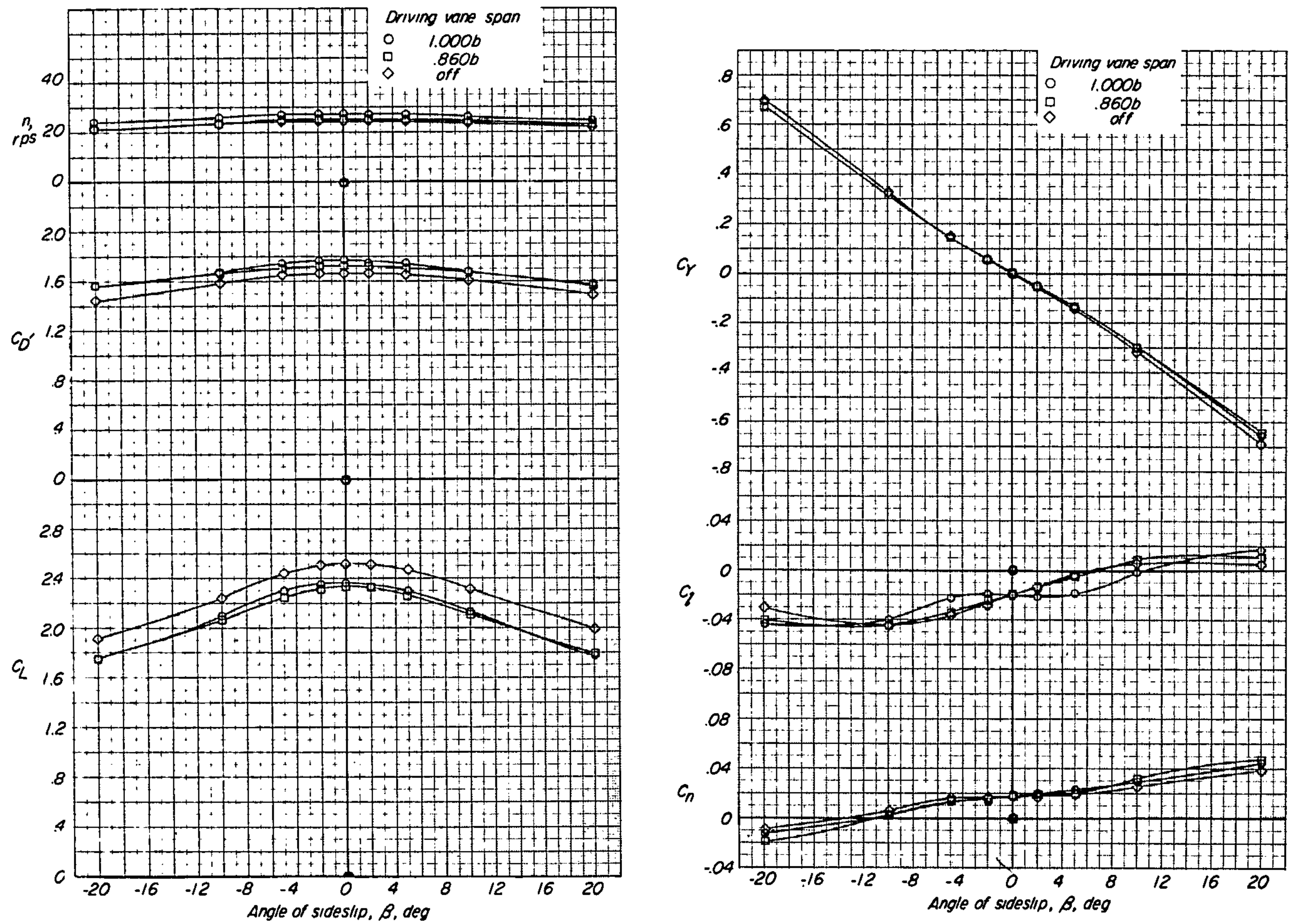
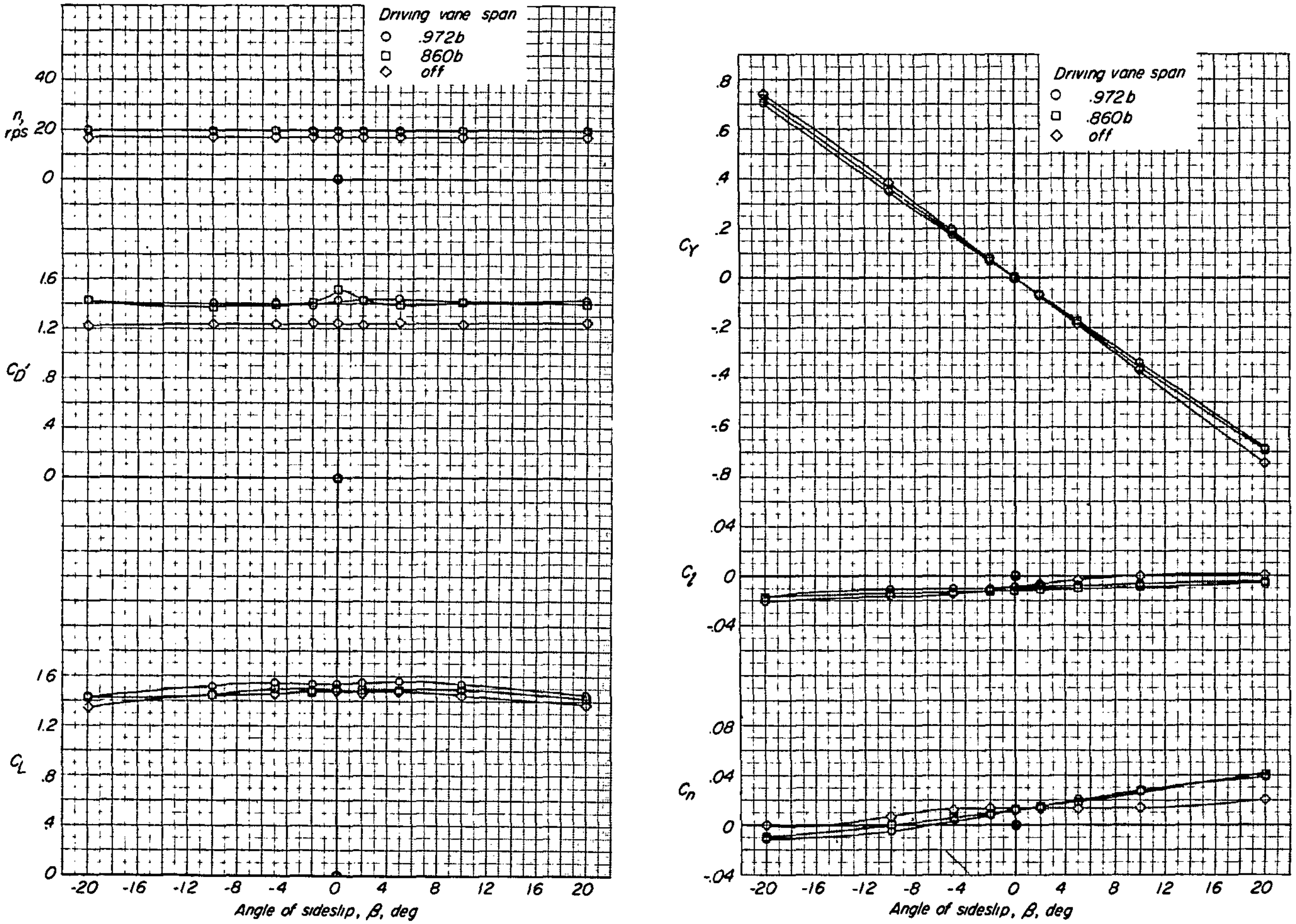


Figure 4.- Variation of C_L, C_D', C_n, C_l, C_Y, and n with angle of sideslip for two configurations of model with span-chord ratio of 3:1. Model end gap = 0.03c.



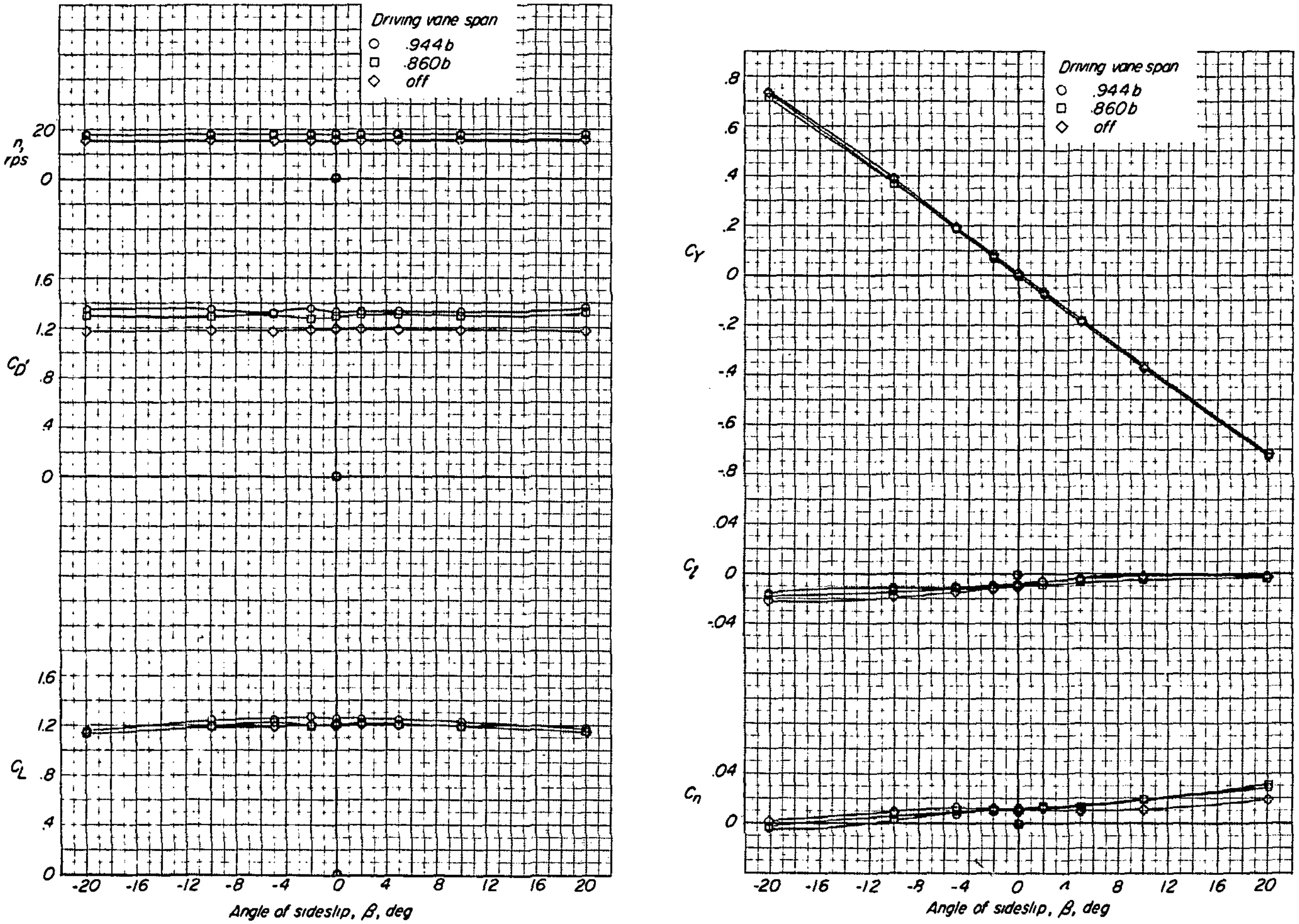
(a) Model end gap = 0.

Figure 5.- Variation of C_L, C_D', C_n, C_l, C_Y, and n with angle of sideslip for several configurations of model with span-chord ratio of 2:1.



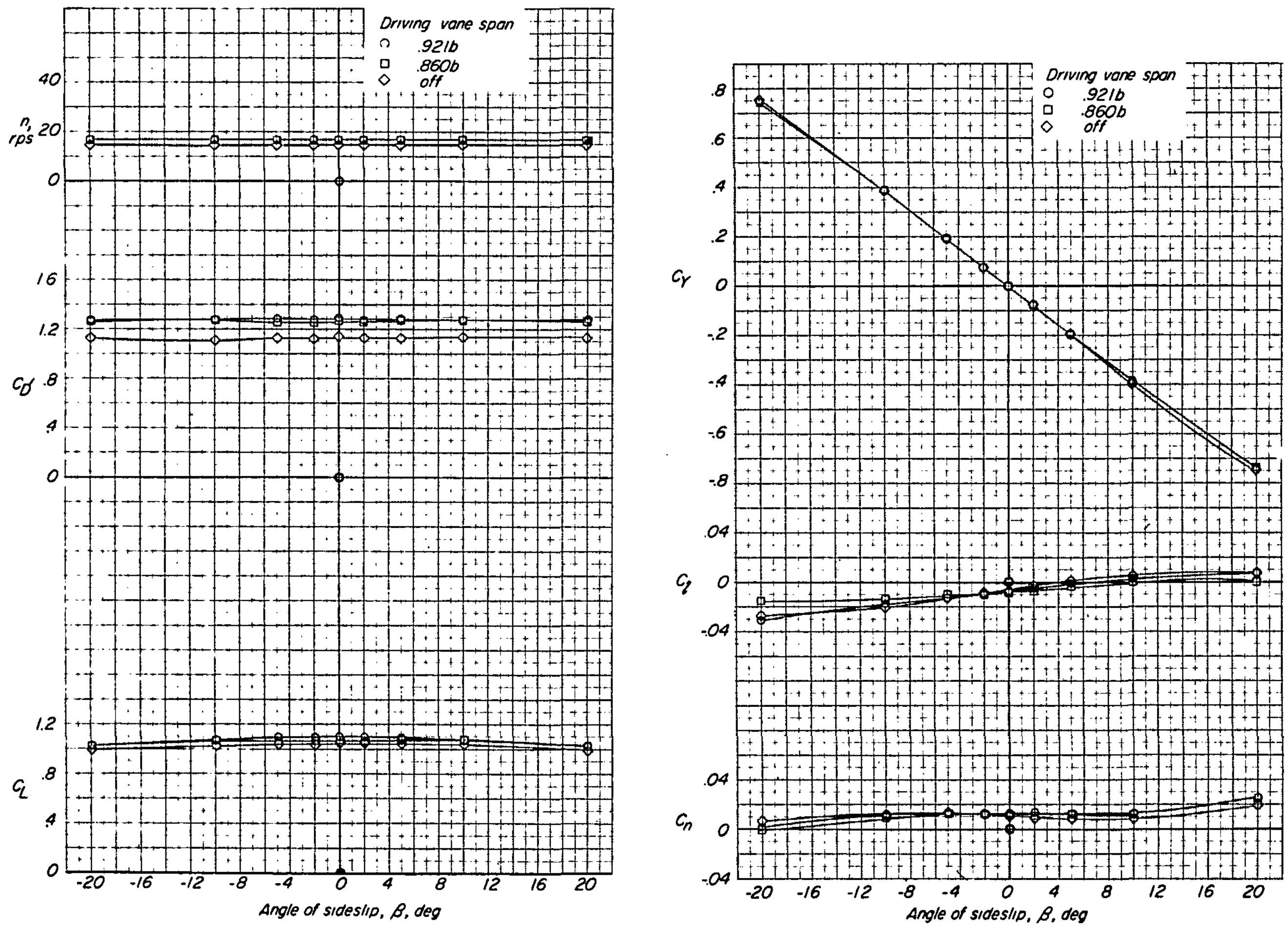
(b) Model end gap = 0.03c.

Figure 5.- Continued.



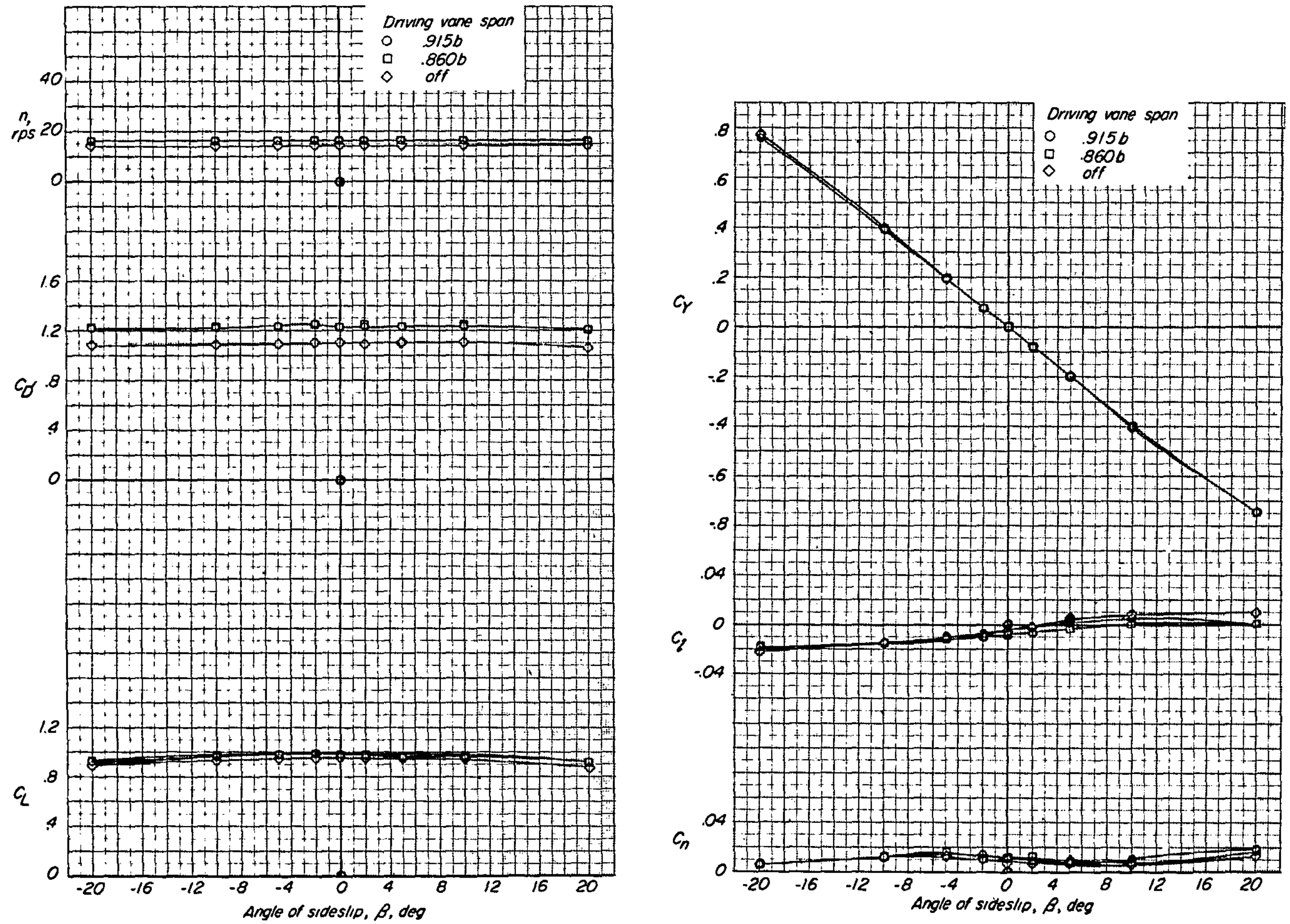
(c) Model end gap = 0.06c.

Figure 5.- Continued.



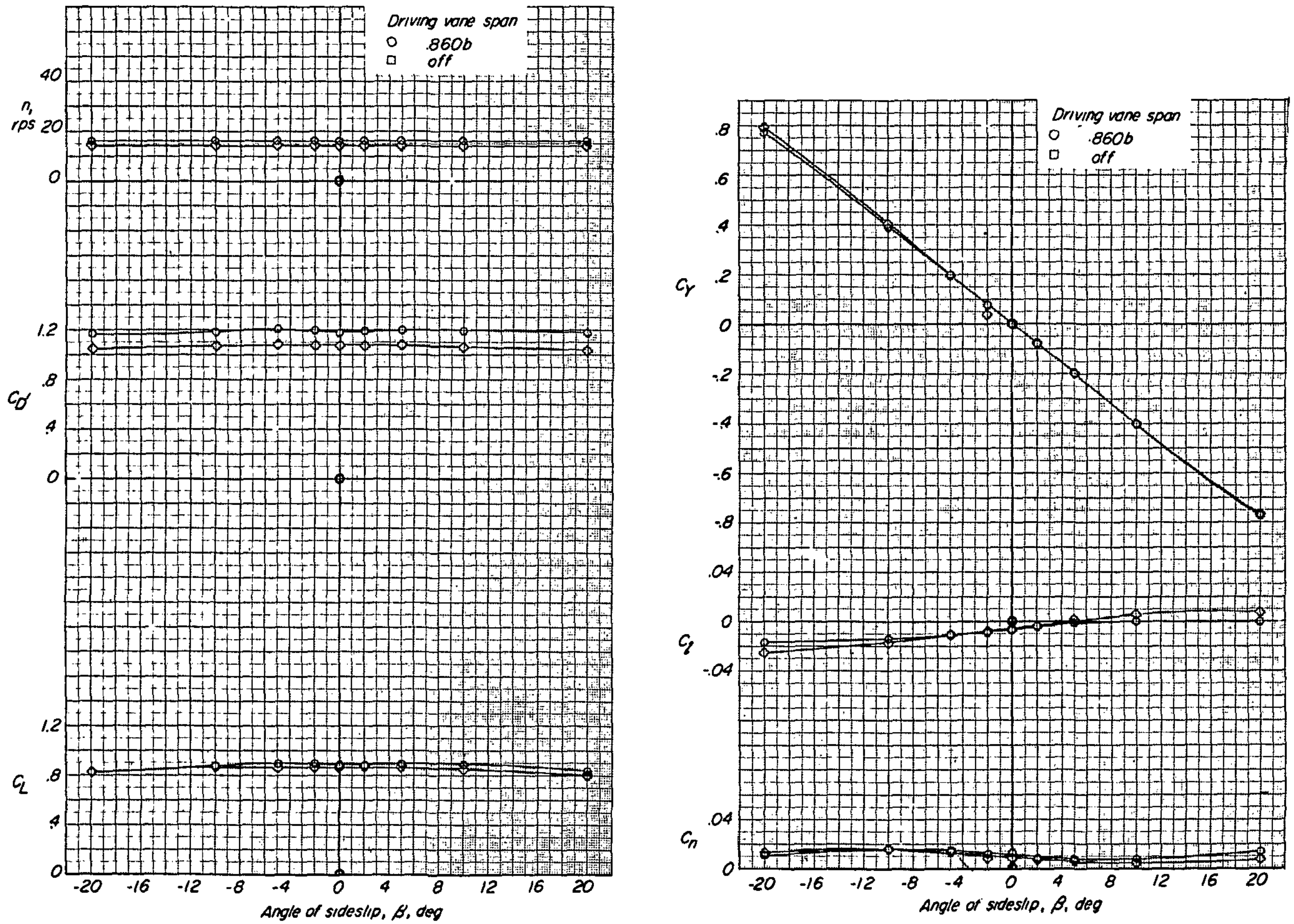
(d) Model end gap = 0.09c.

Figure 5.- Continued.



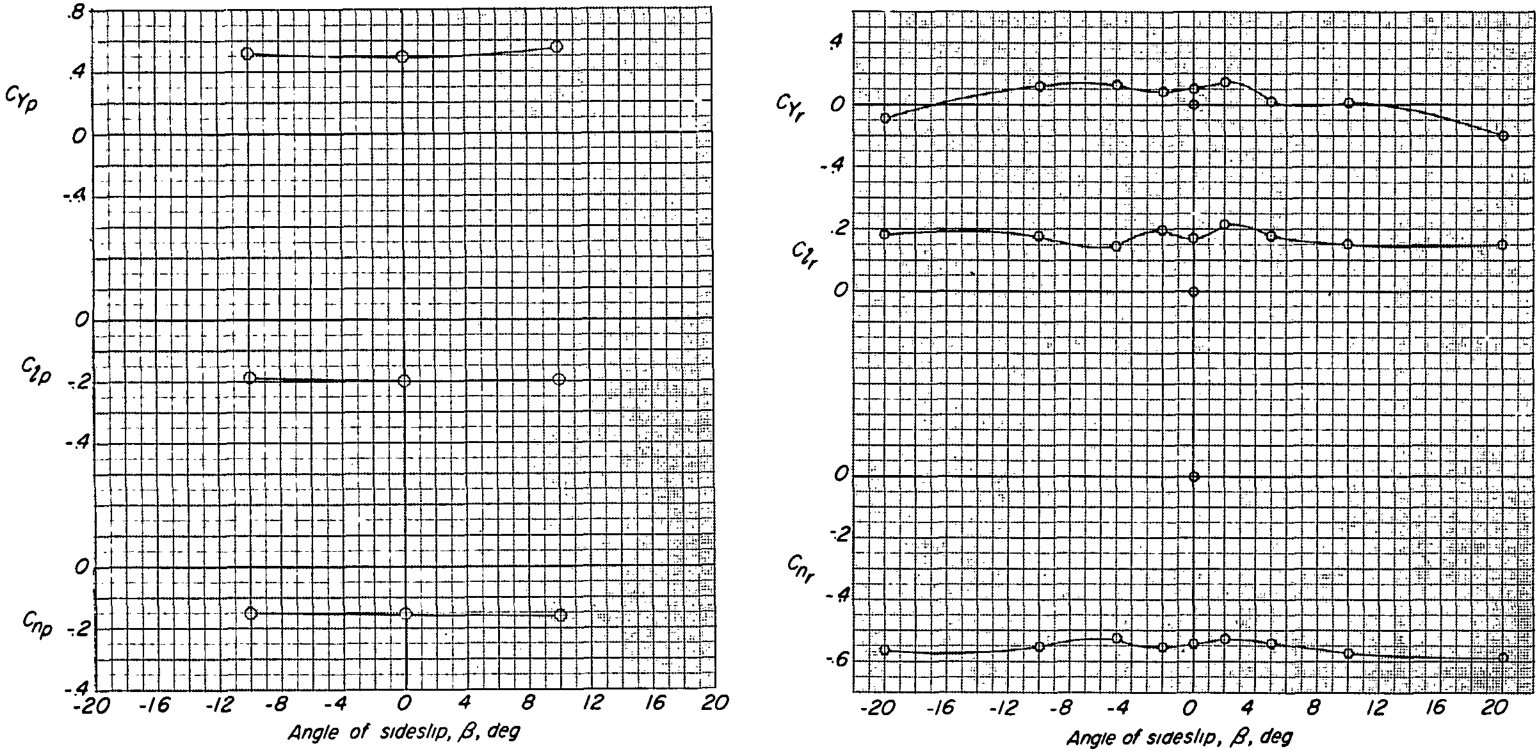
(e) Model end gap = 0.12c.

Figure 5.- Continued.



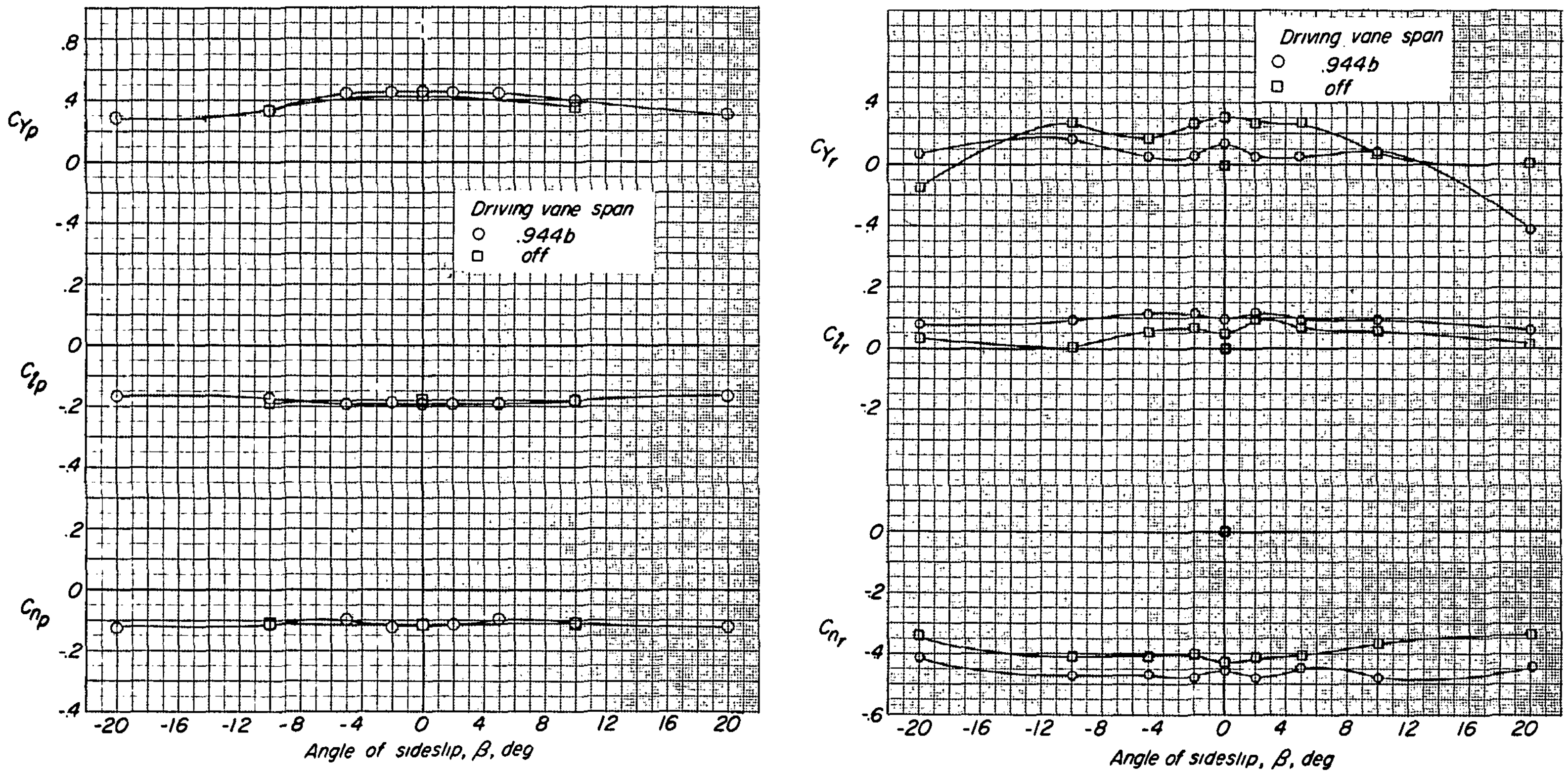
(f) Model end gap = 0.15c.

Figure 5.- Concluded.



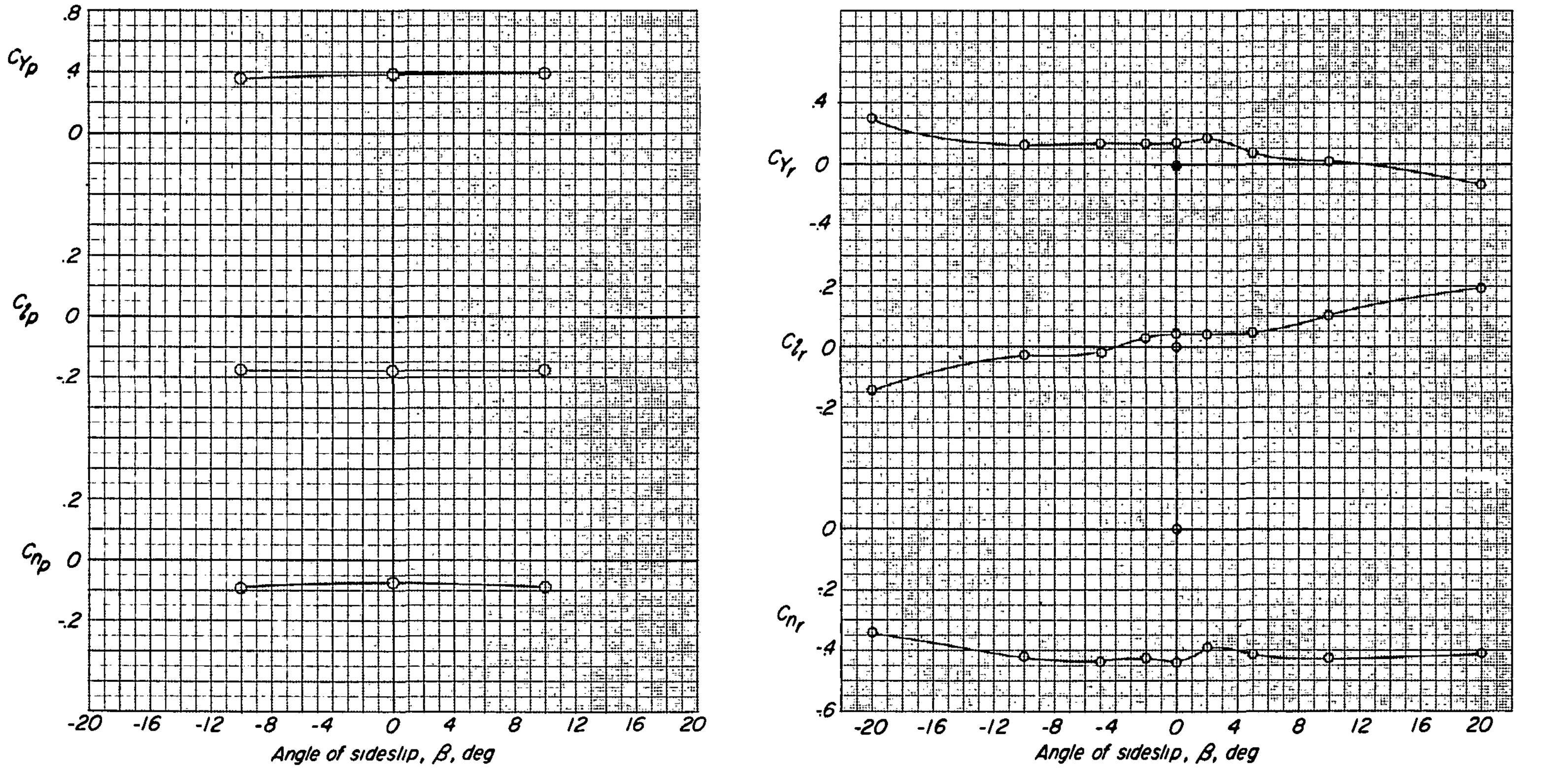
(a) Model end gap = 0.03c. Driving-vane span = 0.972b.

Figure 6.- Variation of the rolling and yawing derivatives for several configurations of model with span-chord ratio of 2:1.



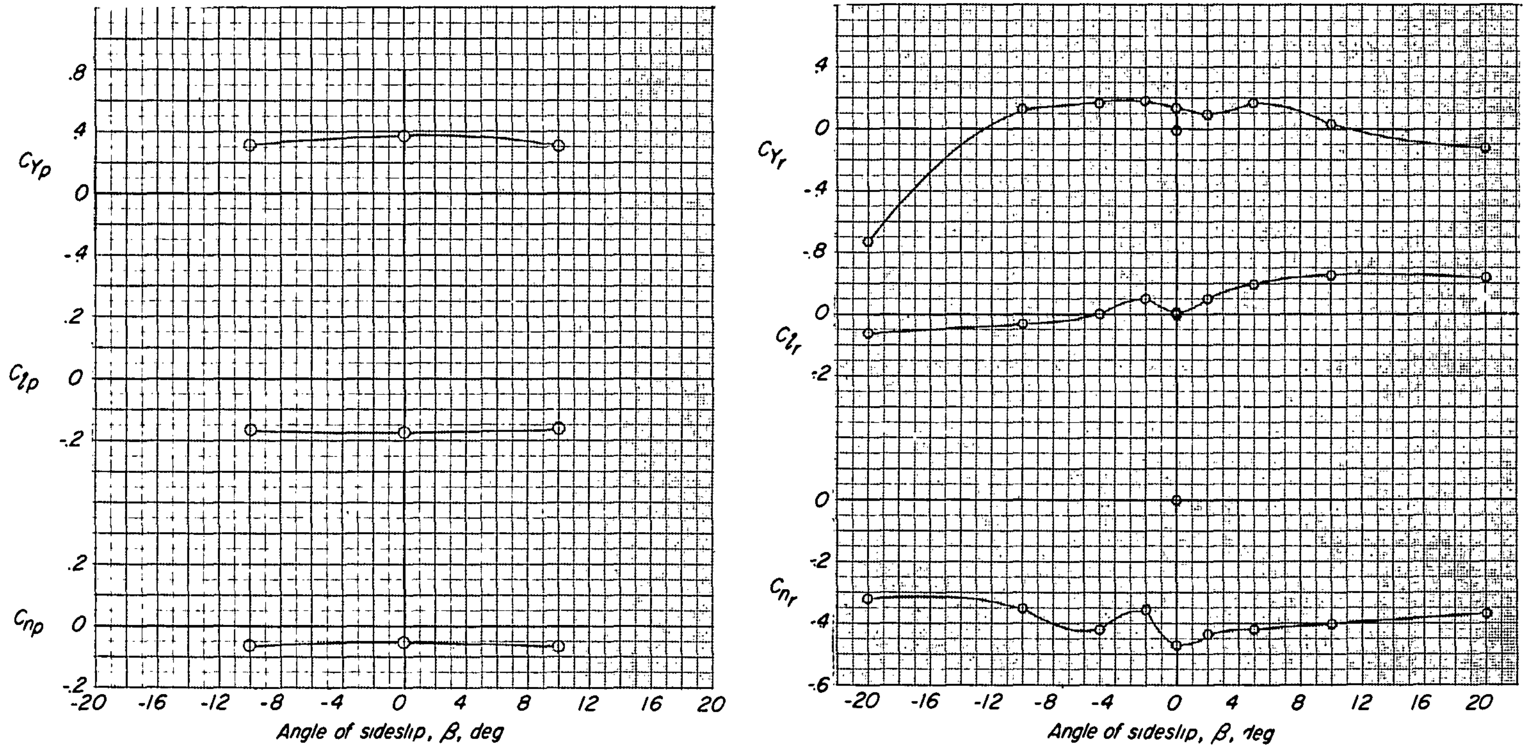
(b) Model end gap = 0.06c. Driving vane off and driving-vane span = 0.944b.

Figure 6.- Continued.



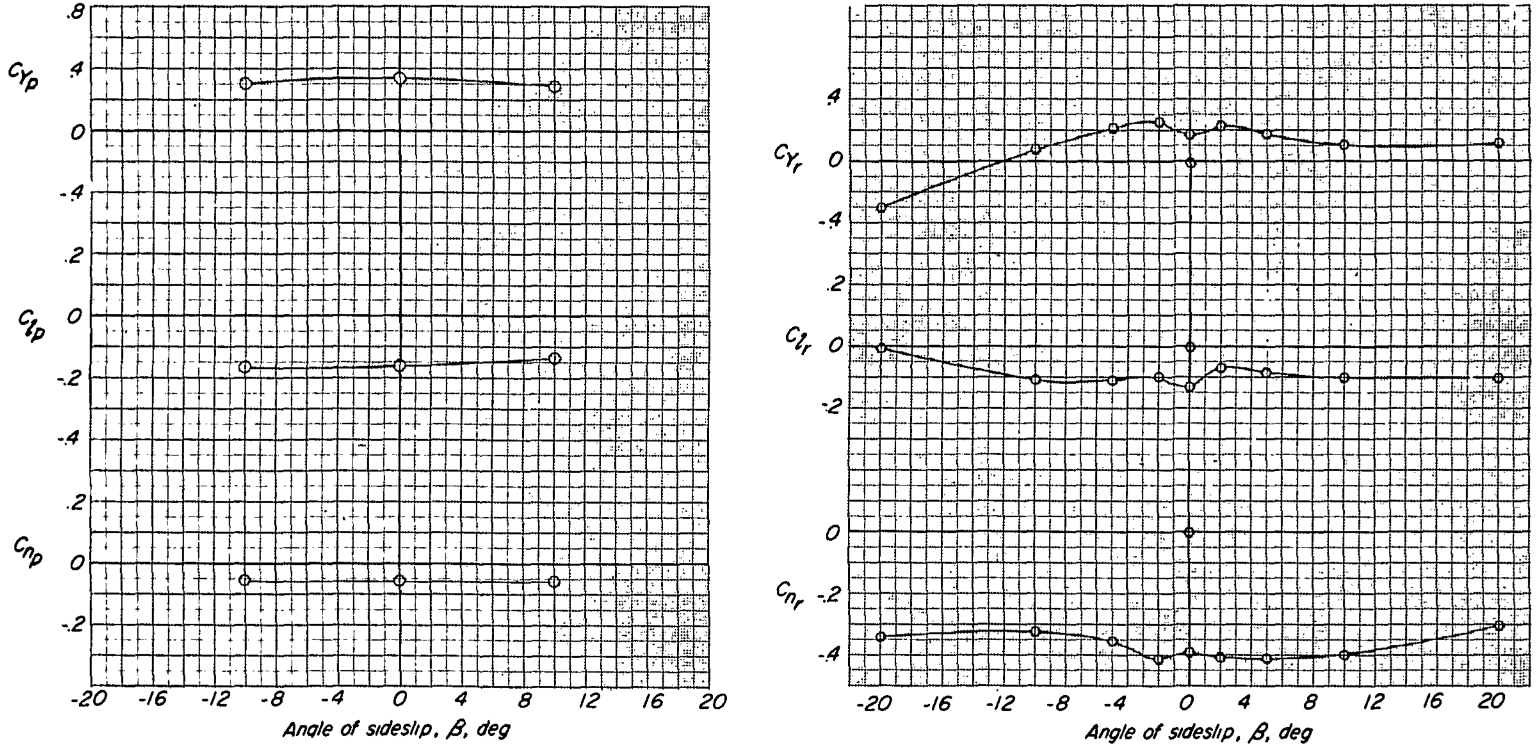
(c) Model end gap = 0.09c. Driving-vane span = 0.921b.

Figure 6.- Continued.



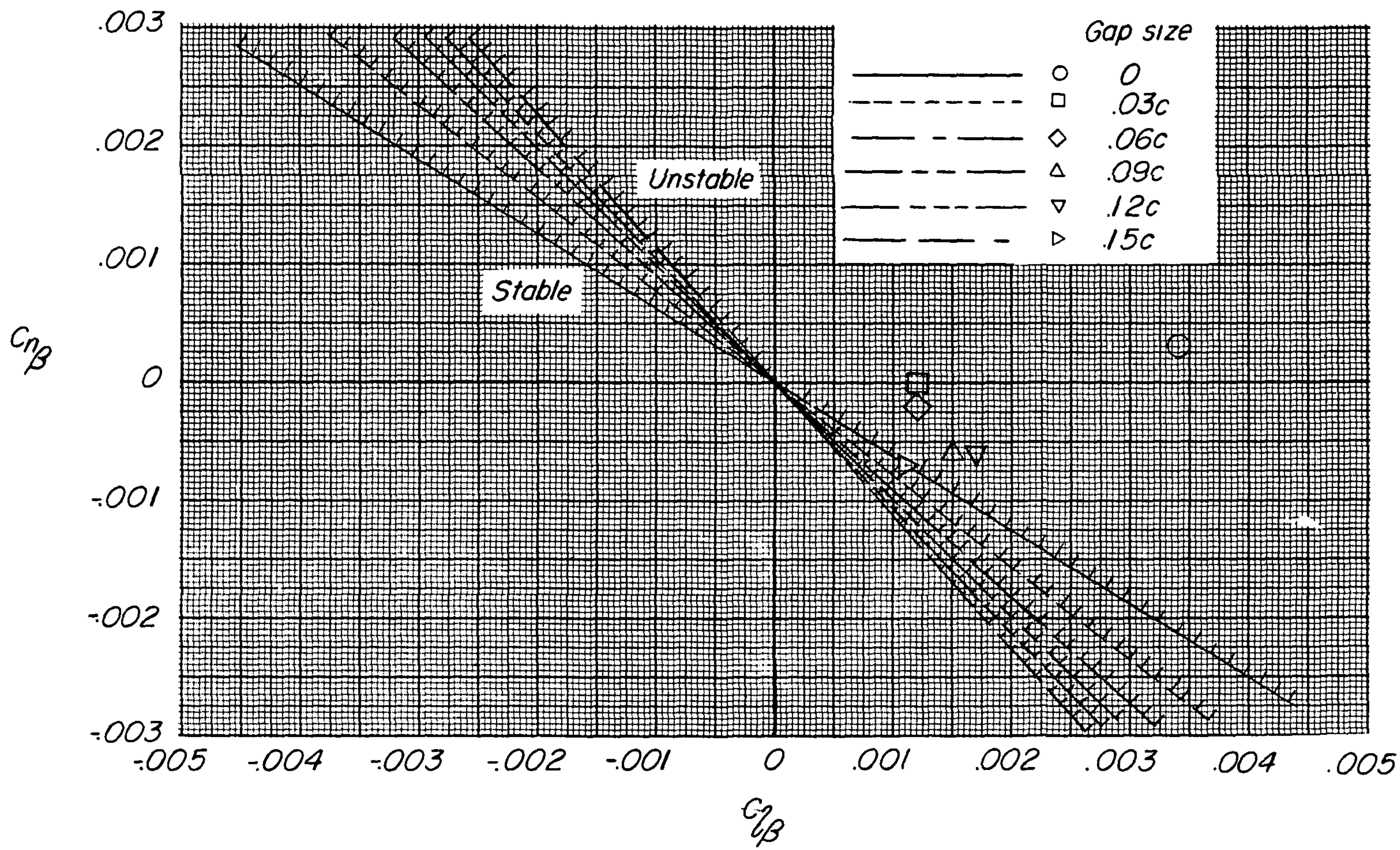
(d) Model end gap = 0.12c. Driving-vane span = 0.915b.

Figure 6.- Continued.



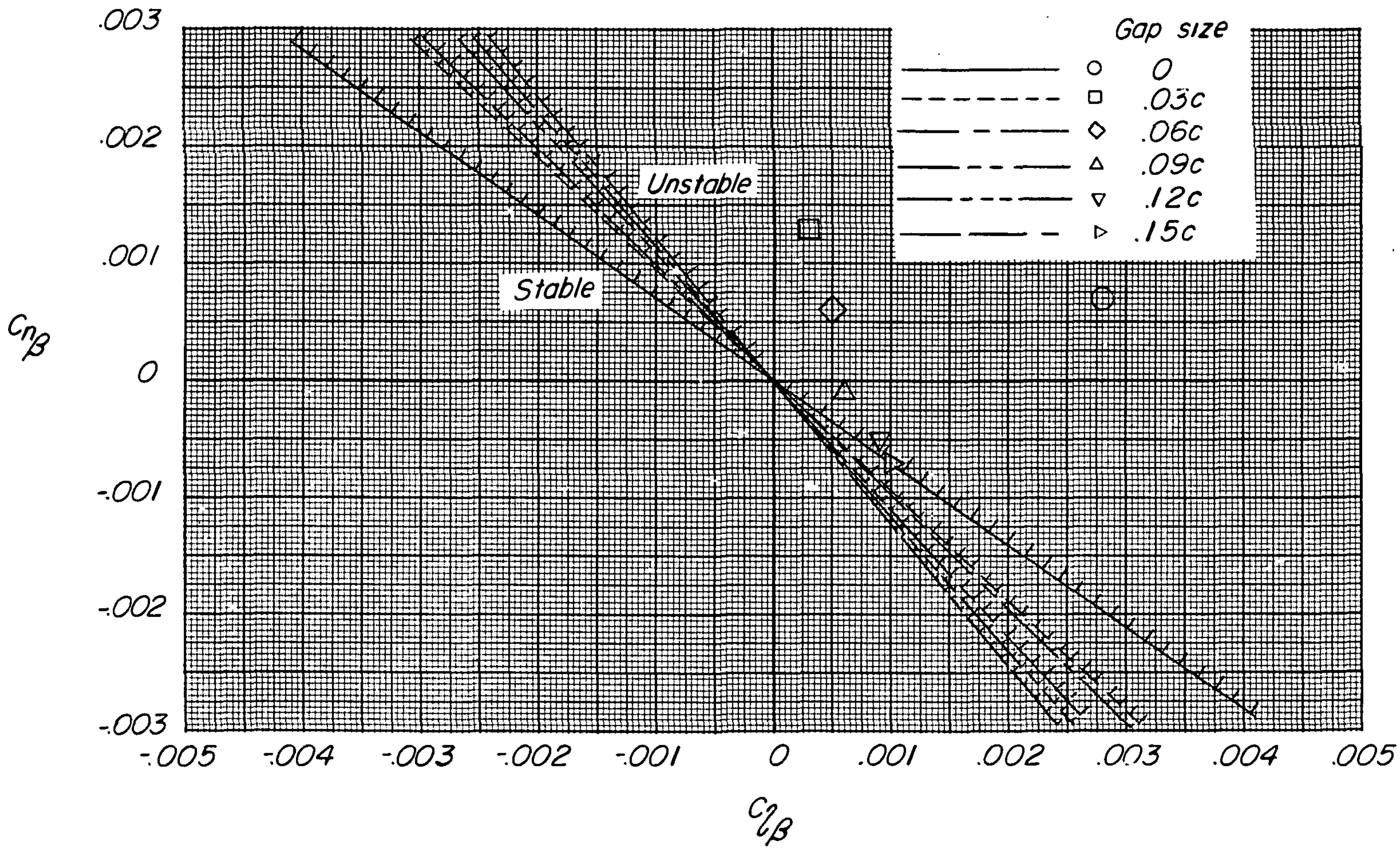
(e) Model end gap = 0.15c. Driving-vane span = 0.860b.

Figure 6.- Concluded.



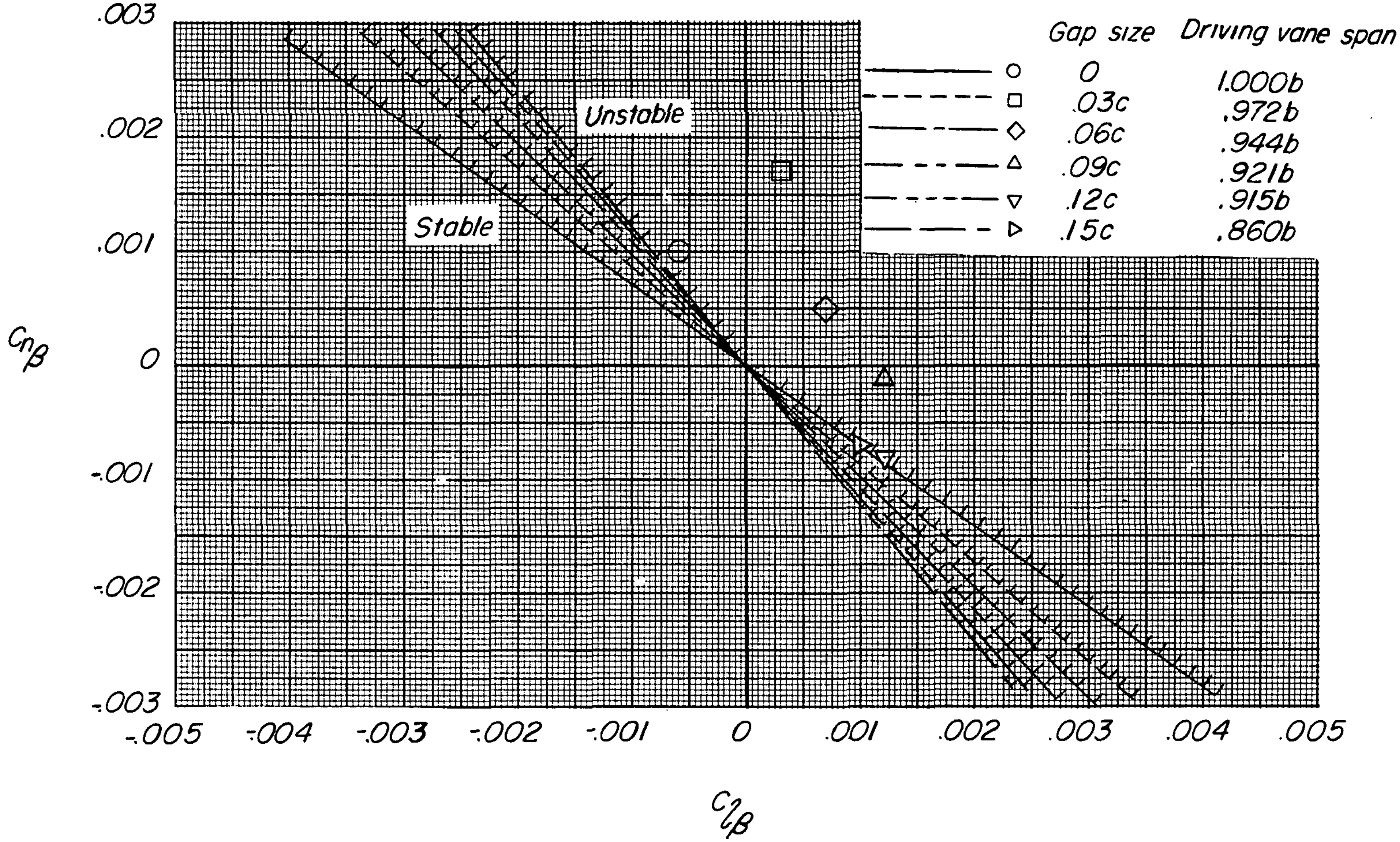
(a) Driving vanes off.

Figure 7.- Spiral-stability boundaries for several configurations of model having span-chord ratio of 2:1 with position of configurations with respect to boundaries.



(b) Constant-span driving vanes = 0.860b.

Figure 7.- Continued.



(c) Various driving-vane spans.

Figure 7.- Concluded.

WIND-TUNNEL INVESTIGATION

AT LOW SPEED OF AERODYNAMIC CHARACTERISTICS OF

ARMY CHEMICAL CORPS MODEL E-112 BOMBLETS WITH

SPAN-CHORD RATIO OF 2:1

By William Letko

ABSTRACT

The static and dynamic aerodynamic characteristics of the Army E-112 bomblets with span-chord ratio of 2:1 were determined at low speed in the Langley stability tunnel. The results showed that all the configurations would be spirally unstable and that a large gap between model tips and end plates tended to reduce the instability.

INDEX HEADINGS

Missiles, Specific Type	1.7.2.2
Stability, Lateral - Static	1.8.1.1.2
Stability, Directional - Static	1.8.1.1.3
Stability, Lateral and Directional - Dynamic	1.8.1.2.2
Damping Derivatives - Stability	1.8.1.2.3

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