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THE EFFECT OF THE SKIS ON THE POWER-OFF STABILITY

CHARACTERISTICS OF A TWIN-ENGINE CARGO AIRPLANE

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WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, U.S. Army Air Forces

THE EFFECT OF THE SKIS ON THE POWER-OFF STABILITY

CHARACTERISTICS OF A TWIN-ENGINE CARGO AIRPLANE.

By Park Y. Wong

SUMMARY

The results of the power-off wind-tunnel tests of a 1/11-scale model of a twin-engine cargo airplane equipped with wheel skis are presented. Longitudinal-, directional-, and lateral-stability characteristics were investigated for two flap positions and three ski positions. The effect on the drag coefficient of fairing the main skis in the retracted position was also investigated.

The test results indicated that the longitudinal-, directional-, and lateral-stability characteristics in pitch and yaw were practically unchanged by the addition of the wheel skis. At a lift coefficient of 0.2 (high-speed condition), the measured drag increment due to the main skis in the retracted position was 0.0017. This value was reduced to 0.0005 when fairings were added between the main skis and the nacelles. The measured drag increment of the tail ski was 0.0005.

INTRODUCTION

At the request of the Air Technical Service Command, tests on a 1/11-scale model of a twin-engine cargo airplane equipped with wheel skis were conducted in the Ames 7- by 10-foot wind tunnel. A three-view drawing of the airplane is presented in figure 1. The purpose of these tests was to investigate the effect of wheel skis on

power-off longitudinal-, directional-, and lateral-stability
characteristics of the model and to investigate the effect
on the drag of fairing the main skis in the retracted posi-
tion.

Pitch and yaw runs were made with the model in the
skis-off condition at two flap positions and with retracted
and extended main landing gear as a measure for comparison
with the skis-on runs. With the model in the skis-on condi-
tion, runs were made with the main skis and gear retracted,
extended for landing on a hard surface, and extended for
landing on snow. For these runs, the tail ski and gear
were always in a fixed position as the tail wheel is non-
retractable. Figure 2 shows detail drawings of the ski
positions tested.

The tests were conducted during the period of
December 16 to December 19, 1944, inclusive. All data
included have been presented previously in preliminary form.

DESCRIPTION OF THE MODEL AND THE AIRPLANE

A 1/5-scale model of a twin-engine cargo airplane of
conventional design was used in the tests. The model
configuration symbols employed are listed in Appendix A and
the full-scale dimensions of the airplane are presented in
table I. Photographs of the model mounted in the tunnel with
the main landing gear and skis retracted, gear and skis
extended for landing on a hard runway, and with gear and skis
extended for snow landing are shown in figures 3, 4, and 5,
respectively.

COEFFICIENTS AND CORRECTIONS

All data are presented as standard NACA coefficients
and are corrected for tares, tunnel-wall interference, and
stream inclination. All coefficients are referred to the
wind axes except when the model is yawed. In the latter
case, the force coefficients C_D' and C_Y' and the moment
coefficients C_m' and C_l' are given about the stability
axes. The coefficients used are defined as follows:

C_L lift coefficient $\left(\dfrac{\text{lift}}{qS}\right)$

C_D drag coefficient $\left(\dfrac{\text{drag}}{qS}\right)$

$C_D{}'$ drag coefficient about the stability axes $\left(\dfrac{\text{drag}}{qS}\right)$

$C_Y{}'$ lateral-force coefficient about the stability axes

   $\left(\dfrac{\text{lateral force}}{qS}\right)$

C_m pitching moment $\left(\dfrac{\text{pitching moment}}{qS\bar{c}}\right)$

$C_m{}'$ pitching-moment coefficient about the stability axes

   $\left(\dfrac{\text{pitching moment}}{qS\bar{c}}\right)$

C_n yawing-moment coefficient $\left(\dfrac{\text{yawing moment}}{qSb}\right)$

$C_l{}'$ rolling-moment coefficient about the stability axes

   $\left(\dfrac{\text{rolling moment}}{qSb}\right)$

C_{D_P} parasite drag coefficient $\left(C_D - \dfrac{C_L{}^2}{\pi A}\right)$

where

q dynamic pressure $\left(\tfrac{1}{2}\rho V^2\right)$

S wing area, square feet

$\bar{c}$ wing mean aerodynamic chord (M.A.C.), feet

b wing span, feet

A wing aspect ratio $\left(\dfrac{b^2}{S}\right)$

Moment coefficients are presented about a center of gravity located at 20.8 percent of the mean aerodynamic chord and 2.7 percent of the mean aerodynamic chord below the thrust line. This is the same reference center of gravity used in reference 1. A line diagram of the reference center-of-gravity location is presented in figure 6.

The angle of attack is measured from the fuselage reference line and the angle of yaw from the plane of symmetry.

A dynamic pressure of 50 pounds per square foot corresponding to a Reynolds number (based on the wing M.A.C.) of 1,300,000 was maintained for all tests.

The stream inclination and tare corrections used in the computations are the same as those used in obtaining the results of reference 1. Definitions of the tunnel-wall corrections may be found in Appendix B.

RESULTS AND DISCUSSION

The effect of wheel skis on the longitudinal characteristics at zero yaw is shown in figure 7 for flaps up and down 45°, with the main landing gear retracted. Figure 8 presents, for the flaps-up condition, the effect of the skis on the longitudinal characteristics of the model with the main landing gear extended, and the condition with flaps down at 45° is shown in figure 9. These figures indicated that the addition of the wheel skis had negligible effect on the longitudinal-stability and lift characteristics.

The effect of the skis on the characteristics of the model in yaw at $\alpha_u = -1°$ and $6°$, with flaps up and main landing gear retracted, is presented in figures 10 and 11. The characteristics at $\alpha_u = 6°$, with flaps down 45° and main landing gear extended, are shown in figures 12 and 13 (α_u, the uncorrected angle of attack referred to the fuselage reference line in degrees). The longitudinal-, directional-, and lateral-stability characteristics of the model in yaw are practically unchanged by the addition of the wheel skis.

The drag coefficient is found to be reduced when the skis in the retracted position are added to the model with flaps down at 45°. (See fig. 7.) However, in the flaps-up condition, a high-speed profile-drag increment (at $C_L = 0.2$) of $\Delta C_{D_p} = 0.0022$ resulted from the addition of the tail ski and the main skis to the retracted landing gear. (See fig. 14.) The fairing of the main skis in the retracted position with model clay, as shown in figure 15, greatly reduced the over-all drag increment to $\Delta C_{D_p} = 0.0010$. By removing the tail ski, the drag increment of the faired main

skis alone (in the retracted position) is found to be $\Delta C_{D_P} = 0.0005$. Hence, the drag increment of the tail

ski is also $\Delta C_{D_P} = 0.0005$.

CONCLUSIONS

The conclusions drawn from the tests of the 1/11-scale model of the twin-engine cargo airplane equipped with wheel skis are as follows:

1. The addition of the wheel skis had a negligible effect on the power-off stability characteristics of the model in pitch and in yaw.

2. At $C_L = 0.2$, the profile-drag increment due to the main skis in the retracted position is 0.0017, while that of the tail ski is 0.0005. The fairing of the main skis in the retracted position with model clay reduces the drag increment to 0.0005.

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

APPENDIX A

MODEL CONFIGURATION KEY

W   wing

B   fuselage

N   nacelles

E   exhaust stacks

H   horizontal tail

V   vertical tail

F   flaps

L   main landing gear extended

L_R main landing gear retracted

L_T tail wheel

L_1 front gear extended, front skis extended

L_2 front gear extended, front skis retracted

L_3 front gear retracted, front skis retracted

L_3' front gear retracted, front skis retracted plus ski
       fairings

L_4 tail wheel plus tail ski

S   standard configuration, $WBNEL_R L_T HV$

APPENDIX B

TUNNEL-WALL CORRECTIONS

The tunnel-wall corrections are defined as follows:

$$\Delta\alpha = (\delta_w + 0.017\overline{c}) \frac{S}{C} C_L \times 57.3 = 0.94 \ C_L$$

$$\Delta C_D = \frac{\delta_w C_L^2 S}{70} = 0.0143 \ C_L^2$$

$$\Delta C_m = -\delta_t \frac{S C_L}{C} \frac{dC_{mt}}{di_t} \times 57.3 = -0.019 \ C_L$$

where

$\Delta\alpha$ tunnel-wall correction to angle of attack, deg

ΔC_D tunnel-wall correction to drag coefficient

ΔC_m tunnel-wall correction to pitching-moment coefficient

δ_w jet-boundary correction factor at the wing = 0.1235

δ_t jet-boundary correction factor at the tail = 0.087

$\dfrac{dC_{m_t}}{di_t}$ change in pitching moment per degree change in stabilizer angle (stabilizer effectiveness) = -0.033/deg (computed)

C   tunnel cross-section area = 70 sq ft

S   wing area = 8.16 sq ft

$\overline{c}$ mean aerodynamic chord = 1.05 ft

Model dimensions used in computing coefficients are as follows:

wing area, sq ft 8.16

wing span, ft 8.60

wing mean aerodynamic chord, ft 1.05

wing aspect ratio 9.06

REFERENCE

1. Belsley, Steven E., and Jackson, Roy P.: The Effect of Amphibious Floats on Power-Off Stability and Control Characteristics of the Douglas C-47 Airplane. NACA CMR, Jan. 1943.

TABLE I.- GEOMETRIC DATA OF TWIN-ENGINE CARGO AIRPLANE

[Dimensions are full scale]

Main Surfaces			
Component	Wing	Horizontal tail	Vertical tail
Area	987 ft²	206.5 ft²	110.2 ft²
Span	94.58 ft	26.7 ft	11.23 ft
Aspect ratio	9.06	3.45	1.145
M.A.C.	11.52 ft	--------	--------
Flap (type)	split	simple (balanced)	simple (balanced)
NACA section	2215 root 2206 tip	modified 0012	modified 0012
Taper ratio	0.300	0.231	0.264
Incidence	2°	2°	--------

Movable Surfaces			
Component	Elevator	Rudder	Flap (Split)
Area aft hinge	62.2 ft²	35.8 ft²	83.5 ft²
Span	26.7 ft	9.26 ft	41.5 ft
Total surface area affected	176.6 ft²	84.0 ft²	552 ft²
Chord	--------	--------	2.01 ft (constant)

Length from c.g. to elevator hinge line, $l_H = 39.7$ ft.
Length from c.g. to rudder hinge line, $l_V = 38.3$ ft.

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94.6'
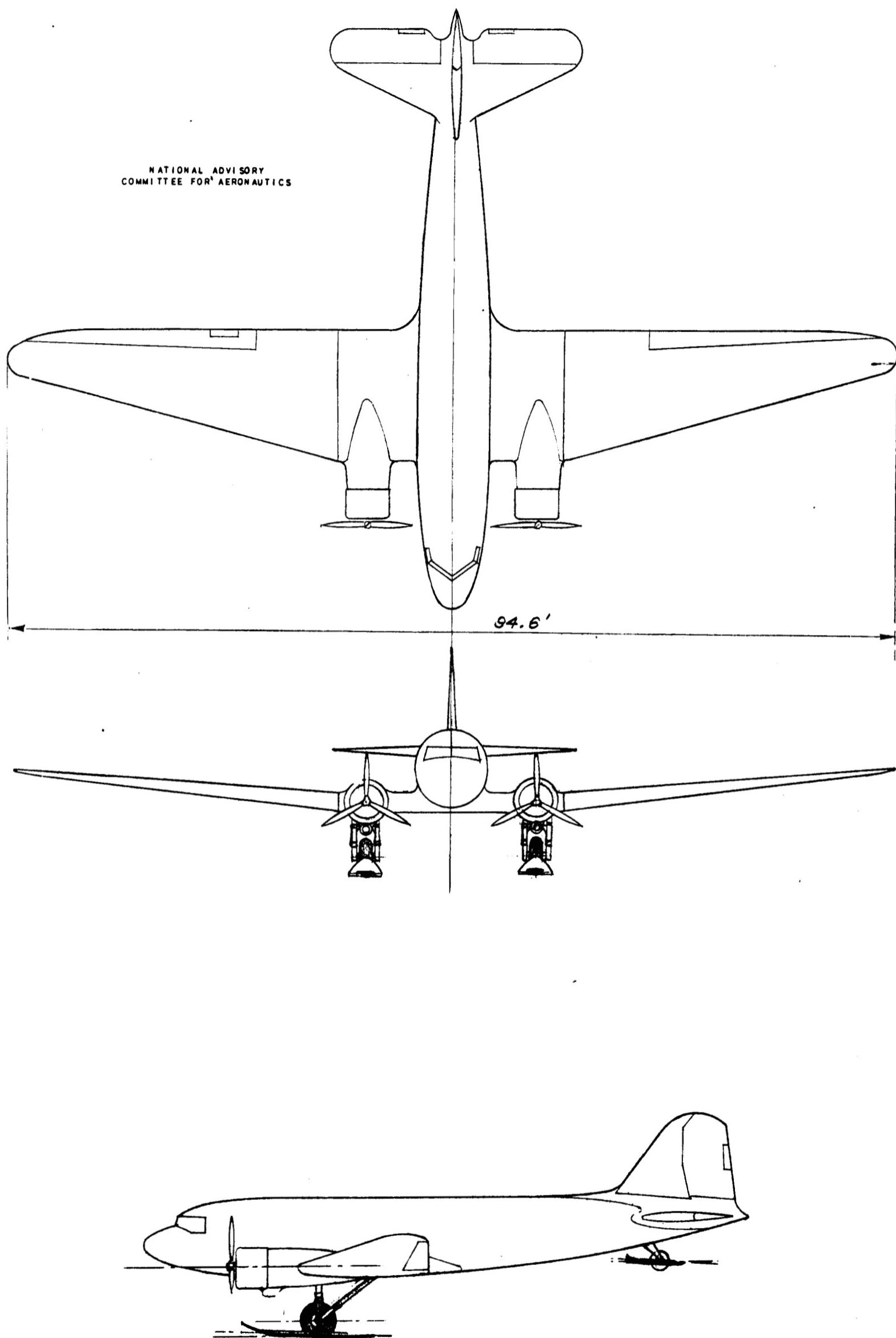
FIGURE 1. — THREE-VIEW DRAWING OF THE TWIN-ENGINE CARGO
AIRPLANE EQUIPPED WITH WHEEL SKIS.

NOTE: ALL SKI ANGLES TAKEN ON TOP
OF SKI BULKHEAD.

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1.33"

⊄ SKIS PIVOT

2° POSITIVE INCIDENCE WITH RESPECT
TO AIRPLANE THRUST LINE.
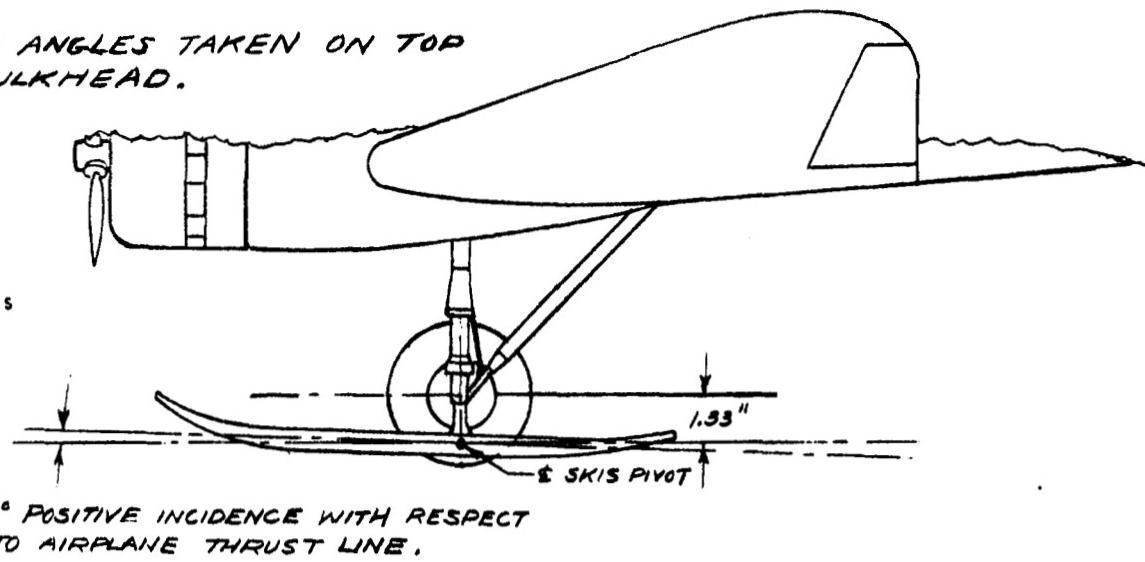
GEAR EXTENDED AND SKIS EXTENDED FOR LANDING ON SNOW ~ CONFIG. = L_1

0.369"

⊄ SKI PIVOT (RADIUS = 1.33" FROM WHEEL CENTER)

4° NEGATIVE INCIDENCE WITH RESPECT
TO AIRPLANE THRUST LINE.
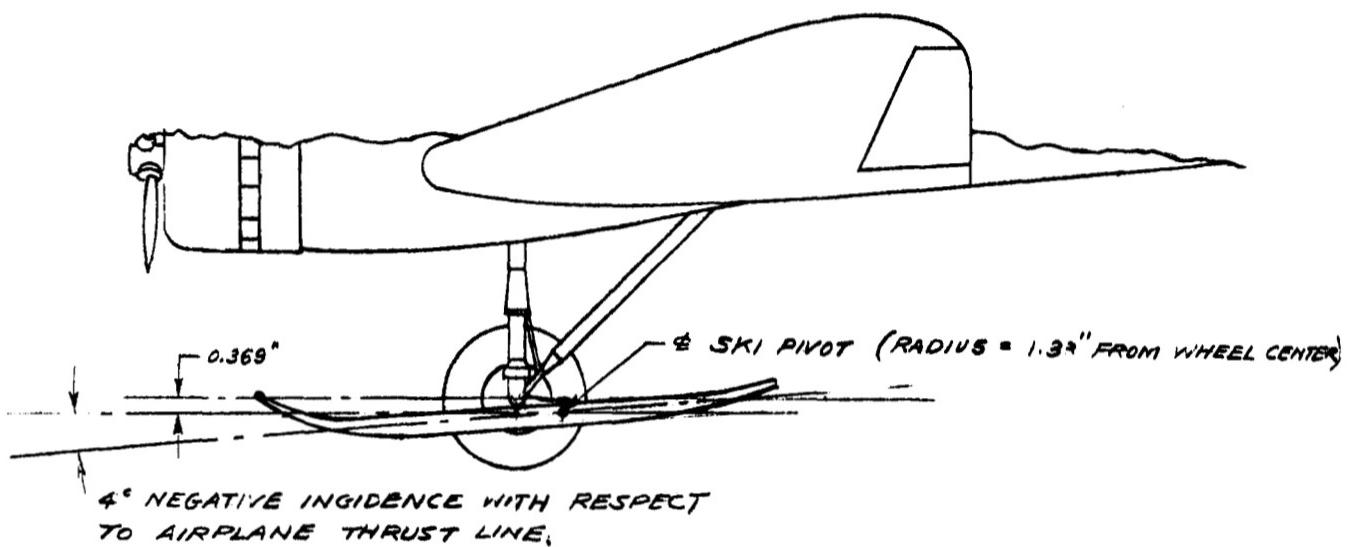
GEAR EXTENDED AND SKIS RETRACTED FOR LANDING ON HARD RUNWAY

CONFIG. = L_2

⊄ SKI PIVOT (RADIUS = 1.33" FROM WHEEL CENTER)
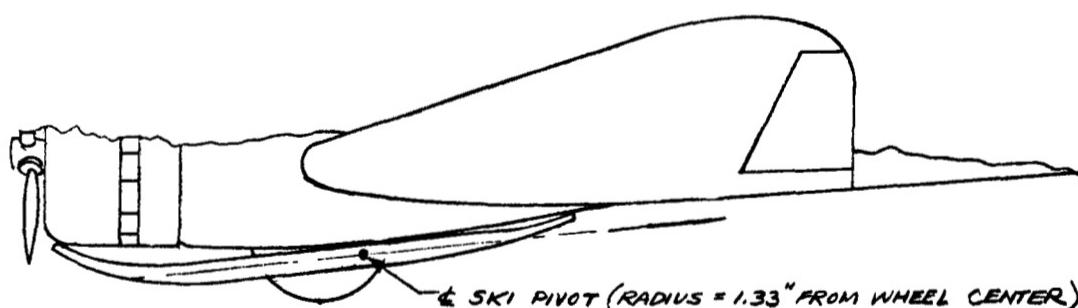
GEAR RETRACTED AND SKIS RETRACTED ~ CONFIG. = L_3

⊄ TAIL SKI PIVOT COINCIDENT WITH WHEEL CENTER.

3° POSITIVE INCIDENCE WITH RESPECT TO
AIRPLANE THRUST LINE.
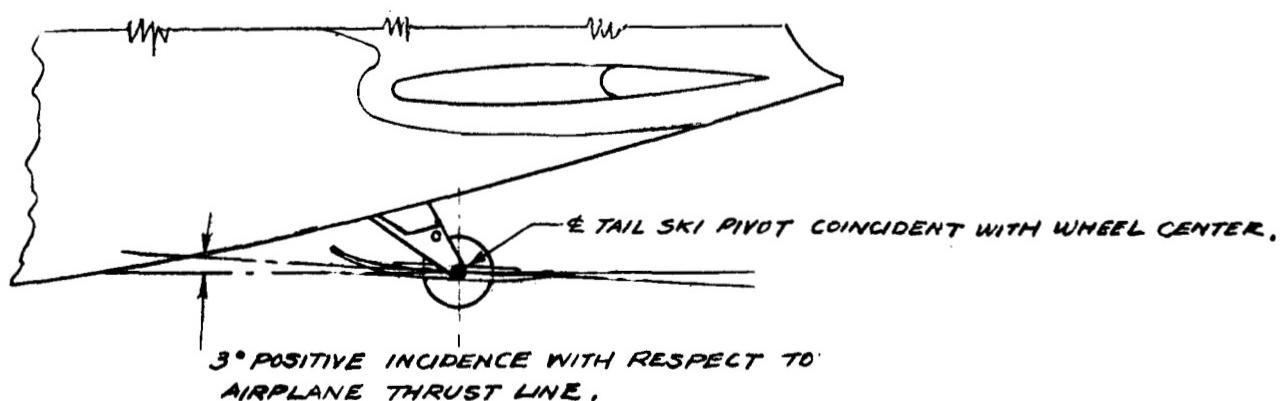
TAIL SKI AT FIXED POSITION ~ CONFIG. = L_4

FIGURE 2.- WHEEL-SKI POSITIONS TESTED ON A 1/11-SCALE MODEL OF
THE TWIN-ENGINE CARGO AIRPLANE.

(a) Front view.

(b) Rear view.

Figure 3.- The 1/11-scale model of the twin-engine cargo airplane showing the skis and gear retracted $(S+L_3 L_4+F^{45})$.
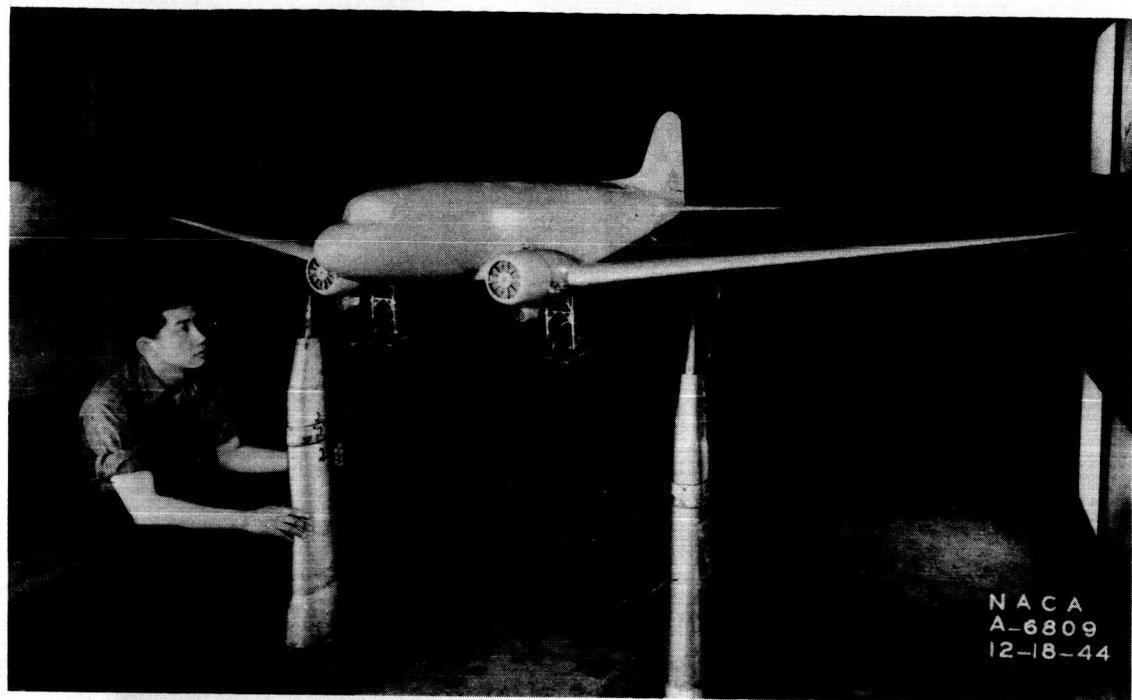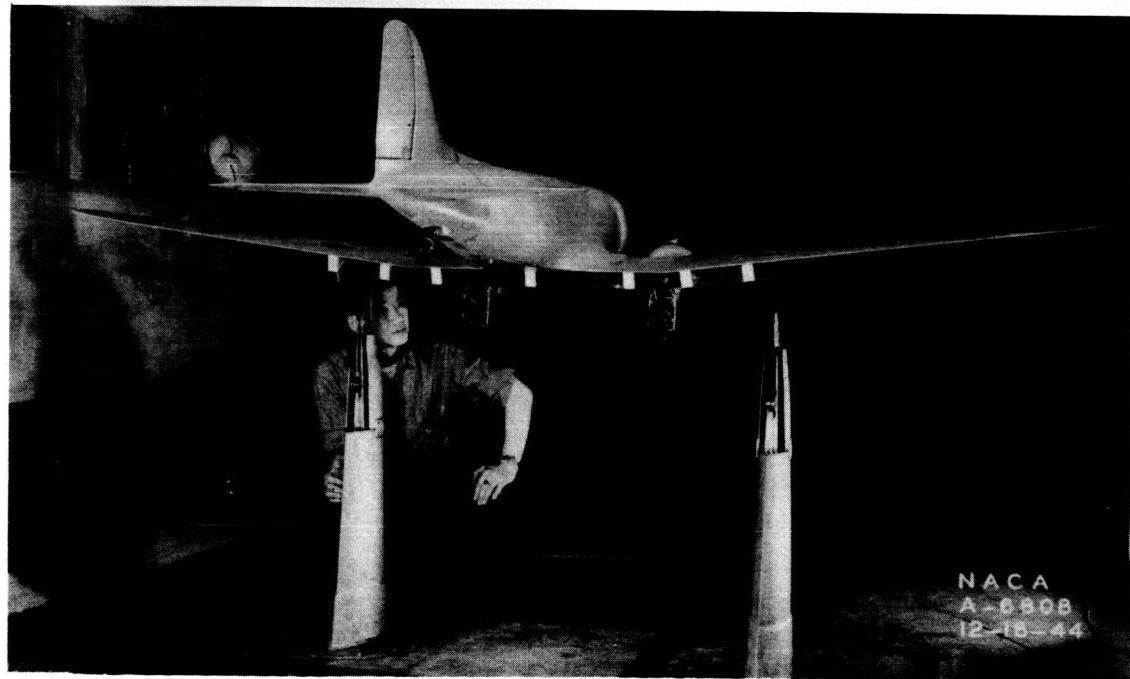
(a) Front view.

(b) Rear view.

Figure 4.- The 1/11-scale model of the twin-engine cargo airplane showing skis and gear extended for landing on a hard runway $(S_+L_2L_4+F^{45})$.

(a) Front view.

(b) Rear view.

Figure 5.- The 1/11-scale model of the twin-engine cargo airplane showing skis and gear extended for landing on snow $(S+L_2 L_4 +F^{45})$.
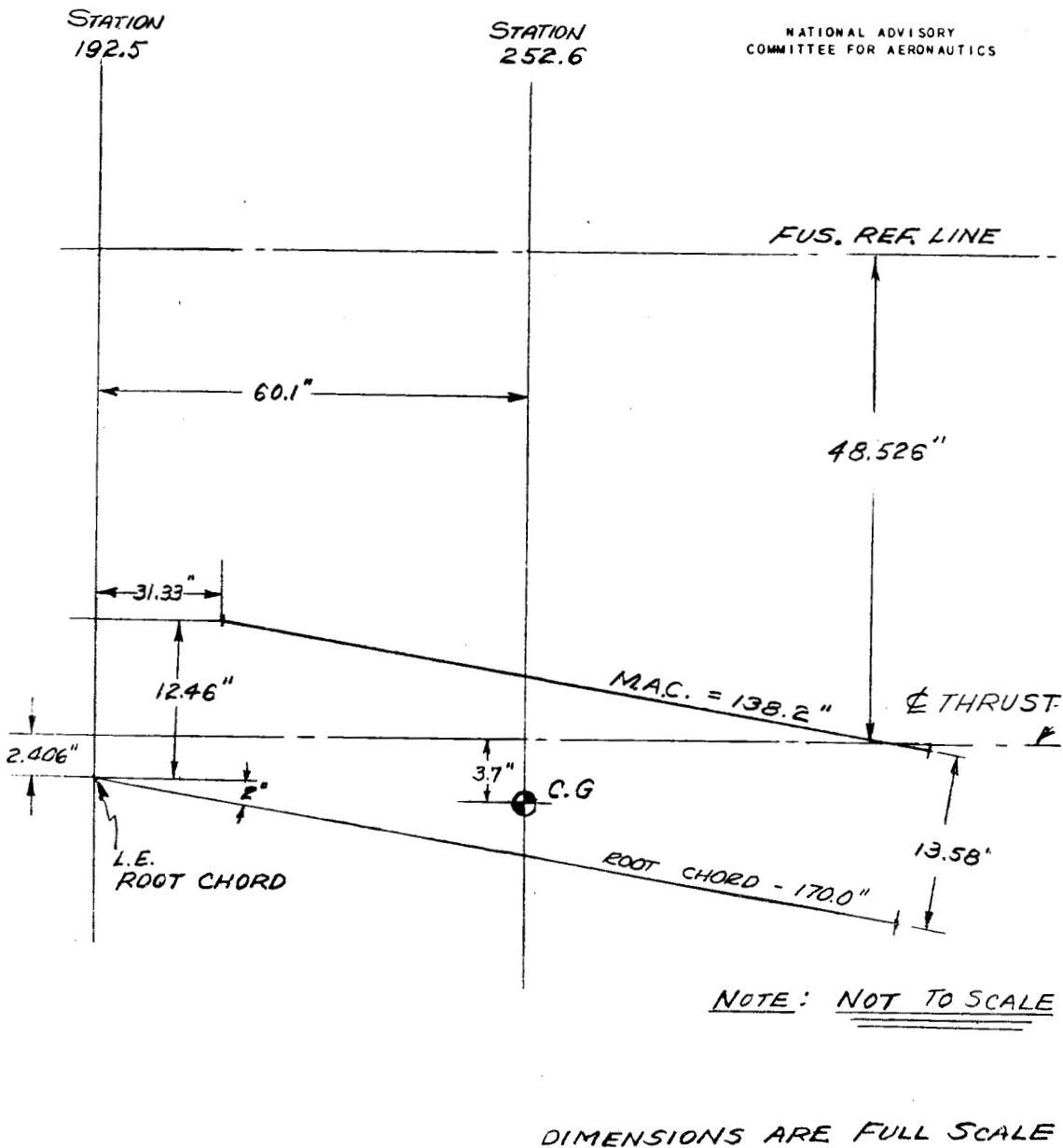
FIGURE 6. — CENTER-OF-GRAVITY LOCATION FOR THE TWIN-ENGINE CARGO AIRPLANE.
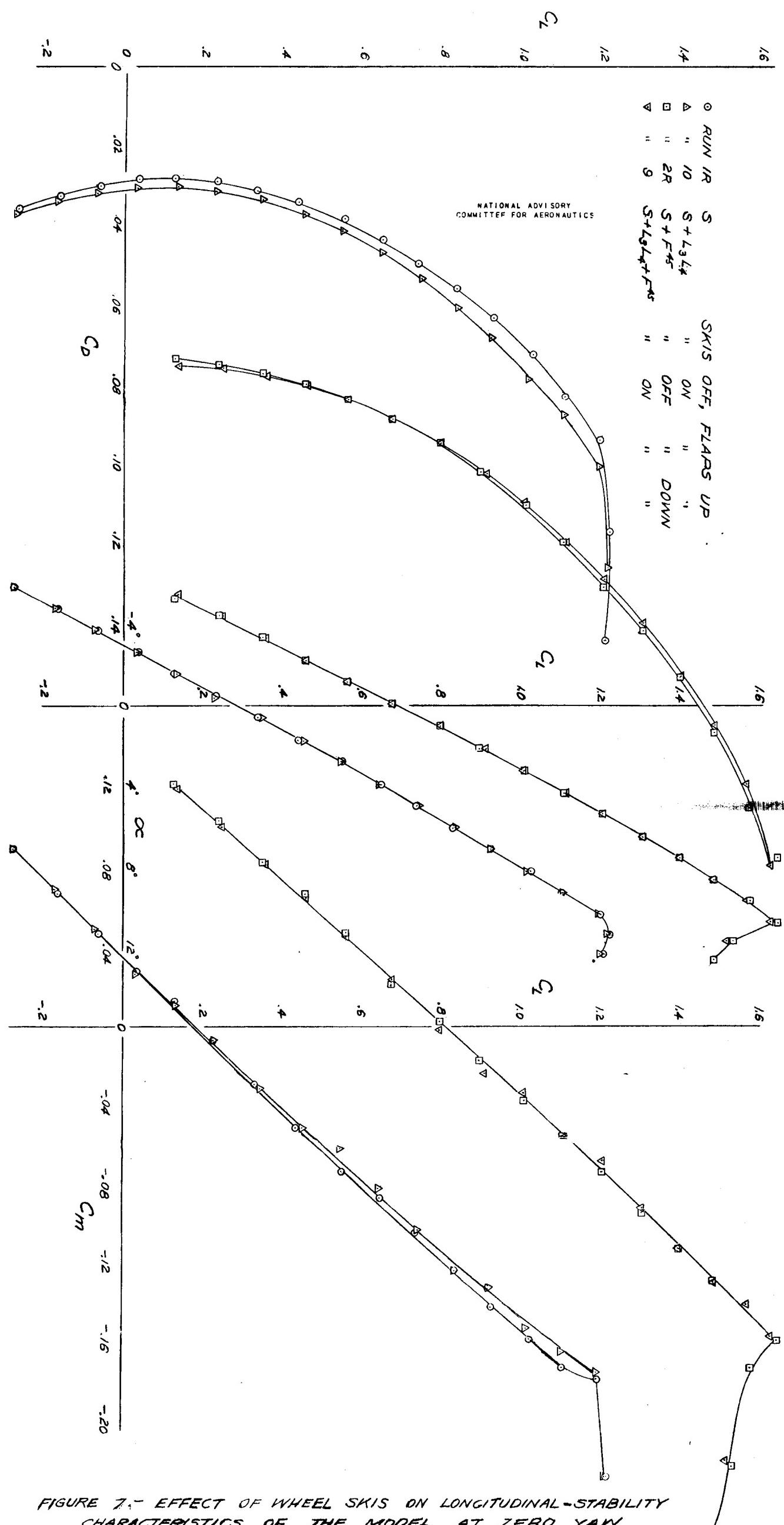
FIGURE 7.- EFFECT OF WHEEL SKIS ON LONGITUDINAL-STABILITY
CHARACTERISTICS OF THE MODEL AT ZERO YAW,
FLAPS UP AND DOWN 45°, MAIN LANDING GEAR RETRACTED,
RUDDER AND ELEVATOR NEUTRAL.

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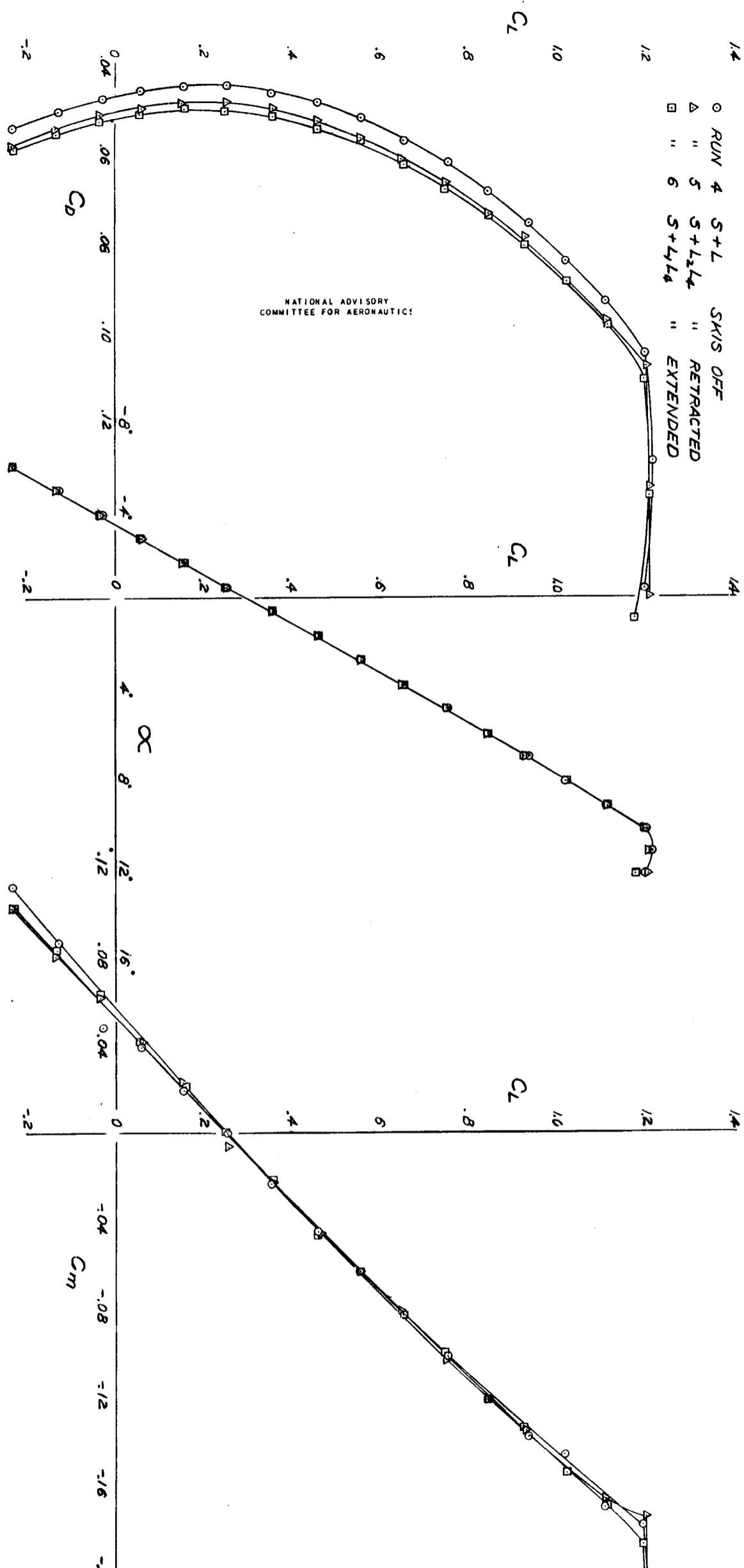
FIGURE 8.- EFFECT OF WHEEL SKIS ON LONGITUDINAL- STABILITY
CHARACTERISTICS OF THE MODEL AT ZERO YAW,
FLAPS UP, MAIN LANDING GEAR EXTENDED, RUDDER AND ELEVATOR
NEUTRAL.

C_L

⊙ RUN 3 S+LF⁴⁵ SKIS OFF
△ " 8 S+L₄₄+F⁴⁵ " RETRACTED
□ " 7 S+L₄+F⁴⁵ " EXTENDED

C_D

C_L

α

C_L

C_m
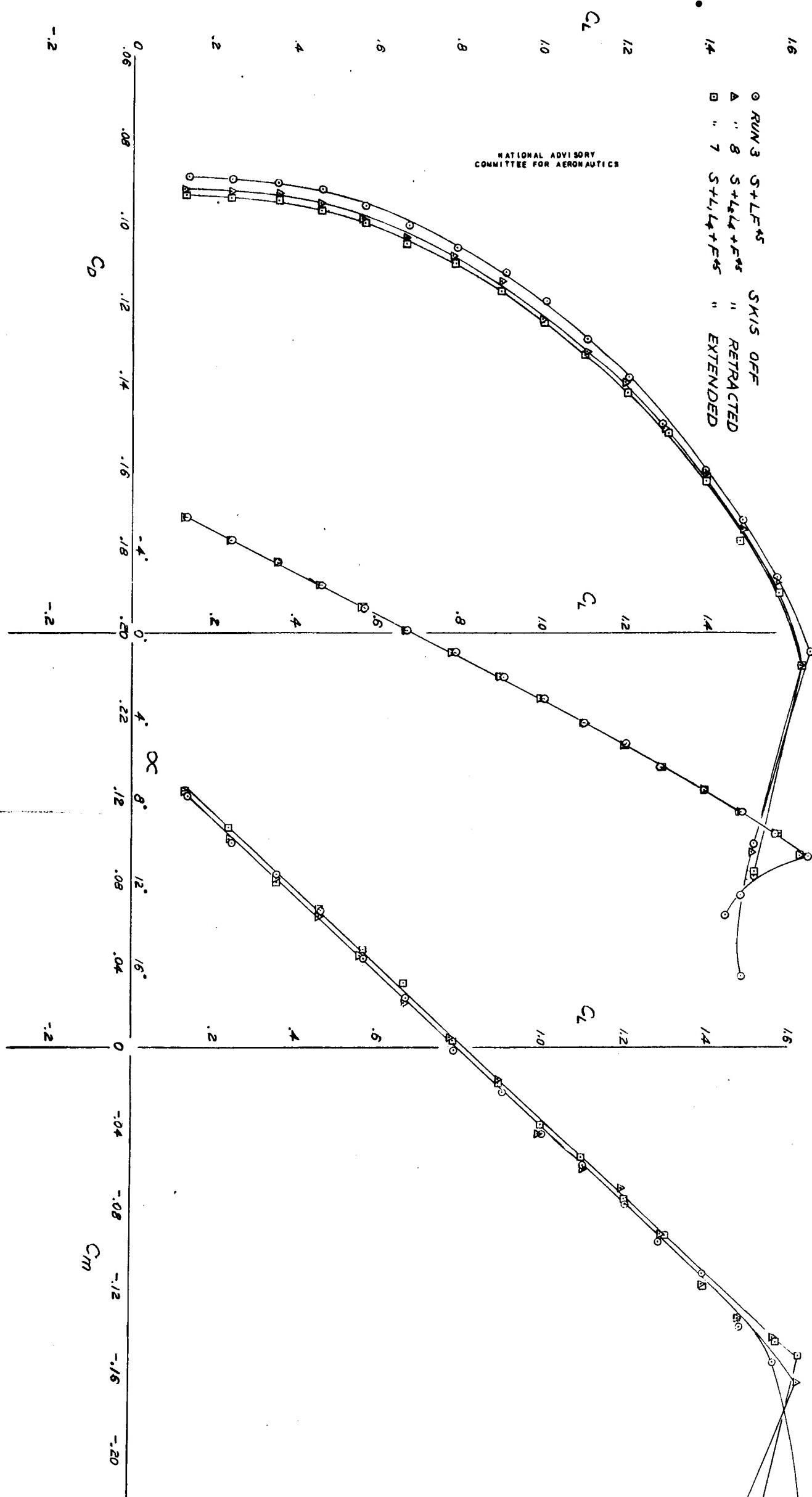
FIGURE 9.— EFFECT OF WHEEL SKIS ON LONGITUDINAL-STABILITY
CHARACTERISTICS OF THE MODEL AT ZERO YAW,
FLAPS AT 45°, MAIN LANDING GEAR EXTENDED, RUDDER
AND ELEVATOR NEUTRAL.

C_L 1.0

.8

.4

C_L

.2

-25 -20 -15 -10 -5 0 5 10 ψ 15 20 25
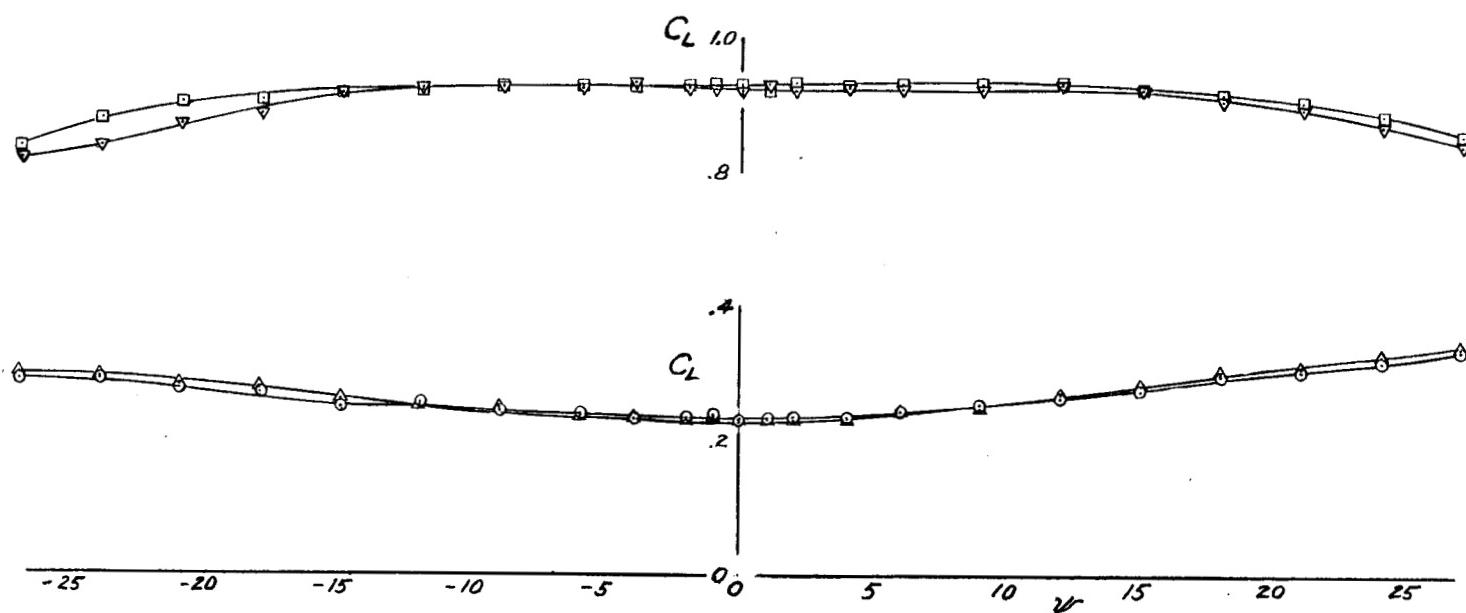
⊙ RUN 16 S SKIS OFF $\alpha_u = -1°$
△ 11 $S + L_3 L_4$ " RETRACTED " "
☐ 17 S " OFF " +6°
▽ 12 $S + L_3 L_4$ " RETRACTED " "

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.06

C_D'

.04

.02

-25 -20 -15 -10 -5 0 5 10 ψ 15 20 25

.1

C_m'

0

-25 -20 -15 -10 10 15 ψ 20 25

-.1

-.2
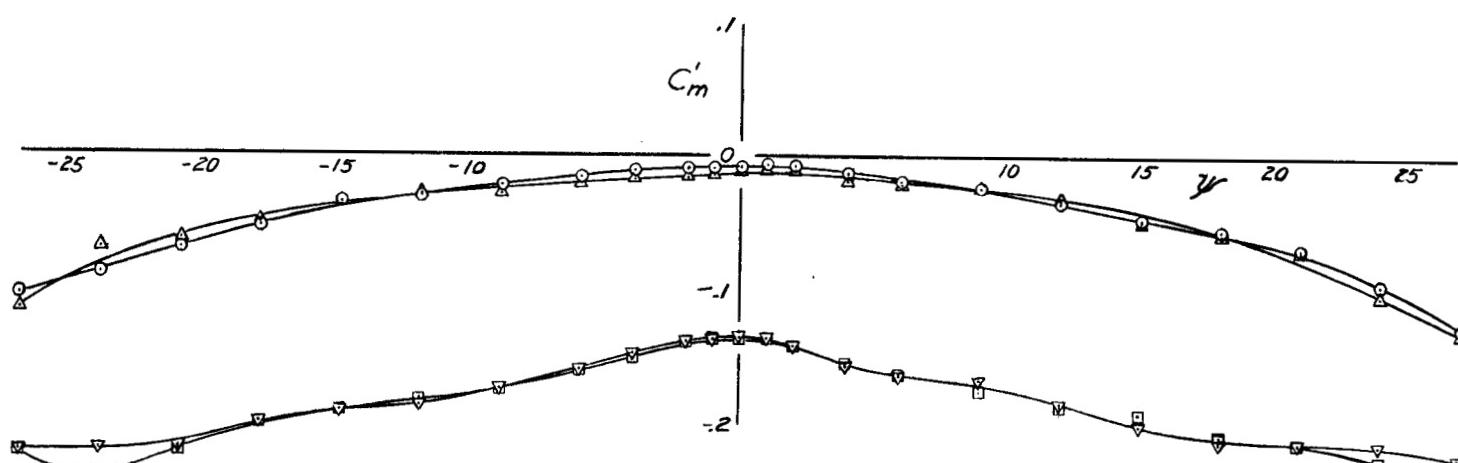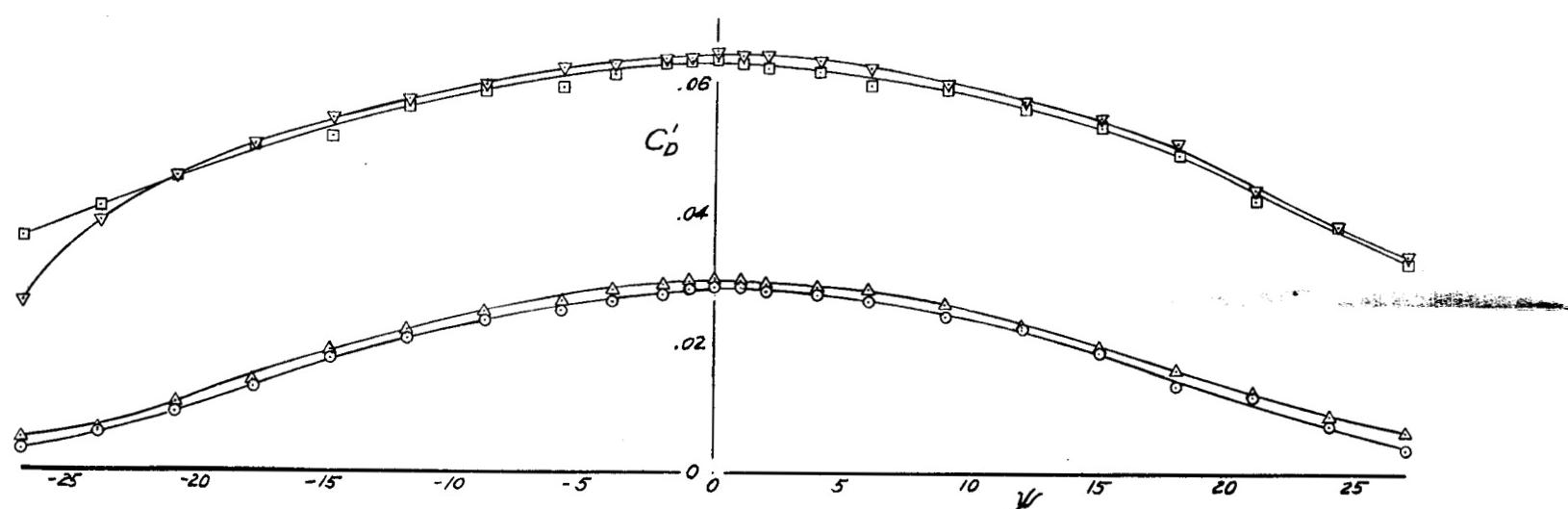
FIGURE 10. - EFFECT OF WHEEL SKIS ON C_L, C_D' AND C_m',
MODEL AT $\alpha_u = -1°$ AND 6°, FLAPS UP, MAIN LANDING GEAR
RETRACTED, RUDDER AND ELEVATOR NEUTRAL.

|				
⊙ RUN 16	S	SKIS OFF	$\alpha_u = -1$	
△	11 $S+L_3 L_4$	" RETRACTED	"	"
□	17 S	" OFF	"	+6
▽	12 $S+L_3 L_4$	" RETRACTED	"	"
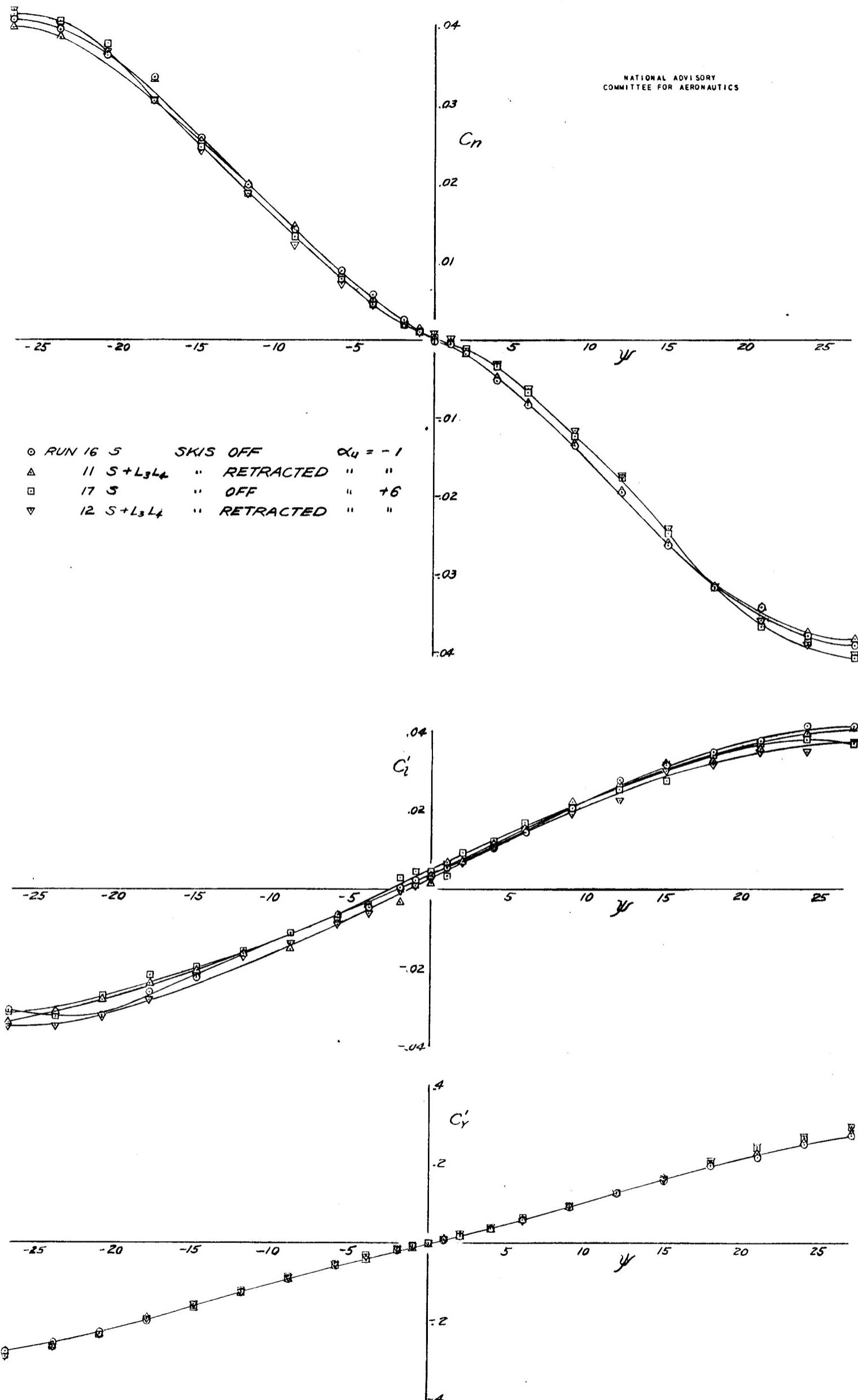
FIGURE 11. - EFFECT OF WHEEL SKIS ON LATERAL-STABILITY CHARACTERISTICS
OF THE MODEL AT $\alpha_u = -1°$ AND 6°, $C_L \cong 0.25$ AND 0.9,
FLAPS UP, MAIN LANDING GEAR RETRACTED, RUDDER AND
ELEVATOR NEUTRAL.
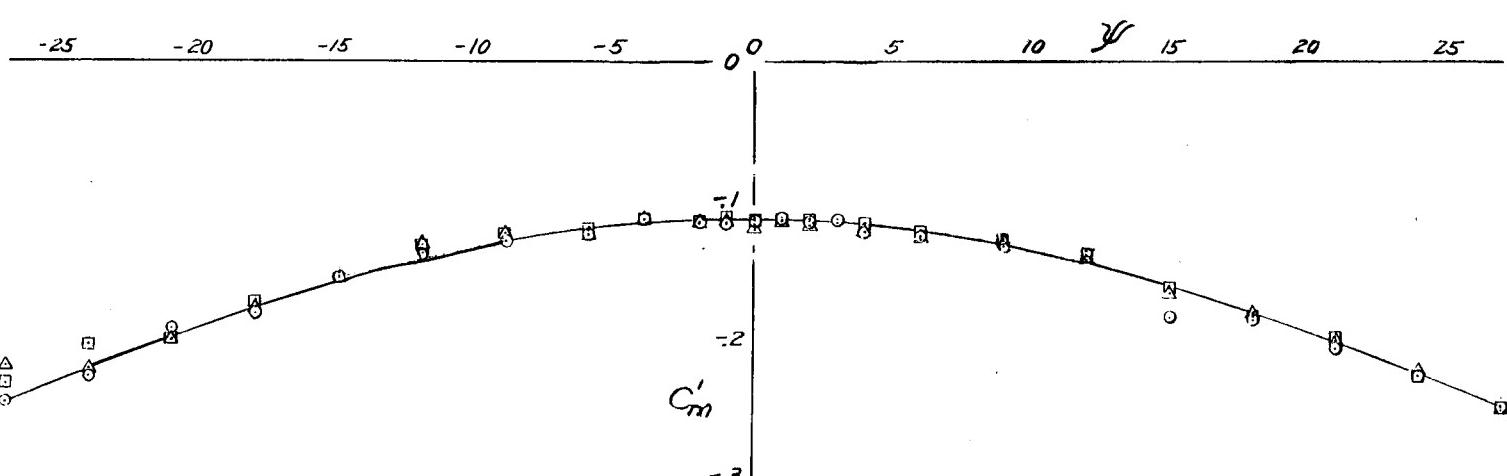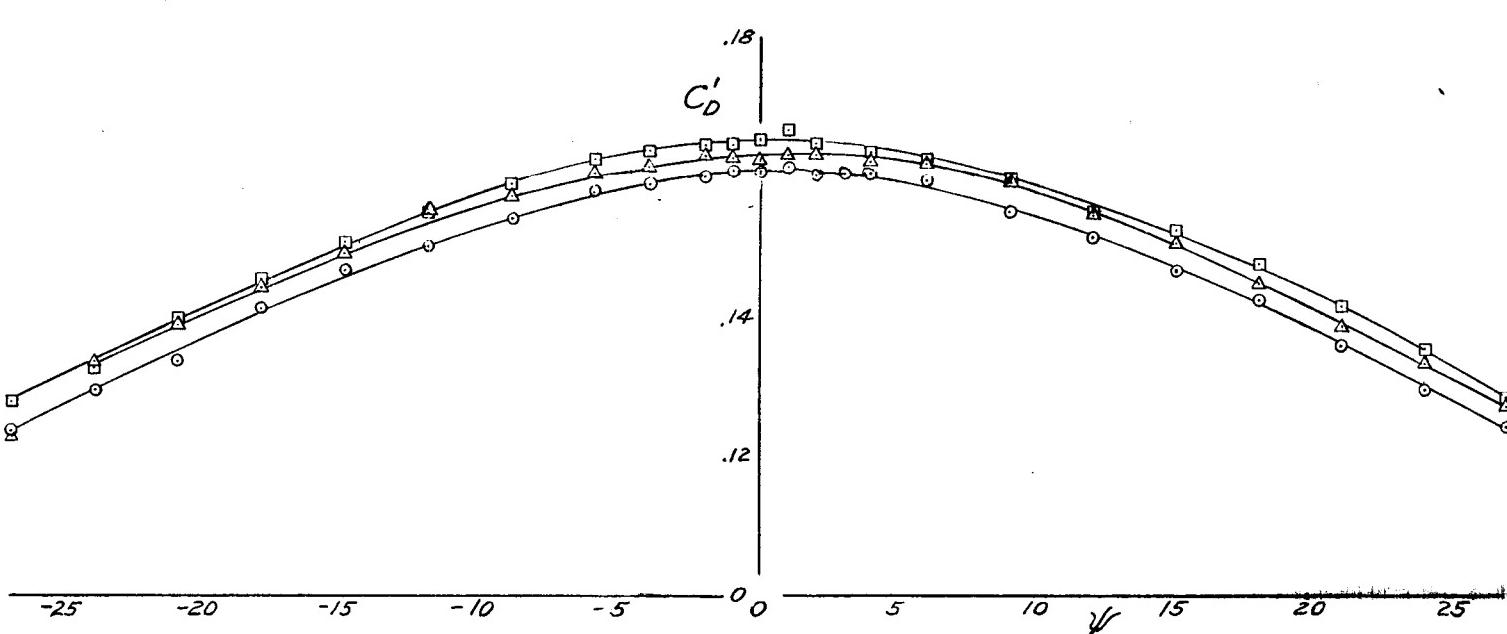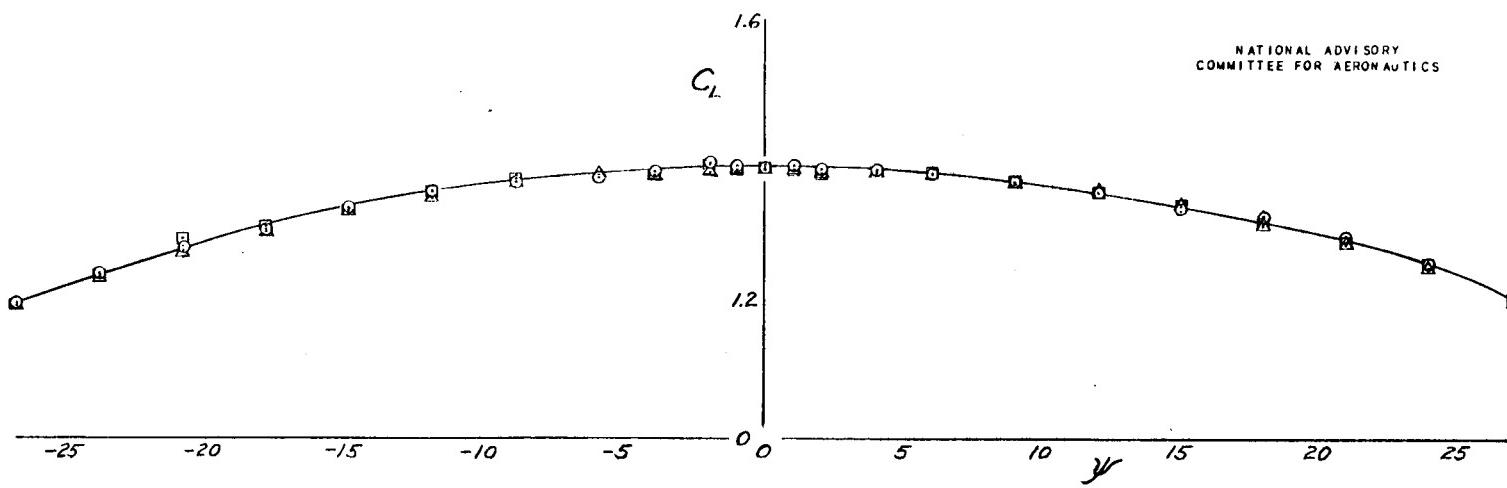
FIGURE 12.- EFFECT OF WHEEL SKIS ON C_L, C_D', AND C_m',
MODEL AT $\alpha_u = 6°$, FLAPS DOWN 45°, MAIN LANDING GEAR EXTENDED,
RUDDER AND ELEVATOR NEUTRAL.

C_n

.04

.03

.02

.01

-25 -20 -15 -10 -5 5 10 15 20 25 ψ

⊙ RUN 15 $S + LF^{45}$ SKIS OFF

▲ 14 $S + L_2 L_4 F^{45}$ " RETRACTED

▣ 13 $S + L_1 L_4 F^{45}$ " EXTENDED

=.01

-.02

=.03

=.04

C_l'

.04

.02

-25 -20 -15 -10 0 5 10 15 20 25 ψ

-.02

-.04

C_Y'

.4

.2

-25 -20 -15 -10 -5 5 10 15 20 25 ψ

-.2

-.4
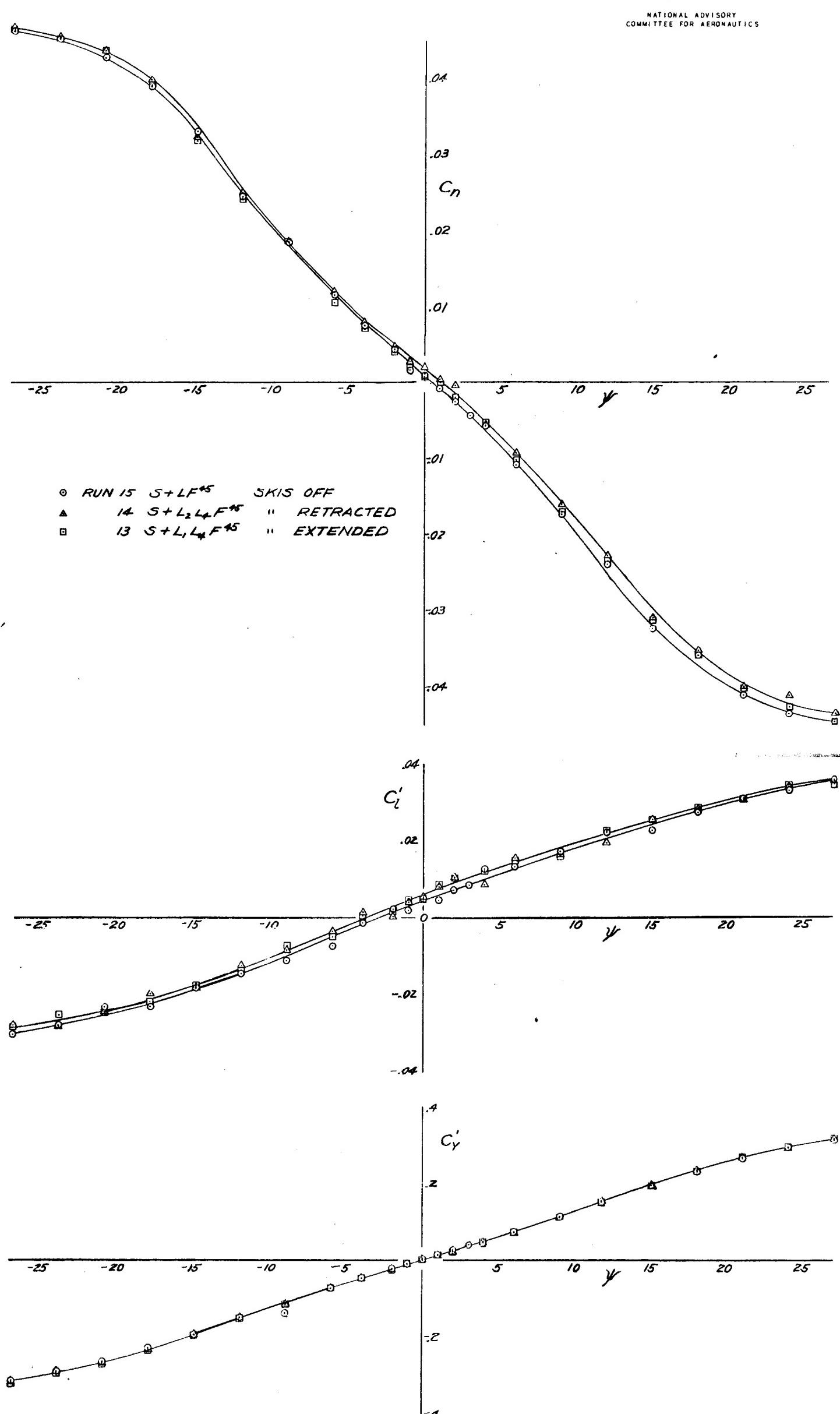
FIGURE 13.- EFFECT OF WHEEL SKIS ON LATERAL-STABILITY CHARACTERISTICS
OF THE MODEL AT $\alpha_u = 6°$, FLAPS DOWN 45°, $C_L \approx 1.4$,
MAIN LANDING GEAR EXTENDED, RUDDER AND ELEVATOR NEUTRAL.
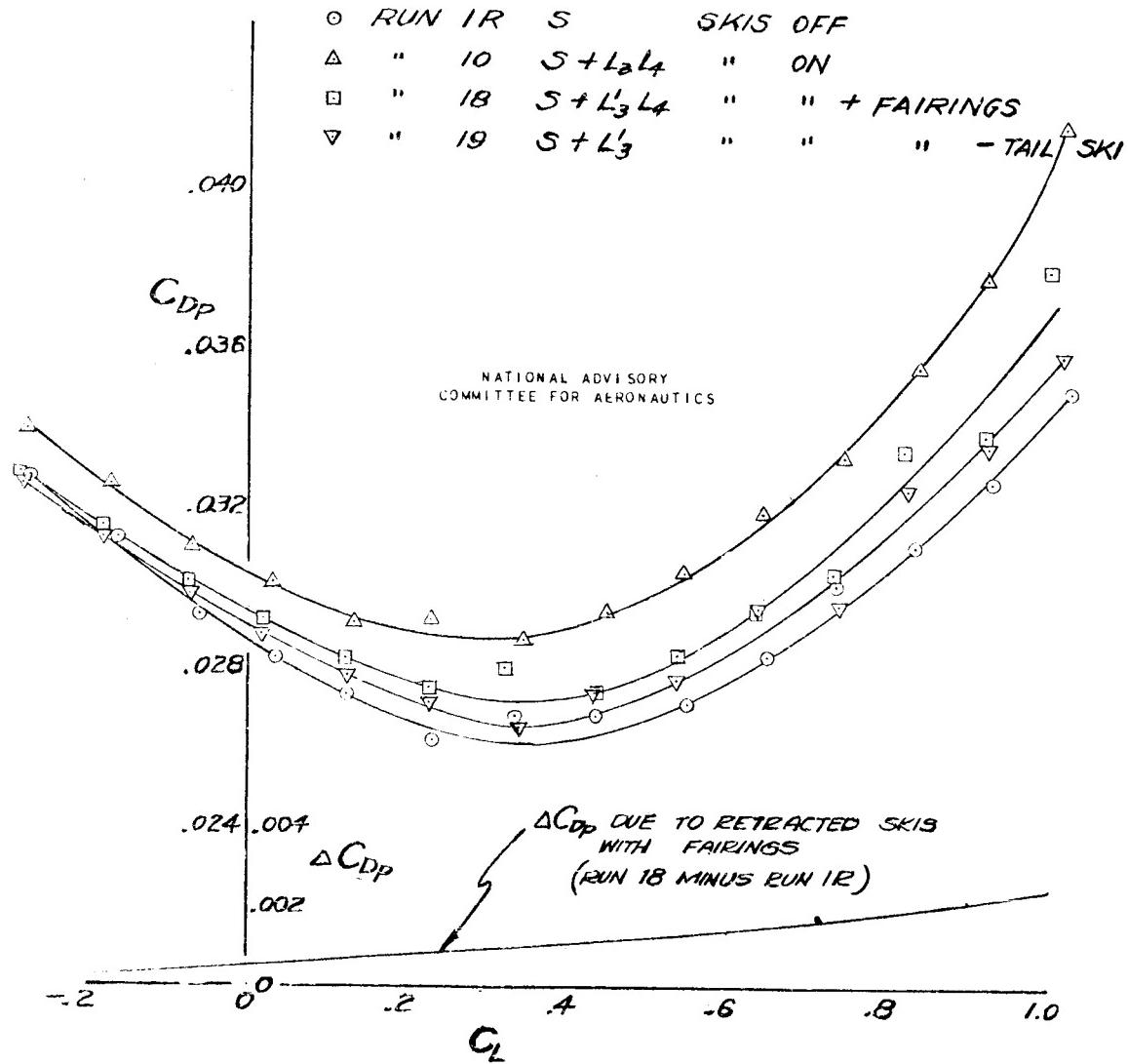
FIGURE 14. — MINIMUM DRAG CHARACTERISTICS OF
THE MODEL WITH THE MAIN WHEEL
SKIS ON AND OFF, TAIL WHEEL SKI ON AND
OFF, WITH AND WITHOUT SKI FAIRINGS,
FLAPS UP.

(a) Front view.
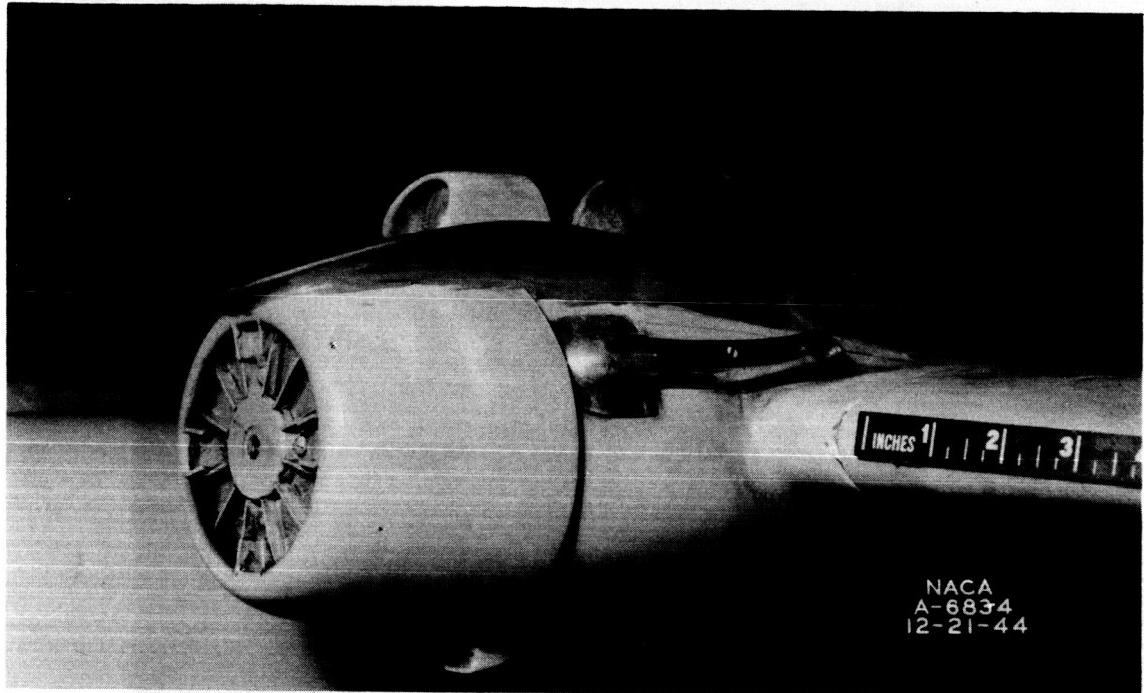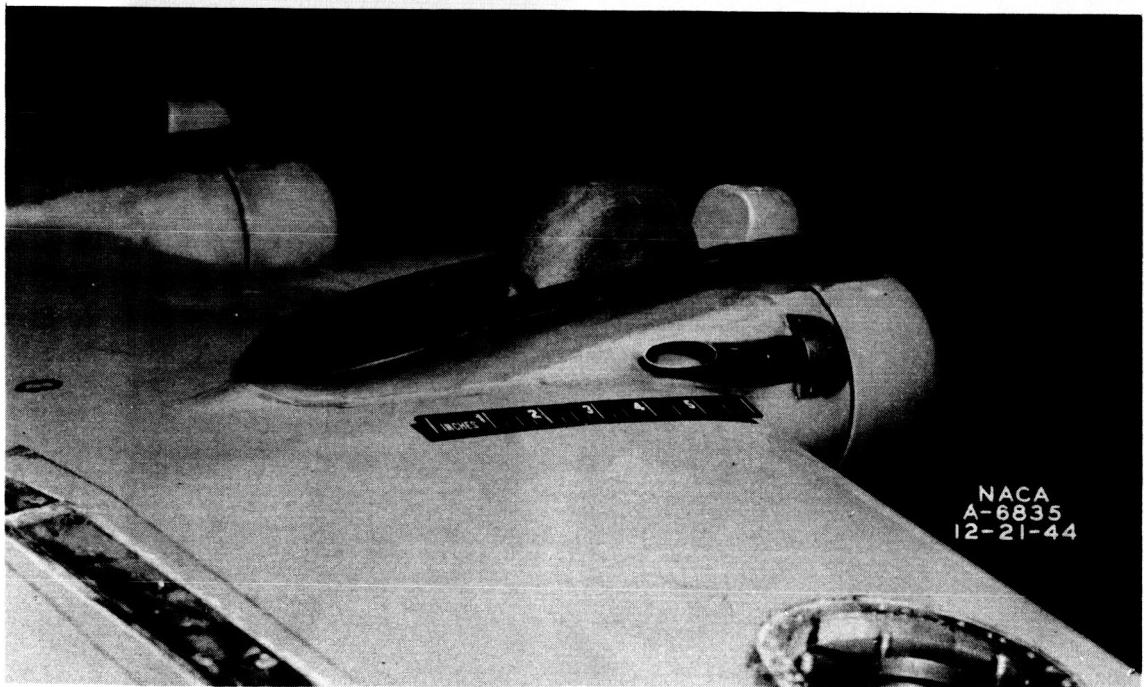
(b) Rear view.

Figure 15.- The 1/11-scale model of the twin-engine cargo airplane
showing the main skis in the retracted position with a clay
fairing added.