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FLYING QUALITIES OF A TWIN-ENGINE PATROL AIRPLANE AS ESTIMATED FROM WIND-TUNNEL TESTS

By Victor I. Stevens, Jr. and George B. McCullough

Ames Aeronautical Laboratory
Moffett Field, California

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

FLYING QUALITIES OF A TWIN-ENGINE PATROL AIRPLANE AS ESTIMATED FROM WIND-TUNNEL TESTS

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SUMMARY

Flying qualities of a twin-engine patrol airplane have been estimated from wind-tunnel test results for the purpose of comparison with flight observations, and as a possible guide in determining changes which would be necessary to improve these qualities.

The results indicate the airplane meets the specifications given in the report "Requirements for Satisfactory Flying Qualities of Airplanes," by R. R. Gilruth, except for the following:

(a) Lack of adequate longitudinal stability in climb and approach conditions

(b) Inability of elevator to maintain the airplane in a three-point attitude near the ground

(c) High stick forces in landing and maneuvering flight

(d) High wheel forces to obtain maximum rate of roll at high speed

(e) Severe rudder-pedal-force reversals at moderate angles of sideslip

(f) High rudder-pedal forces accompanying failure of one engine during take-off

INTRODUCTION

In the body of this report, the flying qualities of an existing twin-engine patrol airplane, as predicted from wind-tunnel tests, are presented and compared with the requirements for satisfactory flying qualities prescribed in reference 1. The required wind-tunnel data are presented in the appendix and were obtained from tests made at the request of the Bureau of Aeronautics, Navy Department, of a 1/9-scale powered model of the airplane. The tests were made in the Ames 7- by 10-foot wind tunnel No. 1, Moffett Field, Calif.

The flying-quality predictions have been made for the purpose of enabling a comparison to be made with the characteristics observed from flight tests with a view toward ascertaining the validity of the methods of computation used in making the predictions. The immediate value of such a comparison lies in the fact that it constitutes a basis for estimating the validity of the predicted flying qualities of a similar proposed patrol airplane which were derived by the same methods. Also, the estimated flying qualities should be of significant aid in suggesting changes to the existing airplane which would improve these characteristics.

DESCRIPTION OF THE AIRPLANE

A three-view drawing of the airplane is presented in figure 1. The mechanical advantage and cockpit-control travel are given in figures 2 and 3. The ratio of pedal force to hinge moment used in the computation of rudder-pedal force was 1.275. General specifications of the airplane are given in tables I, II, and III.

RESULTS AND DISCUSSION

In the following discussion the flying qualities of the airplane are evaluated in terms of the recommended requirements of reference 1. The requirement numbers of reference 1 have been retained to facilitate cross reference. It will be noted that all requirements concerning oscillatory motion have been omitted since the necessary data are not available from the wind-tunnel tests.

The longitudinal characteristics have been determined for normal and light (nose-heavy) loading condition; whereas the lateral characteristics have been determined for the normal loading only, since these latter characteristics are little affected by loading.

The results presented are based on the following assumptions: (1) no deformation of surfaces, either fixed or movable; (2) no deformation of control system; (3) no friction in control system; and (4) all movable surfaces mass balanced. Since the model was not equipped with tabs, the tab effectiveness was estimated from the results presented in reference 2.

Longitudinal Stability and Control

The longitudinal characteristics in steady flight are presented as the variation of elevator angle and stick force with indicated airspeed for the following conditions:

Condition	Power	Flaps and landing gear	[1]Stalling speed, mph		Figure
			Normal load	Light load	
Glide	Propellers windmilling	Retracted	116	104	4
Climb	Rated	Retracted	102	92	4
Landing	Propellers windmilling	Extended	98	88	5
Landing approach	Level flight	Extended	84	73	5

[1]Stalling speed as determined from wind-tunnel tests.

Requirement I-B: Characteristics of elevator control in steady flight.-

1. Static longitudinal stability, as indicated by the variation of elevator angle with speed, should be present for the four conditions listed at all speeds above the stall, except in the climb condition where stability is required only about 120 percent V_{min}. In the glide and landing condition, static stability exists at all speeds above the stall. However, in the approach condition the variation of elevator angle with speed indicates static stability only at speeds above 115 miles per hour (140 percent V_{min}) for normal loading and above 95 miles per hour (135 percent V_{min}) for light loading. Figure 4 shows that in a rated-power climb, stability is present only above 170 miles per hour (167 percent V_{min}) for normal loading and above 135 miles per hour (145 percent V_{min}) for light loading, and that even above these speeds the stability is slight.

2. Stick-free stability should be evident for all of the conditions specified in item 1. The stick-force variation with speed indicates stability at all speeds for the landing and glide condition, except below 150 miles per hour in the normal-load glide. In the landing-approach condition, stick-free stability is exhibited at speeds above 90 miles per hour with light loading and at speeds above 120 miles per hour with normal loading. Stick-free stability is least in the climb condition where stick-force variation shows. Stability only above 135 miles per hour (145 percent V_{min}) for light loading and above 200 miles per hour (196 percent V_{min}) for normal loading.

3. The elevator stick-force gradient is sufficient (0.05 lb per mph) to return the control to trim position throughout the required speed range only in the landing condition for both normal and light loading and in the glide condition for light loading. Owing to the stick-free instabilities noted in item 2, the other conditions fail to meet this requirement.

4. The elevator is sufficiently powerful to maintain steady flight at any speed required of the airplane (figs. 4 and 5).

Requirement I-C: Characteristics of elevator control in accelerated flight.-

The elevator deflection required to pull up to maximum lift and the resulting normal acceleration have been computed for the propellers-windmilling condition (fig. 6). Since the longitudinal stability is greater with propellers windmilling than with power, this is the critical condition for elevator power in pull-ups.

The stick forces and elevator angles required to produce given accelerations in steady turning flight have been computed for 0.6 and 0.8 V_{max} at sea level in the glide and climb conditions (fig. 7).

1. Results in figure 6 indicate that with the propeller windmilling, the elevator is sufficiently powerful to develop either the maximum lift coefficient or the allowable load factor. The maximum lift coefficients used were those obtained in the wind tunnel; therefore, the computed elevator angles are probably unconservative. A sufficient margin of available elevator exists, however, to satisfy the requirement for full-scale conditions.

2. The variation of elevator angle with normal acceleration in steady turning flight produces a smooth curve having a stable slope as desired.

3. The requirement in reference 1 for a highly maneuverable airplane does not directly apply to this airplane, although a definite stick movement is still desirable. A minimum stick travel of approximately 1.2 inches is required at 0.8 V_{max} to reach a load factor of 2.6 with normal loading, and a travel of 2.2 inches is required to reach a load factor of 3.3 with light loading.

4. The requirement, that stick force varies linearly with normal acceleration in steady turning flight, is met for all conditions except climb at 0.6 V_{max} with normal loading. For this condition the results show a slight decrease of stick force with acceleration near the allowable load factor. This is caused by a tendency for the elevator to float into the wind as the wing stall is approached.

5. For airplanes of this class, the gradient of elevator control force as measured in steady turning flight should be

less than 50 pounds per g, and a steady pull force of not less than 30 pounds should be required to obtain the allowable load factor. With normal loading at 0.8 V_{max}, the stick forces are within the above limits for rated power and only slightly above the upper limit for windmilling power. As a result of the negative gradient at high acceleration, pointed out in item 4 above, less than the minimum 30 pounds is required to develop the maximum load factor with normal loading and rated power at 0.6 V_{max}. The stick-force gradients are above the 50 pounds per g limit for all other conditions computed. The condition for which there is greatest stability gives the steepest gradient; that is, propellers windmilling at 0.6 V_{max} with light loading. Here the stick force gradient is 90 pounds per g.

Requirement I-D: <u>Characteristics of the elevator control in landing</u>.-

Ground effects were computed by the method and data of references 3 and 4 and added to tunnel results, because no wind-tunnel tests were made with a ground plane. The final results in terms of elevator deflection and stick force needed for various contact speeds are presented in figure 8. Due to a very large ground effect on this airplane, the elevator is not adequate to hold the airplane off the ground until the three-point attitude is reached. Approximately 5° more up-elevator is needed. With the trim tab set to trim at 122 miles per hour in normal flight, the stick forces are above the recommended 50-pound limit for all normal contact speeds, a maximum pull force of 118 pounds being required if contact is made at 105 miles per hour.

Requirement I-F: <u>Limits of trim change due to power and flaps</u>.-

It is desirable to be able to maintain any given speed when flap and power setting are changed in any manner whatsoever without requiring a stick-force change of more than 50 pounds. For this airplane, any variation of power with flaps either retracted or extended produces stick-force increments within the 50-pound limit (fig. 9). Up to a speed of 130 miles per hour, any combined change of power and flap setting results in stick-force changes within the limits. Since 130 miles per hour is well above the normal operating speed with flaps down, the airplane should be satisfactory in this respect.

Requirement I-G: Characteristics of the longitudinal trimming device.-

The elevator tabs on the airplane are large, and according to estimated tab effectiveness, they should easily reduce stick forces to zero at any speed above 120 percent of V_{min} in the cruise and landing conditions.

Lateral Stability and Control

Aileron characteristics were calculated for a high-speed condition (250 mph indicated airspeed), and a low-speed condition (110 mph indicated airspeed). Figure 10 shows the variation of the wing-tip helix angle $pb/2V$ with control-wheel position, and figure 11, the control-wheel force required to produce a given $pb/2V$. (Previous calculations for similar airplanes indicate that the $pb/2V$ produced with rudder locked is about 0.9 that produced for zero sideslip at 250 miles per hour, and about 0.8 at 110 miles per hour.) The helix angle was computed as $pb/2V = C_l/C_{l_p}$, where C_l was taken from the tunnel data, and C_{l_p}, the damping coefficient due to rolling, as 0.46 from reference 5.

It is emphasized that aileron hinge moments were not obtained for the model. Instead, hinge moments were calculated from the data of reference 6, suitably adjusted for aileron plan form and the effect of rolling velocity on angle of attack. These data are given for a plain flap, whereas this airplane is equipped with piano-hinge ailerons. However, it is believed that the data give reasonably accurate values of control-wheel force.

Requirement II-B: Aileron control characteristics (rudder locked).-

1. The maximum rolling velocity at 250 miles per hour and 110 miles per hour indicated airspeed varies smoothly with and is approximately proportional to the aileron deflection.

2. No calculations of the time required to attain maximum rolling velocity were made.

3. The maximum $pb/2V$ at 250 miles per hour is 0.075, and at 110 miles per hour, it is 0.065 which is sufficiently

close to the required $pb/2V$ of 0.07 to give satisfactory aileron control.

4. The variation of aileron control force with aileron deflection (figs. 10 and 11) is smooth and is great enough to return the control to the trim position.

5. The requirement of a maximum control-wheel force of less than 80 pounds at all speeds below 0.8 V_{max} is met at 110 miles per hour, but at 250 miles per hour (approx. 0.8 V_{max}) the control-wheel force required to obtain $pb/2V$ of 0.07 is 240 pounds. At the climb speed (145 mph indicated airspeed), it is estimated that a $pb/2V$ of 0.07 can be obtained with an 80-pound wheel force.

Requirement II-C: Yaw due to ailerons.-

Calculations of the yaw due to rolling velocity indicate that the sideslip developed as a result of full aileron deflection does not exceed the 20° maximum sideslip specified by the requirements.

Requirement II-D: Limits of rolling moment due to sideslip (dihedral effect).

Calculations of lateral stability and control characteristics of the airplane in steady sideslips were made for the conditions of flight listed in the following table:

Condition	Flaps and gear	Power	Speed (mph)	Figure
Glide	Retracted	Windmilling	145	12
Climb	Retracted	Rated	145	12
Landing	Extended 38°	Windmilling	105	13
Approach	Extended 38°	50% rated	105	13
Wave-off	Extended 38°	100% take-off	105	13
Power failure at take-off	Extended 24°	Left - windmilling Right - 100% take-off	118	14

1. The variations of aileron deflection with angle of sideslip are smooth, aileron deflection increasing progressively with sideslip so that the aileron is always required to depress the leading wing. Thus, the roll due to rudder will always be in the correct direction.

2. Aileron stick forces in yaw are not presented because of lack of aileron hinge-moment data in yaw.

3. The rolling moment due to sideslip is never so great that a reversal of rolling velocity occurs as a result of yaw due to ailerons. However, with asymmetric power at take-off and with rudder undeflected, the rolling moment due to sideslip is greater than the maximum rolling moment provided by the ailerons. Consequently, in the event of failure of the left-hand engine on take-off, right sideslip must be limited to not more than 18° by use of the rudder if steady sideslip is to be maintained.

Requirement II-E: <u>Rudder control characteristics</u>.-

1. The rudder control is everywhere sufficiently powerful to overcome the adverse yawing moment of the ailerons.

2. No calculations were made of the rudder control during take-off and landing, because tests to simulate ground effect were not made in the wind tunnel.

3. Rudder control characteristics with asymmetric power are shown in figure 14. Calculations were made for the critical condition with flaps in the take-off position, gear down, left-hand engine windmilling, and right-hand engine developing take-off power at 118 miles per hour (110-percent min. take-off speed). Results indicate the rudder control is more than sufficient to produce zero sideslip.

4. Control characteristics to provide spin recovery are not considered.

5. Right rudder forces are required to hold right rudder reflections, and left rudder forces are required to hold left rudder deflections for moderate angles of sideslip. However, there exists a severe rudder-force reversal for both the glide and climb conditions at angles of sideslip greater than approximately ±15°, and for the approach condition for the angles of right sideslip, greater than 17°. For the

wave-off condition with trim tab zero, right pedal forces are required for all rudder deflections.

6. With trim tab neutral, the limit of 180 pounds maximum pedal force is not exceeded up to the point of pedal-force reversal with the flaps retracted, but it is exceeded at large angles of sideslip for all conditions with flaps extended 38°. In the event of failure of the left-hand engine at take-off, the minimum pedal force required to maintain steady flight is 320 pounds at 8° of right sideslip.

Requirement II-F: <u>Yawing moment due to sideslip (directional stability)</u>.-

1. This requirement is the same as that discussed under II-C.

2. The yawing moment due to sideslip is such that the rudder always moves in the correct direction (right rudder produces left sideslip and left rudder produces right sideslip), and the angle of sideslip produced is substantially proportional to the rudder deflection for angles of sideslip between ±15°.

3. The rudder-free characteristics of the airplane, as indicated by the rudder-pedal-force variations of figure 12 and 13, indicate that the airplane is not directionally stable throughout the sideslip-angle range for all conditions. Stability characteristics, rudder free, are summarized in the following table:

Condition	Rudder-free stability	Figure
Glide	Unstable beyond approximately ±15° sideslip	12
Climb	Unstable beyond approximately ±10° sideslip	12
Landing	Unstable beyond 12° of left sideslip	13
Approach	Unstable beyond 12° of right sideslip	13
Wave-off	Unstable beyond 9° of right sideslip	13

4. The results of extreme asymmetric power with flaps deflected 24°, gear down, presented in figure 14, show that straight flight cannot be maintained by sideslipping with the rudder free when trimmed for straight flight on symmetric power. This is the result of a fin stall which causes a hinge moment tending to produce greater rudder deflections at moderate angles of sideslip. The same is also true with flaps and gear retracted with rated power on the right-hand engine, left-hand engine windmilling, as is revealed by inspection of the wind-tunnel data.

Requirement II-G: Cross-wind-force characteristics.-

As is shown in figures 12 and 13, the variation of angle of bank with angle of sideslip is such that an increase in right bank accompanies right sideslip and vice versa for all conditions. The effect of power is to cause right bank to accompany zero sideslip. This effect is greatest for the wave-off condition where 2° of right bank is necessary to hold zero sideslip. Also, the effect of power is to increase the cross force as is shown by increased variation of angle of bank with sideslip angle as power increases.

Requirement II-H: Pitching moment due to sideslip.-

The variation of elevator deflection for longitudinal trim with flaps down in steady sideslips is shown in figures 12 and 13. For all conditions, not more than 1° of elevator movement is required to maintain trim when the rudder is moved 5° right or left from its position for straight flight.

Requirement II-I: Power of rudder and aileron trimming devices.-

1. Calculations show that the rudder trim tab when fully deflected (25°) is capable of trimming the airplane within 5° of sideslip with maximum asymmetry of power, flaps 24°, and gear down, at 118 miles per hour. For all other conditions, the tab should be capable of trimming to zero rudder force at zero sideslip.

The case of extreme asymmetry of power is also a critical condition for aileron trim tabs. The estimated tab effectiveness indicates that at speeds about 140 percent V_{min}, the tabs should be able to reduce wheel forces to zero at zero sideslip with extreme asymmetry of power.

CONCLUSIONS

From the preceding discussion, the following may be concluded:

1. Characteristics of elevator control indicate that in steady flight the elevator possesses adequate power, but both static and stick-free stability are low, particularly in the approach and climb conditions in which stick-force variations indicate approximate neutral stability through a large portion of the speed range.

2. In accelerated flight, the elevator exhibits satisfactory characteristics except for large stick forces which, in the extreme case, produce a stick-force gradient of 90 pounds per g in steady turning flight.

3. In landing, the elevator lacks sufficient power to keep the airplane off the ground until the three-point attitude is reached, and stick forces are high for all contact speeds.

4. Trim changes due to power and flaps are reasonable and should not be uncomfortable to control.

5. The elevator trim tab is sufficiently powerful to trim the stick forces to zero for any normal flight condition.

6. The aileron power is marginal and the wheel forces are very high. Yaw due to ailerons is easily within prescribed limits.

7. Rudder power is satisfactory, although there is a severe rudder-pedal-force reversal encountered between 10° and 20° of sideslip for all conditions computed except landing.

8. Rudder-pedal forces are high at large angles of sideslip with flaps extended and become extreme for the case of failure of one engine at take-off.

9. Rudder-fixed directional stability appears to be

satisfactory but, with rudder free, stability is lacking at moderate angles of yaw as a result of fin stall.

10. Cross-wind forces are in the proper direction and are of such magnitude that the angle of bank produced should give the pilot indication of sideslip.

11. Pitching moment due to sideslip is moderate.

12. The power of the rudder trim tab is marginal for the failure of one engine on take-off, but is satisfactory elsewhere. Aileron trim tab should be satisfactory.

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

APPENDIX

TEST RESULTS

This appendix contains the results of wind-tunnel tests from which the flying qualities presented in the body of the report were estimated. All these data have been transmitted previously in preliminary form.

A three-view drawing of the airplane is given in figure 1. The key to the configuration symbols used is given in table IV. Photographs of the model mounted in the wind tunnel are given in figure 15. The important model dimensions are given in table V. Power was supplied by two electric motors driving two 3-blade, right-hand rotation, 1/9-scale propellers. Hinge moments were measured by means of wire-resistance-type strain gages, and measurements for each of the rudders were taken independently. Hinge-moment coefficients are based on the dimensions of one rudder.

All of the tests (except those with propellers windmilling) were made at constant thrust. Data from each series of constant-thrust tests were plotted against thrust coefficient T_c. Thus, it is possible to obtain characteristics corresponding to any power condition within the T_c range covered. The relation of T_c to C_L required to match full-scale operation (fig. 16) was furnished by the manufacturer of the airplane. The propeller-blade angle (30^o at the 0.75 radius section) was selected as a good compromise between take-off and cruise blade angle and was not changed throughout the tests. The T_c vs V/nD relationship (fig. 17) was determined experimentally in the wind tunnel. Model power conditions were selected by use of the curves described.

All data are given in NACA standard coefficient form referred to the stability axes and are corrected for strut interference and tare drag, flow inclination, and tunnel-wall effect. The dimensions on which coefficients are based and the corrections applied are given in table V. Pitching-moment coefficients are referred to the center of gravity for normal gross weight (26,500 lb) gear up, which is 29.80 percent of the mean aerodynamic chord aft of the leading edge of the mean aerodynamic chord (measured parallel to the fuselage reference line), and 2.03 percent M.A.C. below the fuselage reference line.

For the purpose of presenting results, the tests have been divided into three parts: (1) tests in pitch with elevator deflected; (2) tests in yaw with rudders deflected; and (3) tests in pitch and yaw with the left-hand aileron deflected.

<u>Tests with elevator deflected</u>.- Tests in pitch with the elevator deflected were made with propellers windmilling, and for several values of T_c, both with flaps retracted and with flaps deflected 38^o. The landing gear was extended for all tests made with flaps deflected. Results are presented in the following figures:

Figure	Flaps (deg)	δ_e (deg)	Power condition	Tail
18	0	-20, -10, -5, 0, 5, 10	Propellers windmilling	On
19(a), (b)	0	-15, -10	T_c = WM, 0.1, 0.2	On
20(a), (b)	0	-5	T_c = WM, 0.1, 0.3, 0.5, 0.7	On
21(a), (b)	0	0	T_c = WM, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8	On
22(a), (b)	0	5	T_c = WM, 0.1, 0.3, 0.5, 0.7	On
23(a), (b)	0	10	T_c = WM, 0.1, 0.3, 0.5, 0.7	On
24(a), (b)	0	--	T_c = WM, 0.1, 0.3, 0.5, 0.7	Off
25	38	-35, -25, -15, -5, 0, 5	Propellers windmilling	On
26(a), (b)	38	-5	T_c = WM, 0.2, 0.5, 0.7, 0.9, 1.1	On
27(a), (b)	38	0	T_c = WM, 0.2, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.5	On
28(a), (b)	38	5	T_c = WM, 0.2, 0.5, 0.7, 0.9, 1.1	On
29(a), (b)	38	--	T_c = WM, 0.2, 0.5, 0.7, 0.9, 1.1	Off

Characteristics corresponding to rated power with flaps retracted and to take-off power with flaps extended, obtained from the above curves, are presented in the following figures:

Figure	Flaps (deg)	δ_e (deg)	Power condition	Tail
30*	0	-5, 0, 5, 10	Rated power, gross weight 26,500 pounds	On and off
31	38	-5, 0, 5	Take-off power, gross weight 26,500 pounds	On and off

For the purpose of determining the effects of change of tail incidence, tests in pitch were made with a tail incidence of 3.9° measured with respect to the fuselage reference line. The results of these tests, together with results of identical tests with tail normal (0°) are given in the figures listed below.

Figure	Flaps (deg)	i_t (deg)	Power condition
32	0	0, 3.9	Propellers windmilling
33	0	0, 3.9	Rated power, gross weight, 26,500 pounds
34	38	0, 3.9	Propellers windmilling
35	38	0, 3.9	Take-off power, gross weight, 26,500 pounds

Tests with rudders deflected.- Tests in yaw were made with the rudders deflected from 30° to -30° with propellers windmilling and for several normal power conditions. With flaps retracted, tests were made at the climb attitude ($C_L = 0.85$, $\alpha_u = 6°$), and with flaps deflected 38° at the attitude corresponding to a C_L of about 1.6 ($\alpha_u = 6°$). Results are presented in the following figures:

Figure	Flaps (deg)	δ_r (deg)	Power condition	T_c
36, 37	0	0, ±10, ±15, ±20, ±25, ±30	Propellers windmilling	--
38, 39	0	0, ±10, ±15, ±20, ±25, ±30	Rated power at gross weight 26,500 pounds	0.23
40, 41	38	0, ±10, ±15, ±20, ±25, ±30	Propellers windmilling	--
42, 43	38	0, ±10, ±15, ±20, ±25, ±30	50% rated power at gross weight 26,500 pounds	.27
44, 45	38	0, ±10, ±15, ±20, ±25, ±30	Take-off power at gross weight 26,500 pounds	.58
46	38	0, ±10, ±15, ±20, ±25, ±30	Take-off power at gross weight 21,380 pounds	.74

In addition, tests were made to simulate conditions corresponding to single-engine operation after the failure of one engine. Tests with flaps retracted were made at the climb attitude ($C_L = 0.85$, $\alpha_u = 6^\circ$). Tests with the flaps deflected 24° were made at an attitude corresponding to a $C_L = 1.30$ ($\alpha_u = 6^\circ$) to simulate single-engine failure on take-off. Results are presented in the following figures:

Figure	Flaps (deg)	δ_r (deg)	Power condition	T_c
47	0	0, -10, -15, -20	Left, windmilling - right, rated power at gross weight 26,500 lb.	0.23
48	24	0, -10, -15, -20, -25	Left, windmilling - right, take-off power at gross weight 26,500 lb.	.46
49	24	0, -10, -15, -20, -25	Left, windmilling - right, take-off power at gross weight 21,380 lb.	.59

Tests with ailerons deflected.- Tests to determine the effectiveness of the ailerons were made with propellers removed, because it was believed the aileron characteristics would not be affected by the application of power. The left-hand aileron only was deflected from 10° to -25°. A pitch test and a yaw test were made for each aileron deflection. The yaw tests with flaps retracted were made at the climb attitude (C_L = 0.85, $\alpha_u = 6^{\circ}$), and with flaps deflected, at an attitude corresponding to a C_L of about 1.6 ($\alpha_u = 6^{\circ}$). The results are presented in the following figures:

Figure	Type	Flaps (deg)	δ_a (deg) (approx.)
50	Pitch	0	10, 5, 0, -5, -10, -15, -20, -25
51	Yaw	0	10, 5, 0, -5, -10, -15, -20, -25
52	Pitch	38	10, 5, 0, -5, -10, -15, -20, -25
53	Yaw	38	10, 5, 0, -5, -10, -15, -20, -25

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TABLE I.- GENERAL CHARACTERISTICS

Type	Patrol airplane
Engines (two)	Pratt and Whitney, R-2800 series
Ratings (each)	
Take-off	2000 horsepower at 2700 rpm at sea level
Military	2000 horsepower at 2700 rpm at sea level to 1500 feet; 1600 horsepower at 2700 rpm at 13,500 feet
Normal	1600 horsepower at 2400 rpm at 5700 feet; 1450 horsepower at 2400 rpm at 13,000 feet
Gear ratio	16:9
Propeller	Hamilton Standard, constant speed
Diameter	10.50 feet
Blades	three: No. 6477A-12
Normal loading condition	
Gross weight	26,500 pounds
Center-of-gravity position (percent M.A.C. aft of leading edge of M.A.C. parallel to the fuselage reference line)	29.8%
(Percent M.A.C. below fuselage reference line)	2.0%
Wing loading	46 pounds per square foot
Minimum loading condition	
Gross weight	21,380 pounds
Center-of-gravity position (percent M.A.C. aft of leading edge of M.A.C. parallel to the fuselage reference line)	23.9%
(Percent M.A.C. below fuselage reference line)	4.5%
Wing loading	37.1 pounds per square foot
Tail lengths	
Elevator hinge line to center of gravity (29.8% M.A.C.)	31.2 feet
Rudder hinge line to center of gravity (29.8% M.A.C.)	31.3 feet

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TABLE II.- WING AND TAIL PLANE DIMENSIONS

	Wing	Horizontal tail	Vertical tail
Area (sq ft)	[1]576	133.96	64.11
Span (ft)	65.5	25.86	7.90
Aspect ratio	7.45	5.0	1.95
Taper ratio	[2]3.42:1	--	--
Dihedral	6.25°	none	none
Incidence (with respect to fuselage reference line)	2°	0°	--
Root section	NACA 23018 modified by trailing-edge extension	NACA 0013	approximately NACA 0007
Tip section	NACA 23009	NACA 0009	--
Twist (geometric)	none	none	none
M.A.C. (ft)	[1]10.27		
Root chord (ft)	[2]13.78	6.67	5.20

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[1]Includes trailing-edge extension.
[2]Exclusive of trailing-edge extension.

TABLE III.- MOVABLE SURFACE DIMENSIONS

	[1] Ailerons	[2] Elevator		[1] Rudder	Flaps (Fowler)
		[3] Up	Down		
Area aft of hinge line (sq ft)	17.45	40.1	35.1	15.8	52.3
Span (ft)	11.25	20.21 at hinge line	17.90 at hinge line	7.89	15.72
[4] Percent span	34.35	78.2	69.3	100	48
Average chord (ft)	2.44	1.98	1.96	2.00	3.33
Balance, type	--	boost tab	boost tab	paddle balance and boost tab	--
Balance area, (sq ft)	0	5.3	5.3	1.6	--
Percentage balance	0	13.2	15.1	10.2	--
Control travel (deg)	25 up, 8 down	32	25	±30	38
Trim-tab area (sq ft)	0.64	2.015	2.015	1.905	--
Tab span (ft)	1.90	4.25	4.25	3.10	--
Tab travel (deg)	26 up 24-1/2 down	26	24.5	±25	--
Boost ratio δ_t / δ	--	-0.35	-0.35	-0.17	--

[1] Dimensions given for one surface only.
[2] Elevator angle measured with respect to stabilizer chord neglecting 3° droop.
[3] A tail flap between sections of elevator operates for up elevator only.
[4] Percent span defined as ratio of control span to total span of surface affected.

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TABLE IV.- CONFIGURATION KEY

S	Standard configuration, airplane in normal flying condition except for propellers (that is, wing, nacelles, fuselage, turret, horizontal and vertical tail, flaps and landing gear retracted)
P	Propellers
G	Landing gear extended
F	Flaps deflected (amount denoted by superscript)
H	Horizontal tail
V	Vertical tail

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TABLE V.- SYMBOLS AND COEFFICIENTS

All coefficients are given in NACA standard form based on the following dimensions:

Wing area (including trailing-edge extension)		=	7.11	square feet
M.A.C. (including trailing-edge extension)		=	1.141	feet
Span		=	7.28	feet
Elevator area aft of hinge line,	S_e	=	0.4335	square feet
Elevator chord aft of hinge line, av.,	c_e	=	0.2183	feet
Rudder area aft of hinge line	S_r	=	0.195	square feet/rudder
Rudder chord aft of hinge line, av.,	c_r	=	0.223	feet

α_u, angle of attack of fuselage reference line

α, angle of attack of fuselage reference line corrected for flow inclination and jet-boundary effect

C_{h_e} $\dfrac{\text{elevator hinge moment}}{q\,S_e\,c_e}$, positive when moment tends to depress trailing edge of elevator

C_{h_r} $\dfrac{\text{rudder hinge moment}}{q\,S_r\,c_r}$, positive when moment tends to move trailing edge of rudder to the left

i_t, angle of incidence of horizontal tail with respect to fuselage reference line

δ_e, elevator deflection, positive when trailing edge of elevator is down

δ_r, rudder deflection, positive when trailing edge of rudder is to the left

δ_a, aileron deflection (left aileron only) positive when trailing edge of aileron is depressed

The following tunnel-wall corrections were applied and are all additive:

$$\Delta C_{D_T} = \delta_1 \frac{S}{C} C_{L_u}^{2}$$

$$\Delta\alpha_T = \delta_1 \frac{S}{C} C_{L_u} \times 57.3$$

$$\Delta C_{m_T} = -\delta_2 \frac{S}{C} C_{L_u} \times 57.3 \times \frac{dC_m}{di_t}$$

where

δ_1 = 0.115

δ_2 = 0.089

C = 70 square feet

C_{L_u} = uncorrected lift coefficient

$\dfrac{dC_m}{di_t}$ = -0.041

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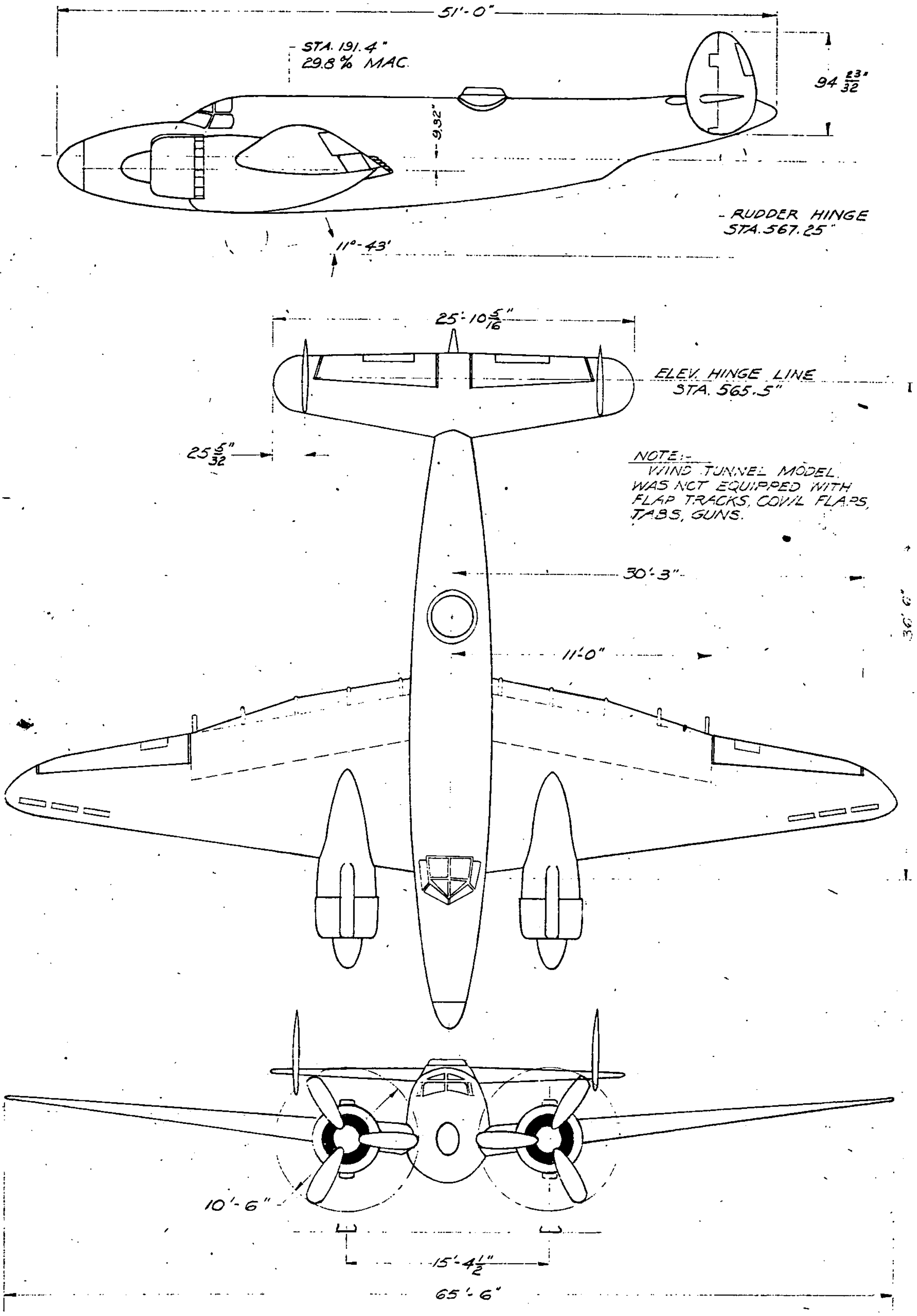

FIGURE 1.- THREE-VIEW DRAWING OF TEST AIRPLANE

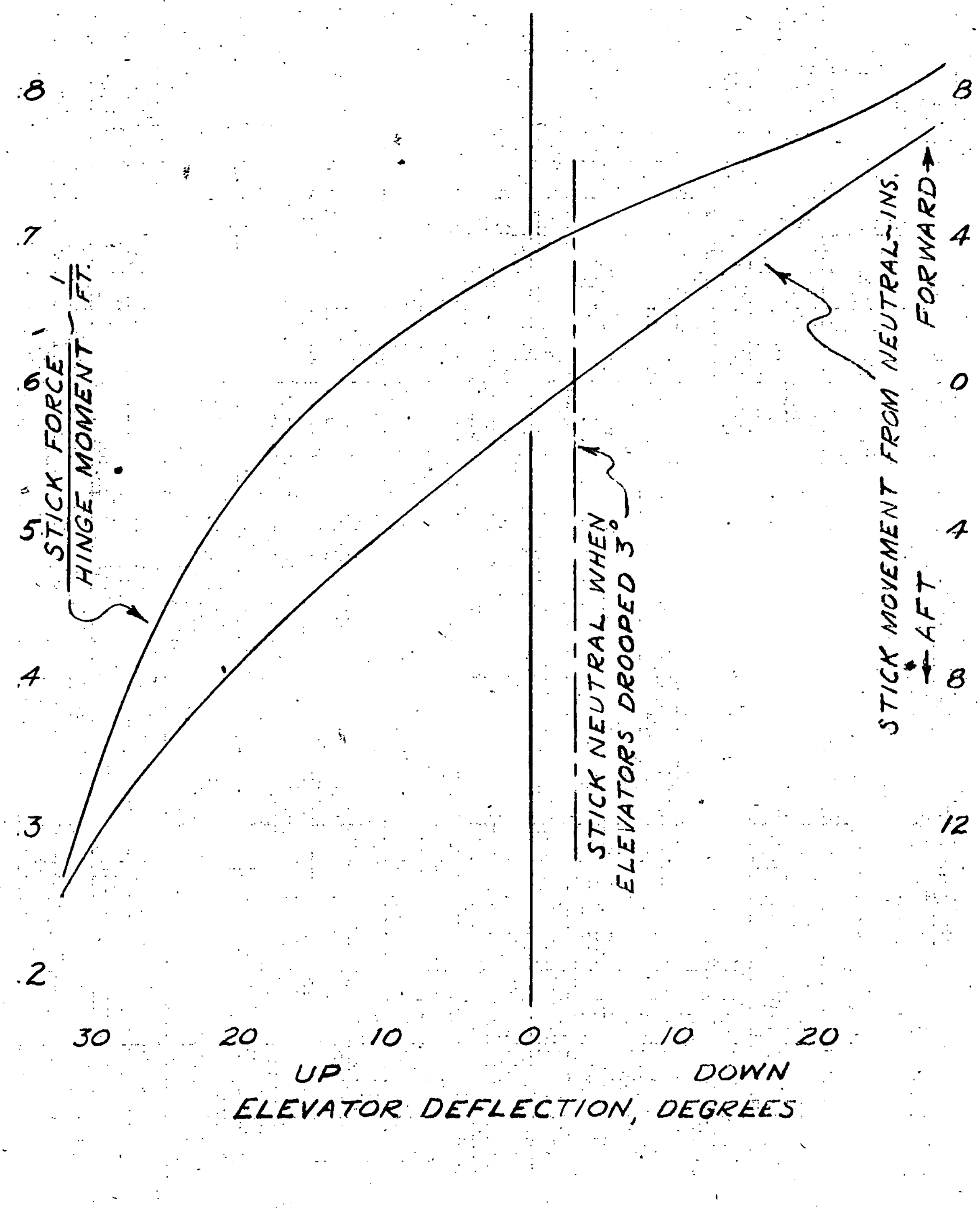

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FIGURE 2.- MECHANICAL ADVANTAGE AND STICK MOVEMENT OF THE ELEVATOR CONTROL SYSTEM FOR THE TEST AIRPLANE.

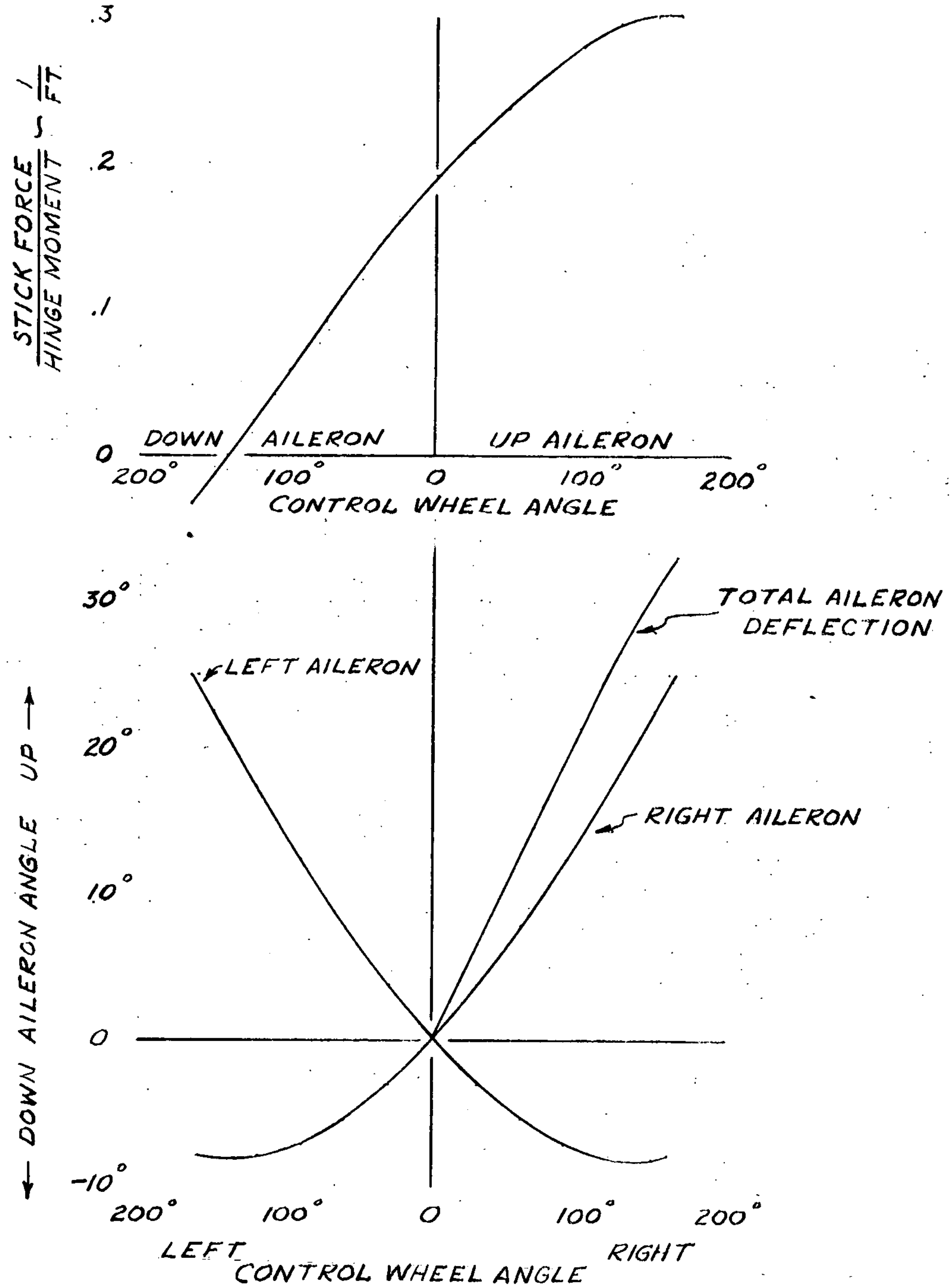

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FIGURE 3.- AILERON LINKAGE CHARACTERISTICS.

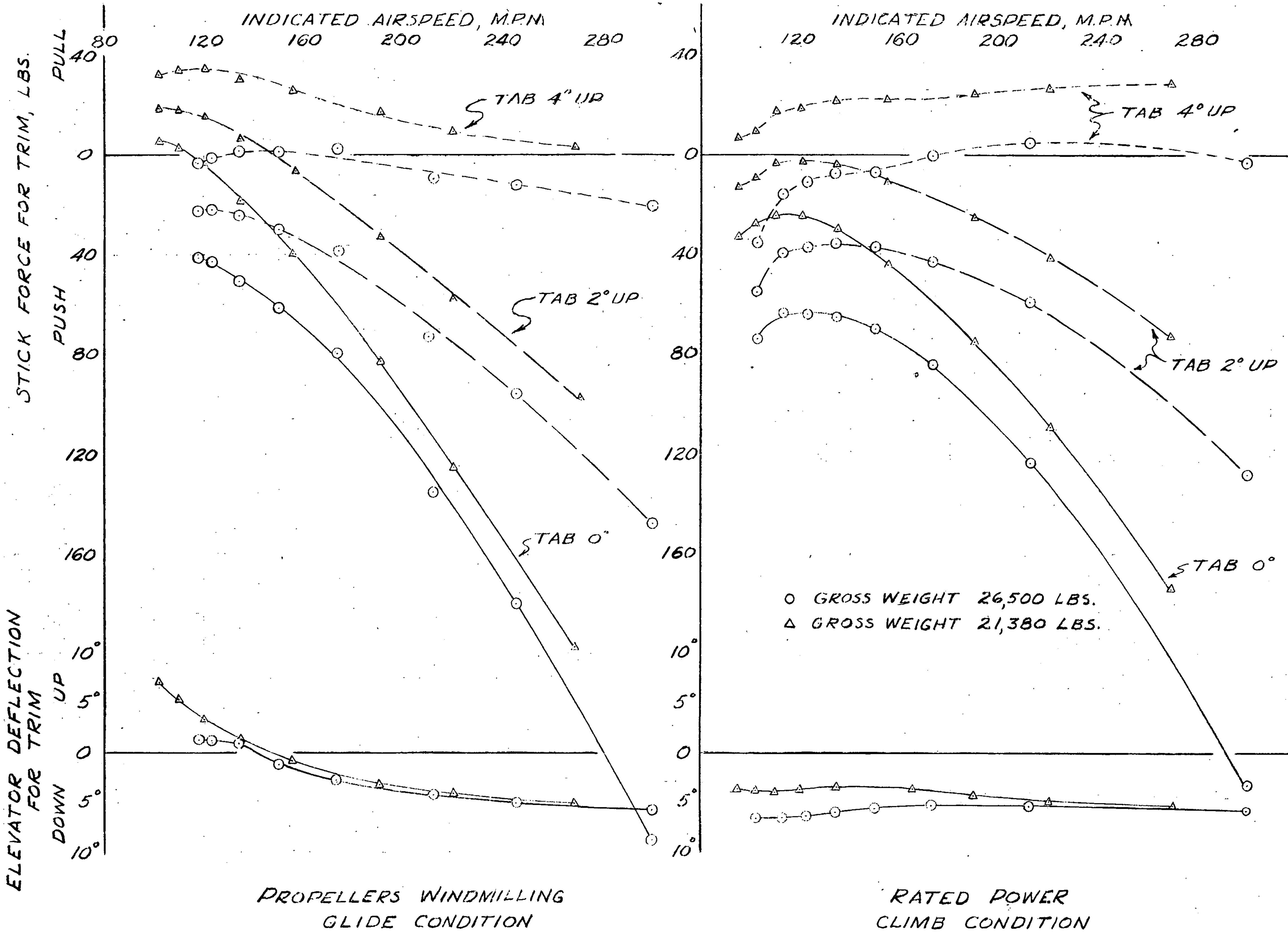

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FIGURE 4.- VARIATION OF STICK FORCE AND ELEVATOR DEFLECTION FOR TRIM WITH INDICATED AIRSPEED. FLAPS AND GEAR RETRACTED

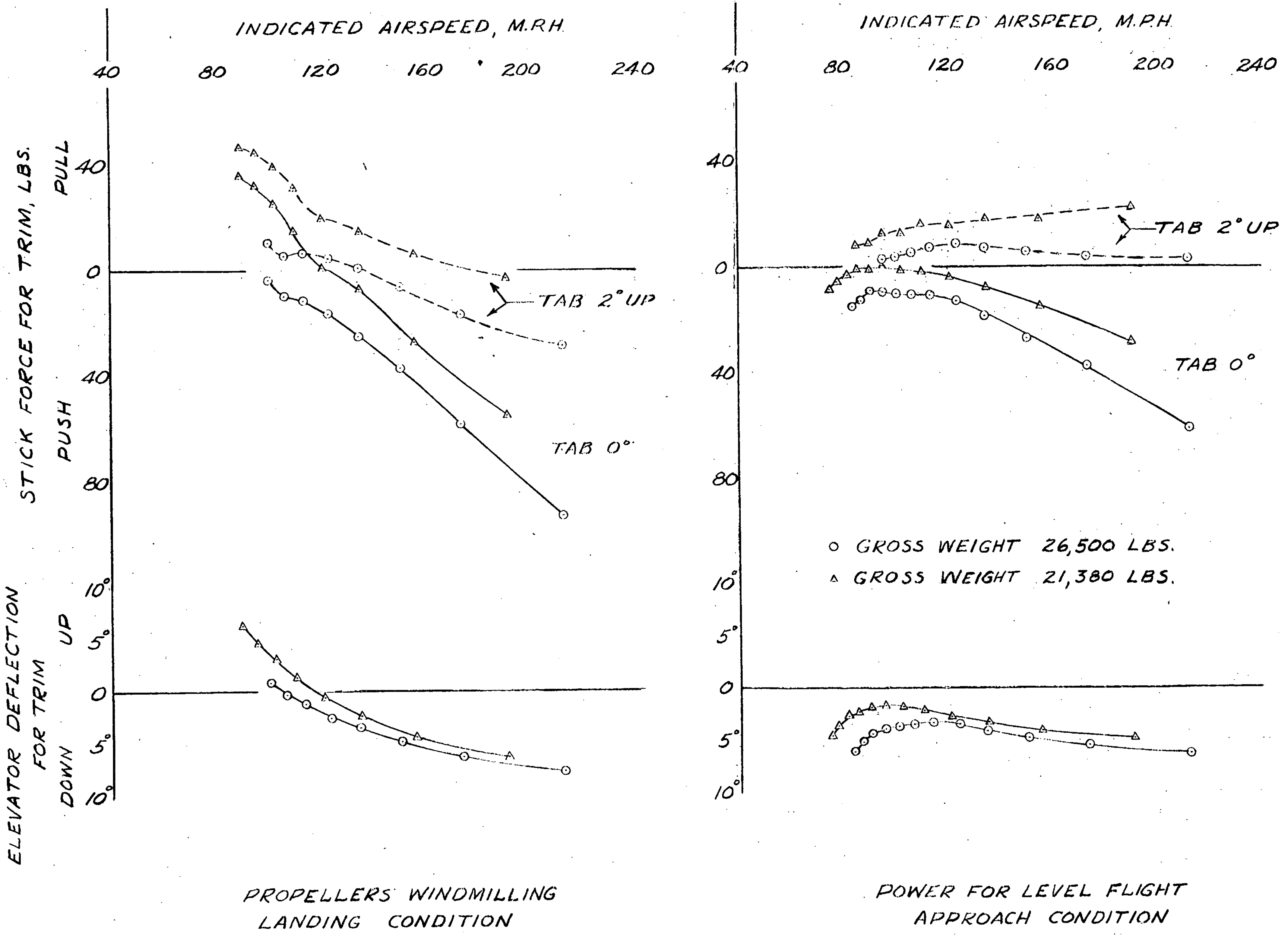

FIGURE 5- VARIATION OF STICK FORCE AND ELEVATOR DEFLECTION FOR TRIM WITH INDICATED AIRSPEED. FLAPS 38°, GEAR EXTENDED.

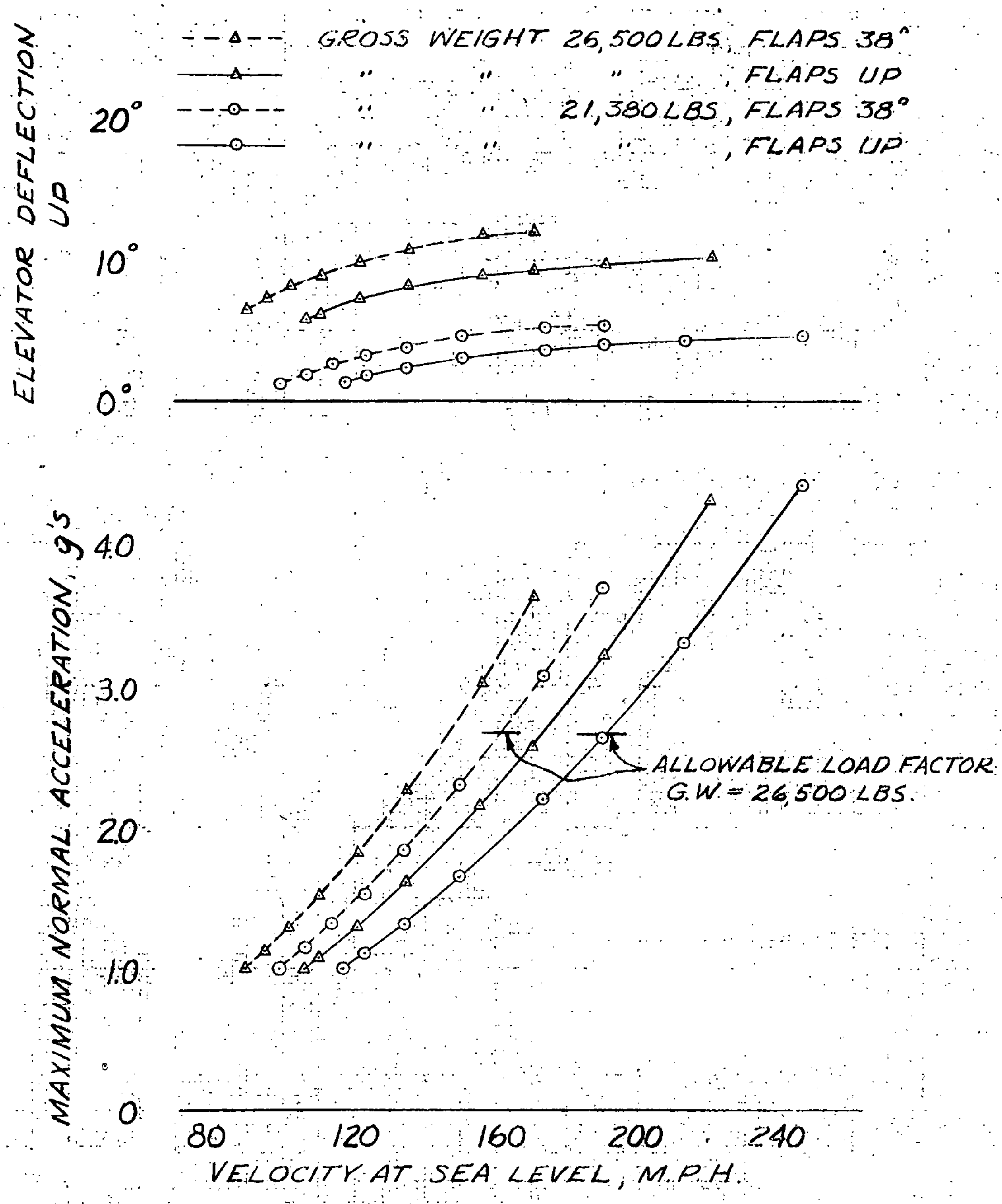

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FIGURE 6- ELEVATOR DEFLECTION REQUIRED AND MAXIMUM NORMAL ACCELERATION OBTAINABLE IN PULL-UPS. PROPELLERS WINDMILLING.

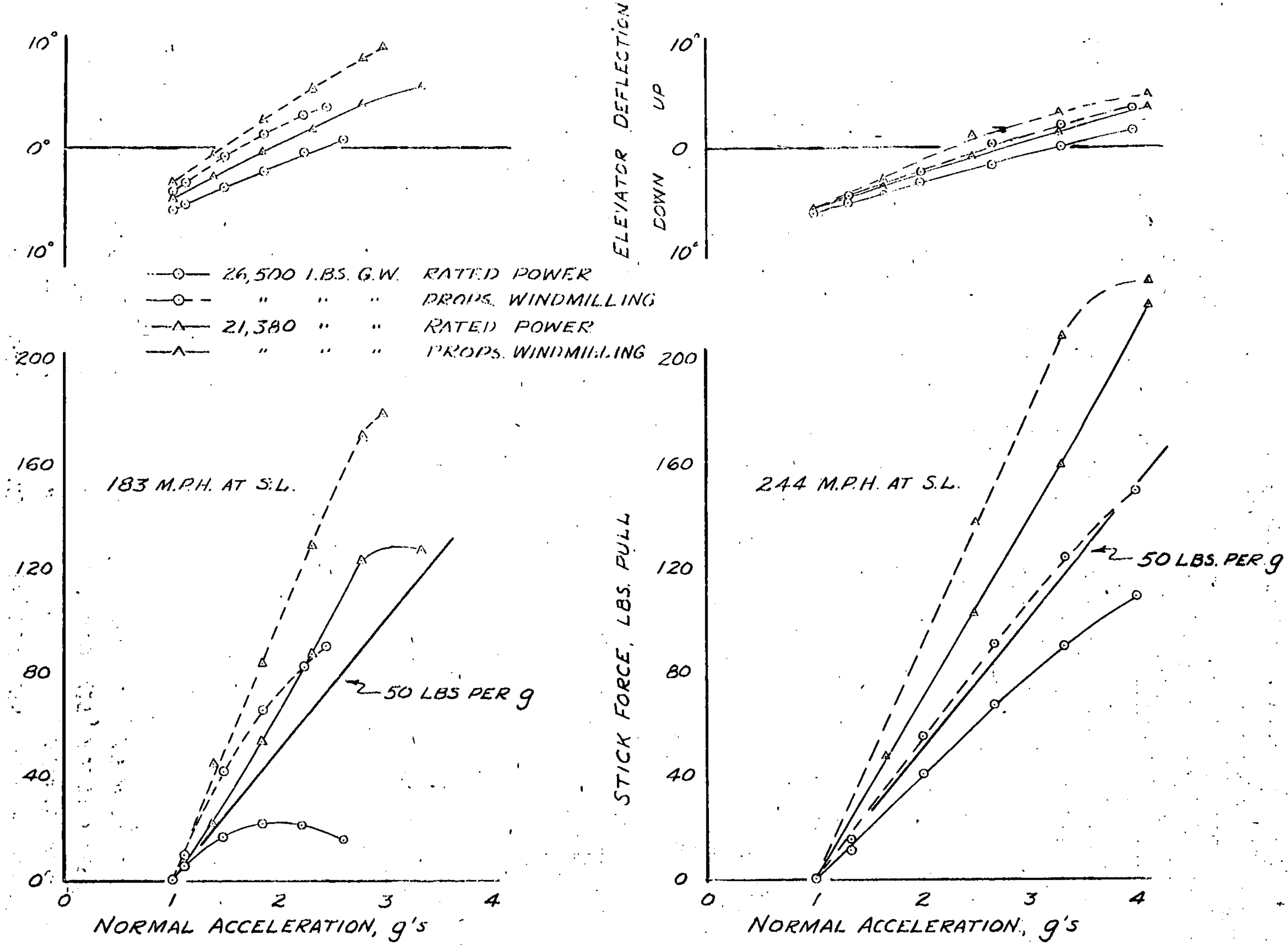

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FIGURE 7.- VARIATION OF STICK FORCE AND ELEVATOR DEFLECTION WITH NORMAL ACCELERATION IN STEADY TURNING FLIGHT. FLAPS AND LANDING GEAR RETRACTED.

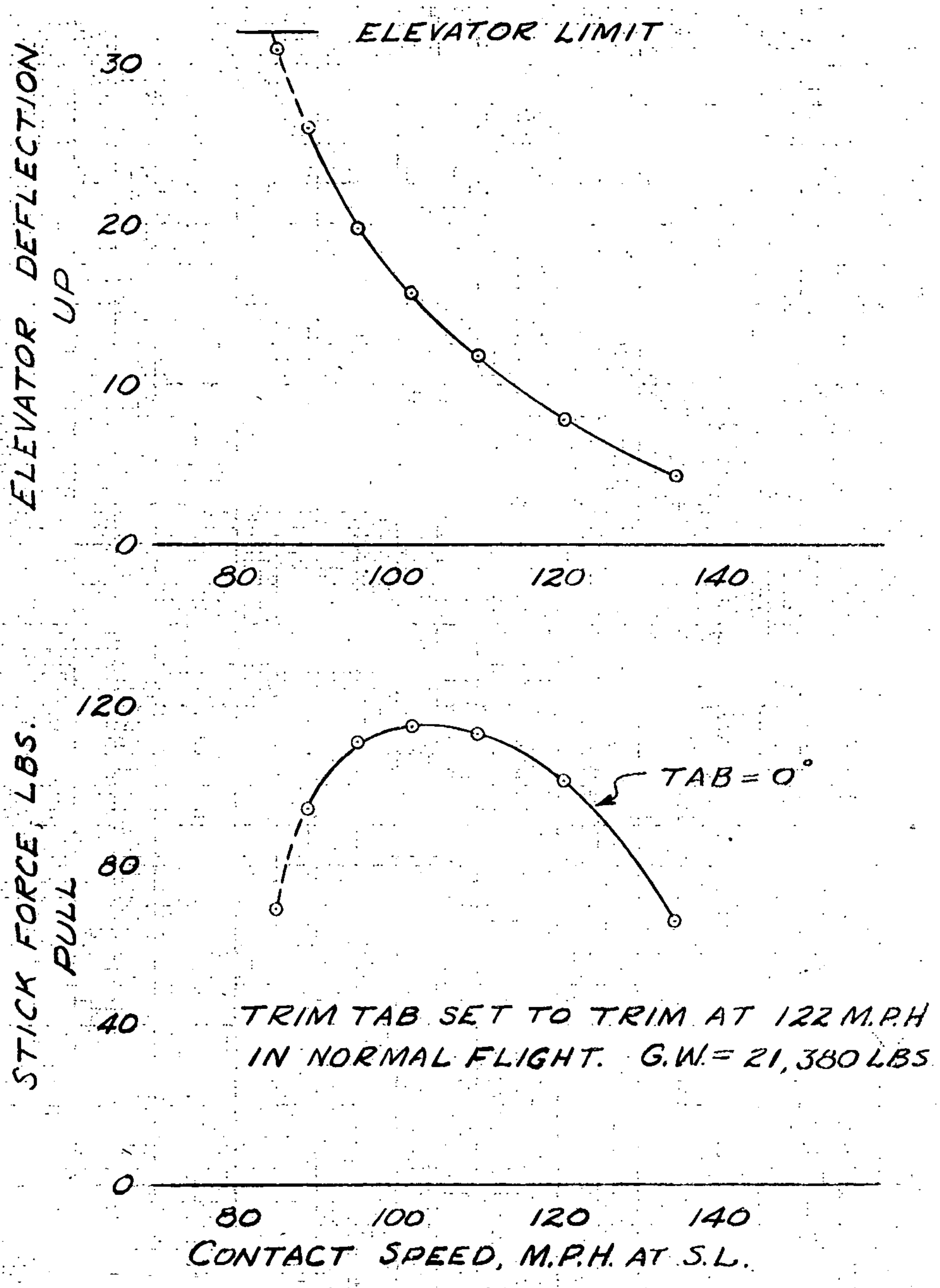

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FIGURE 8.- ELEVATOR DEFLECTION AND STICK FORCE TO TRIM IN THE PRESENCE OF THE GROUND VS CONTACT SPEED, FLAPS 38°, GEAR EXTENDED.

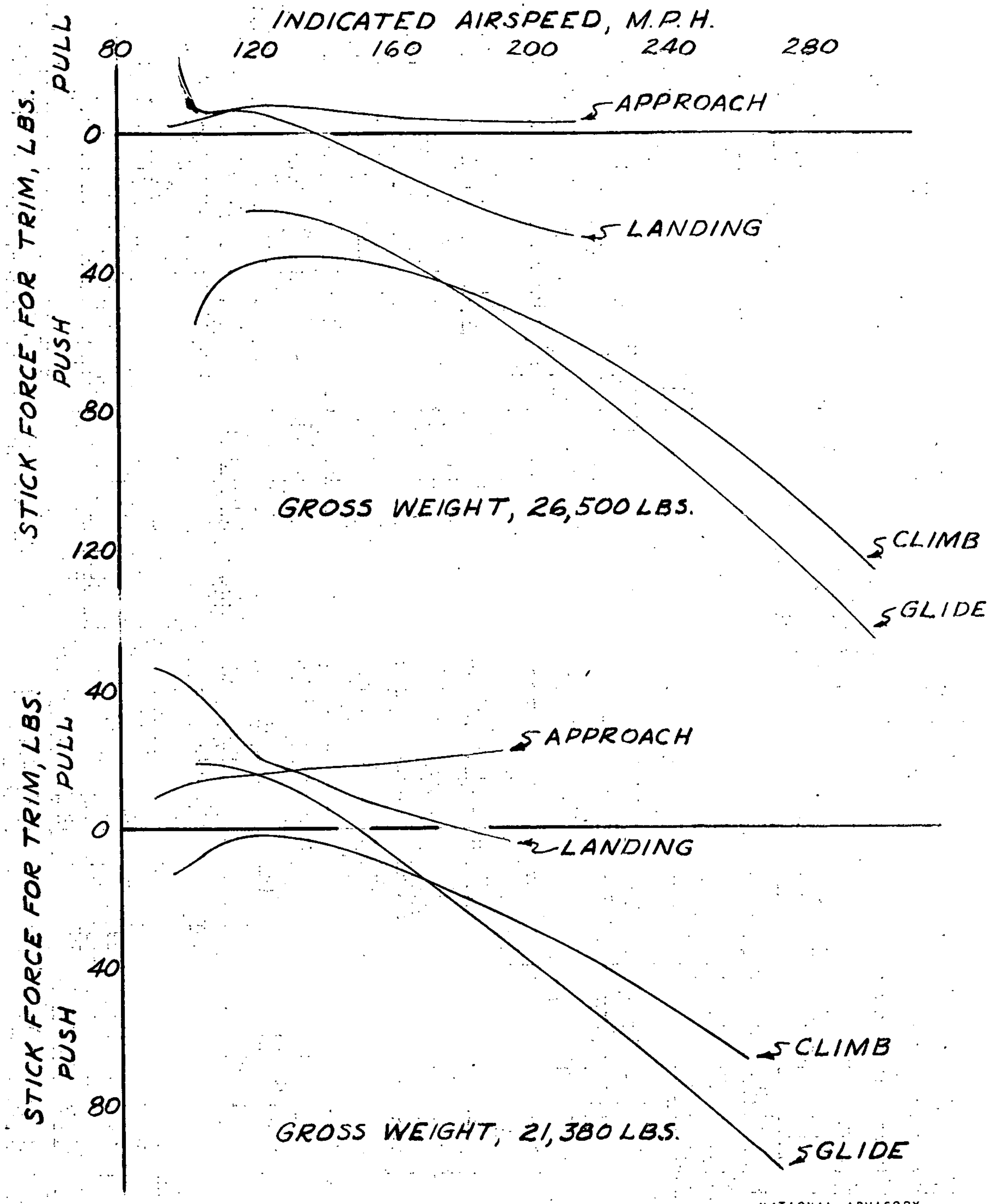

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FIGURE 9.- EFFECT OF POWER AND FLAP SETTING ON LONGITUDINAL TRIM WITH TRIM TAB 2° UP.

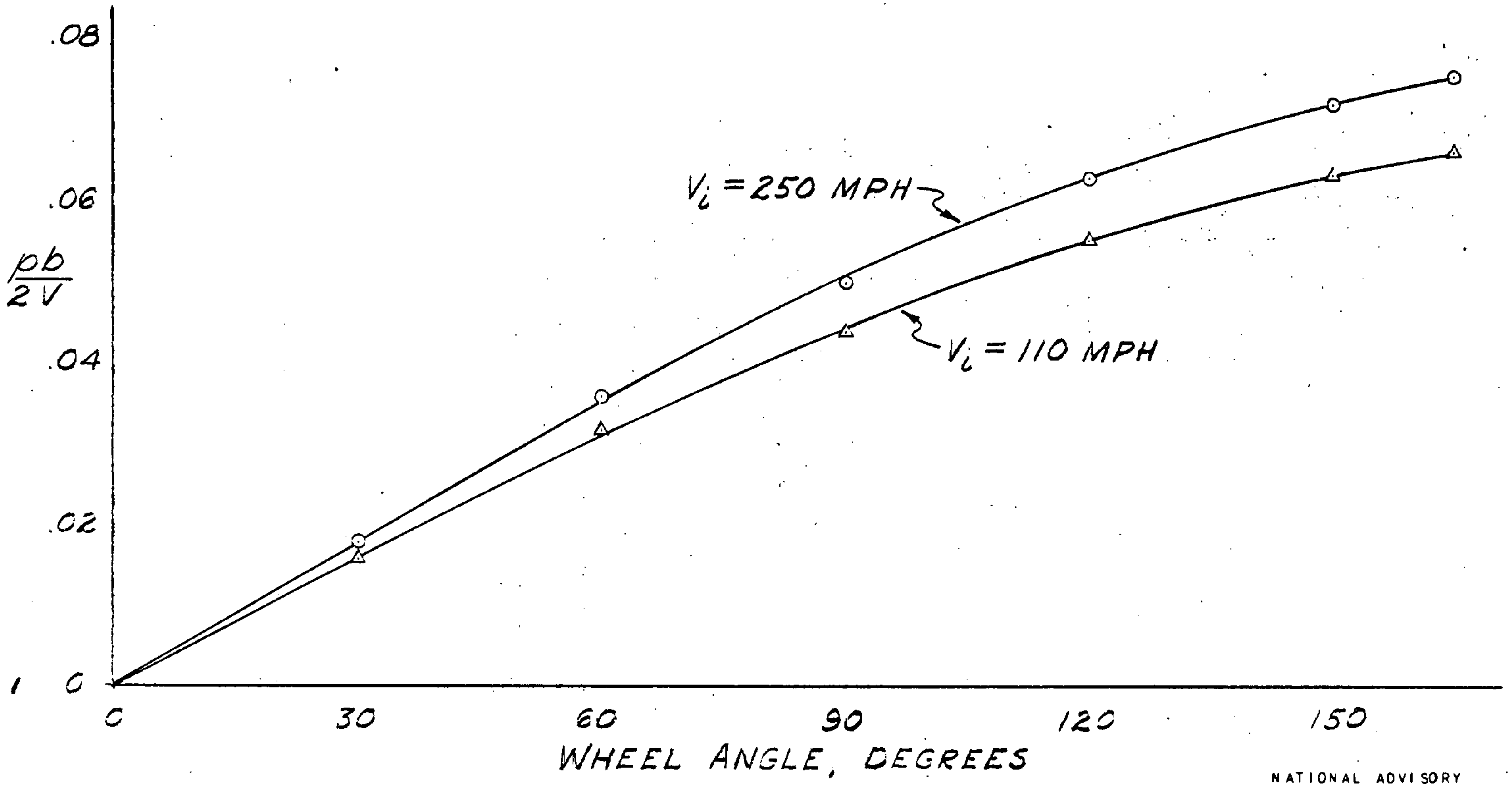

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FIGURE 10.- VARIATION OF $pb/2V$ WITH CONTROL WHEEL ANGLE, DEGREES. RUDDER LOCKED.

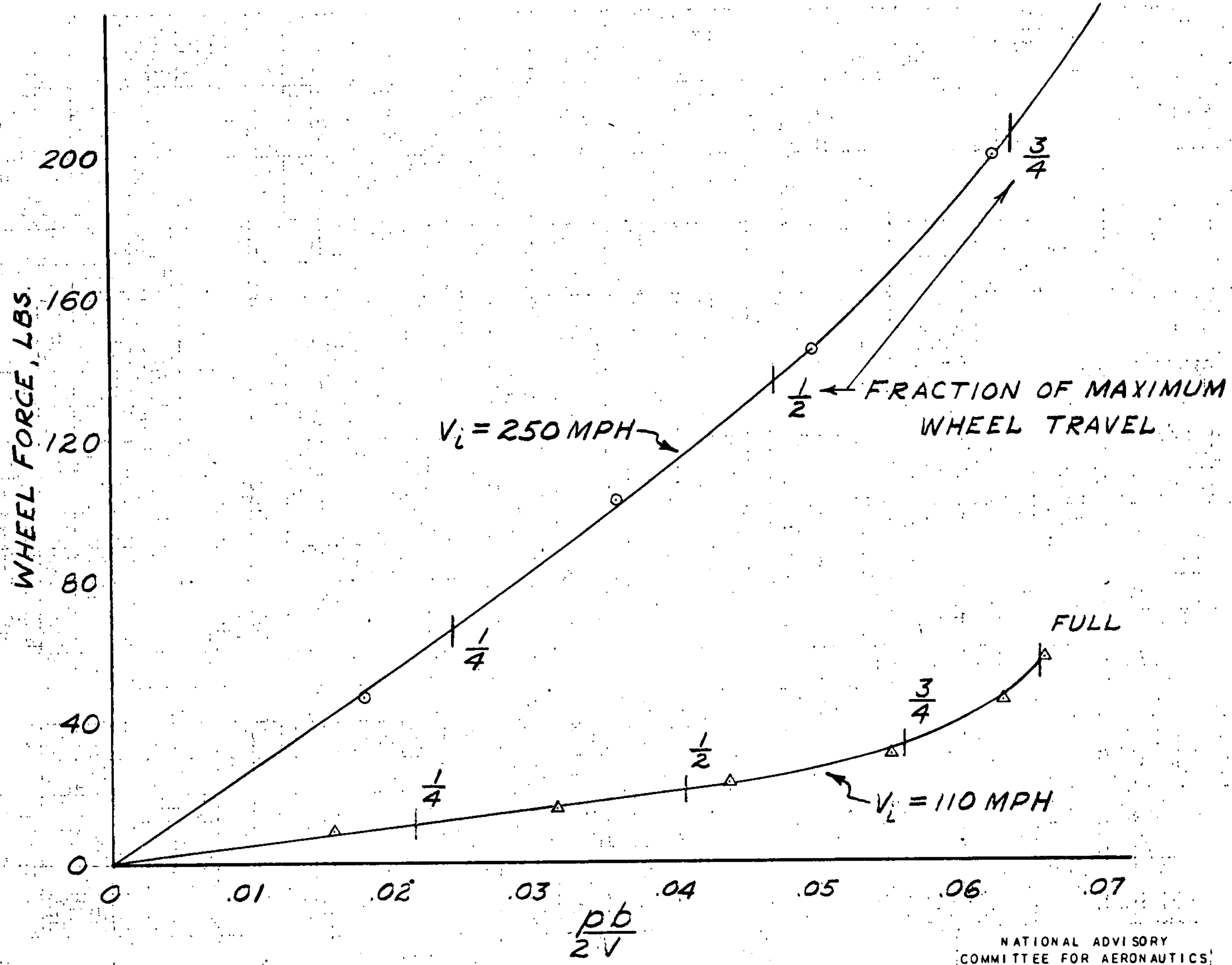

FIGURE 11.- VARIATION OF WHEEL FORCE WITH $pb/2V$. RUDDER LOCKED

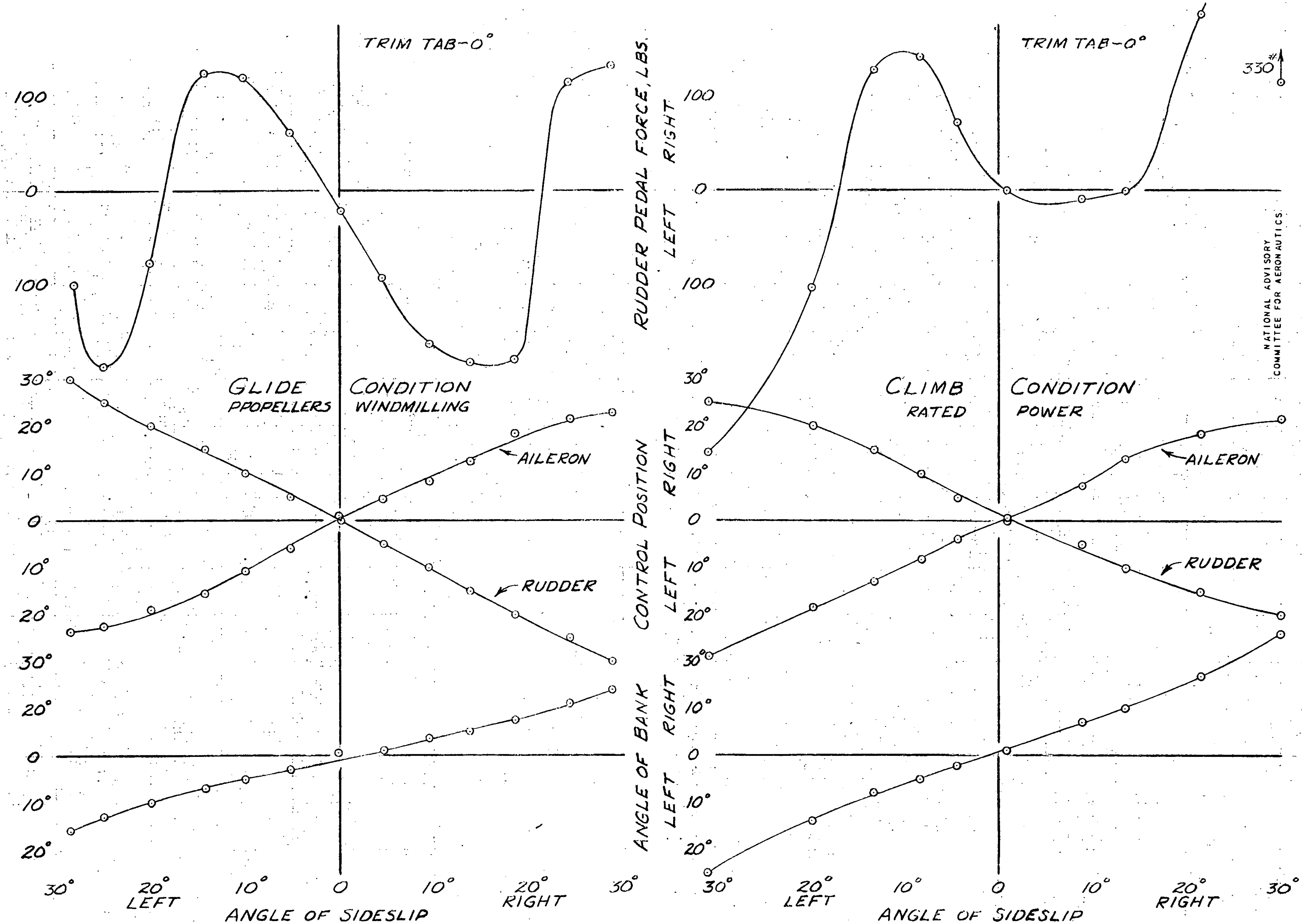

FIGURE 12.- CHARACTERISTICS IN STEADY SIDESLIP. FLAPS AND GEAR RETRACTED, GROSS WEIGHT 26,500 LBS., INDICATED AIRSPEED 145 M.P.H.

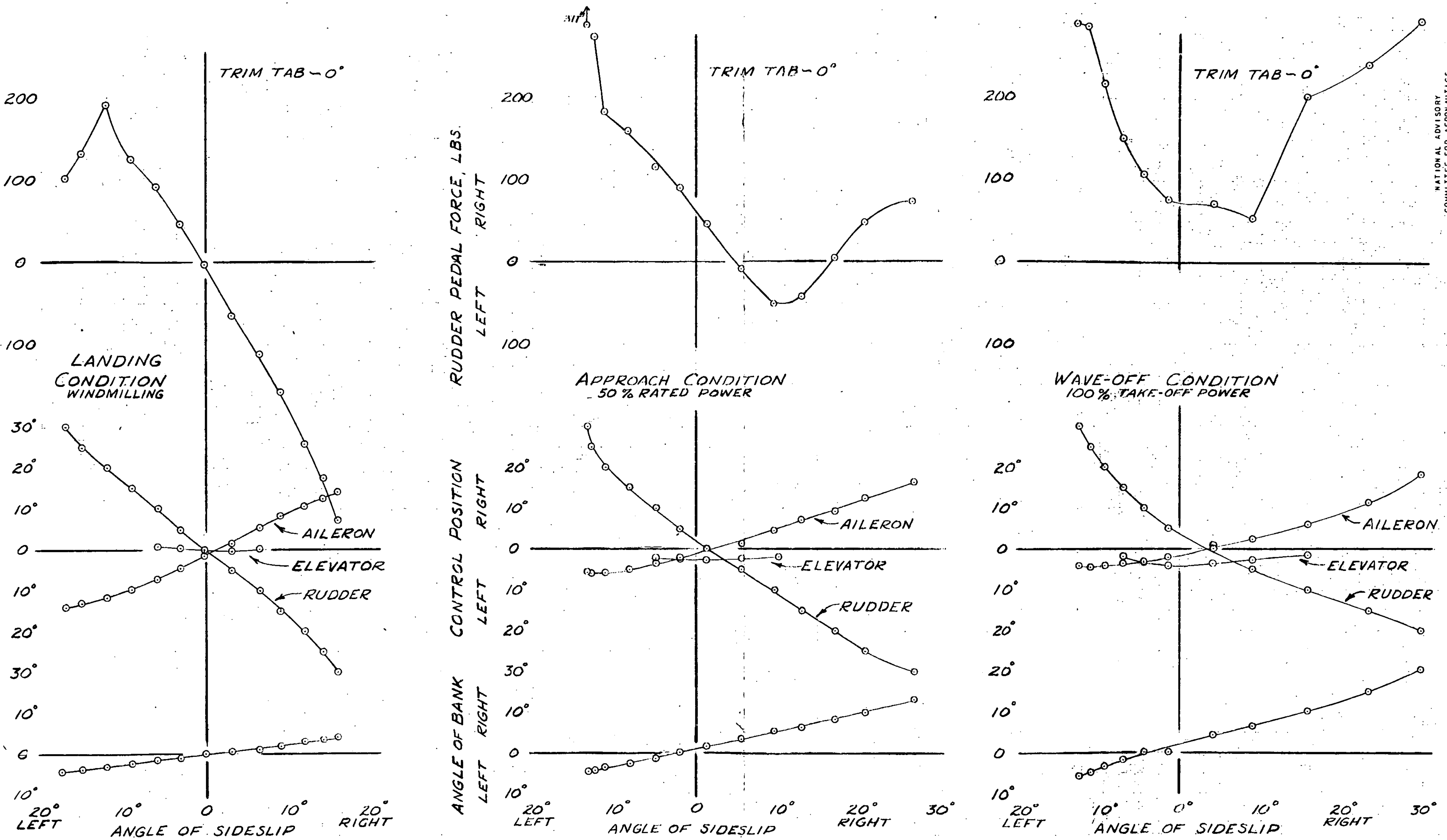

FIGURE 13-CHARACTERISTICS IN STEADY SIDESLIP. FLAPS 38°, GEAR EXTENDED, GROSS WEIGHT 26,500 LBS., INDICATED AIRSPEED 105 M.P.H.

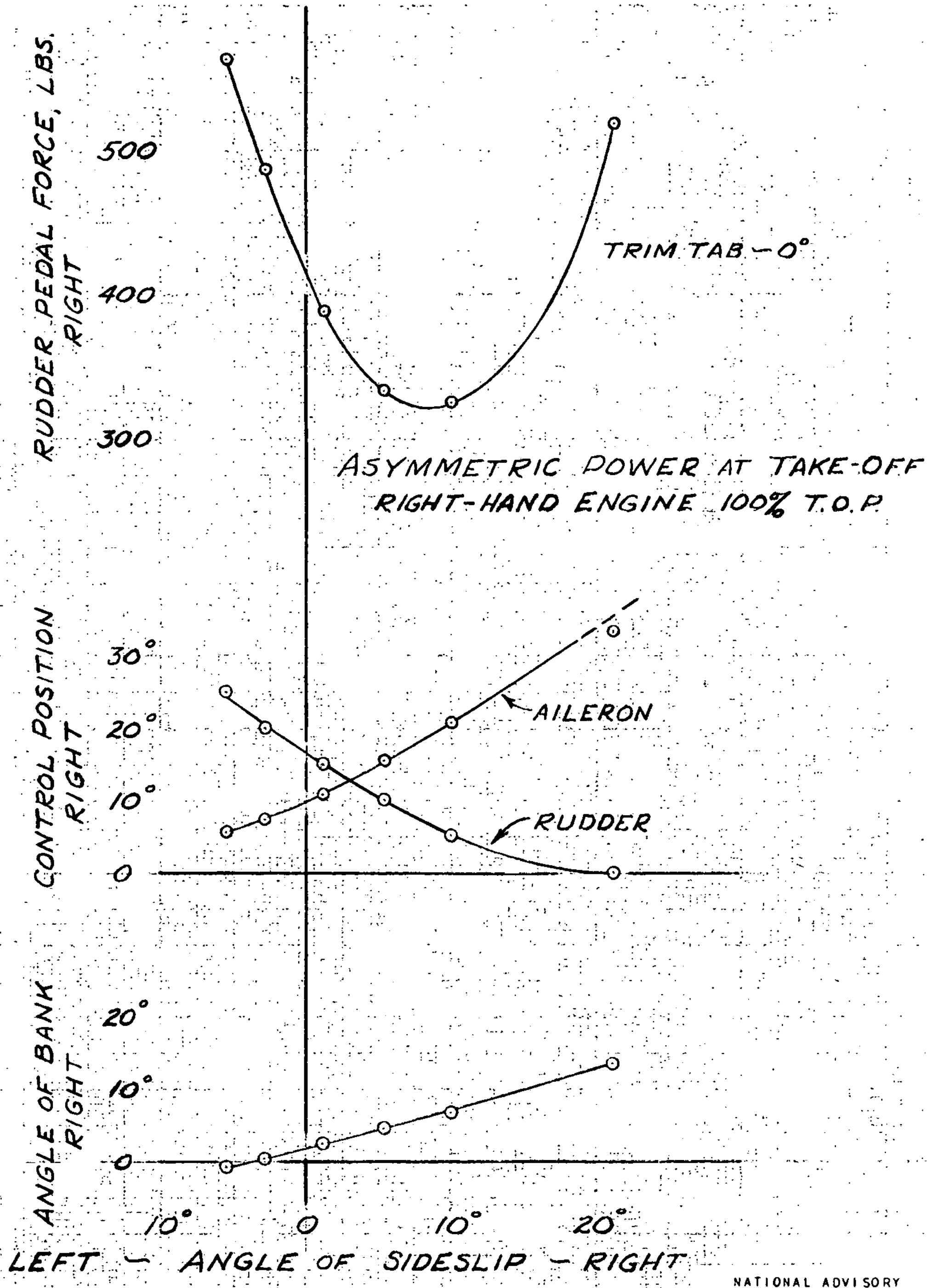

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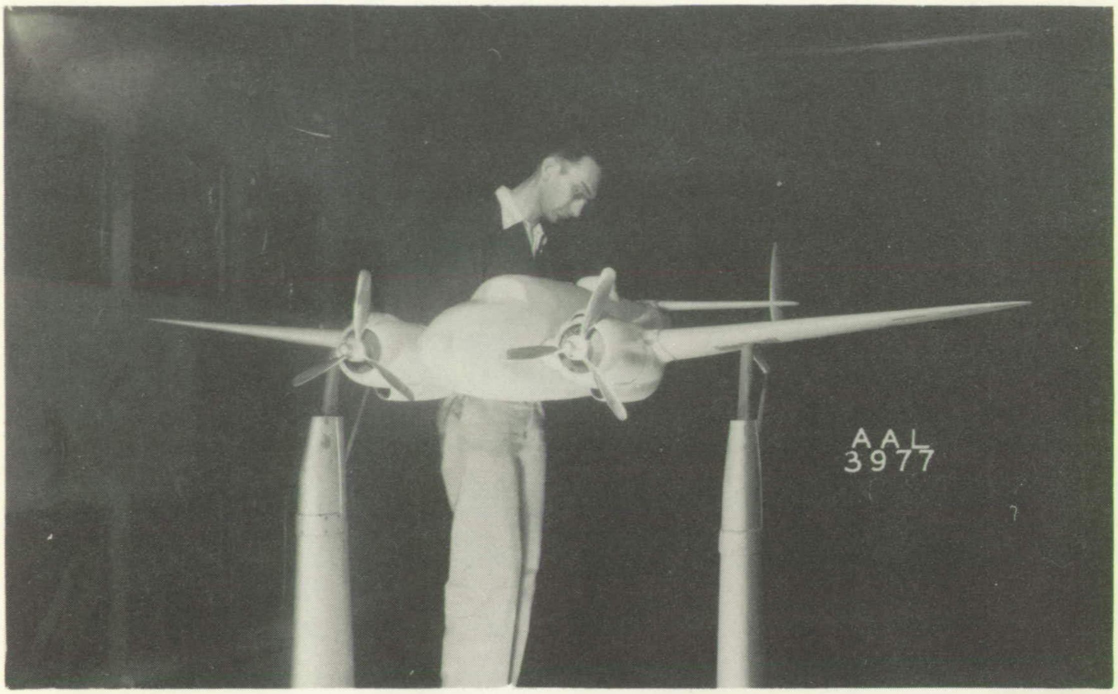
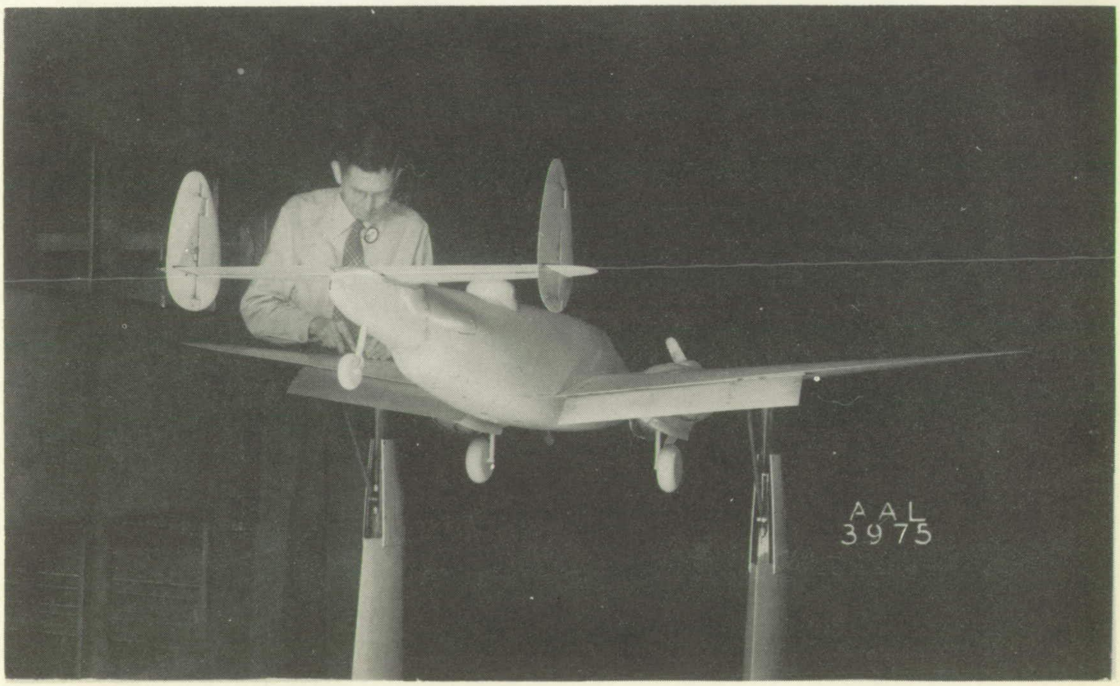
FIGURE 14- CHARACTERISTICS IN STEADY SIDESLIP, FLAPS 24°, GEAR EXTENDED, GROSS WEIGHT 26,500 LBS., INDICATED AIRSPEED 118 M.P.H.



(a) Front view, flaps up.



(b) Rear view, flaps down.

Figure 15.- Photographs of the test model mounted in the 7- by 10-foot wind tunnel.

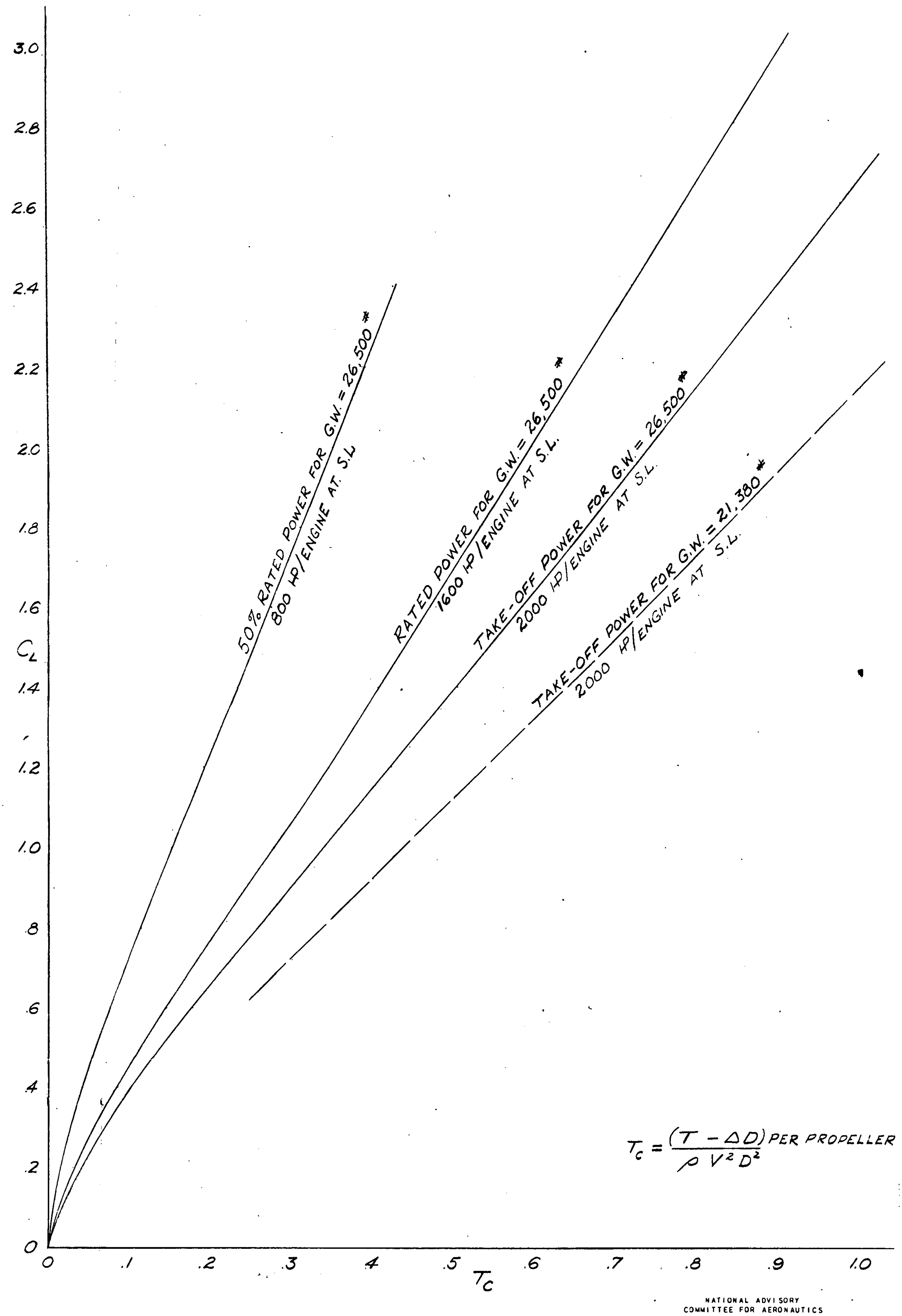


FIGURE 16.- VARIATION OF THRUST COEFFICIENT WITH LIFT COEFFICIENT FOR THE TEST AIRPLANE.

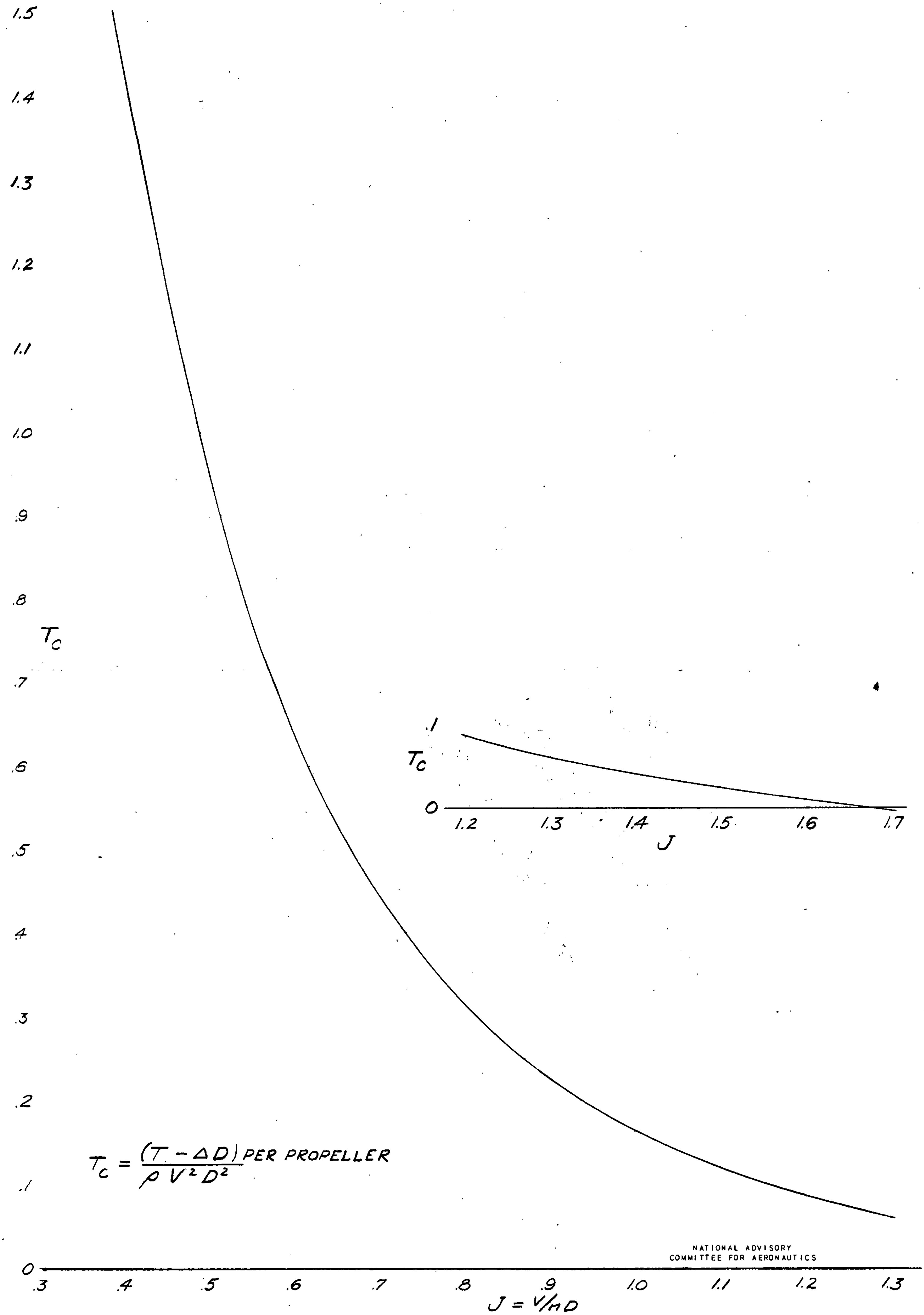


FIGURE 17.- VARIATION OF THRUST COEFFICIENT WITH V/nD FOR THE TEST MODEL.

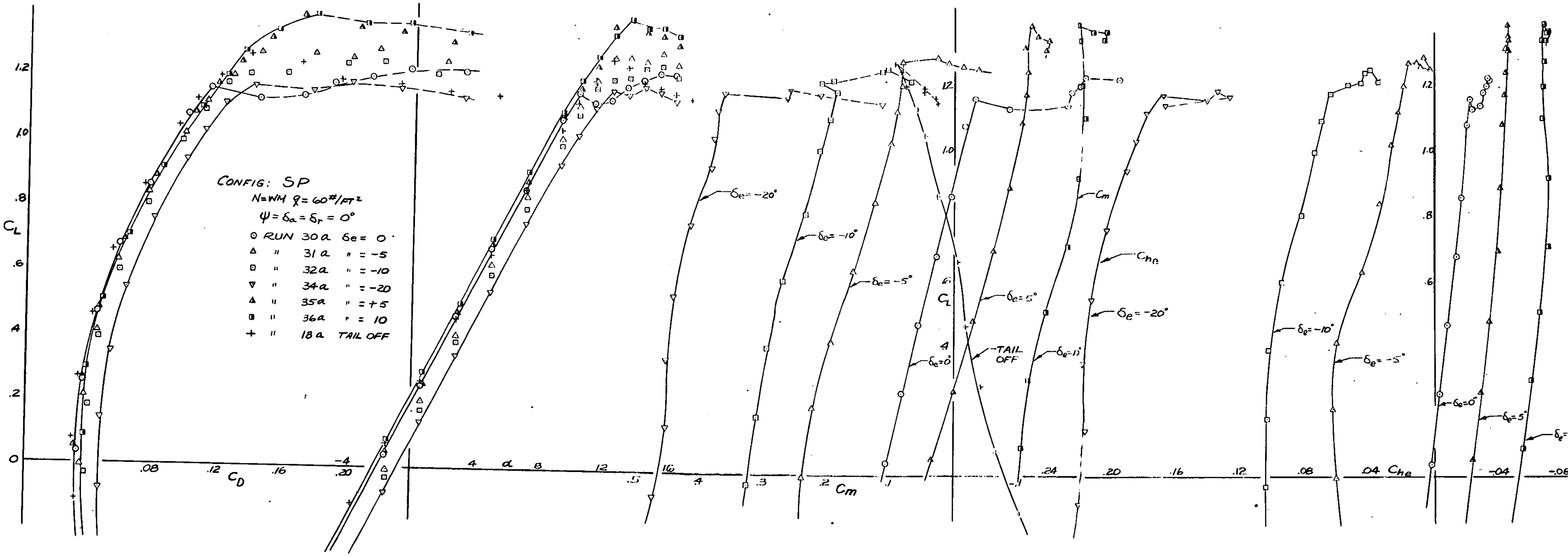


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FIGURE 18.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED. FLAPS AND GEAR RETRACTED, PROPELLERS WINDMILLING.

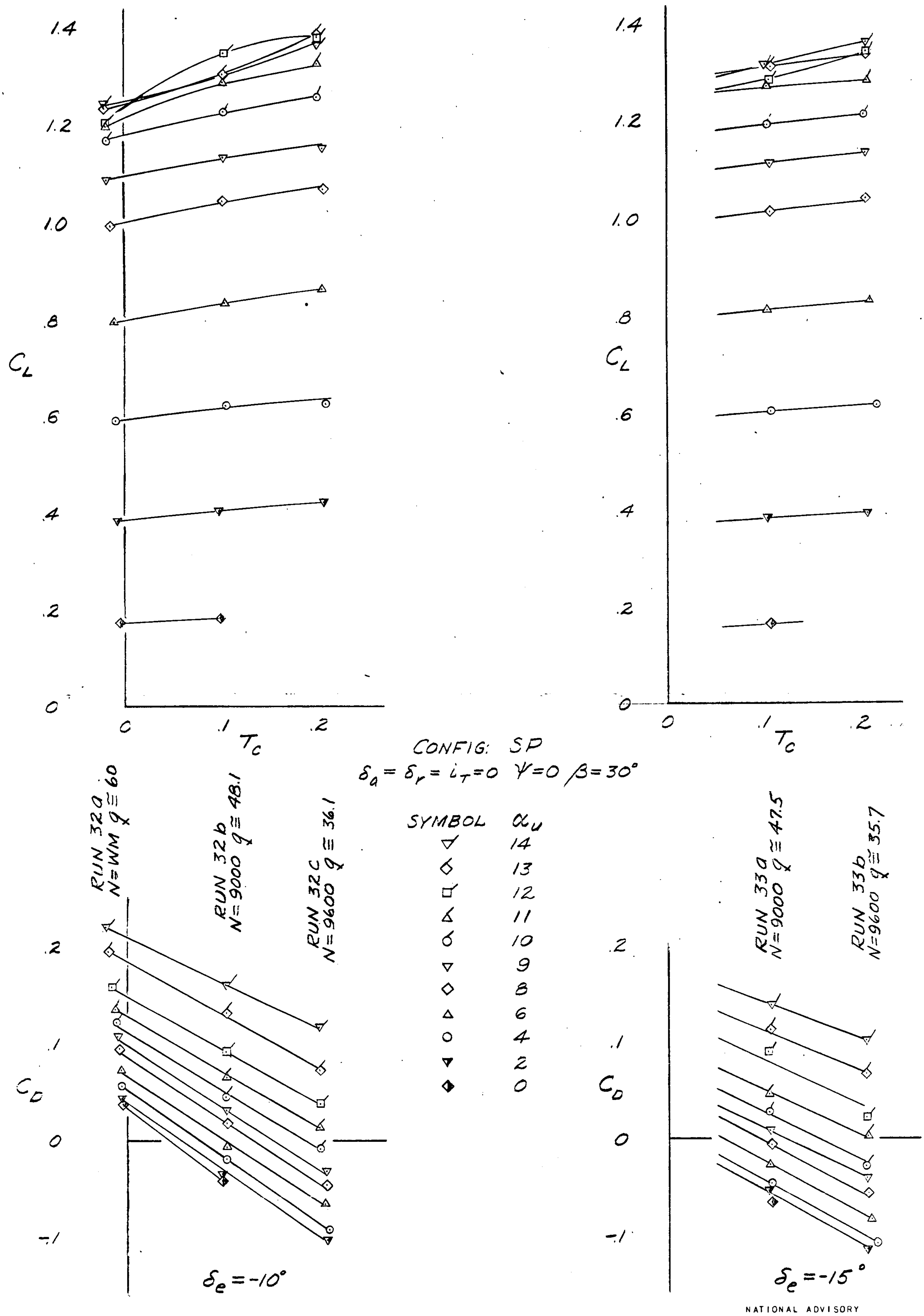

FIGURE 19A-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED. FLAPS AND GEAR RETRACTED, T_c VARIABLE.

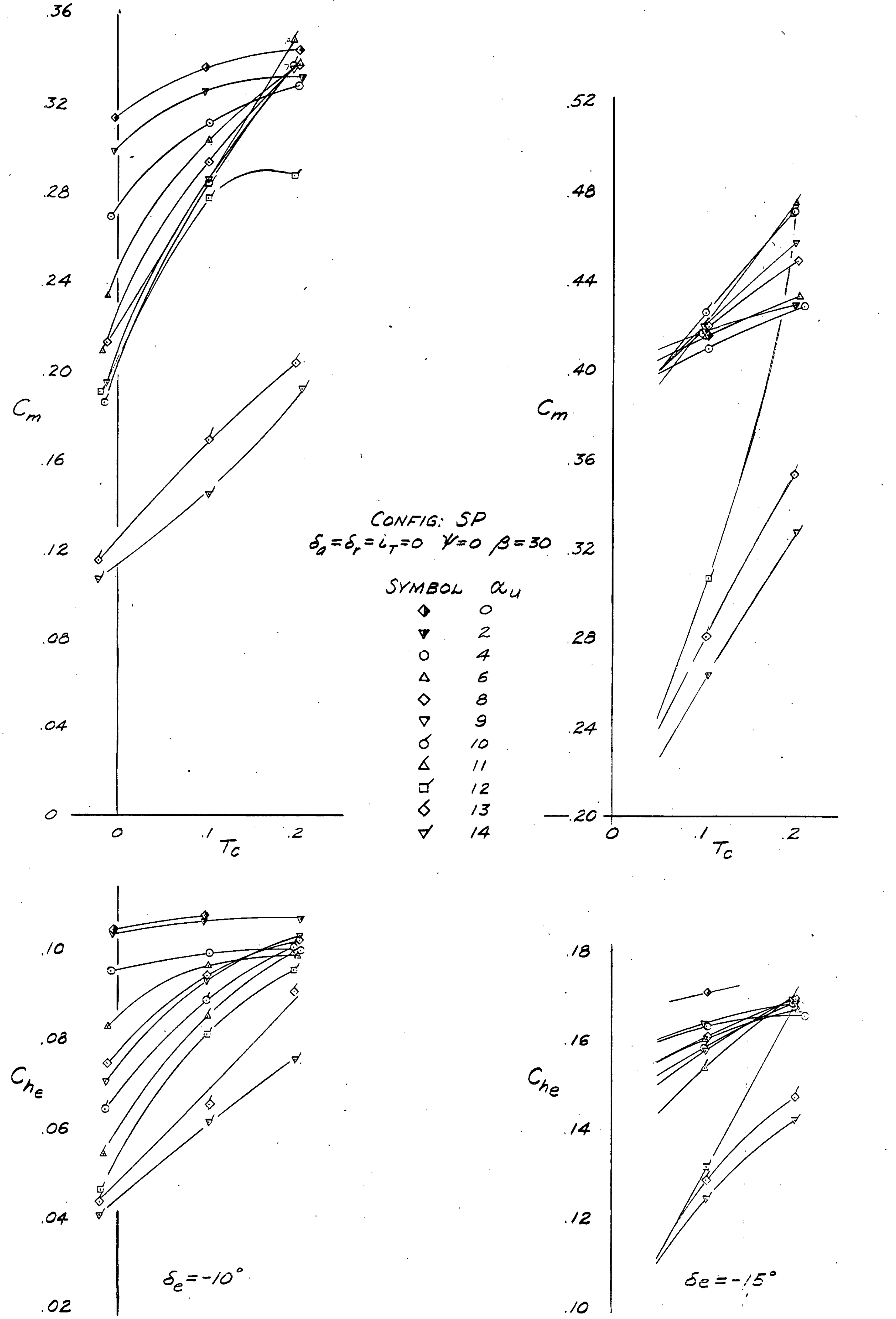

FIGURE 19B.-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED. FLAPS AND GEAR RETRACTED, T_c VARIABLE.

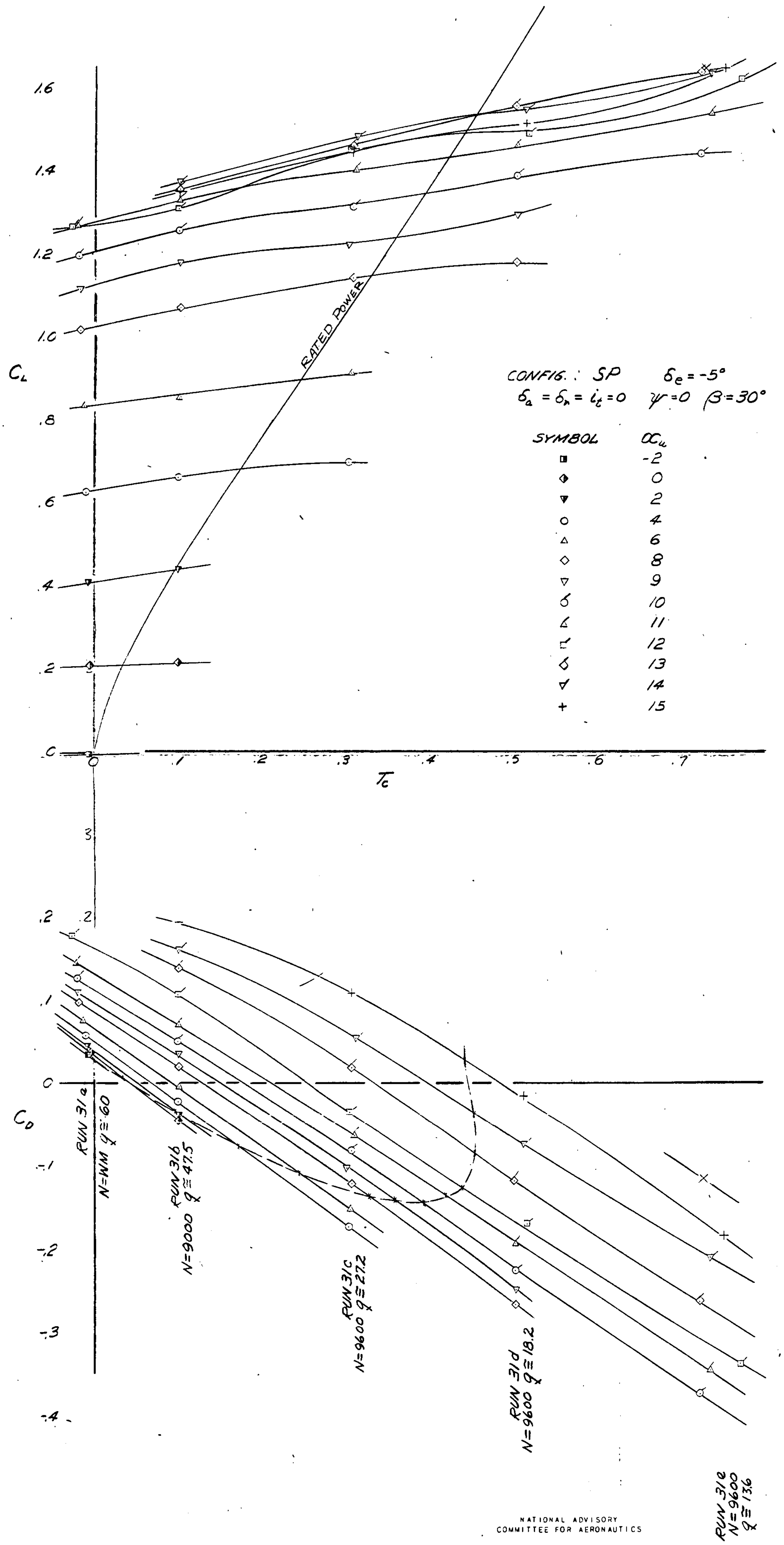

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FIGURE 20A-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED -5°. FLAPS AND GEAR RETRACTED, T_c VARIABLE

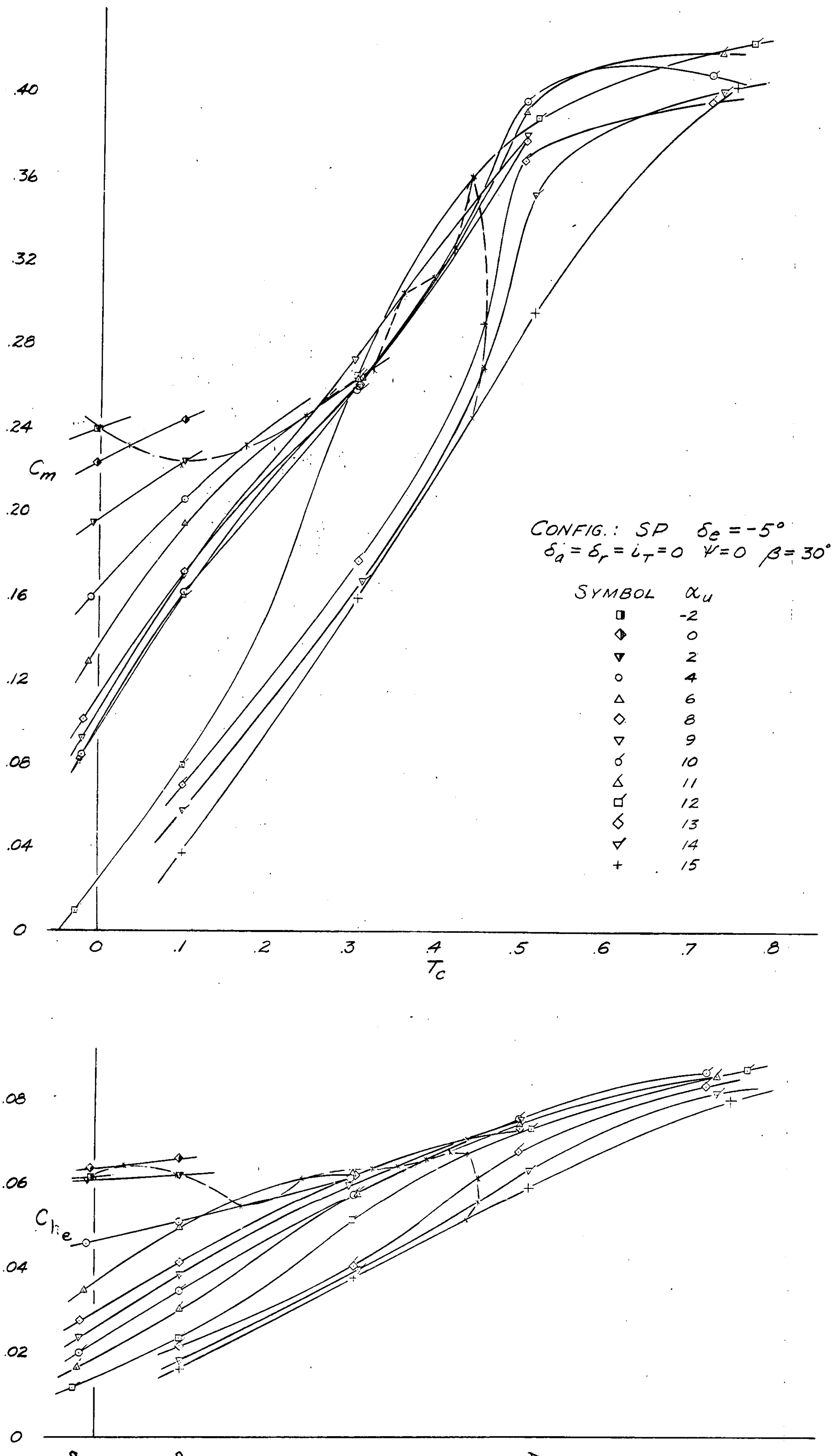

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FIGURE 20B - CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED -5°. FLAPS AND GEAR RETRACTED, T_c VARIABLE

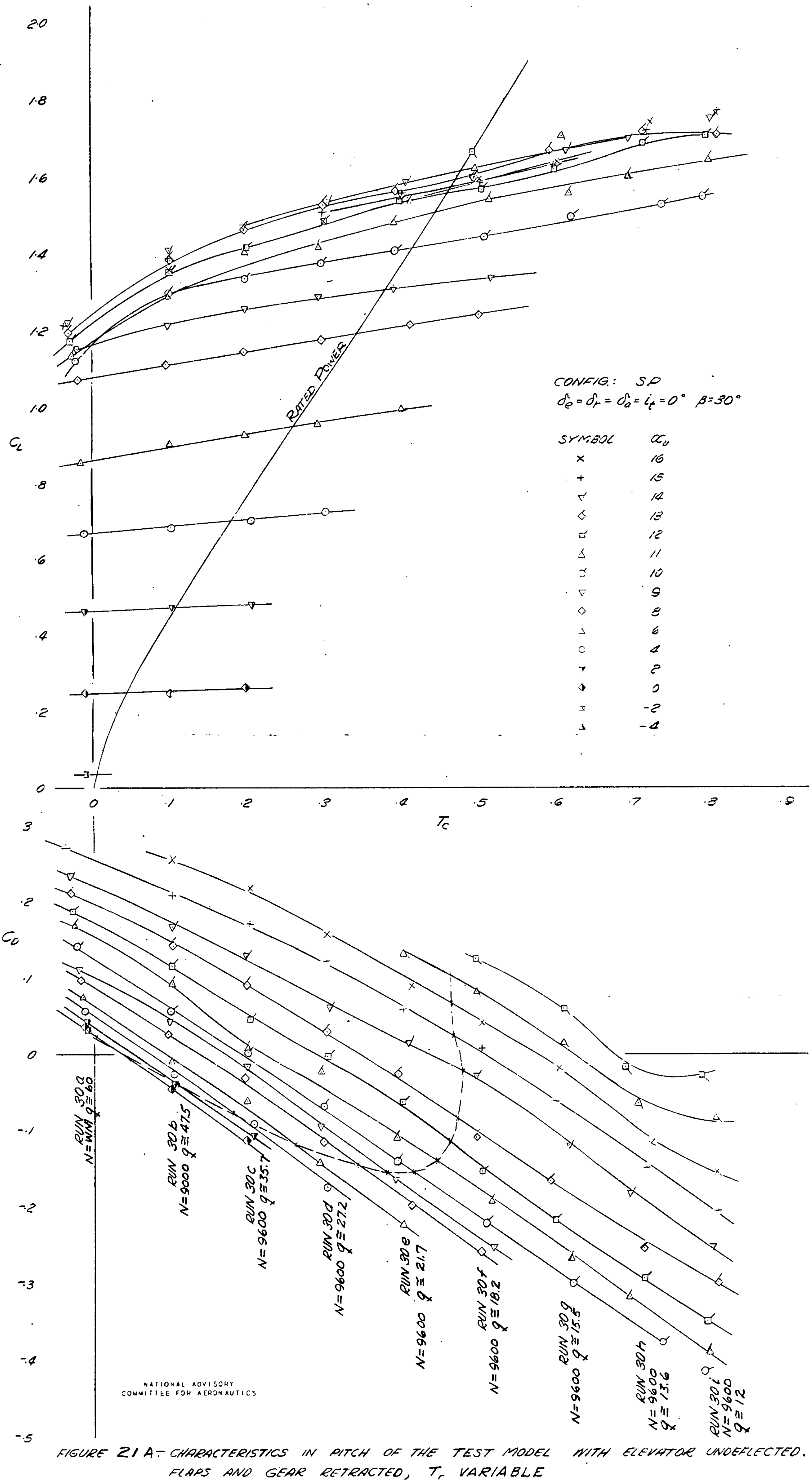

FIGURE 21 A - CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR UNDEFLECTED. FLAPS AND GEAR RETRACTED, T_c VARIABLE

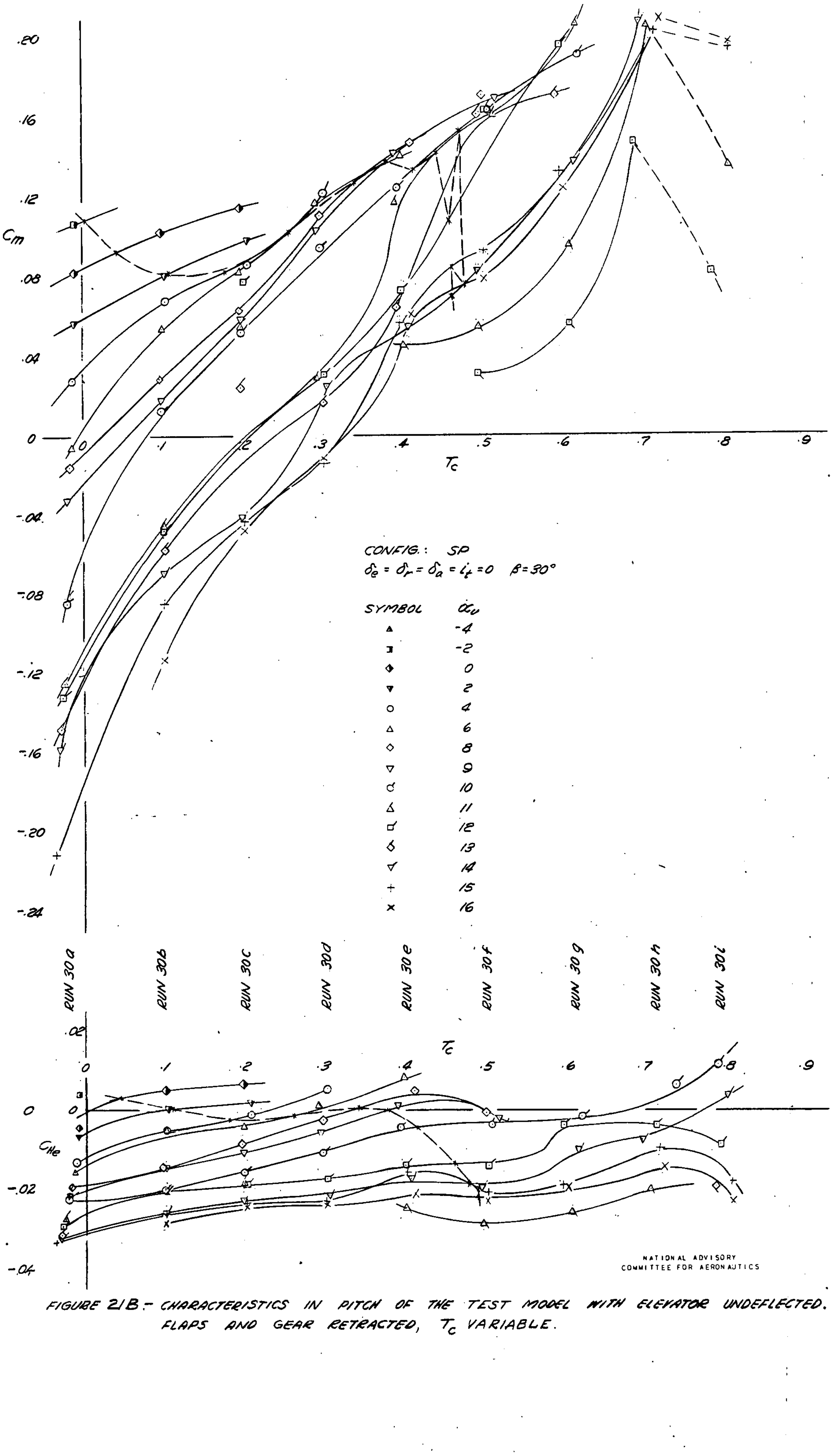

FIGURE 21B.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR UNDEFLECTED. FLAPS AND GEAR RETRACTED, T_c VARIABLE.

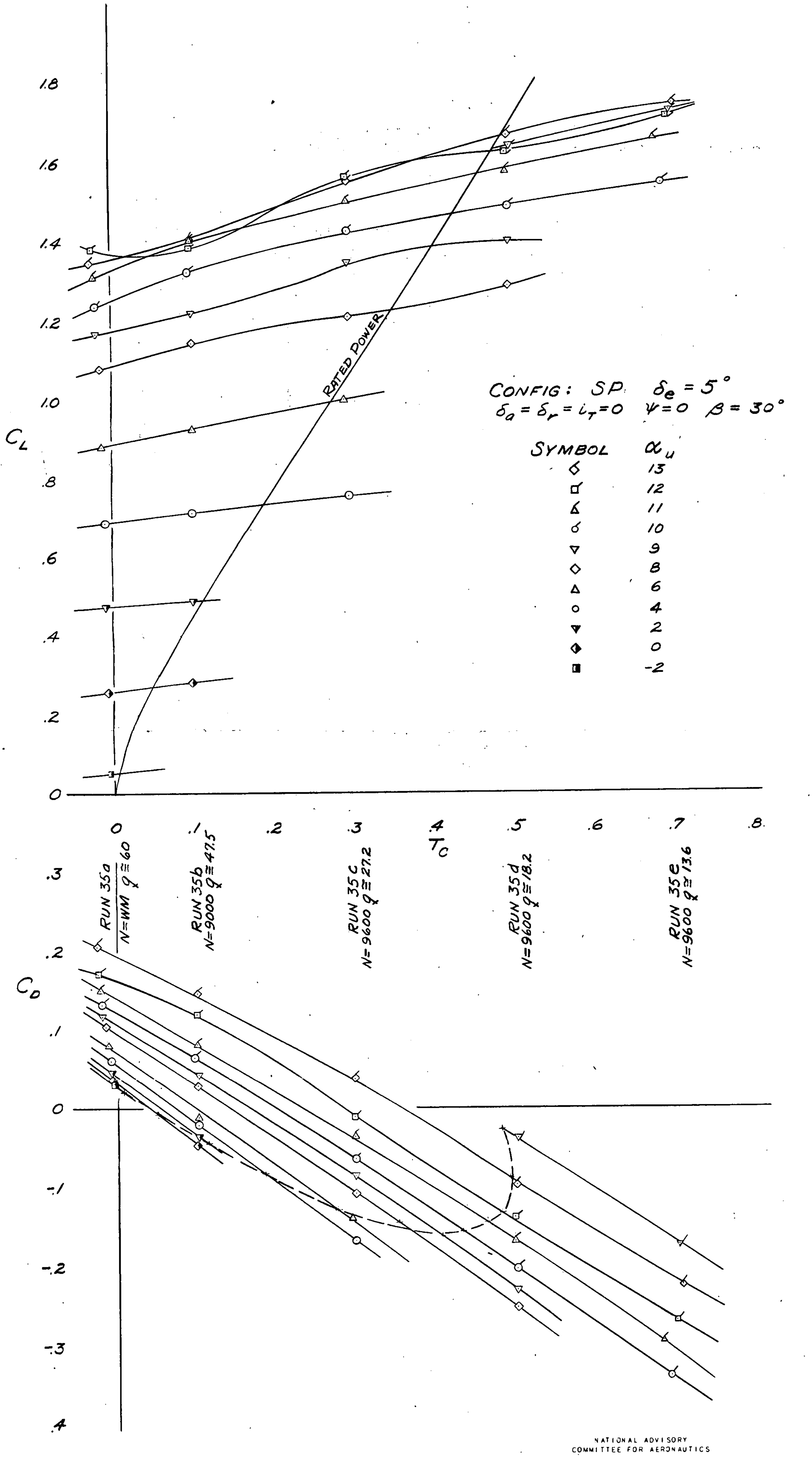

FIGURE 22A:- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED +5° FLAPS AND GEAR RETRACTED, T_c VARIABLE.

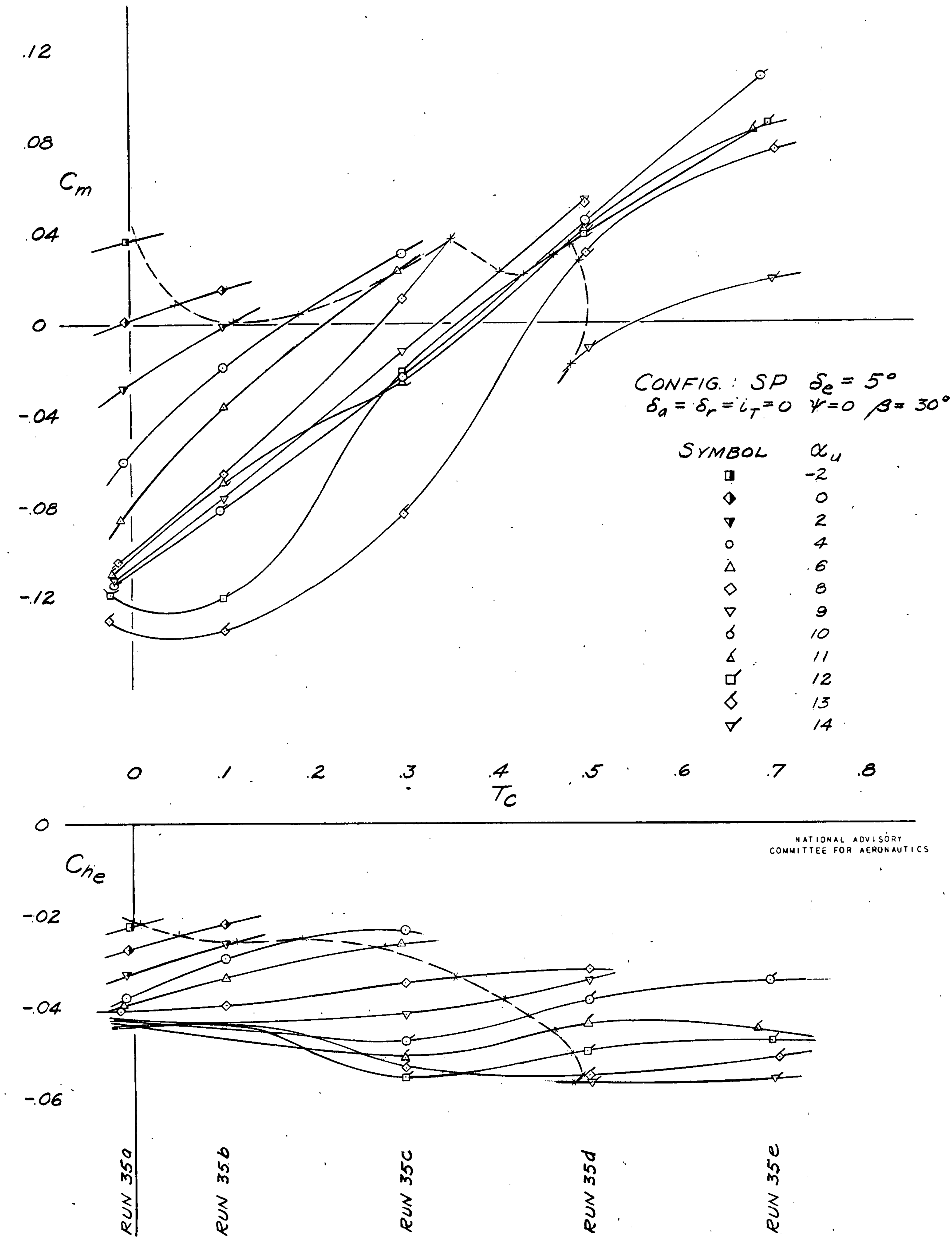

FIGURE 22B:-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED +5° FLAPS AND GEAR RETRACTED, T_c VARIABLE.

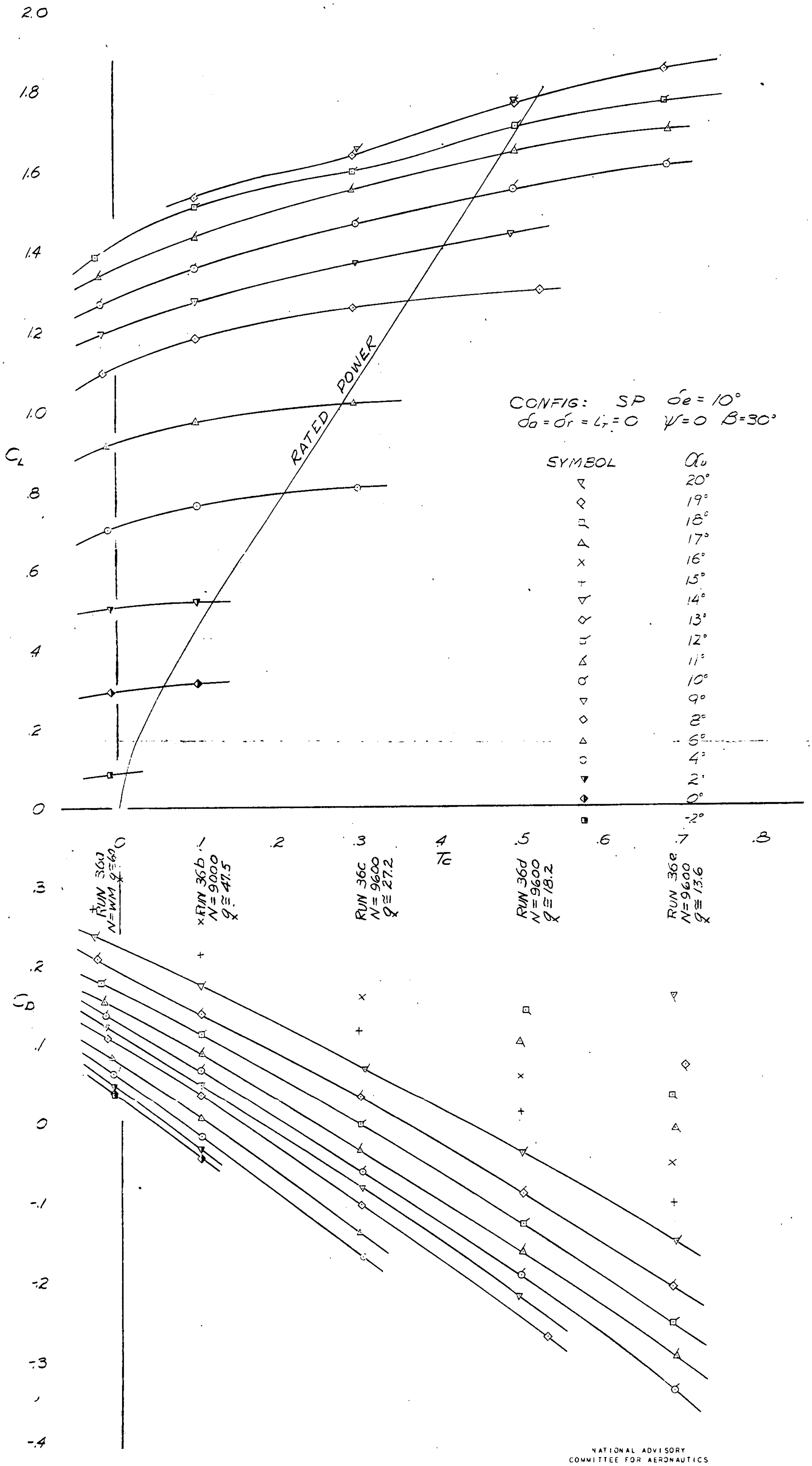

FIGURE 23A.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED +10°. FLAPS AND GEAR RETRACTED, T_c VARIABLE.

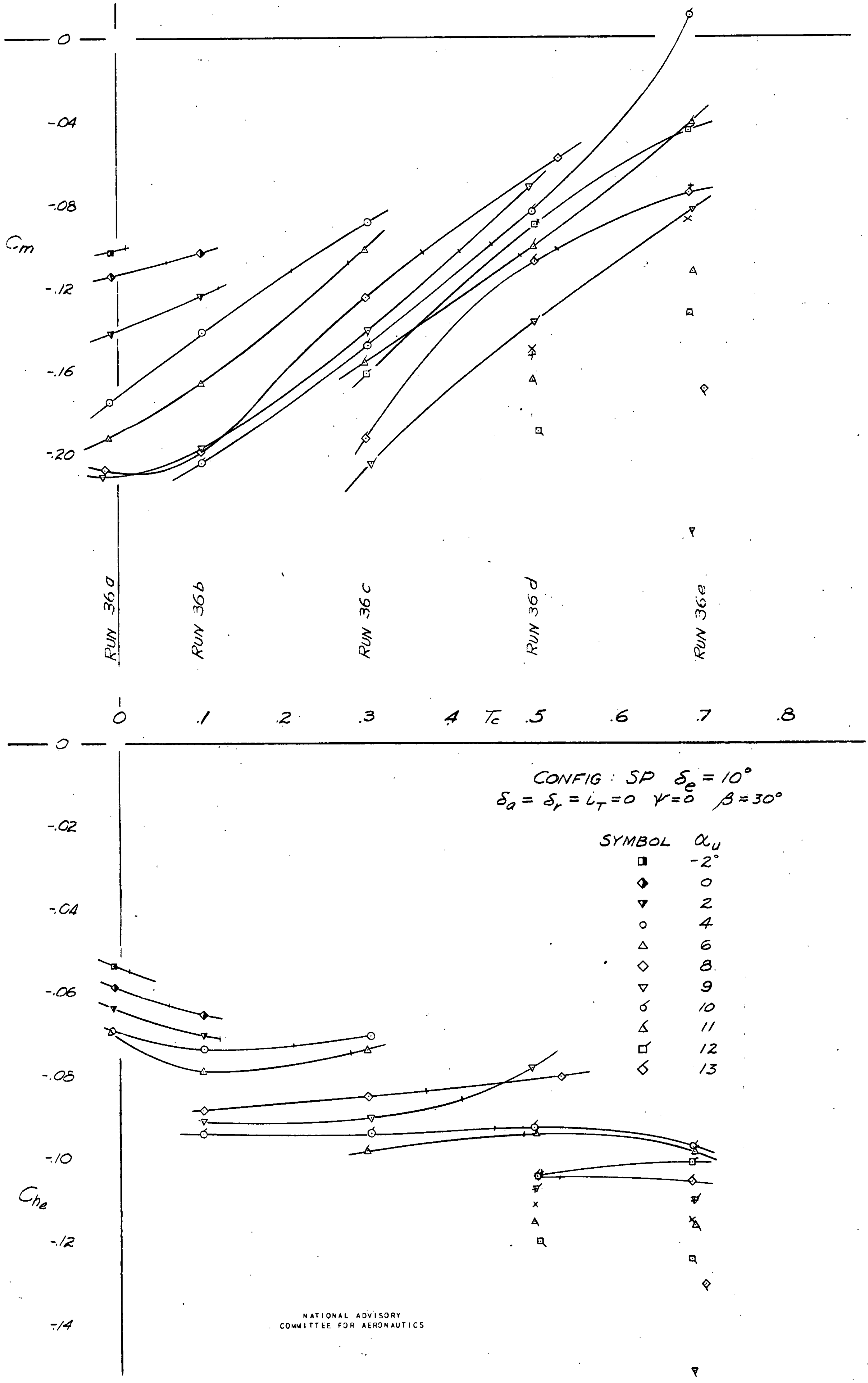

FIGURE 23B.- CHARACTERISTICS IN PITCH OF TEST MODEL WITH ELEVATOR DEFLECTED +10°. FLAPS AND GEAR RETRACTED, T_c VARIABLE.

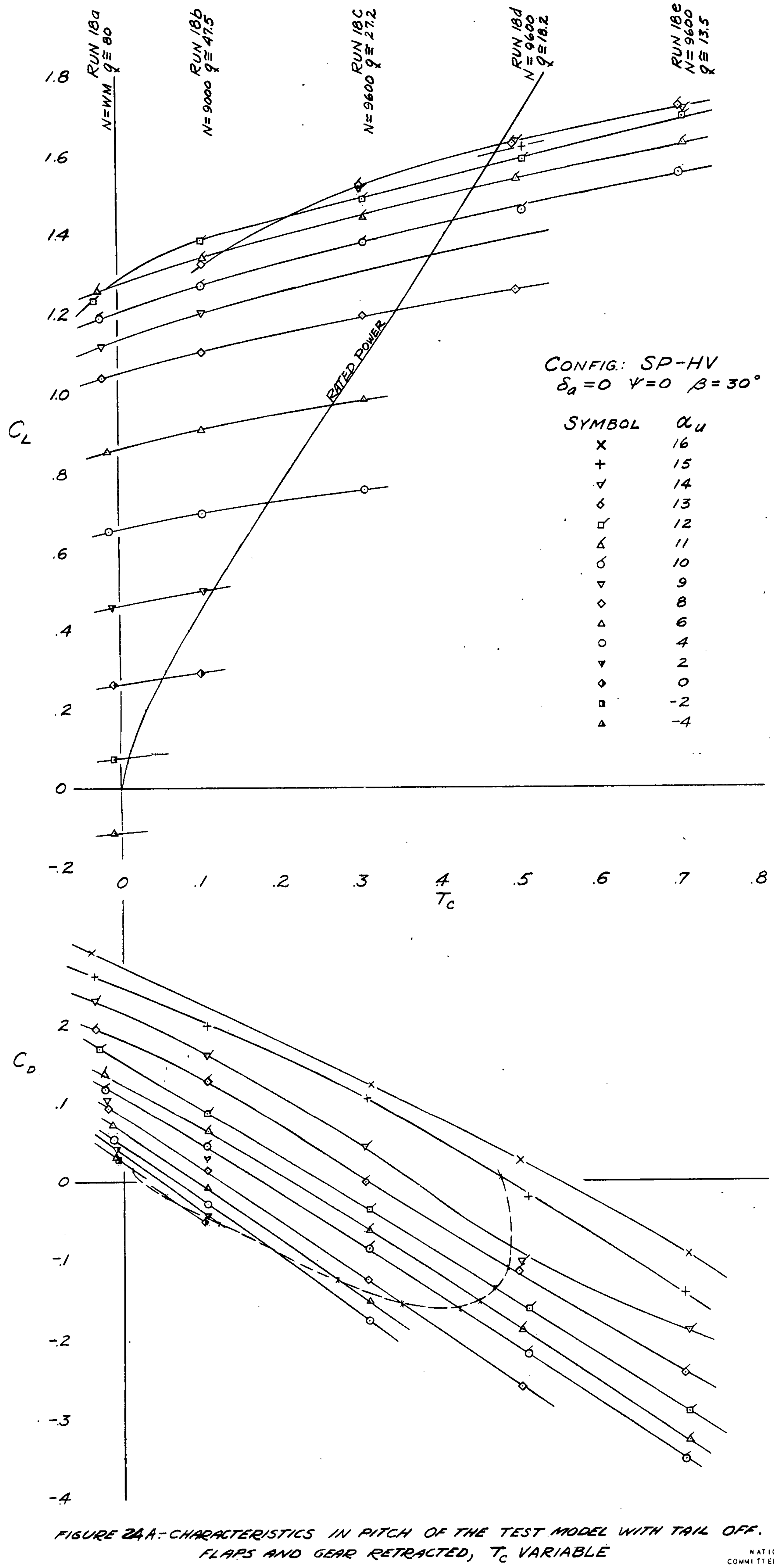

FIGURE 24A.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH TAIL OFF. FLAPS AND GEAR RETRACTED, T_c VARIABLE

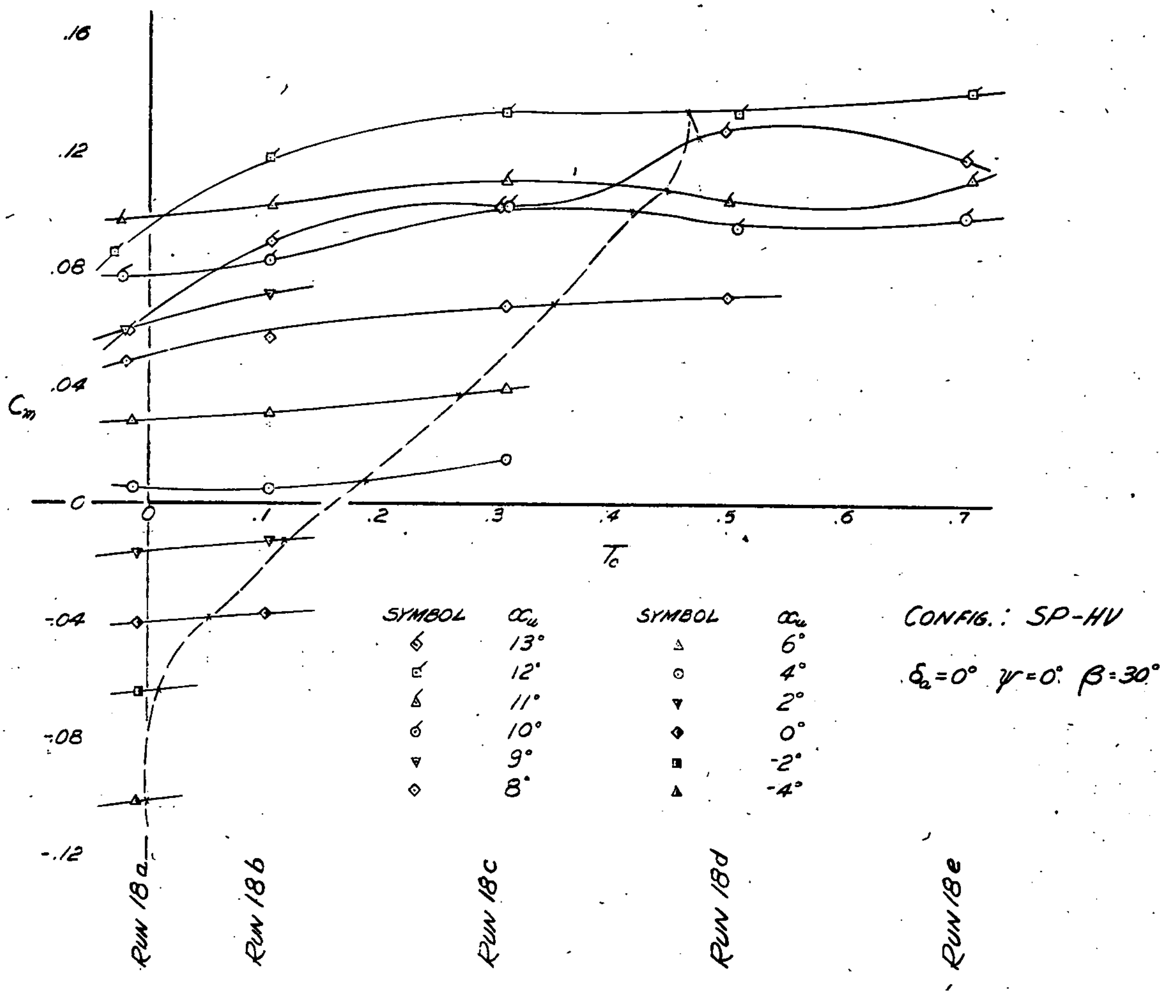

FIGURE 24-B.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH TAIL OFF. FLAPS AND GEAR RETRACTED, T_c VARIABLE.

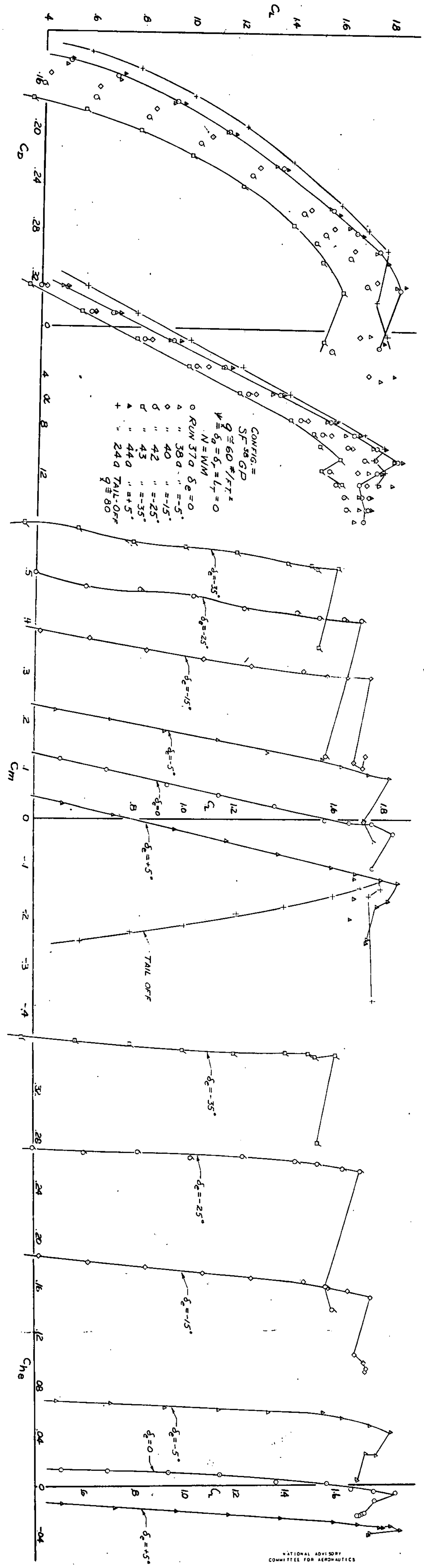

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FIGURE 25-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED., FLAPS 38°, GEAR EXTENDED, PROPELLERS WINDMILLING.

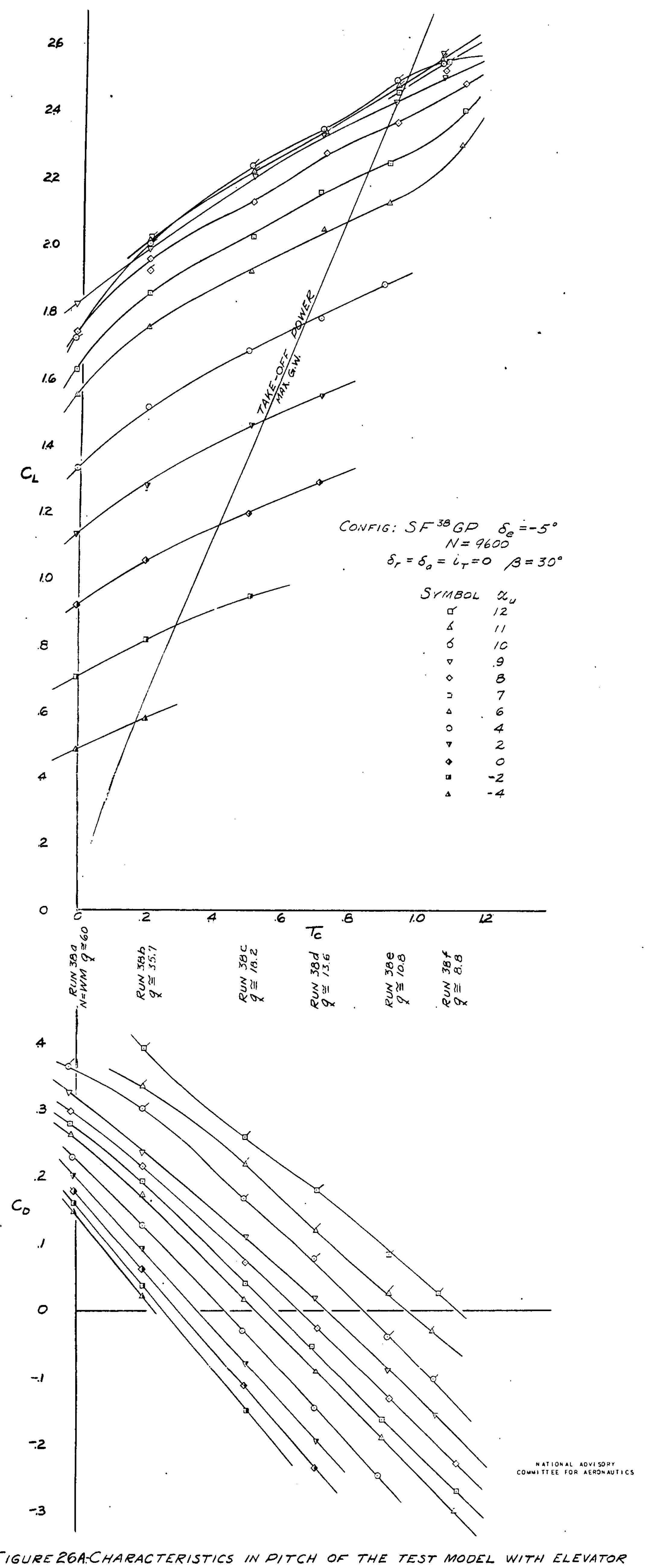

FIGURE 26A-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED −5°, FLAPS 38°, GEAR EXTENDED, T_c VARIABLE.

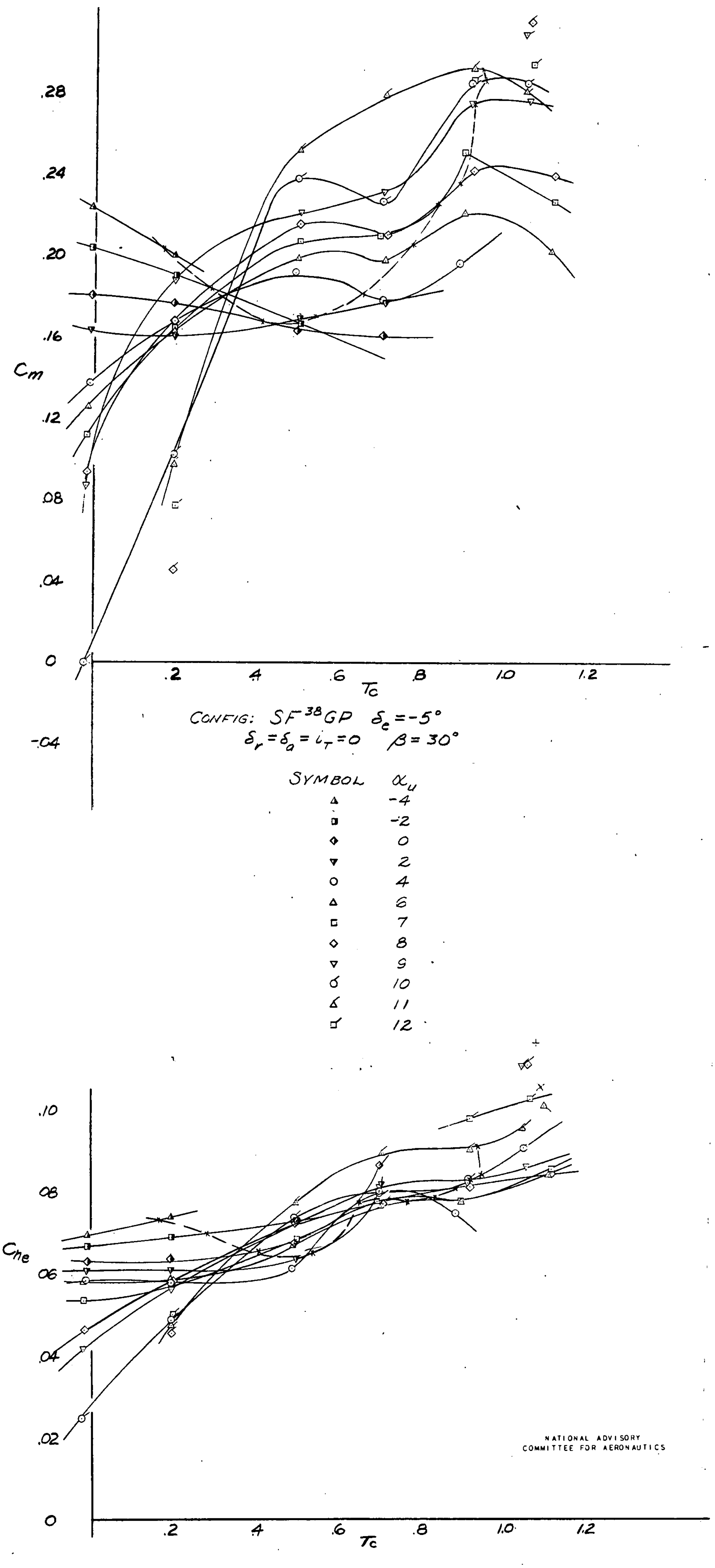

FIGURE 26B: CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED -5°. FLAPS 38°, GEAR EXTENDED, T_c VARIABLE

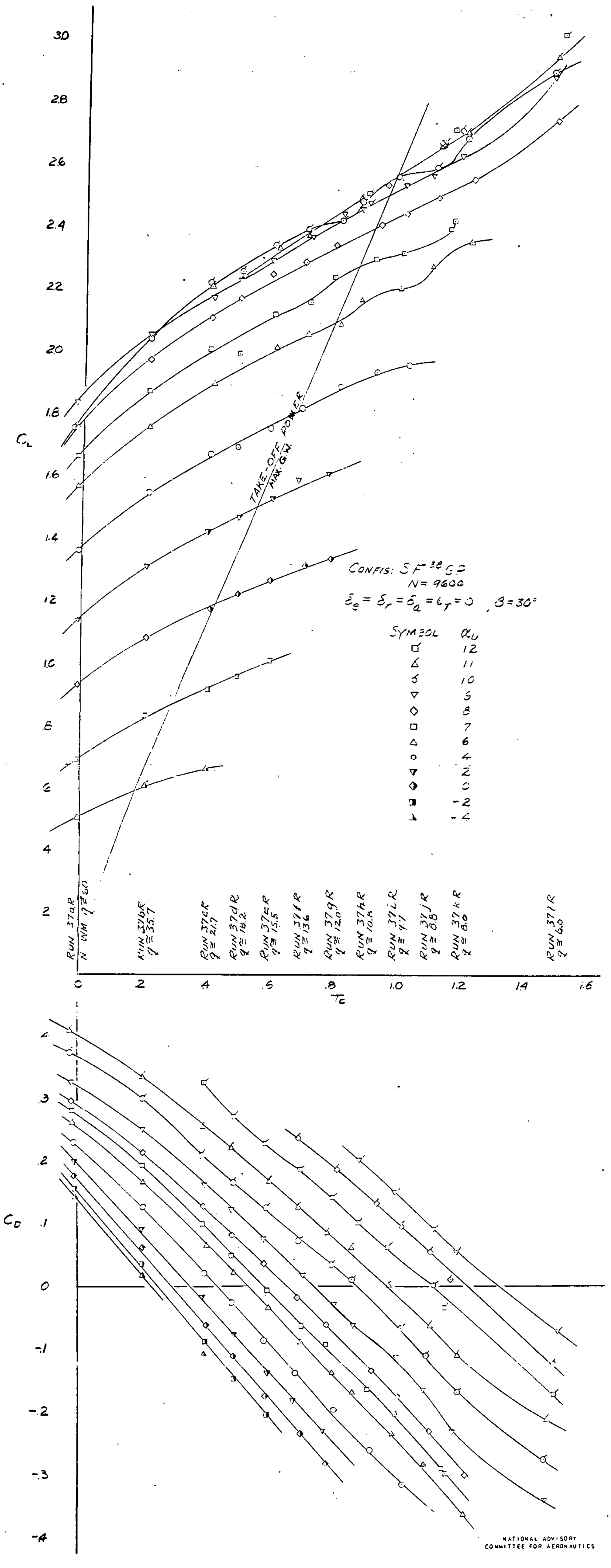

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FIGURE 27A: CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR UNDEFLECTED. FLAPS 38°, GEAR EXTENDED, T_c VARIABLE.

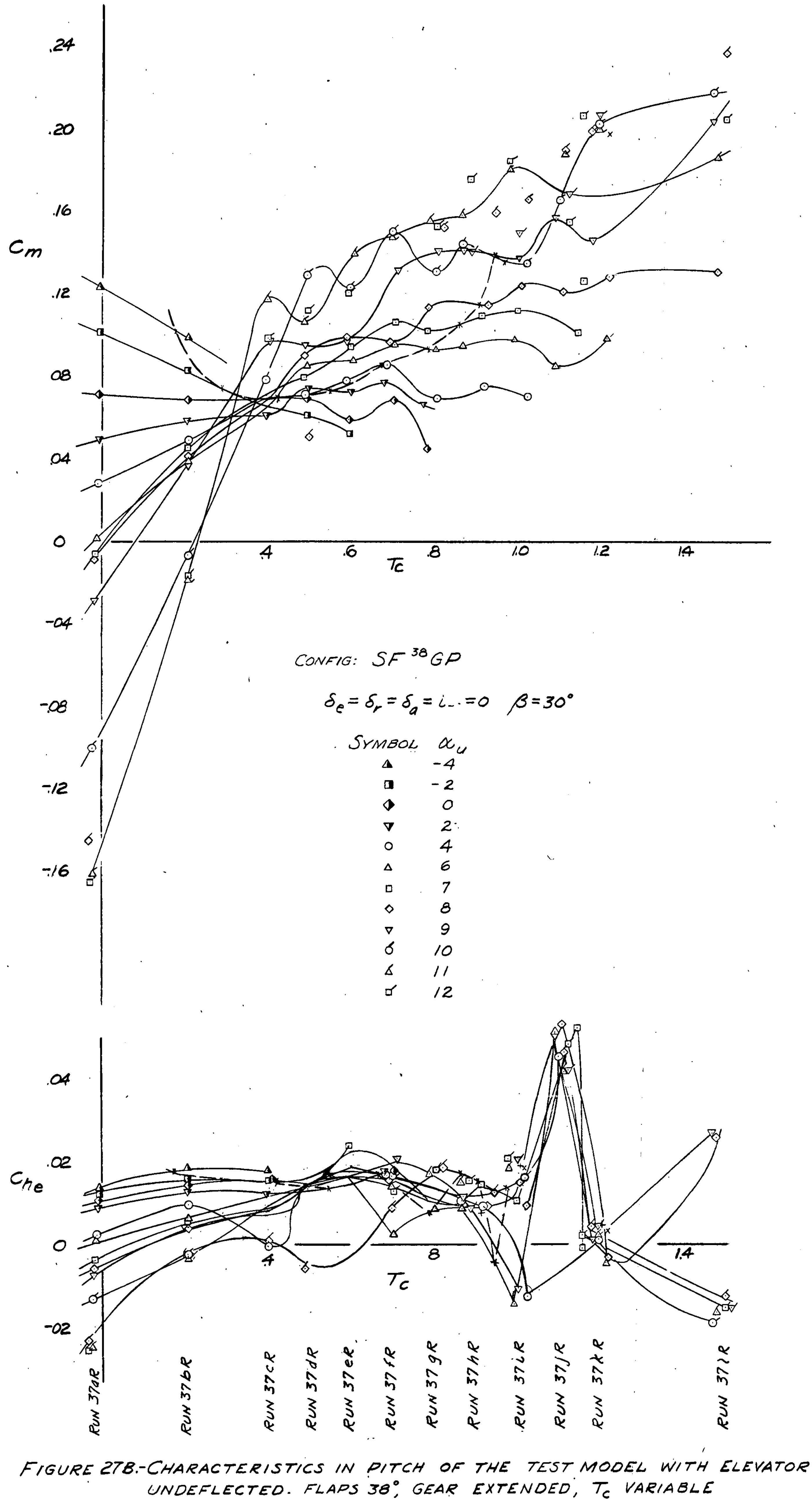

FIGURE 27B.-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR UNDEFLECTED. FLAPS 38°, GEAR EXTENDED, T_c VARIABLE

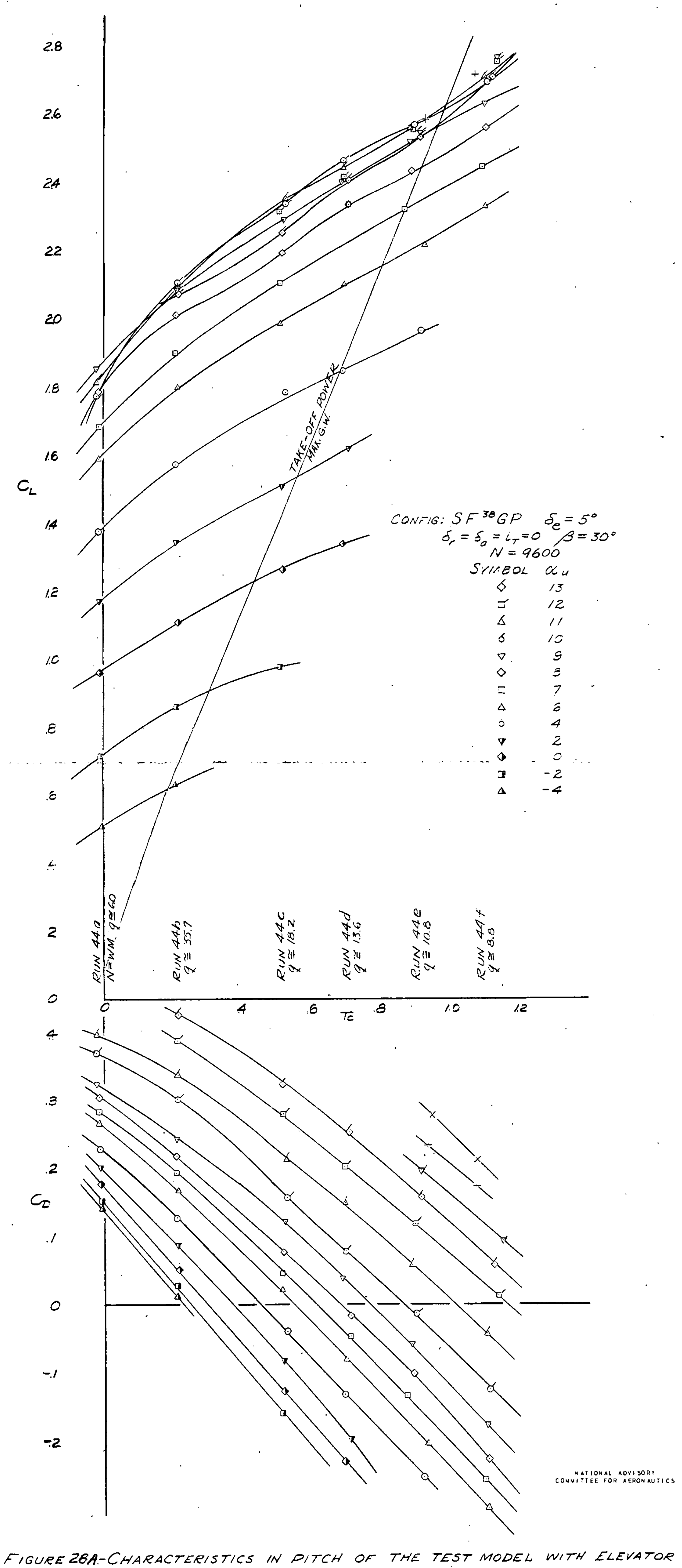

FIGURE 28A.-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED 5°. FLAPS 38°, GEAR EXTENDED, T_c VARIABLE.

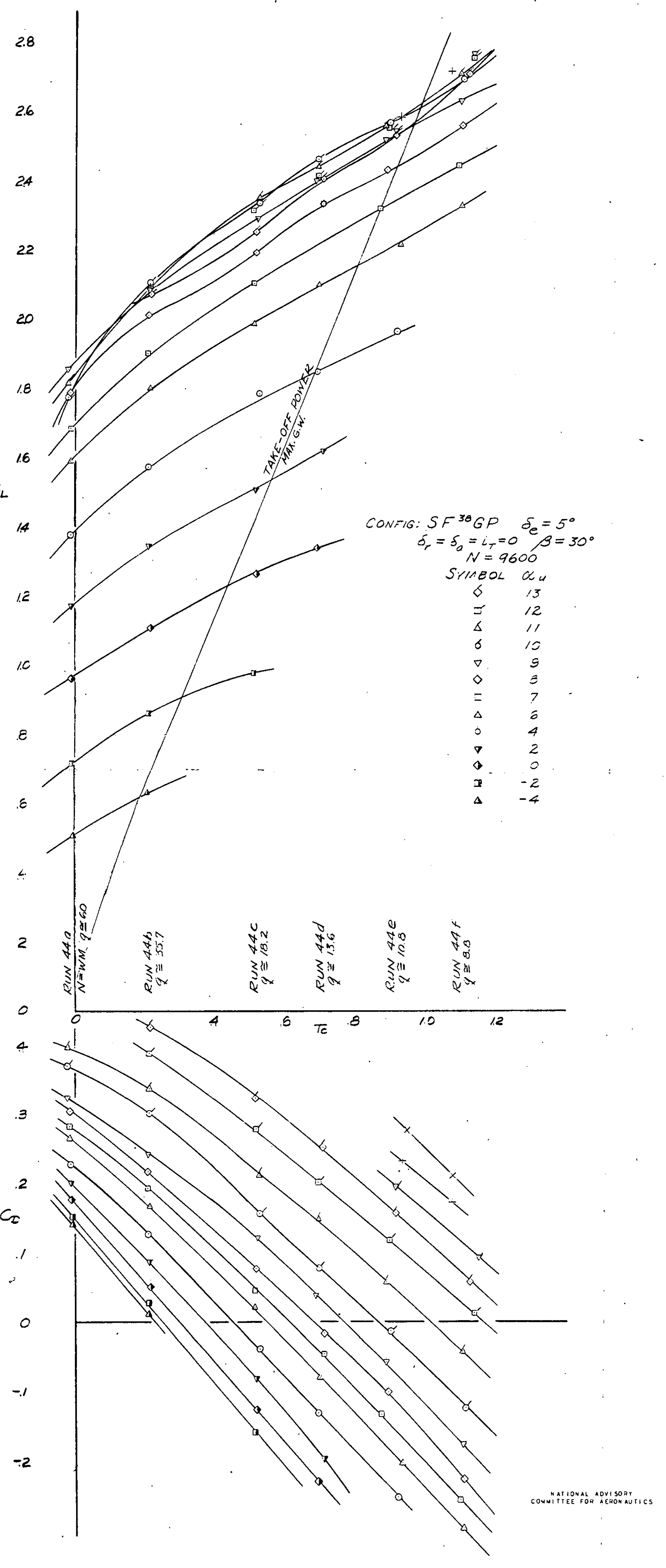

FIGURE 28A-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED 5°. FLAPS 38°, GEAR EXTENDED, T_c VARIABLE.

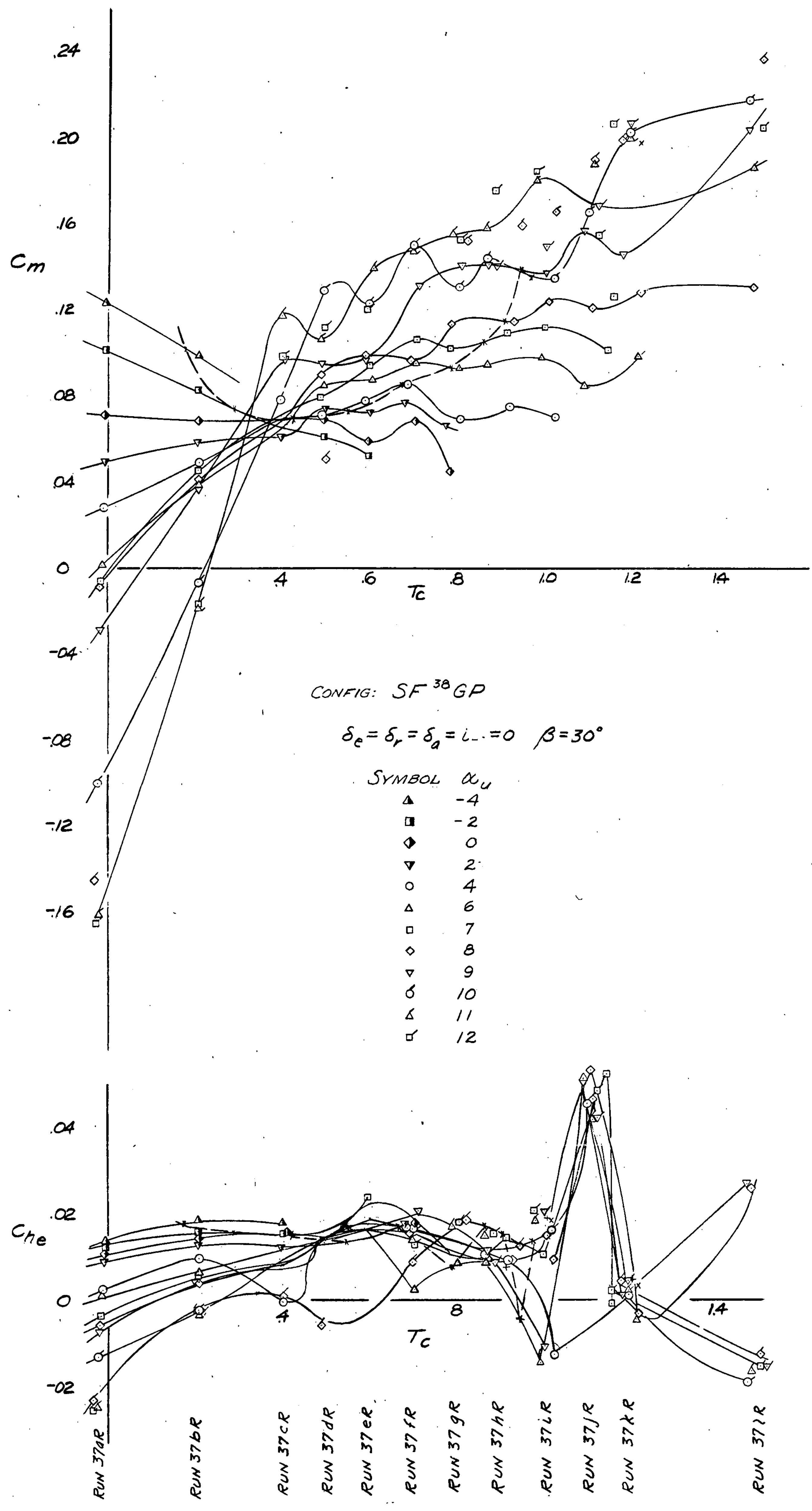

FIGURE 27B.-CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR UNDEFLECTED. FLAPS 38°, GEAR EXTENDED, T_c VARIABLE

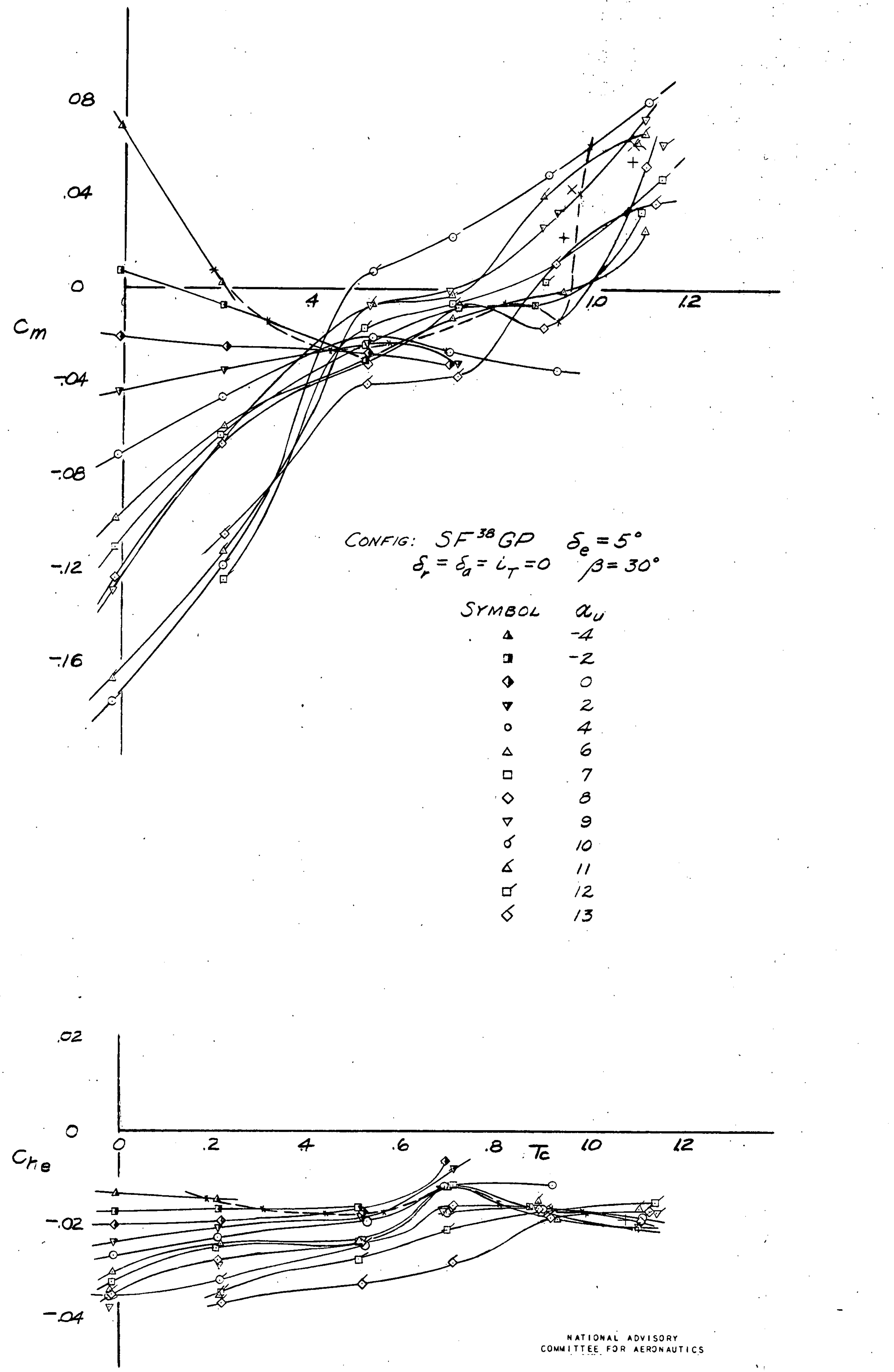

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FIGURE 28B.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED 5°, FLAPS 38°, GEAR EXTENDED, T_c VARIABLE.

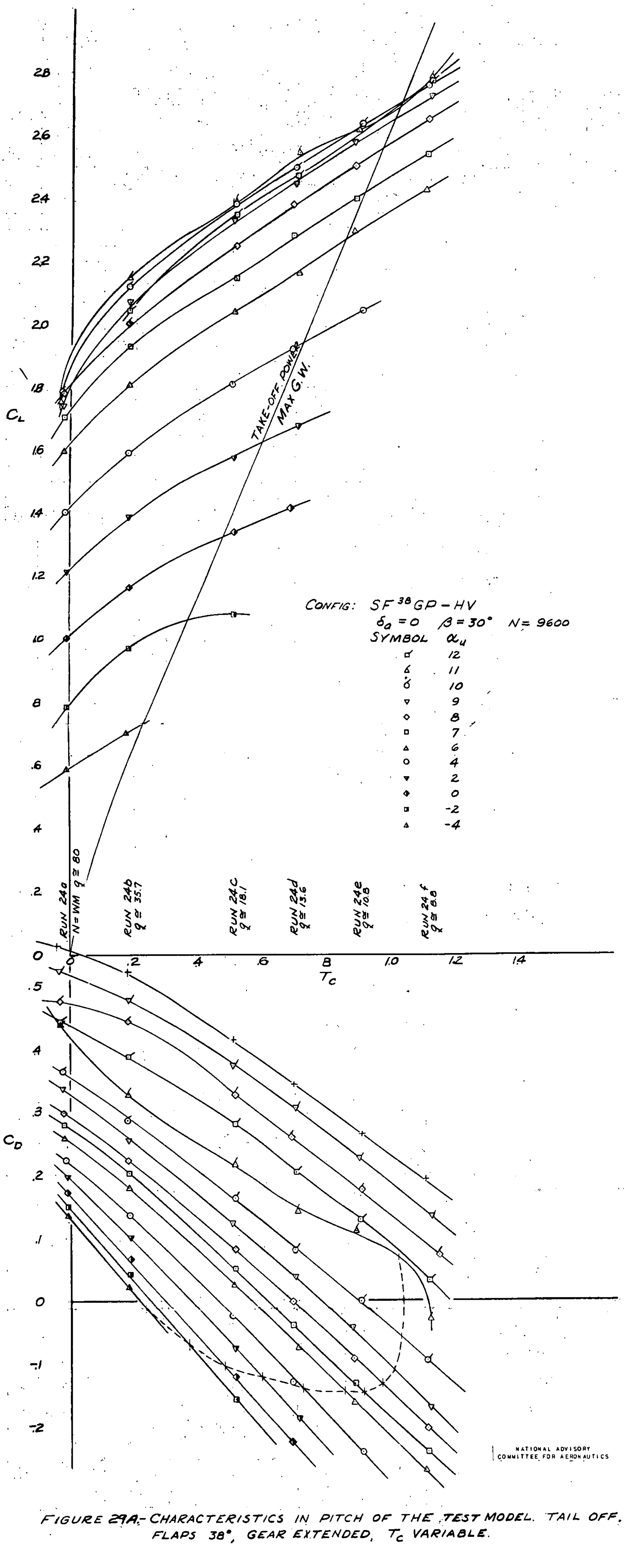

FIGURE 29A.- CHARACTERISTICS IN PITCH OF THE TEST MODEL. TAIL OFF, FLAPS 38°, GEAR EXTENDED, T_c VARIABLE.

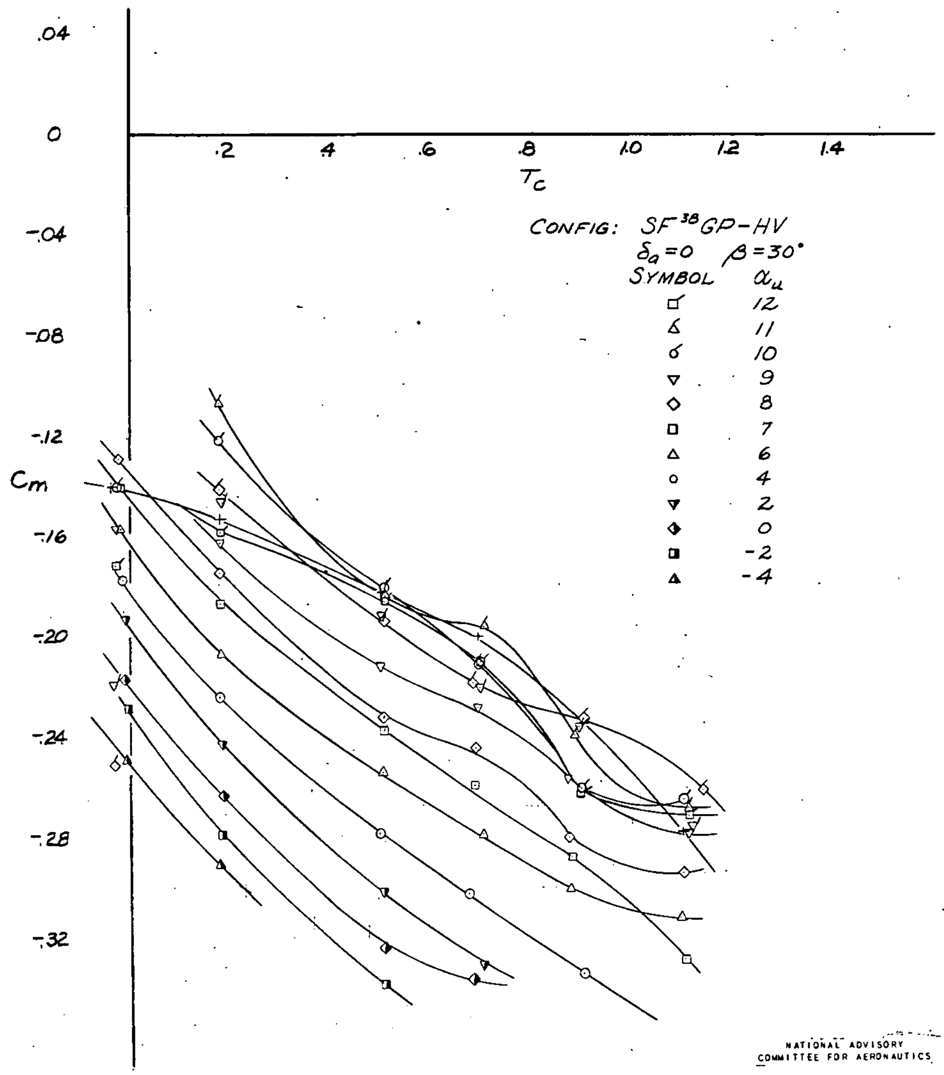

FIGURE 29B.- CHARACTERISTICS IN PITCH OF THE TEST MODEL. TAIL OFF. FLAPS 38°, GEAR EXTENDED, T_c VARIABLE

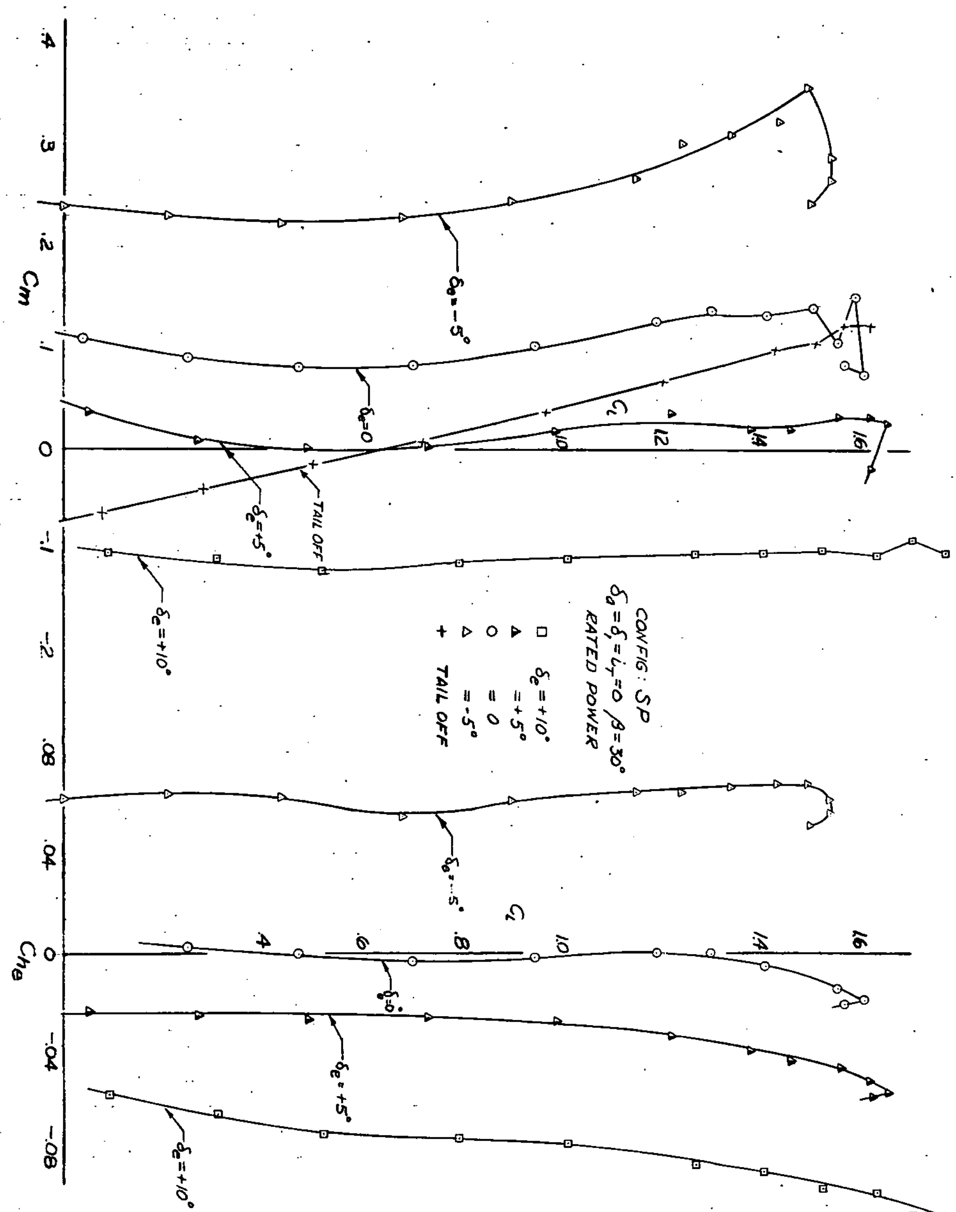

FIGURE 30.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED. FLAPS AND GEAR RETRACTED, RATED POWER. GROSS WEIGHT 26,500 LBS.

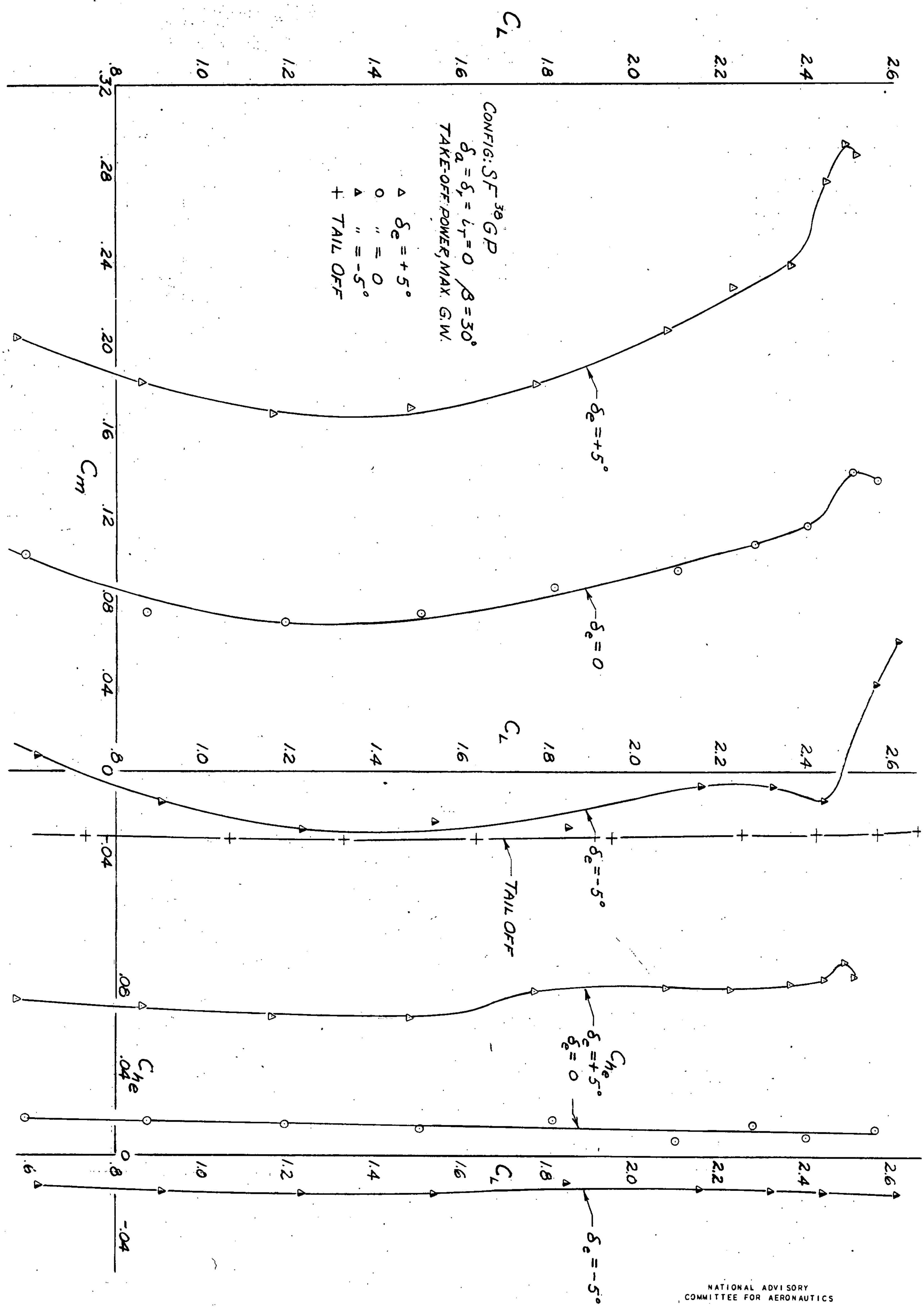

FIGURE 31.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH ELEVATOR DEFLECTED. FLAPS 38°, GEAR EXTENDED, TAKE-OFF POWER GROSS WEIGHT 26,500 LBS.

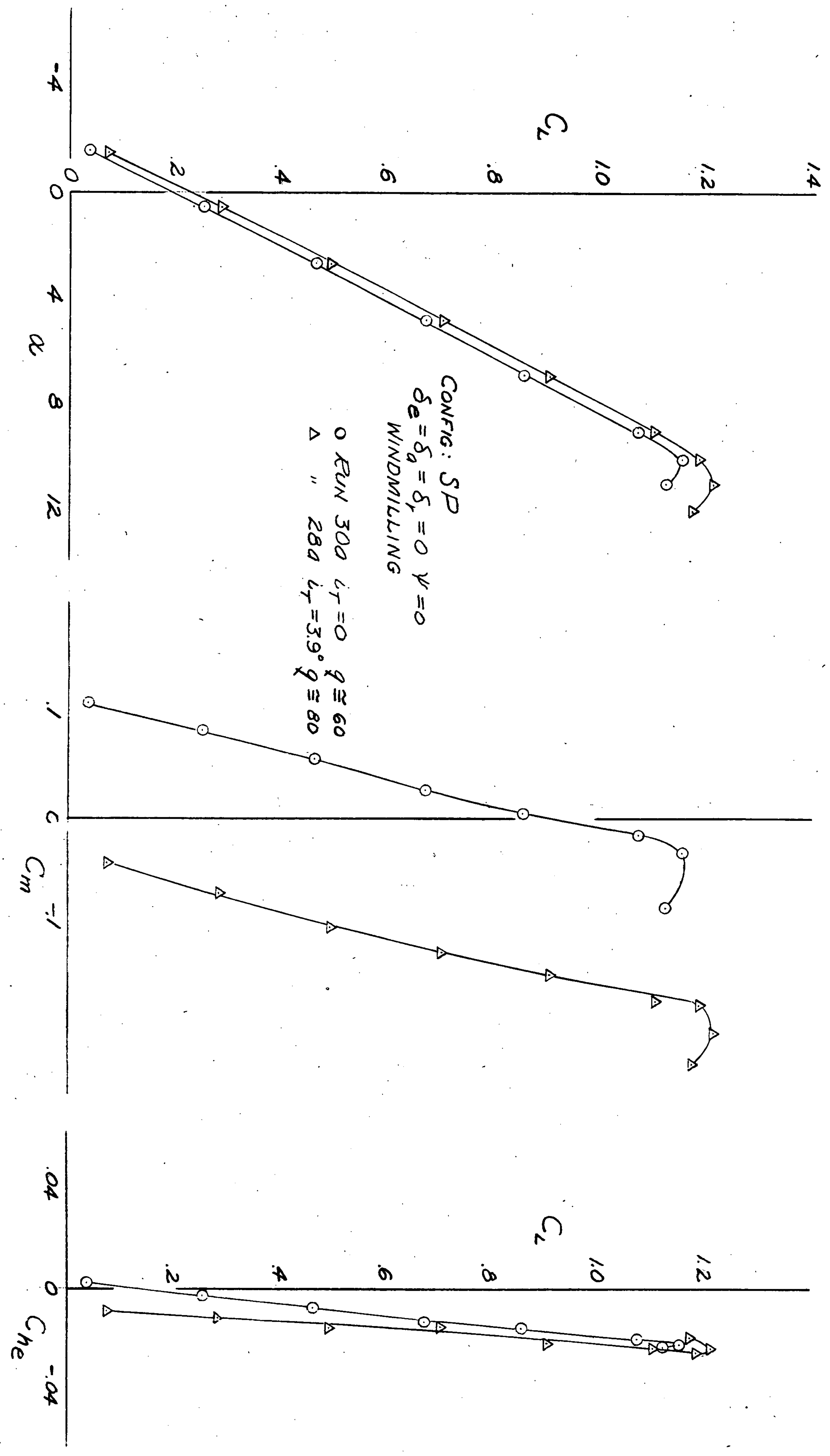

FIGURE 32.- CHARACTERISTICS IN PITCH OF THE TEST MODEL FOR TWO VALUES OF TAIL INCIDENCE. FLAPS AND GEAR RETRACTED, PROPELLERS WINDMILLING.

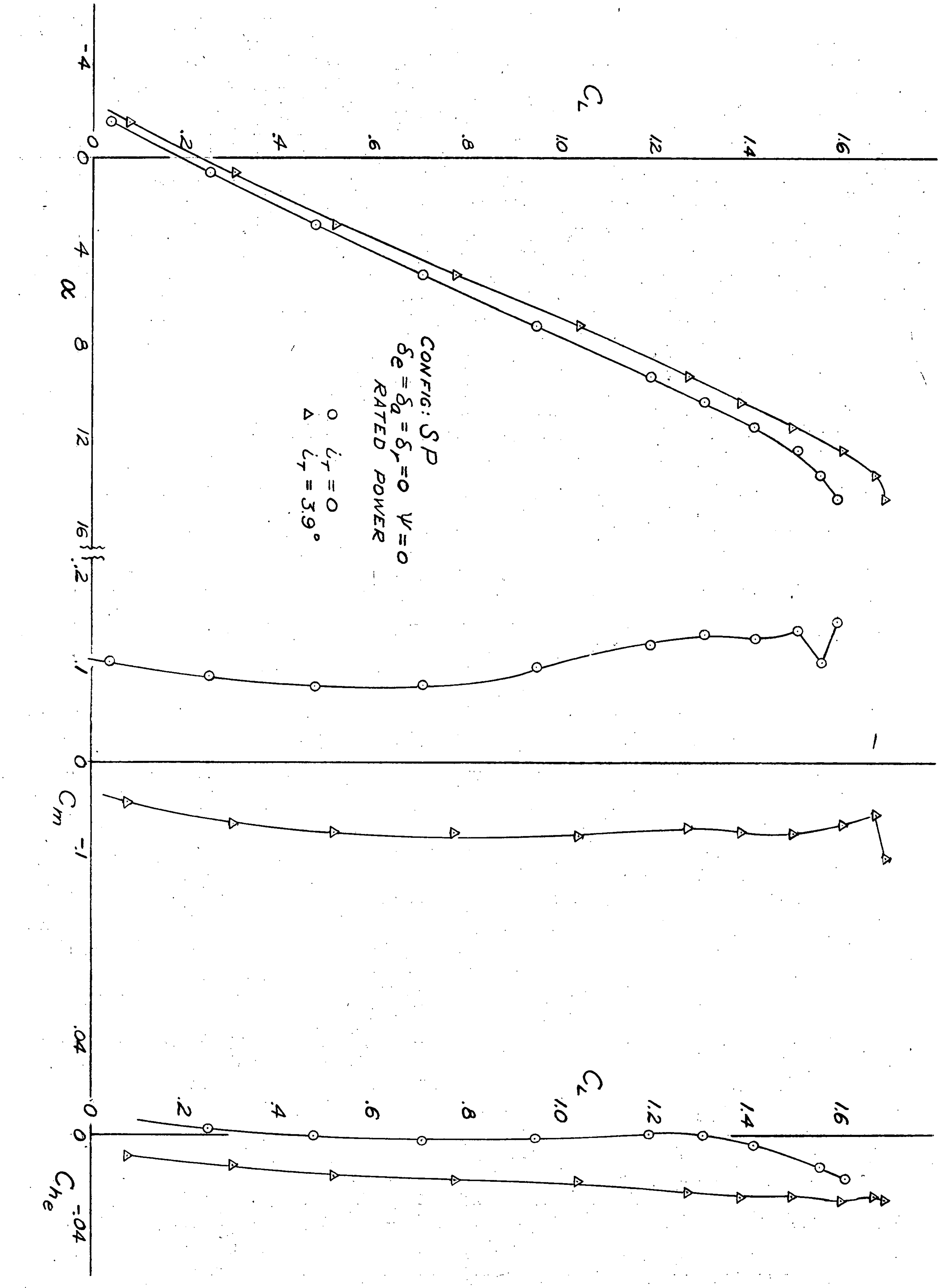

FIGURE 33.- CHARACTERISTICS IN PITCH OF THE TEST MODEL FOR TWO VALUES OF TAIL INCIDENCE. FLAPS AND GEAR RETRACTED, RATED POWER, GROSS WEIGHT 26,500 LBS.

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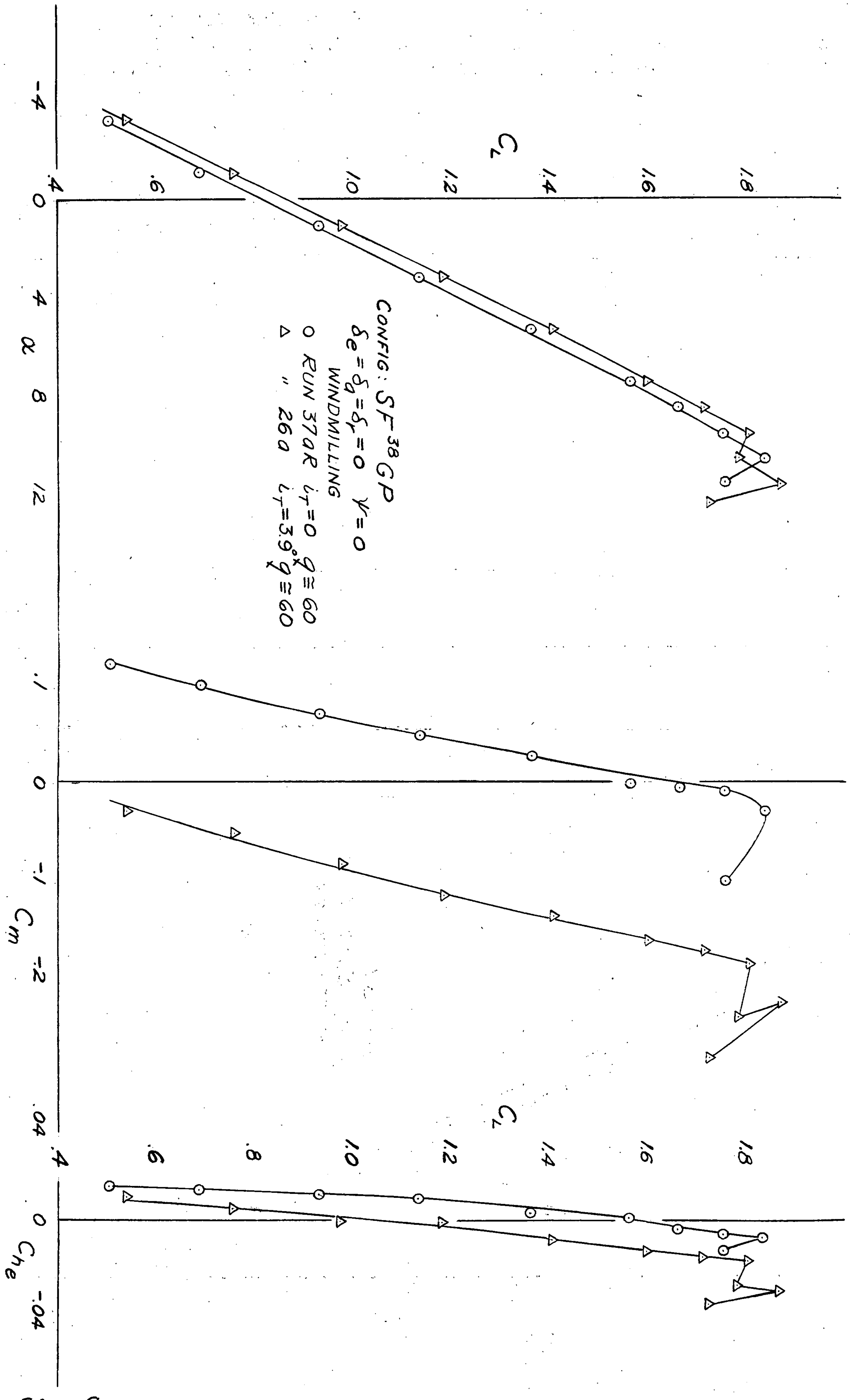

FIGURE 34.- CHARACTERISTICS IN PITCH OF THE TEST MODEL FOR TWO VALUES OF TAIL INCIDENCE. FLAPS 38°, GEAR EXTENDED. PROPELLERS WINDMILLING.

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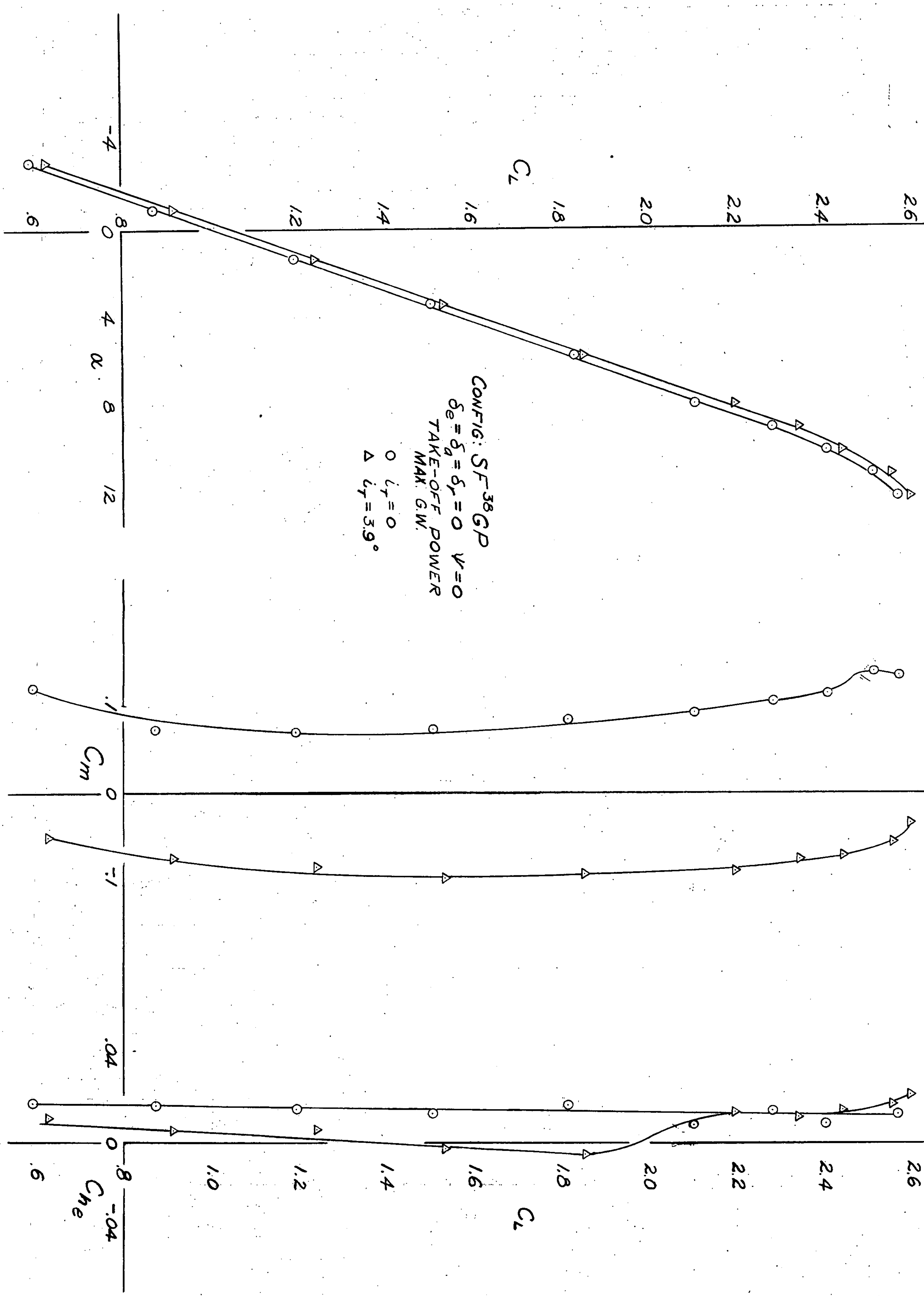

FIGURE 35.- CHARACTERISTICS IN PITCH OF THE TEST MODEL FOR TWO VALUES OF TAIL INCIDENCE. FLAPS 38°, GEAR EXTENDED, TAKE-OFF POWER, GROSS WEIGHT 26,500 LBS.

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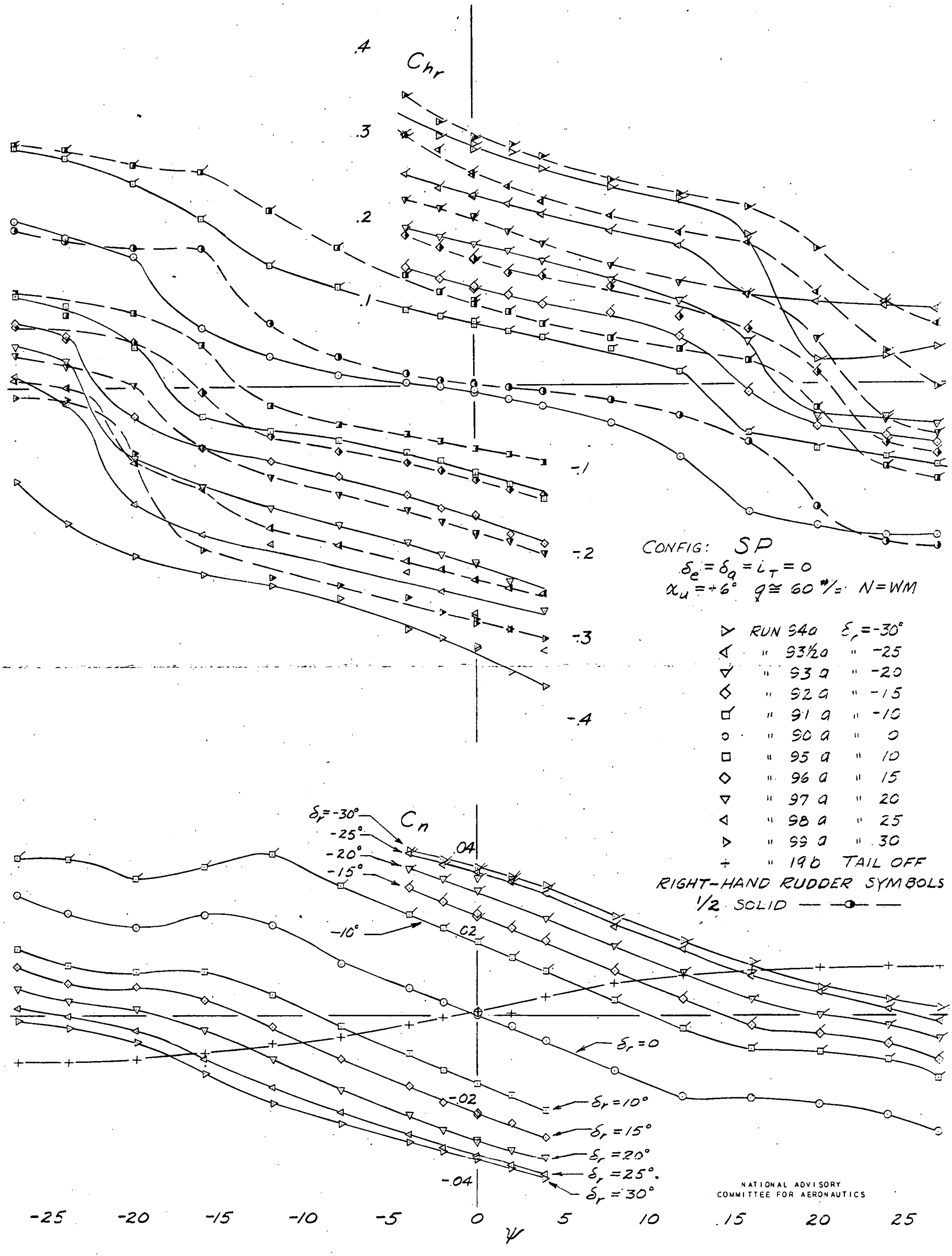

FIGURE 36.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS AND GEAR RETRACTED, PROPELLERS WINDMILLING.

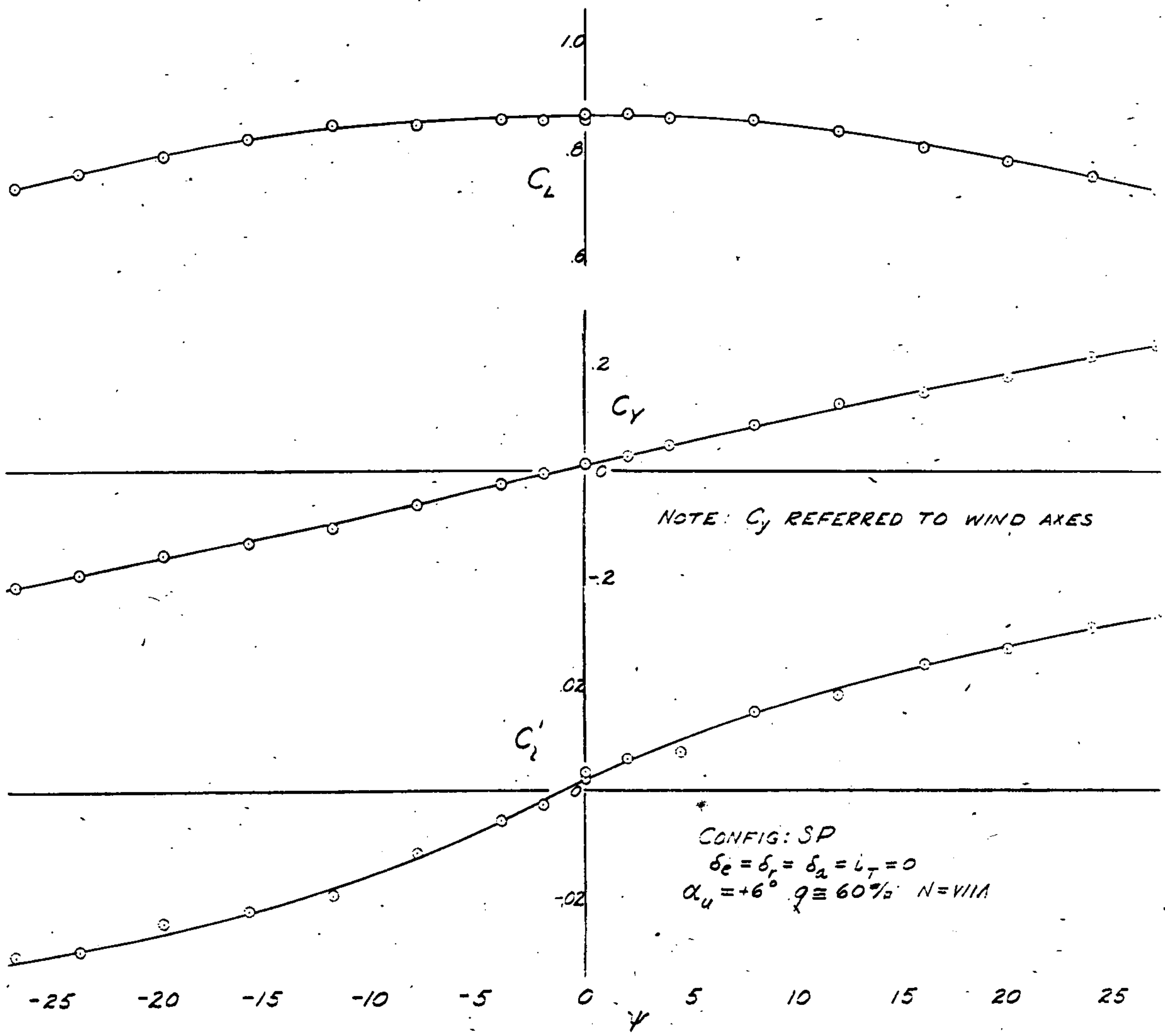

FIGURE 37.- VARIATION OF C_L, C_Y AND C_l' WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS AND GEAR RETRACTED. PROPELLERS WINDMILLING.

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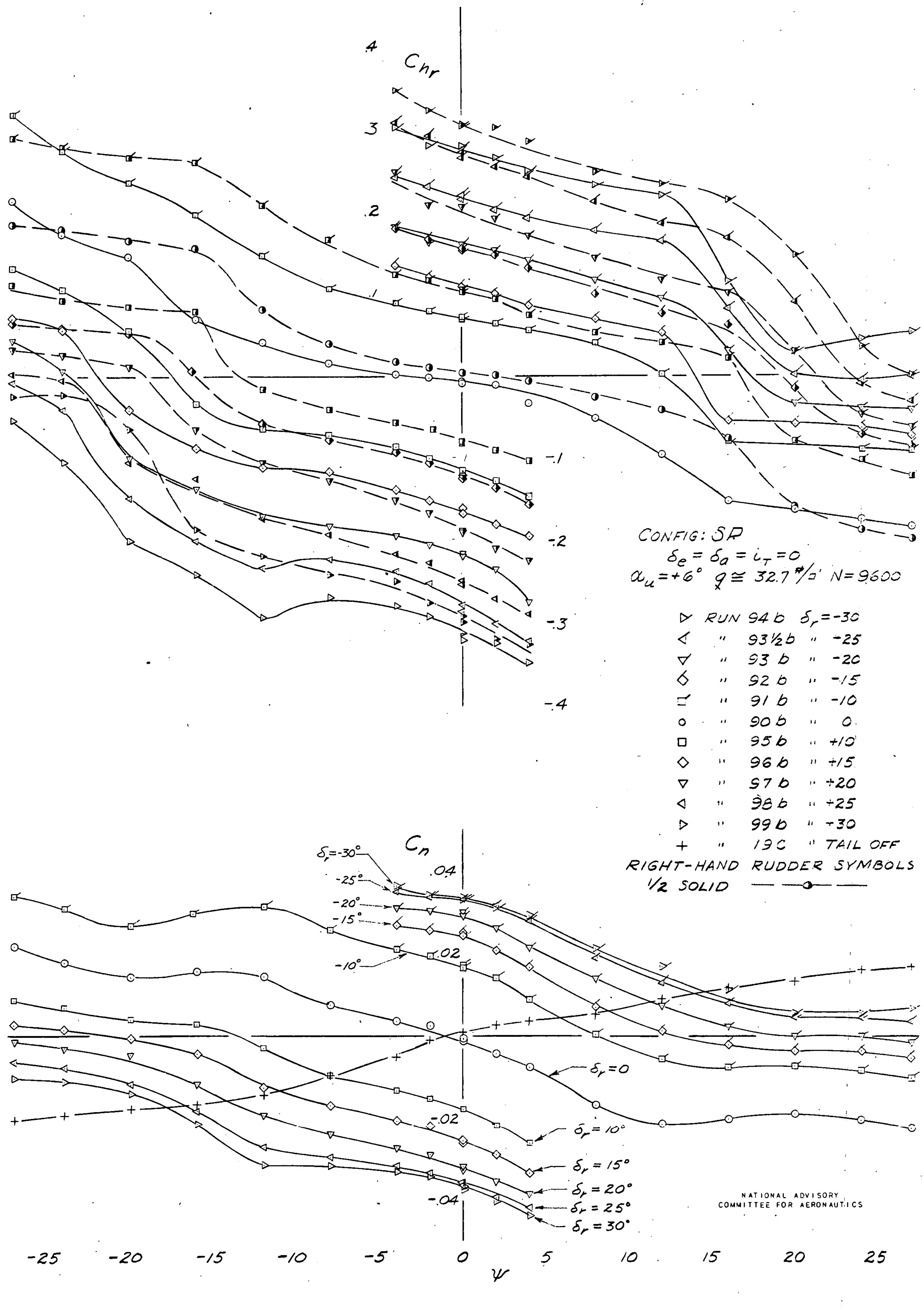

FIGURE 38.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS AND GEAR RETRACTED, RATED POWER, GROSS WEIGHT 26,500 LBS.

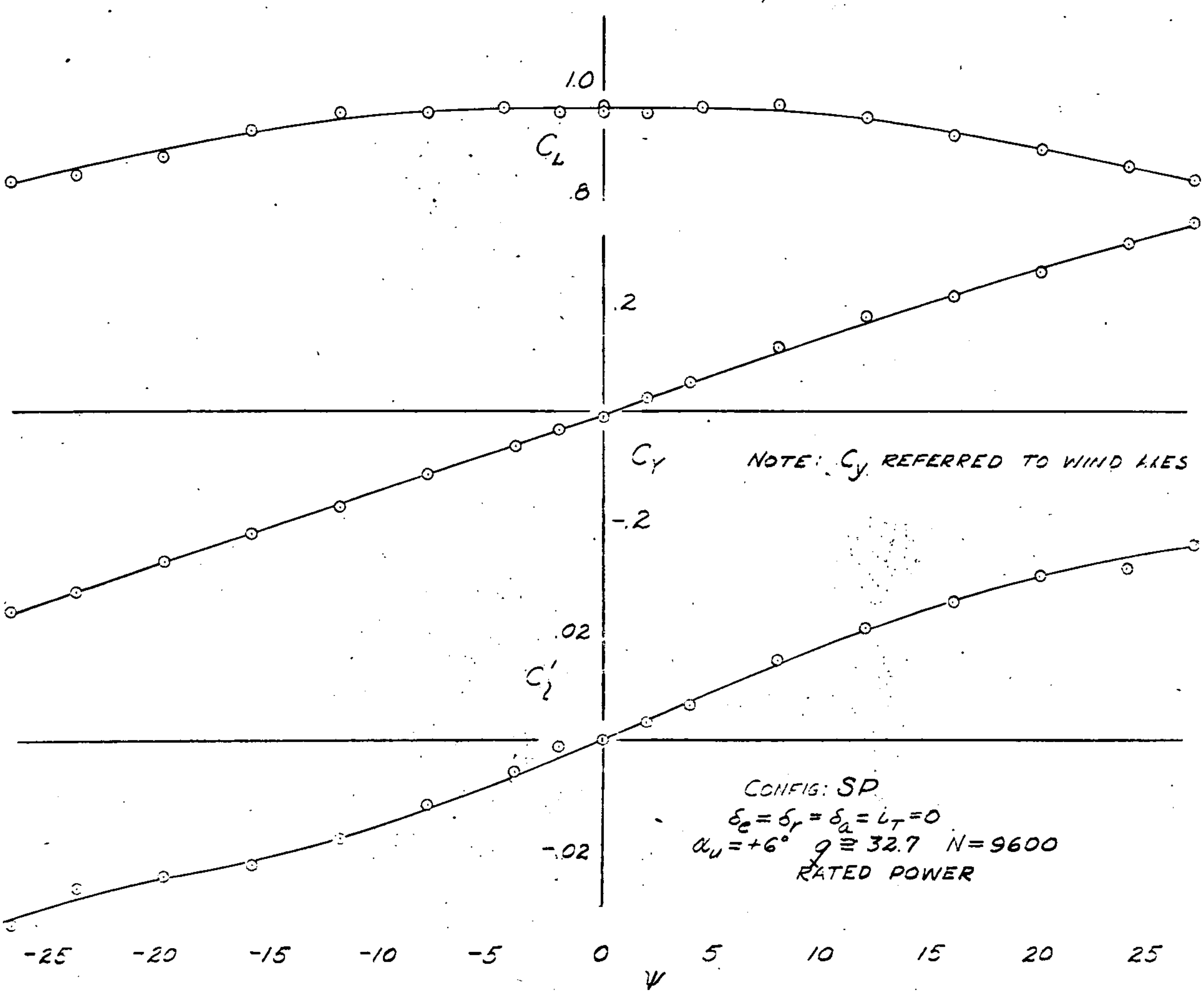

FIGURE 39.- VARIATION OF C_L, C_Y AND C_l' WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS AND GEAR RETRACTED, RATED POWER, GROSS WEIGHT 26,500 LBS.

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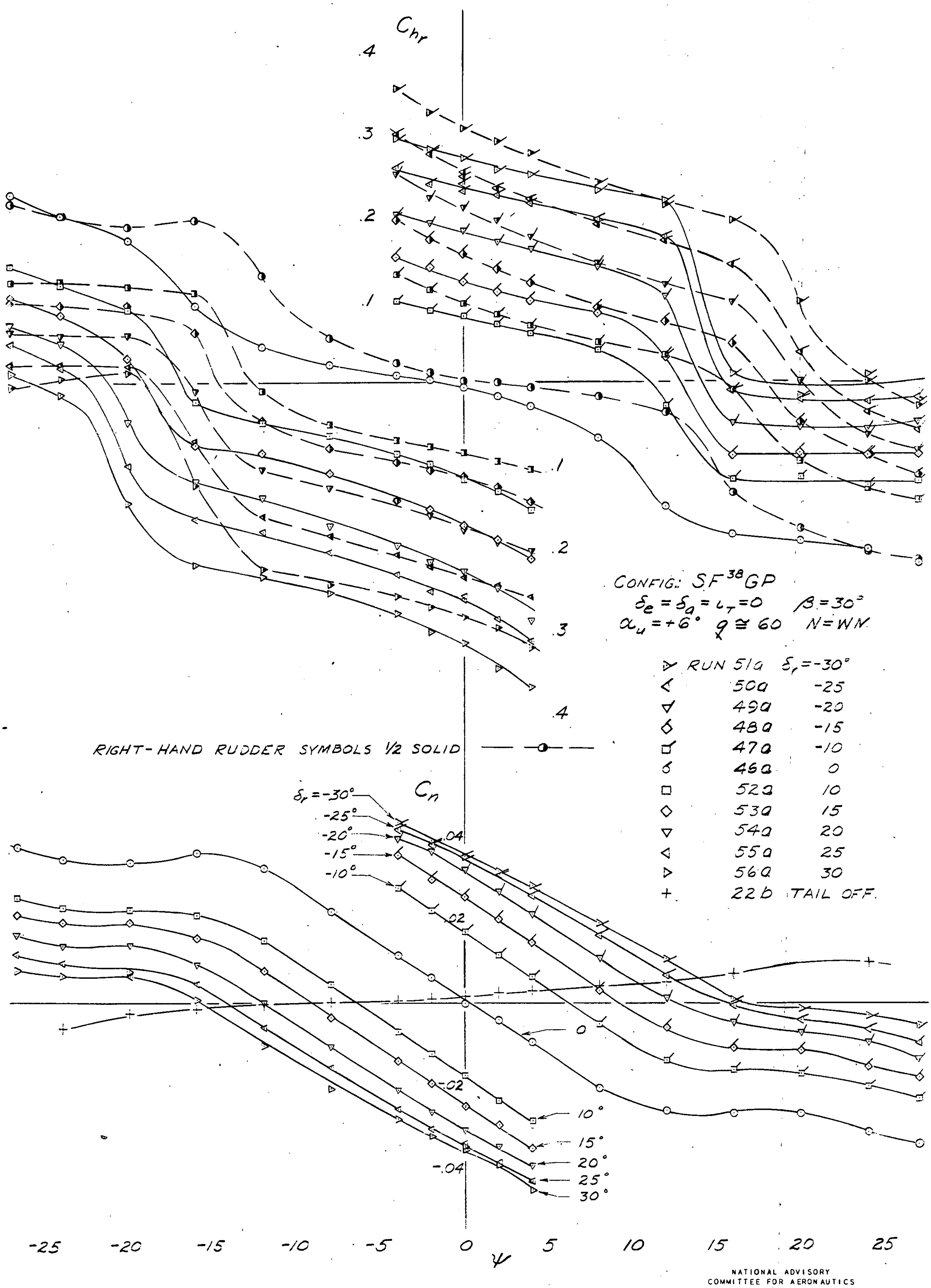

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FIGURE 40.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS 38°, GEAR EXTENDED, PROPELLERS WINDMILLING.

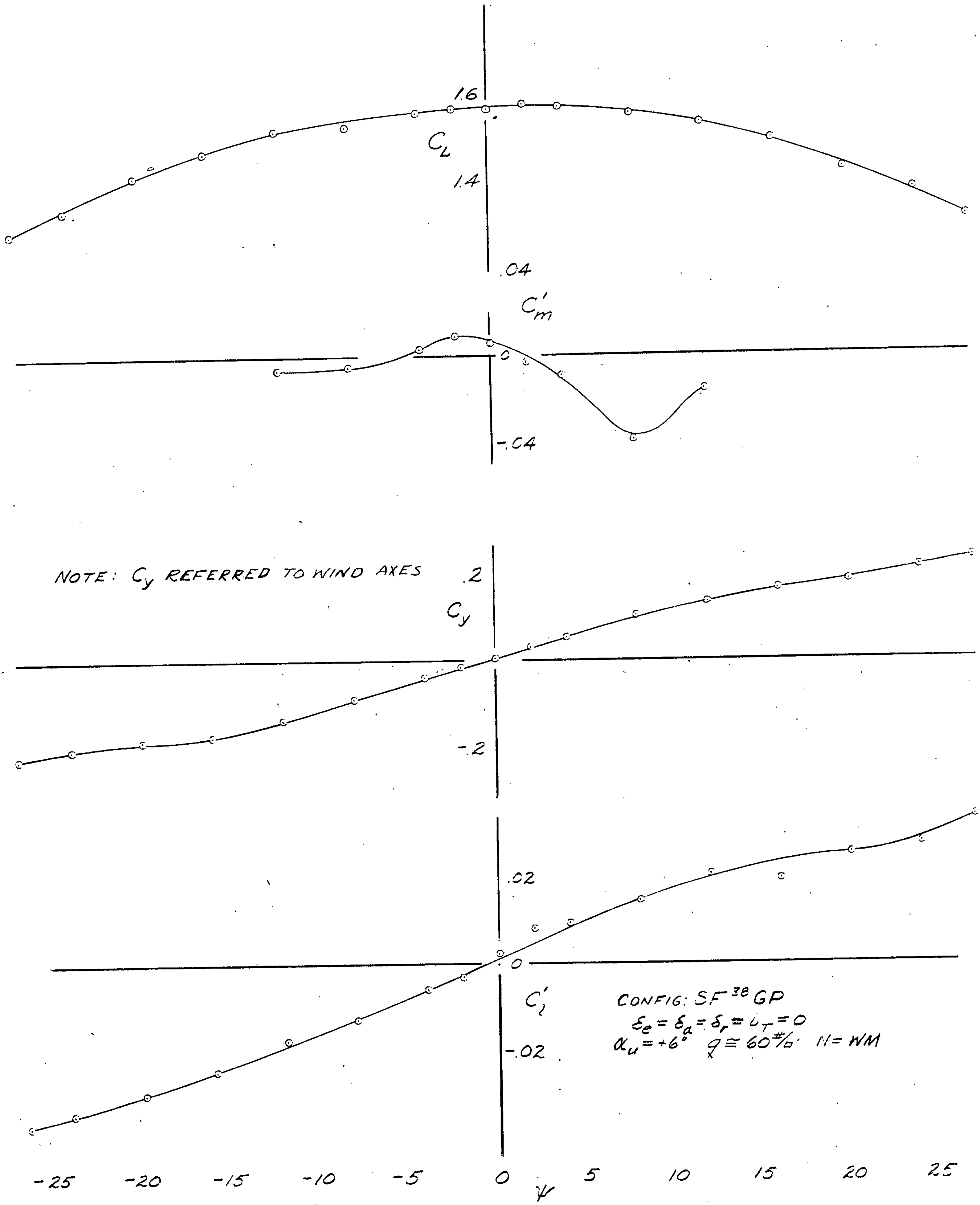

FIGURE 41.- VARIATION OF C_L, C_m', C_Y AND C_l' WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS 38°, GEAR EXTENDED, PROPELLERS WINDMILLING.

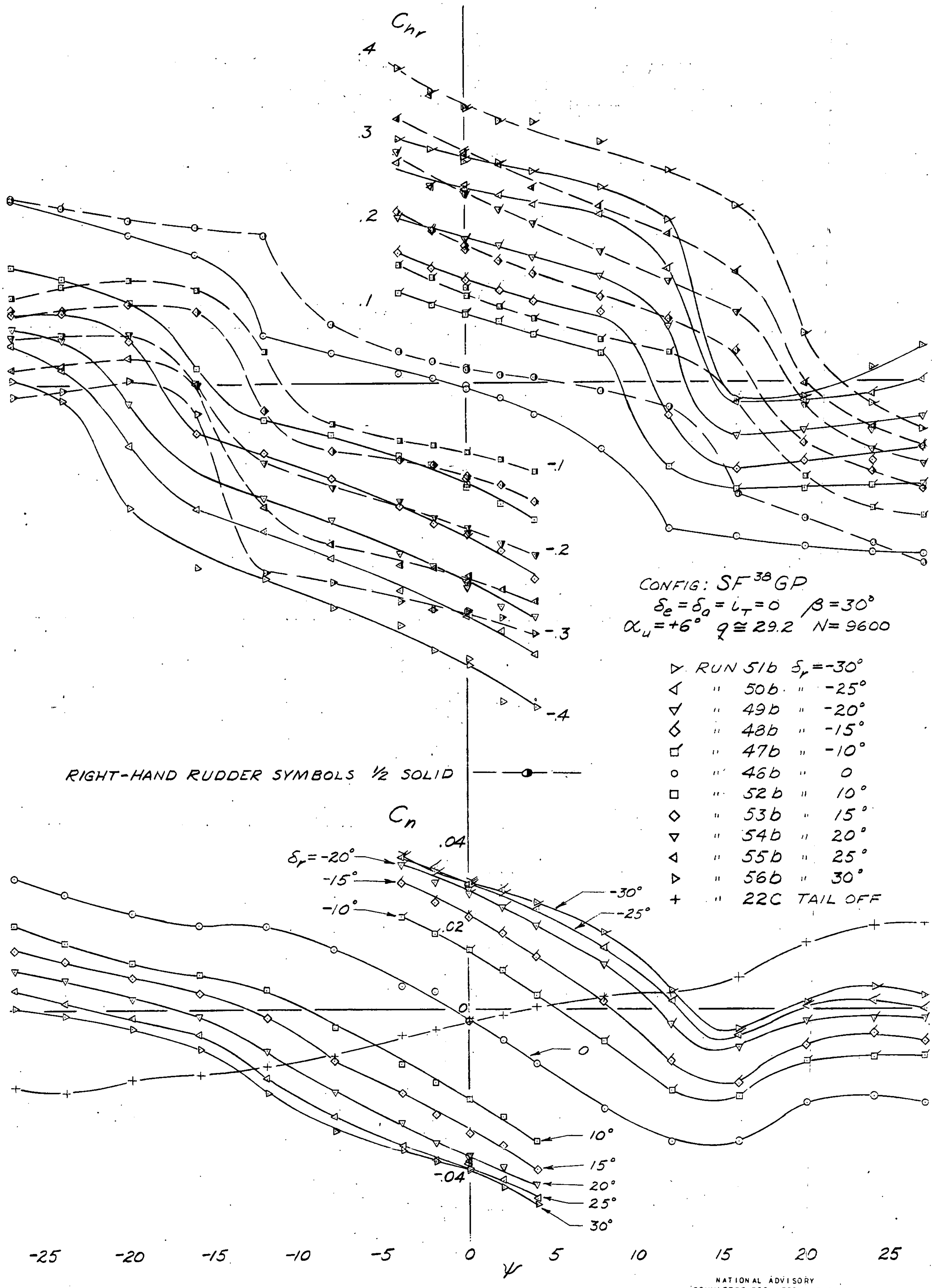

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FIGURE 42.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS 38°, GEAR EXTENDED, 50% RATED POWER, GROSS WEIGHT 26,500 LBS.

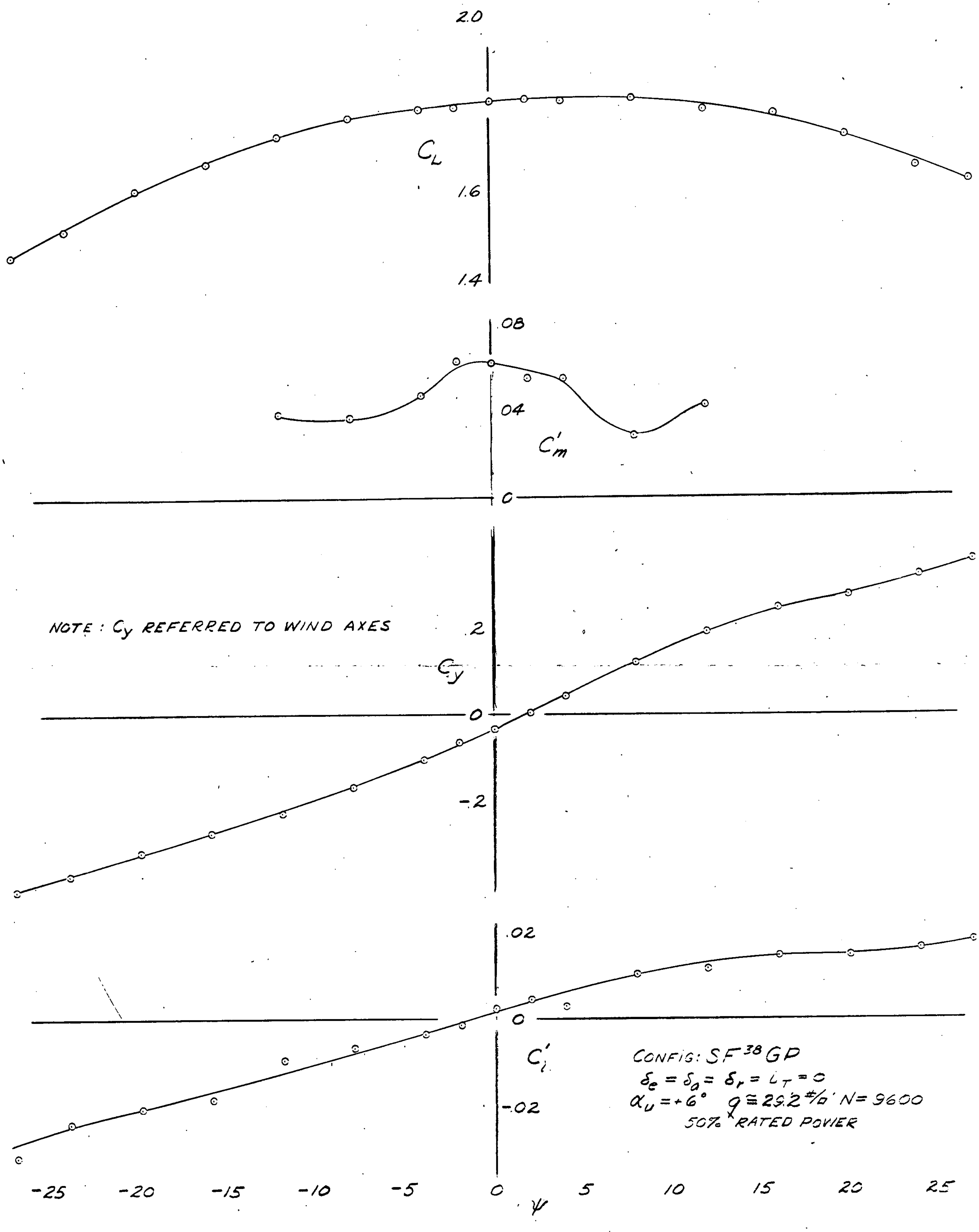

FIGURE 43.- VARIATION OF C_L, C_m', C_y AND C_l' WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS 38°, GEAR EXTENDED, 50% RATED POWER, GROSS WEIGHT 26,500 LBS.

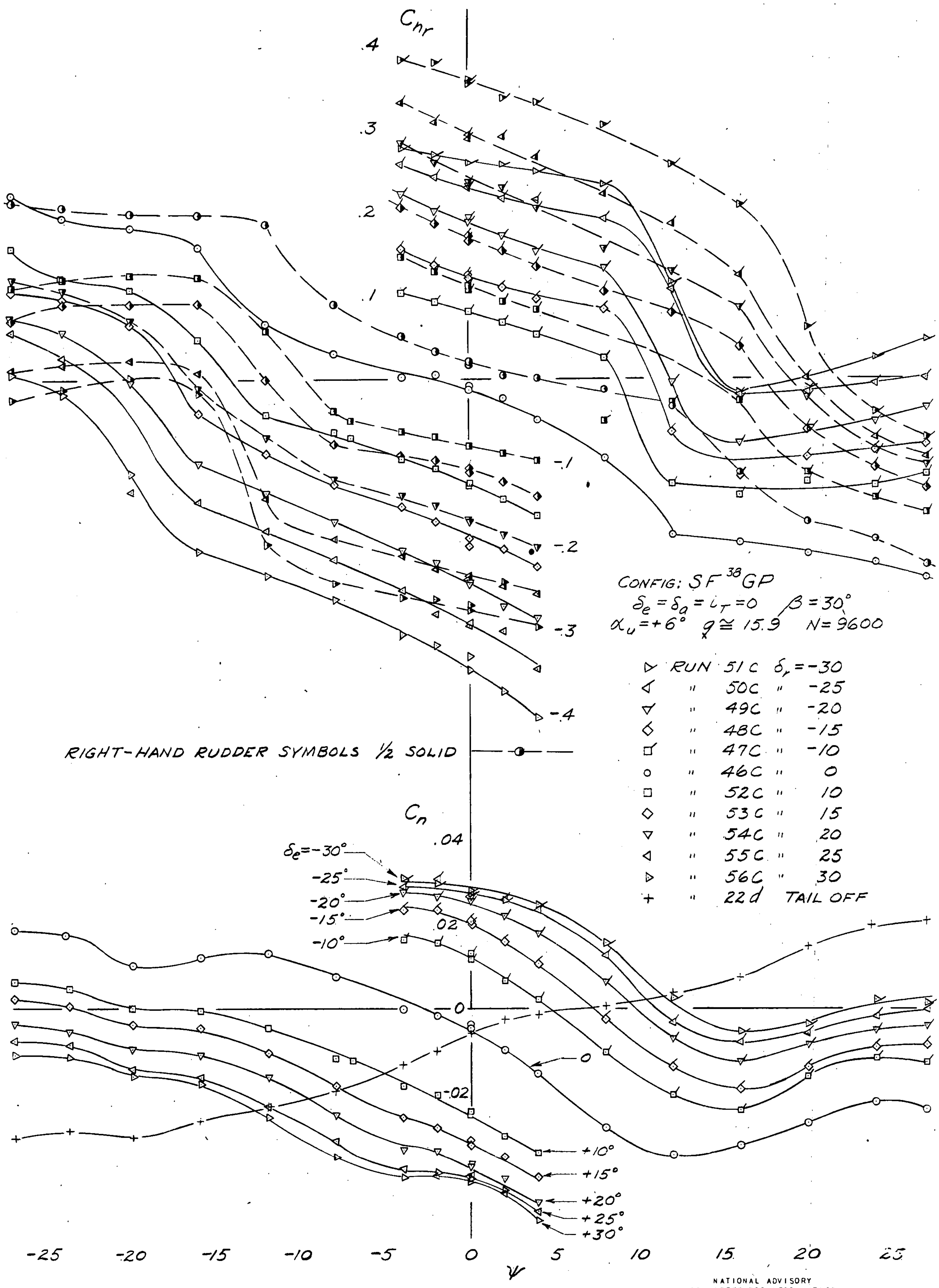

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FIGURE 44.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS 38°, GEAR EXTENDED, TAKE-OFF POWER, GROSS WEIGHT 26,500 LBS.

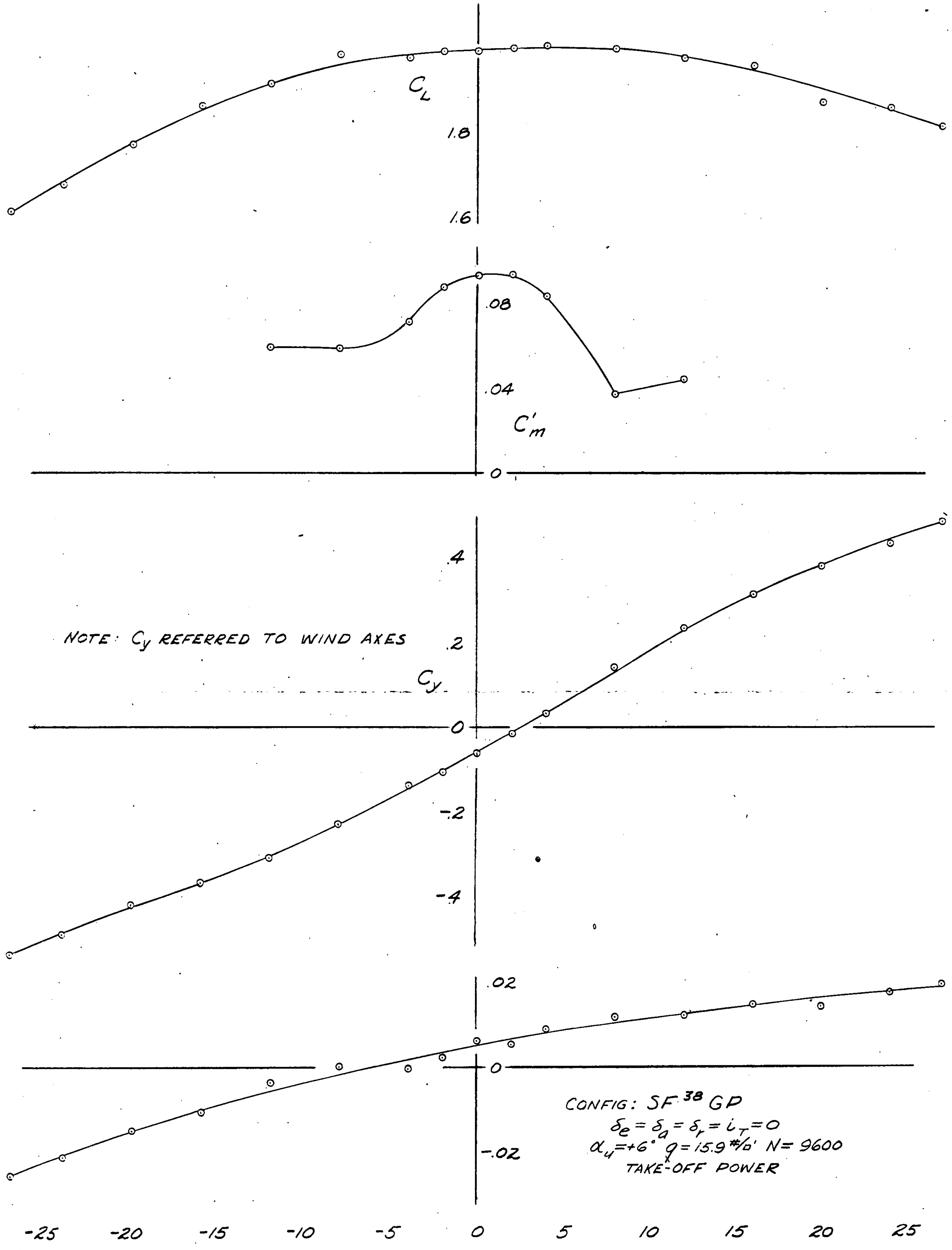

FIGURE 45.- VARIATION OF C_L, C'_m, C_y, AND C'_l WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS 38°, GEAR EXTENDED, TAKE-OFF POWER, GROSS WEIGHT 26,500 LBS.

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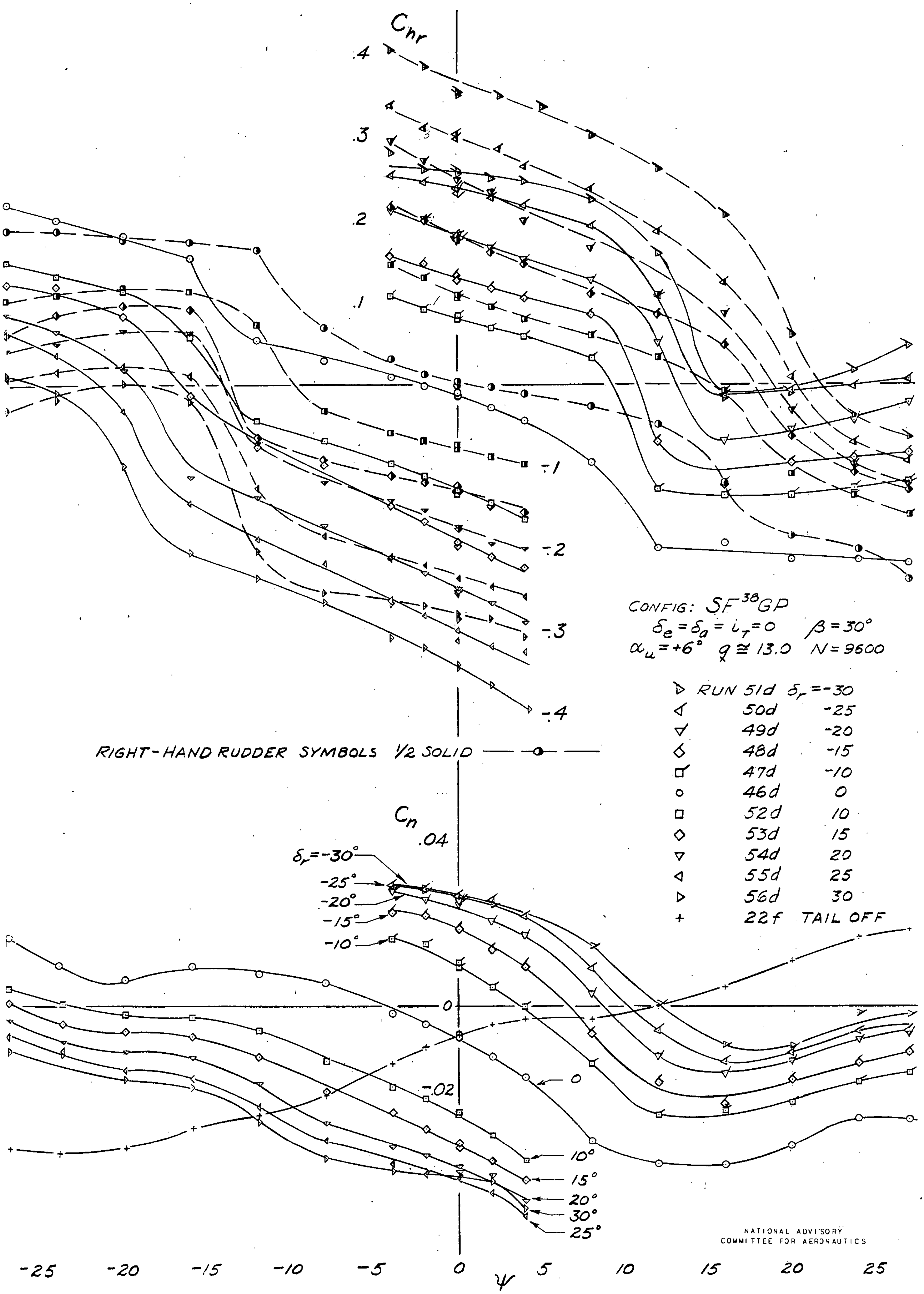

FIGURE 46.- VARIATION OF YAWING MOMENT AND RUDDER HINGE MOMENT WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS 38°, GEAR EXTENDED, TAKE-OFF POWER. GROSS WEIGHT 21,380 LBS.

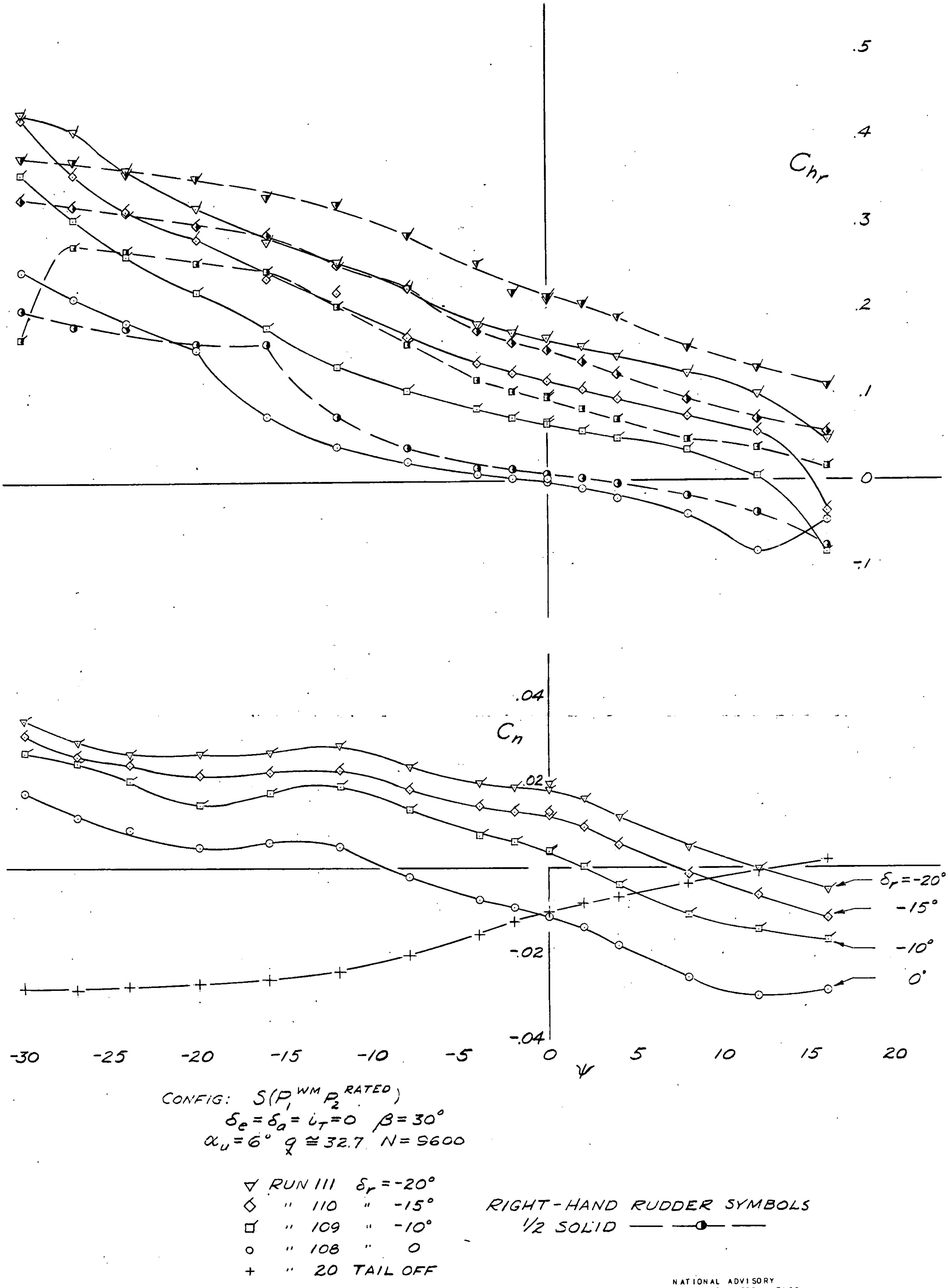

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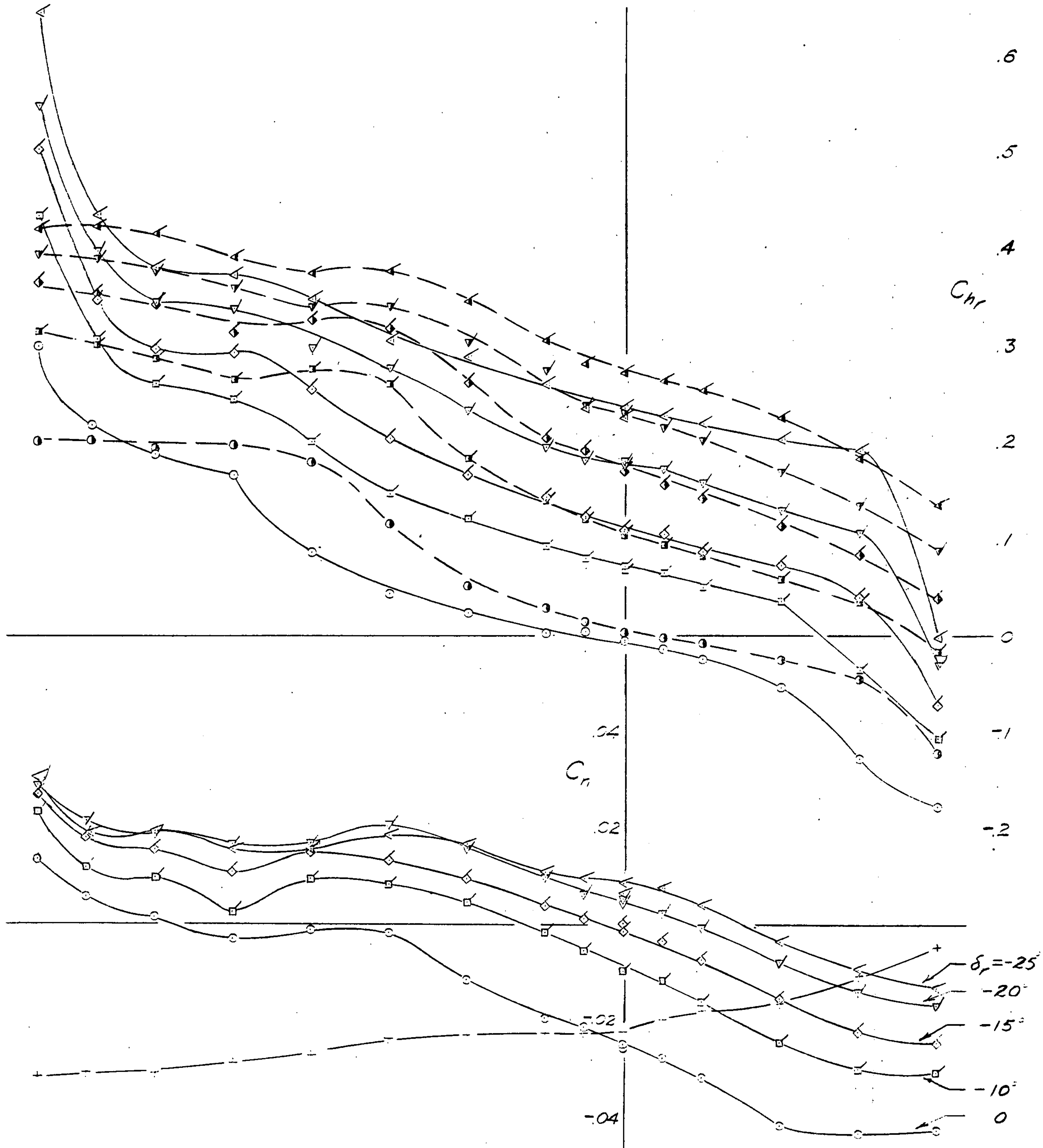
FIGURE 47.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS AND GEAR RETRACTED, LEFT-HAND MOTOR WINDMILLING, RIGHT-HAND MOTOR RATED POWER, GROSS WEIGHT 26,500 LBS.



CONFIG: $SF^{24}G(P_1^{WM} P_2^{T.O.P.\ MAX\ GW})$
$\delta_e = \delta_a = i_T = 0 \quad \beta = 30°$
$\alpha_u = 6° \quad q \cong 191 \quad N = 3600$

< RUN 80 a	$\delta_r = -25°$	
∇ 79 a	-20°	
◇ 78 a	-15°	RIGHT-HAND RUDDER SYMBOLS
⊏ 77 a	-10°	1/2 SOLID ——◐——
○ 76 a	0°	
+ 21 a	TAIL OFF	

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FIGURE 48.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS DEFLECTED 24°, GEAR EXTENDED, LEFT-HAND MOTOR WINDMILLING, RIGHT-HAND MOTOR TAKE-OFF POWER, GROSS WEIGHT 26,500 LBS.

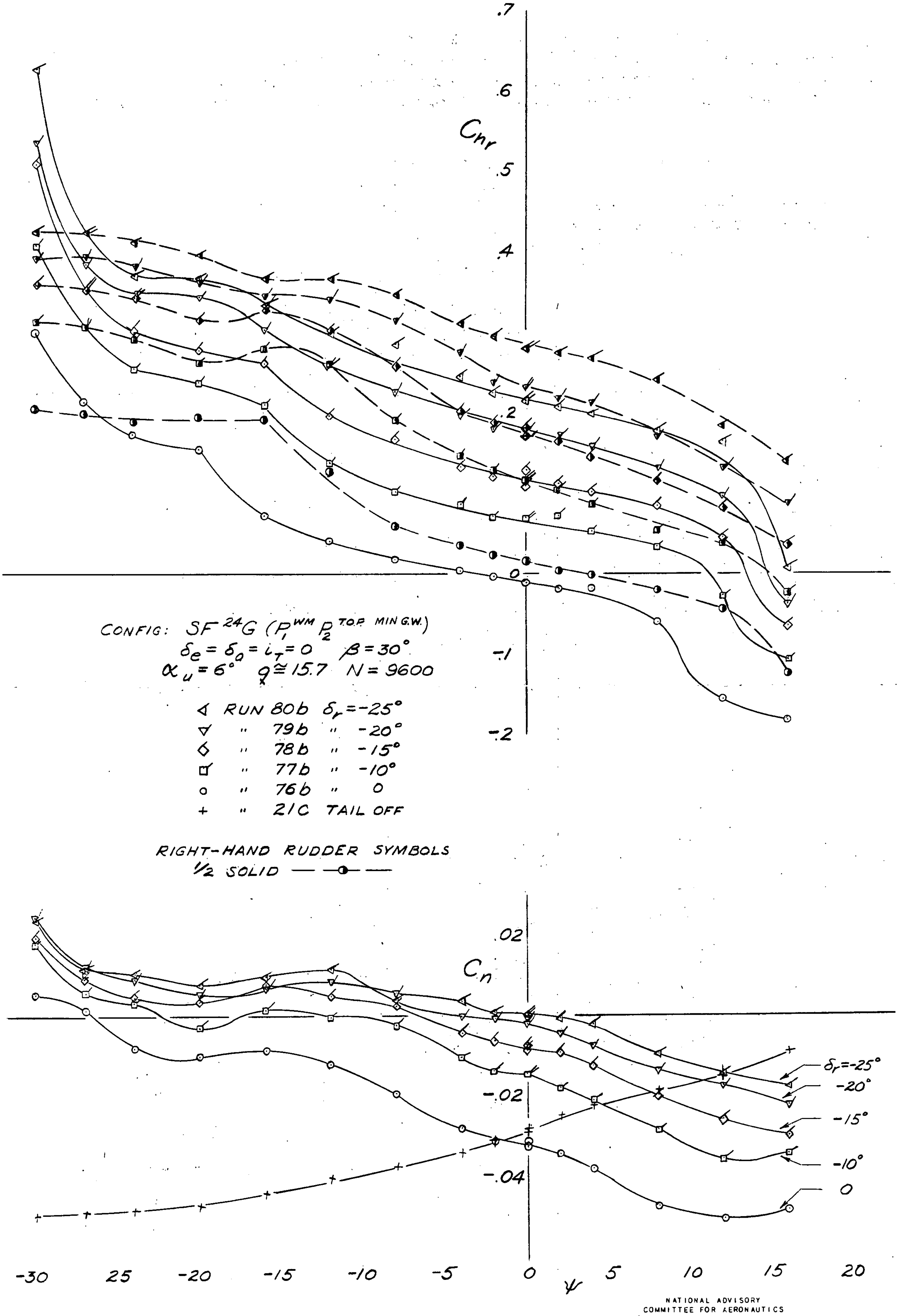

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FIGURE 49.- VARIATION OF YAWING MOMENT AND RUDDER HINGE-MOMENTS WITH ANGLE OF YAW FOR THE TEST MODEL. FLAPS DEFLECTED 24°, GEAR EXTENDED, LEFT-HAND MOTOR WINDMILLING, RIGHT-HAND MOTOR TAKE-OFF POWER, GROSS WEIGHT 21,380 LBS.

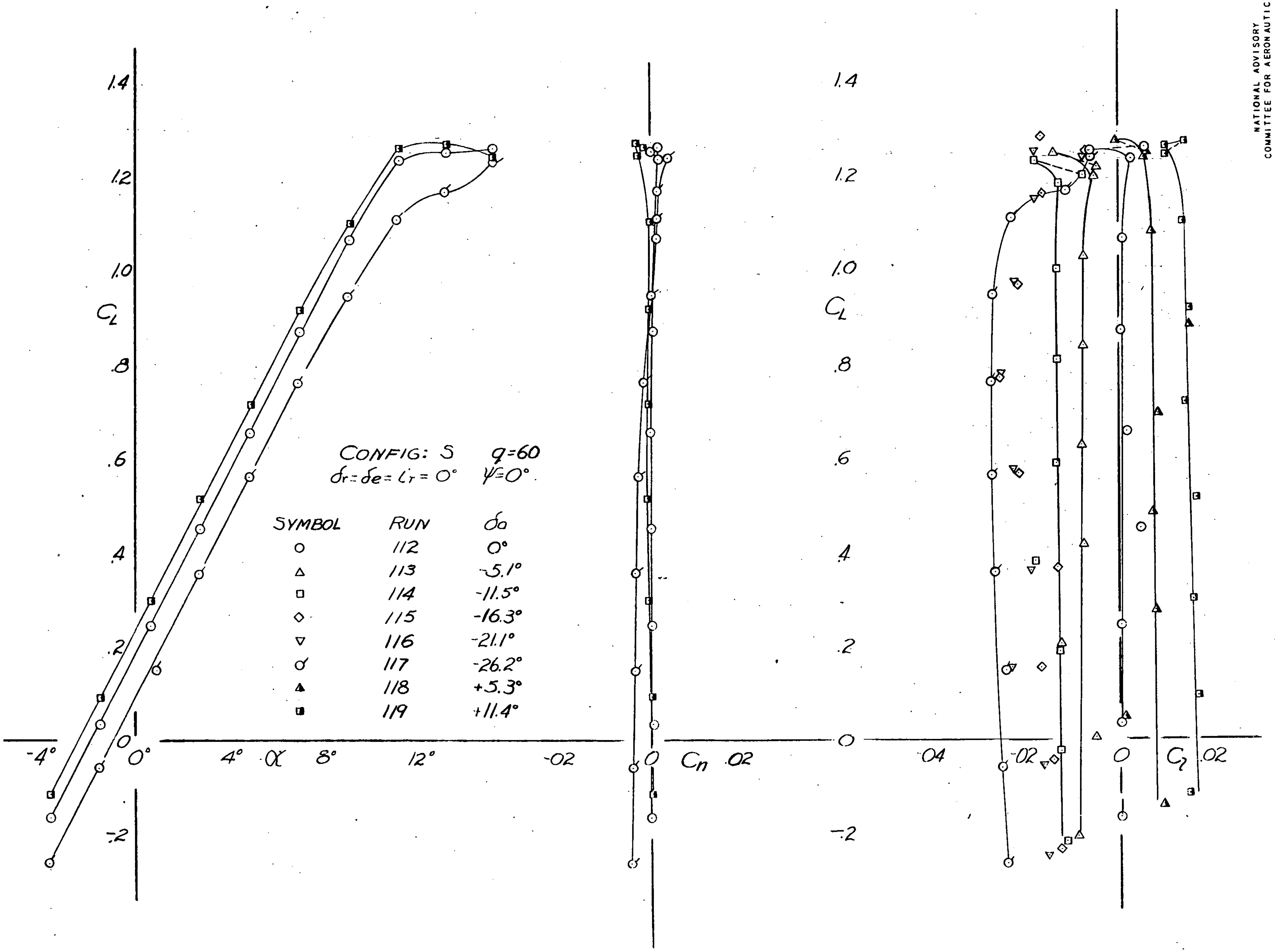

FIGURE 50.- CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH LEFT-HAND AILERON DEFLECTED. FLAPS AND GEAR RETRACTED, PROPELLERS REMOVED.

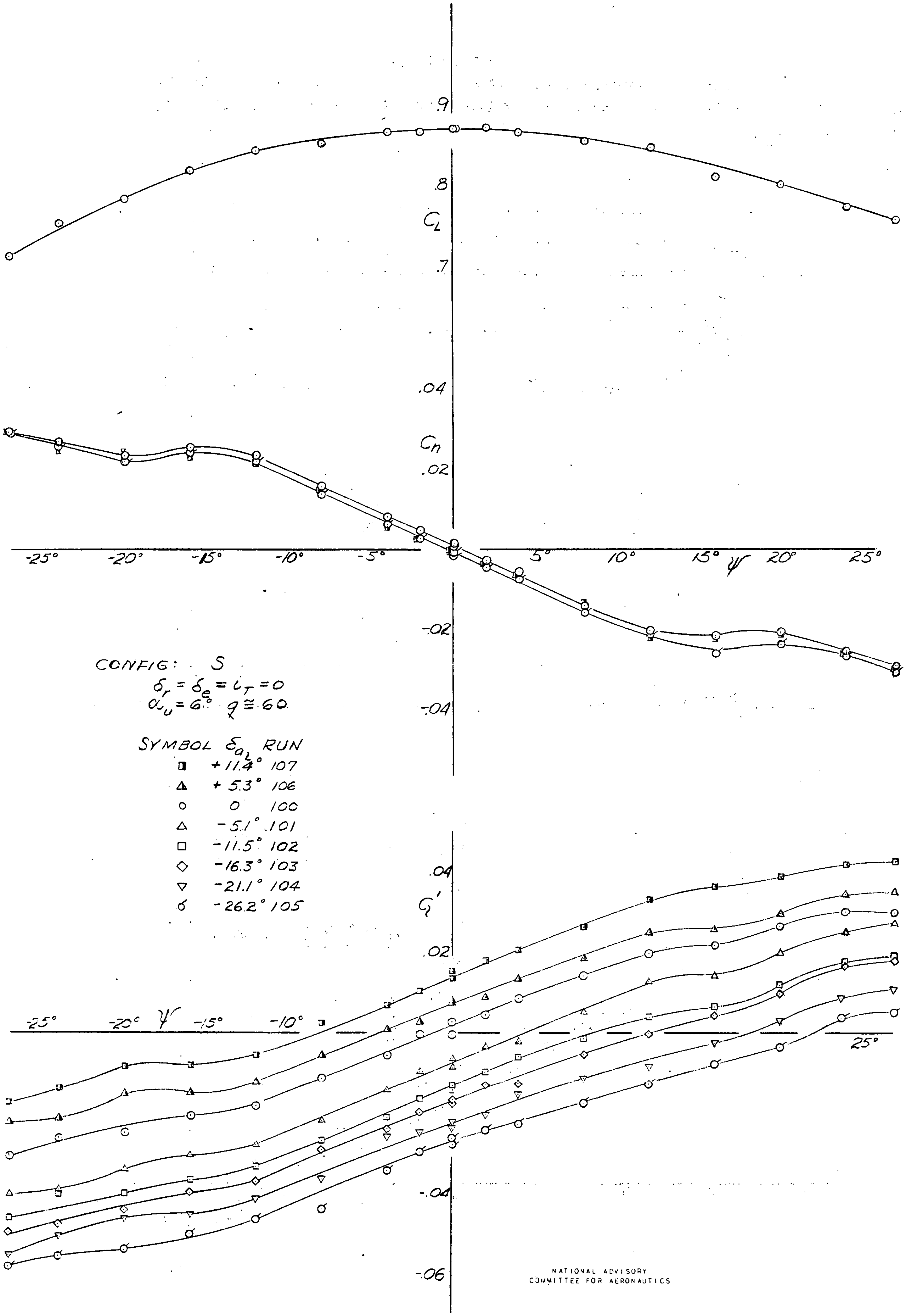

FIGURE 51.- CHARACTERISTICS IN YAW FOR THE TEST MODEL WITH THE LEFT-HAND AILERON DEFLECTED, FLAPS AND GEAR RETRACTED, PROPELLERS REMOVED.

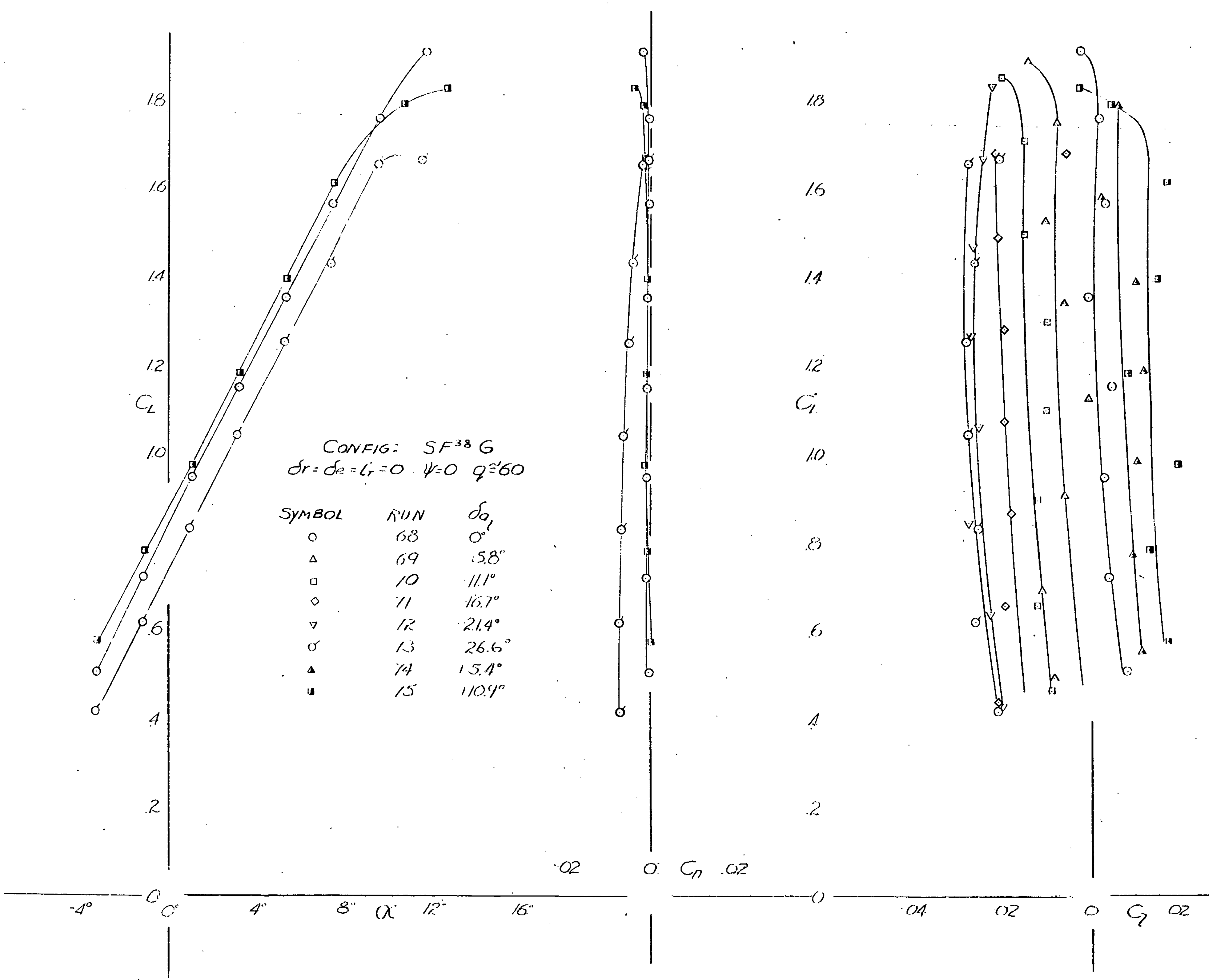

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FIGURE 52: CHARACTERISTICS IN PITCH OF THE TEST MODEL WITH LEFT-HAND AILERON DEFLECTED. FLAPS 38°, GEAR EXTENDED, PROPELLERS REMOVED.

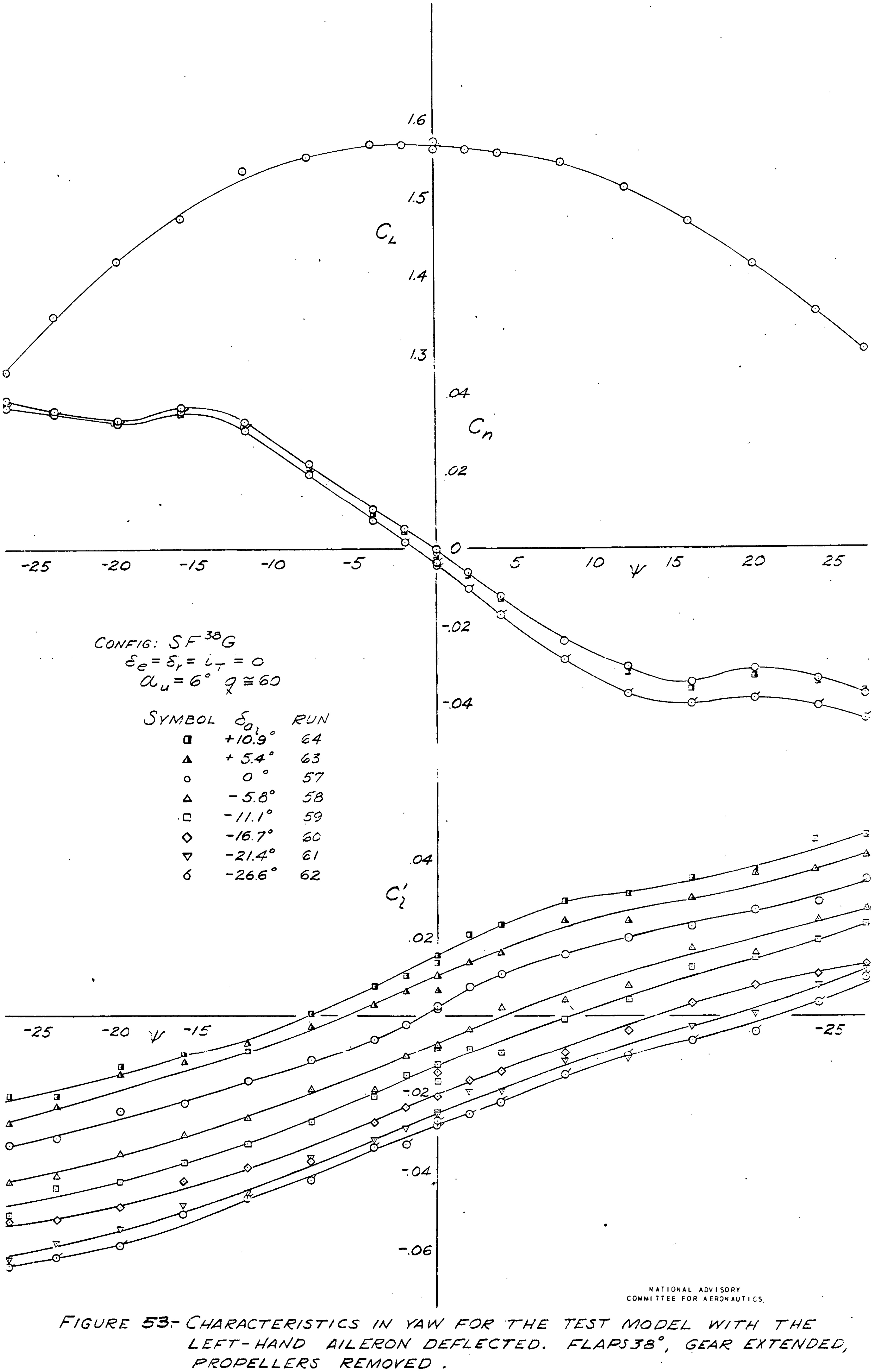

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FIGURE 53.- CHARACTERISTICS IN YAW FOR THE TEST MODEL WITH THE LEFT-HAND AILERON DEFLECTED. FLAPS 38°, GEAR EXTENDED, PROPELLERS REMOVED.