[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

October 1943 as
Advance Restricted Report 3J18

FREE-FLIGHT-TUNNEL INVESTIGATION OF THE EFFECT OF MODE OF PROPELLER ROTATION UPON THE LATERAL-STABILITY CHARACTERISTICS OF A TWIN-ENGINE AIRPLANE MODEL WITH SINGLE VERTICAL TAILS OF DIFFERENT SIZE

By Marvin Pitkin

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NACA WARTIME REPORTS are reprints of papers originally issued to provide rapid distribution of advance research results to an authorized group requiring them for the war effort. They were previously held under a security status but are now unclassified. Some of these reports were not technically edited. All have been reproduced without change in order to expedite general distribution.

3 1176 01354 2858

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

FREE-FLIGHT-TUNNEL INVESTIGATION OF THE EFFECT OF MODE OF PROPELLER ROTATION UPON THE LATERAL-STABILITY CHARACTERISTICS OF A TWIN-ENGINE AIRPLANE MODEL WITH SINGLE VERTICAL TAILS OF DIFFERENT SIZE

By Marvin Pitkin

SUMMARY

The effect of direction of propeller rotation upon the dynamic lateral-stability characteristics of a twin-engine airplane model equipped with single vertical tails of three different sizes has been investigated in the NACA free-flight tunnel. The effects of flap deflection and amount of power were also studied.

Little effect of power and of direction of propeller rotation upon lateral stability was observed for the condition of the model with flaps up. The principal effect of direction of propeller rotation for this condition was the trim change accompanying the mode of rotation in which both propellers turned right hand. With flaps deflected, however, power and mode of propeller rotation had a pronounced effect on lateral stability. The mode of propeller rotation in which both blades moved down in the center gave the most satisfactory dynamic lateral stability of the three modes of rotation investigated. The mode-of-rotation effects observed in these tests were correlated with force and air-flow-survey data from other sources.

The most satisfactory lateral-stability characteristics of the model in flight were encountered for the model with large vertical-tail areas.

INTRODUCTION

The direction of rotation of the propellers on twin-engine airplanes is becoming of greater importance because

of the increase in engine power and the accompanying effects on airplane stability. Recent tests (reference 1) have shown that, although the direction of propeller rotation has a pronounced effect on both static longitudinal and lateral stability, no single mode of rotation was found to give the best results for all conditions. In order to provide more data on the subject and to determine the effect of mode of propeller rotation on the actual flight behavior of an airplane model, tests have been conducted in the NACA free-flight tunnel on a 1/20-scale model of the twin-engine airplane in the medium bomber class represented in reference 1.

Three modes of propeller rotation were investigated as follows:

(1) Asymmetric propeller rotation, propeller blades on both engines turning right hand

(2) Outboard propeller rotation, propeller blades on both engines going up near the fuselage

(3) Inboard propeller rotation, propeller blades on both engines going down near the fuselage

In order to isolate the effect of mode of rotation for both the flaps-up and the flaps-down conditions, three sizes of vertical tail were employed, which made it possible to place the model in stability regions in which relatively small changes in stability could be more readily detected. The effect of mode of propeller rotation on the general flight characteristics of the model was determined with reference to the effects on lateral stability and control.

APPARATUS AND METHODS

Wind Tunnel

The tests were made in the NACA free-flight tunnel, a complete description of which will be found in reference 2. Figure 1 is a photograph of the test section of the tunnel showing a powered model being tested in flight.

In the flight tests, the unrestrained model flies freely in the tunnel under the remote control of a pilot. A second operator adjusts the airspeed, tunnel angle, and

power to the motor in the model to correspond to the desired flight conditions. After the lateral trim and the longitudinal trim of the model have been adjusted for the particular test conditions, the stability of the model in uncontrolled flight is observed and the effectiveness of the controls is determined. Motion-picture records of flights are taken by three cameras mounted at the top, side, and rear of the tunnel.

Model

A three-view drawing of the 1/20-scale model is presented in figure 2 and photographs of the model are shown in figure 3. A simple wire landing gear was installed on the model as shown in figure 2 to provide sufficient ground angle for take-off and to absorb shock in landings. Sketches of the three vertical tails used in the tests are shown in figure 4. The dimensional characteristics of the airplane as scaled-up from model values are given in the following table:

Wing:	
Area, square feet	675.90
Span, feet	72.61
Aspect ratio	7.80
Root chord, inches	161.13
Tip chord, inches	67.00
Mean aerodynamic chord, inches	120.09
Root section	NACA 23017
Tip section	NACA 4409-R
Percent chord line with zero sweepback	33
Sweepback at leading edge, degrees	4.2
Dihedral angle, degrees	2
Incidence, degrees	3
Geometric twist (washout), degrees	2.5
Taper ratio	2.4:1
Fuselage:	
Length, feet	54.5
Section	Circular
Frontal area, square feet	38.5
Horizontal tail:	
Total area, square feet	183.20
Span, feet	26.85
Aspect ratio	3.94
Dihedral angle, degrees	
For flaps-up tests	7.5
For flaps-down tests	.0

Stabilizer setting, degrees 1.50
Length from center line of elevator hinge to center of gravity of airplane, feet 28.90
Elevator balance area, square feet 10.63
Elevator area aft center line of hinge, square feet 53.00

Vertical tail 2
Total area, square feet 74.90
Span, feet 10.68
Aspect ratio 1.54
Length from center line of rudder hinge to center of gravity of airplane, feet 27.40
Fin area, square feet 35.66
Rudder area, square feet 39.24
Rudder-balance area, square feet 9.14
Rudder area aft hinge line, square feet 30.10
(Pertinent data for tail 1 and tail 3 are given in fig. 4.)

Aileron: (one of two)
Area aft of hinge line, square feet 20.91
Span, feet 11.41
Mean chord, inches 17.0

Flap:
Total flap area, square feet 80.3
Area aft of hinge line, square feet 65.8
Total span, feet 38.4
Type . . . . . .Slotted

The mass characteristics of the model represented a full-scale airplane possessing a wing loading of 66 pounds per square foot with the center of gravity located at 21 percent of the mean aerodynamic chord. The full-scale radii of gyration represented by the model loading are as follows:

Radius of gyration about longitudinal axis, k_X, feet 9.36
Radius of gyration about lateral axis, k_Y, feet. . 11.40
Radius of gyration about normal axis, k_Z, feet . . 14.35

Electromagnetic mechanisms were installed in the model to provide the abrupt deflections of the ailerons, rudder, and elevator necessary for controlling the model in flight. The aileron mechanism was adjusted to provide equal up-and-down movements varying from ±18° to ±20°. Rudder deflections varying from ±6° for the large tail to ±13° for the small tail were used in conjunction with the ailerons to

provide proper control coordination. For longitudinal control, abrupt elevator deflections of ±3° or ±4° were used.

The model was powered by a direct-current controllable-speed electric motor rated 1/8 horsepower at 15,000 rpm. The motor was located between the wing spars at the center line of the fuselage and was geared to each propeller at a ratio of 3:1.

Power Conditions

The torque characteristics of the model gearbox unit were determined by Prony brake tests and the thrust of the propellers was measured at dynamic pressures of 0, 1.9, and 4.1 pounds per square foot. These tests indicated that, in order to absorb full model power at maximum efficiency for the desired propeller speed of 5000 rpm, two different types of propeller would be required in the tests. Single-blade, statically balanced propellers having a blade angle of 40° at the 0.75 radius were required for the flaps-up tests. For the flaps-down tests, however, two-blade propellers having a blade angle of 30° at the 0.75 radius were necessary because of the reduced airspeed.

The thrust developed in the flight tests was determined from the difference between the flight-path angle with power on and the angle with propellers off at the same lift coefficient. The full-scale torque and thrust coefficients represented by the model are shown in figure 5. Based on assumed full-scale values of propeller efficiency, also shown in figure 5, the model power conditions simulated 3000 full-scale brake horsepower for the flaps-up condition and 2370 full-scale brake horsepower for the flaps-down condition for two engines at sea level.

SYMBOLS

C_L lift coefficient (lift/qS)

T_c thrust coefficient for one engine (effective thrust/$\rho V^2 D^2$)

Q_c torque coefficient for one engine (torque/$\rho V^2 D^3$)

D propeller diameter

ρ density of air, slugs per cubic foot

V free-stream velocity

V_1 local velocity

q free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

q_1 local dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V_1{}^2\right)$

q_1/q ratio of local dynamic pressure at tail to free-stream dynamic pressure

k_X radius of gyration about X-axis

k_Y radius of gyration about Y-axis

k_Z radius of gyration about Z-axis

C_{n_β} rate of change of yawing-moment coefficient with angle of sideslip (directional-stability factor), per radian

S wing area, square feet

TESTS

The lateral stability and control characteristics of the model were investigated at windmilling and high-power conditions for three modes of propeller rotation. All tests were made with each of three vertical tails and with the partial-span slotted flaps retracted and fully deflected. The flight tests were run at a lift coefficient of 0.57 corresponding to a tunnel velocity of 47 miles per hour for the flaps-retracted condition and at a lift coefficient of 1.0 corresponding to a tunnel velocity of 36 miles per hour for the flaps-deflected condition.

CRITERIONS

Four criterions were utilized to evaluate the results obtained in the free-flight tests. These results were based

on visual observations of the pilot and observer, and on motion-picture records.

1. Steadiness.- A "steadiness" rating that was concerned chiefly with the over-all smoothness of motion of the model was assigned each condition. Flights that had smooth, gentle, and infrequent deviations from a given course, controls fixed, were given a high steadiness rating; whereas violently erratic flights were given a low rating. Visual observation of extended flights was the only method employed to obtain this rating.

2. Spiral stability.- The spiral-stability ratings of the model were determined by carefully trimming the model laterally and noting the tendency to diverge in either direction following a slight change in bank, caused by gusts or control movement. A definite tendency to diverge was taken as an indication of spiral instability.

3. Adverse yawing.- The adverse-yawing rating is a function of the aileron yawing-moment characteristics and the static directional-stability factor C_{n_β}. Inasmuch as the aileron-control characteristics were held constant throughout the tests, the adverse yaw served as a measure of the static directional-stability characteristics of the model. Adverse-yawing ratings were obtained by pilot observations and by motion-picture records of the direction and amplitude of yawing produced when only the ailerons were used to maintain heading.

4. Oscillatory directional stability.- Ratings of the oscillatory directional-stability characteristics of the model with controls fixed were obtained by visual observation and from motion-picture records of the damping of yawing oscillations induced by abrupt control deflections. Conditions in which oscillations damped out quickly were accorded high oscillatory-stability ratings.

RESULTS AND DISCUSSION

The lateral-stability and control flight ratings are given in table I for all test conditions. The results for both the flaps-up and the flaps-down condition are given for lift coefficients corresponding to approximately 150 percent of the minimum speed for the particular condition. The thrust

coefficient for each engine was 0.045 for flaps up and 0.075 for flaps down. Although this difference in thrust coefficient probably influenced the comparison of the two flap conditions, it is believed that the principal differences in stability noted were due to flap position.

Effect of Vertical-Tail Area

The effect of decreasing fin area upon the oscillatory directional stability (that is, damping of the yawing oscillations) followed the adverse trends normally expected and is illustrated in figure 6. The typical increase in the period of the lateral oscillations with decrease in tail area is clearly evident.

In general, increasing the vertical-tail area decreased the spiral stability, as was expected. This reduction of stability had no adverse effect upon the flight behavior of the model. In fact, increasing the vertical-tail area led to a marked increase in the steadiness of the model. Even though the model possessed a slight degree of spiral instability in certain cases, flights made with the larger tails 1 and 2 produced the "grooved" flights desired by bomber pilots.

The results plotted in figure 7 show the effect of reducing the fin area upon the adverse yawing oscillations caused by aileron application. The customary increase of adverse yaw with decrease in fin area is clearly brought out by these data. These results are of general interest because they illustrate that the appearance of instability may under certain conditions be brought about by the influence of controls.

The results of the vertical-tail-area tests followed expected trends and thus indicated that variation of vertical-tail area could be utilized to emphasize the effects of mode of propeller rotation.

Effect of Power

The flight tests showed essentially no effect of power upon the lateral-stability characteristics of the model for the flaps-up condition. (See table I.) For the flaps-down condition, however, power application resulted in an increase in adverse yawing, an increase in spiral stability, and a

noticeable reduction of oscillatory stability for all modes of propeller rotation. A marked reduction in the directional-stability factor C_{n_β} was thus indicated. A considerable reduction in steadiness accompanied these changes and sizable yawing oscillations were encountered with aileron application for model conditions that, with flaps retracted, had possessed excellent flight characteristics. In general, for power-on conditions, the lateral stability was considerably less with flaps down than with flaps up.

Figure 8 illustrates the adverse effect of power application for the flaps-down condition upon the damping of the lateral oscillations of the model with controls fixed even for high initial values of C_{n_β} (with vertical tail 1). The adverse effect of power for the flaps-down condition is also indicated in figures 9 and 10 in which are presented comparisons of values obtained from motion-picture records of the power-on adverse-yawing curves with the corresponding adverse-yawing curves for windmilling conditions.

The destabilizing effect of power application upon the directional-stability characteristics for flaps-down flights may be chiefly ascribed to wing-nacelle stability characteristics. The data contained in reference 1 show that the unstable moment of the wings and nacelles for flaps-down conditions was markedly increased by power application for all modes of propeller rotation.

Effect of Mode of Rotation

Flaps-up.- The flight tests showed little effect of direction of propeller rotation when the flaps were up. A study of table I reveals that the main effects of direction of propeller rotation were the out-of-trim changes associated with the asymmetric mode (both blades turning right hand). Although neither aileron nor rudder adjustment from windmilling conditions was required for powered flight for the symmetric modes, about 6° right aileron and 4° right rudder were required to trim the model when the asymmetric mode was employed.

Although the stability changes with mode of rotation were small, a distinction between the relative merits of the various modes of rotation could be made when the smallest

vertical tail (tail 3) was employed. Flights made with inboard rotation (blades coming down near fuselage) showed the adverse yawing characteristics and the long-period oscillations associated with low values of C_{n_β} and indicated that this mode of rotation had the most detrimental effect on lateral stability of the three modes investigated. It should be observed, however, that this destabilizing effect of this mode, although distinquishable, was not large and merely caused a change in the oscillatory flight ratings from C (poor) to D (unsatisfactory).

Flaps-down.- As was the case for the flaps-up condition, the asymmetric mode of rotation was the only mode observed to cause considerable out-of-trim changes with power application when the flaps were lowered. The effect of mode of rotation upon lateral stability, however, was more clearly discernible for the flaps-down tests and was of much larger magnitude.

The inboard mode of rotation, which had induced the least oscillatory directional stability for flaps-up flights, gave the most oscillatory directional stability of the three modes of rotation when flaps were lowered. Although this effect was largest for flights with tail 3, for which the power-off stability was least, it was also noticeable for flights in which other tails were used.

Outboard propeller rotation (blades coming up near fuselage) was responsible for the largest detrimental change in oscillatory stability with power observed in the flight tests. Upon application of power the oscillatory-stability rating with tail 3 was changed from rating B (fair) to rating D (unsatisfactory). Long-period oscillations further indicative of low directional-stability factor C_{n_β} were also observed in flights for this condition.

The asymmetric mode, although not responsible for as large a change in stability as outboard rotation, gave less directional stability than inboard rotation and led to unsatisfactory lateral behavior for flights with tail 3. During these flights the model performed a yawing oscillation of constant amplitude, roughly between 0° and 10°, flew yawed at two trim points, and eventually diverged in yaw to the extent of completely reversing heading. Motion-picture records of the roll and yaw characteristics during a flight at this condition are presented in figure 11. This figure

indicates that, because of low inherent directional stability, the adverse yawing moment of the ailerons was able to yaw the model past the point at which it became statically directionally unstable.

A possible explanation of the effects of propeller rotation upon directional-stability characteristics has been devised for both flap conditions based on the air-flow patterns in the tail plane. Stüper has shown in reference 3 that the slipstream of a tractor propeller is split by the wing and is displaced laterally in the direction of its tangential velocity and reunites in a distorted pattern after leaving the trailing edge of the wing. This phenomena was verified by Sweberg in reference 4, in which are presented power-on air-flow surveys in the tail region of a twin-engine airplane equipped with left-hand propellers. The results of reference 4 show that the slipstream pattern behind a propeller and wing is practically independent of angle of attack or amount of power but is primarily dependent upon flap configuration for its shape. For flaps-up conditions this slipstream pattern eventually assumes a roughly elliptic shape after passing over the wing and the velocity regions in the tail plane are symmetrically distributed behind the projected propeller plane. Consequently, little effect of direction of rotation upon the tail surfaces is indicated. Deflection of the flaps, however, displaces the slipstream jet downward and distorts the dynamic pressure distribution into a kidney-like shape at the tail plane with a concentration of high velocities on the down-going side of the propellers.

In effect then, for inboard rotation, the slipstream velocities converge on the tail surfaces when flaps are lowered, whereas for outboard rotation they diverge from the tail. These data, when correlated with force data from reference 1, may be used to explain the results of the present tests.

The data in reference 1 show that with flaps retracted, the application of power or the mode of propeller rotation had little effect upon the stability characteristics of the wing, nacelles, and fuselage. The air-flow data of reference 4 indicate little effect of mode of rotation upon air-flow patterns at the tail. Relatively little effect of mode of rotation upon the lateral-stability characteristics of a twin-engine airplane in the flaps-retracted condition should be expected. This premise was confirmed by the present tests.

The force data of reference 1 show that for the flaps-down condition, however, power causes a large decrease in the directional-stability factor C_{n_β} for all modes of rotation for the wing and nacelles. Any effect of mode of rotation upon the directional stability of the airplane would therefore be a result of power effects on the fuselage and on the vertical tail. The effect of mode of rotation upon the directional stability due to the fuselage is not clearly understood at present. Incomplete data indicate that fuselage effects due to mode of propeller rotation are small and similar in nature to the far larger effects of the vertical tail surfaces. It is therefore believed that a satisfactory indication of the effect of mode of propeller rotation can be obtained by a study of its effects upon the vertical tail surfaces.

The slipstream patterns previously discussed indicate that, because of the inboard shift of the high-velocity regions of the stipstream, inboard rotation will cause an increase in the directional-stability factor C_{n_β} due to the tail for small through moderately large angles of yaw. The value of C_{n_β} for this condition should reach a maximum at some moderate angle of yaw, at which point the vertical tail is partly immersed in the direct slipstream jet. For outboard propeller rotation, the vertical tail will not enter the slipstream jet until a much larger angle of yaw is reached because of the initial outboard displacement of the slipstream with this propeller mode. The effect of the asymmetric mode (propellers turning right hand) upon directional stability would be dependent upon direction of yaw and would lead to peak values of C_{n_β} at moderate positive and at large negative angles of yaw.

The reasoning in the preceding paragraphs appears substantiated by existent force data. Figure 12 presents force data obtained from reference 1 and from unpublished tests made in the LMAL 7- by 10-foot tunnel for the flaps-down condition for two twin-engine models tested with three modes of propeller rotation. The lateral shift of the slipstream is plainly distinguishable from these data and the variation of C_{n_β} with propeller rotation is as previously discussed. These force data confirm the previous conclusions drawn herein from the tests and from hypothesis as to the advantageous nature of inboard propeller rotation for normal angles of yaw. The effect of the asymmetric mode is also clearly defined and is similar to the effect produced by inboard

propeller rotation for positive yaw and to the effect of outboard propeller rotation for negative yaw.

CONCLUSIONS

The following conclusions are based on results of power-on flight tests of a twin-engine model with single vertical tails of three different sizes in the free-flight tunnel. Three modes of propeller rotation were investigated - asymmetric rotation (propellers turning right hand), outboard propeller rotation (propeller blades going up near the fuselage), and inboard propeller rotation (propeller blades going down near the fuselage).

1. The greatest effects of power and direction of propeller rotation on lateral-stability characteristics were encountered with flaps deflected.

2. With flaps deflected, application of power decreased the directional stability for the three modes of propeller rotation.

3. The asymmetric mode of propeller rotation had a large effect upon lateral trim. Neither of the two symmetrical modes of rotation required control deflections for trim, whereas the asymmetric mode required approximately 6° right aileron and 4° right rudder deflections for straight flight.

4. Mode of propeller rotation with flaps up had little effect on the lateral stability although blades coming up in the center gave the least reduction in oscillatory directional stability. With flaps down, however, the rotation with blades going down in the center gave the least reduction in this respect.

5. The most satisfactory dynamic lateral flight behavior was encountered with models having large vertical tails.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Rogallo, Francis M., and Swanson, Robert S.: Wind-Tunnel Tests of a Twin-Engine Model to Determine the Effect of Direction of Propeller Rotation on the Static-Stability Characteristics. NACA A.R.R., Jan. 1943.

2. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. T.N. No. 810, NACA, 1941.

3. Süper, J.: Effect of Propeller Slipstream on Wing and Tail. T.M. No. 874, NACA, 1938.

4. Sweberg, Harold H.: The Effect of Propeller Operation on the Air Flow in the Region of the Tail Plane for a Twin-Engine Tractor Monoplane. NACA A.R.R., Aug. 1942.

TABLE I

FLIGHT RATINGS OF TWIN-ENGINE MODEL AS TESTED IN THE FREE-FLIGHT TUNNEL[1]

Vertical tail	Power condition	Mode of Propeller Rotation: Outboard propeller rotation				Asymmetric propeller rotation				Inboard propeller rotation			
		Steadiness	Spiral stability	Adverse yawing	Oscillatory stability	Steadiness	Spiral stability	Adverse yawing	Oscillatory stability	Steadiness	Spiral stability	Adverse yawing	Oscillatory stability
Flaps up; $C_L = 0.58$; $T_c = 0.045$ per engine													
1 (large)	Windmilling	A	B	A	A	A	B	A	A	A	B	A	A
	Full power	A	B	A	A	A	B	A	[2]A	A	B	A	A
2 (medium)	Windmilling	B	B+	B+	B+	B	B+	B	B+	B	B+	B	B+
	Full power	B	B+	B	B+	B	B+	B	[2]B+	B	B+	B	B+
3 (small)	Windmilling	C	B+	C	C	C	B	C	C-	C	B	C	C
	Full power	C	B+	C-	C	C	B+	C-	[2]C-	D	B+	D	D
Flaps down; $C_L = 1.00$; $T_c = 0.075$ per engine													
1 (large)	Windmilling	A	C	B+	A	A	C	B+	A	A	C	A	A
	Power-on	B	C+	B	B+	B	C+	B-	[2]B+	B+	C+	A	A
2 (medium)	Windmilling	B	C+	B	B+	B	C+	B+	B+	B	C	B	B+
	Power-on	B-	B	B	B-	B-	B	B-	[2]B-	B	C	B	B
3 (small)	Windmilling	C+	B	C+	B	C+	B	C+	C	C+	B	C+	B
	Power-on	D	B+	D	D	D	B+	D	[2]D	C+	B	C	C

[1]Flight ratings:

Rating	Steadiness	Spiral Stability	Adverse yawing	Oscillatory stability
A	Very steady flight	Stable	None	Oscillations heavily damped
B	Steady flight	Slightly stable	Slight	Oscillations moderately damped
C	Erratic flight	Slightly unstable	Large and troublesome	Oscillations slightly damped
D	Violently erratic flight	Unstable	Too excessive for continued flight	Oscillations neutral or negatively damped
+	Indicates condition slightly better than letter designated			
-	Indicates condition slightly worse than letter designated			

[2]Trim changes with power

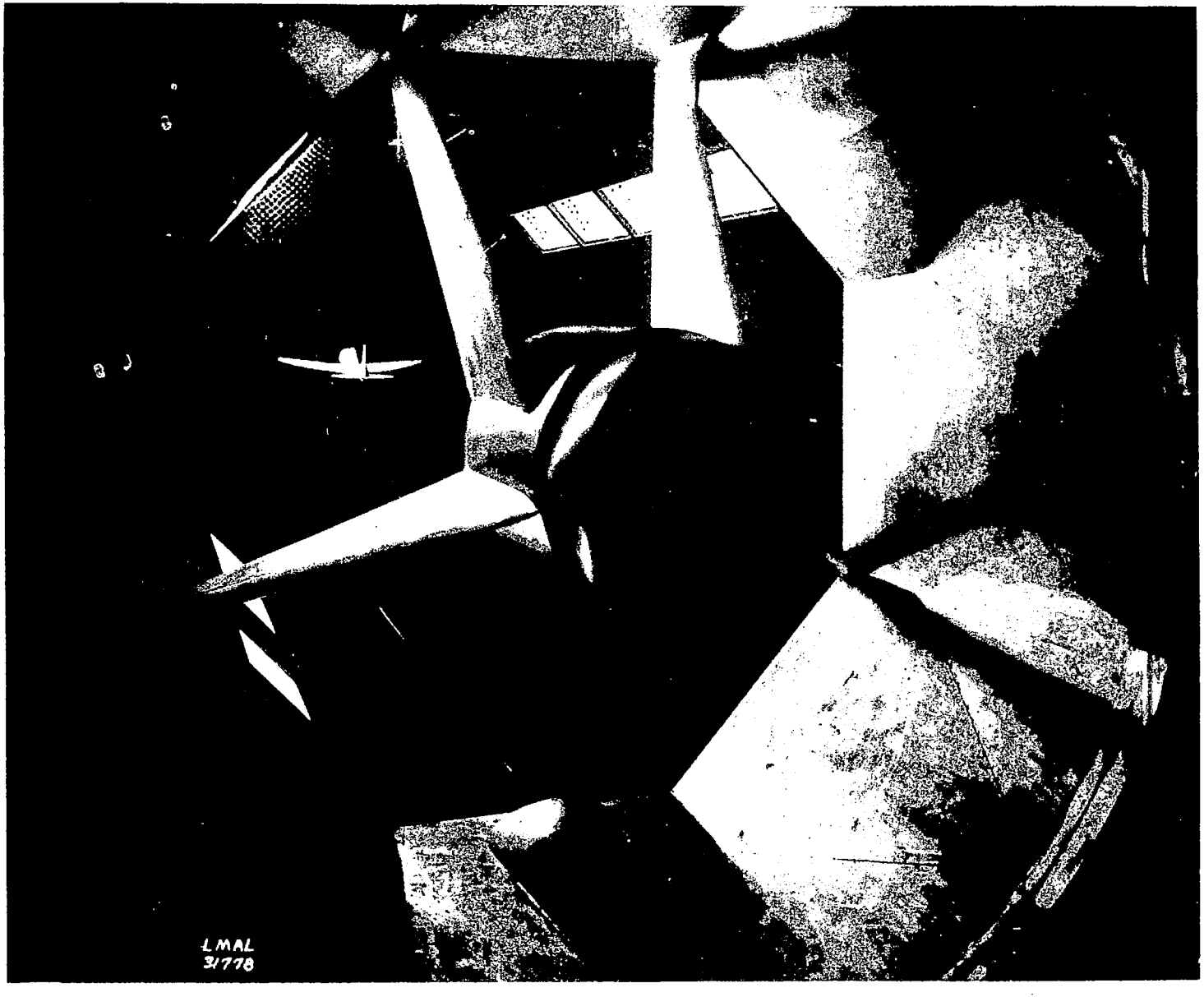


Figure 1.- Test section of NACA free-flight tunnel showing powered model in flight.

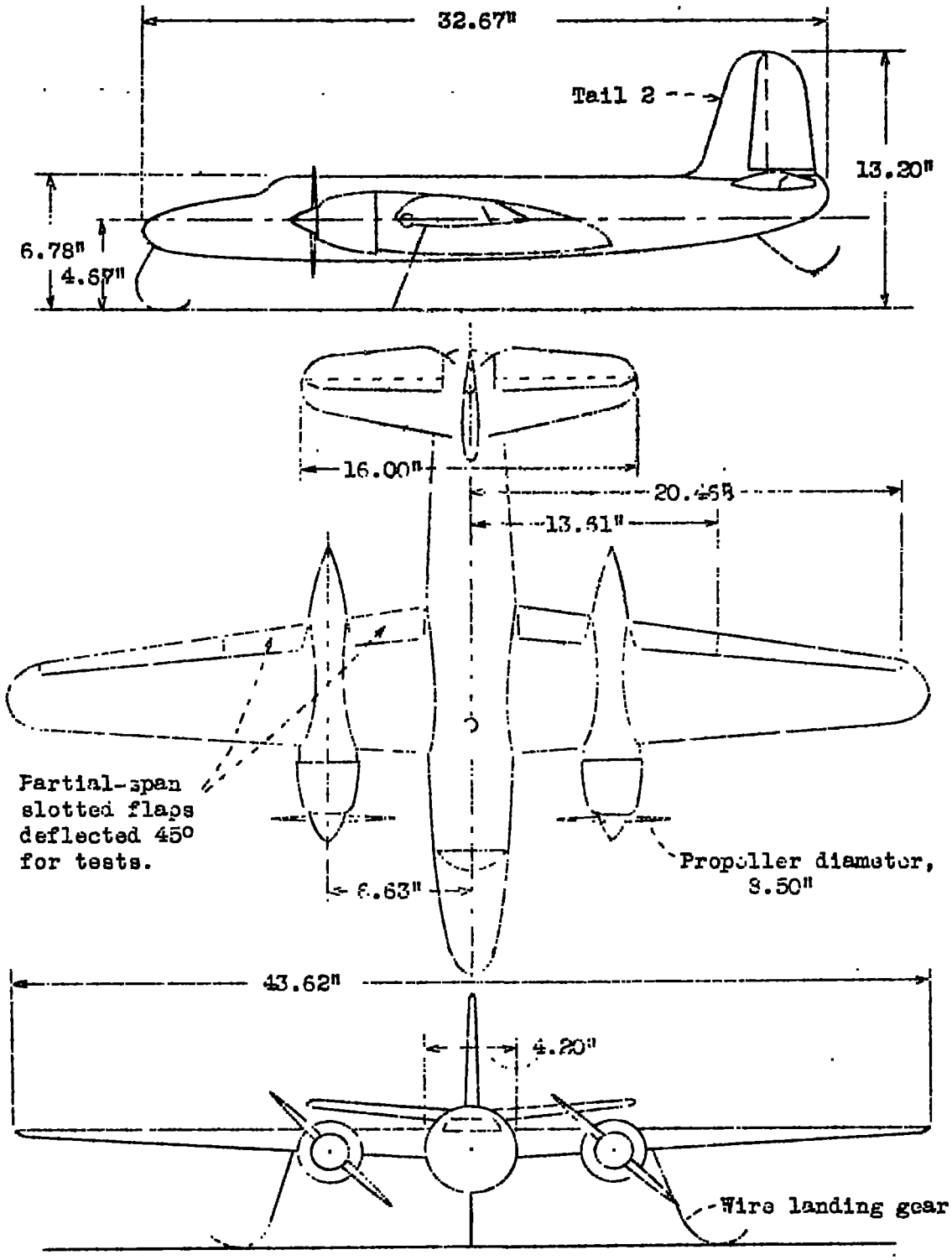
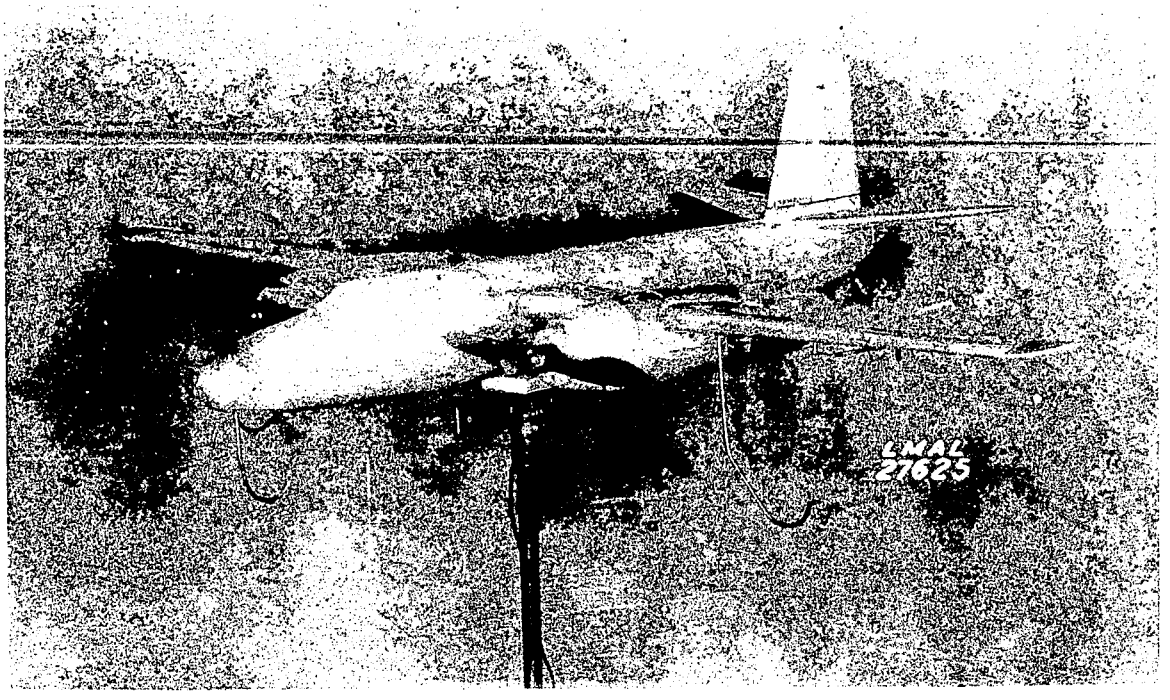
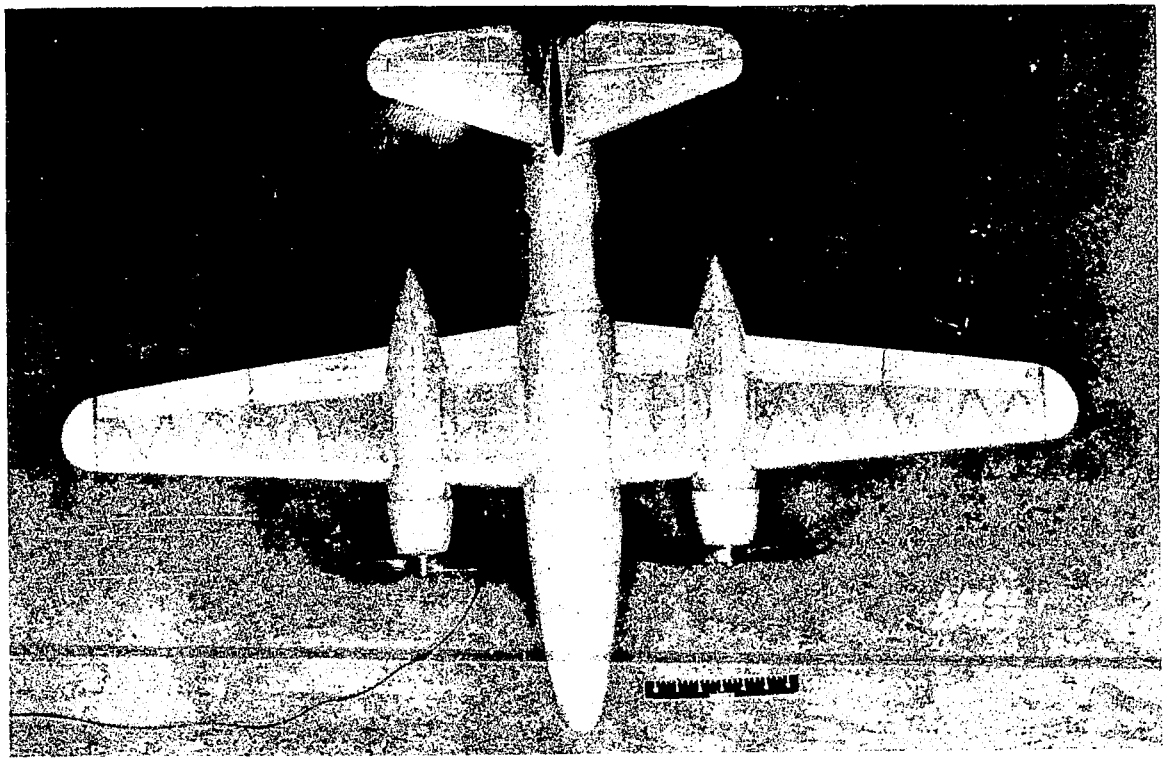


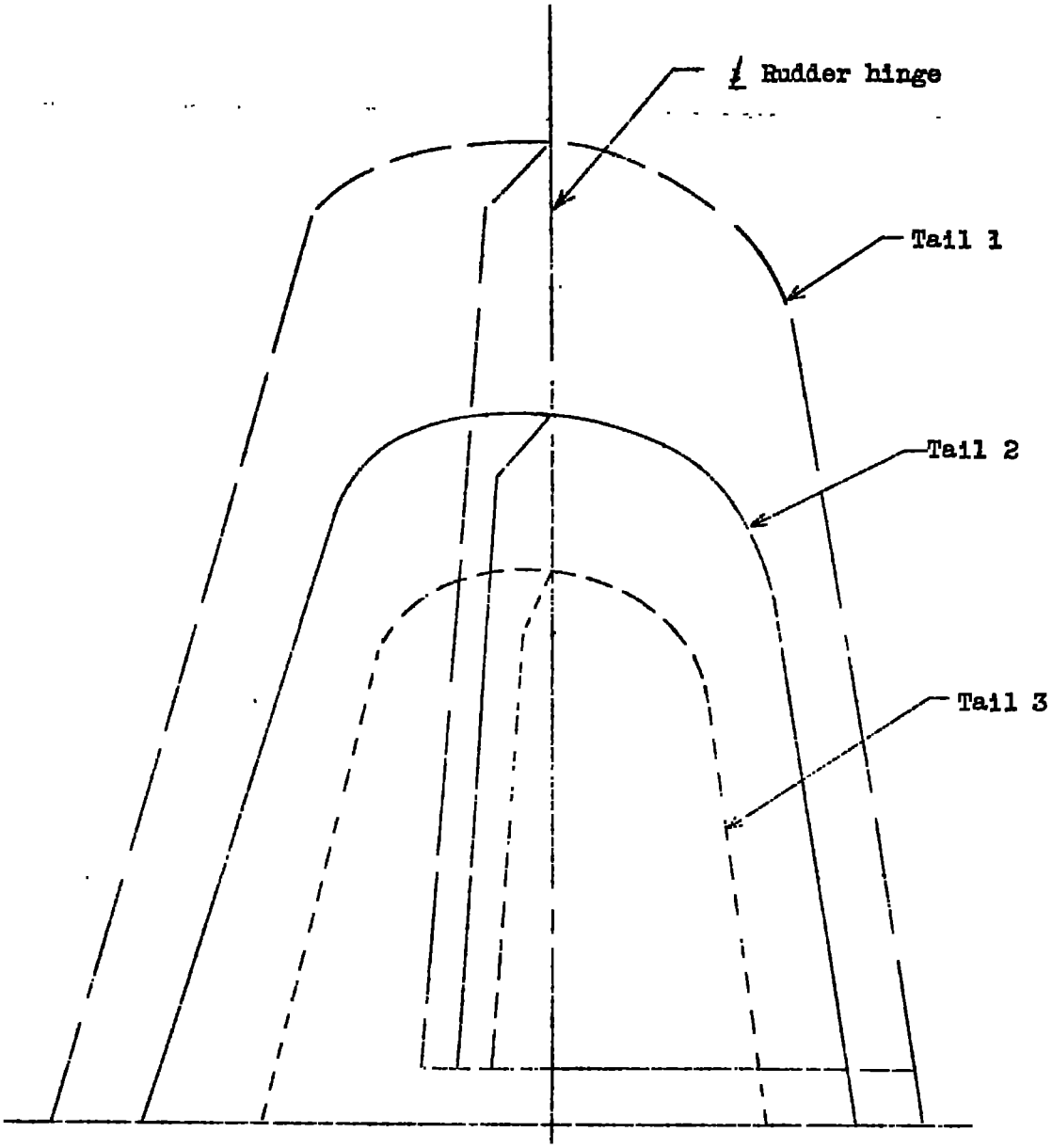
Figure 2.- Three-view drawing of 1/20-scale twin-engine model tested in free-flight tunnel.





(b) Top view

Figure 3.- Photographs of 1/20-scale model of twin engine airplane tested in the NACA free-flight tunnel. Vertical tail 2



Vertical tail	Areas, percent wing area			Aspect ratio
	Total area	Rudder balance area	Rudder area aft ℄ hinge	
1	16.57	5.05	6.67	1.54
2	11.05	1.35	4.45	
3	5.52	6.70	2.22	

Figure 4.- Sketches of three vertical tail surfaces used on twin-engine model tested in free-flight tunnel.

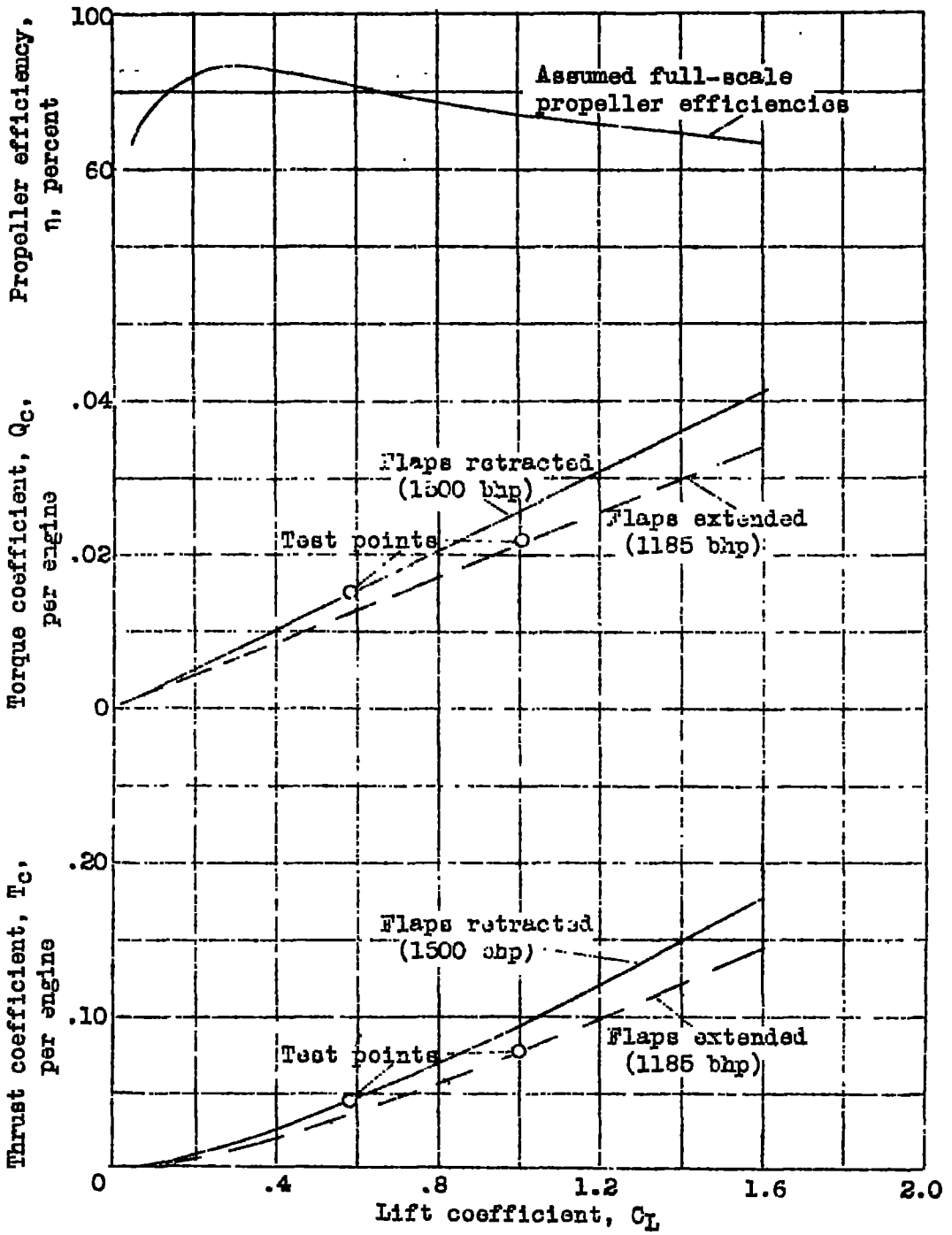


Figure 5.- Full-scale power conditions at sea level simulated by twin-engine model in free-flight tunnel tests.

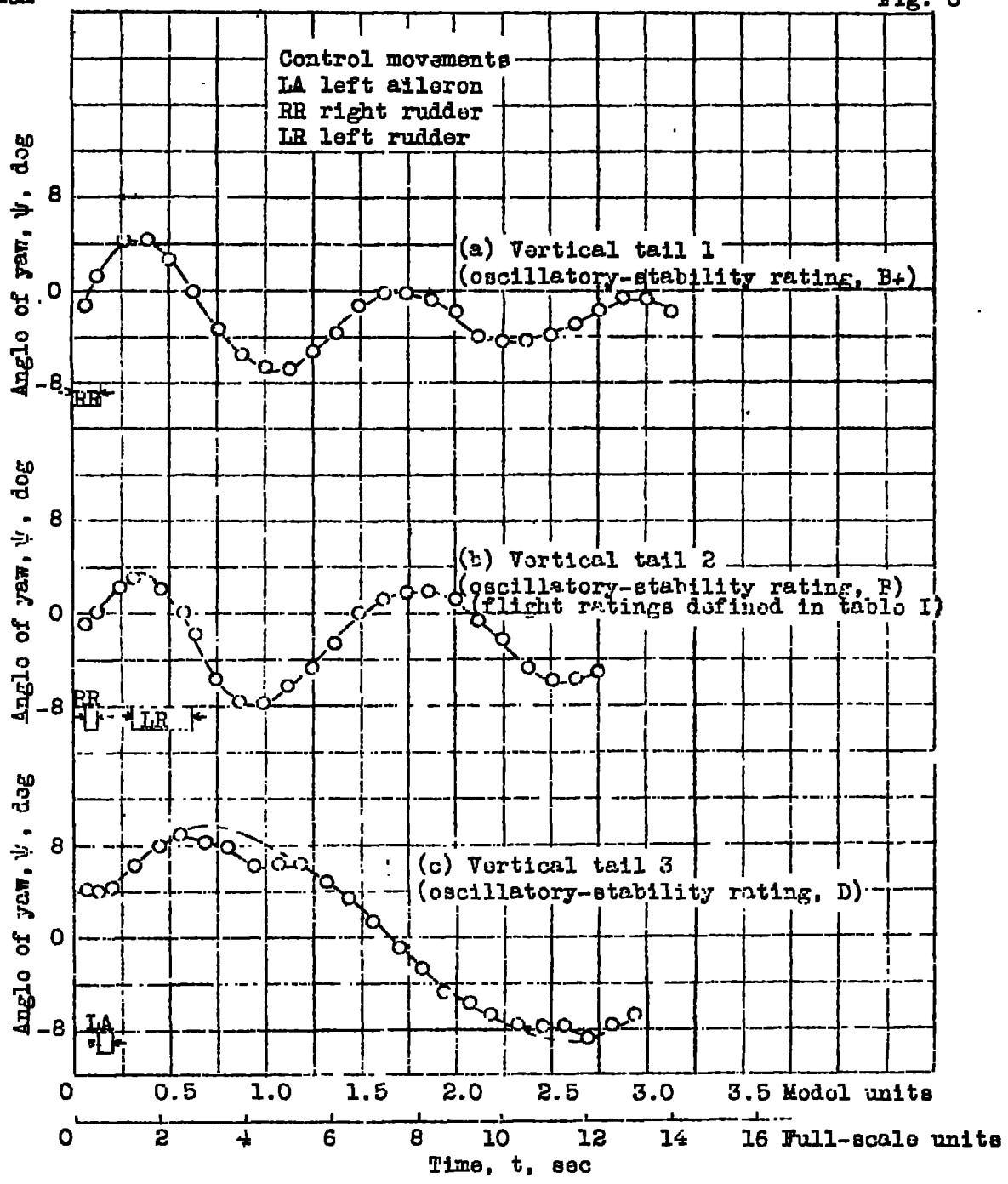


Figure 6.- Effect of vertical area on the oscillatory-stability characteristics of the twin-engine airplane model tested in the free-flight tunnel. Flaps down, T_c=0.075, outboard rotation (A).

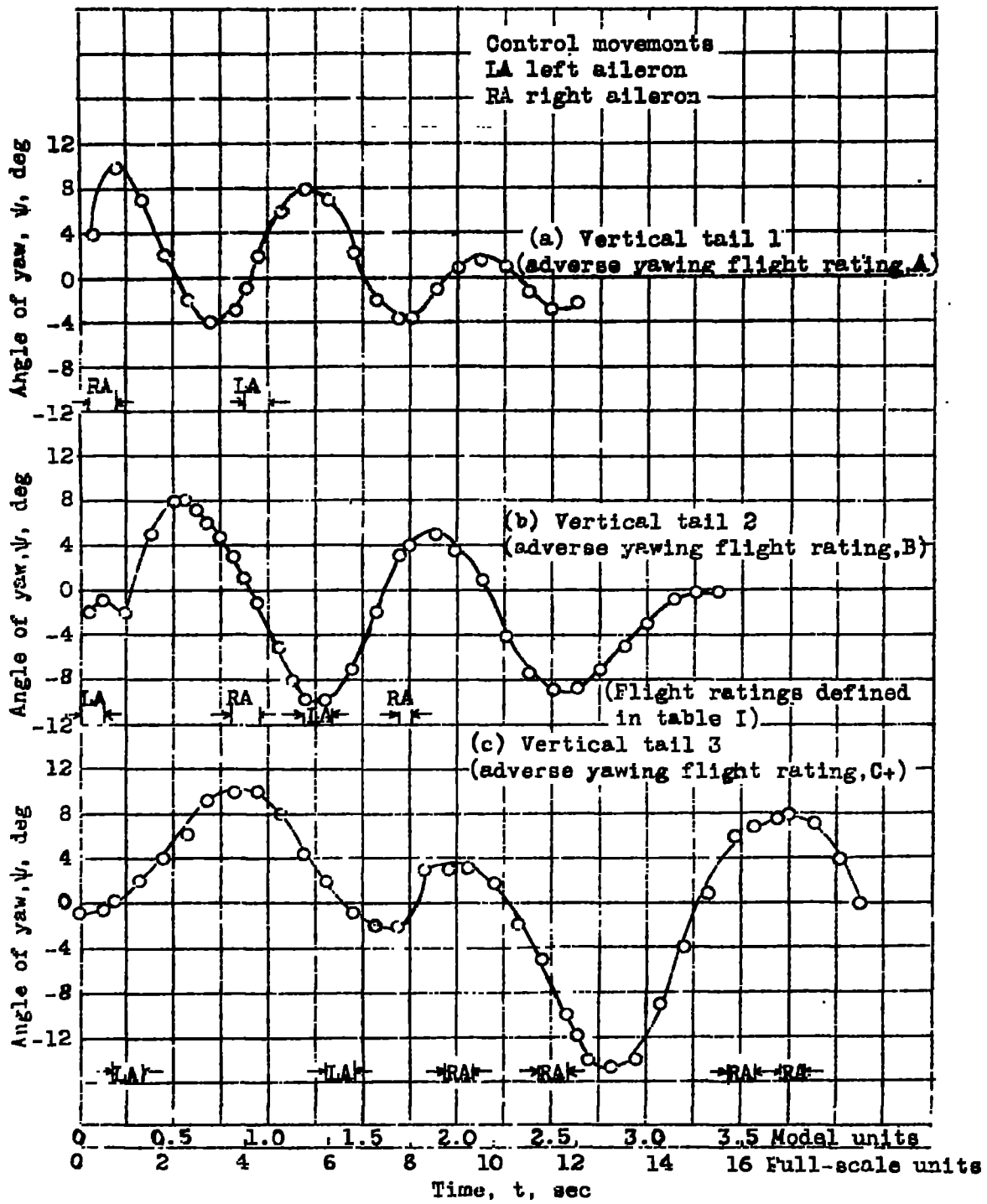


Figure 7.- Effect of vertical tail area on adverse yawing characteristics of twin-engine airplane model. Flaps down, windmilling power, inboard rotation (↷).

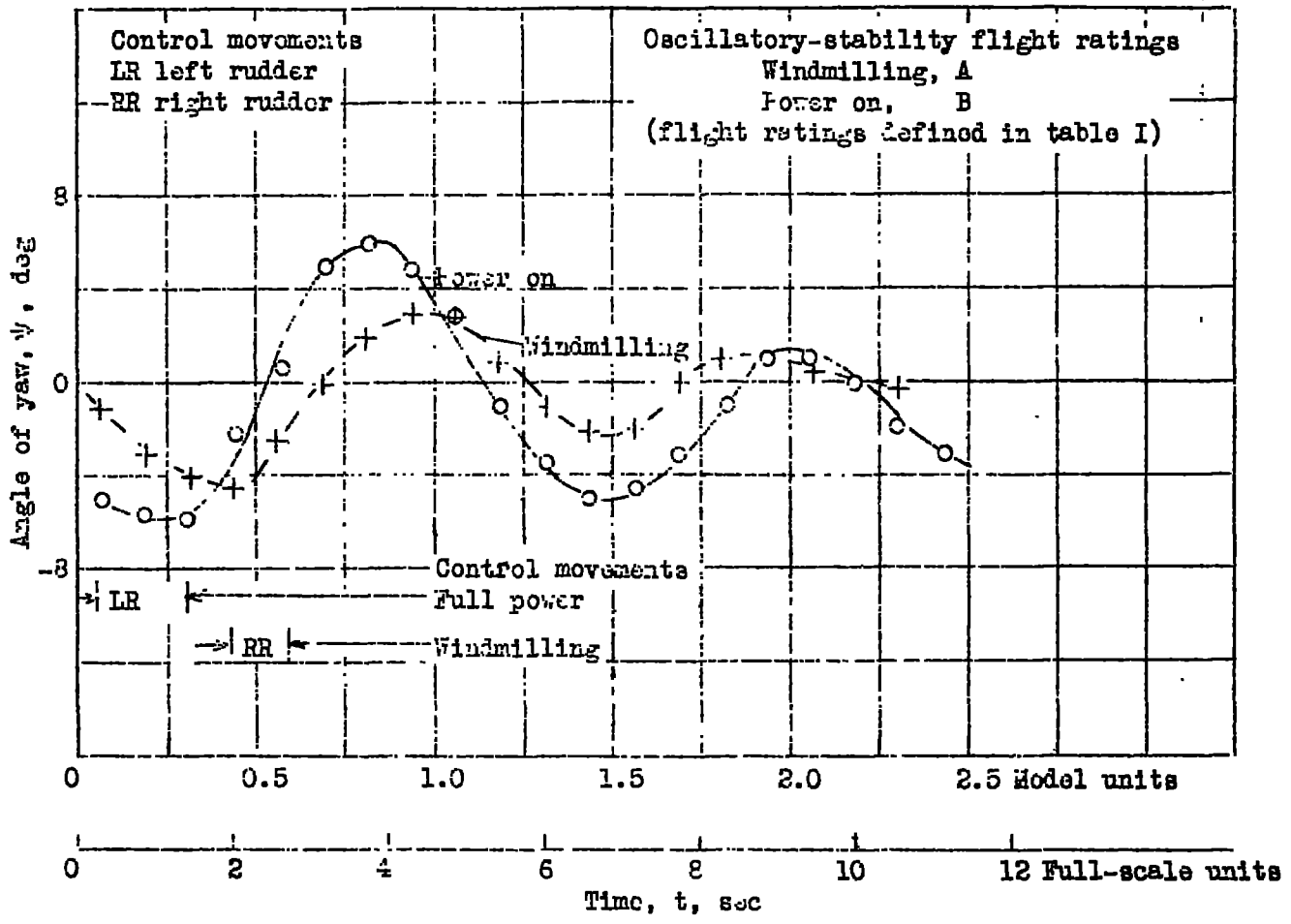


Figure 8.- Effect of power on the directional-stability characteristics of the twin-engine airplane model tested in the free-flight tunnel. Flaps down, vertical tail 1, asymmetric rotation 2.

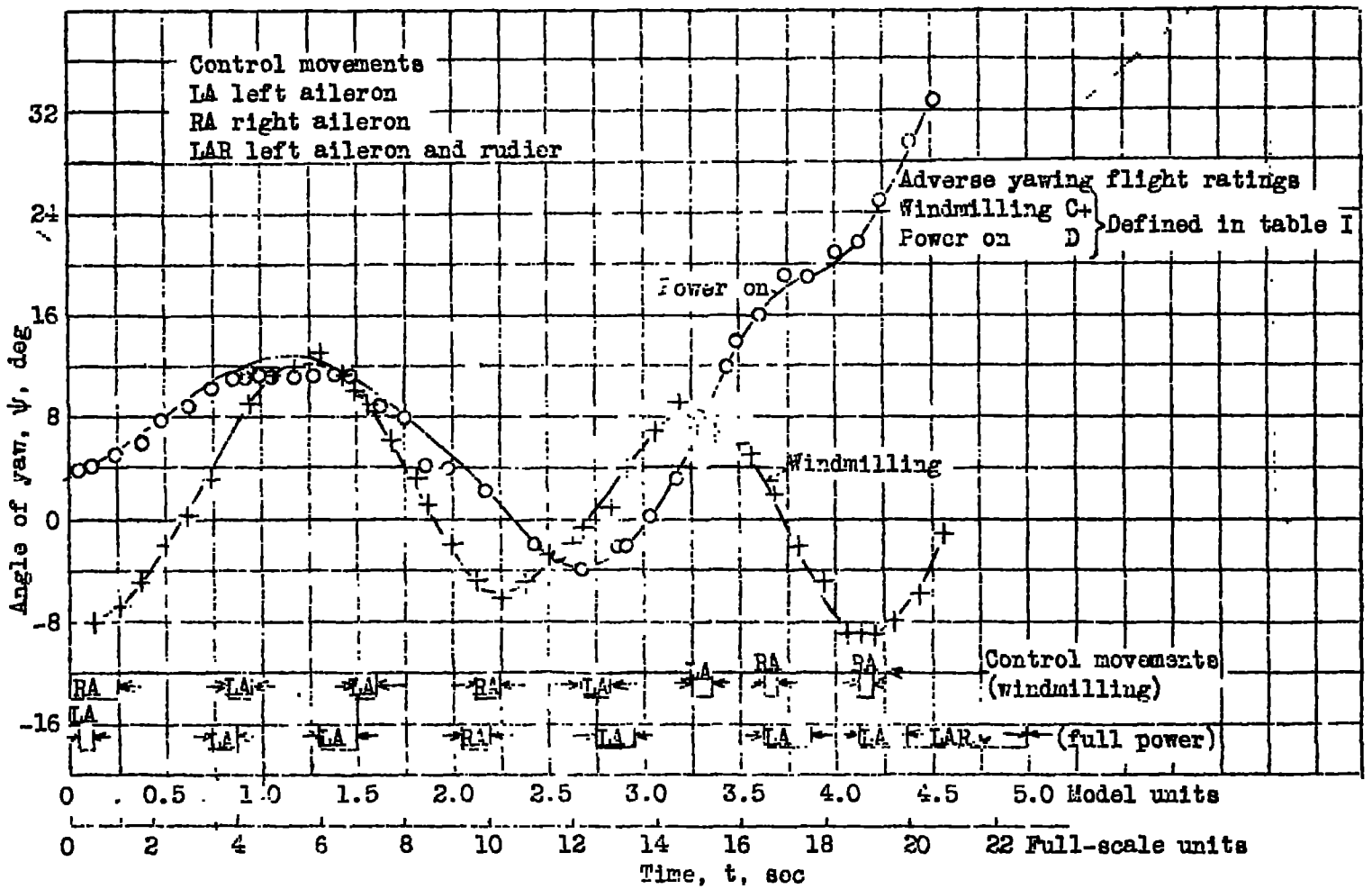


Figure 9.- Effect of power on the adverse yawing characteristics of twin-engine airplane model tested in the free-flight tunnel. Flaps down, vertical tail 3, asymmetric rotation $\mathcal{M}$.

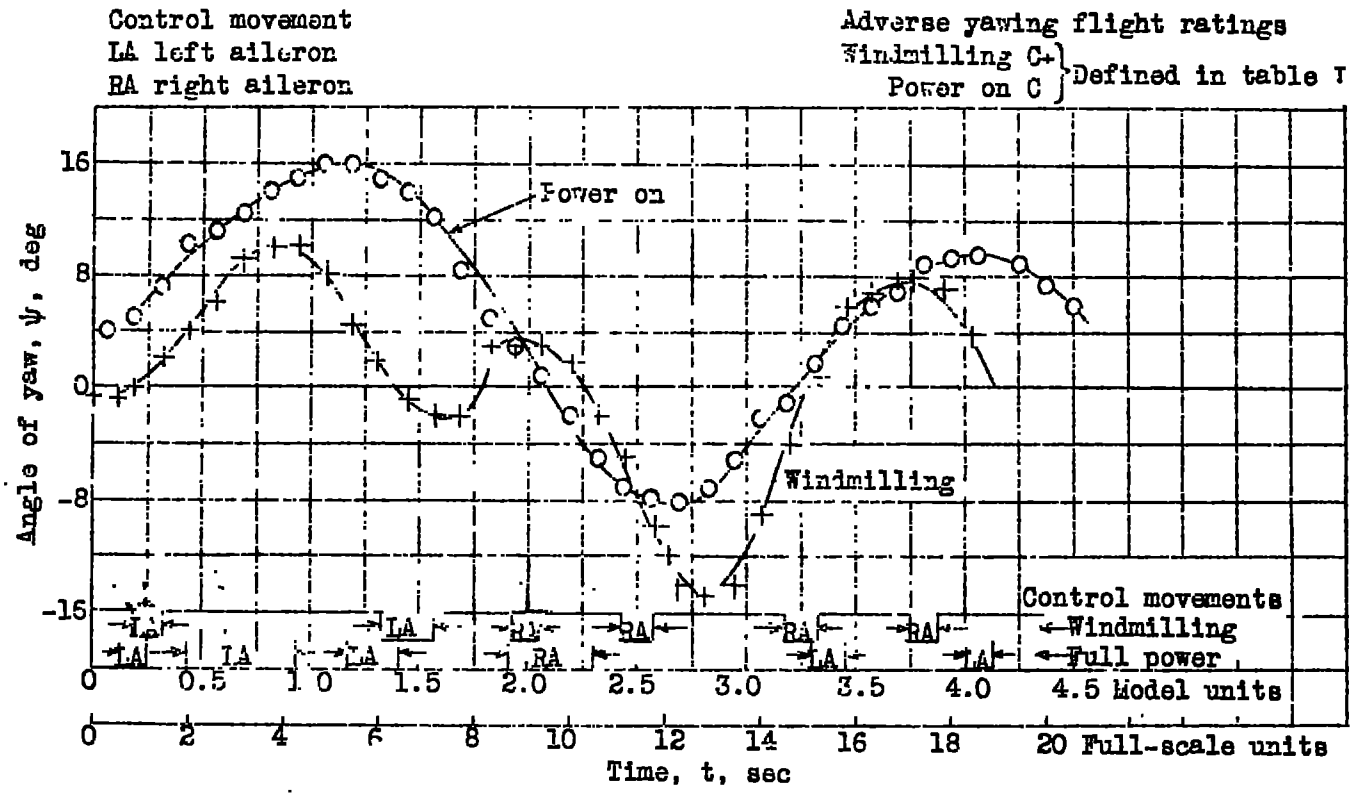


Figure 10.- Effect of power on the adverse yawing characteristics of twin-engine airplane model tested in the free-flight tunnel. Flaps down, vertical tail 3, inboard rotation ↷.

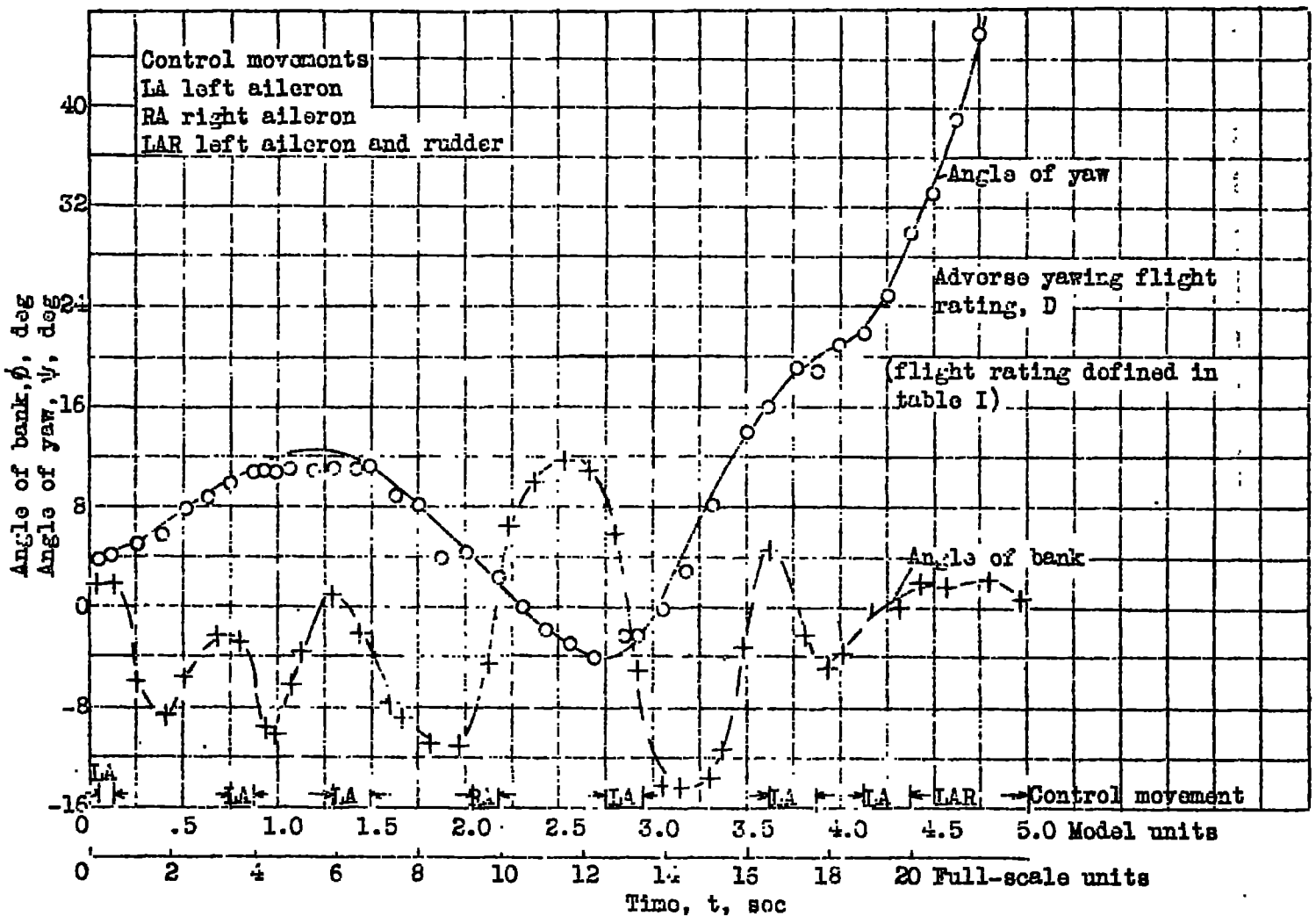


Figure 11.- Directional divergence caused by aileron application. Flaps down, asymmetric rotation ↶↷, vertical tail 3, T_c=0.075 per engine.

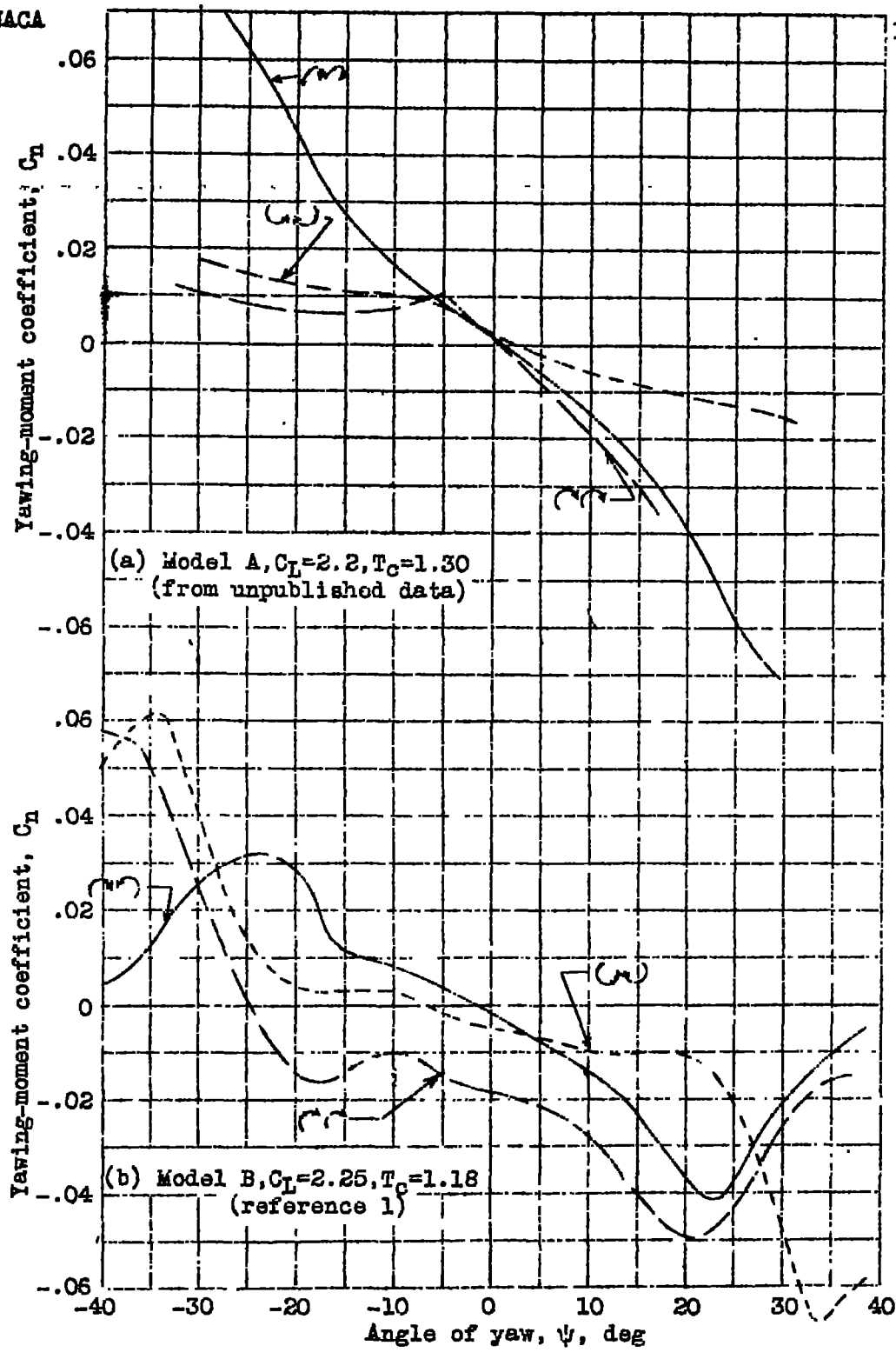


Figure 12.- Influence of direction of propeller rotation upon the yawing-moment coefficient C_n of two twin-engine models in yaw. Flaps-down condition.

LANGLEY RESEARCH CENTER
3 1176 01354 2858