TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 810

PRELIMINARY STABILITY AND CONTROL TESTS IN THE NACA FREE-FLIGHT WIND TUNNEL AND CORRELATION WITH FULL-SCALE FLIGHT TESTS

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Washington
June 1941

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SUMMARY

The study of stability and control of airplanes by means of dynamic scale models in the NACA 12-foot free-flight wind tunnel is described. Preliminary tests of a 1/12-scale model of the P-36A airplane were used to develop the testing technique and to afford a comparison of tests of a model in the tunnel with flight tests of the corresponding airplane. Qualitatively, the general behavior of the model was in agreement with the behavior of the airplane, but, quantitatively, the longitudinal stability of the model was greater than that of the airplane and the aileron control was somewhat weaker. This quantitative disagreement is probably a result of local separation due to the low Reynolds numbers of the tests, which affects a direct comparison with full-scale tests but which should not vitiate comparisons of different models or modifications to a given model. It is believed that the free-flight tunnel affords a useful means of determining the relative stability and control characteristics of different models and that it will be particularly useful in the development of new airplane designs.

INTRODUCTION

The advancement of the art of designing airplanes, particularly new types, that will have desired flying characteristics has long been handicapped by the complexity of stability and control theory and by the current unpredictable nature of some of the fundamental derivatives involved. Realizing the advantage of being able to study stability and control problems with a free-flying model in the controlled conditions of a wind tunnel, the

NACA in 1937 completed the development of a 5-foot free-flight wind tunnel and in 1939 constructed the present 12-foot free-flight wind tunnel in which a dynamic model may be flown under control. Variation of any dimension of the model can be readily accomplished and the effect on the flying qualities can be determined. Models of proposed airplanes can also be inspected and undesirable stability or control characteristics can be discovered and corrected in the initial design stages.

This report describes the operation of the 12-foot free-flight wind tunnel and presents some results obtained with a 1/12-scale model of a P-36A airplane equipped with a motor and a propeller for power-on tests. A comparison of these results with full-scale flight tests of the P-36A airplane is given and discussed in some detail. The shortcomings, as well as the usefulness, of the tunnel are thus evaluated.

NACA 12-FOOT FREE-FLIGHT TUNNEL

The NACA free-flight tunnel is a simple open-return tunnel of octagonal cross section, 12 feet wide at the throat and 32 feet long. A drawing of the tunnel is given in figure 1. The tunnel is so arranged that its longitudinal axis, and thus the air stream, may be inclined at different angles to the horizontal. A hydraulic jack provides control over the tunnel angle. Suitable guide vanes and screens are installed in the entrance cone of the tunnel to insure uniform air-flow distribution. The housing is spherical; so the relation of the tunnel to the wall does not vary with tunnel angle. The tunnel is equipped with a voltage control for the propeller-drive motor that provides an extremely flexible air-speed regulation. A photograph of the test section of the tunnel showing a model being adjusted before flight is given in figure 2(a) and a model in flight is shown in figure 2(b).

A tunnel operator stationed at the side of the tunnel test chamber adjusts the air speed in the tunnel to the speed of the model and accommodates the tunnel angle to the flight-path angle of the model. The operator thus controls the longitudinal and the vertical location of the model in the tunnel. This operator also controls the power input to the model for powered flight.

The direction of flight of the model or the lateral position of the model in the tunnel is controlled by a "pilot" who operates the normal airplane control surfaces by means of electromagnetic mechanisms in the model. The power is supplied to these mechanisms, as well as to the model propeller-drive motor, through a light flexible cable that trails behind the model.

The pilot is the principal observer because he has control of the model and can detect deficiencies in stability or control. The pilot's observations give a direct qualitative indication of the stability and control; records from three 35-millimeter moving-picture cameras mounted to photograph the motion of the model in three mutually perpendicular planes supply quantitative data on the stability characteristics of the model and its response to control displacements. Neon lamps in the common field of the three cameras indicate the control displacement.

The tunnel may be operated at air speeds from 0 to 90 feet per second and can accommodate glide angles of 40° or climb angles of 15°. The operating technique will be illustrated by describing a typical take-off. Assume that the desired test is to be made at cruising-speed level flight. The model rests on the floor with the wheels locked to prevent rolling and with the elevators set at the proper angle for the desired flight. Power is supplied to the model propeller and the air speed in the tunnel is slowly raised. The tail of the model rises and, when the estimated flight speed and flight power are reached, the pilot moves the elevator up momentarily to overcome the ground effect, and the model rises to the center of the tunnel. If the estimated air speed and power are correct for the particular elevator setting, little further adjustment is required for steady flight. The pilot then flies the model in the test section and notes the stability and the response to control movements.

SYMBOLS

W weight

S wing area

b wing span

t time

P	period of oscillation
V	velocity
C_L	lift coefficient
C_D	drag coefficient
δ_a	aileron deflection
δ_e	elevator deflection
δ_r	rudder deflection
α	angle of attack
ϕ	angle of bank
θ	angle of pitch
β	angle of sideslip
ψ	angle of yaw
C_n	yawing-moment coefficient
C_{n_β}	directional stability ($\partial C_n/\partial \beta$)
p	rolling velocity
q	pitching velocity
r	yawing velocity
x	longitudinal position
y	lateral position
z	vertical position
I_X	moment of inertia about X axis
I_Y	moment of inertia about Y axis
I_Z	moment of inertia about Z axis

MODEL

The models used in the free-flight tunnel are dynamic-scale models of the corresponding airplane. The normal span used is about 40 inches, which establishes a normal scale ratio of about 1:12 for single-engine airplanes. For this size model, it is possible to obtain the correct weight and the weight distribution by using practically solid balsa wings with a hollow balsa fuselage. The electric drive motor for the propeller weighs about as much, in proportion, as the airplane engine plus the disposable load; so the mass factors work out correctly. The particular details to be considered will be shown in the following description of the Curtiss P-36A airplane model, which has been tested in the tunnel for development of testing technique and correlation with full-scale test results.

The dynamic model of the P-36A airplane used in the investigation was 1/12 scale and was constructed of balsa. A three-view drawing is given in figure 3 and a photograph taken before the motor was installed is reproduced as figure 4. The dimensional characteristics of the airplane are given in table I. In preliminary tests made before the motor was installed in the model, the direct scaled-down values of weight and moment of inertia were used. After installation of the motor and the propeller, however, the weight of the model slightly increased and the moments of inertia were correspondingly increased so that the model then corresponded to the airplane flying at an altitude of 6000 feet. The wing loadings and the moment-of-inertia errors are given in table II. The general relations of the dimensions, the mass, and the motions of dynamically similar airplanes are given in table III. The relations for the 1/12-scale model are also shown.

In power-on tests, the model propeller was driven by a direct-current electric motor capable of delivering 1/8 horsepower at 15,000 rpm. The power was controlled by varying the input voltage from 10 to 150 volts. A gear ratio of 2.44:1 was used between the motor and the propeller so that the V/nD ratios of the model would approximate those of the airplane. The propellers were not exact scale models of the airplane propellers but were two-blade wooden propellers of the correct diameter, selected because they were easily obtained in the quantities required. On account of the nature of the tests, in which crashes were frequent, 20 propellers were required to complete the tests. This departure from true scale was accepted because other tests had shown that the effect of power on the stability and the control of an airplane is primarily a function of thrust loading. The thrust was directly computed from the difference between the tunnel angles required for flight with power off (propeller removed) and power on at the same air speeds without consideration of the propeller characteristics.

The controls were operated by three special electromagnetic mechanisms, one for each control. A view showing a typical installation of the motor and the control mechanisms is given in figure 5. Each mechanism consists of a spring-centered clapper-type armature mounted between wound cores so wired that the clapper may be abruptly pulled to either core. The clapper is connected to the control surface through push rods and bell cranks in such a manner that the desired control may be abruptly moved to a definite setting as needed. The time that the control is held deflected is varied to suit the disturbance to be corrected or to produce a desired motion.

The angular velocities of the model are from three to five times faster than those of the corresponding airplane, as indicated in table III; split-second timing on the part of the pilot is therefore necessary to control the model. Experience with a graduated control system showed that, because of the quick response required, the pilot rarely used partial deflection of the control stick but usually used full control and varied the time of deflection. The abrupt-deflection mechanism produces the same effect and provides a simple and a satisfactory control system.

The neutral setting of the control surfaces may be varied on the ground to change the trim as needed, and the mechanism linkage may be varied to change the control movement obtained. The aileron and the rudder mechanisms are wired to a single control stick through selector switches that permit actuation by the stick of either control independently or both controls simultaneously. The elevator mechanism is wired to a separate stick operated by the left hand of the pilot. The trailing wire that conducts power to the mechanisms and the motor consists of nine or more separate conductors braided into a single unit. The wire weighs less than 1 percent as much as the model and is attached to the model at the bottom of the fuselage near the center of gravity. The effect of this wire on the characteristics of the model has not been determined, but it is believed to be small.

TESTS

In the free-flight tunnel, the P-36A model was tested with the conditions shown in table II. The elevator deflections were varied over a range necessary to permit flights from the high speed of the tunnel down to the stalling speed of the model. With the propeller installed, the power was varied from zero (windmilling condition) to the maximum obtainable with the motor, which corresponded to 600 thrust horsepower for the airplane. The dynamic longitudinal-stability characteristics were observed for each condition and the period of the oscillations determined from motion-picture records of the motion. The longitudinal control was determined by photographing the motion of the model for abrupt pull-ups and push-downs. At the stalling speed, observations were made of the behavior of the model following a stall.

The lateral-stability tests consisted of direct observations of the control-fixed behavior of the model and a study of the response to various control movements. The spiral-stability characteristics were determined by carefully trimming the model laterally and noting the tendency to diverge in either direction following a slight change in bank. Lateral oscillations were disclosed most readily by abruptly deflecting the rudder. The correlation of stability and control was studied by attempting to fly the model on a fixed course, correcting for deviations due to gustiness and other causes. For this test the ailerons and the rudder were used together and then separately. Finally, the ailerons were used alone with the rudder free to aline itself with the air stream.

The lateral-control tests consisted in abruptly deflecting the ailerons or the rudder and recording the motion. These tests were made only for conditions that could be compared directly with flight. For the comparisons with the flight tests, all the data for the model have been corrected for scale to correspond to the airplane. Records of equilibrium conditions in steady sideslips were obtained for only the landing condition. Ailerons and rudders were set against each other for trim and the resulting sideslip and bank angles were measured.

The data for the flight comparisons were taken from an unpublished report on the flying qualities of the P-36A airplane as measured by the NACA. Supplementary information of a qualitative nature used in the present report was obtained from observations of NACA pilots.

RESULTS AND DISCUSSION

Longitudinal Stability and Control

Static stability.- The static longitudinal control and stability characteristics as indicated by the elevator deflection required to trim at different lift coefficients are shown in figure 6 with flaps up and landing gear up and in figure 7 with flaps down and landing gear down. The data are given for various amounts of thrust horsepower as indicated. It will be seen that power has a marked effect on the elevator deflections required for trim. This result has been found from other tests to be caused by the reduced static stability and the increased elevator effectiveness with power on.

The data from the free-flight tunnel are compared with corresponding flight test data in figure 8. The comparison indicates a rather large scale effect on the elevator deflection required to trim; the free-flight-tunnel results indicate greater stability for all conditions than is shown by the flight data. The only agreement is in the fact that both sets of tests show a marked reduction in stability due to power. The large static stability of the model is attributed to the low scale of the tests in which the flow conditions over the wing and the tail surfaces are different from those in the full-scale tests; the model probably has a thicker boundary layer than the full-scale airplane over the rear portion of the wing together with some local separation. This separation could possibly be reduced by the use of wing slots or more favorable low-scale wing sections and will be given consideration in future tests.

The lift and the drag characteristics of the model determined from flights in the tunnel are given in figure 9 and are compared with corresponding data from tests of a 1/5-scale model in the 7- by 10-foot tunnel. The slope of the lift curve agrees well with the large-scale tests, but the usual effect of scale on maximum lift and drag coefficients is evident. The use of a wing slot in the tests of the model in the free-flight tunnel would extend the lift curve to a higher angle of attack and would give comparable values of maximum lift coefficients. Further research is necessary, however, to develop a slot that would extend the angle-of-attack range without affecting the pitching-moment characteristics.

Dynamic stability.- The dynamic longitudinal stability of the P-36A model in the free-flight tunnel was quite objectionable. At speeds above 130 miles per hour an unstable oscillation was noticeable, as shown in figure 10. As the speed decreased, the damping increased. The period of the oscillation for different air speeds is shown in figure 11. The straight line in the figure is an empirical average of the period of the phugoid oscillation for various airplanes as measured in flight. The period for the P-36A airplane was not measured in flight, but it is believed that the periods of the phugoid oscillation would be represented fairly well by the line shown. It appears, therefore, that the oscillations in the free-flight tunnel as measured are not the normal phugoid oscillations but are the result of conditions peculiar to the model. The decrease of the period with increasing air speed suggests a form of control-free motion that has been encountered in flight with other airplanes but not with the P-36A. This oscillation is a function of elevator weight, inertia moments, and friction, as well as of the aerodynamic characteristics. No attempt was made to approximate the scale mass factors for the elevator on the model because it was thought that the model condition represented the condition with controls fixed. The small amount of play in the system, however, may have been sufficient to make the mass factors important. Further research will be necessary to clear up this point.

The P-36A model was particularly sensitive to disturbances in pitch at high speed, and continuous use of the elevator was necessary to maintain flight for power on, as well as for power off. The airplane pilot did not find this condition to be true in flight tests. The difference is probably due to the higher pitching velocities associated with the small-scale model. (See table III.)

Elevator maneuvers.- The effectiveness of the elevators in changing the attitude of the model in the free-flight tunnel was investigated by making push-downs and pull-ups from steady flight in the tunnel. These tests were made with flaps and landing gear up. A typical set of data is shown in figure 12. The pitching velocity per degree of elevator deflection has been computed for different air speeds and is plotted in figure 13. Maximum angular velocities were quickly reached in the free-flight tunnel tests, which were made with a relatively small elevator deflection. In the flight tests of the airplane, large elevator deflections were used and maximum velocities were not reached; a comparison between tunnel and flight elevator maneuvers is therefore not possible.

Stalling characteristics.- The stalling characteristics of the model were observed throughout the tests for the various conditions. In all cases the rolling was violent following the stall and continued flights were not possible in the stalled condition. The stalling speed was much higher, relatively, in the tunnel than in flight because the low scale of the model tests caused the stall to occur at a much lower angle of attack. In the flight tests of the airplane, the stall was sudden and violent and could be produced with very little warning. This conclusion agrees with the free-flight tunnel observations.

Lateral Stability and Control

Spiral stability.- In the free-flight tunnel, spiral instability is indicated by the tendency of the model to increase the sideslip velocity and the angle of bank when it is given a slight initial angle of bank and the controls are fixed. It is necessary to have the model in perfect lateral trim during this test. For conditions near neutral stability, either slightly stable or unstable, the rates of convergence or divergence are small so that it becomes difficult to determine the stability, the effect being an apparently wide band of conditions for neutral stability instead of the theoretically narrow range.

The P-36A model in the tunnel with the flaps up and the landing gear up appeared to be spirally stable over the speed range flown for any condition of power. The required use of the lateral controls to maintain steady flight was normal. With the flaps down and the landing gear down, however, a marked spiral instability was encountered that made continued flights difficult because of the constant need for lateral control. Any slight disturbance would result in a rapid increase in angles of bank and sideslip that had to be corrected quickly to avert a crash. With the rudder free the spiral instability was improved, probably because of a reduction in directional stability (C_{n_β}), and the amount of control required of the pilot was reduced. An increase in speed and power likewise reduced the spiral instability.

In the flight tests of the airplane, the spiral stability was not directly determined, but the general behavior of the airplane agrees well with the free-flight tunnel observations. In flight the effect of dihedral was small throughout the flight range but was reasonably well correlated with the fin area except at low speeds, flaps down. At these speeds, the dihedral was not sufficient to raise a wing. A decrease in effective dihedral is generally associated with a decrease in spiral stability.

Lateral oscillations.- The characteristics of the lateral oscillation with fixed controls may be determined in the free-flight tunnel by deflecting the rudder abruptly and then returning it to neutral. Ordinarily several cycles may be recorded before the model reaches the tunnel wall. With the P-36A model in the tunnel, however, it was difficult to obtain long records because the model would move rapidly following a large rudder deflection and would not oscillate noticeably with a small deflection, indicating that the oscillations were well damped. Consequently, only a few records were obtained in which the period of the lateral oscillation could be determined. A comparison of the periods of oscillation of the model with the periods determined in flight tests of the airplane is given in figure 14. The tunnel data are in reasonable agreement with full-scale data, although the points are slightly below the flight curves. The flight tests also showed that the oscillations were well damped, reducing in amplitude to one-half in less than one cycle.

Lateral control.- The ailerons and the rudder were investigated in the tunnel as a coordinated lateral-control system and individually as a means for producing angular velocities. First, the ailerons and the rudder were electrically interconnected so that a single movement of the control stick would produce a movement of both the ailerons and the rudder abruptly and fully to a predetermined deflection. The ratio and the amount of the deflections could be varied by changing the control linkage before the tests were started. It was therefore possible to determine the amount of aileron control necessary for adequate controllability and also to determine the amount of rudder necessary to avoid noticeable sideslipping. The ailerons and the rudder were also tested separately as a means of control, and the resulting changes in heading and in bank were measured. In a final test the rudder control rod was disconnected so that the rudder was free to aline itself with the air stream and the model was controlled with the ailerons alone. This test was rather severe but was useful in revealing conditions of low directional stability.

The ratings of the P-36A model for different methods of control are given in table IV. The ratings are based on experience obtained with the models of a number of current airplanes and with several experimental types. The lateral control was considered excellent for all conditions of power, flaps, and landing gear when the rudder was properly coordinated with the ailerons. It was found that about one-half the aileron travel available on the airplane gave adequate control and a rudder deflection of 8°, or about one-fourth the available travel on the airplane, was sufficient to avoid noticeable sideslipping at the lowest air speeds. With some other models it has been found necessary to use the full travel available for satisfactory control; so it seems that the P-36A control should be entirely satisfactory. These findings agreed in general with the full-scale tests in which it was found that the response to rudder, ailerons, or elevator in normal flight was entirely adequate.

For the ailerons used alone in the tunnel with the rudder fixed, the control was satisfactory for all conditions except at the lowest speeds with power on, with flaps up and landing gear up. In this condition the adverse yawing was objectionable. In the airplane tests it was also noted that at low speeds with flap up the fin effect gradually tapered off so that large adverse yawing was noted.

A typical aileron maneuver is given in figure 15 for the model with landing gear down and flaps down and with the propeller removed. The data were taken from photographic records of the motion following abrupt right aileron deflection followed by abrupt left aileron deflection for recovery. The rolling velocity reached a maximum one-sixth second after the ailerons were deflected. This result agrees well with the scaled value obtained with the airplane. The sideslip angle was computed from the angle of yaw and the lateral velocity in the tunnel. Similar records were obtained for various other conditions and the maximum rolling velocities were computed.

The data are summarized in figure 16 and compared with flight-test values. There was a considerable scatter of the data owing mainly to the inability to obtain steady conditions before application of the control. The P-36A model was particularly difficult to hold steadily in one position. The average values are about 30 percent lower than the flight values for the airplane. The values with flaps down were somewhat higher than the corresponding ones with flaps up.

Control with rudder alone was difficult, if not impossible, in all cases with the model in the tunnel. Abrupt application of the rudder always caused the model to drop to the floor of the tunnel because of the diving moment accompanying sideslip. With flaps down, lateral control by rudder alone was impossible for any power condition because a low wing could not be raised by the use of the rudder, although a rudder deflection from a level attitude would produce roll. With the airplane in flight at minimum speed with the flaps down, if a wing dropped, the airplane would continue to turn toward the low wing against full opposite rudder. A pronounced diving tendency was likewise noticed in flight.

With flaps up, control with the rudder was improved particularly with power on, but the improvement was not sufficient to insure continuous flight. A slightly banked wing could be picked up with rudder alone, as shown in figure 17. In this run, the model was initially banked to the left 6° and was sideslipping to the left. A rudder deflection of 18° eventually succeeded in reversing the direction of bank and the lateral motion. The yawing velocities produced by various amounts of rudder are given in figure 18. A close agreement is shown with the airplane yawing velocities determined in flight.

With the rudder free to float and with ailerons used alone for lateral control, good control was possible only with flaps down. In fact, with flaps down the control appeared to be better at low speeds with the rudder free than with the rudder fixed. Although this result appears to be contrary to the normal conception, it is probably explained by the reduction in the control requirement because of the improvement in spiral stability obtained by freeing the rudder. With flaps up, freeing the rudder made flights impossible, particularly at the lowest speeds with power on. The large angles of sideslip accompanying use of the ailerons for lateral control made recovery impossible in the space available in the tunnel. A flight comparison is not available for this condition.

Steady sideslips.- It is possible to make steady sideslips in the tunnel by setting the rudder over various amounts and by trial, trimming the model with opposite aileron. The model will fly in a banked and a yawed attitude. It was possible to obtain a direct comparison with flight tests of the airplane for the flap-down, power-off condition. The comparison is made in figure 19 and it can be seen that fair agreement was obtained. The rudder deflections for different amounts of sideslip agree well, as do the results for the rudder maneuvers, but the aileron deflections required are higher for the model, indicating either lower aileron effectiveness or greater dihedral effect on the model. The previous results of the aileron tests indicate that the aileron moments were the probable cause of the disagreement. The angles of bank and the effect of sideslip on elevator position required for flight at the same air speed agree well with flight values.

CONCLUDING REMARKS

The study of the stability and the control characteristics of a 1/12-scale model of the P-36A airplane in the NACA free-flight tunnel served to develop the testing technique and to afford a comparison of tests of a model with flight tests of the corresponding airplane. In general, the behavior of the model was in fair agreement with the airplane, although quantitatively the longitudinal stability of the model was found to be greater than for the airplane--and the ailerons were somewhat weaker. The rudder effectiveness shown for the model agreed well with that for the airplane.

The increased longitudinal stability and the decreased aileron control of the model are attributed to local separation of the air flow over the rearward portion of the wing as a consequence of the low Reynolds numbers of the tunnel tests. It is believed that in future tests this separation may be reduced and the results improved by the use of wing slots or special airfoil sections on the model. The slots would also be helpful in extending the angle of attack and the lift coefficient at which stalling occurs.

Although the quantitative disagreements with full-scale data are appreciable, it is believed that, with an understanding of their nature, magnitude, and direction, correct general conclusions may be drawn from the model data regarding the stability and the control of the airplane represented, particularly where the relative merits of different modifications are desired. The free-flight tunnel should be very useful in the development of new airplane designs.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 18, 1941.

TABLE I

DIMENSIONAL CHARACTERISTICS OF THE CURTISS P-36A AIRPLANE

Engine:	
Type -	
Pratt & Whitney R-1830-17; gear ratio, 3:2	
Horsepower -	
Take-off, at 2700 rpm	1200
Climbing, at 2550 rpm	1050
Cruising, at 2325 rpm	700
Propeller:	
Type -	
Curtiss electric, three-blade	
Diameter, ft	10
Blade-angle setting at 40 in. -	
Low, deg	22
High, deg	47
Weight:	
Empty, lb	4504
Normal gross, lb	5750
Moments of inertia:	
Landing gear down -	
I_X, slug-ft^2	2100
I_Y, slug-ft^2	4500
I_Z, slug-ft^2	5910
Landing gear up -	
I_X, slug-ft^2	2020
I_Y, slug-ft^2	4477
I_Z, slug-ft^2	6028
Center of gravity:	
Landing gear down -	
Back of wing leading edge, in.	24.0
Percent of M.A.C.	26.7
Below thrust line, in.	4.85
Landing gear up -	
Back of wing leading edge, in.	25.5
Percent of M.A.C.	28.6
Below thrust line, in.	3.45
Over-all dimensions:	
Length, ft	29
Height (flying attitude), ft	9
Wing loading W/S, lb per sq ft	24.1
Wing:	
Area [1], sq ft	236
Span, ft	37.3
Aspect ratio	5.9
Airfoil sections -	
197 in. from center line of fuselage	NACA 2209
At the root, 1.645 ft below thrust line	NACA 2215

TABLE I.- CONTINUED

Wing:	
Dihedral, deg	6
Taper ratio	2.5:1
M.A.C., ft	6.80
Sweepback at wing leading edge	1°19'
Angle of wing setting, deg	1
Flap:	
Area [2], sq ft	34.80
Type -	
Partial split	
Travel, deg down	45
Span [3] -	
Ft	19.70
Percent b	52.6
Chord [2], ft	1.76
Aileron:	
Area [2] -	
Sq ft	14.06
Percent S	7.8
Type -	
Slotted	
Travel -	
Deg up	24
Deg down	11
Span -	
Ft	13.88
Percent b	37.2
Maximum chord [2], ft	1.19
Balance area, sq ft	4.24
Tail:	
Horizontal -	
Area [4] -	
Sq ft	48.00
Percent S	20.3
Center of gravity to hinge line (landing gear up), ft	17.6
Angle of tail setting, deg	2
Span, ft	12.80
Elevator area [2], sq ft	15.40
Maximum chord [2], ft	1.69
Travel -	
Deg up	28
Deg down	25
Above thrust line, ft	1.66
Elevator balance area, sq ft	3.80

See footnotes at end of table.

TABLE I.- CONTINUED

Tail:	
Vertical -	
Area -	
Sq ft	20.74
Percent S	8.78
Center of gravity to hinge line (landing gear up), ft	17.75
Span, ft	6.13
Rudder balance area, sq ft	1.94
Rudder area[2], sq ft	11.80
Travel, deg right or left	30
Area above horizontal tail, sq ft	16.26
Span above horizontal tail, sq ft	3.90

[1]Includes ailerons and portion of wing through fuselage.
[2]Includes only area back of hinge line.
[3]Does not include gap beneath fuselage.
[4]Includes area through fuselage.

TABLE II

TEST CONDITIONS OF THE 1/12-SCALE MODEL OF THE P-36A AIRPLANE

Landing gear	Flaps	Power	W/S (lb/sq ft)	Center of gravity (percent M.A.C.)	Moment-of-inertia error[1]		
					ΔI_X (percent)	ΔI_Y (percent)	ΔI_Z (percent)
Down	Down, up	Off[2]	2.20	26.7	1.6	-5.8	5.1
Up	-do--	-do--	2.05	28.6	4.3	-3.1	10.0
Down	Down	On	2.48	26.7	-.8	-16.6	2.0
Up	Up	-do--	2.35	28.6	-4.7	-15.8	0

[1]Percentage deviation from correct scaled values.
[2]Power off corresponds to propeller removed.

TABLE III

DYNAMIC RELATIONSHIPS

[For dynamic similarity the given relations hold, where N is the scale ratio.]

	General	1/12 scale
Linear dimensions	N	1/12
Area	N^2	1/144
Volume and weight	N^3	1/1728
Moments of inertia	N^5	1/248832
Wing loading, W/S	N	1/12
Linear velocities	$\sqrt{N}$	1/3.465
Linear accelerations	Constant	1
Angular velocities	$1/\sqrt{N}$	3.465
Angular accelerations	$1/N$	12
Propeller speed	$1/\sqrt{N}$	3.465
Horsepower	$N^{7/2}$	1/5986
V/nD	Constant	1
Reynolds number	$N^{3/2}$	1/41.6

TABLE IV

FLYING QUALITIES OF THE 1/12-SCALE MODEL OF THE CURTISS P-36A AIRPLANE

Conditions				Stability[1]		Control[2]			
Landing gear	Flaps	Power	C_L	Longitudinal stability	Spiral stability	Ailerons and rudder	Ailerons alone, rudder fixed	Ailerons alone, rudder free	Rudder alone
Down	Down	Off	1.00	B-	D	A	B-	B	D+
Do	do	do	.35	D	D+	A	A-	A-	
Do	do	On	1.00	B	C	A	B		D
Do	do	do	.35	C-	C+	A	A		
Up	Up	Off	.65	C	A	A	B-	C+	
Do	do	do	.35	D	A	A	B-		D
Do	do	On	.65	B	A	A	C	D+	C
Do	do	do	.35	C-	A	A	A		C

[1]Stability rating: A, stable; B, slightly stable; C, neutral; D, unstable.

[2]Control rating: A, excellent; B, fair; C, poor; D, flight impossible.

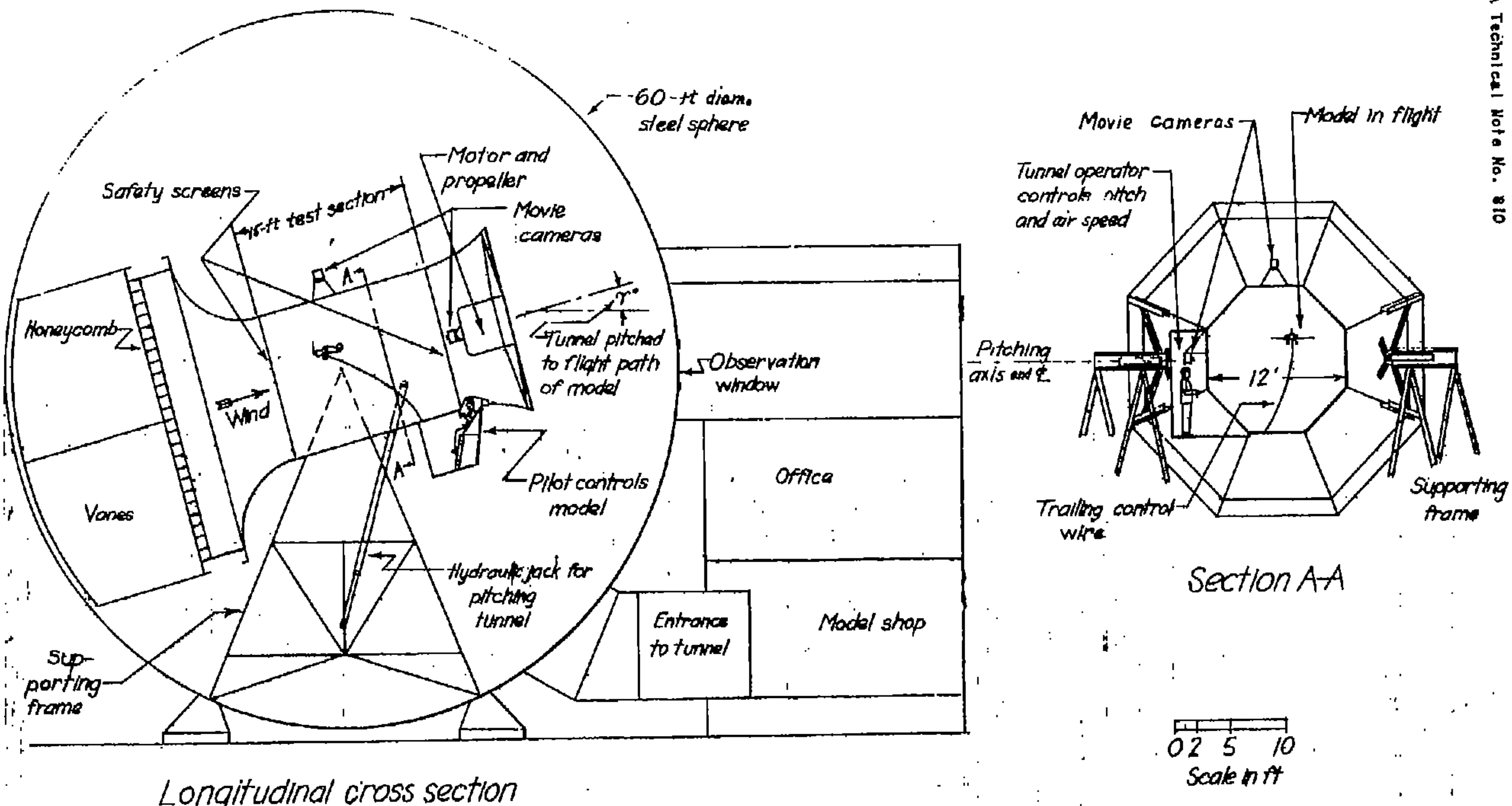


FIGURE 1.— N A C A 12-foot free-flight wind tunnel.

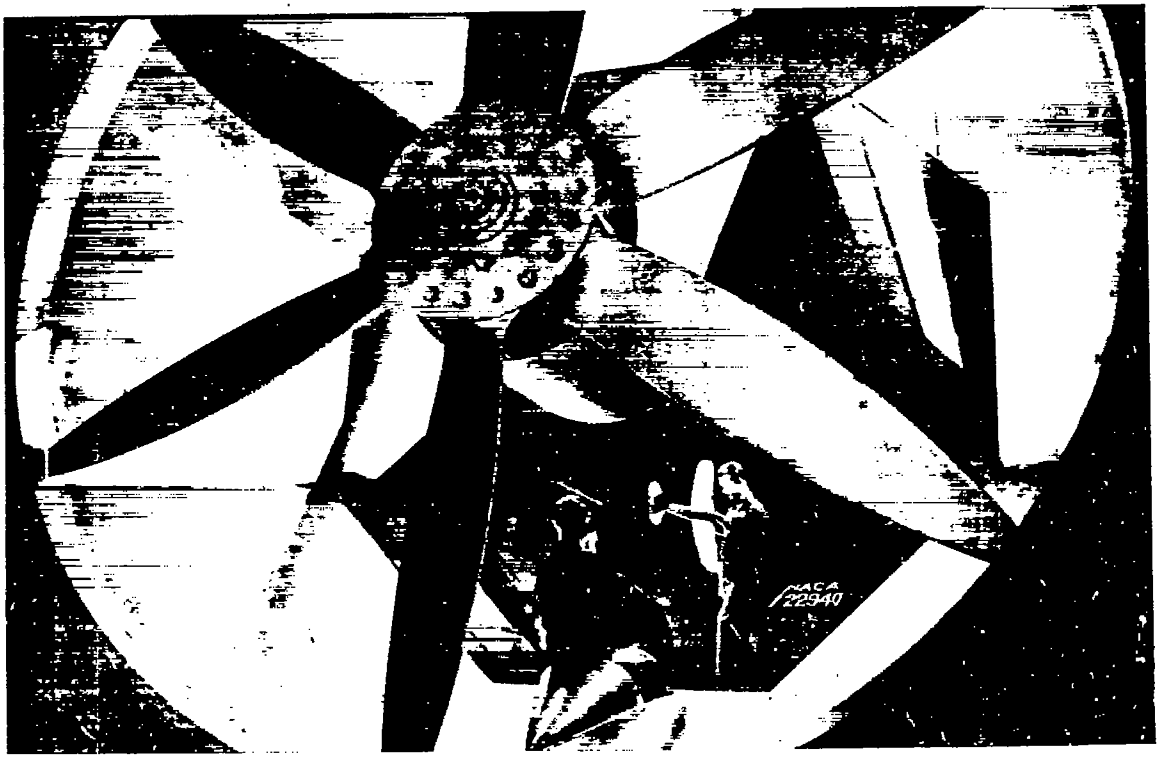


Figure 2a.– View of the test section of the free-flight tunnel showing a model being adjusted before flight.

Figure 2b.– View of the test section of the free-flight tunnel looking upstream throught the propeller, showing a model in flight under test.

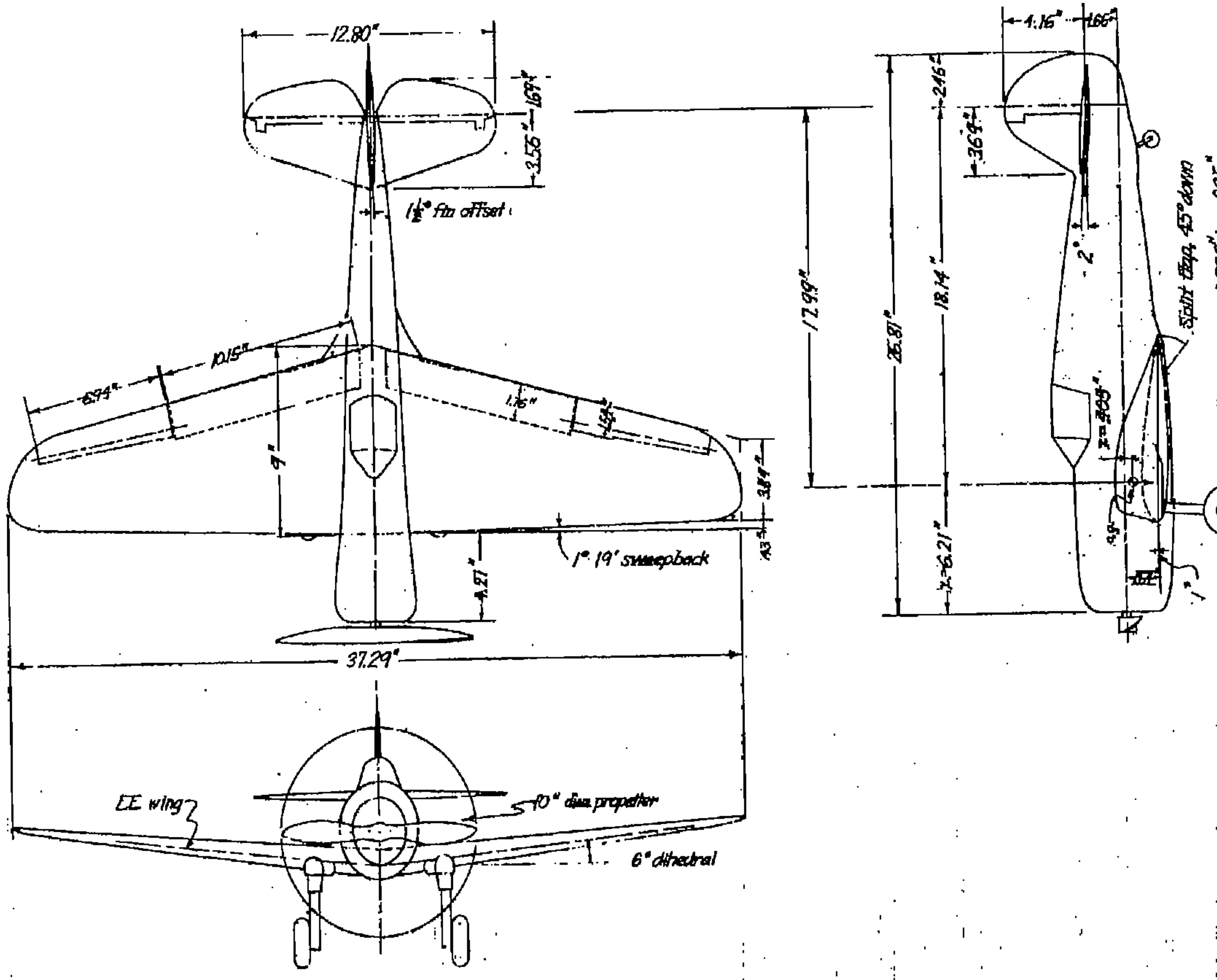


FIGURE 3.—The Curtiss P-36A model (1/2-scale) tested in the 12-foot free-flight tunnel.

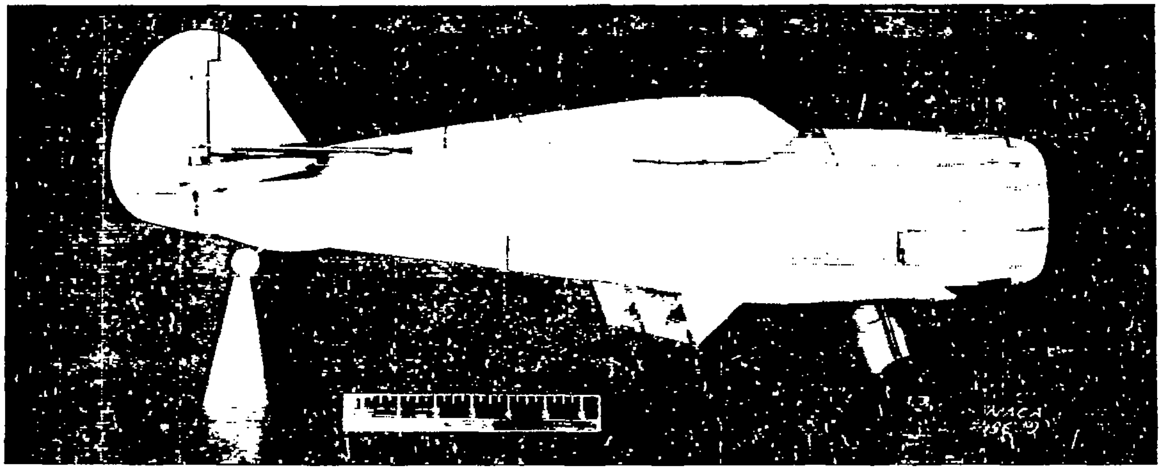


Figure 4.- View of 1/12 scale model of P-36A airplane as tested in the free-flight tunnel before installation of propeller.

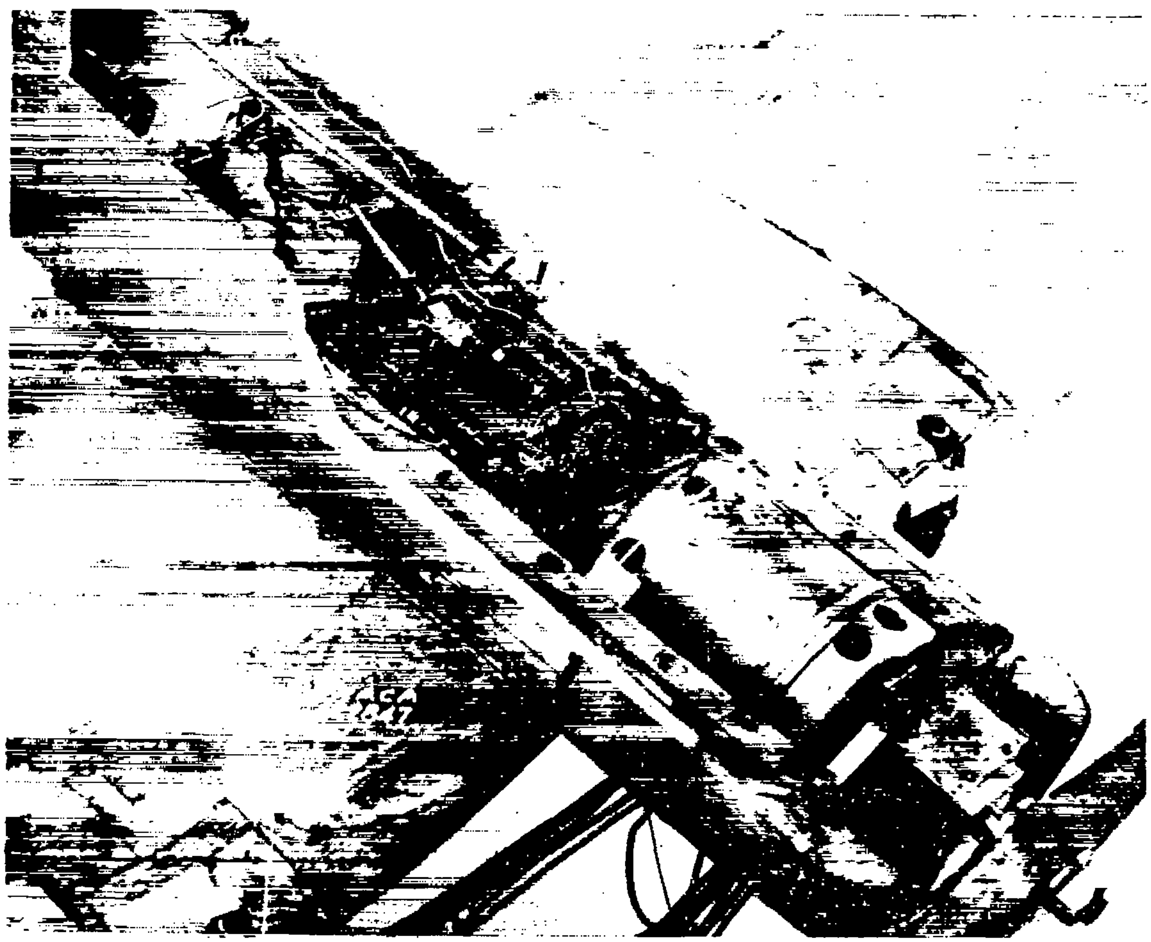


Figure 5.- View of a typical control-mechanism installation in a model.

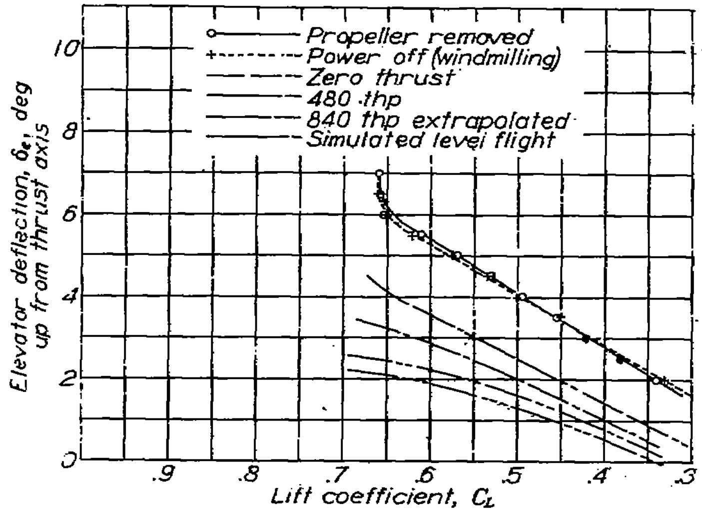


Figure 6.- Static-stability characteristics of a 1/12-scale model of a Curtiss P-36A airplane tested in the NACA free-flight tunnel. Landing gear up; flaps up; center of gravity, 28.6 percent M.A.C.

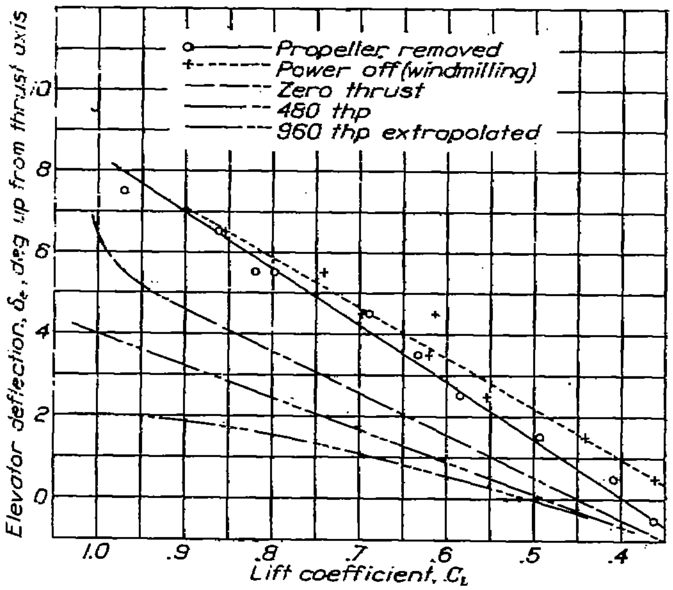


Figure 7.- Static-stability characteristics of a 1/12-scale model of a Curtiss P-36A airplane tested in the NACA free-flight tunnel. Landing gear down; flaps 45° down; center of gravity, 26.7 percent M.A.C.

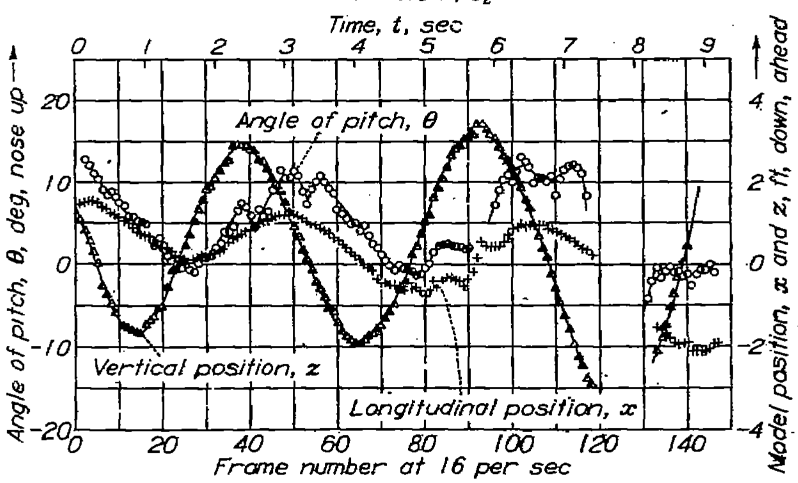


Figure 10.-A typical longitudinal oscillation of a 1/12-scale model of a Curtiss P-36A airplane showing the displacements with time. Landing gear up; flaps up; propeller off; C_L= 0.58.

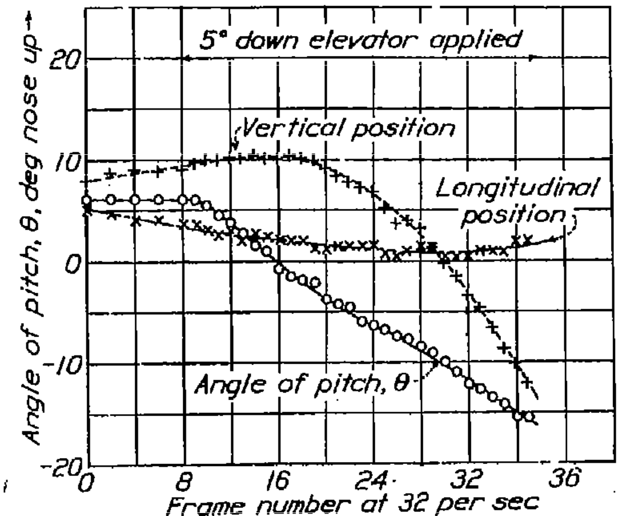


Figure 12.- A typical push-down maneuver of a 1/12-scale model of a Curtiss P-36A airplane showing the displacements with time due to 5° abrupt elevator deflection. Landing gear up;flaps up;level-flight power; C_L= 0.61.

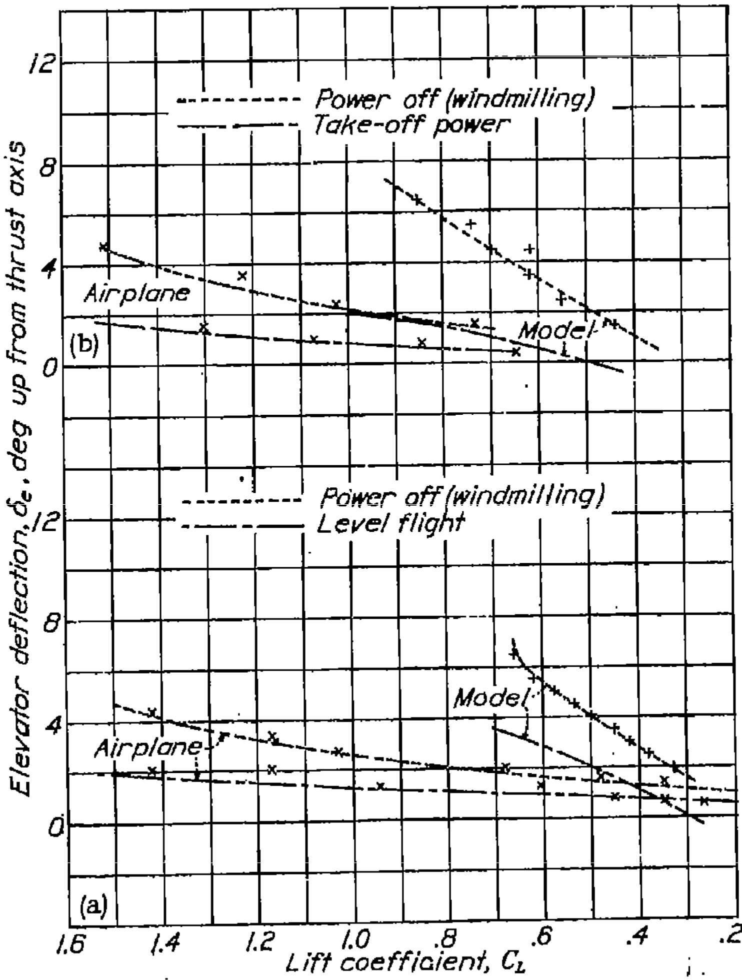


Figure 8.- Elevator deflections required to trim at different lift coefficients for a P-36A airplane in flight compared with a 1/12-scale model in the free-flight tunnel.

(a) Landing gear up;flaps up;center of gravity, 28.6 percent M.A.C.
(b) Landing gear down;flaps 45° down;center of gravity,26.7 percent M.A.C.

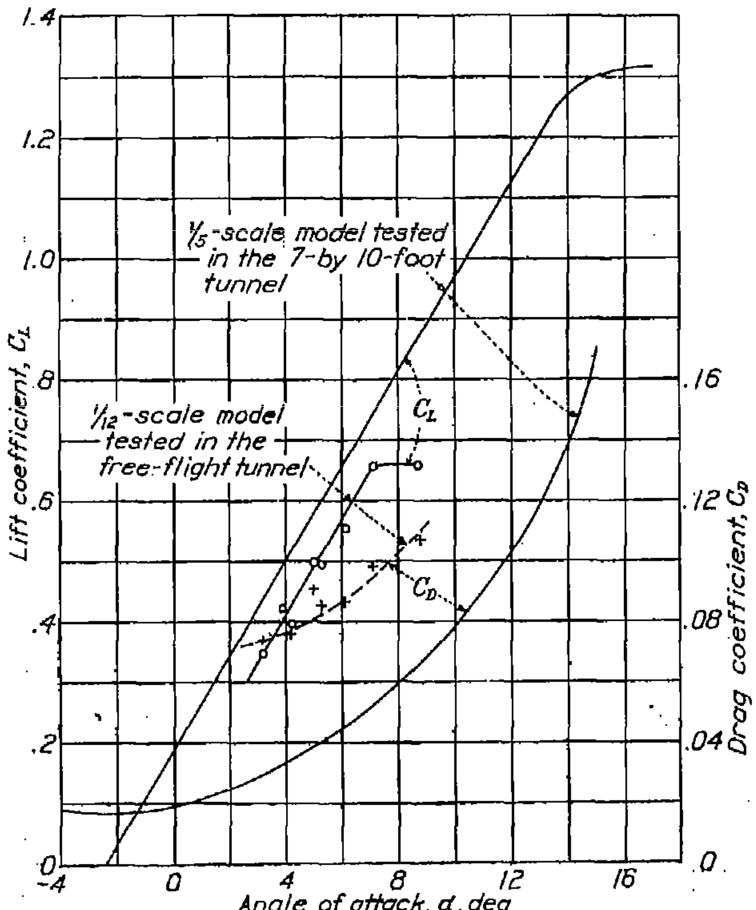


Figure 9.- Lift and drag characteristics of a 1/12-scale model of the curtiss P-36A airplane tested in the free-flight tunnel compared with those of a 1/5-scale model tested in the 7-by 10-foot tunnel. Landing gear up; flaps up; propeller removed.

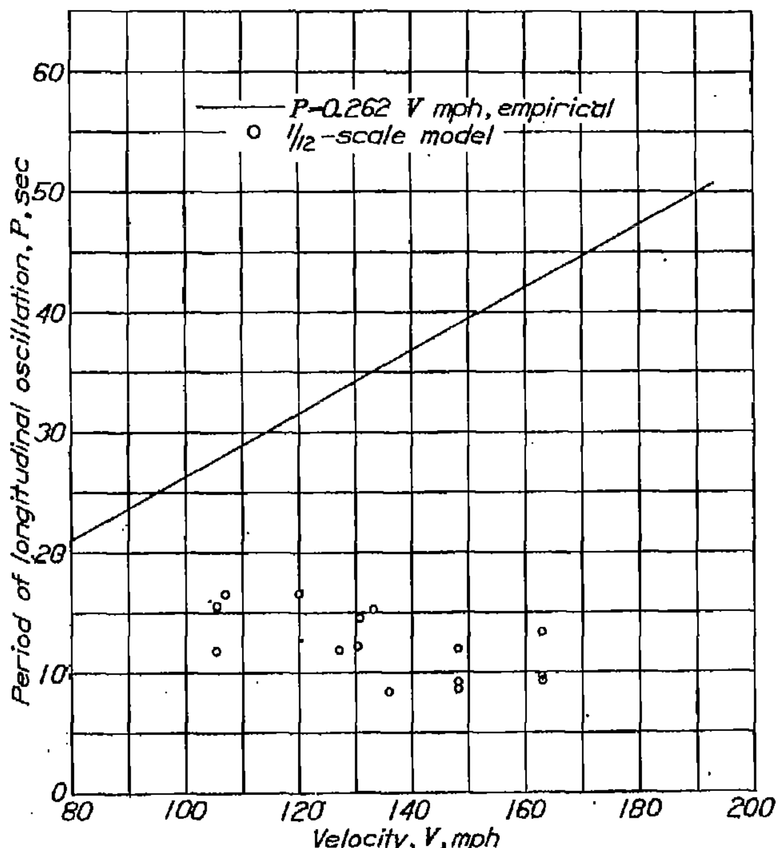


Figure 11.- Period of the longitudinal oscillation of a 1/12-scale model of the Curtiss P-36A airplane compared with the empirical value of the phugoid oscillation derived from tests of a number of airplanes.

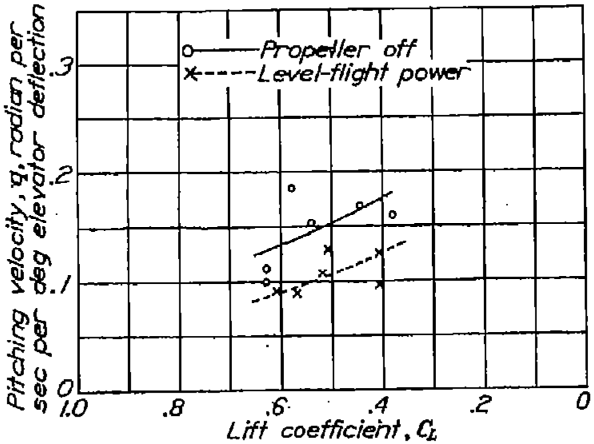
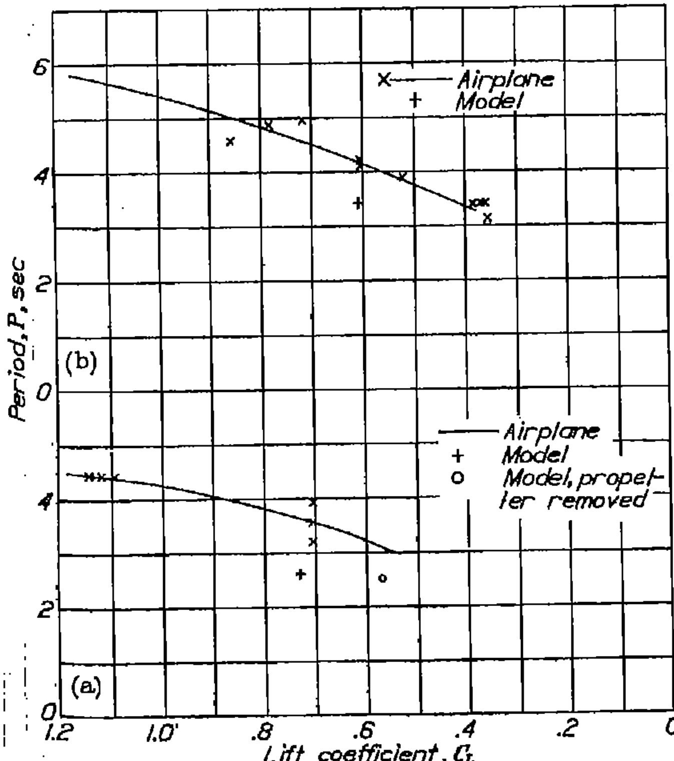
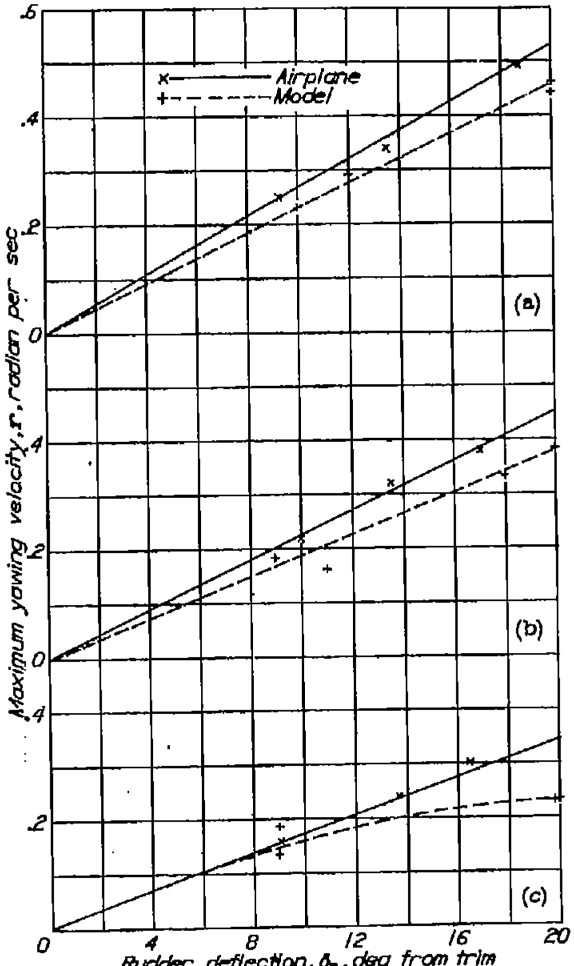


Figure 13.- Elevator effectiveness in producing pitching velocity of a 1/12-scale model of a Curtiss P-38A airplane. landing gear up; flaps up.



(a) Landing gear down; flaps 45° down
(b) Landing gear up; flaps up.

Figure 14.- Period of lateral oscillation of a P-38A airplane in flight compared with free-flight-tunnel data of a 1/12-scale model. Power off.



(a) Landing gear up; flaps up; power on. (b) landing gear up; flaps up; power off (windmilling). (c) landing gear down; flaps 45° down; power off (windmilling).
Figure 18.- Effectiveness of the rudder in producing yawing velocity of a P-38A airplane in flight compared with free-flight-tunnel data of a 1/12-scale model. C_L = 0.65.

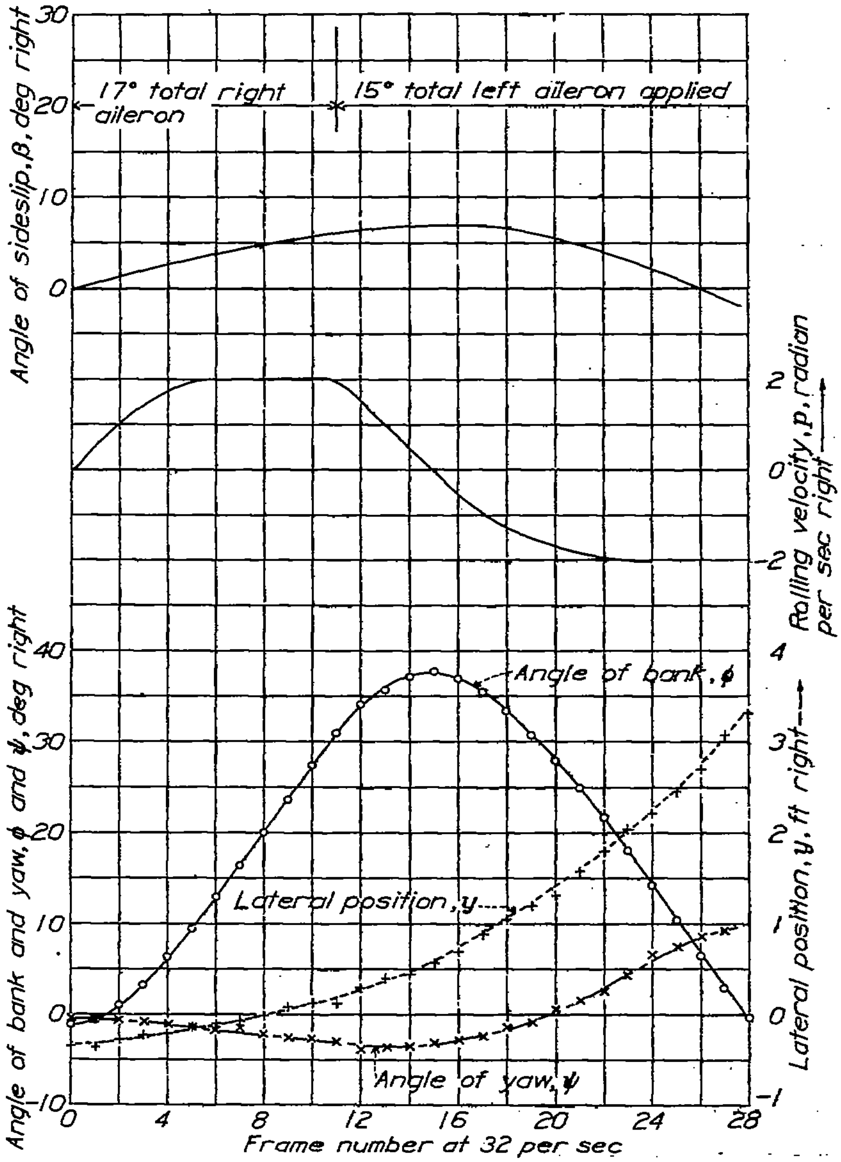


Figure 15.-A typical abrupt aileron maneuver of a 1/12-scale model of a Curtiss P-36A airplane showing the displacements with time due to abrupt aileron deflection. Landing gear down; flaps 45° down; propeller removed. C_L= 0.58.

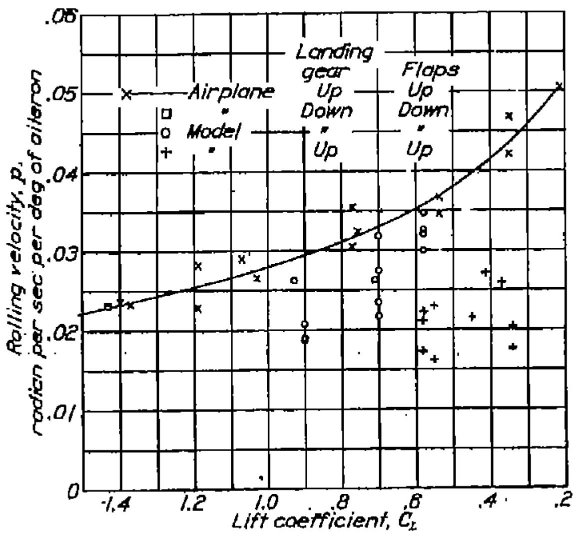


Figure 16.- Aileron effectiveness of a 1/12-scale model of the Curtiss P-36A airplane compared with the airplane measured by steady rolling velocities in abrupt aileron maneuvers. Deflection, 75 percent; power on and off.

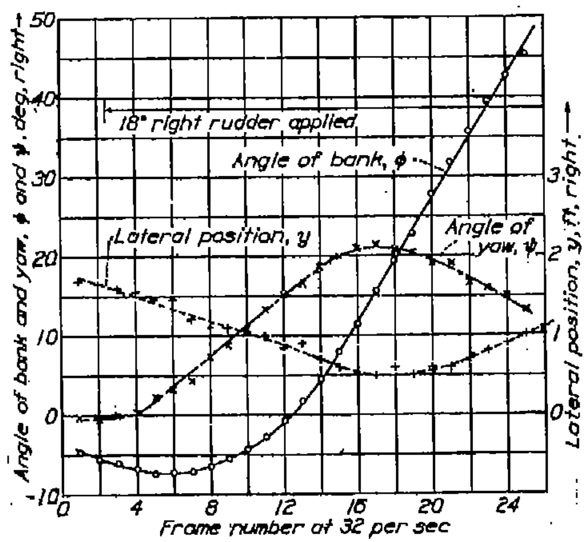


Figure 17.- A typical abrupt rudder maneuver of a 1/12-scale model of a Curtiss P-36A airplane showing displacements with time due to abrupt rudder deflection. Landing gear up; flaps up; power off; C_L= 0.65.

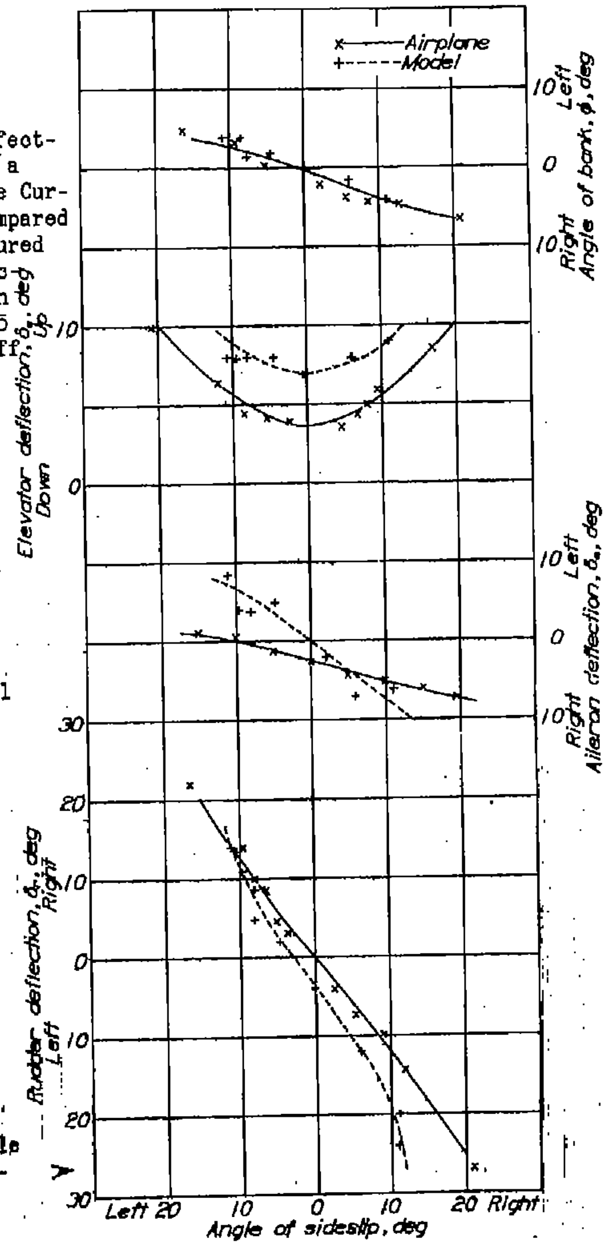


Figure 19.- Steady sideslip characteristics of a P-36A airplane in flight compared with a 1/12-scale model tested in the free-flight tunnel. Flaps down; Landgear down; power off (windmilling); C_L= 1.0.