NACA RM No. L8F07

NACA

RESEARCH MEMORANDUM

A COMPARISON OF FLIGHT MEASUREMENTS WITH CALCULATIONS OF THE LOSS IN ROLLING EFFECTIVENESS DUE TO WING TWIST

By

T. V. Cooney and Bertram C. Wollner

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
August 27, 1948

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

A COMPARISON OF FLIGHT MEASUREMENTS WITH CALCULATIONS OF THE LOSS IN ROLLING EFFECTIVENESS DUE TO WING TWIST

By T. V. Cooney and Bertram C. Wollner

SUMMARY

A flight investigation was conducted with a fighter-type airplane to determine the loss in rolling effectiveness due to wing twist, and the results are compared with the loss in rolling effectiveness calculated by use of a simplified method.

The computed rolling velocities showed good agreement with experimentally determined rolling velocities throughout the Mach number range covered by the flights. Extrapolation of the flight data indicated a Mach number for reversal which agreed well with that obtained from calculations.

INTRODUCTION

The influence of structural flexibility on performance is aggravated by the high speeds at which present-day aircraft are designed to operate. Deformations such as twisting of the wings caused by deflecting conventional ailerons result in large reductions in rolling velocity with ultimate reversal of aileron control.

A number of methods are available for calculating this loss in rolling velocity due to wing twist and the speed at which aileron reversal occurs. The methods which establish an equilibrium between elastic and aerodynamic forces along the span require considerable computation. (See references 1 and 2 for example.) Although based on exact formulas, these methods are limited in accuracy to the accuracy with which the pertinent aerodynamic parameters and their variation with Mach number are known.

Simplified procedures also exist which permit a big saving in computation time. One such method (reference 3) is based on the semi-rigid wing concept and replaces the actual wing with an equivalent wing. Reversal-speed calculations carried out by use of this simplified method showed such good agreement with the reversal speed obtained by the more lengthy method of successive approximations outlined in reference 2 that use of the simplified method was amply justified.

Another simplified procedure is given in reference 4 where charts and formulas derived by use of lifting-line theory and a specified stiffness distribution are presented. Over-all induction effects are accounted for, and the variation of rolling velocity with Mach number as well as the reversal speed may be determined with a minimum of calculation time.

In order to determine the correlation to be expected between losses in rolling velocity calculated by use of the simplified procedure of reference 4 and experimentally determined losses, a flight-test program was undertaken. Experimental data were obtained from rolling flights made through the speed range up to $M = 0.7$. Aerodynamic and structural parameters required for the calculations were obtained from two-dimensional wind-tunnel tests conducted in the Langley 8-foot high-speed tunnel and from static torsional stiffness tests made at the Langley aircraft loads calibration laboratory.

SYMBOLS

Symbols used in the present paper are defined as follows:

b	wing span, feet
S	wing area, square feet
$\bar{c}$	mean geometric wing chord, feet (S/b)
m_{θ_r}	wing torsional stiffness at reference station (midaileron), foot-pounds per radian
τ	rolling-moment-loss parameter
γ	helix-angle parameter
θ	angle of twist, degrees
δ	aileron deflection, degrees
p	rolling velocity, radians per second
$pb/2V$	wing-tip helix angle, radians
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
a	speed of sound, feet per second
V	true airspeed, feet per second
M	Mach number (V/a)

$1/\sqrt{1 - M^2}$ Glauert compressibility correction factor

ρ air density, slugs per cubic foot

$d\alpha/d\delta$ rate of change of wing angle of attack with aileron deflection for constant normal force at section

$dc_m/d\delta$ rate of change of section pitching-moment coefficient with aileron deflection for constant normal force at section

APPARATUS AND TESTS

Airplane

Flights were made with a single-engine, low-wing, fighter-type airplane, having a wing approximately elliptic in plan form, with a span of 40.8 feet and an aspect ratio of 5.55. Ailerons were of the Frise type with no differential gearing. The ratio of the aileron chord aft of the hinge to the over-all wing chord varied along the aileron span and was equal to 0.21 at the midaileron-span station. A three-view drawing of the airplane is shown in figure 1 and a sketch of the wing plan form and reference section at the midaileron station is shown in figure 2.

Instrumentation

Standard NACA photographic recording instruments were used to measure airspeed, pressure altitude, rate of roll, rate of yaw, aileron and rudder position, and sideslip angle. All records were synchronized by means of 0.1-second timer.

Airspeed measurements were made by use of a fixed static and total head tube mounted on a boom extending approximately 1 chord length ahead of the left wing tip. The installation was calibrated for position error.

The vane for measurements of sideslip angle was mounted on a boom located near the right wing tip.

Electrical control-position transmitters were used to measure aileron position and rudder position, the transmitters for measurement of aileron position being attached directly to the aileron actuating rods to eliminate effects of control-system elasticity.

The twist of the right wing at a station just inboard of the mid-aileron station was obtained in flight by use of the installation shown in figure 3. An aluminum-alloy rod of circular cross section 1 inch in diameter was attached rigidly to the rib at wing station 64 and extended outboard through the wing to the station at which measurement of wing twist was made. At this measurement station an aluminum-alloy bar extended fore and aft and was attached to front and rear spars. The spanwise rod and chordwise bar were joined at the measurement station by a fitting and necked-down deflection beam on which a strain gage was mounted. Twisting of the wing caused this necked-down portion of the fitting to deflect, and the variation of twist as transmitted by the strain gage was recorded with a galvanometer located in the fuselage.

The installation for measuring twist was calibrated by using a hydraulic jack to apply increments of up-load at the rear spar. In order to measure the actual twist of the wing, dial gages were located at front and rear spars of the wing root chord and of the wing stations corresponding to the inboard and outboard ends of the twist rod.

Comparison of the recorded twist obtained when a pure torque was applied to the wing, and when the hydraulic jack was used to produce bending and torsion simultaneously, indicated that the presence of wing bending did not affect measurements of twist.

FLIGHT TESTS

All flights were made with power on and with the airplane in the clean condition. In trimmed level flight the ailerons were deflected abruptly and held at constant deflection until the maximum rolling velocity was attained. Aileron deflections were limited to approximately 5° by a chain attached to the control stick; the rudder was held fixed throughout the maneuver. Rolls to left and right were made at an altitude of 10,000 feet up to $M = 0.7$ during which rolling velocity, the resulting sideslip angle and yawing velocity, aileron deflections, and wing twist were measured.

In order to account for the loss in rolling velocity due to sideslip an additional flight was made to determine the sideslipping characteristics of the airplane. Measurements of aileron deflection and angle of sideslip were made during steady sideslips to right and left up to $M = 0.6$ at 10,000 feet.

METHOD AND RESULTS

Experimentally Determined Rolling Velocity

Typical time histories of measurements made in left rolls are shown in figure 4. From time histories of the type shown, the maximum rolling velocity and the airspeed and aileron angle at the time of maximum rolling velocity were obtained. The mean of right and left aileron angles was used in computing the corresponding wing-tip helix angle per unit aileron deflection $\frac{pb/2V}{\delta}$. Figure 5 shows the variation of $\frac{pb/2V}{\delta}$ with the factor $q\Big/\sqrt{1 - M^2}$. In this figure the circled points represent values of $\frac{pb/2V}{\delta}$ measured in rudder-fixed rolls and the squared points represent these measured values corrected for rolling-velocity losses due to sideslip. The correction to be applied to measured values of $\frac{pb/2V}{\delta}$ was determined from a knowledge of the sideslip angle and aileron deflection occurring at the time of maximum rolling velocity in rudder-fixed rolls, and the aileron angle required to balance sideslip in steady sideslipping flight.

Calculated Rolling Velocity

Pearson and Aiken (reference 4) have used lifting-line theory in the derivation of formulas to compute rolling-effectiveness losses and aileron-reversal speed. Charts are also presented which, when used in conjunction with simplified formulas, considerably reduce the computation time. In the development of these charts, induced-lift effects have been taken into account and a cubic wing-torsional-stiffness curve has been assumed.

Formulas derived in reference 4 when combined and modified to a form suitable for present calculations result in

$$\frac{p}{\delta} = M\gamma \frac{a}{b/2}\left(\frac{d\alpha}{d\delta} - \frac{\tau \frac{dc_m}{d\delta} \frac{q}{\sqrt{1 - M^2}} S\bar{c}}{2m_{\theta_r}}\right) \tag{1}$$

which indicates zero rolling velocity (aileron reversal) when

$$\frac{\tau \frac{dc_m}{d\delta} \frac{q}{\sqrt{1 - M^2}} S\bar{c}}{2m_{\theta_r}} = \frac{d\alpha}{d\delta} \tag{2}$$

The aerodynamic parameters, structural parameters, and geometry of the airplane required to calculate the rolling-effectiveness loss and aileron reversal speed are listed as follows:

Wing torsional stiffness at midaileron station m_{θ_r}, foot-pounds per radian	516,000
$dc_m/d\delta$	0.575
$d\alpha/d\delta$	0.450
γ	0.920
τ	0.250
Wing span, b, feet	40.8
Mean geometric chord, $\bar{c}$, feet	7.3
Wing area, S, square feet	300

The value of torsional stiffness given above was obtained by taking the average of the values given in figure 6 for right and left wings at the midaileron station. The torsional-stiffness distribution shown in figure 6 was determined from static tests made at the Langley aircraft loads calibration laboratory, and was obtained by applying equal and opposite torques to the wings outboard of the midaileron station.

The aerodynamic parameters $dc_m/d\delta$ and $d\alpha/d\delta$ were obtained from tests made in the Langley 8-foot high-speed tunnel on an airfoil section similar to the section at the midaileron of the test airplane but having an aileron-chord to wing-chord ratio of 0.20. Values shown above are the low-speed values modified by an amount proportional to the theoretical differences existing for aileron-chord to wing-chord ratios of 0.20 and 0.21.

The parameters γ and τ are constants which depend on the taper ratio and spanwise location of the ailerons and were obtained from the charts presented in reference 4.

In figure 7 is shown the p/δ variation with Mach number at 10,000 feet as determined from calculations made using equation (1) as well as the experimentally determined rolling velocities. The full line in the figure represents the rolling-velocity variation calculated by use of the low-speed value of $d\alpha/d\delta$ throughout the Mach number range while the long-dash line represents the rolling-velocity variation calculated using the change in $d\alpha/d\delta$ with Mach number as given in reference 5.

When the indicated substitutions are made in equation (2), a reversal $q/\sqrt{1 - M^2}$ of 1460 pounds per square foot is indicated.

Wing-Twist Measurements

Figure 8 shows the twist produced by a unit aileron deflection at a station just inboard of the midaileron station on the right wing. The twist measurements were obtained by using the instrument, which was described in the section on instrumentation, attached at the inboard end to a wing rib 64 inches from the airplane center line. As a result the measured twist was the twist of the reference station relative to station 64. Calculations of the twist distribution over the wing indicated that the twist relative to the airplane center line would be approximately 10 percent greater than that shown in figure 8.

DISCUSSION OF RESULTS

The $\frac{pb/2V}{\delta}$ obtained in right and left rolls, modified to account for the rolling-velocity loss due to sideslip, shows a linear variation when plotted against the parameter $q/\sqrt{1 - M^2}$ (fig. 5). Extrapolation of these flight data indicates a reversal $q/\sqrt{1 - M^2}$ of 1275 pounds per square foot equivalent to $M = 0.843$ at 10,000 feet, while the calculations indicated 1460 pounds per square foot $(M = 0.855)$ as the reversal $q/\sqrt{1 - M^2}$ (fig. 7).

An extrapolation of the flight data to Mach numbers of 0.8 or greater is of rather questionable validity in view of the fact that the flight data did not exceed $M = 0.7$. At sea level, however, a value of $q/\sqrt{1 - M^2}$ of 1275 pounds per square foot represents a Mach number of only 0.75 which should be a good approximation to the reversal Mach number at this altitude.

The variation of wing twist caused by deflecting the aileron as measured in rolling flights was found from figure 8 to increase with q according to the factor $1/\sqrt{1 - M^2}$. Since the amount of wing twist produced by deflecting an aileron results directly from the pitching moment produced by the deflected aileron, the results shown in figure 8 indicate that the assumption for $dc_m/d\delta$ made in the calculations was valid within the Mach number range covered by the flight tests.

In the simplified formulas used for the preceding calculations $d\alpha/d\delta$ was assumed to be a constant while $dc_m/d\delta$ was varied according to the Glauert compressibility correction factor. Figure 7 shows that calculations which take into account wing flexibility give good agreement with results obtained from flight tests. Closer agreement resulted when both wing flexibility and the effects of compressibility on $d\alpha/d\delta$ were considered in the calculations.

The variation of $d\alpha/d\delta$ with Mach number will generally not be known for the specific wing-aileron combination under consideration. In such cases it appears that the use of the simplified procedure of Pearson and Aiken will give results that only slightly overestimate the rolling ability of the airplane.

CONCLUSIONS

1. Use of a simplified method for calculation of the loss in rolling velocity due to wing twist for a fighter-type airplane showed good agreement with flight results.

2. Closer agreement was obtained when the effects of compressibility on the aerodynamic parameter $d\alpha/d\delta$ were included in the calculations.

3. Calculation of the Mach number at which aileron reversal would occur agreed well with results obtained by extrapolation of flight data.

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

REFERENCES

1. Harmon, Sidney M.: Determination of the Effect of Wing Flexibility on Lateral Maneuverability and a Comparison of Calculated Rolling Effectiveness with Flight Results. NACA ARR No. 4A28, 1944.

2. Shornick, Louis H.: The Computation of the Critical Speeds of Aileron Reversal, Wing Torsional Divergence and Wing-Aileron Divergence. MR No. ENG-M-51/VF18, Addendum 1, Materiel Center, Army Air Forces, Dec. 19, 1942.

3. Hirst, D. M.: On the Calculation of Critical Reversal Speeds of Wings. R. & M. No. 1568, British A.R.C., 1934.

4. Pearson, Henry A., and Aiken, William S., Jr.: Charts for the Determination of Wing Torsional Stiffness Required for Specified Rolling Characteristics or Aileron Reversal Speed. NACA Rep. No. 799, 1944.

5. Luoma, Arvo A.: Effect of Compressibility on Section Characteristics of an Airfoil with a Round-Nose Slotted Frise Aileron. NACA TN No. 1075, 1946.

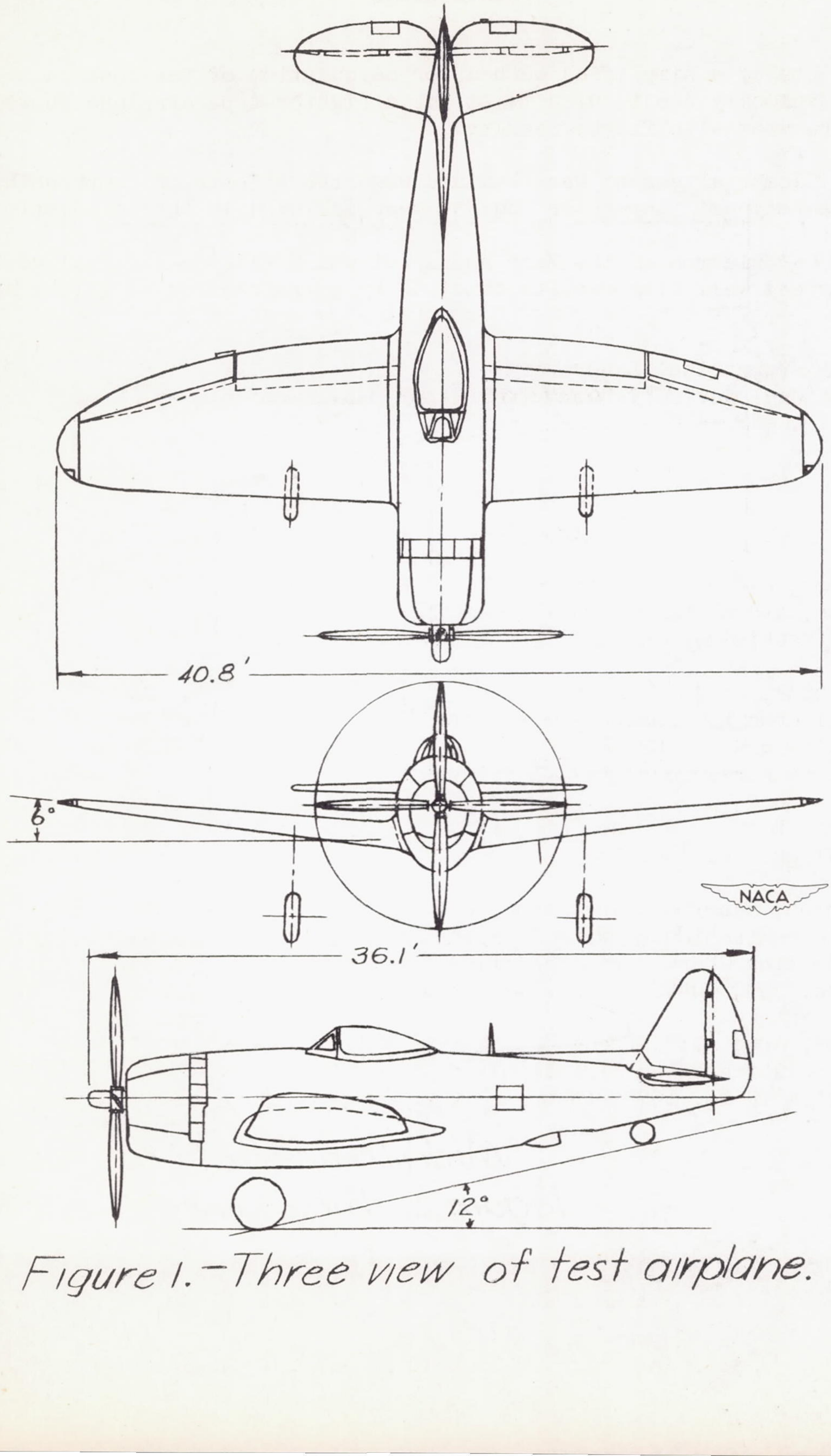
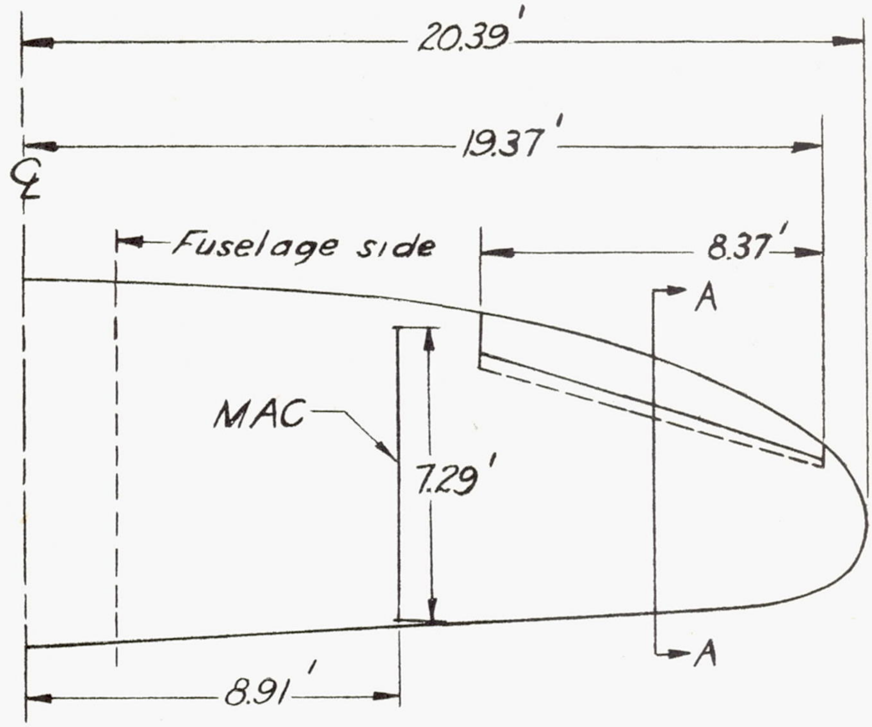


Figure 1.-Three view of test airplane.



Section A-A
Midaileron station
Figure 2.- Wing layout.

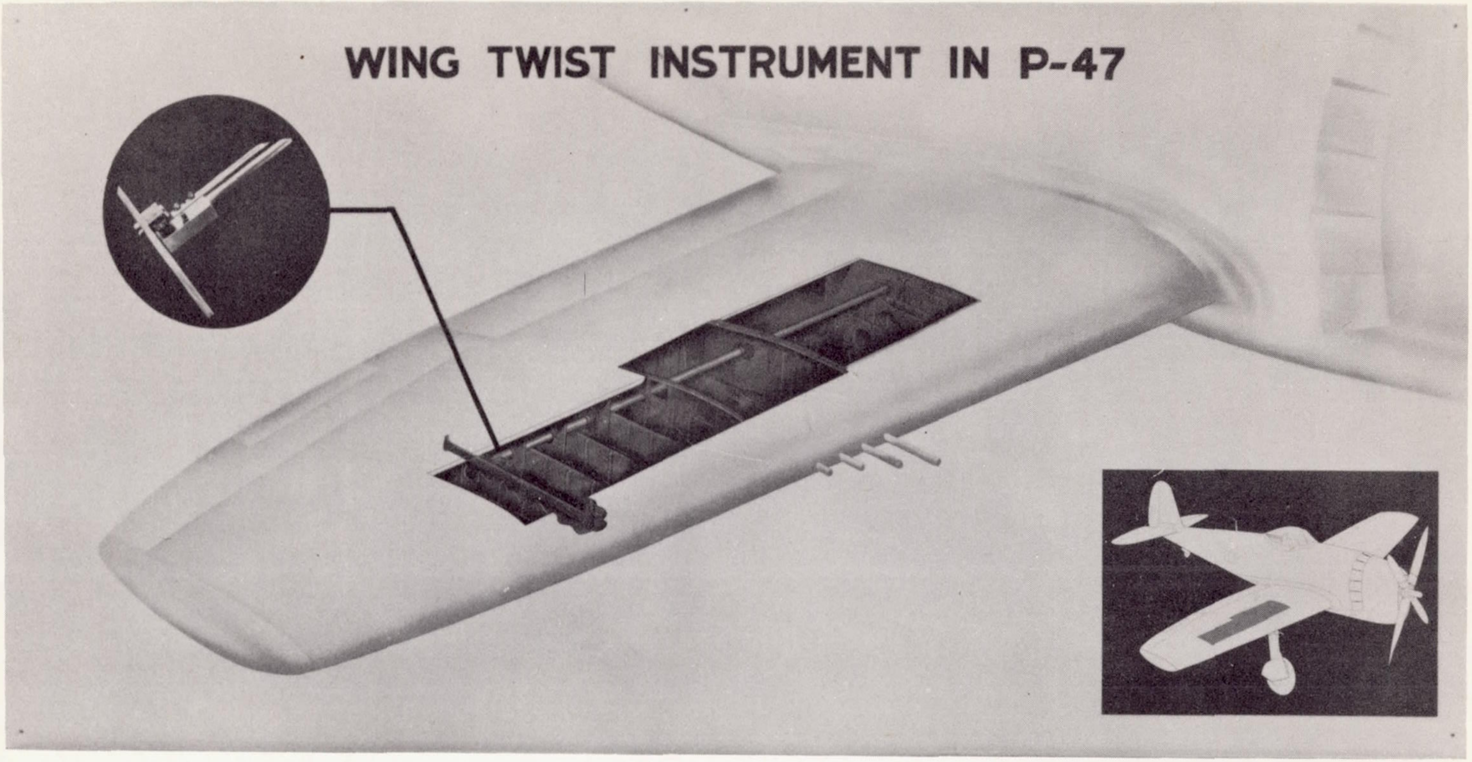
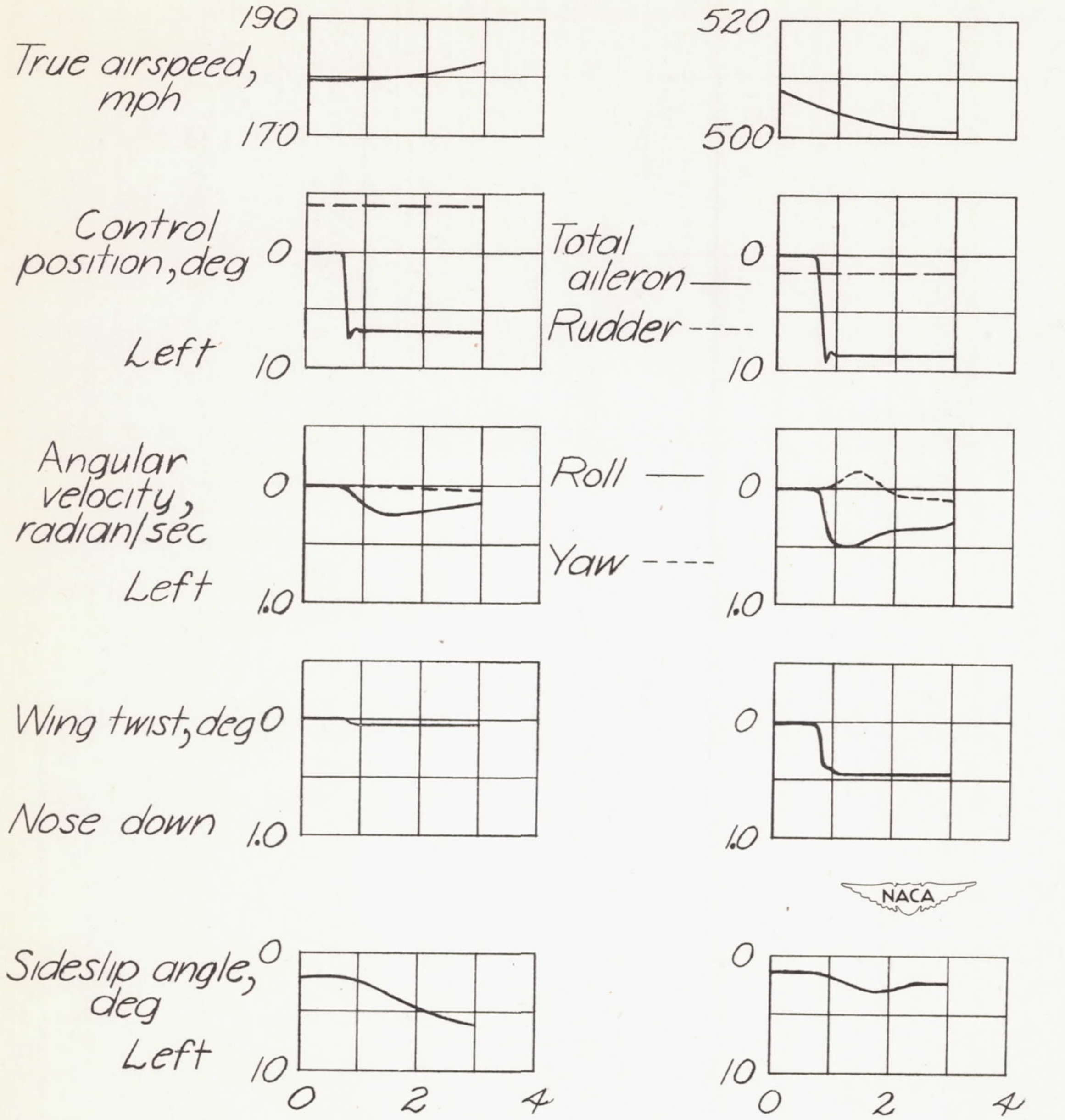


Figure 3.- Wing-twist-instrument installation.

NACA

L-55615



(a) Left roll at 150 mph indicated airspeed.

(b) Left roll at 440 mph indicated airspeed.

Figure 4.—Typical time histories of abrupt aileron rolls with rudder held fixed; airplane in clean condition; power on at 10,000-foot altitude.

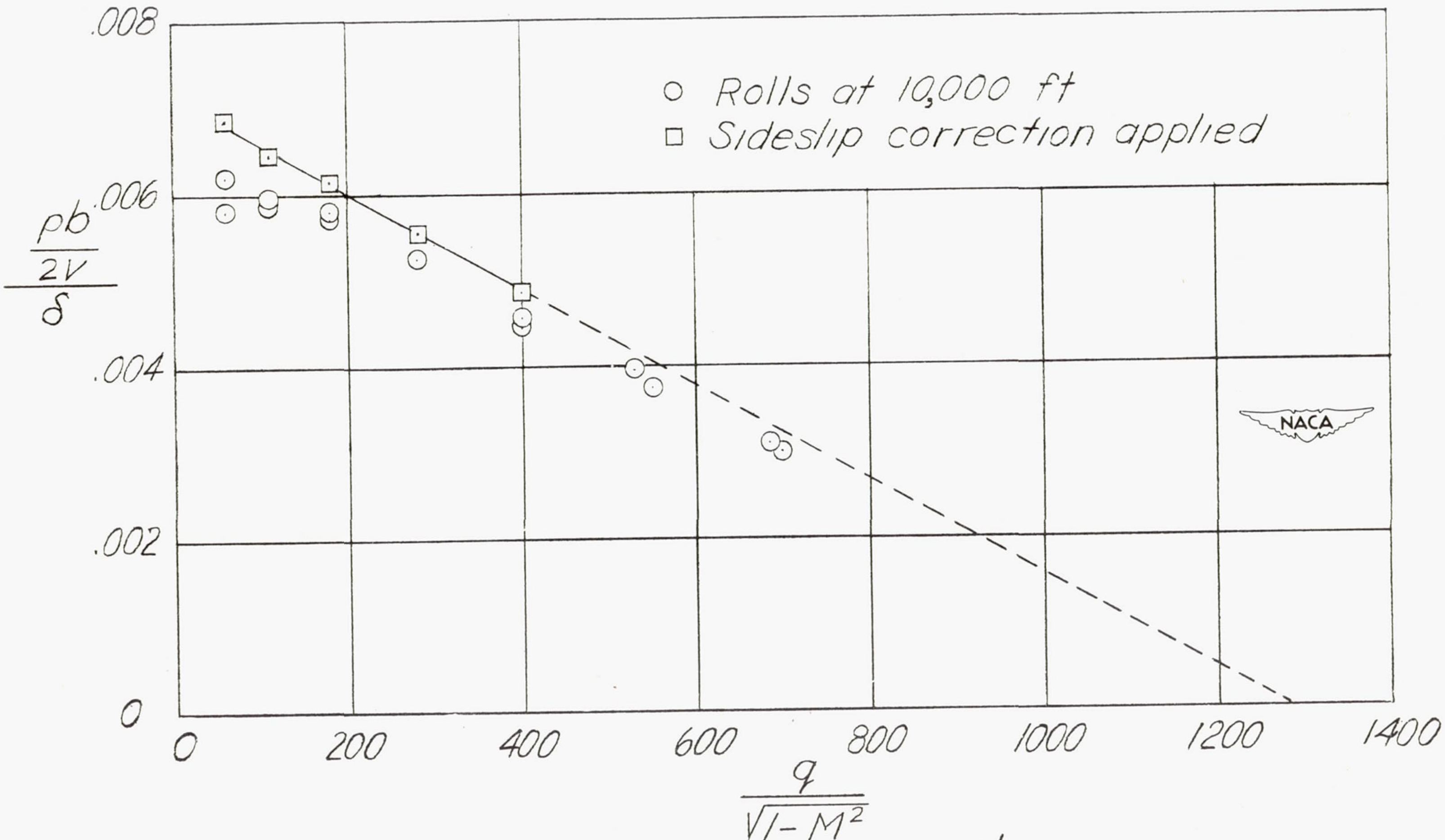


Figure 5.- Variation of wing-tip helix angle $\frac{pb}{2V}$ per unit aileron angle with the parameter $\frac{q}{\sqrt{1-M^2}}$

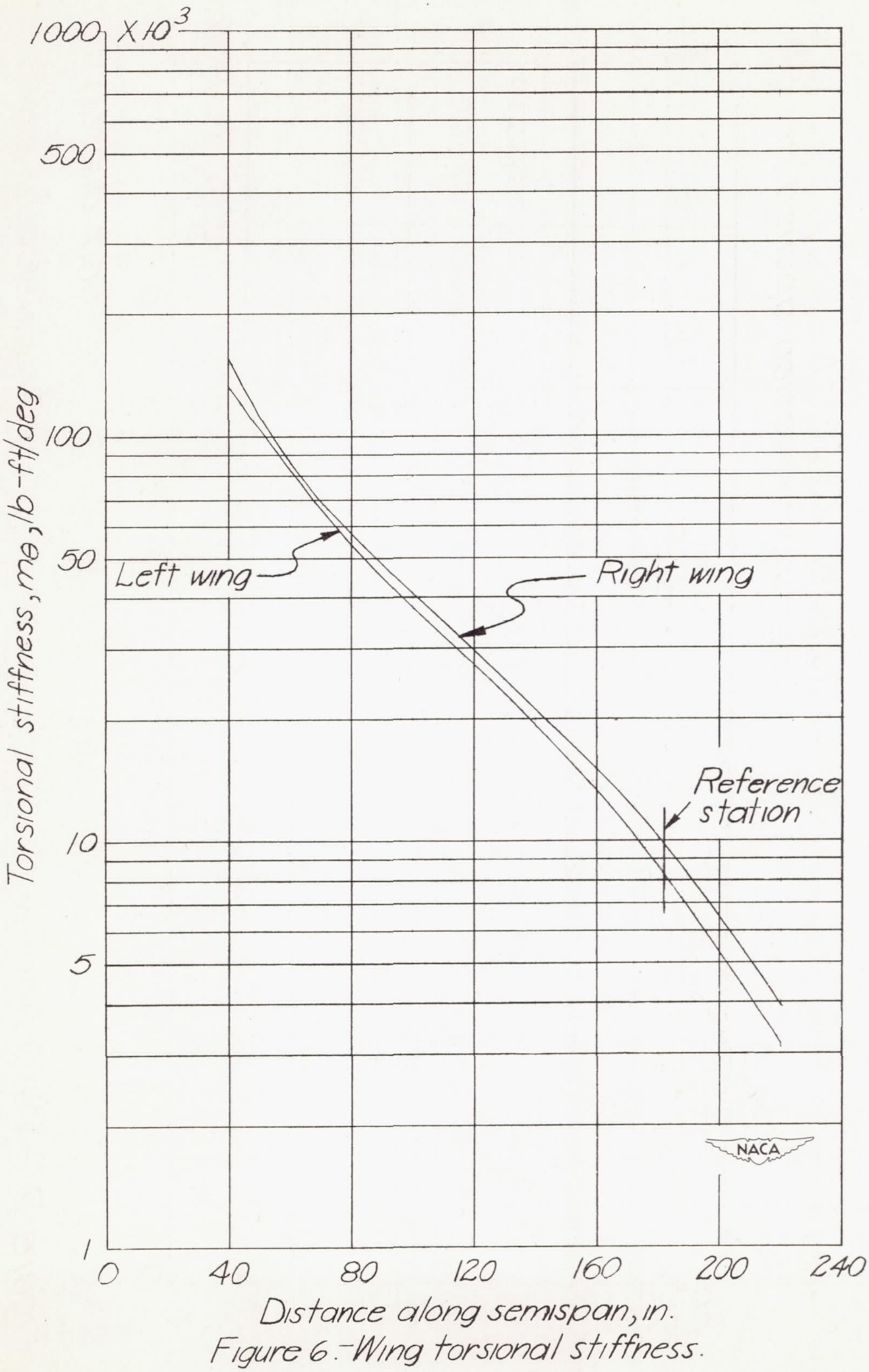


Figure 6.- Wing torsional stiffness.

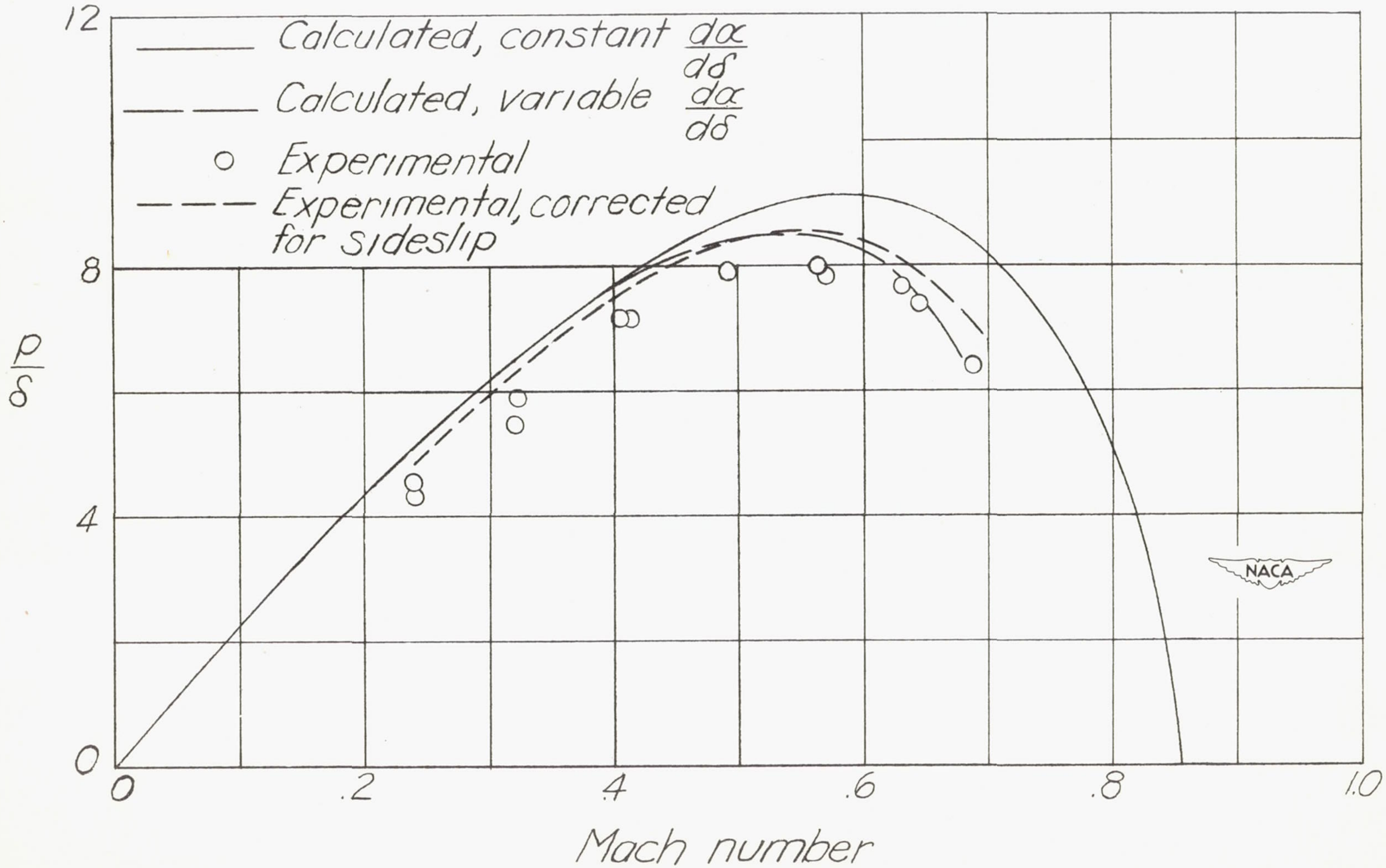


Figure 7. - Variation with Mach number of rolling velocity per unit aileron angle at 10,000 feet.

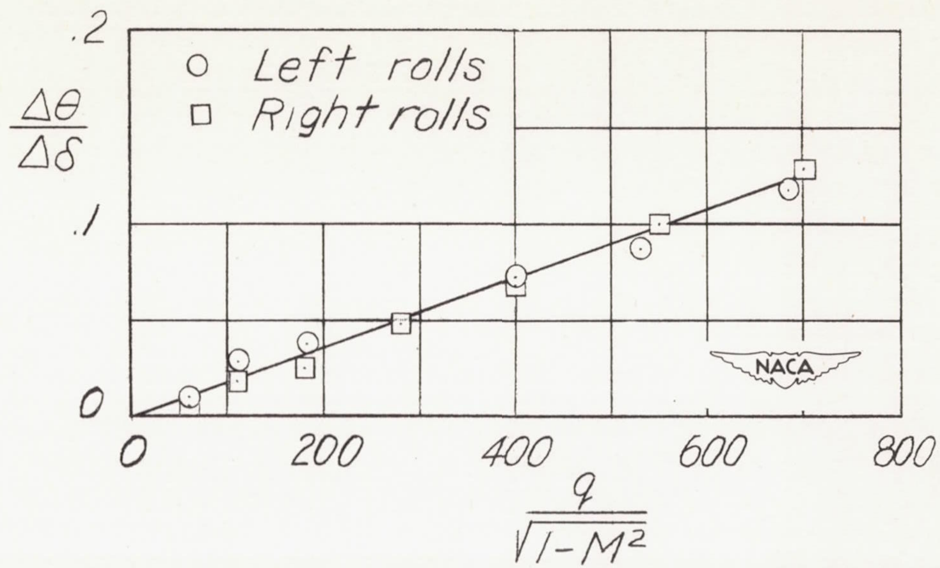


Figure 8.– Variation of increment in twist produced by aileron deflection with the parameter $\frac{q}{\sqrt{1-M^2}}$.