NACA

RESEARCH MEMORANDUM

ROLLING EFFECTIVENESS OF ALL-MOVABLE WINGS AT SMALL

ANGLES OF INCIDENCE AT MACH

NUMBERS FROM 0.6 TO 1.6

By H. Kurt Strass and Edward T. Marley

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
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ROLLING EFFECTIVENESS OF ALL-MOVABLE WINGS AT SMALL ANGLES OF INCIDENCE AT MACH NUMBERS FROM 0.6 TO 1.6

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SUMMARY

Experimental data have been obtained of the rolling effectiveness of several all-movable wing configurations by means of rocket-propelled test vehicles in free flight. The results are compared with some available methods of estimation. These results validate the use of the simple equation derived by a strip integration and originally presented in NACA RM L50G14b over a wide range of application as a means of estimating the rolling effectiveness of all-movable wings.

INTRODUCTION

The wing-control effectiveness data obtained by the Langley Pilotless Aircraft Research Division are normally presented for models having zero wing incidence. The data obtained from models having small but measurable wing incidence resulting from practical construction tolerances must therefore be corrected to a nominal average wing incidence value of zero. The experimental data presented herein were primarily obtained for the purpose of verifying the use of the equation $\frac{pb}{2V} = \frac{2i_w}{57.3}\left(\frac{1 + 2\lambda}{1 + 3\lambda}\right)$ (derived in the appendix) which was originally presented in reference 1 as a means of correcting rolling effectiveness to zero incidence. Inasmuch as the current investigation related to the problem of predicting rolling effectiveness of aircraft configurations having all-movable wings, a comparison is made of the $pb/2V$ values estimated from strip theory and the estimated values from references 2, 3, and 4 with the experimental values of this investigation. These three methods of estimating the $pb/2V$ values for various Mach numbers are also compared with similar experimental data obtained by a different technique described in reference 2.

Three wing plan forms were tested, an untapered wing having 0° and 45° sweep and a delta wing having a 45° swept leading edge. (It is considered that these plan forms represent a sufficiently wide range for assuming that the demonstrated agreement with the simplified incidence correction theory should hold true for wings with plan forms intermediate to those for which data are available.)

All experimental data presented in this paper, excluding the experimental data taken from reference 2, were obtained by means of rocket-propelled test vehicles in free flight.

SYMBOLS

A	aspect ratio, (b^2/S)
b	diameter of circle swept by wing tips (with regard to rolling characteristics this diameter is considered to be the effective span of the three fin models), feet
M	Mach number
p	rolling velocity, radians per second
V	flight-path velocity, feet per second
$pb/2V$	wing-tip helix angle, radians
S	area of two wing panels measured to fuselage center line
i_w	average wing incidence for three wings, positive when tending to produce clockwise roll when model is viewed from rear, degrees
λ	taper ratio, ratio of tip chord to root chord at model center line
Λ	angle of leading-edge sweep, degrees
R	Reynolds number based upon mean exposed free-stream chord

MODELS AND TECHNIQUE

The general arrangement of the test vehicles used in this investigation is shown by the sketches in figure 1 and by the photograph presented as figure 2.

Three different wing plan forms of varying angles of incidence comprising a total of seven models were constructed. The wings of all models were mounted with preset angles of incidence. The average measured incidence value of each of the test vehicles together with the wing geometry is presented in table I. The total exposed wing area for each model was 1.563 square feet.

The test vehicles were propelled by a two-stage rocket-propulsion system up to a Mach number of about 1.6. The variation of Mach number with Reynolds number is shown in figure 3. Time histories of the rolling velocity obtained with special radio equipment and flight-path velocity obtained by Doppler radar were recorded during a 12-second period of coasting flight following sustained-rocket burnout. These data together with radiosonde atmospheric data provided information for the computation of all-movable airfoil rolling effectiveness in terms of the parameter $pb/2V$ as a function of Mach number. A detailed discussion of the testing technique can be found in reference 5.

ACCURACY

The experimental accuracy is estimated to be within the following limits:

	Subsonic	Supersonic
$pb/2V$	±0.0015	±0.0010
M	±0.005	±0.005

The accuracy of Δi_w (uncertainty of measured values) is ±0.03°.

The sensitivity of the experimental technique is such that much smaller irregularities in the variation of $pb/2V$ with Mach number may be detected.

METHODS OF ESTIMATION

The control-effectiveness parameter $pb/2V$ as a function of Mach number has been estimated for purposes of comparison in this paper by three methods.

The method of reference 1 was derived by using simple strip theory assuming steady-state rolling conditions to exist and the aircraft or missile to have symmetrical wing sections. (See the appendix.)

The aerodynamic coefficients for the theoretical estimation of control effectiveness by the method of reference 2 were derived by the use of linearized supersonic theory. Body effects were accounted for by assuming zero pressure in that part of the wing covered by the fuselage.

The third method of estimation employs the combined use of the stability derivatives C_{l_δ} and C_{l_p} from references 3 and 4, respectively, where C_{l_δ} is the rolling coefficient due to aileron deflection $\frac{\partial C_l}{\partial \delta}$ (for this particular case, the aileron chord was considered equal to the wing chord) and C_{l_p} is the rolling moment coefficient due to roll $\frac{\partial C_l}{\partial \frac{pb}{2V}}$. The values used in those particular reports were derived by using supersonic linearized theory to obtain the pressure over an isolated wing, assuming that the body is not present.

RESULTS AND DISCUSSION

The data obtained during the present investigation are presented in figures 4 to 6 as curves of $pb/2V$ against Mach number. Figure 4 presents the experimental data for the unswept, untapered wings for three different angles of incidence as compared with three methods of estimation. Except in the region from $0.85 \leq M \leq 0.95$, the agreement of the calculated values based upon strip theory with the experimental values is good throughout the Mach number range shown. The erratic changes in $pb/2V$ which take place in the experimental curves in this region are due to a wing-dropping phenomenon and are discussed in reference 6. In the higher Mach number range from $M = 1.4$ to $M = 1.65$, the calculated $pb/2V$ values from reference 2 and from the combined use of references 3 and 4 approach the experimental values.

A comparison of the control-effectiveness data from the untapered 45° swept models with the calculated values from strip theory is shown in figure 5. Strip theory precludes any effect of wing sweep and is in reasonably good agreement with the experimental data.

Preliminary calculations indicate that the increase in $pb/2V$ above $M = 1.3$ is an aeroelastic phenomenon and is caused by the differences in wing load distribution due to incidence and damping when the model is in steady-state roll.

The $pb/2V$ values for the delta wing model and the calculated values from strip theory for such a model are shown as functions of Mach number in figure 6. Throughout the speed range these calculated values agree favorably with the experimental values.

Figure 7 presents the experimental and theoretical data from reference 2, figure 20, compared with the estimated values from references 1, 3, and 4. The equation of reference 1 provides values which show close agreement with the experimental values from reference 2. At the higher Mach numbers shown in this figure, the estimated values from references 1 and 2 practically coincide, while those calculated from the combination of references 3 and 4 remain slightly higher.

The above results indicate that the strip-theory equation provides an accurate method of predicting the rolling effectiveness $pb/2V$ for missiles or aircraft having all-movable wings. The facility with which the calculations can be carried out plus the wide range of Mach number values and plan forms for which this equation holds contribute to its practicability for such a use.

CONCLUSIONS

On the basis of the present investigation of the rolling effectiveness of several all-movable wing configurations it is possible to conclude that:

The simple strip-theory equation of NACA RM L50G14b provides a means for rapidly estimating the rolling effectiveness of all-movable wings over a wide range of wing plan forms. Except at transonic speeds $(0.85 \leqq M \leqq 0.95)$, this rolling effectiveness can be estimated throughout the Mach number range of 0.6 to 1.6 with good accuracy.

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

APPENDIX

DERIVATION OF SIMPLE STRIP-THEORY EQUATION

The derivation of the rolling effectiveness $pb/2V$ due to a differential incidence i_w is as follows:

In the general case, assume a wing with symmetrical profile and tapering linearly in plan form. The expression for the chord at any spanwise station y is

$$c = c_r\left[1 - \frac{2y}{b}(1 - \lambda)\right] \tag{1}$$

where c_r is the root chord at model center line. When two-dimensional lift is assumed to exist across the span, the expression for the lift over an incremental strip $c\,dy$ due to i_w is

$$\Delta L = i_w c_{l_\alpha} qc\,dy \tag{2}$$

where c_{l_α} is the two-dimensional lift-curve slope and q is the dynamic pressure.

The rolling moment m due to this incremental lift is $m = y\Delta L$.

The total rolling moment due to i_w is

$$\begin{aligned} M_{i_w} &= \int_0^{b/2} m \\ &= i_w c_{l_\alpha} q c_r \int_0^{b/2} \left[1 - \frac{2y}{b}(1 - \lambda)\right] y\,dy \\ &= i_w c_{l_\alpha} q c_r (b/2)^2 \left(\frac{1 + 2\lambda}{6}\right) \end{aligned} \tag{3}$$

In the steady-state rolling condition (constant rolling velocity), the damping moment due to roll must be equal to the rolling moment due to i_w.

In addition to the initial wing incidence, the angle of attack caused by rolling at any station along the span is

$$\alpha_{rad} = \frac{2y}{b}\left(\frac{pb}{2V}\right)$$

In a manner similar to that employed in the derivation of equation (3), the expression for the damping moment due to roll is

$$M_{pb/2V} = (pb/2V)c_{l_\alpha} qc_r(b/2)^2 \left(\frac{1 + 3\lambda}{12}\right) \qquad (4)$$

At steady-state

$$M_{i_w} = M_{pb/2V}$$

Solving this relationship for the steady-state tip helix angle $pb/2V$ due to i_w gives

$$pb/2V = 2i_w\left(\frac{1 + 2\lambda}{1 + 3\lambda}\right) \qquad (5)$$

where i_w is measured in radians;

$$pb/2V = \frac{2i_w}{57.3}\left(\frac{1 + 2\lambda}{1 + 3\lambda}\right) \qquad (6)$$

where i_w is measured in degrees.

REFERENCES

1. Strass, H. Kurt, Fields, E. M., and Purser, Paul E.: Experimental Determination of Effect of Structural Rigidity on Rolling Effectiveness of Some Straight and Swept Wings at Mach Numbers from 0.7 to 1.7. NACA RM L50G14b, 1950.

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6. Stone, David G.: Wing-Dropping Characteristics of Some Straight and Swept Wings at Transonic Speeds as Determined with Rocket-Powered Models. NACA RM L50C01, 1950.

TABLE I

DESCRIPTION OF INDIVIDUAL TEST MODELS

Figure	Model	i_w (deg)	Λ (deg)	A	λ	NACA airfoil section (Parallel to model center line)
1(a)	1	0.04	0	3.7	1	65A009
	2	.49				
	3	.97				
1(b)	1	-0.15	45	3.7	1	65A009
	2	.55				
	3	.97				
1(c)	1	0.74	45	4.0	0	65A006

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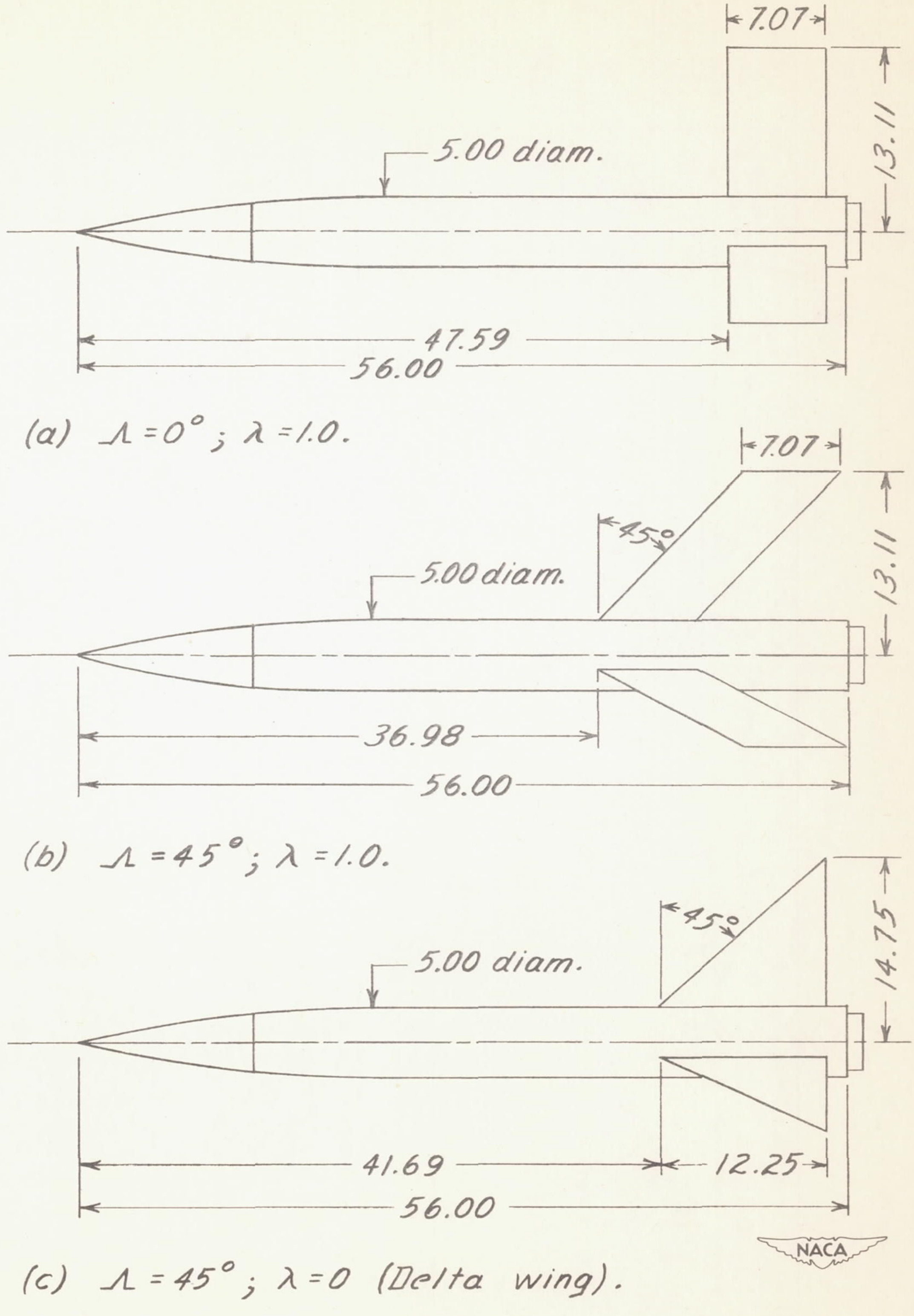
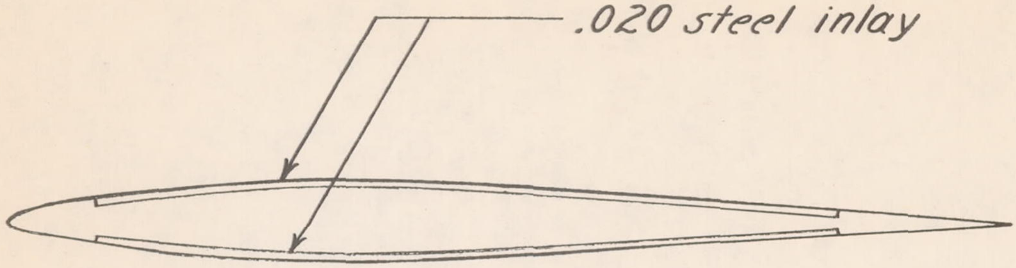
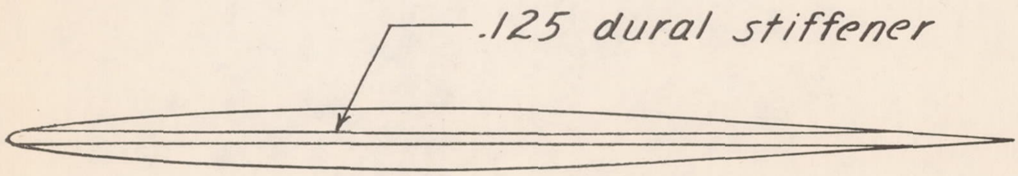


Figure 1.- Geometry of test vehicles. Dimensions are in inches.



Airfoil contour - NACA 65A009
Material - laminated spruce

(d) Typical cross-section for models (a) and (b).



Airfoil contour - NACA 65A006

(e) Typical cross-section for model (c).

Figure 1.- Concluded.

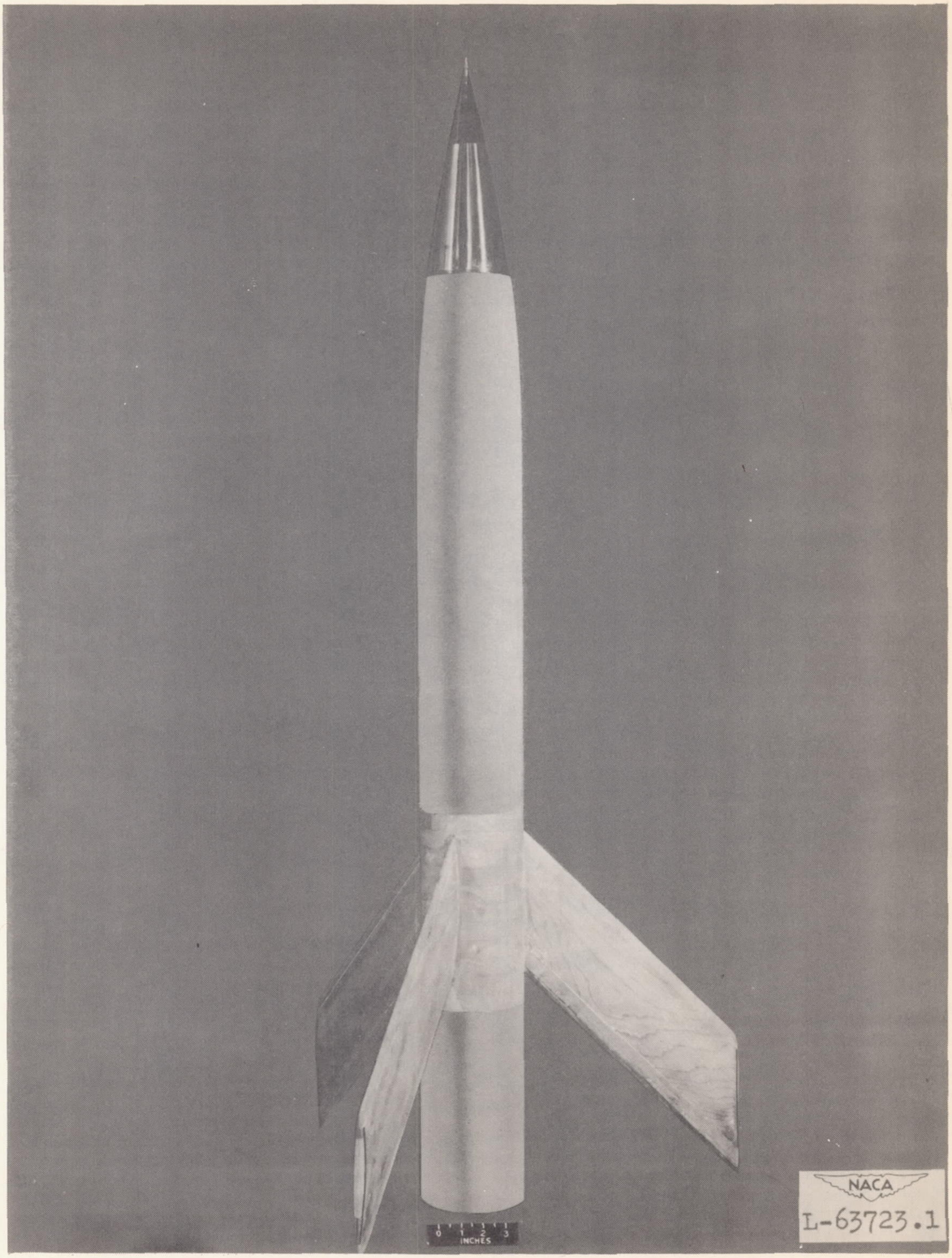


Figure 2.- Typical test vehicle.

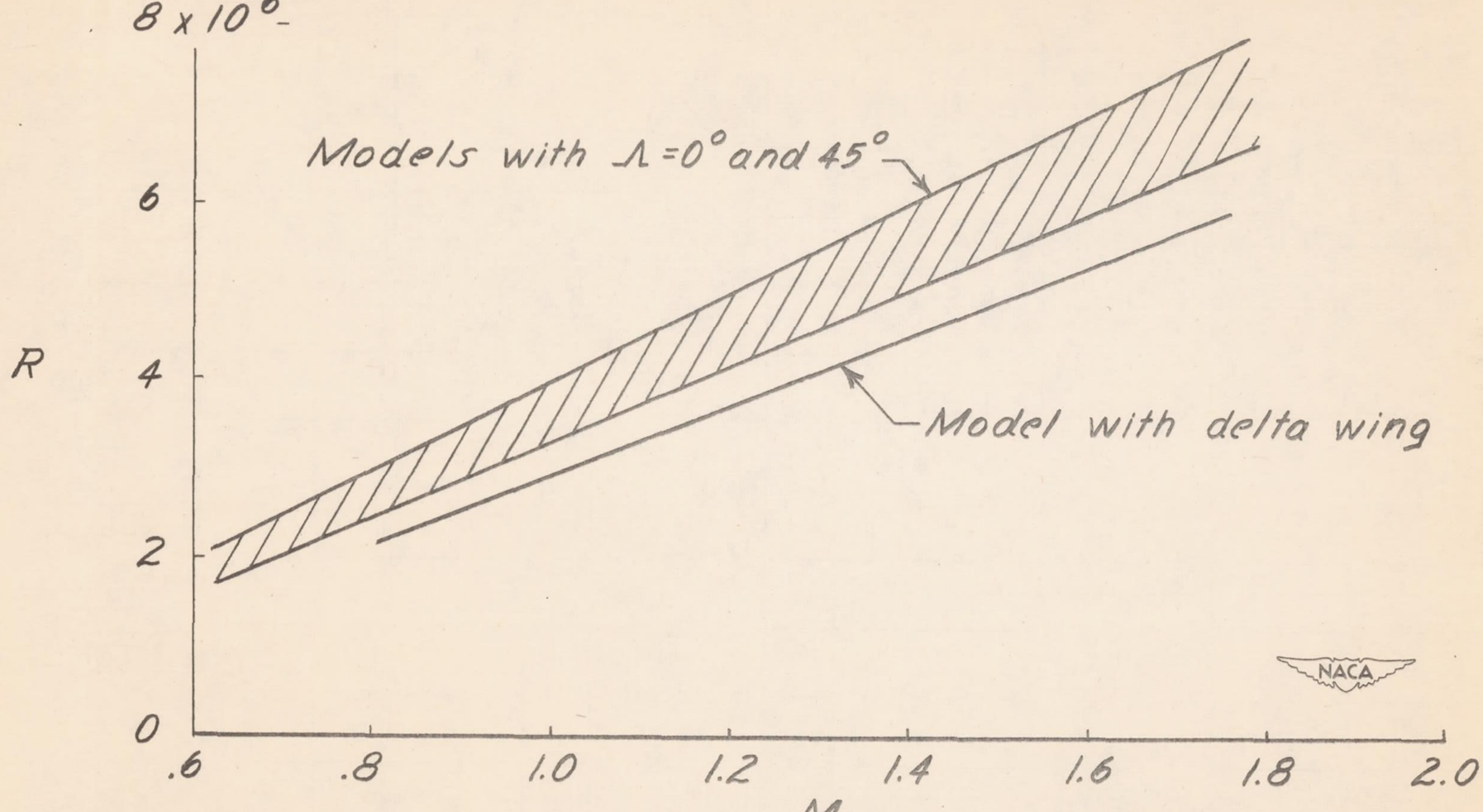


Figure 3.- Range of Reynolds numbers.

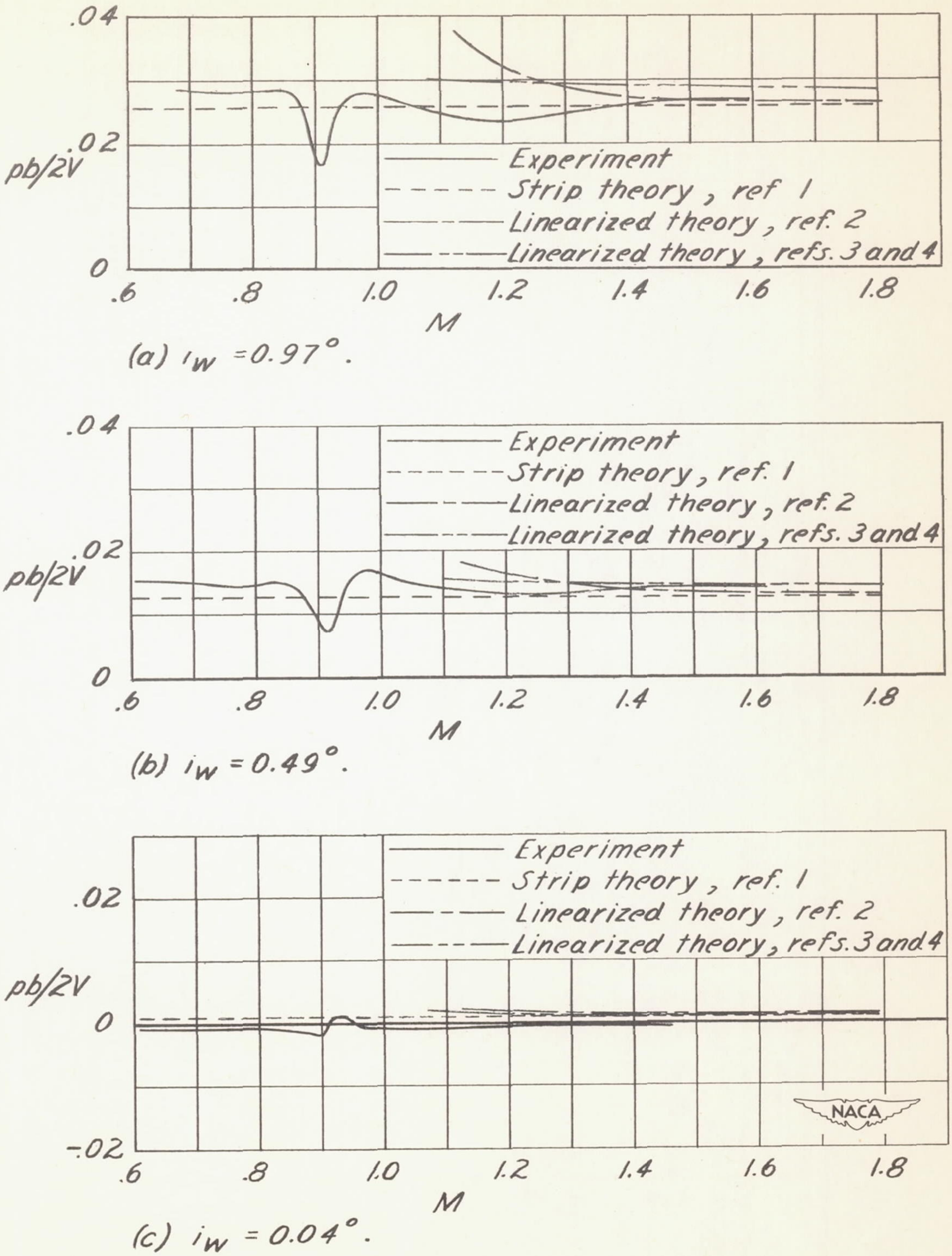


Figure 4.- Comparison of estimated and measured variation of rolling effectiveness with Mach number. $\Lambda = 0^{\circ}$; $\lambda = 1.0$; NACA 65A009 airfoil section.

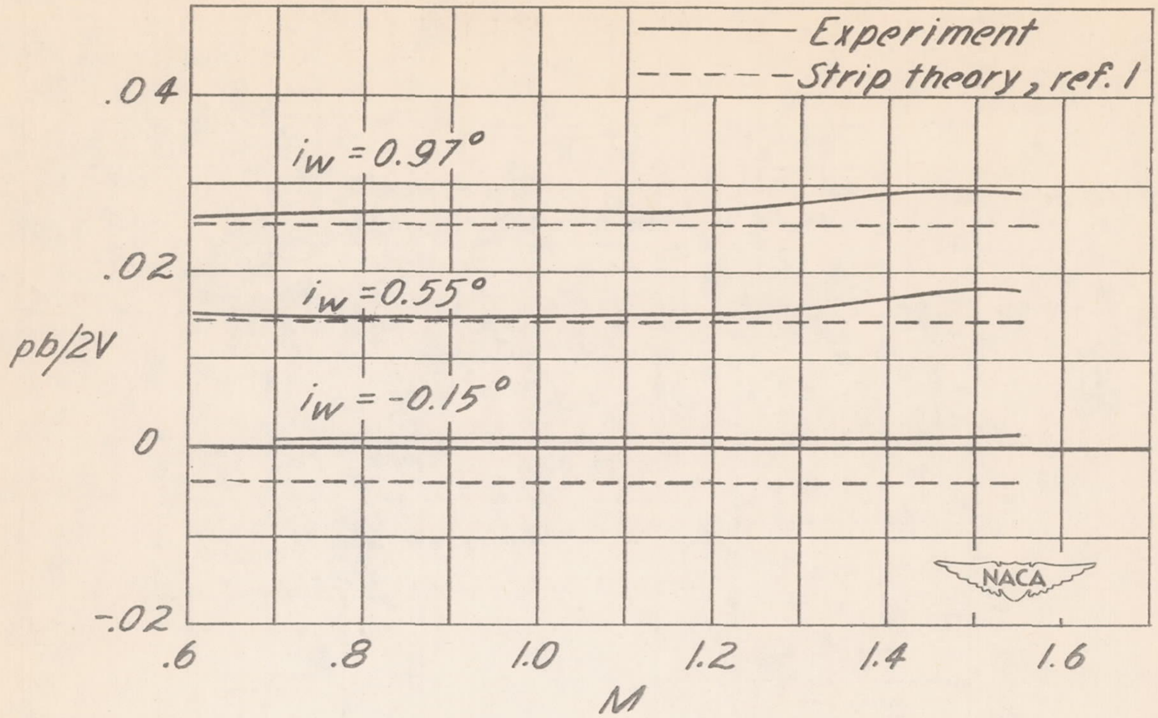


Figure 5.- Comparison of estimated and measured variation of rolling effectiveness with Mach number. $\Lambda = 45^{\circ}$; NACA 65A009 airfoil section; $\lambda = 1.0$.

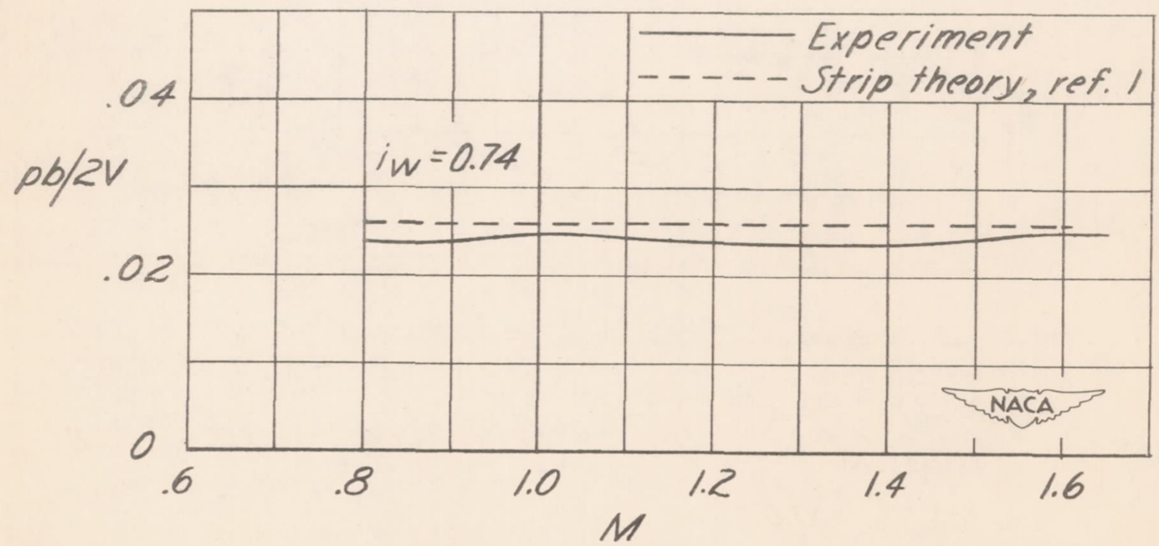


Figure 6.- Comparison of estimated and measured variation of rolling effectiveness with Mach number. Delta wing; $\Lambda = 45^{\circ}$; NACA 65A006 airfoil section; $\lambda = 0$.

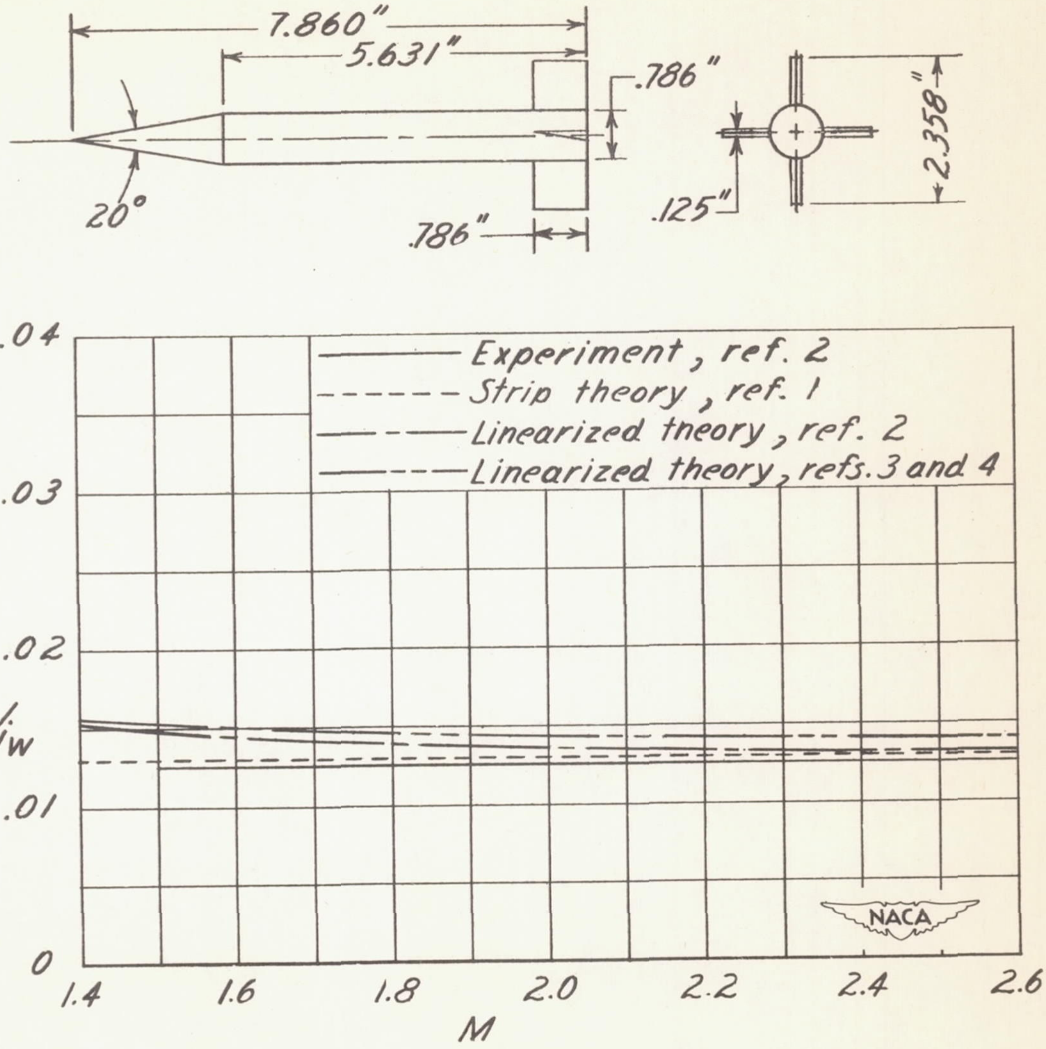


Figure 7.- Variation of rolling effectiveness per degree of wing incidence with Mach number for experimental models from reference 2 and the estimated values from references 1, 2, 3, and 4. $\Lambda = 0^{\circ}$; $\lambda = 1.0$. Sketch of reference 2 test missile is shown above.