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RESEARCH MEMORANDUM

COMPARATIVE TESTS OF THE ROLLING EFFECTIVENESS OF
CONSTANT-CHORD, FULL-DELTA, AND HALF-DELTA AILERONS ON
DELTA WINGS AT TRANSONIC AND SUPERSONIC SPEEDS

By Carl A. Sandahl and H. Kurt Strass

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Langley Air Force Base, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

COMPARATIVE TESTS OF THE ROLLING EFFECTIVENESS OF
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SUMMARY

Comparative tests of the rolling power of plain constant-chord, full-delta, and half-delta ailerons on delta wings having 45° and 60° leading-edge sweepback have been made utilizing rocket-propelled test vehicles in free flight. The rolling power of the constant-chord ailerons was reduced abruptly in the Mach number range from 0.9 to 1.0. For a given ratio of aileron area to wing area, the full-delta ailerons had a higher level of effectiveness at supersonic speeds than the constant-chord or half-delta ailerons. The half-delta ailerons had the smallest variation of effectiveness with Mach number and were about as effective as the full-delta ailerons at $M = 1.9$. The wing-aileron rolling effectiveness of the half- and full-delta ailerons can be accurately predicted by calculations based on the linearized flow equations. Similar calculations for the constant-chord ailerons yield values which are considerably larger than the measured values.

INTRODUCTION

Of the numerous wing plan forms which have been proposed for flight at transonic and supersonic speeds, the delta plan form affords certain aerodynamic and structural advantages. In an approach to the problem of providing such wings with adequate aerodynamic control surfaces, comparative tests of the rolling power of several delta-wing aileron configurations have been made. Plain constant-chord, full-delta, and half-delta ailerons were tested with delta wings having 45° and 60° leading-edge sweepback. A half-delta configuration identical to that used in the investigations reported in reference 1 was also tested. The tests, which were made in free flight with rocket-propelled test vehicles by means of the technique described in reference 2, permit the evaluation of the rolling power of wing-aileron configurations continuously over the

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Mach number range from about 0.7 to as high as 1.9. The flight tests were conducted at the Langley Pilotless Aircraft Research Station, Wallops Island, Va. The present paper includes and extends the work reported in reference 3.

SYMBOLS

$pb/2V$	wing-tip helix angle, radians
p	rolling velocity
b	diameter of circle swept by wing tips
V	flight-path velocity
M	Mach number
A	aspect ratio $\left(\frac{4}{\tan \Lambda_{LE}} \right)$
S_a	aileron area
S	exposed wing area
Λ_{LE}	sweepback of wing leading edge
δ	aileron deflection measured in plane normal to wing chord plane and parallel to model center line, degrees
ϵ	semivertex angle of wing (complement of Λ_{LE})
μ	Mach angle $\left(\tan^{-1} \frac{1}{\sqrt{M^2 - 1}} \right)$
$m = \frac{\tan \epsilon}{\tan \mu}$	

DESCRIPTION OF TECHNIQUE

Only a brief description of the technique will be given in this paper; a more complete discussion is contained in reference 2.

Test Vehicles

The general arrangement of the test vehicles is shown in figure 1. The geometric details of the wing-aileron configurations tested are given in figure 2 and further pertinent information is given in table I. The constant-chord and the full-delta ailerons were formed by deflecting the wing chord plane at the required hinge-line locations. Half-delta aileron configurations 5 and 6 were tested with the gap due to aileron deflection open and sealed. Configuration 7 was tested only with the gap sealed by the fence as shown in figure 2. Photographs of some of the test vehicles are shown in figure 3.

The bodies of the test vehicles were constructed of balsa except at the wing attachment where spruce was employed. Some of the wings (configurations 1, 2, 3, and 6) were constructed with a laminated spruce core to which a steel skin was cycle-welded to provide the required rigidity. The remaining configurations were of solid duralumin. For all configurations, the exposed wing area was 1.563 square feet.

Tests

The launching of the test vehicles was accomplished at the Wallops Island test facility of the Langley Pilotless Aircraft Research Division. The test vehicles were propelled by a two-stage rocket system to a Mach number of about 1.9. During a 12-second period of flight following rocket-engine burnout, in which time the test vehicles coasted to a Mach number of about 0.7, measurements of the rolling velocity produced by the ailerons (obtained with special radio equipment designated spinsonde) and the flight-path velocity (obtained with Doppler radar) were made. These data, in conjunction with atmospheric data obtained with radiosondes, permitted the evaluation of the rolling effectiveness of the particular wing-aileron configuration under investigation in terms of the parameter $\frac{pb}{2v/\delta}$ as a function of the flight Mach number. The scale of the tests is indicated by the curve of Reynolds number against Mach number in figure 4.

Accuracy

The accuracy is estimated to be within the following limits:

$\frac{pb}{2v/\delta}$	(due to limitations on model constructional accuracy)	± 0.0005
$\frac{pb}{2v/\delta}$	(due to limitations on instrumentation)	± 0.0005
M	± 0.01

It should be noted, as pointed out in reference 2, that, owing to the relatively small rolling moment of inertia the values of $\frac{pb}{2V/\delta}$ obtained during the larger part of the flight are substantially steady-state values even though the test vehicles are experiencing an almost continuous rolling acceleration or deceleration. Except for the Mach number range from 0.9 to 1.1, in which range abrupt changes in rolling velocity may occur, the deviation from steady-state conditions is estimated to be within 3 percent. Inasmuch as it is not now possible to estimate the damping in roll of these models with suitable accuracy in the Mach number range from about 0.9 to 1.1, an accurate calculation of the deviation from steady-state conditions cannot be made. However, for an extreme example having a rolling acceleration of 100 radians per second per second and assuming a damping-in-roll derivative of 0.2, the maximum deviation would be about 10 percent.

RESULTS AND DISCUSSION

The results of the present investigation are shown in figure 5 as curves of the wing-aileron rolling-effectiveness parameter $\frac{pb}{2V/\delta}$ as functions of Mach number. The rolling-effectiveness results are summarized in figure 6 and are compared with calculations based on the linearized supersonic-flow equations in figures 7 to 9. The theoretical calculations, which in all cases applied to isolated wings only, were based on the wing plan form defined in figure 10. The damping in roll was obtained from reference 5 for all cases. The results presented are for essentially infinitely rigid wings.

Effect of leading-edge sweepback.- The effect of leading-edge sweepback on the rolling effectiveness of the configurations tested can be noted in figure 5. For the constant-chord ailerons (fig. 5(a)), increasing the sweepback from 45° to 60° increased the subsonic effectiveness, decreased the abruptness of the loss of rolling power in the Mach number range from 0.9 to 1.0, and increased the rolling power at moderate supersonic Mach numbers. At the highest Mach numbers investigated, the rolling power is independent of leading-edge sweep for the values tested.

For the full-delta ailerons (fig. 5(b)), increasing the leading-edge sweep from 45° to 60° decreased the rolling power about 20 percent at Mach numbers less than 1.0. Above a Mach number of 1.0, increasing the leading-edge sweep had little effect on the rolling effectiveness.

For the half-delta ailerons (fig. 5(c)), the main effect of increasing the leading-edge sweep was to increase slightly the rolling power at moderate supersonic speeds. The effect of gap seal for these configurations is negligible.

Comparison of rolling effectiveness.- The rolling effectiveness of the configurations tested is compared in figure 6. In figure 6 the results were averaged for those configurations for which results were obtained from two models. Of the configurations tested, the constant-chord ailerons exhibited the largest variation of effectiveness over the Mach number range and the lowest effectiveness at supersonic speeds. The full-delta ailerons have the highest effectiveness at supersonic speeds. For the same ratio of control area to wing area, the effectiveness of the half-delta ailerons is less than that of the full-delta ailerons and, of the configurations tested, has the smallest variation over the speed range.

Comparison with theory.- In figures 7 and 8 the experimental results obtained are compared with results calculated using methods based on the linearized equations of supersonic flow. The results for the constant-chord ailerons were calculated according to reference 5 with a correction for the effects of finite trailing-edge angle given in reference 6. The calculated results for the full-delta aileron were obtained from reference 7 for the case of the Mach lines behind the leading edge and from reference 8 for the case of the Mach lines ahead of the leading edge. The calculated results for the half-delta ailerons for the case of the Mach lines ahead of and behind the leading edges were obtained from references 8 and 5, respectively.

Except for the constant-chord ailerons, the agreement between theory and experiment is good. This agreement, however, is probably fortuitous because other tests (reference 1) have shown that the theoretical values of both the aileron rolling moment and wing damping in roll are higher than experimental values by roughly the same factor. The experimental values for the constant-chord ailerons are considerably lower than the theoretical values, probably due to the adverse effects of wing and fuselage boundary layer which would be larger for the constant-chord ailerons than for the other ailerons tested. In order to establish if there was agreement between the shapes of the theoretical and experimental curves, the results for the constant-chord ailerons in figures 7(a) and 8(a) were plotted as relative values in figure 9. From figure 9 it appears that the theory can, at least, predict the shape of the effectiveness curves for constant-chord ailerons.

Also shown in figure 8(c) is the rolling effectiveness at a Mach number of 1.9 obtained in the wind-tunnel tests of configuration 7 reported in reference 1. Good agreement is obtained between the wind-tunnel test point and theory. The theoretical curve also agrees well with the results of the present tests.

CONCLUSIONS

The following conclusions regarding the rolling effectiveness of delta wing-aileron configurations are based on the tests reported herein:

1. The rolling power of constant-chord plain ailerons on delta wings having a 45° leading-edge sweep is reduced abruptly in the Mach number range from 0.9 to 1.0. Increasing the leading-edge sweep to 60° decreased the abruptness of the loss of effectiveness at transonic speeds and increased the effectiveness at moderate supersonic speeds, but had little effect at the limits of the Mach number range investigated ($M = 0.8$ to 1.9).
2. For a given ratio of control area to wing area, full-delta aileron configurations have a higher level of rolling power at supersonic speeds than constant-chord or half-delta ailerons.
3. Half-delta ailerons have the smallest variation of effectiveness with Mach number of the configurations tested. At $M = 1.9$ the rolling effectiveness is comparable to that of the full-delta control.
4. The wing-aileron rolling effectiveness of half-delta and full-delta aileron configurations can be accurately predicted by calculations based on the linearized flow equations. Similar calculations for constant-chord plain ailerons predict accurately the variation of effectiveness with Mach number, but yield absolute values of effectiveness which are considerably higher than the measured values.

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2. Sandahl, Carl A., and Marino, Alfred A.: Free-Flight Investigation of Control Effectiveness of Full-Span 0.2-Chord Plain Ailerons at High Subsonic, Transonic, and Supersonic Speeds to Determine Some Effects of Section Thickness and Wing Sweepback. NACA RM L7D02, 1947.
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TABLE I

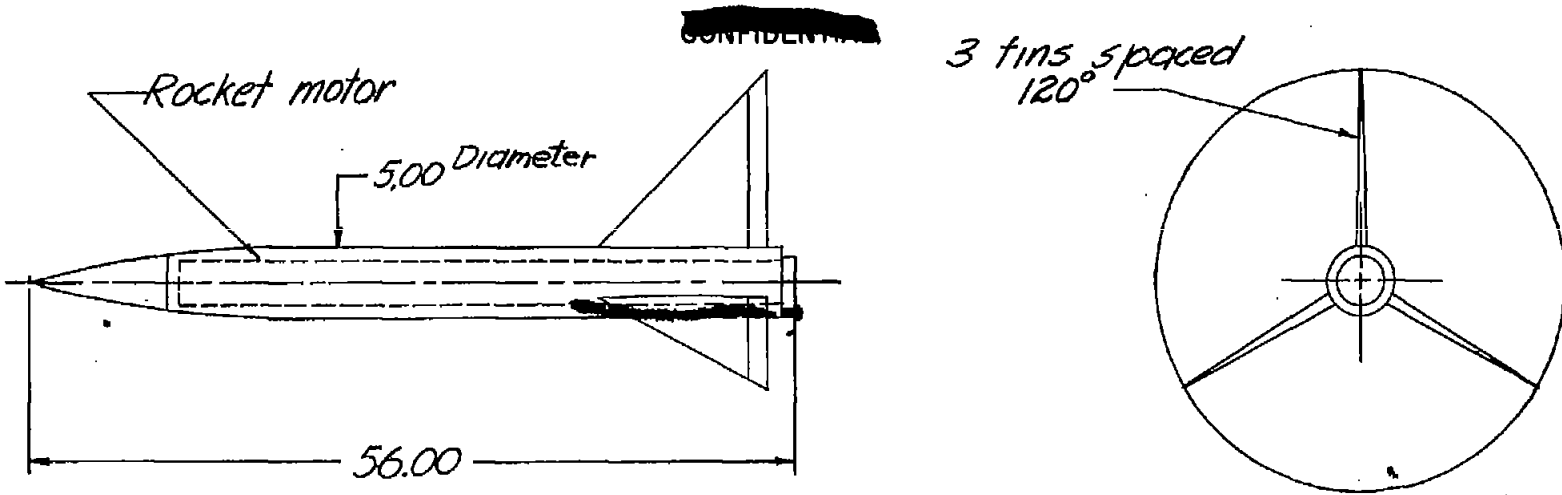
GEOMETRIC CHARACTERISTICS OF MODELS

	MODEL											
	1a	1b	2a	2b	3	4	5a	5b	6a	6b	7a	7b
Aspect ratio A	4.00	4.00	2.31	2.31	4.00	2.31	4.00	4.00	2.31	2.31	2.31	2.31
Wing leading-edge sweep-back, degrees	45	45	60	60	45	60	45	45	60	60	60	60
Airfoil section in free-stream direction	65A006	65A006	65A006	65A006	65A006	65A006	65A006	65A006	65A006	65A006	Hexagonal	Hexagonal
Aileron type	Plain constant chord	Plain constant chord	Plain constant chord	Plain constant chord	Full delta	Full delta	Half delta	Half delta	Half delta	Half delta	Half delta	Half delta
Ratio of exposed aileron area to exposed wing area	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.11	0.11
Aileron deflection δ , degrees	5.5	4.9	5.0	5.0	5.0	5.0	5.0	4.9	4.8	5.9	5.5	7.6
Gap due to aileron deflection	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed	Open	Open	Sealed	Sealed	Sealed

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^aLower case letter indicates identical models of given configuration.



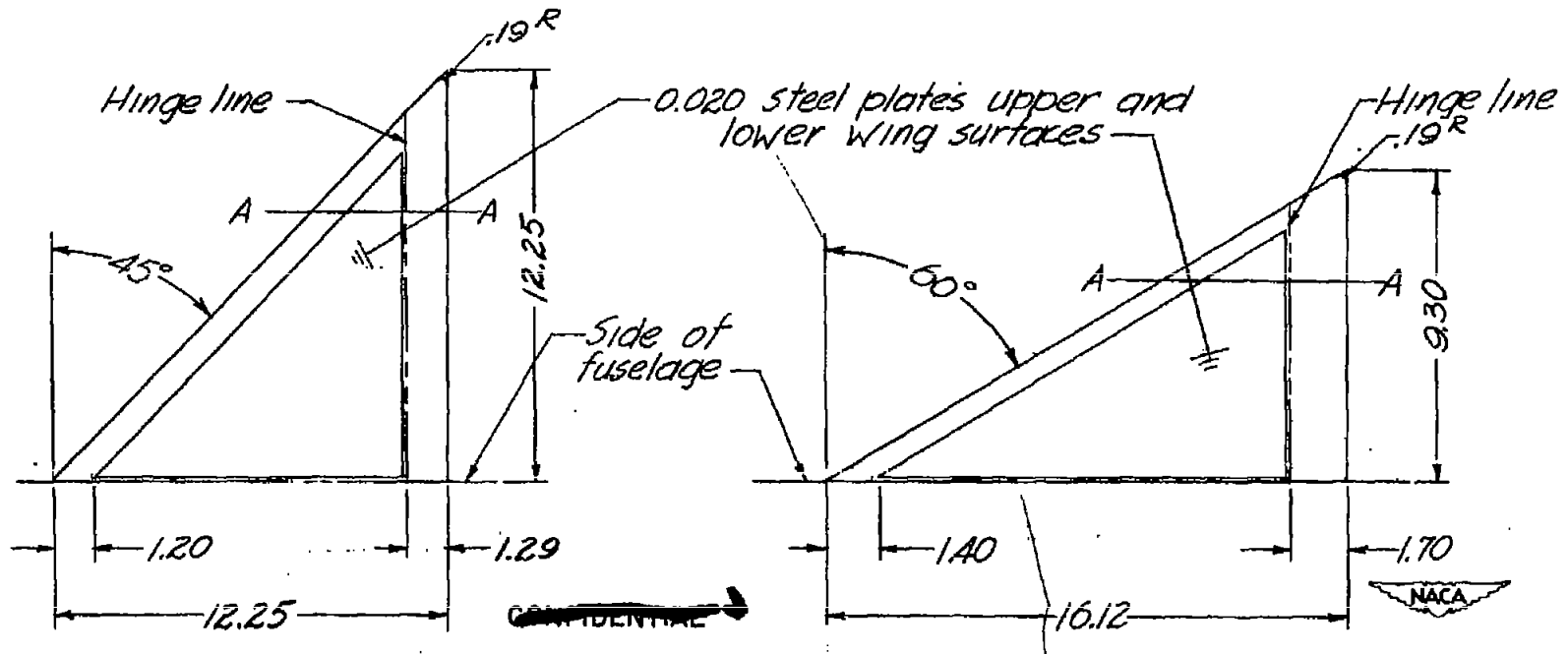
Fuselage ordinates	
Station	Diameter
0	0
2.50	1.22
5.00	2.30
7.50	3.16
10.00	3.92
12.50	4.52
15.00	4.88
17.50	5.00

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Figure 1.- General arrangement of test vehicles. Dimensions are in inches.

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(a) Configuration 1.

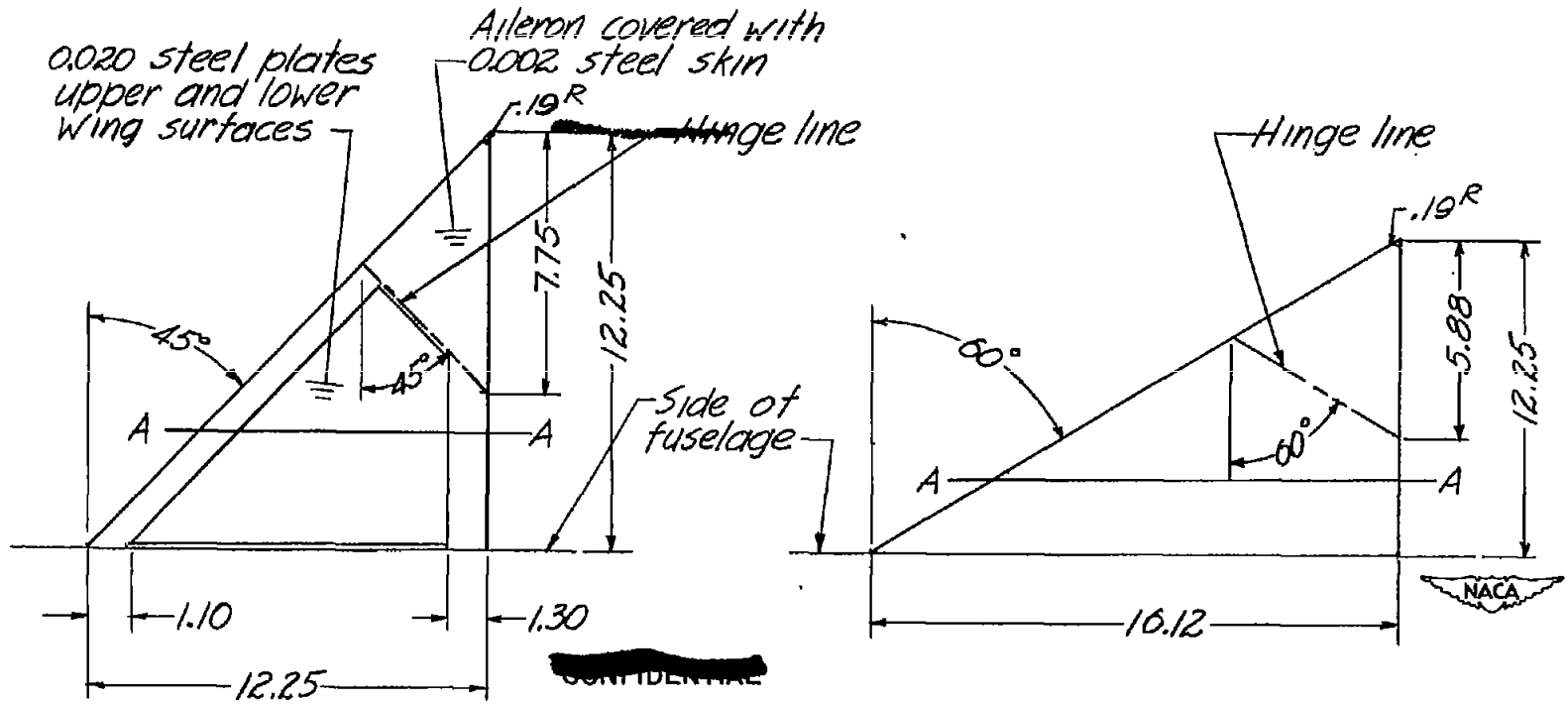
Laminated spruce core.

(b) Configuration 2.

Laminated spruce core.

Figure 2.- Details of configurations tested. Dimensions are in inches.

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Section A-A NACA 65A-006



(c) Configuration 3.

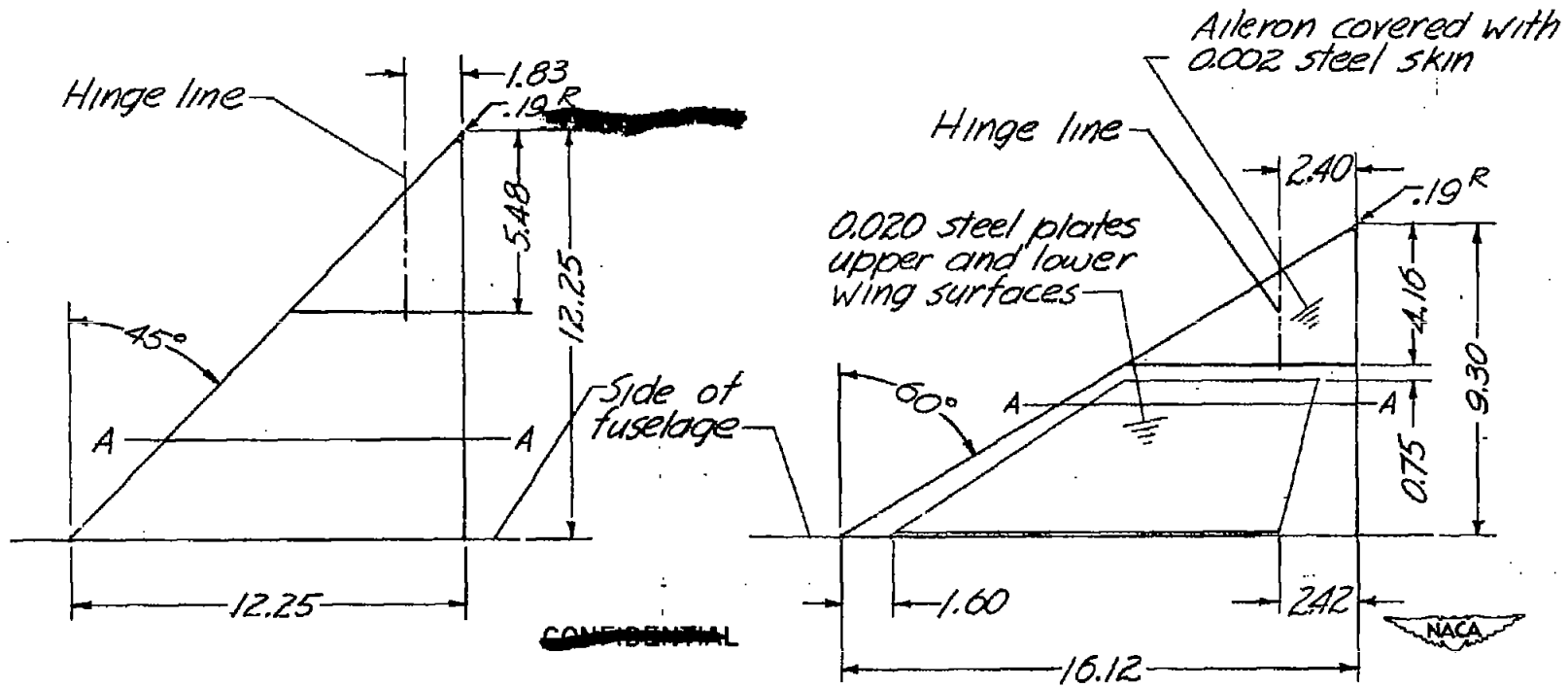
Laminated spruce core.

(d) Configuration 4.

Solid duralumin.

Figure 2.- Continued.

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Section A-A, NACA 65A-006

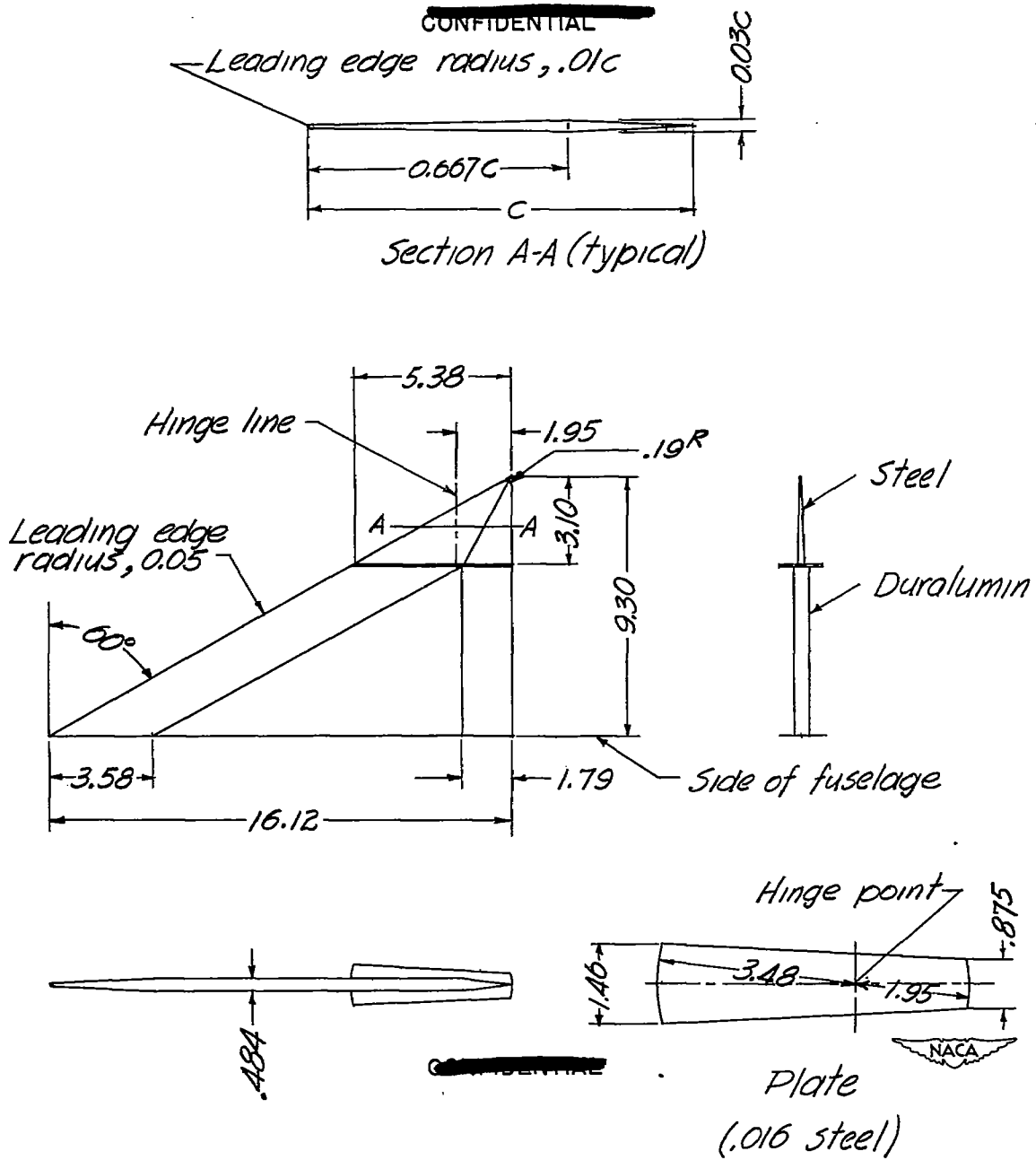


(e) Configuration 5.

Solid duralumin.

(f) Configuration 6.

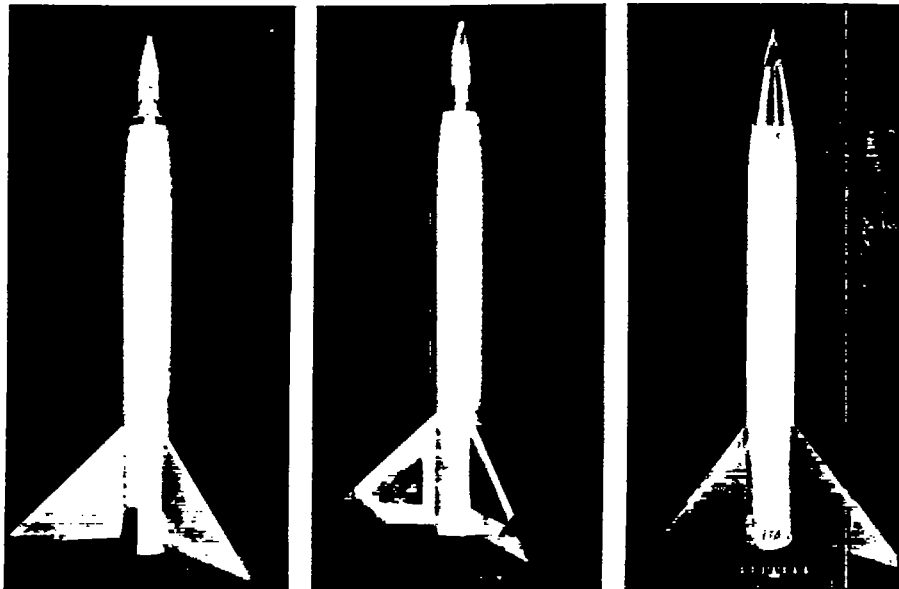
Laminated spruce core.



(g) Configuration 7.

Figure 2.- Concluded.

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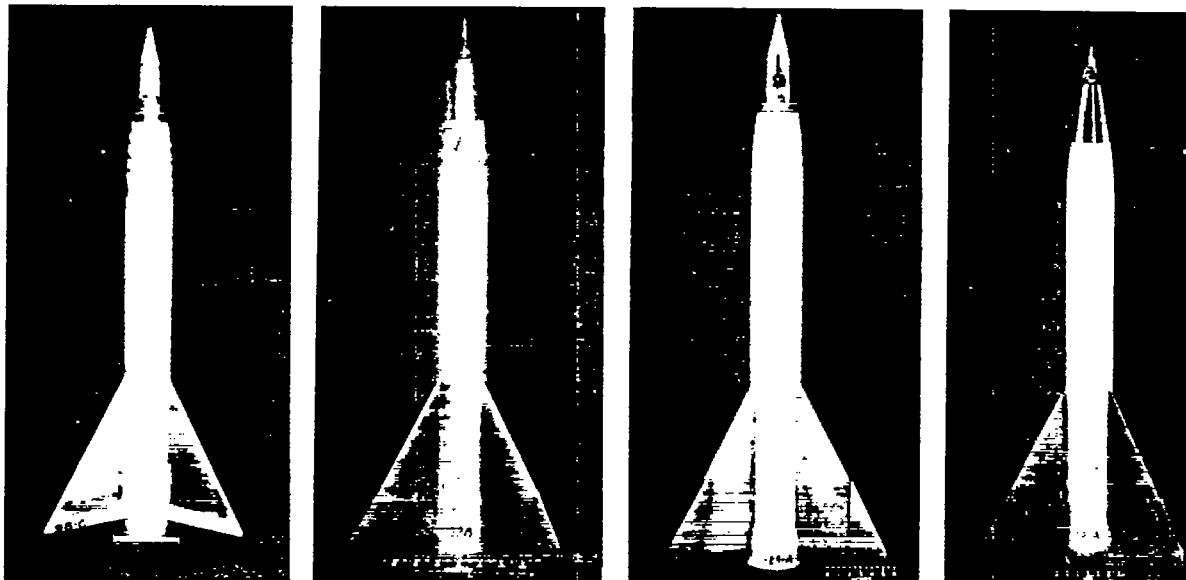


Constant-chord ailerons
Configuration 1

Full-delta ailerons
Configuration 3

Half-delta ailerons
Configuration 5

(a) $\Lambda_{L.E.} = 45^\circ$.



Constant-chord ailerons
Configuration 2

Full-delta ailerons
Configuration 4

Half-delta ailerons
Configuration 6

Half-delta ailerons
Configuration 7

(b) $\Lambda_{L.E.} = 60^\circ$.



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Figure 3.- Photographs of configurations tested.

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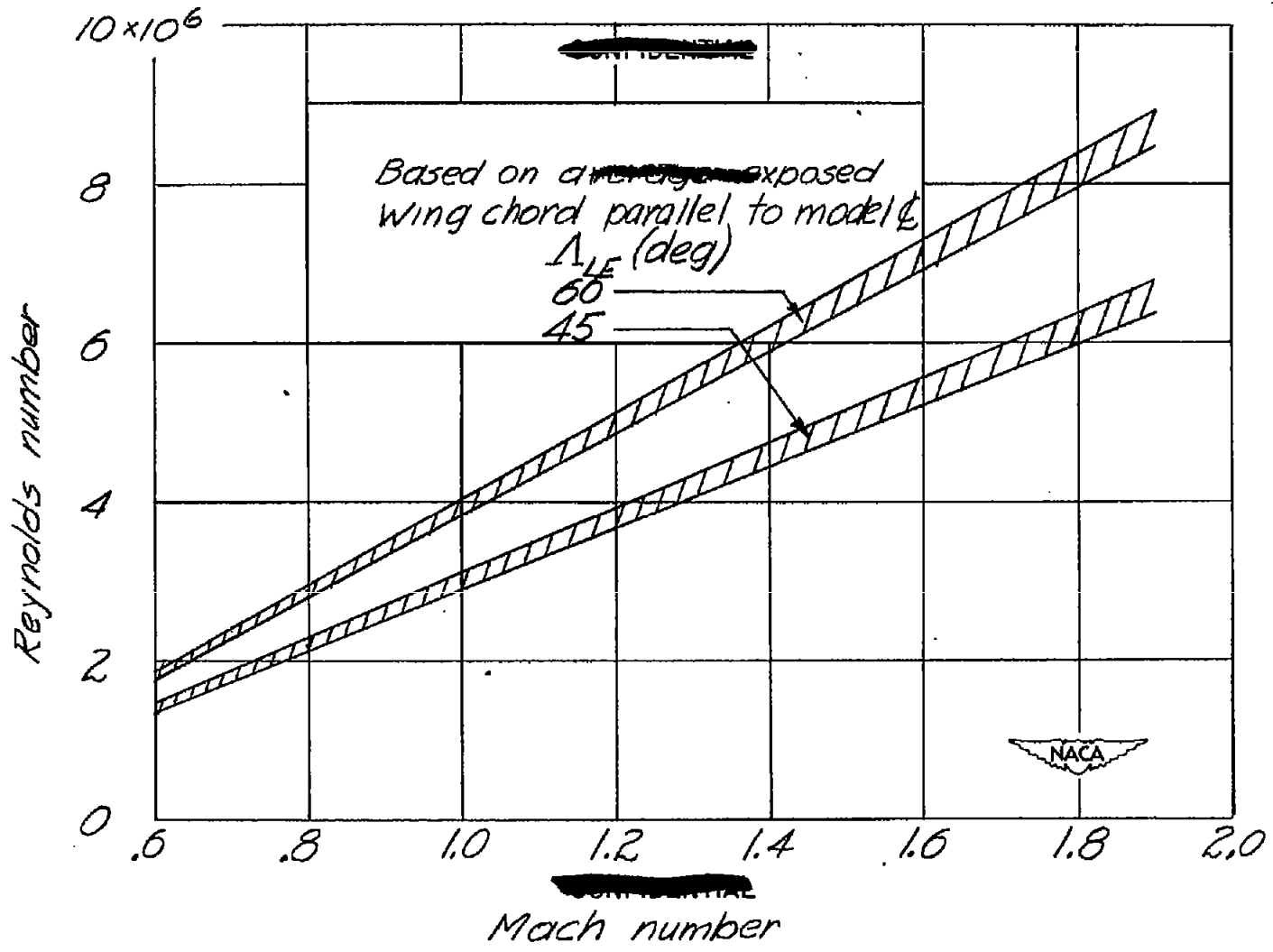
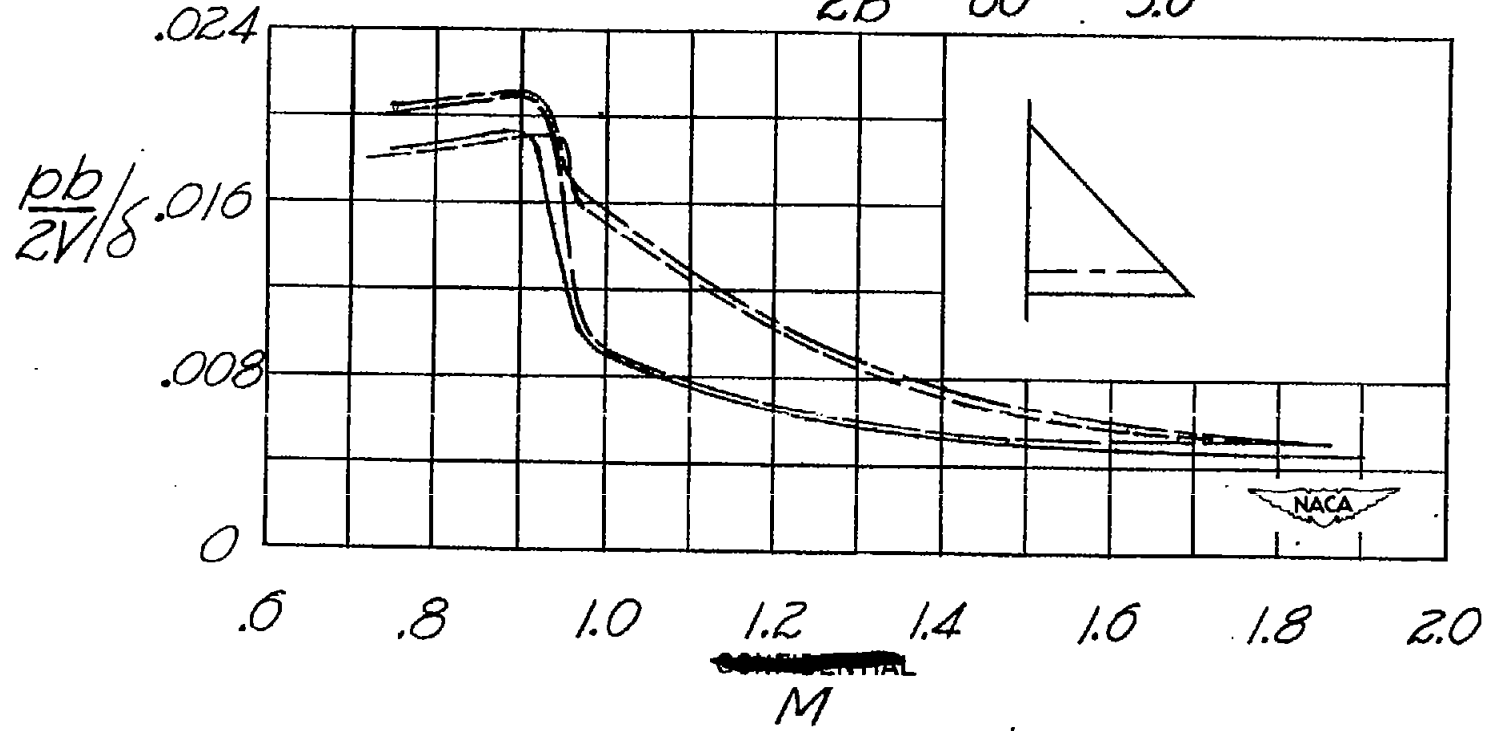


Figure 4.- Variation of Reynolds number with Mach number for the range of climatic conditions during ~~tests~~

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Model	Δ_{LE} (deg)	δ (deg)
1a	45	5.5
1b	45	4.9
2a	60	5.0
2b	60	5.0



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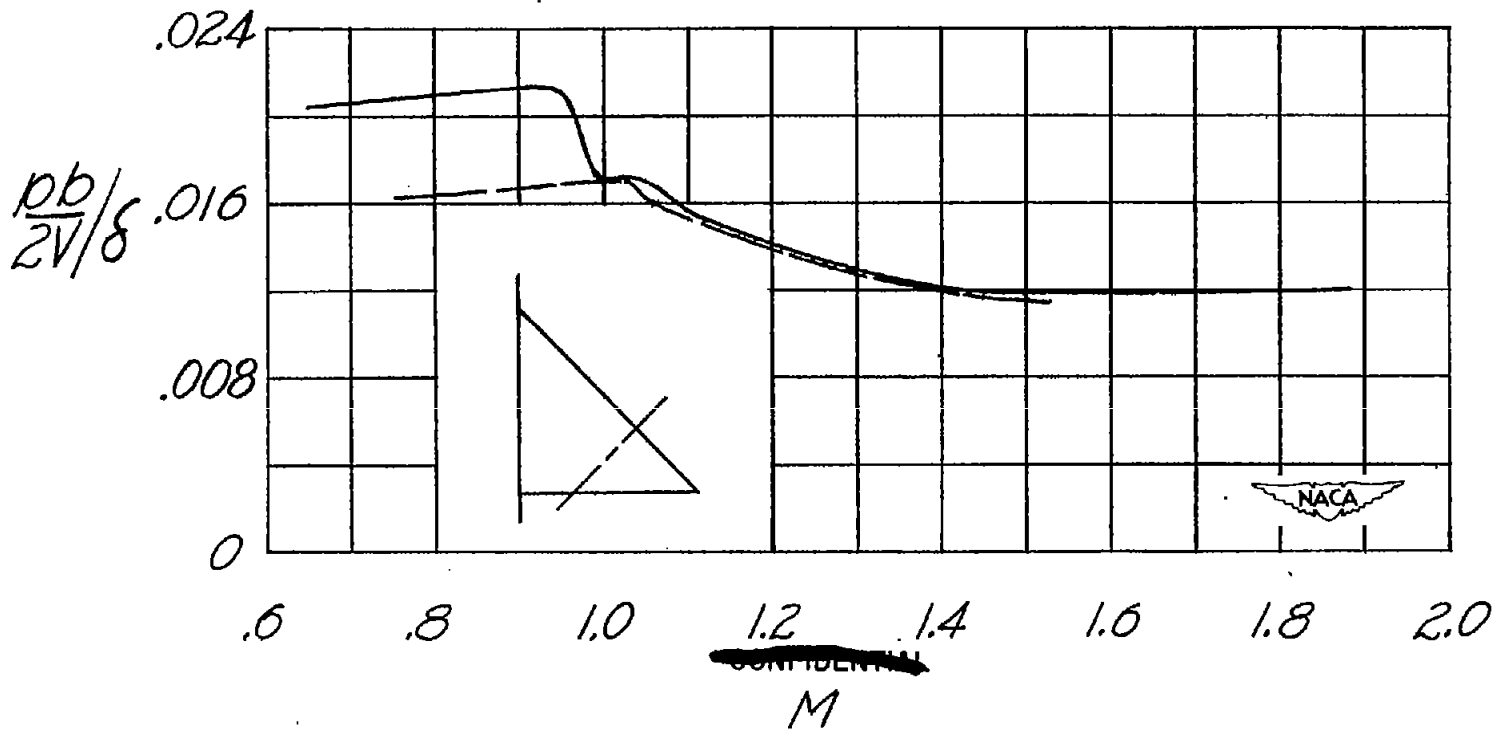
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(a) Constant-chord ailerons; $\frac{s_B}{s} = 0.20$.

Figure 5.- Experimental results.

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Model	Λ_{LE} (deg)	δ (deg)
3	45	5.0
4	60	5.0



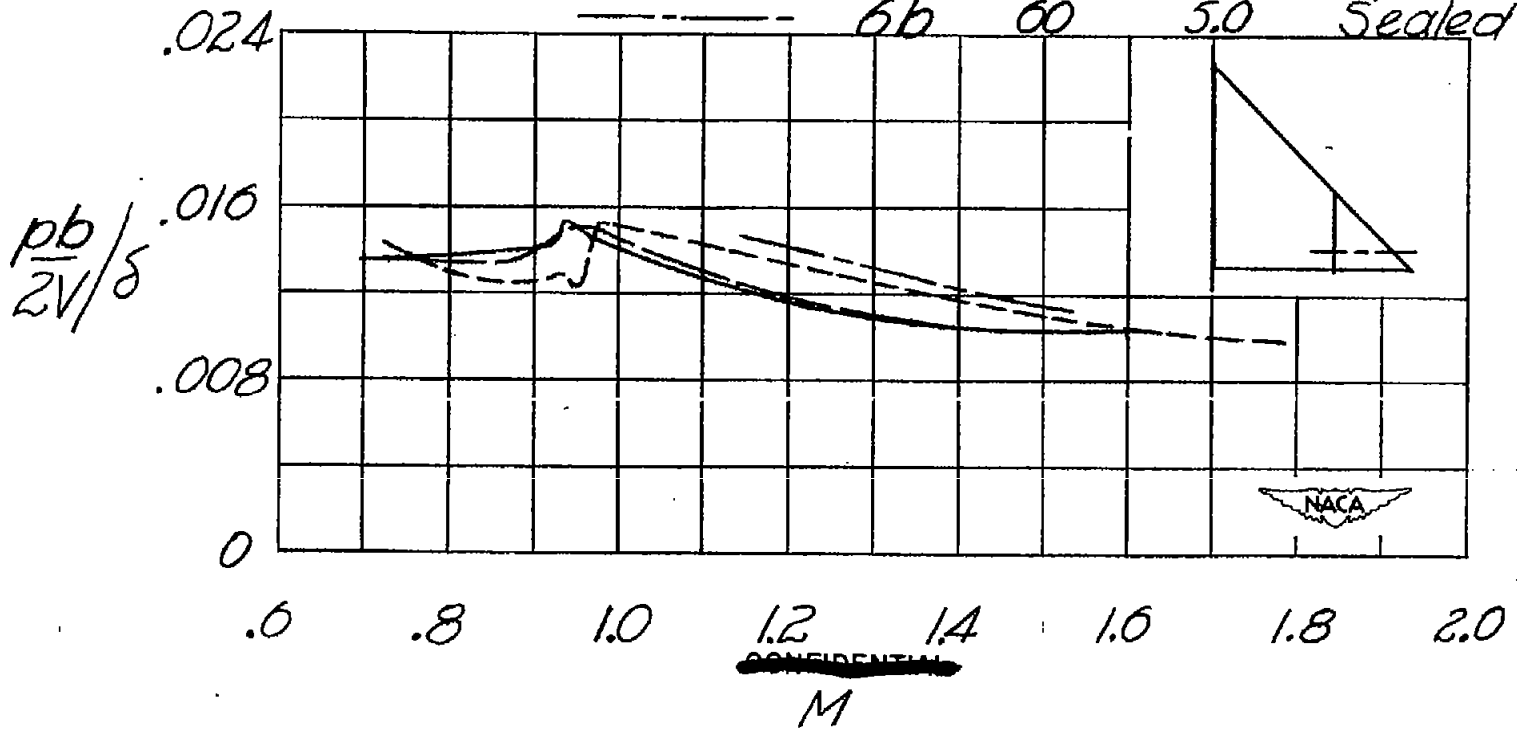
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(b) Full-delta ailerons; $\frac{\delta_a}{\delta} = 0.20$.

Figure 3.- Continued.

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Model	Δ_{LE} (deg)	δ (deg)	Gap
————— 5a	45	5.0	Sealed
————— 5b	45	4.9	Open
- - - - - 6a	60	4.8	Open
- - - - - 6b	60	5.0	Sealed

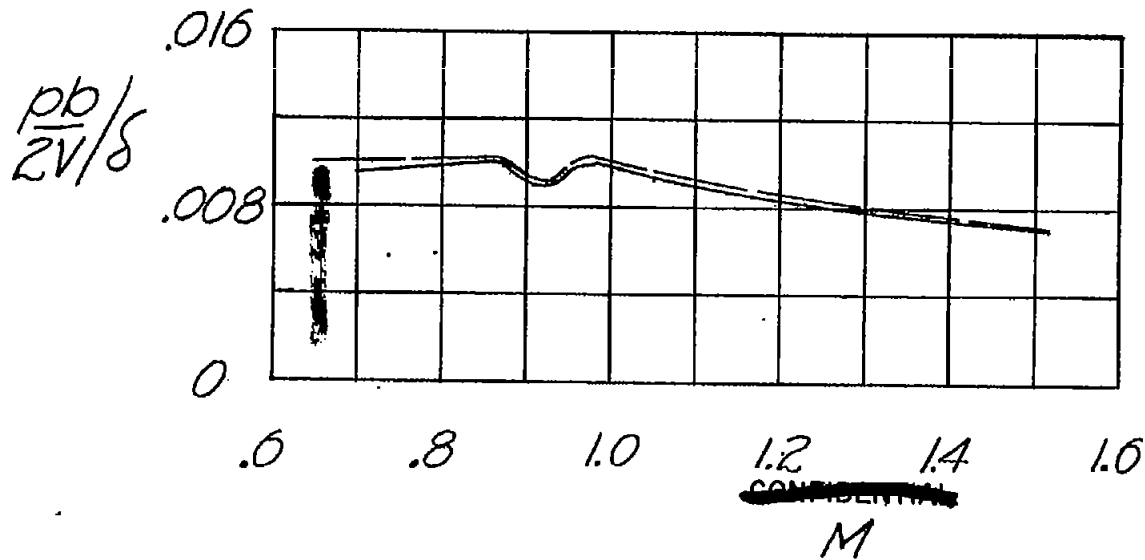


(c) Half-delta ailerons; $\frac{S_a}{S} = 0.20$.

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Figure 5.- Continued.

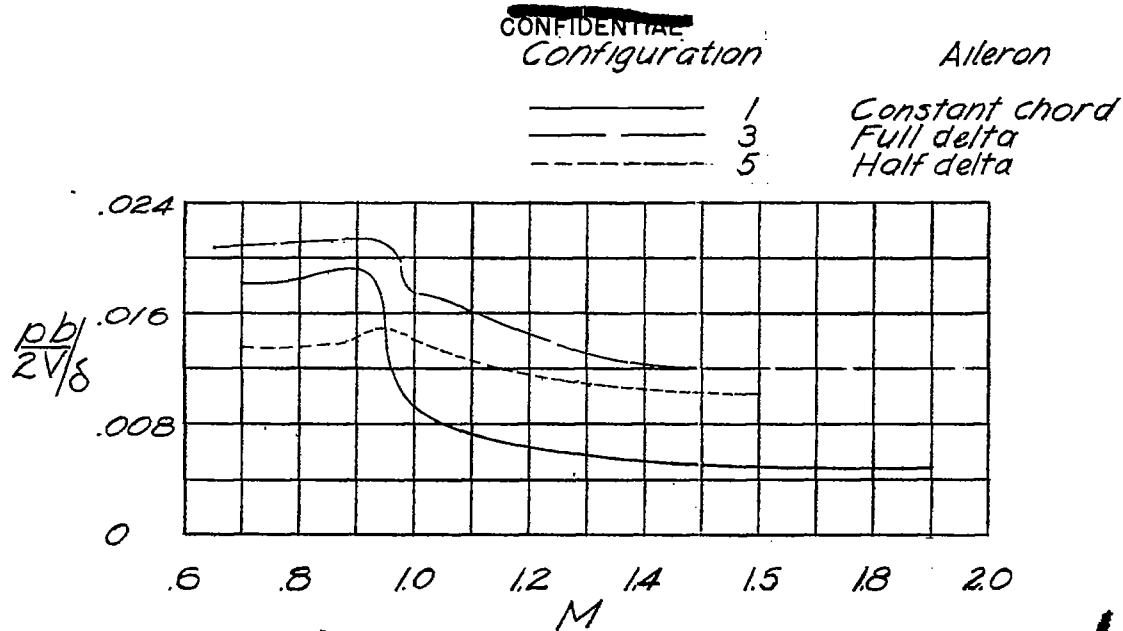
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Model	Δ_{LE} (deg)	δ (deg)
7a	60	5.5
7b	60	7.6

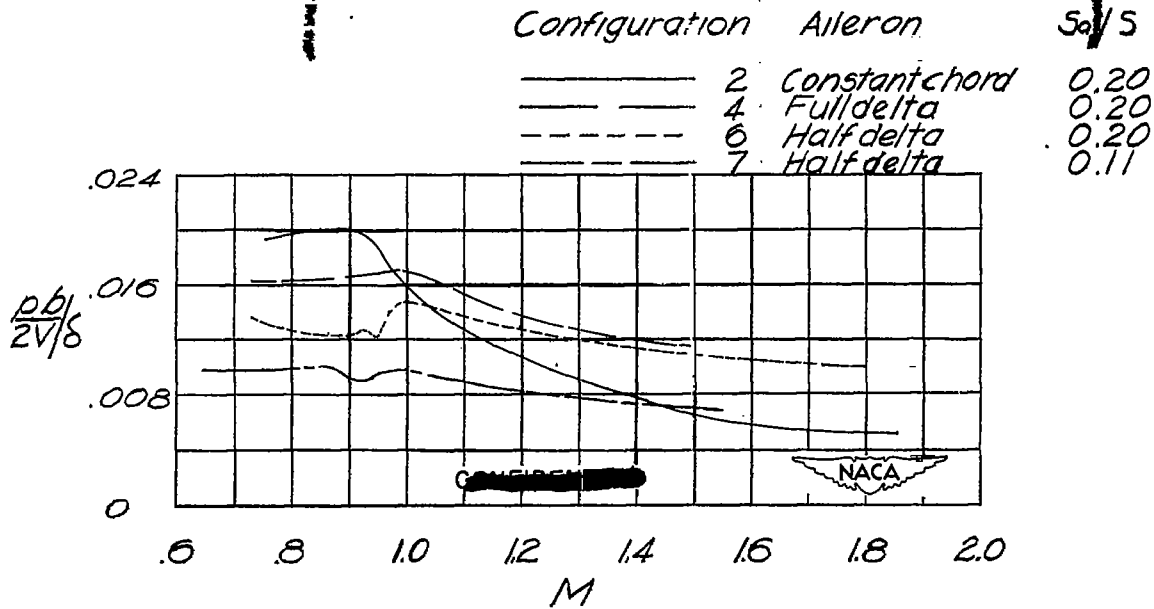


(d) Half-delta ailerons; $\frac{S_a}{S} = 0.11$.

Figure 5.- Concluded.



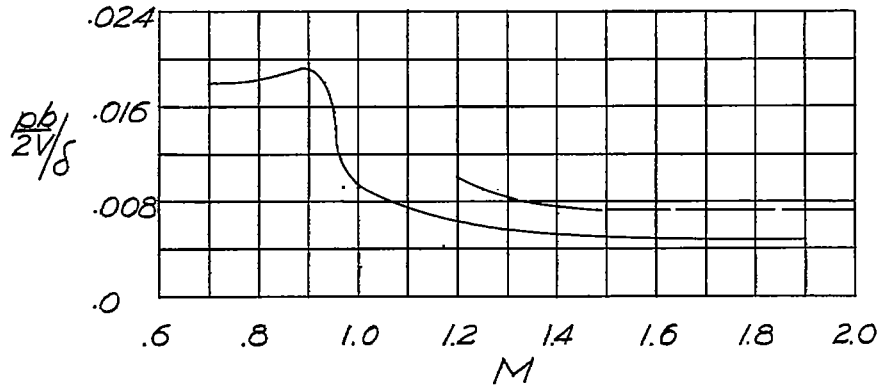
(a) $\Lambda_{L.E.} = 45^\circ$; $\frac{S_B}{S} = 0.2$.



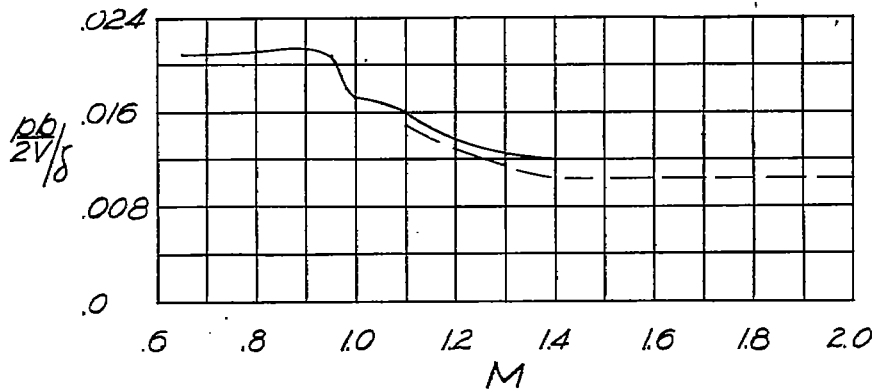
(b) $\Lambda_{L.E.} = 60^\circ$.

Figure 6.- Comparison of experimental results.

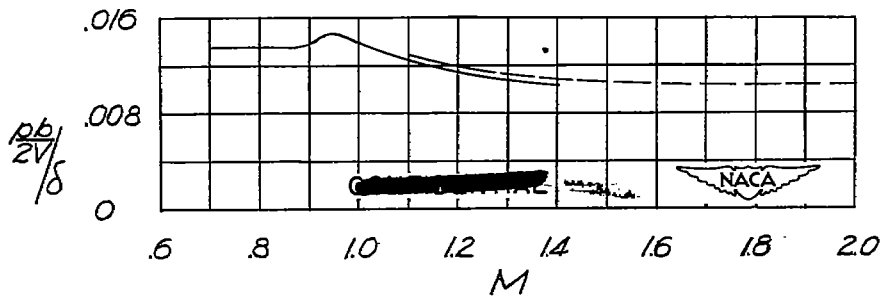
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Experiment ———
Theory ———



(a) Constant-chord ailerons. Configuration 1; $\frac{S_a}{S} = 0.2$.

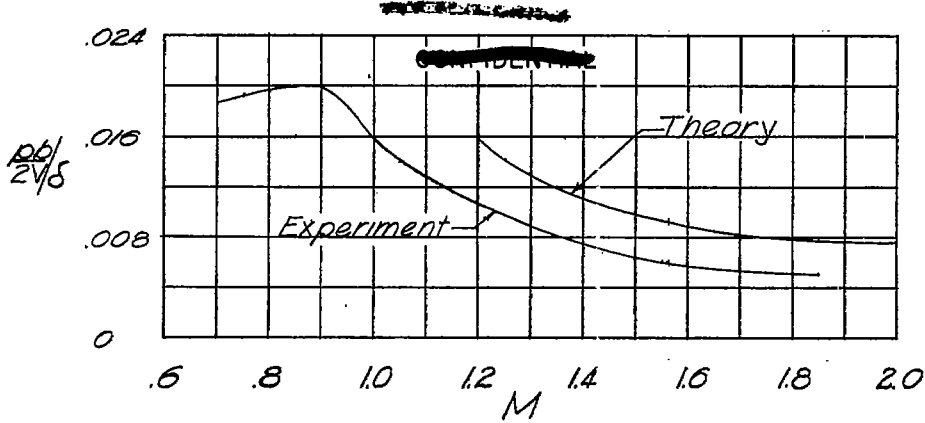


(b) Full-delta ailerons. Configuration 3; $\frac{S_a}{S} = 0.2$.

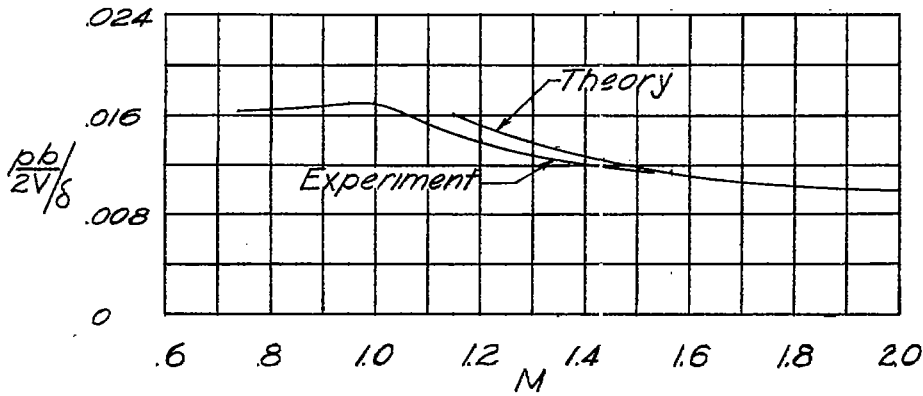


(c) Half-delta ailerons. Configuration 5; $\frac{S_a}{S} = 0.2$.

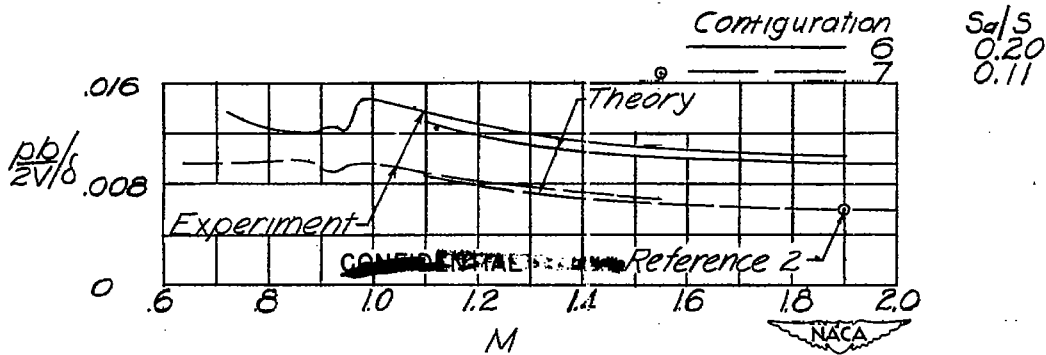
Figure 7.- Comparison of experimental results with theory. $\Lambda = 45^\circ$.



(a) Constant-chord ailerons. Configuration 2; $\frac{S_a}{S} = 0.2$.



(b) Full-delta ailerons. Configuration 4; $\frac{S_a}{S} = 0.20$.



(c) Half-delta ailerons.

Figure 8.- Comparison of experimental results with theory. $\Lambda = 60^\circ$.

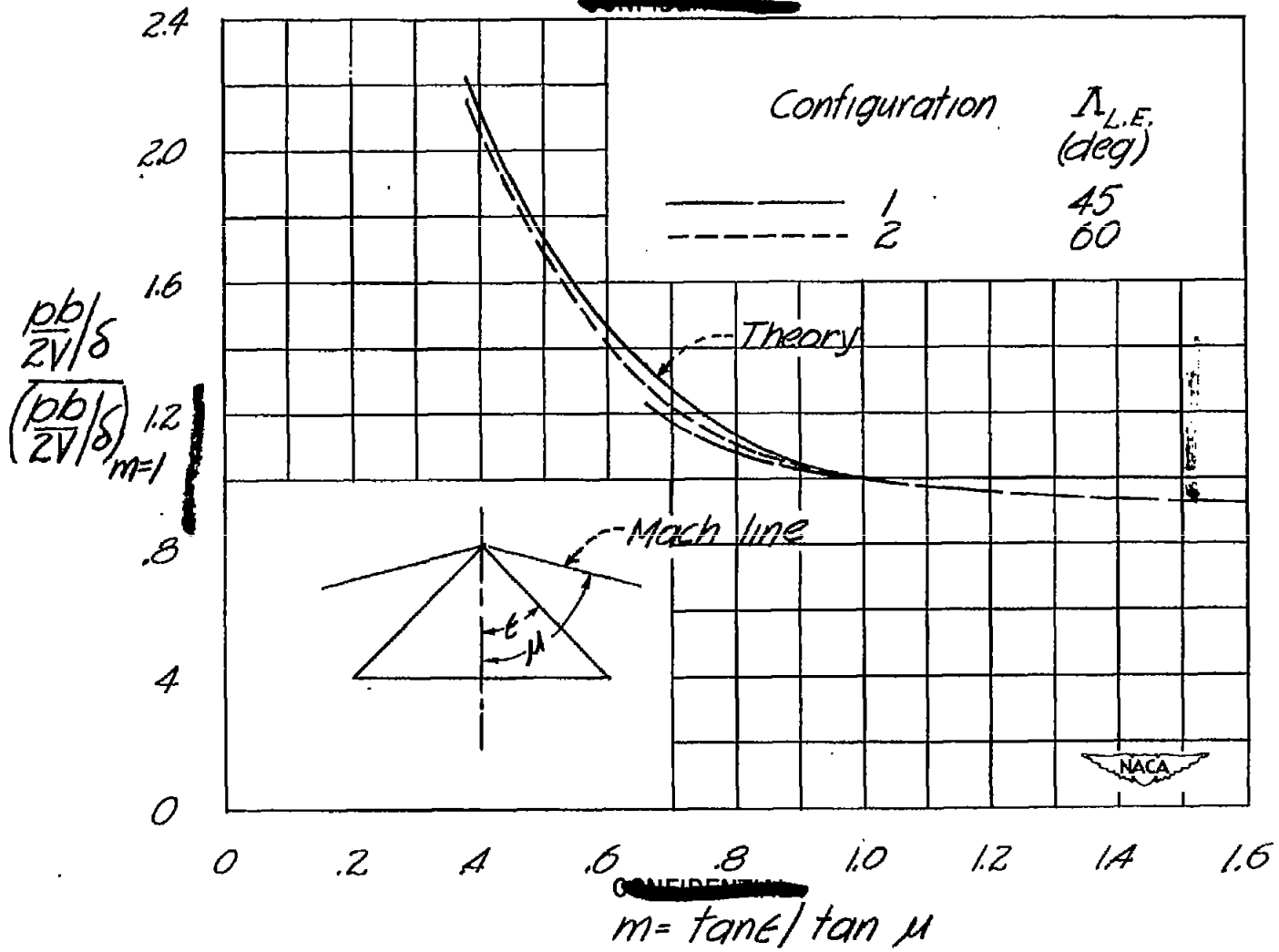


Figure 9.- Comparison of experimental and theoretical results.
 Constant-chord ailerons.

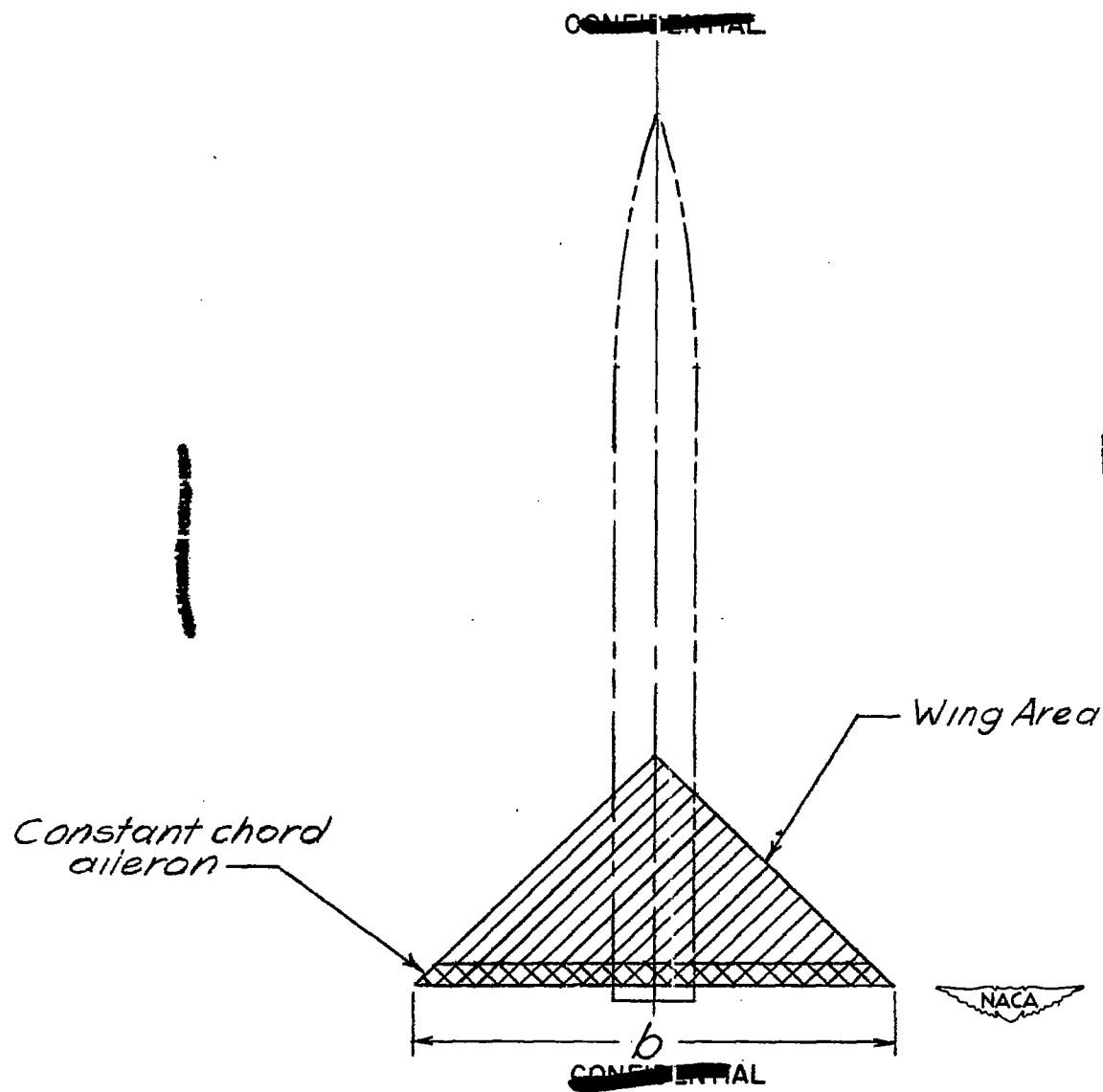


Figure 10.- Wing configuration considered in making calculations.