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RESEARCH MEMORANDUM

SOME EFFECTS OF FUSELAGE INTERFERENCE, WING INTERFERENCE, AND SWEEPBACK ON THE DAMPING IN ROLL OF UNTAPERED WINGS AS DETERMINED BY TECHNIQUES EMPLOYING ROCKET-PROPELLED VEHICLES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SOME EFFECTS OF FUSELAGE INTERFERENCE, WING INTERFERENCE, AND SWEEPBACK ON THE DAMPING IN ROLL OF UNTAPERED WINGS AS DETERMINED BY TECHNIQUES EMPLOYING ROCKET-PROPELLED VEHICLES

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SUMMARY

An experimental investigation employing techniques which utilized rocket-propelled vehicles in free flight has been made to determine some effects of fuselage interference, wing interference, and sweepback on the damping-in-roll characteristics of untapered wings with an aspect ratio of 3.7 and NACA 65A009 airfoil sections between Mach number 0.6 and Mach number 1.7. Results of this investigation show that damping in roll was maintained by each configuration tested. The damping in roll of configurations with either straight or sweptback wings was essentially unchanged by the presence of a fuselage having a fuselage-diameter - wing-span ratio of 0.191. Increasing the number of either straight or 45° sweptback semispan wings decreased the damping-in-roll coefficients at supersonic Mach numbers. Changing the angle of sweepback from 0° to 45° decreased the damping in roll, particularly at supersonic speeds, and reduced the severity of apparent changes in damping in roll in the transonic region. Agreement between experiment and theory for straight wings, possibly because of a section-thickness effect, was within experimental accuracy at only the lowest subsonic speeds investigated, was poor at low supersonic speeds, but improved with increasing supersonic speed. Experimental results obtained for sweptback wings agreed with theory throughout the subsonic range.

INTRODUCTION

The Langley Pilotless Aircraft Research Division has conducted an investigation to determine the effects of fuselage interference, wing interference, and sweepback on the damping-in-roll characteristics of untapered wings with an aspect ratio of 3.7 and NACA 65A009 airfoil sections parallel to the free-stream direction. In this investigation tests were made in the high-subsonic, transonic, and supersonic speed ranges with two techniques, both utilizing rocket-propelled test vehicles in free flight but employing different methods of measurement. One technique employed sting-mounted configurations (reference 1) and had a Reynolds number range of approximately 0.8×10^6 to 2.7×10^6, while the other technique employed torque nozzles (reference 2) and had a Reynolds number range of approximately 2.2×10^6 to 8.0×10^6. All flight tests were made at the Pilotless Aircraft Research Station, Wallops Island, Va.

SYMBOLS

C_{l_p}	damping-in-roll coefficient $\left(\frac{\partial C_l}{\partial\left(\frac{pb}{2V}\right)}\right)$
C_l	rolling-moment coefficient $\left(\frac{L}{qSb}\right)$
$\frac{pb}{2V}$	wing-tip helix angle, radians
L	rolling moment, foot-pounds
q	dynamic pressure, pounds per square foot
S	total included wing area, obtained by extending leading and trailing edges of each semispan wing to center line, square feet
S'	included area of two semispan wings, obtained by extending leading and trailing edges to center line, square feet
b	wing span, diameter of circle swept by wing tips, feet
d	maximum fuselage diameter, feet

d/b	fuselage-diameter - wing-span ratio
Λ	sweepback angle of leading edge, degrees
λ	taper ratio, ratio of chord at wing tip to chord at center line
A	aspect ratio $\left(\frac{b^2}{S'}\right)$
p	rolling velocity, radians per second
V	flight-path velocity, feet per second
M	Mach number
R	Reynolds number, based on wing chord

CONFIGURATIONS TESTED

The configurations tested during this investigation had, as common features, wings without taper or lateral controls, an aspect ratio of 3.7, and NACA 65A009 airfoil sections in the free-stream direction. These configurations were divided into two general groups, one for those with straight wings and the other for those with sweptback wings. Each group was composed of the following configurations; two semispan wings without a fuselage (fig. 1(a)), two semispan wings on a pointed cylindrical fuselage (fig. 1(b)), three semispan wings on a pointed cylindrical fuselage (figs. 1(c) and 1(d)), and four semispan wings on a pointed cylindrical fuselage (fig. 1(e)). In figure 2 these configurations are further described and associated with the techniques with which they were tested. Furthermore, it may be noted in figure 2 that similar configurations tested by the two techniques were nearly identical scale versions of one another.

Configurations tested with the sting-mount technique were small, contained neither instrumentation nor a propulsion system, and were machined from steel stock and fitted with wooden fuselage parts. Configurations tested with the torque-nozzle technique were larger, contained instrumentation and a rocket motor, and had reinforced wooden wings mounted on wooden fuselages.

TEST PRODEDURES

Sting-Mount Technique

A configuration tested by the sting-mount technique was attached to the sting, which included a torsion spring balance to measure rolling moment, on the forward end of the test vehicle (fig. 3(a)). During flight the test configuration was rolled by the test vehicle which had each of its fins set at an angle of incidence (fig. 2(a)). Time histories of the rolling velocity, flight-path velocity, and rolling moment generated by the test configuration were obtained by standard NACA procedures and used in conjunction with radiosonde measurements of atmospheric conditions encountered during flight to permit evaluation of the damping-in-roll coefficient as a function of Mach number. A complete description of this technique may be found in reference 1.

Torque-Nozzle Technique

With the torque-nozzle technique, part of the thrust supplied by the rocket motor contained within the fuselage of the configuration being tested was converted by a special nozzle (fig. 3(b)) to a torque which forced the configuration to roll. Time histories of rolling velocity, flight-path velocity, torque, and moment of inertia were obtained and used in conjunction with radiosonde measurements of atmospheric conditions to complete equations expressing equilibrium during accelerating and decelerating flight. The variation of C_{l_p} with Mach number was obtained by solving these equations simultaneously under the same Mach number conditions. A complete description of this technique may be found in reference 2.

ACCURACY

Sting-Mount Technique

The systematic errors, due to limitations of the measuring and recording systems, in the values of C_{l_p} obtained by the sting-mount technique and presented herein are estimated to be within the following limits:

M	Error in C_{l_p}
0.7	± 0.058
0.9	± 0.032
1.2	± 0.017
1.6	± 0.010

However, in reference 1 the results obtained for nearly identical configurations show better agreement than the estimated maximum possible errors for those configurations indicated. The maximum possible errors in Mach number are estimated to be less than ±0.01.

Experimental results contained in reference 3 showing the effect of incidence on the variation of wing-tip helix angle with Mach number for scale models of configurations 5 and 6 were used to correct the data obtained for these configurations for incidence due to construction inaccuracies. The experimental results in reference 3, while not strictly applicable because of differences in configurations, were also used to correct the data obtained for configurations 1 to 4 since the corrections, which were small, were applied to data which did not differ greatly from the results obtained for configurations 5 and 6.

Torque-Nozzle Technique

The maximum possible error, due to limitations of the measuring and recording systems and to variations in torque, in the values of C_{l_p} obtained by the torque-nozzle technique and presented herein is less than ±0.040 throughout the Mach number range investigated.

RESULTS AND DISCUSSION

Test data obtained for the configurations tested by the sting-mount technique are presented in figure 4 as curves showing the variation of rolling-moment coefficient C_l and wing-tip helix angle $pb/2V$ with Mach number.

Data obtained for the configurations tested by the torque-nozzle technique are presented in figure 5 as curves showing the variation of wing-tip helix angle $pb/2V$ with Mach number for accelerating and coasting flight. The faired lines drawn across abrupt changes in $pb/2V$ during coasting flight are used in the computation of the C_{l_p} values as explained in reference 4.

Effect of Fuselage

Experimental results showing the variation of the damping-in-roll coefficients with Mach number for configurations with and without fuselages and with either two straight semispan wings or two sweptback semispan wings are presented with some theoretical damping-in-roll values in figure 6. The experimental results show that damping in roll was maintained by each configuration throughout the Mach number range investigated.

The presence of a fuselage of such size that the fuselage-diameter - wing-span ratio was 0.191 had no appreciable effect on the damping in roll of the configuration with straight wings except in the transonic and low supersonic regions. In the transonic region, where the measured damping in roll may be influenced by the wing-dropping phenomenon experienced by straight wings with NACA 65A009 airfoil sections (reference 5), adding the fuselage to two straight semispan wings caused the abrupt changes in C_{l_p} to occur at slightly lower Mach numbers. The addition of a fuselage to two straight semispan wings also increased C_{l_p} in the lower supersonic region where a similar, though smaller, increase is indicated by theory (references 6 and 7).

The presence of a fuselage $\left(\frac{d}{b} = 0.191\right)$ did not have any effect on the damping in roll of the configuration with two sweptback semispan wings in the transonic and supersonic regions. In the subsonic region the results, although indicating a decrease in C_{l_p} when the fuselage was added, agree within the limits of experimental accuracy.

Other comparisons with theoretical damping-in-roll values in figure 6 show that the experimental results obtained for the configuration with two straight semispan wings agreed within experimental accuracy with theoretical values for isolated wings (reference 8) at the lowest Mach number investigated but diverged with increasing subsonic Mach number. In the low supersonic range the experimental results obtained for the configuration with straight semispan wings were lower than those calculated by the linearized-flow method for isolated wings of zero thickness (reference 7); however, the agreement improved with increasing Mach number. The difference between experimental and theoretical values for the configuration with two straight semispan wings in the high-subsonic and the supersonic regions may be due to a section-thickness effect as discussed in references 1 and 9, in which agreement improved with decreasing thickness.

The agreement between experiment and theory for the sweptback wings, figure 6(b), was excellent in the subsonic range; however, experiment was considerably lower than theory (reference 7) at the Mach number at which the leading edge became supersonic.

Effect of Number of Semispan Wings

The variation of the damping-in-roll coefficients with Mach number for two series of wing-fuselage configurations, one with straight wings ($\Lambda = 0^{\circ}$) and the other with sweptback wings ($\Lambda = 45^{\circ}$), with two, three, and four semispan wings mounted on pointed cylindrical bodies is presented in figure 7. These results show that damping in roll was maintained by each configuration throughout the Mach number range investigated.

The results obtained for the configurations with straight wings (fig. 7(a)) show that, with each increase in the number of semispan wings, the damping-in-roll coefficient decreased in the low-supersonic region where data were obtained for configurations with two, three, and four semispan wings. At $M = 1.05$ the C_{l_p} value obtained for the configuration with four semispan wings was approximately 70 percent of that obtained for the configuration with two semispan wings. The difference between C_{l_p} values obtained for configurations with two and three semispan wings was a maximum in the lower supersonic range and decreased to within the limits of experimental accuracy as the Mach number increased. At subsonic speeds the differences between the results were within the limits of experimental accuracy and therefore indicate no effect of the number of straight semispan wings on the damping in roll. In the transonic region, where the wing-dropping phenomenon experienced by straight wings with NACA 65A009 airfoil sections (reference 5) may influence the measured damping in roll, the abrupt changes in C_{l_p} occurred at lower Mach numbers with each increase in the number of straight semispan wings.

The subsonic results presented in figure 7(a), obtained for the configurations with straight semispan wings and fuselages, agree within experimental accuracy with the results obtained by wind-tunnel tests (reference 10) of configurations that were nearly identical scale models of those reported herein except for airfoil section and lateral controls.

Excellent agreement is shown in figure 7(a) between the results obtained for configuration 5 (sting-mount technique) and configuration 7 (torque-nozzle technique), both of which had three straight semispan wings on a fuselage. These results are also presented and discussed more fully in reference 4.

The results obtained for the configurations with sweptback wings (fig. 7(b)) show that with each increase in number of semispan wings the damping-in-roll coefficient decreased in the supersonic region. Theoretical results in reference 11 show a similar decrease in C_{l_p} with each increase in the number of delta semispan wings. At $M = 1.05$ the damping-in-roll coefficient obtained for the configuration with four semispan wings is shown to be approximately 65 percent of that obtained for the configuration with two semispan wings. In the subsonic region these results, though mostly within the limits of experimental accuracy, indicate a decrease in C_{l_p} when the number of semispan wings was increased from two to three or four.

Damping-in-roll results from reference 12 for a nearly identical scale model of configuration 6 were somewhat higher than the present results (fig. 7(b)) in the subsonic region, but the variation with Mach number was similar in both tests. The damping-in-roll values from references 10 and 12 were obtained for configurations with deflected ailerons by measuring the rolling velocities with the configurations free to roll and by measuring the rolling moments with the configurations restrained.

Effect of Sweepback

The variations of the damping-in-roll coefficients with Mach number for the different configurations tested are presented and arranged in figure 8 to show the effects of changing the sweepback angle of the leading edge from 0° to 45°. It is shown that increasing the sweepback decreased the damping in roll, particularly in the supersonic range, and reduced the severity of the apparent changes in damping in roll in the transonic region. Furthermore, the damping-in-roll coefficients obtained for the configurations with sweptback semispan wings show, in general, a loss and a partial recovery as the Mach lines emanating from the wing apex or the wing leading edge - fuselage juncture approach and cross the leading edges.

CONCLUSIONS

The results of an investigation, made with techniques utilizing rocket-propelled vehicles, to determine some effects of fuselage interference, wing interference, and sweepback on the damping-in-roll characteristics of untapered wings of aspect ratio 3.7 and with NACA 65A009 airfoil sections in the Mach number range between 0.6 and 1.7 indicate the following conclusions:

1. Damping in roll was maintained by each configuration tested throughout the Mach number range investigated.

2. The damping in roll of configurations with either straight or 45° sweptback wings was essentially unchanged by the presence of a fuselage of such size that the fuselage-diameter - wing-span ratio was 0.191.

3. In the supersonic range the damping-in-roll coefficients of

configurations with either straight or 45° sweptback wings decreased with each increase in the number of semispan wings.

4. Changing the angle of sweepback from 0° to 45° decreased the damping in roll, particularly at supersonic speeds, and reduced the severity of apparent changes in damping in roll in the transonic region.

5. Agreement between experiment and theory for straight wings, possibly because of a section-thickness effect, was within experimental accuracy at only the lowest subsonic speeds investigated, was poor at low supersonic speeds, but improved with increasing supersonic Mach number. Experimental results obtained for sweptback wings agreed with theory throughout the subsonic range.

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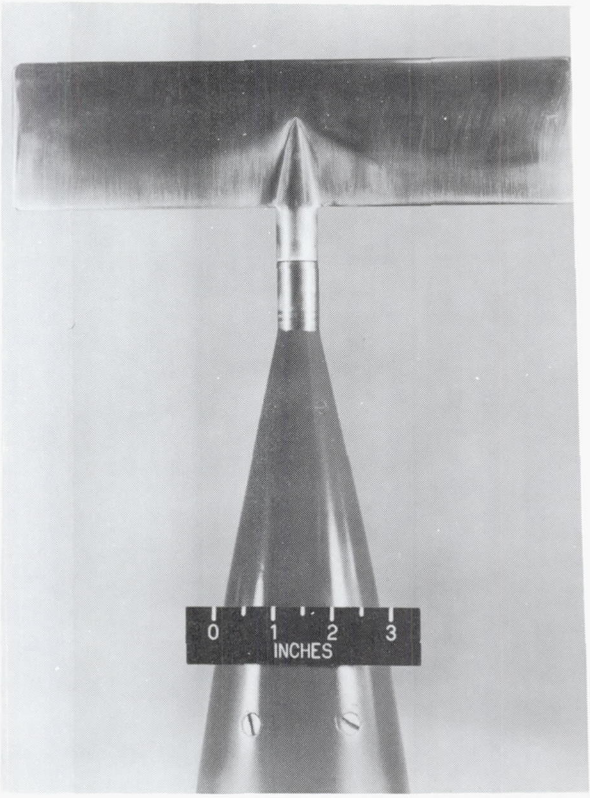
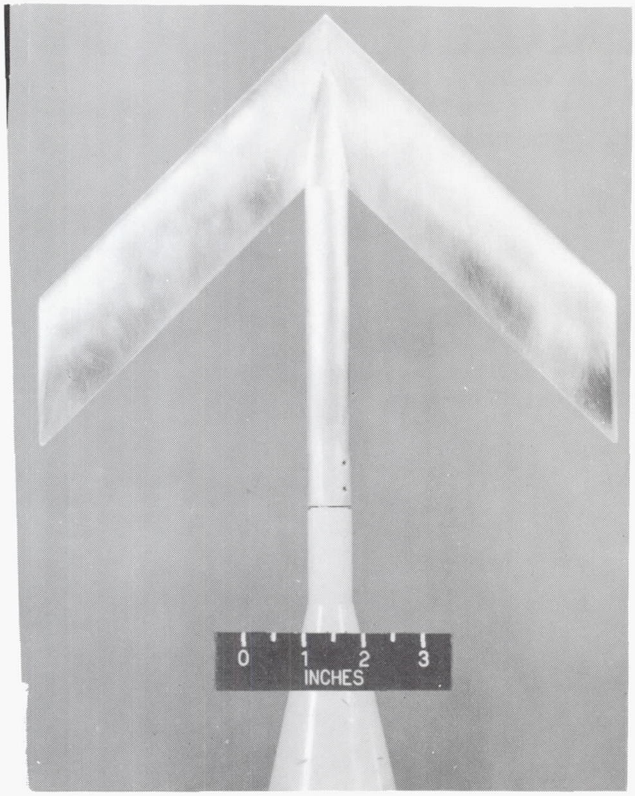


Configuration 1



Configuration 2

(a) Two semispan wings. Sting-mount technique.

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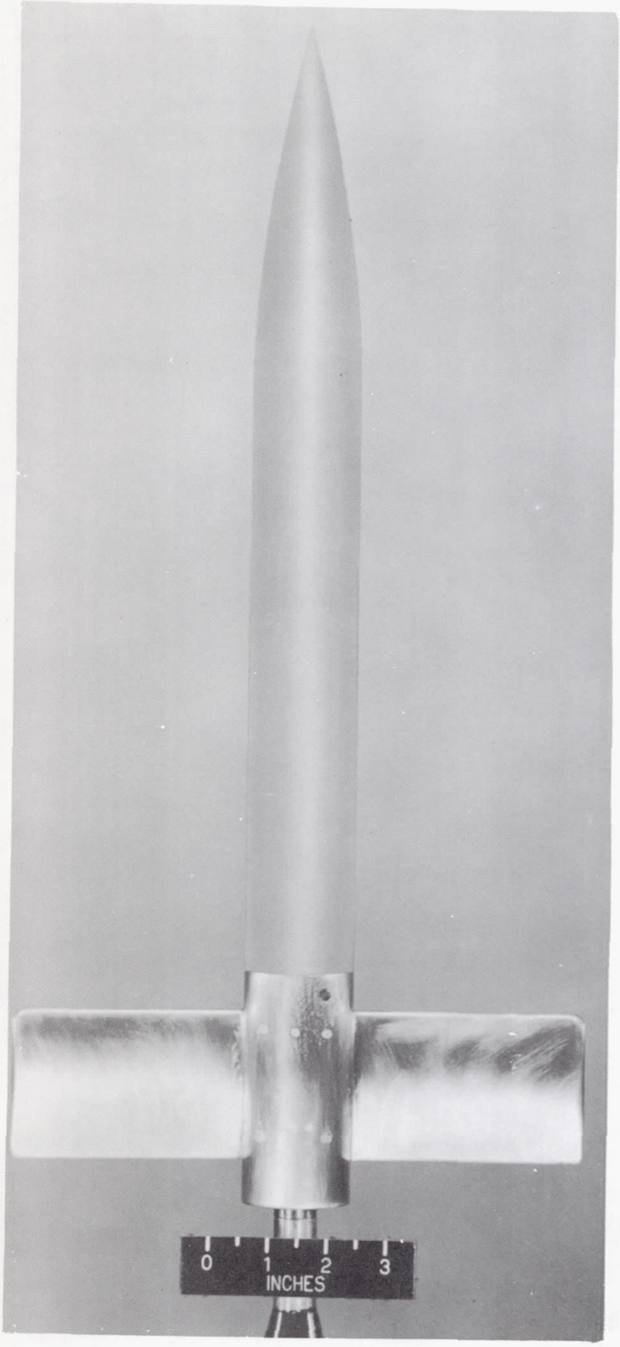
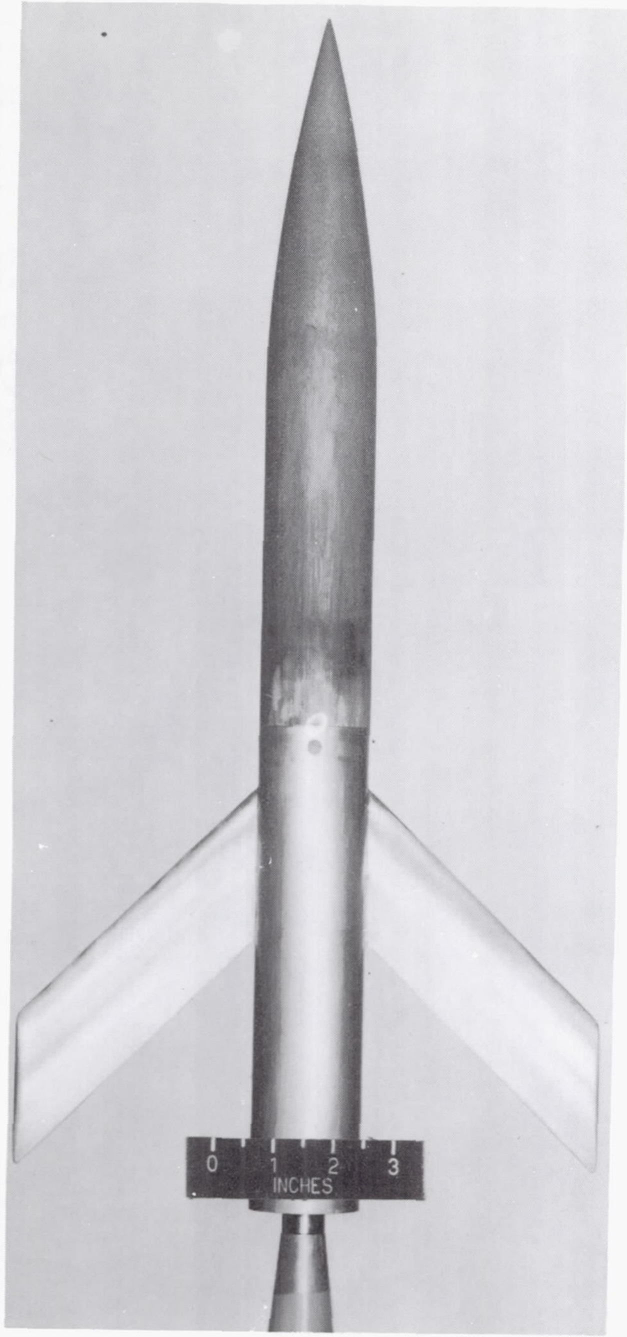
Figure 1.- Photographs of configurations tested.



Configuration 3



Configuration 4

(b) Two semispan wings and fuselage. Sting-mount technique.

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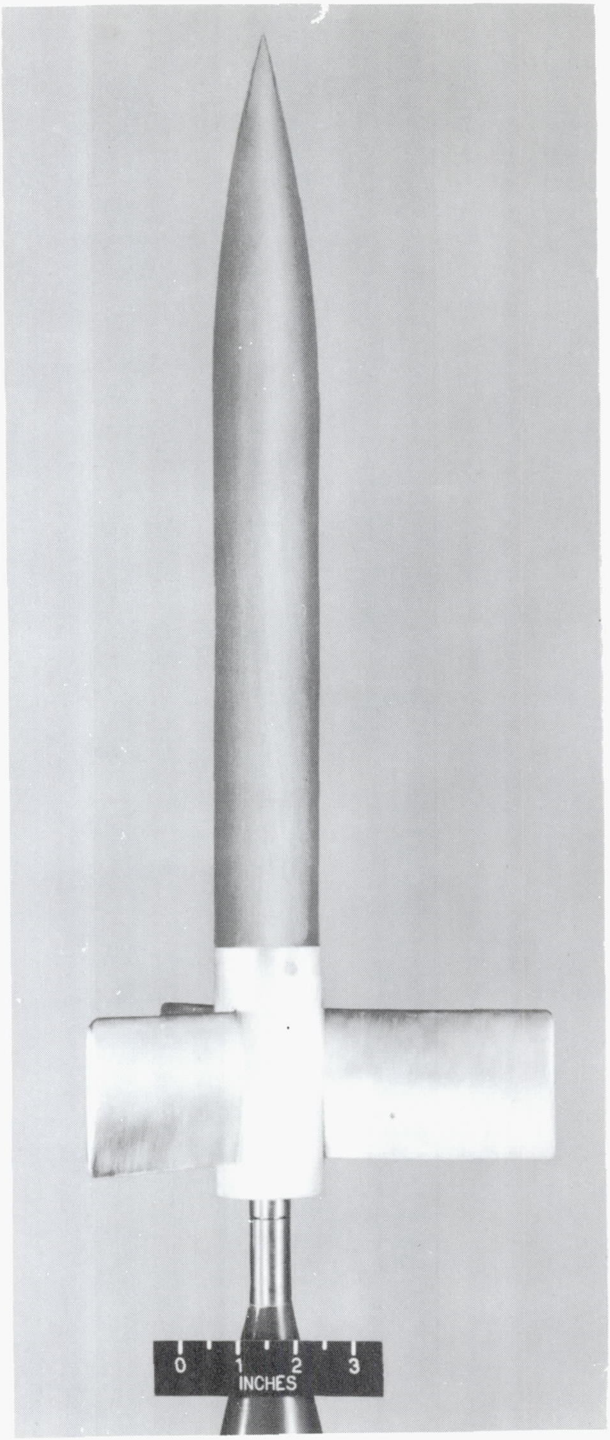
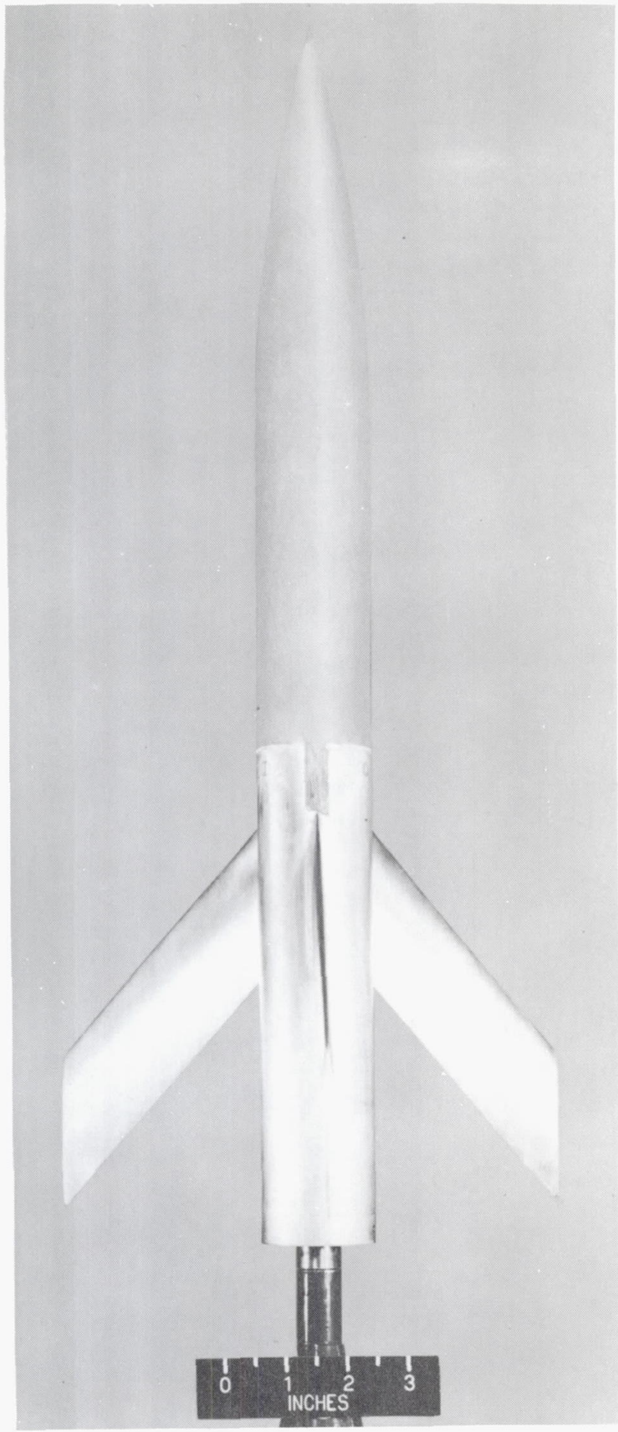
Figure 1.- Continued.



Configuration 5



Configuration 6

(c) Three semispan wings and fuselage. Sting-mount technique.

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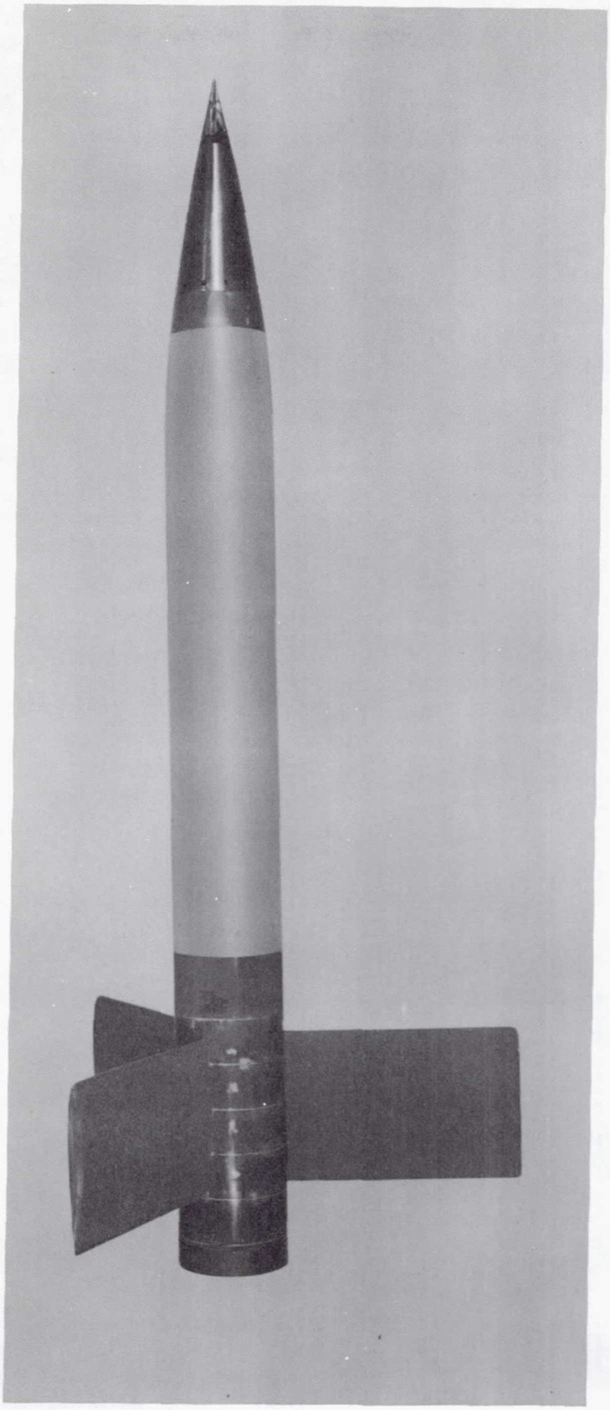
Figure 1.- Continued.



Configuration 7

(d) Three semispan wings and fuselage. Torque-nozzle technique.

Figure 1.- Continued.

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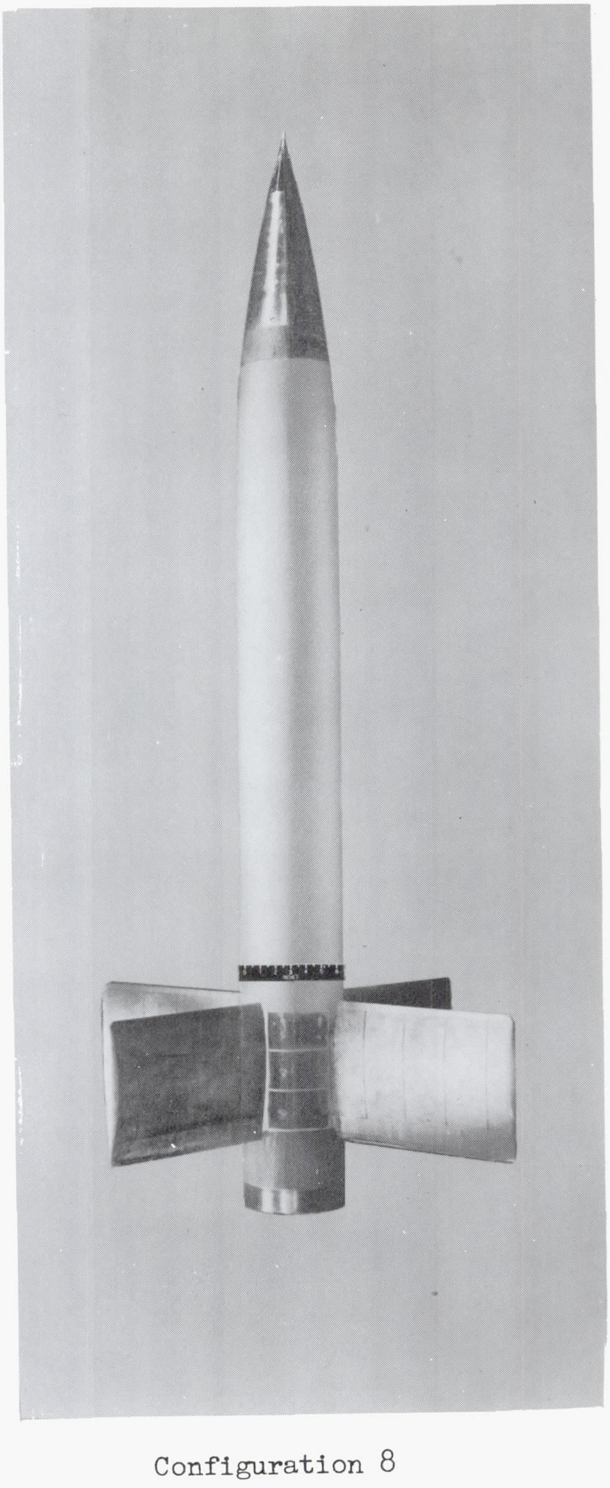
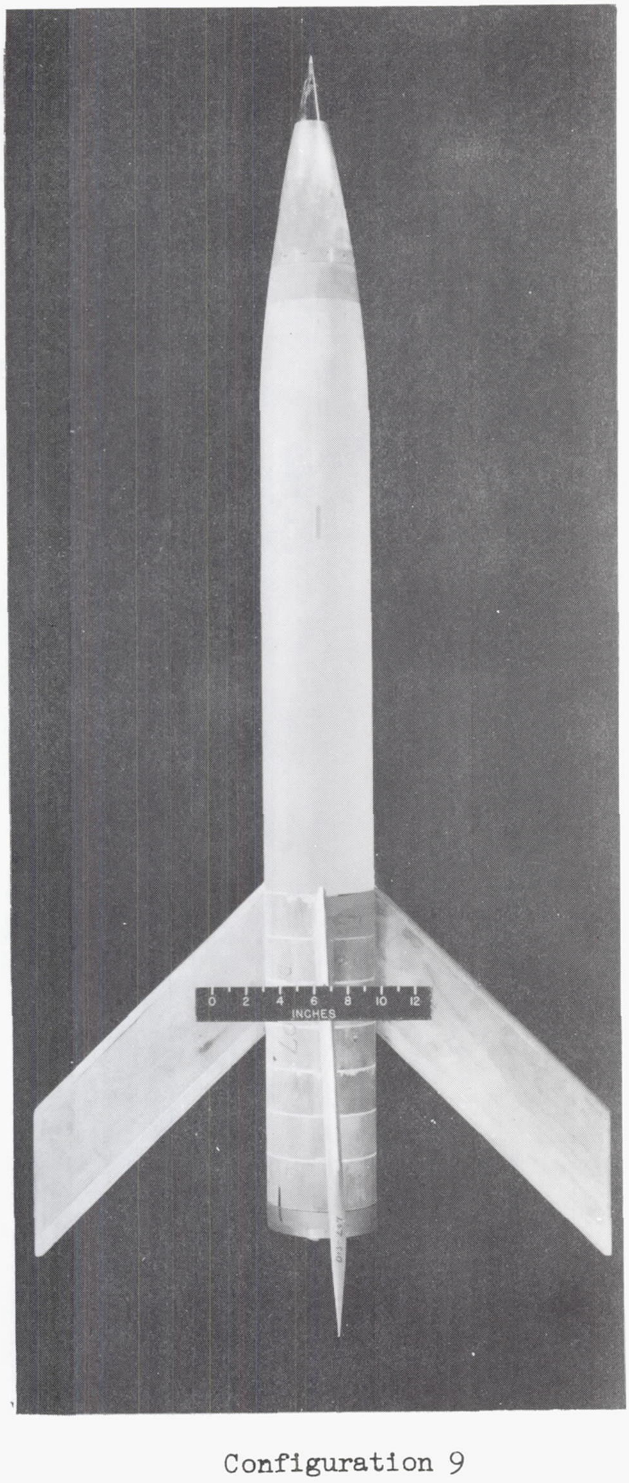


Configuration 8



Configuration 9

(e) Four semispan wings and fuselage. Torque-nozzle technique.

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Figure 1.- Concluded.

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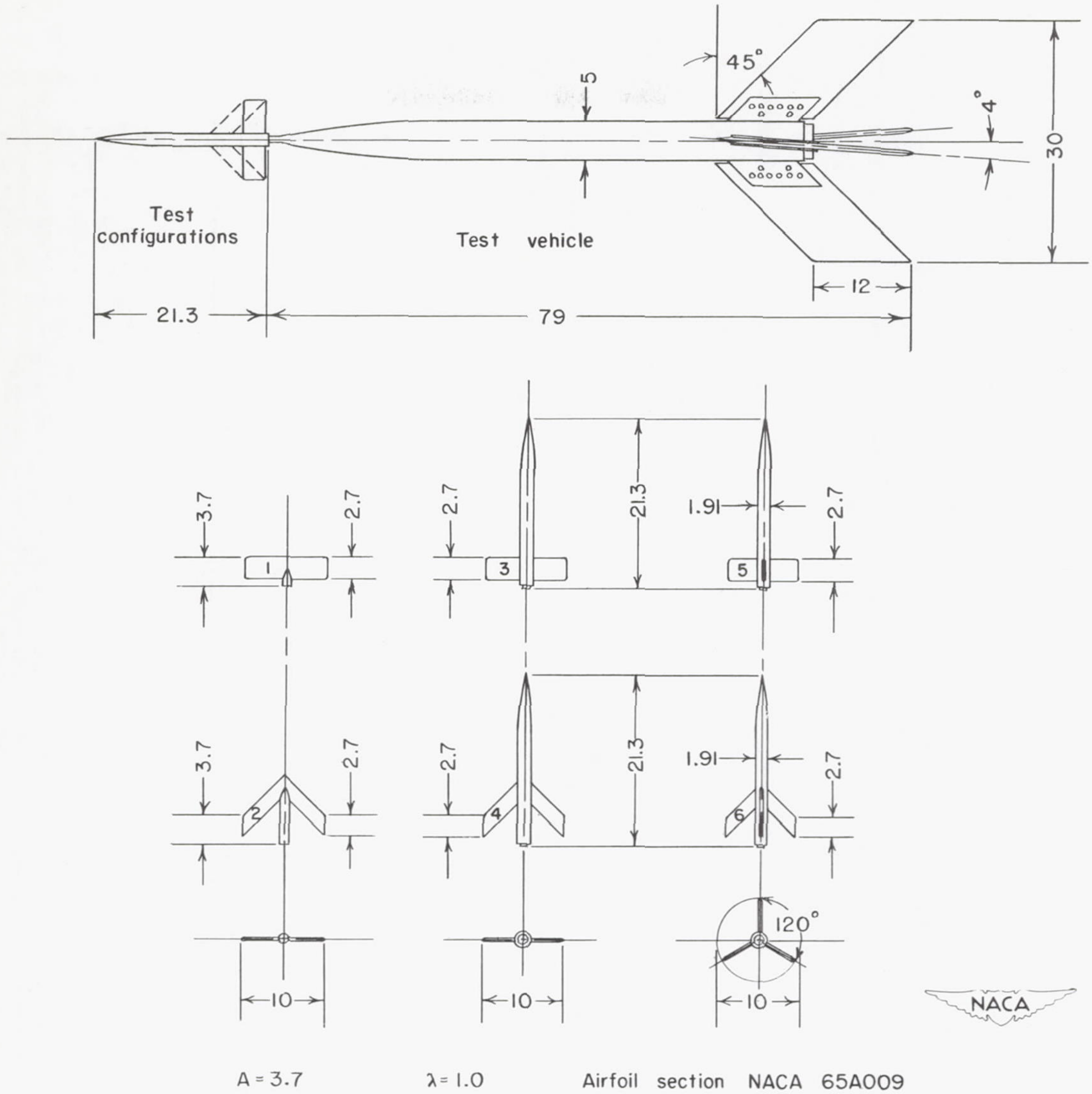
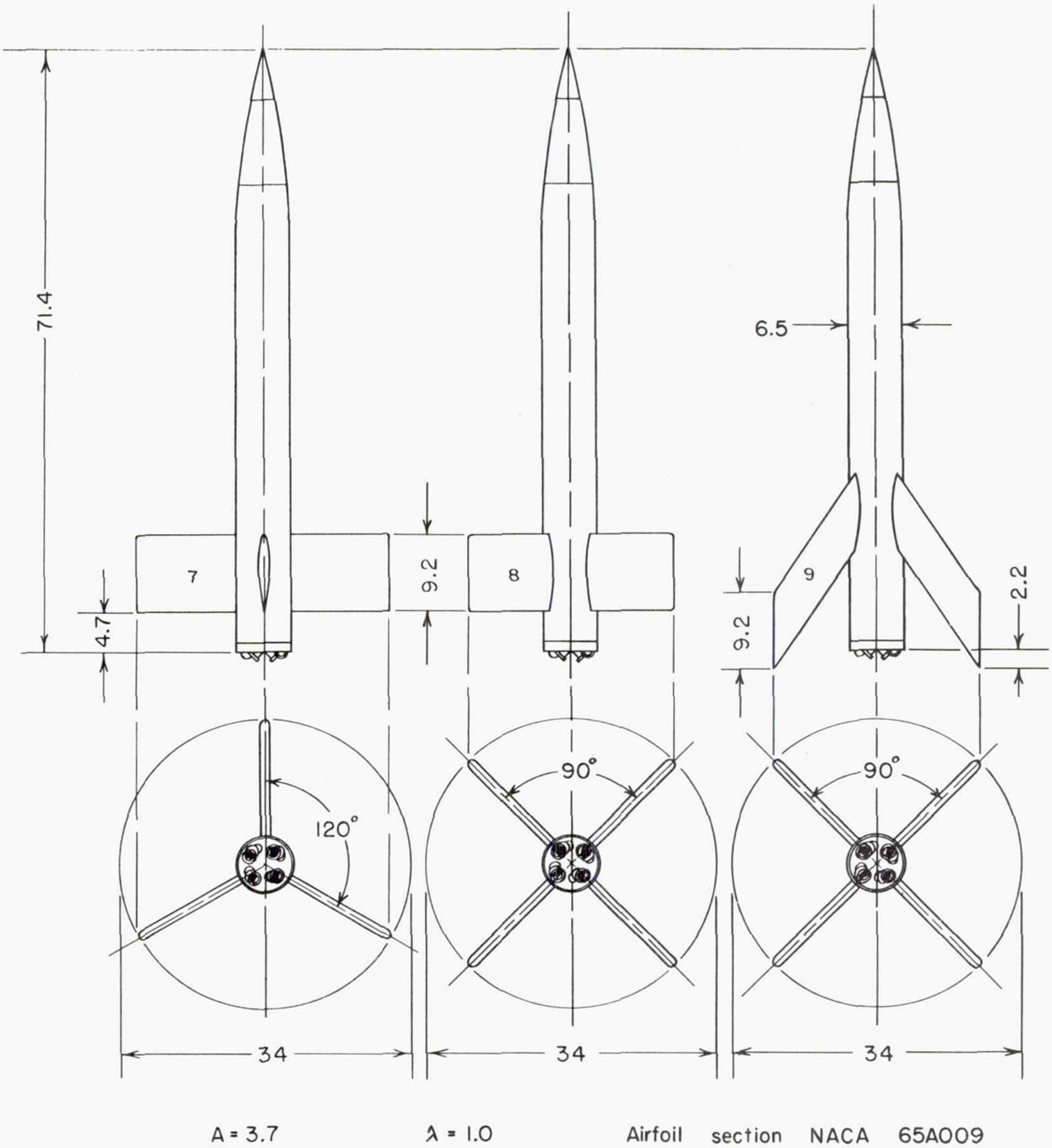


TEST CONFIGURATIONS

Configuration	Sweep, Λ (deg)	Number of semispan wings	Fuselage	Wing area, S (sq ft)	Reynolds number range	d/b
1	0	2	Off	0.188	0.78×10^6 to 2.71×10^6	0
2	45	2	Off	.188	.75 to 2.48	0
3	0	2	On	.188	.81 to 2.61	.191
4	45	2	On	.188	.76 to 2.29	.191
5	0	3	On	.282	.81 to 2.59	.191
6	45	3	On	.282	.80 to 2.23	.191

(a) Sting-mount technique.

Figure 2.- Geometric details of configurations tested. All dimensions are in inches.

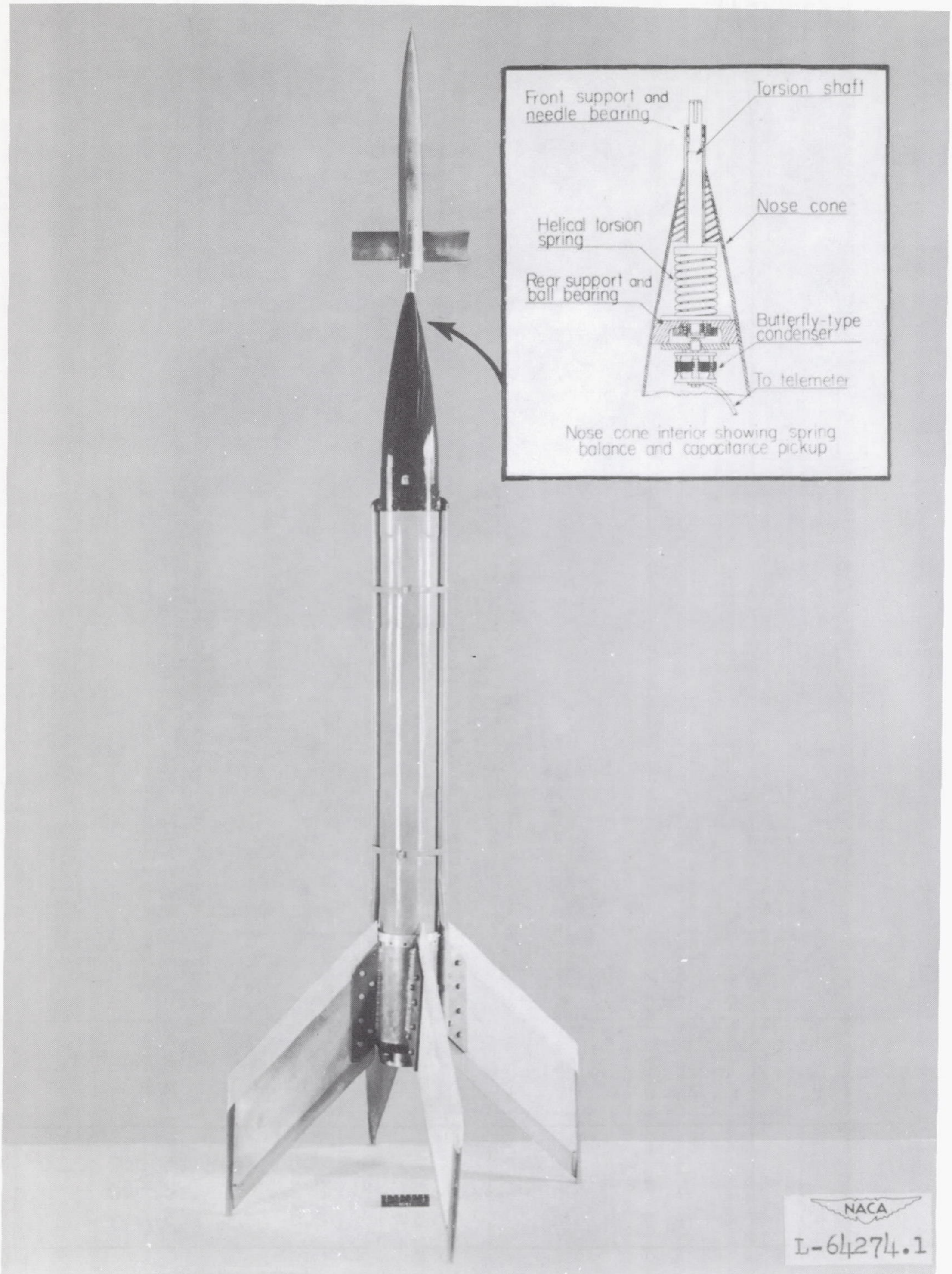


TEST CONFIGURATIONS

Configuration	Sweep, Λ (deg)	Number of semispan wings	Fuselage	Wing area, S (sq ft)	Reynolds number range	d/b
7	0	3	On	3.25	2.6×10^6 to 8.0×10^6	0.191
8	0	4	On	4.34	2.2 to 6.0	.191
9	45	4	On	4.34	2.8 to 6.5	.191

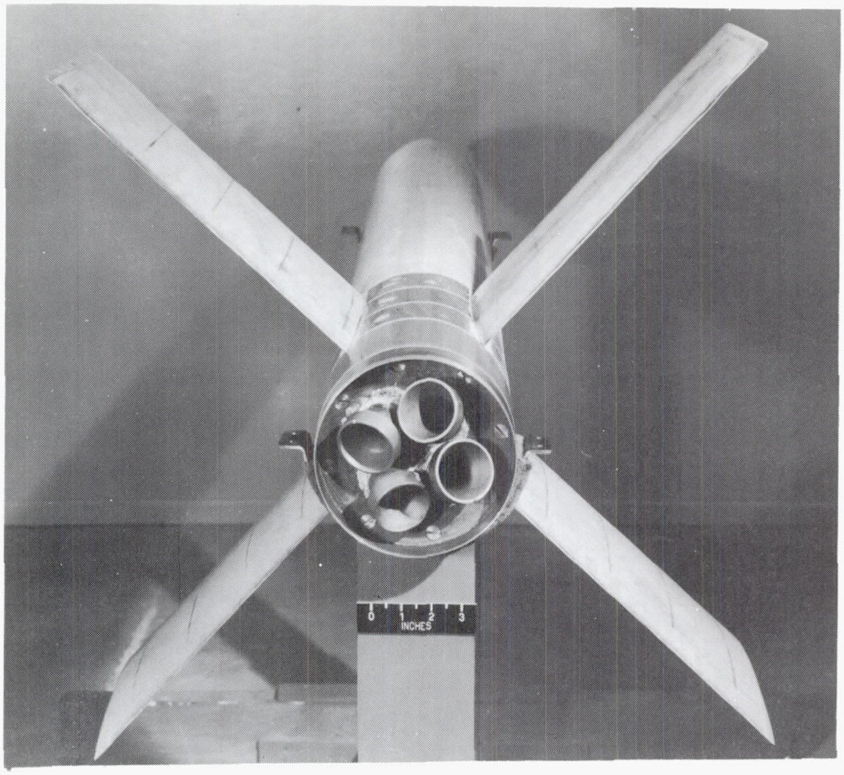
(b) Torque nozzle technique.

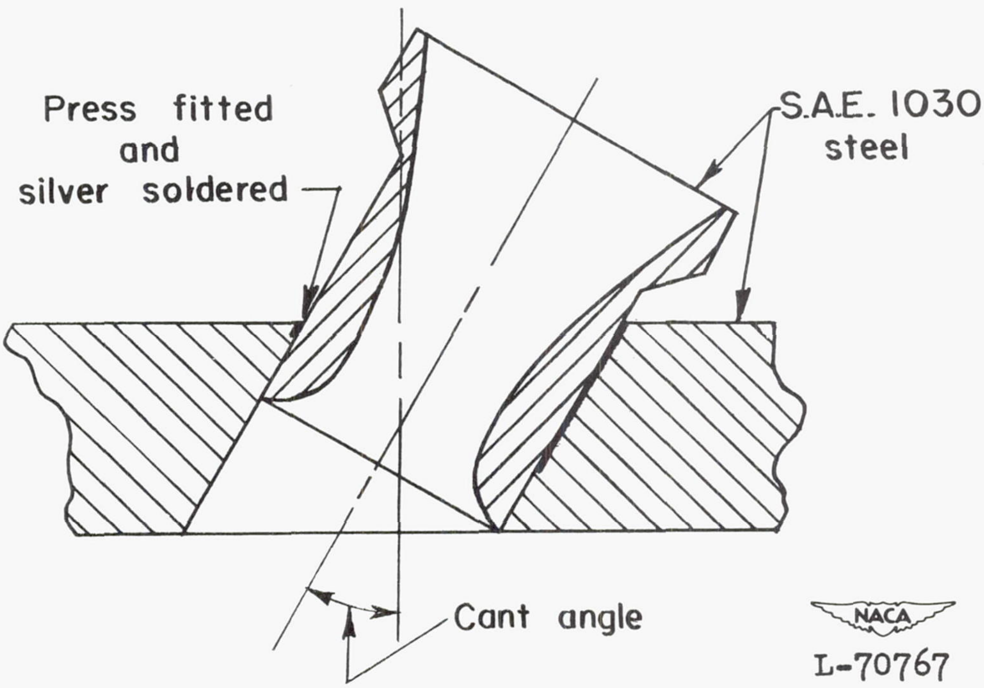
Figure 2.- Concluded.



(a) Sting arrangement used by sting-mount technique.

Figure 3.- Details of the test vehicles used in this investigation.





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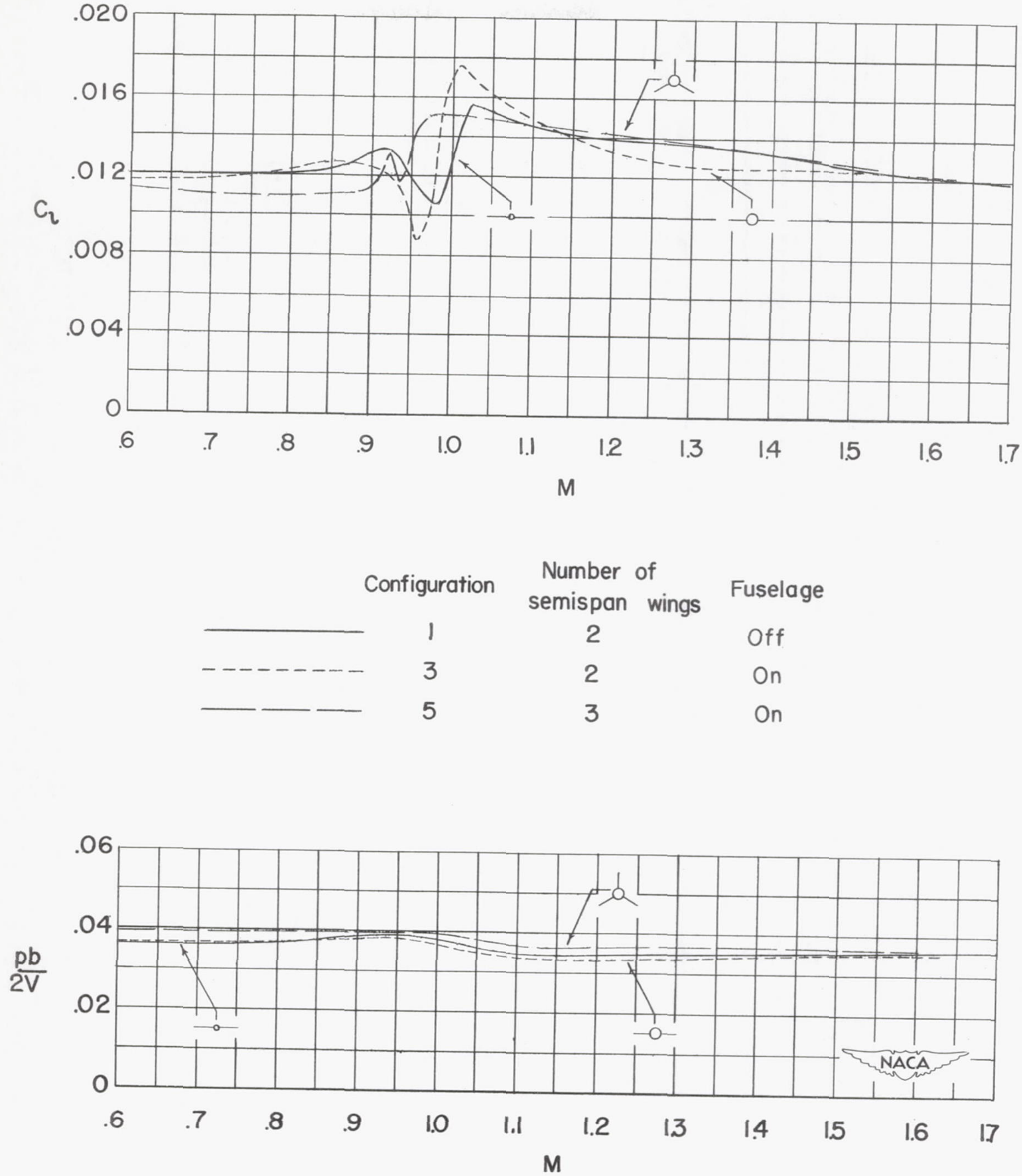
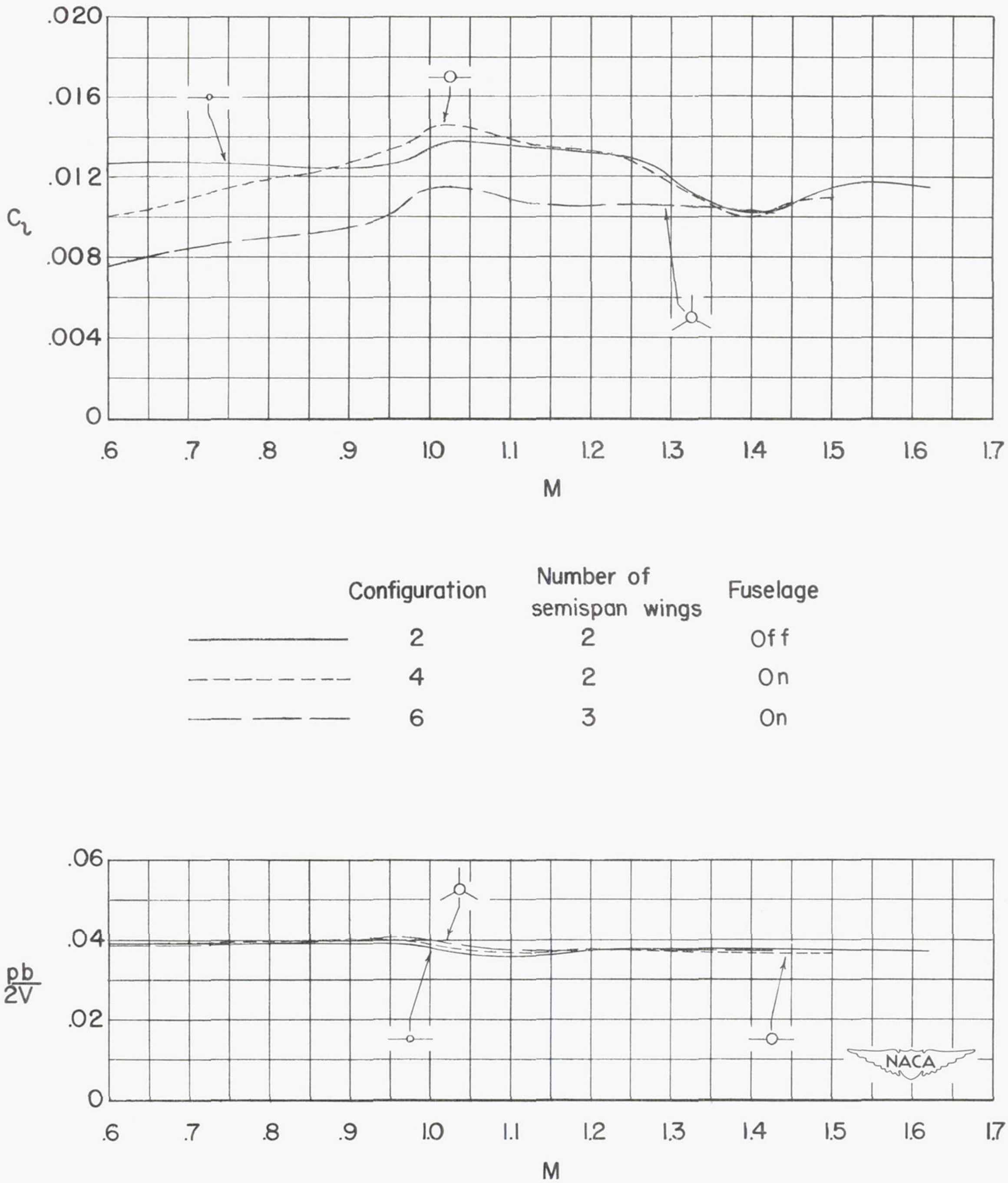
(b) Nozzle arrangement used by torque-nozzle technique.

Figure 3.- Concluded.



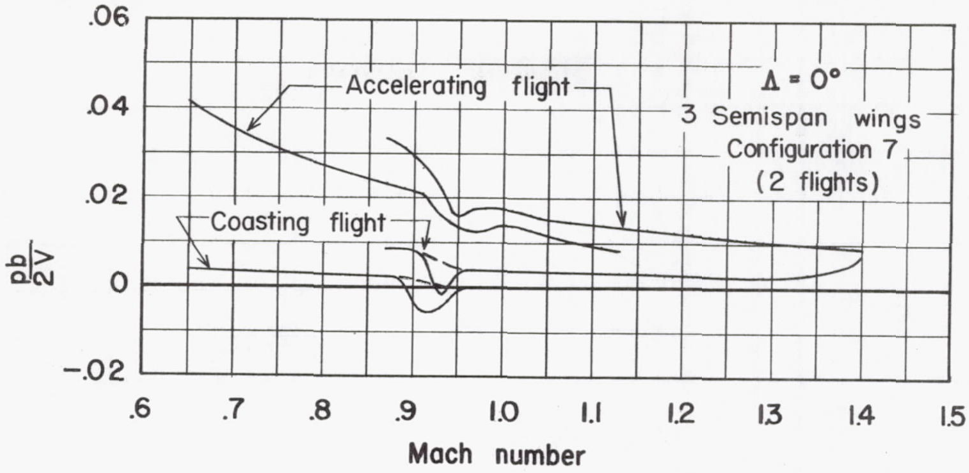
(a) $\Lambda = 0^{\circ}$.

Figure 4.- Test data obtained for configurations tested by the sting-mount technique.

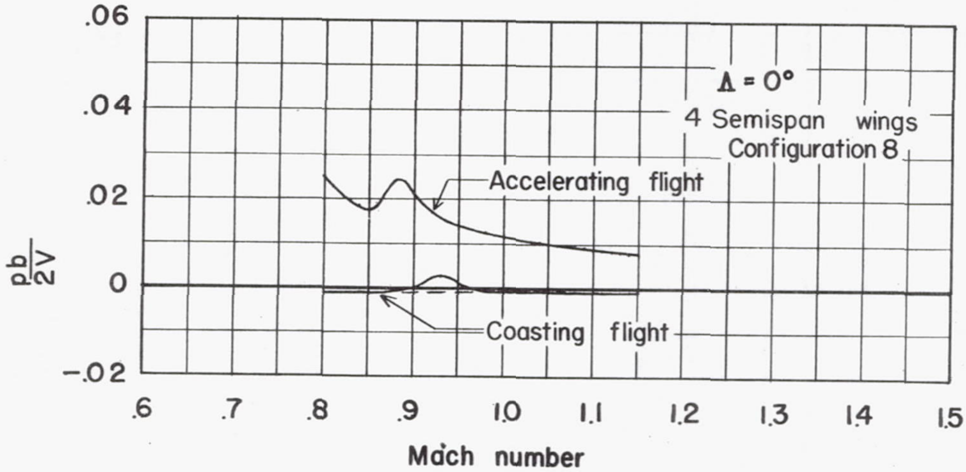


(b) $\Lambda = 45^{\circ}$.

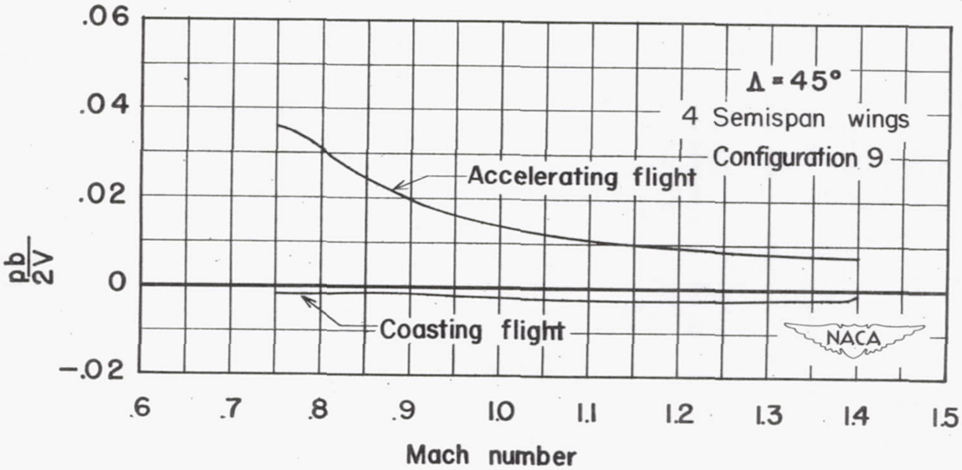
Figure 4.- Concluded.



(a) Straight wings.

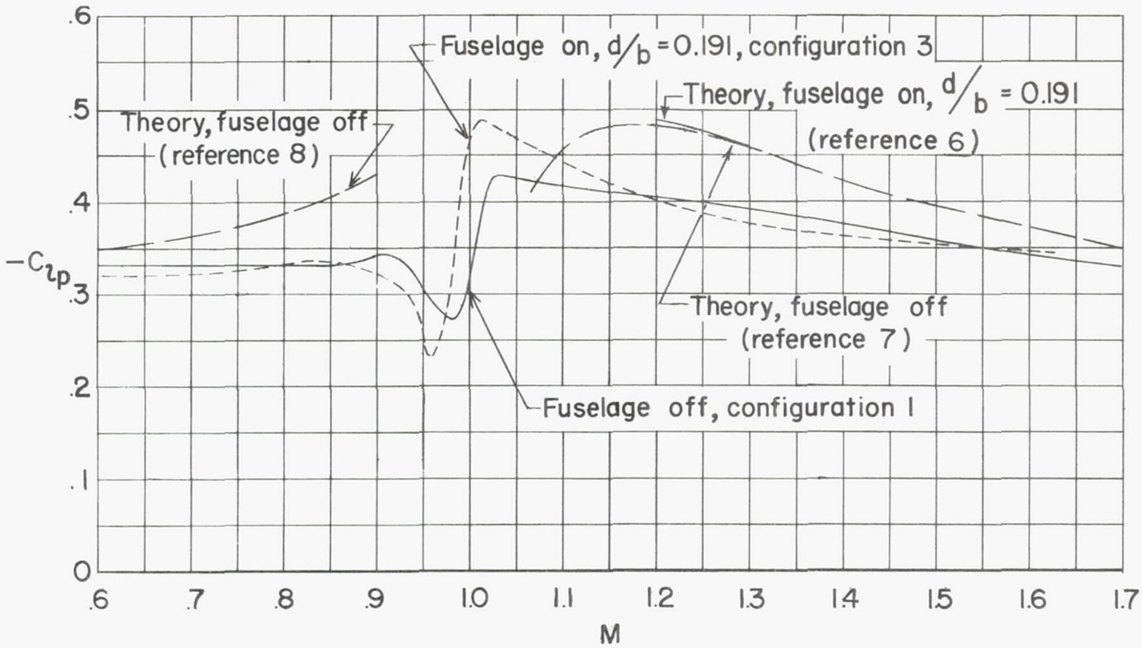


(b) Straight wings.

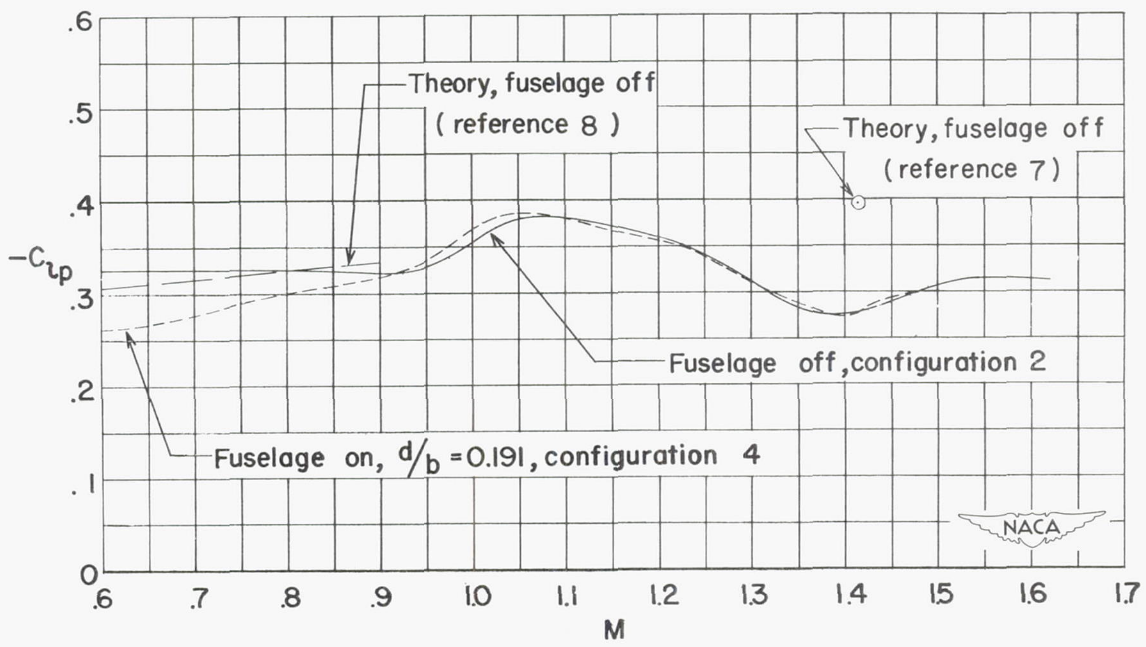


(c) Swept wings.

Figure 5.- Test data obtained for configurations tested by torque-nozzle technique.

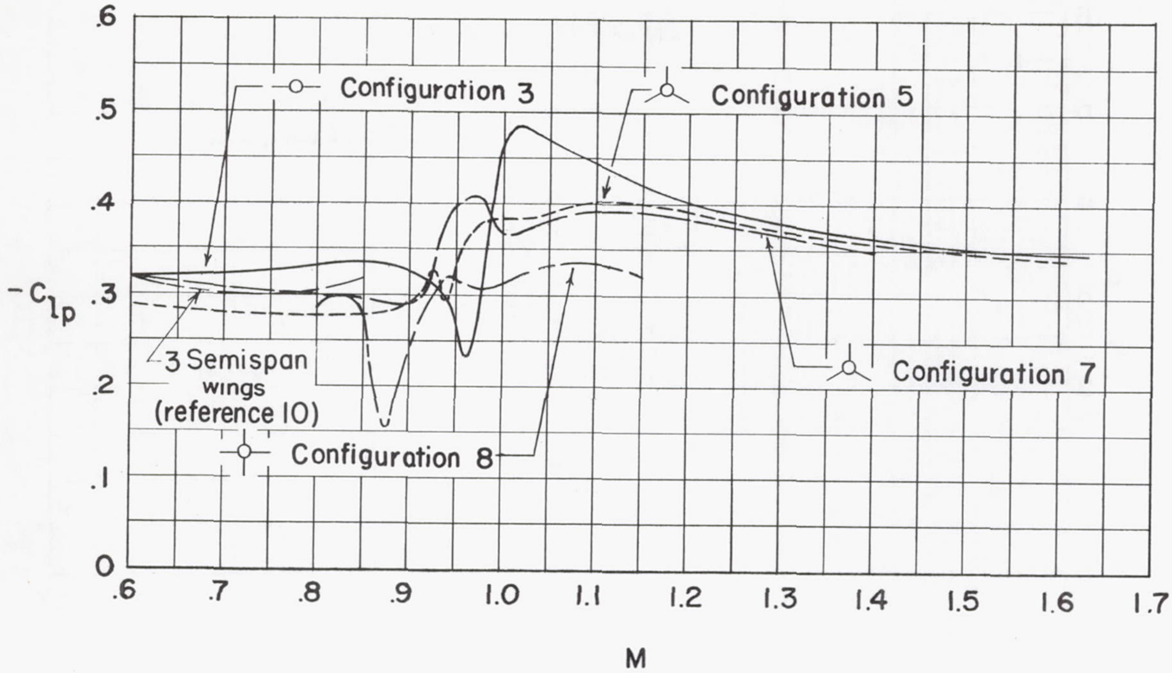


(a) $\Lambda = 0^{\circ}$.

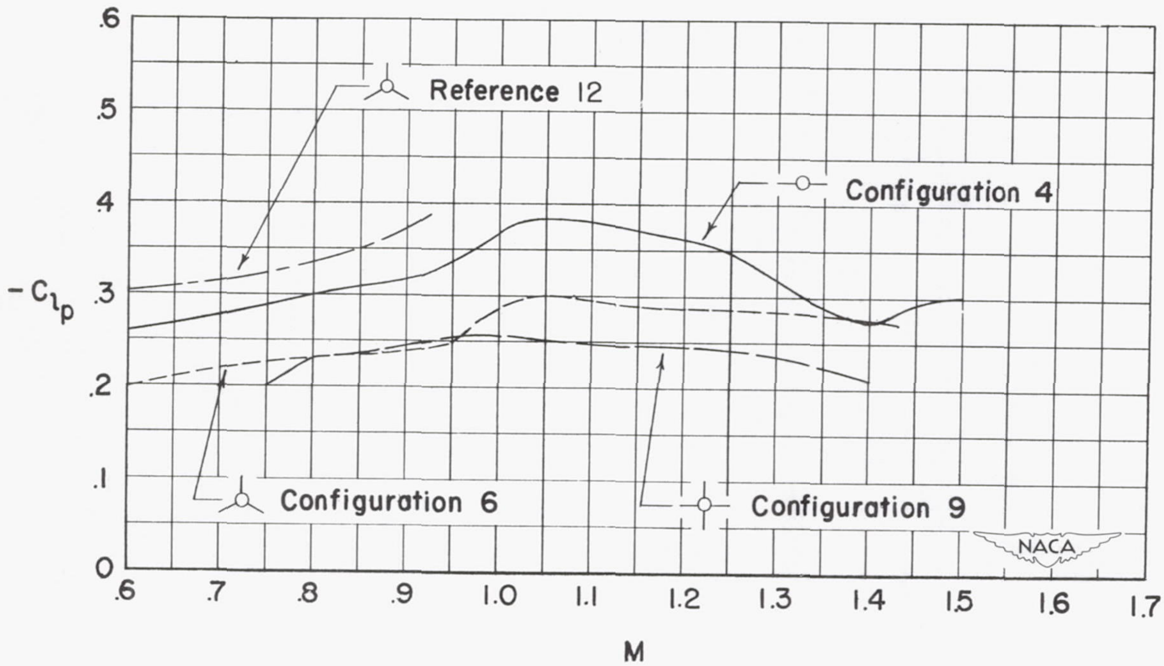


(b) $\Lambda = 45^{\circ}$.

Figure 6.- Effect of a fuselage with a fuselage-diameter - wing-span ratio of 0.191 on the variation of the damping-in-roll coefficient with Mach number.

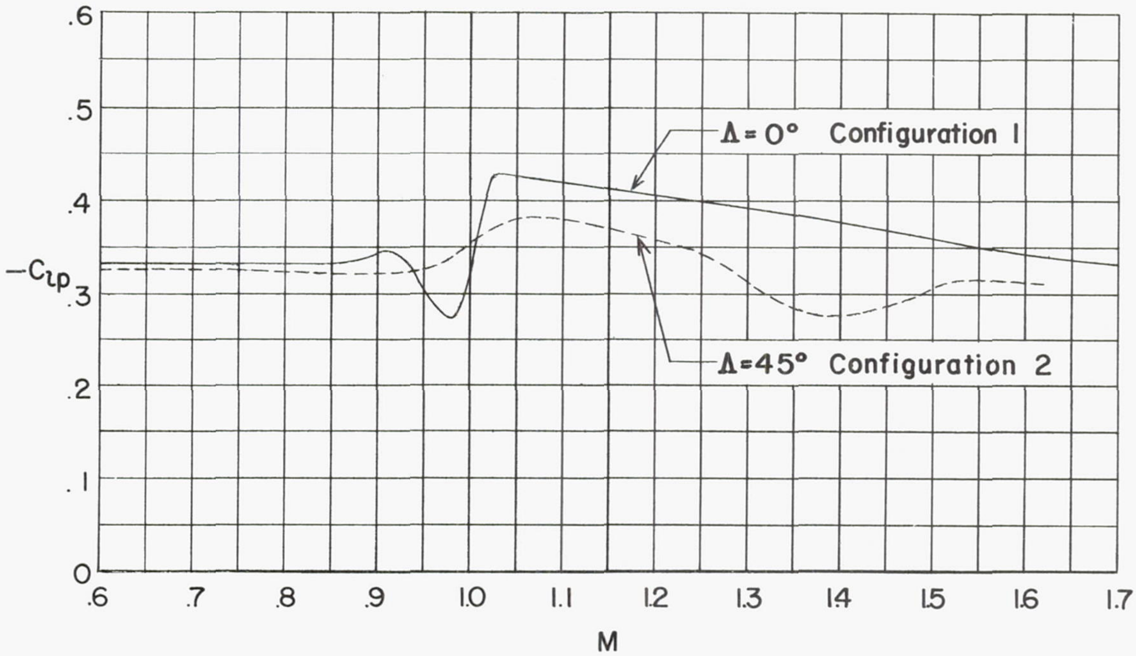


(a) $\Lambda = 0^{\circ}$.

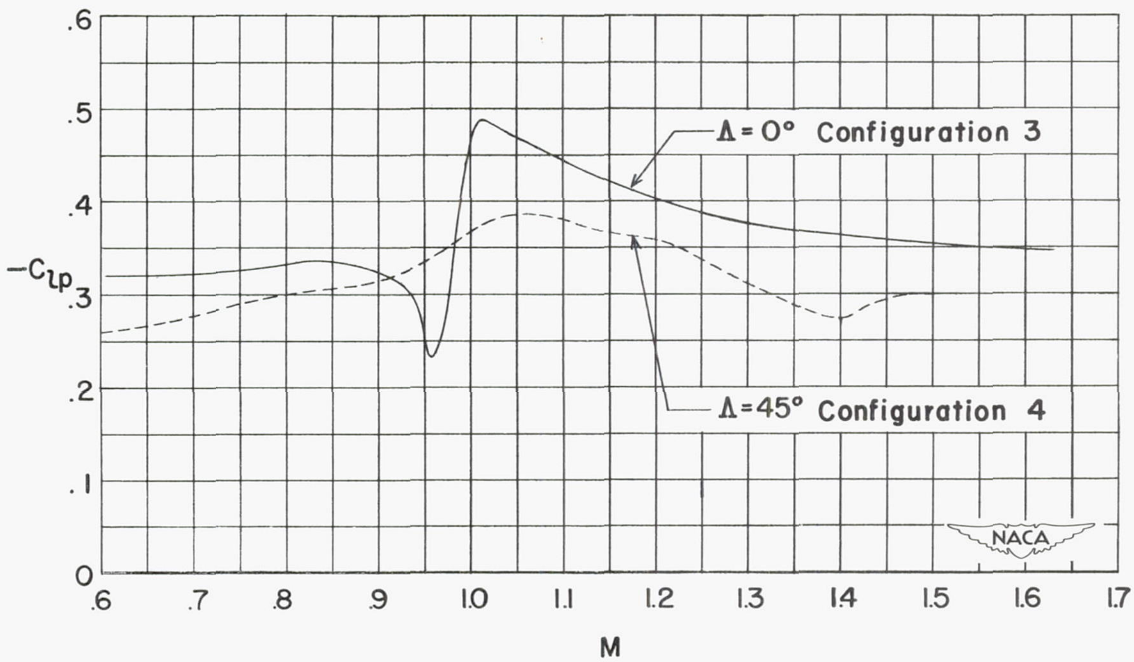


(b) $\Lambda = 45^{\circ}$.

Figure 7.- Effect of the number of semispan wings on the variation of the damping-in-roll coefficient with Mach number.

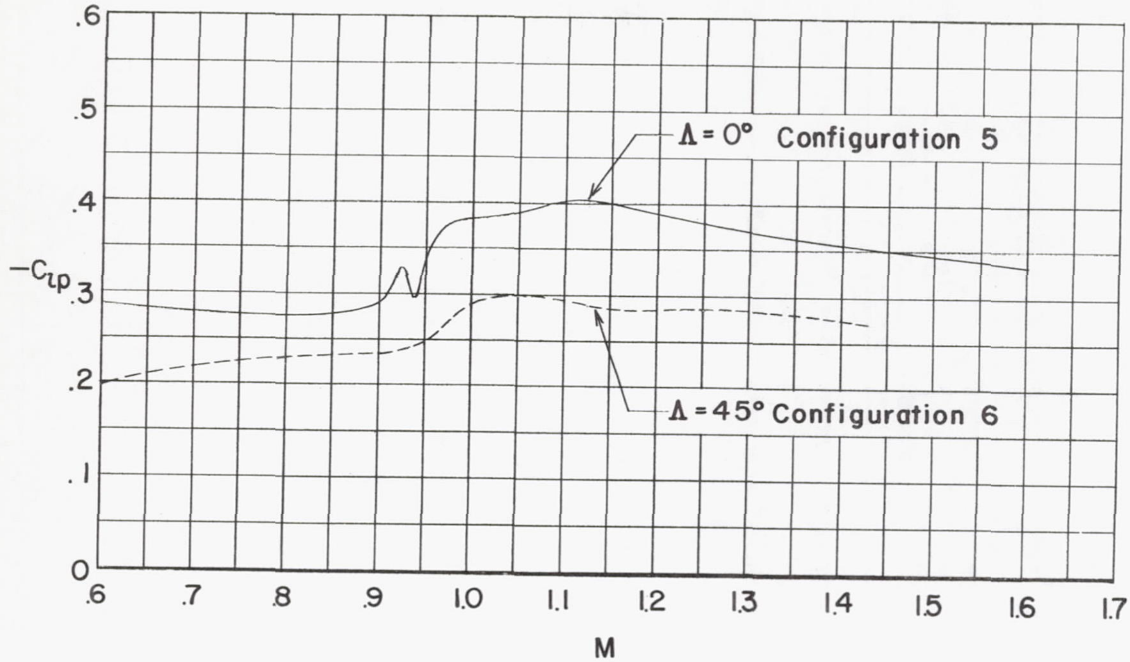


(a) Two semispan wings without fuselage.

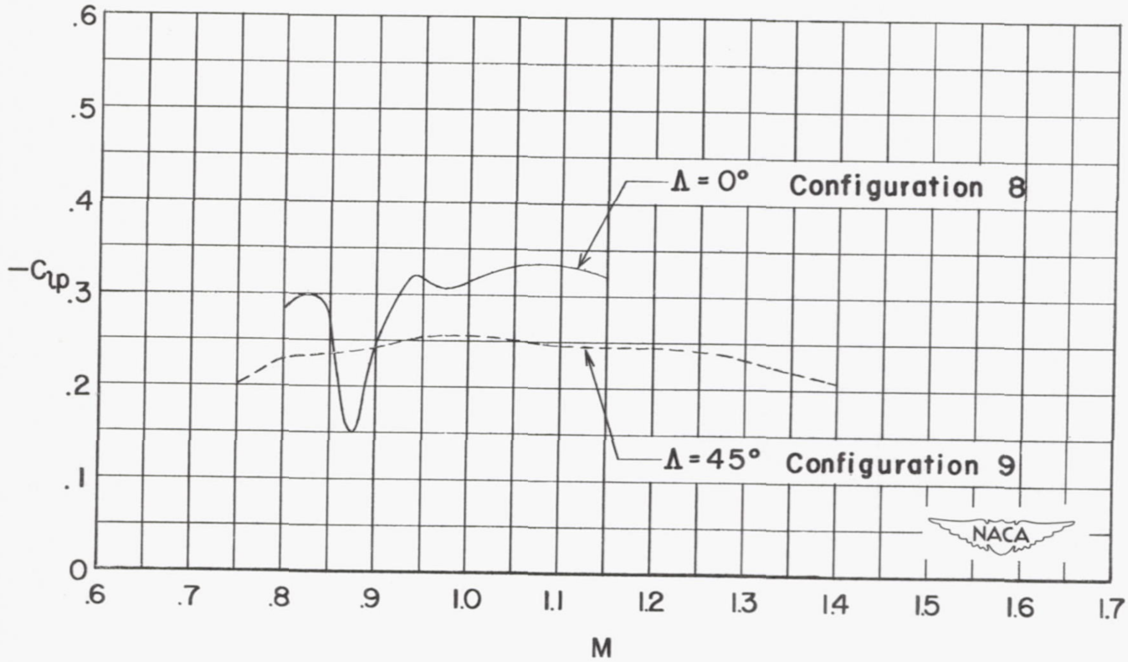


(b) Two semispan wings with fuselage.

Figure 8.- Effect of sweepback on the variation of the damping-in-roll coefficient with Mach number.



(c) Three semispan wings with fuselage.



(d) Four semispan wings with fuselage.

Figure 8.- Concluded.