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RESEARCH MEMORANDUM

ADDITIONAL FREE-FLIGHT TESTS OF THE ROLLING EFFECTIVENESS OF SEVERAL WING-SPOILER ARRANGEMENTS AT HIGH SUBSONIC, TRANSONIC, AND SUPERSONIC SPEEDS

By

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SUMMARY

Several wing-spoiler arrangements have been tested as a part of a general investigation of aerodynamic control at supersonic speeds which is being conducted by the Langley Pilotless Aircraft Research Division using rocket-propelled test vehicles.

The results show that chordwise spoiler location is a critical factor in determining an effective control for use over a wide Mach number range. A sharp-edge spoiler projecting 0.02 chord above the wing surface had less drag and greater over-all effectiveness when located at 0.8 chord than when located at 0.4 or 0.6 chord.

The sharp-edge spoiler at 0.8 chord was much more effective in the subsonic region and slightly more effective in the supersonic region than a wedge-type spoiler at the same location; however, the sharp-edge spoiler had considerably more drag. In comparison with a plain, full-span aileron deflected 4.4°, the sharp-edge spoiler was considerably less effective throughout most of the Mach number range except for a small range near Mach number 0.9. Below Mach number 0.9 the drag increment of the wing plus sharp-edge spoiler was approximately five times the drag of the wing and plain aileron. At higher Mach numbers the drag coefficients were approximately equal.

INTRODUCTION

The Langley Pilotless Aircraft Research Division is now engaged in an experimental investigation of aerodynamic controls utilizing rocket-propelled test vehicles in free flight. The exploratory phase of this investigation is being conducted with the RM-5 test vehicle with which data relating to the rolling capabilities of various wing-control combinations are obtained. Descriptions of the test technique and results obtained previously for the rolling effectiveness of plain ailerons are given in references 1 to 4.

Inasmuch as spoiler-type controls offer the possibility of obtaining some degree of control effectiveness with small hinge moments, an experimental investigation of the rolling effectiveness of a number of wing-spoiler configurations has been conducted with the aforementioned technique. The purpose of the present paper is to present results obtained recently relating to the rolling characteristics of a full-span sharp-edge spoiler with an 0.02-chord projection above the wing surface at several chordwise positions and also to the relative effectiveness of the sharp-edge spoiler and a wedge-type spoiler located at the 80-percent-chord line. The sharp-edge spoiler and an 0.2-chord plain, sealed aileron with 4.4° deflection (reference 4) are also compared as a matter of interest. While the present results do not present a sufficient number of different configurations to permit the evaluation of the effectiveness of spoilers at transonic and supersonic speeds due to the fact that only one spoiler extension (0.02 chord) and aileron deflection $(\delta_a = 4.4^{\circ})$ was investigated, they do, however, indicate the effectiveness characteristics of typical spoiler arrangements.

SYMBOLS

$pb/2V$ wing-tip helix angle, radians

p rolling velocity, radians per second

b diameter of circle swept by wing tips, feet (with regard to rolling characteristics, considered to be effective span of 3-fin RM-5 models)

V flight-path velocity, feet per second

C_D drag coefficient based on total exposed wing area of 1.563 square feet

C_{l_p} damping coefficient, based on area of one wing taken to center line of vehicle

M Mach number

b_1 diameter of circle swept by wing tips minus fuselage diameter

S_1 exposed area of two wing panels

A exposed aspect ratio $\left(\frac{{b_1}^2}{S_1}\right)$

h spoiler extension above wing surface

c wing chord parallel to model center line

δ_a aileron deflection measured in plane perpendicular to chord plane and parallel to model center line

MODELS AND TESTS

The general arrangement of the RM-5 test vehicles used in the present investigation is shown in figure 1 and the photograph of figure 2. A photograph of a typical test vehicle with booster on the launcher is shown in figure 3. The airfoil section used on all the configurations in this investigation was the NACA 65-009, the exposed wing area was 1.563 square feet, and the aspect ratio A was 3.0. The configuration employing the full-span, plain, 0.2c sealed aileron had an aileron deflection δ_a of 4.4°.

The launching of the test vehicles is accomplished at the Wallops Island, Va. test facility. The test vehicles are propelled by a two-stage rocket-propulsion system to a Mach number of about 1.8. During a 10-second period of coasting flight following rocket-motor burnout, time histories of the rolling velocity are obtained with special radio equipment and the flight-path velocity is obtained by the use of Doppler radar. These data, in conjunction with atmospheric data obtained with radiosondes, permit the evaluation of the aileron rolling effectiveness in terms of the parameter pb/2V as a function of Mach number. In addition, the variation of drag coefficient with Mach number is obtained by a method involving the differentiation of the curve of flight-path velocity against time for power-off flight. The variation in Reynolds number with Mach number for the range of climatic conditions encountered during the tests is presented in figure 4.

The experimental accuracy based on previous experience is estimated to be within the following limits:

pb/2V (due to limitations on the instrumentation) . . . . ±0.003
C_D (at subsonic speeds) . . . . ±0.003
C_D (at supersonic speeds) . . . . ±0.002
M . . . . ±0.01

The limits of accuracy due to constructional differences are shown by the flights of duplicate models.

Inertia effects on the experimental values are believed to be negligible everywhere except in the regions where there are large changes in rolling velocity which generally occur between $M = 0.85$ and $M = 1.0$. Calculations based on the results presented for model 75(b) (which had the greatest variation in $pb/2V$) show that at $M = 0.93$, for example, where $\frac{dp}{dt} = 307$ radians per second square, the measured value is in error by a factor of approximately 20 percent using $C_{l_p} = 0.26$. On either side of this region, where rapid changes exist, the error is approximately 2 or 3 percent. (See reference 1.)

A complete discussion of the testing technique is contained in references 1, 2, and 3.

RESULTS AND DISCUSSION

The results of the present tests are presented in figures 5 to 7 as curves of $pb/2V$ and C_D against Mach number. A complete description of the configurations discussed in this paper is presented in figure 1. Positive rolling effectiveness is taken to be in a direction opposite to the spoiler extension. In cases where more than one model of the same number designation is mentioned, the letter designation denotes successful repeat flights of the same configuration.

Rolling effectiveness.- Spoiler location appears to be critical to a greater or lesser degree depending on the Mach number range in which the vehicle is operating. From examination of the curves of $pb/2V$ against Mach number in figure 5, it is apparent that in the region below $M \approx 0.9$ spoiler location is extremely critical. Unfortunately, only partial records were obtained from both test vehicles employing spoilers at the 80-percent-chord point. However, spoilers located at this chordwise position maintained good control as low as $M = 0.73$ based on the one flight for which data were available.

Moving the spoiler location to 60 percent of the chord caused a large variation in $pb/2V$ with Mach number below $M = 0.9$. The value of $pb/2V$ decreased from 0.064 at $M = 0.86$, where the values from the 0.6-chord and 0.8-chord positions were the same, to approximately 0.02 at $M = 0.53$. The discrepancy between the two models with the spoiler at the 0.6-chord location for the region between $M = 0.88$ and $M = 0.93$ is inexplicable at this time.

An extreme variation in $pb/2V$ with Mach number is evidenced when the spoiler is located at the 0.4-chord station. The value of $pb/2V$ varies from slightly negative at $M = 0.50$ to a peak of 0.096 at $M = 0.87$ and then decreases to a negative value of -0.008 at $M = 1.01$. Above $M = 1.0$ a positive trend in effectiveness is in evidence which continues until $M = 1.35$ where the value of $pb/2V = 0.014$. Beyond $M = 1.35$ a slight decrease in effectiveness with increasing Mach number occurs until at the highest Mach number observed for this vehicle, $M = 1.76$, the value of $pb/2V = 0.005$.

Above $M = 0.93$, the variation of $pb/2V$ with Mach number for the configurations with the spoiler at the 0.6-chord point and the 0.8-chord point agreed within the limits of experimental accuracy.

Figure 6 compares the variation of rolling effectiveness and drag with Mach number for two types of spoiler ailerons located at the 0.8-chord position on an NACA 65-009 airfoil section. From the lowest velocity at which data for both types of spoilers are available to $M = 0.93$, the sharp-edge spoiler has greater effectiveness than the wedge spoiler. At $M = 0.93$, the effectiveness curves for the two types of spoilers approach each other and maintain approximately the same relationship throughout the Mach number range up to the highest Mach number tested, $M = 1.75$, with the sharp-edge spoiler appearing to be slightly more effective. However, as the spread between the curves throughout this Mach number range is of the same order as that caused by estimated experimental error, it eliminates any positive conclusions being drawn regarding their relative effectiveness at Mach numbers greater than 0.93.

Figure 7 compares the rolling effectiveness of the sharp-edge spoiler at the 0.8-chord location with a 0.2-chord, full-span, sealed aileron on wings of the same plan form and section, previously compared in reference 4. This comparison is extremely limited because it is for only one spoiler and aileron deflection but clearly presents the greater drag of this type spoiler in the subsonic region. However, the spoiler maintained rolling effectiveness until $M = 0.91$ as opposed to the plain aileron which lost effectiveness at $M = 0.85$. The decision to use a spoiler extension of 2 percent $\left(\frac{h}{c} = 0.02\right)$ was based on an estimation using low-speed data of the spoiler extension at the 0.8-chord location necessary to equal the control of a 0.2-chord plain aileron at a deflection of 5°.

Drag measurements.- The drag-coefficient data obtained in this present investigation are included as a matter of interest and to illustrate the relation between transonic drag rise and control effectiveness. In examining these data, consideration should be made of the section angle-of-attack distribution along wing span caused by model rotation. A point to consider is the fact that within the accuracy of measurement the variation of drag coefficient with Mach number presented in figure 5 shows a fairly uniform increment of drag rise with increasing forward location of the sharp-edge spoiler which was approximately true for the entire Mach number range for which comparable data exist. However, it is interesting to note that at Mach numbers above about 1.4 the drag values of the three configurations tended to approach a common value.

Figure 6 compares the drag characteristics of the sharp-edge and wedge-type spoilers. The drag of the sharp-edge spoiler was appreciably greater than the wedge type for the entire Mach number range tested except for the region between $M = 0.9$ and 1.0 where the values were approximately equal. An indication of the extremely high drag of the sharp-edge spoiler at subsonic speeds is given by the comparison with the drag of the plain aileron in figure 7. The drag of the wing plus sharp-edge spoiler was approximately five times the drag of the wing and plain-aileron combination below $M \approx 0.9$. At higher Mach numbers the drag coefficients were approximately equal.

CONCLUSIONS

On the basis of the results of flight tests of the spoiler and aileron configurations presented herein, the following conclusions may be drawn:

1. Chordwise spoiler location appears to be critical for both rolling effectiveness and drag with the 0.8-chord location having the least drag and the highest over-all effectiveness. In the supersonic range the rolling effectiveness for the 0.6-chord and 0.8-chord locations agreed within the experimental accuracy.

2. In the Mach number range below Mach number 0.9, the sharp-edge spoiler was much more effective than the wedge type. However, above Mach number 0.9, the results for the two types of spoilers agreed within the experimental accuracy. The drag coefficient for the sharp-edge spoiler was appreciably greater than the drag of the wedge spoiler throughout the entire Mach number range tested except for a limited region between Mach numbers 0.9 and 1.0 where the drag coefficients were approximately equal.

3. The plain, sealed, 0.20-chord aileron for a deflection of 4.4° had greater rolling effectiveness than the sharp-edge spoiler throughout most of the Mach number region where comparable data exist except for the transonic region where the spoiler maintained effectiveness to a higher Mach number.

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REFERENCES

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2. Sandahl, Carl 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 Wing Sweepback, Taper, Aspect Ratio, and Section Thickness Ratio. NACA RM No. L7F30, 1947.

3. Sandahl, Carl A., and Strass, H. Kurt: Additional Results in 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 Wing Sweepback, Aspect Ratio, Taper, and Section Thickness Ratio. NACA RM No. L7L01, 1948.

4. Sandahl, Carl A.: Free-Flight Investigation of the Rolling Effectiveness of a Wing-Spoiler Arrangement at High Subsonic, Transonic, and Supersonic Speeds. NACA RM No. L8A07, 1948.

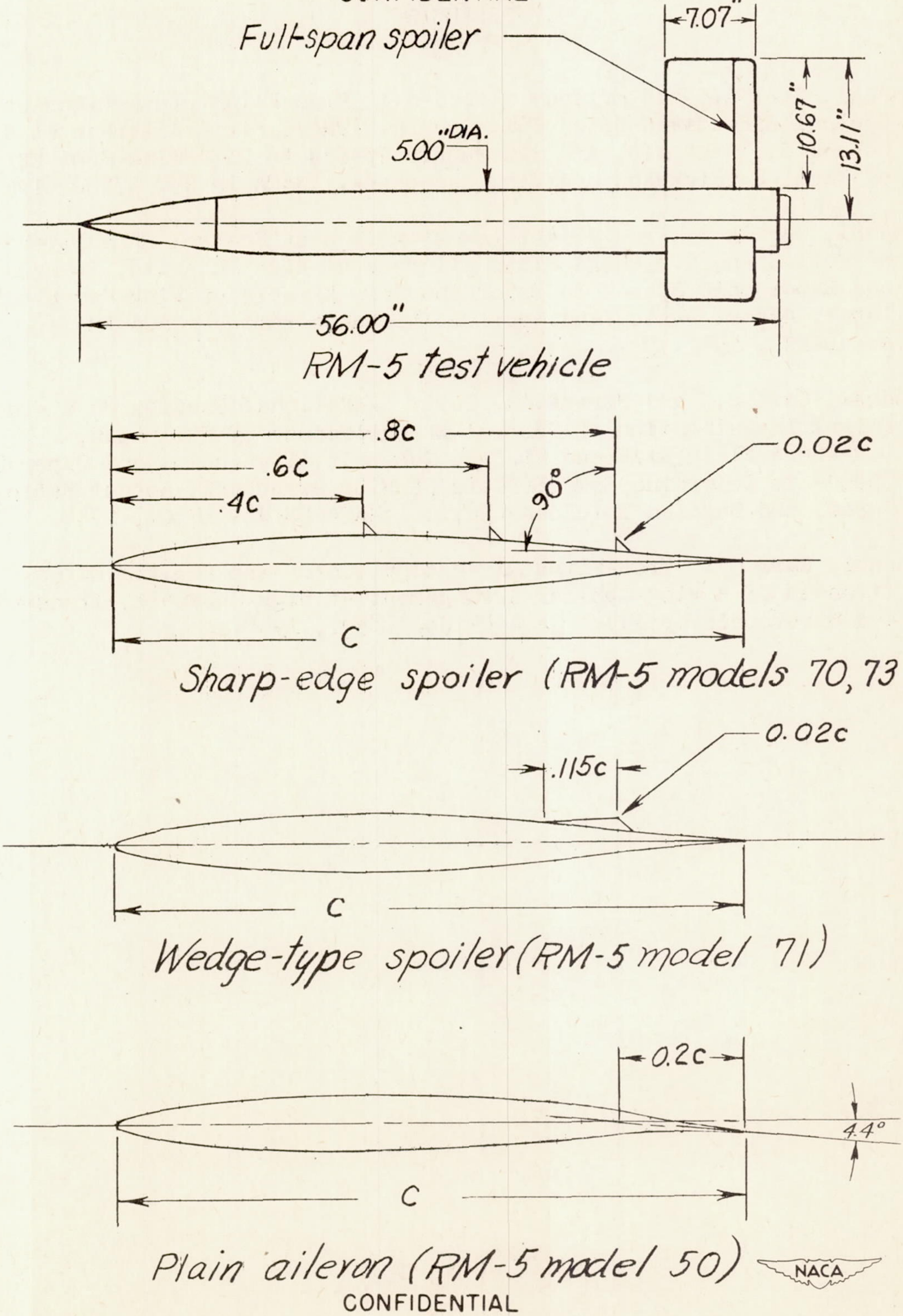

Figure 1.- General arrangement of RM-5 test vehicles.
NACA 65-009 airfoil.

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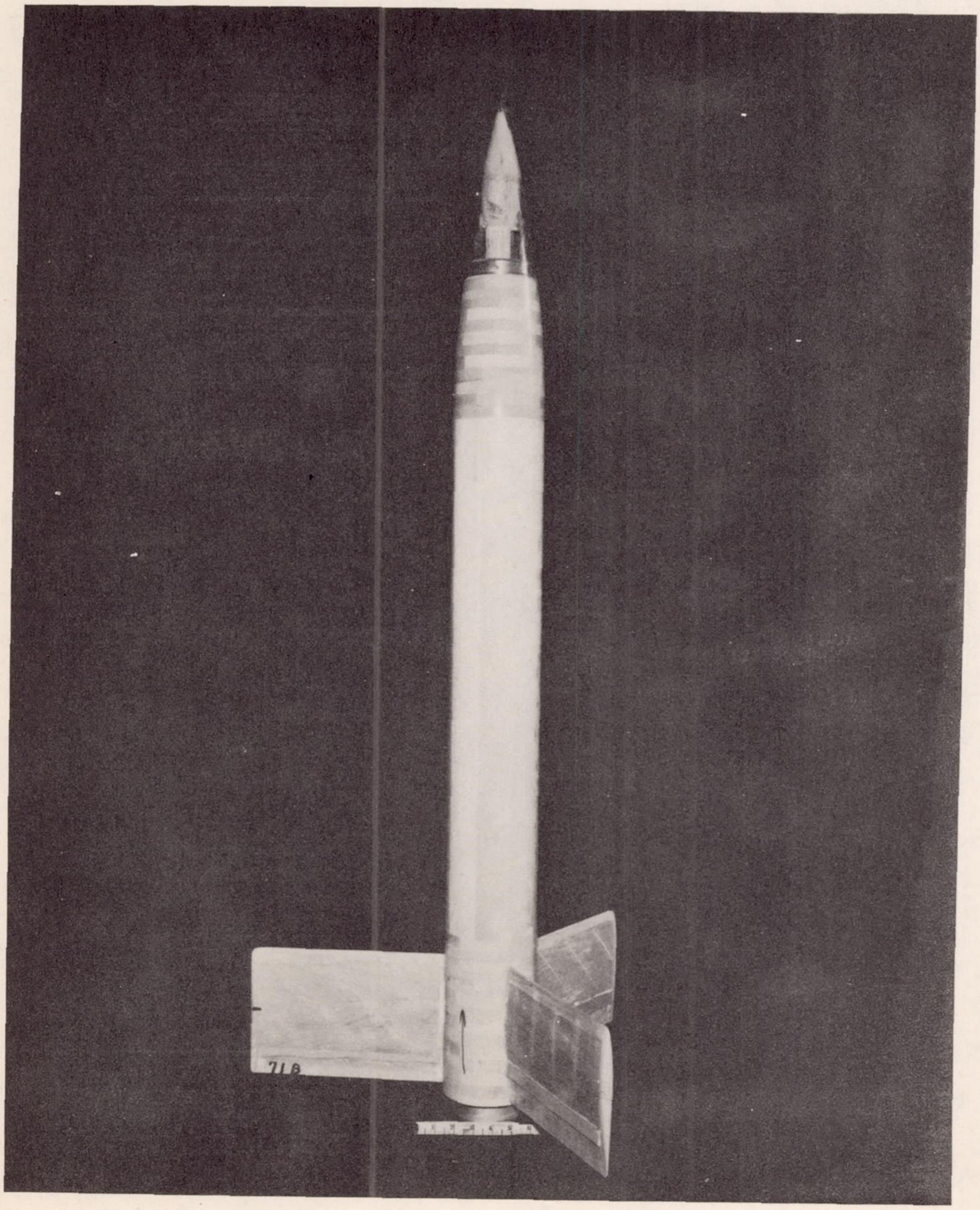

Figure 2.- General arrangement of the RM-5 test vehicles.

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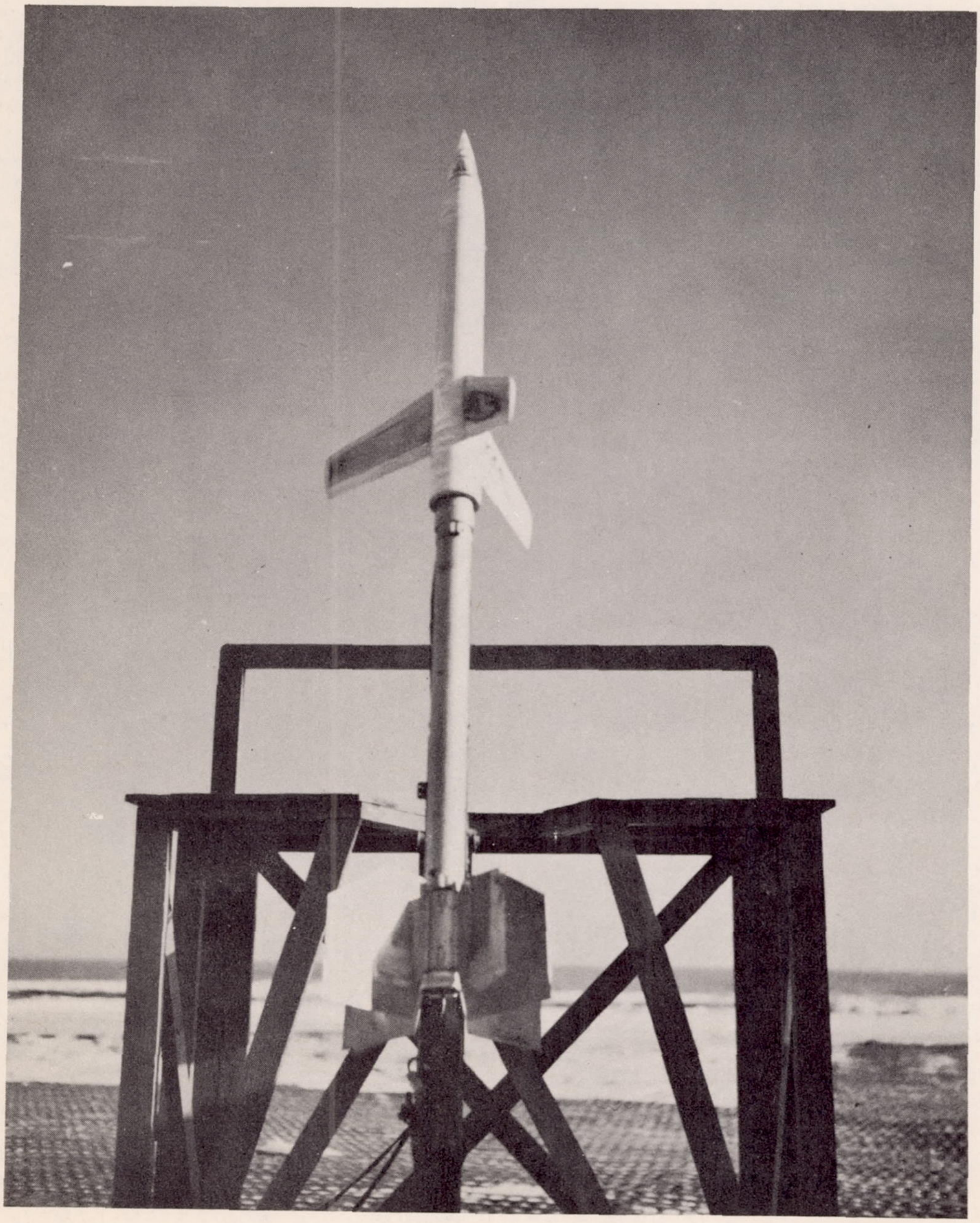

Figure 3.- Typical RM-5 test vehicle prior to launching.

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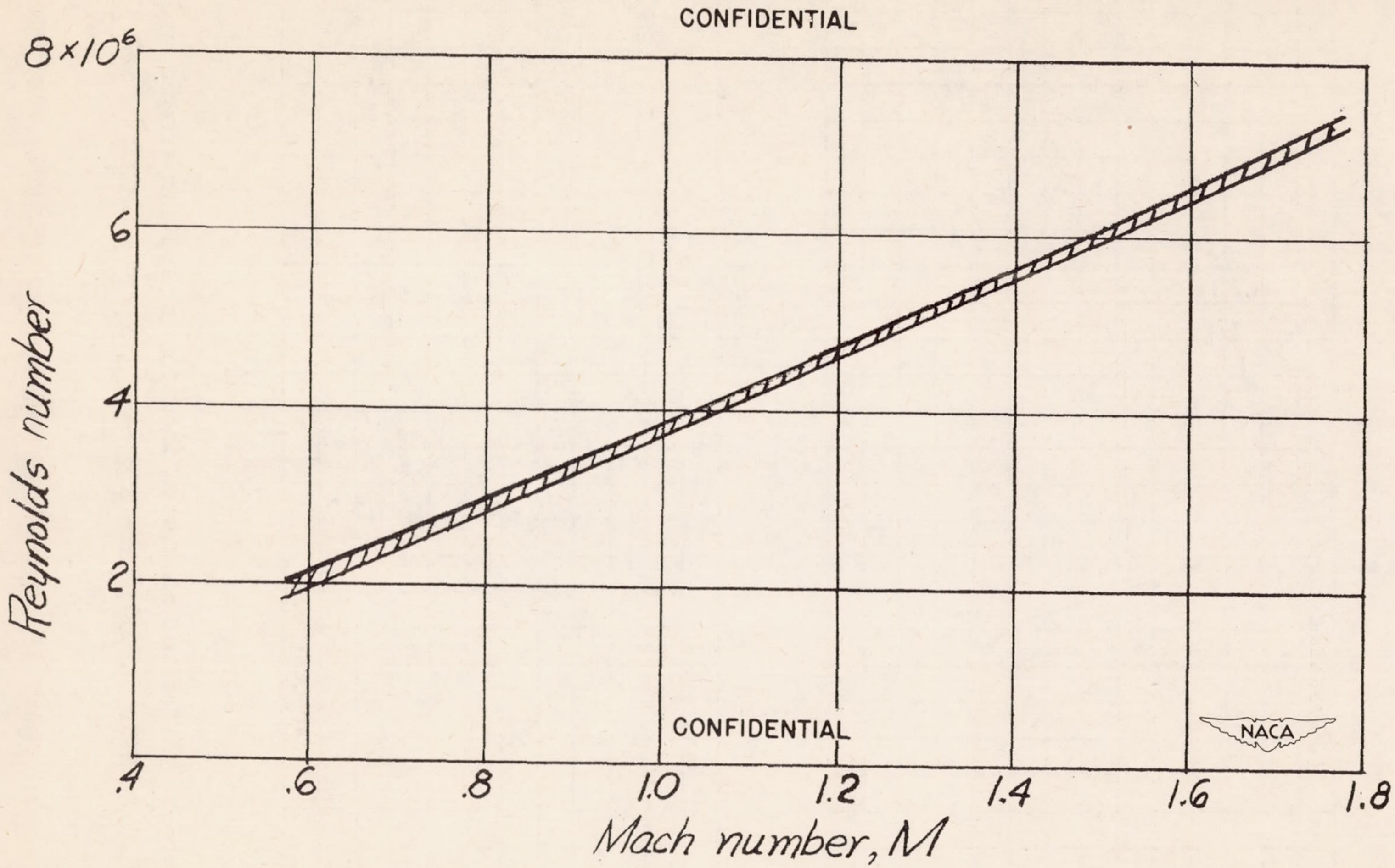

Figure 4.- Over-all variation of Reynolds number with Mach number for present tests.

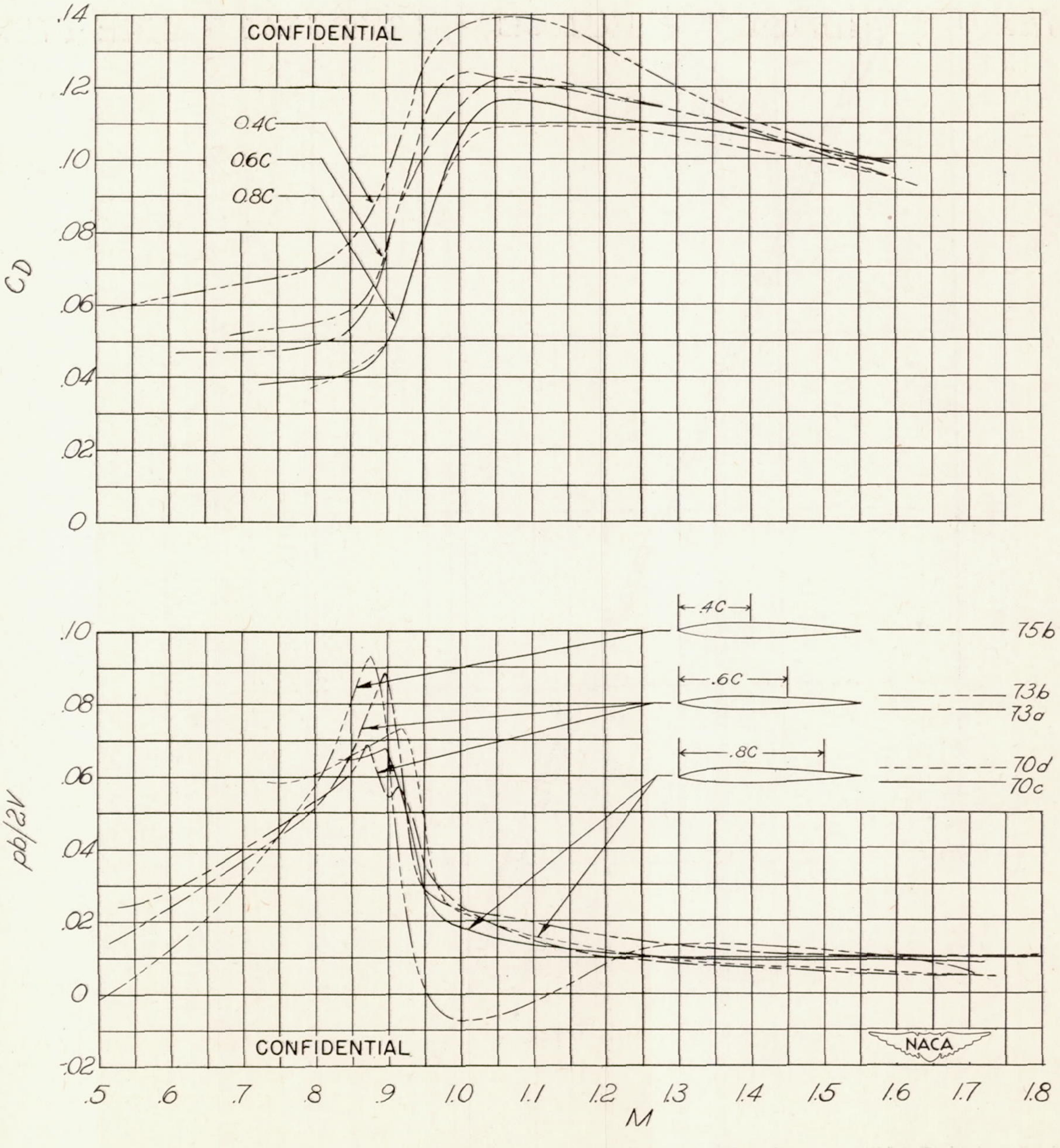

Figure 5.- Effect of chordwise location on spoiler effectiveness. NACA 65-009; $\Lambda = 0^{\circ}$; $A = 3.0$; $\frac{h}{c} = 0.02$.

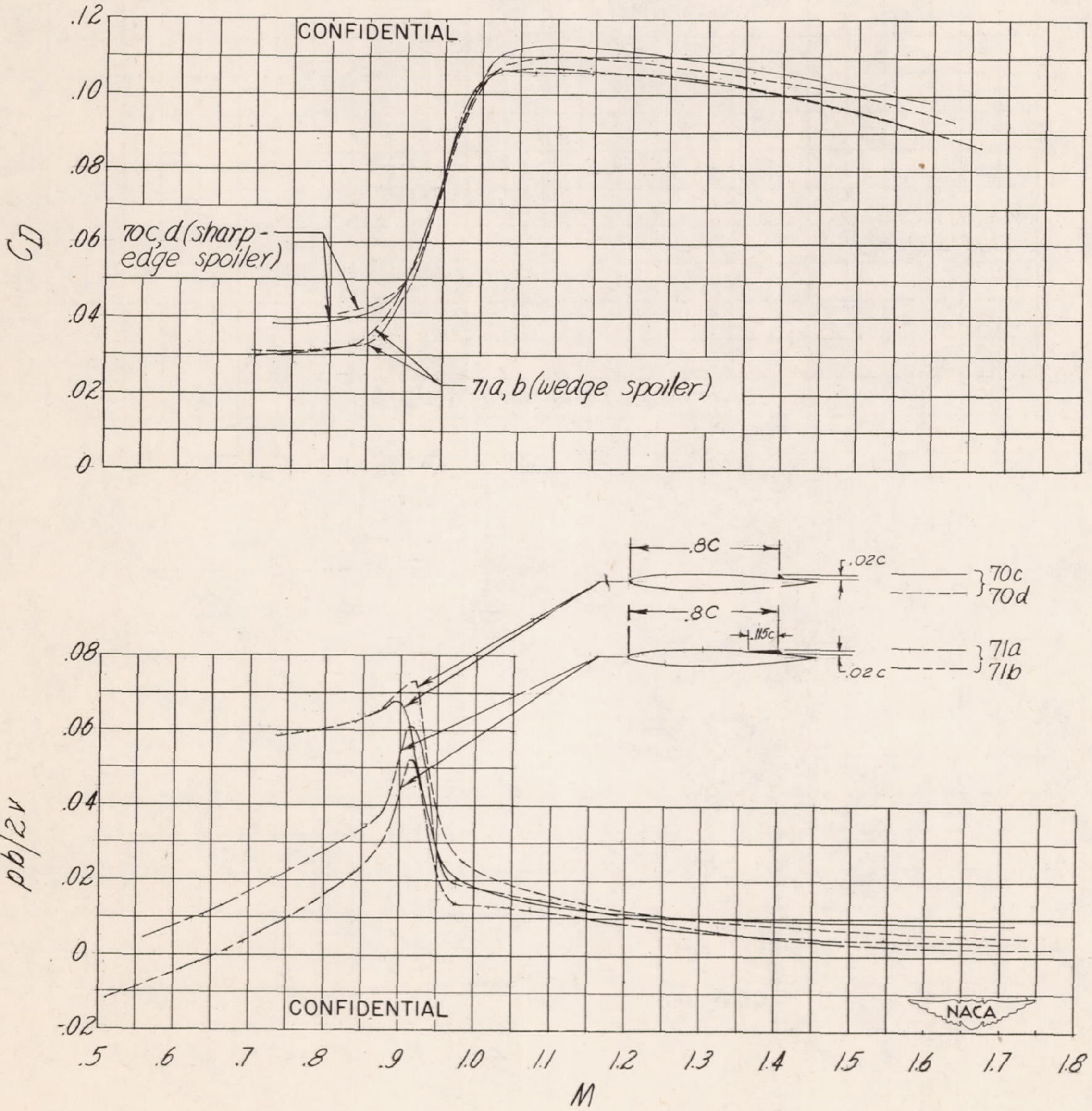

Figure 6.- Comparison of rolling effectiveness and drag coefficient for two types of spoiler ailerons. Airfoil section, NACA 65-009; $\Lambda = 0^{\circ}$; $A = 3.0$.

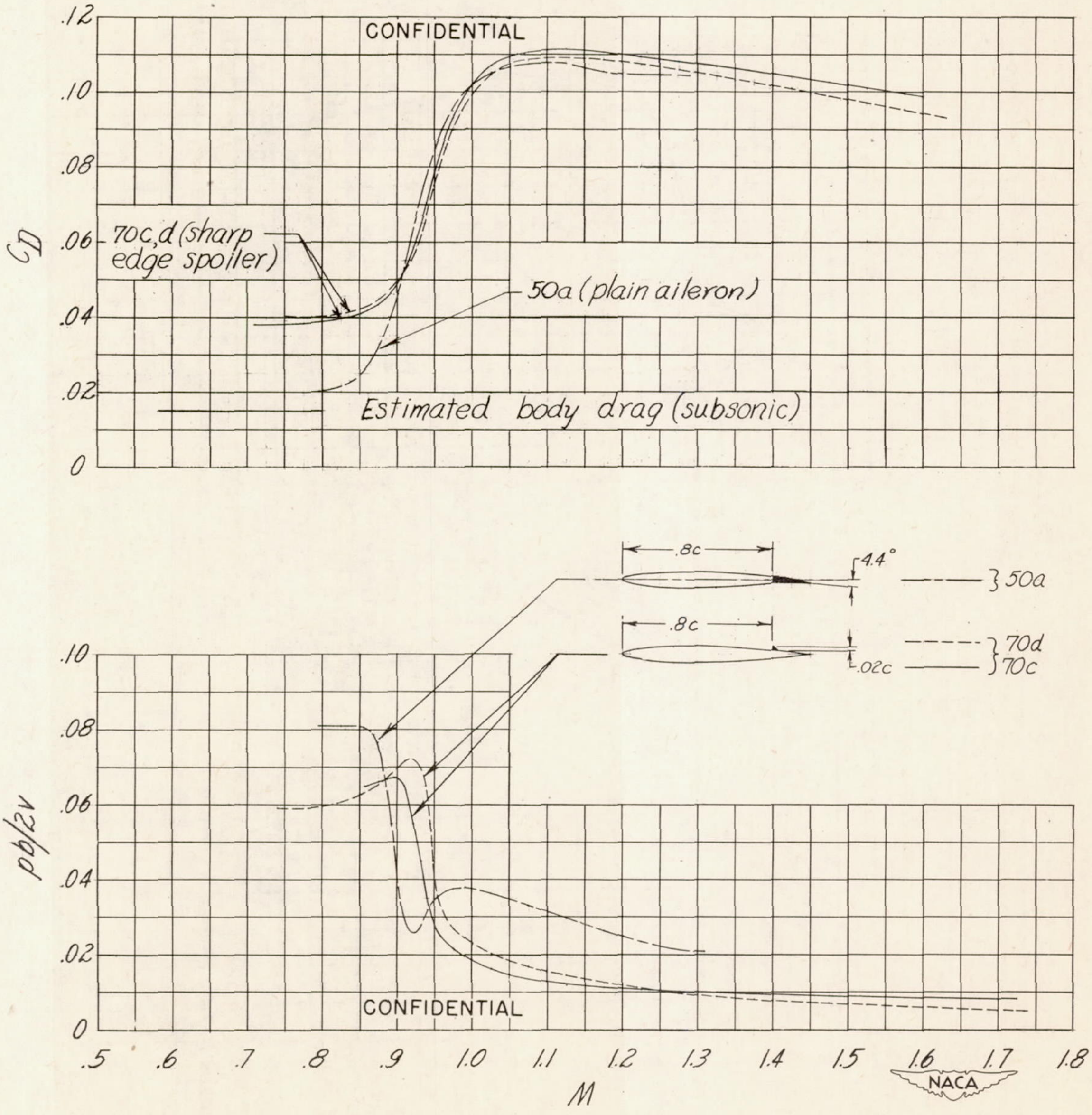

Figure 7.- Comparison of rolling effectiveness and drag coefficient for plain and spoiler ailerons. Airfoil section, NACA 65-009; $\Lambda = 0^{\circ}$; A = 3.0 (reference 4).