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# RESEARCH MEMORANDUM

# FLIGHT MEASUREMENTS OF THE WING-DROPPING TENDENCY OF A STRAIGHT-WING JET AIRPLANE AT HIGH SUBSONIC MACH NUMBERS

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## SUMMARY

Flight tests were conducted on a straight-wing fighter-type jet airplane to investigate the lateral-control characteristics associated with a wing-dropping tendency encountered at high subsonic Mach numbers.

The chief factors found to account directly for the wing-dropping tendency were a progressive reduction in aileron-control effectiveness with increasing Mach number, and an increase in effective dihedral above a Mach number of 0.8 which made the lateral trim particularly sensitive to small changes in sideslip angle.

## INTRODUCTION

The increase of airplane speeds into the transonic range has introduced problems due to the effects of compressibility and separation of the air flow. One problem, that of the development of a rolling moment at high Mach numbers, has been noted in flight tests and in rocket-powered model tests. This rolling moment may appear in steady straight flight at zero sideslip because of geometric asymmetry existing in a model or airplane, or in flight not at zero sideslip because of changes in rolling moment due to sideslip. In rocket-powered model tests the model is allowed to roll, and the rolling moment is measured in terms of the resulting $pb/2V$ and called "wing-dropping." In piloted-flight investigations it is not practical to let the airplane roll at high Mach numbers, therefore the rolling moment is measured in terms of the aileron deflection required for lateral balance, using the aileron deflection as a measure of the "wing-dropping tendency."

A previous flight investigation (reference 1) indicated that the wing-dropping tendency on a swept-wing fighter aircraft resulted from an initial directional asymmetry, an abrupt increase in effective dihedral, and a reduction in lateral-control effectiveness. Rocket-powered model tests (reference 2) demonstrated that wing dropping may occur on straight wings with conventional airfoil sections having thickness ratios of 9 percent or greater and with thinner sections having abrupt contour changes such as a double-wedge type. Sweepback was found to moderate or eliminate the wing dropping depending on the magnitude of the sweep angle.

The purpose of the present report is to supply data on the lateral and directional characteristics of a straight-wing airplane at high subsonic speeds and to consider the degree to which aileron effectiveness and effective dihedral account for the observed wing-dropping tendency.

## SYMBOLS

| | |
|---|---|
| $C_{l_\beta}; \frac{\partial C_l}{\partial \beta}$ | rate of change of rolling-moment coefficient with sideslip angle |
| $C_{l_{\delta_a}}; \frac{\partial C_l}{\partial \delta_a}$ | rate of change of rolling-moment coefficient with aileron angle |
| $\frac{\partial \delta_a}{\partial \beta}$ | rate of change of aileron angle with sideslip angle |
| $\delta_a$ | total aileron angle, degrees |
| $\beta$ | sideslip angle, degrees |
| $M$ | Mach number |
| $h_p$ | pressure altitude, feet |

## TEST EQUIPMENT

Figure 1 is a three-view drawing of the test airplane. A photograph showing a three-quarter rear view of the test airplane is given in figure 2. Some of the airplane geometric characteristics are listed in table I.

Standard NACA optical recording instruments were used to record the test data. Rolling acceleration used in determining aileron effectiveness was measured by either of two means: the slope of an NACA turnmeter record or a Statham angular accelerometer.

## RESULTS AND DISCUSSION

Results are presented in figure 3 of the variation with Mach number of aileron deflection required for steady, straight flight at 35,000 feet for various constant values of sideslip angle. These data show that the wing-dropping tendency, as indicated by the abrupt change in aileron deflection at the higher Mach numbers, is, in general, such that a right sideslip produces a left roll-off and left sideslip, a right roll-off tendency. It will be noted that relatively small changes in sideslip angle, of the order of $1^{\circ}$, can cause changes in aileron angle for balance of the order of $13^{\circ}$ and reverse the direction of the wing-dropping tendency. From this it can be inferred that the direction and also the magnitude of the wing-dropping tendency would be significantly influenced by any directional asymmetry existing in the airplane. By the same token, the use of directional trim changes is a powerful means of controlling the wing-dropping tendency.

An example of the effect of changing the directional trim of the test airplane for the wings-level condition is given in figure 4. The difference in setting up the directional trim resulting in flight conditions I and II at the two sideslip values shown in figure 4 was unnoticeable to the pilots because of the small change of angle of bank with sideslip angle existing at the low Mach number wings-level trim condition. The data in figure 4 show that by changing the trim sideslip angle from approximately $1.4^{\circ}$ right to $0^{\circ}$ at low Mach numbers the aileron angle for balance was changed from $15^{\circ}$ right to $3^{\circ}$ left at the highest test Mach number, 0.858. It appears that there is no fixed directional trim setting, and therefore sideslip angle, which would produce balance throughout the Mach number range without the use of aileron deflection. Instead, a variation in directional trim setting corresponding to a variation of sideslip angle with Mach number such as that shown in figure 5 would be necessary.

The wing-dropping tendency indicated by the pronounced change in aileron deflection shown in figure 3 may be due to a number of factors. The most obvious factor is the expected reduction in aileron effectiveness occurring at the higher Mach numbers. If a constant lateral asymmetry is present throughout the Mach number range, an increase in aileron deflection will be required as the aileron control loses effectiveness with increasing Mach number. For the test airplane the data in figure 6 show that a rapid reduction in aileron effectiveness[1] $C_{l_{\delta_a}}$ started at approximately 0.8 Mach number. The effectiveness dropped off to 12.5 percent of its low Mach number value at the highest Mach number. These data, obtained at both high and low altitudes (35,000 and 5,000 feet) over equivalent dynamic pressure ranges, show that aeroelastic deformation (wing twist) is not responsible for the reduction in $C_{l_{\delta_a}}$ occurring at the higher Mach numbers.

Another factor, previously mentioned in reference 1 as accounting for the wing-dropping tendency, is an increase in effective dihedral occurring at higher Mach numbers. For the test airplane approximately a two-and-one-half-fold increase in [2]$C_{l_\beta}$ is shown by the data in figure 7.

Figure 8 indicates the extent to which the aileron deflection required for balance in steady straight flight at 1° right sideslip angle is influenced by the two main factors – the reduction in $C_{l_{\delta_a}}$ and the increase in $C_{l_\beta}$. If a constant rolling-moment asymmetry is assumed throughout the Mach number range equal to that which exists at $M=0.5$, the data indicate that the aileron angle for balance would vary from 1° right to 6° right. This is attributable solely to the reduction in $C_{l_{\delta_a}}$. If, in addition, the increase in $C_{l_\beta}$ is taken into account, it is shown that an additional 6° of right aileron angle is required at the highest Mach number. The flight data indicate a further increase in lateral asymmetry with Mach number attributable to sources other than the change in $C_{l_{\delta_a}}$ and $C_{l_\beta}$. This increase presumably is due to irregularities existing in the left and right wing panels causing differences in panel lift which vary with Mach number.

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[1] The aileron effectiveness $C_{l_{\delta_a}}$ was obtained from measurements of rolling acceleration in rudder-fixed aileron-roll reversals at the point where the rolling velocity was zero. The variation of $C_l$ with $\delta_a$ was linear over the range of measurements (±15° at low Mach numbers to 2.5° left to 11.5° right at the highest Mach number).

[2] The values of $C_{l_\beta}$ were obtained from

$$C_{l_\beta} = \frac{\partial C_l}{\partial \delta_a} \frac{\partial \delta_a}{\partial \beta}$$

where $\partial\delta_a/\partial\beta$ was taken from tests in steady sideslips. The variation of $\delta_a$ with $\beta$ was linear over the range of measurements and covered sideslip angles varying from ±6° at low Mach numbers to 2° left to 1° right at the highest Mach number.

## CONCLUSIONS

Results of flight tests conducted on a straight-wing jet aircraft to investigate the lateral-control characteristics associated with a wing-dropping tendency showed the following:

1. The chief factors found to account directly for the wing-dropping tendency were a progressive reduction in aileron-control effectiveness with increasing Mach number and an increase in effective dihedral above a Mach number of 0.8.

2. The reduction in aileron effectiveness and the increase in effective dihedral made the lateral trim particularly sensitive to small changes in sideslip angle at the higher Mach numbers.

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## REFERENCES

1. Rathert, George A., Jr., Rolls, L. Stewart, Winograd, Lee, and Cooper, George E.: Preliminary Flight Investigation of the Wing-Dropping Tendency and Lateral-Control Characteristics of a 35° Swept-Wing Airplane at Transonic Mach Numbers. NACA RM A50H03, 1950.

2. 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 TEST AIRPLANE

| | |
|---|---|
| Gross weight, pounds (av. in flt.) | 10,900 |
| Wing | |
| Area, square feet | 260 |
| Span, feet | 36.42 |
| Aspect ratio | 5.1 |
| Airfoil section | |
| Root | Republic R-4 45-1512-9 |
| Tip | Republic R-4 45-1512-9 |
| M.A.C., feet | 7.38 |
| Incidence (root), degrees | 0 |
| Twist, degrees | -2 |
| Horizontal tail | |
| Area, square feet | 48.5 |
| Span, feet | 14.95 |
| Aspect ratio | 4.6 |
| Airfoil section | |
| Root | Republic R-4 40-010 |
| Tip | Republic R-4 40-010 |
| Incidence, degrees | 0 |
| Elevator area, square feet | 13 |

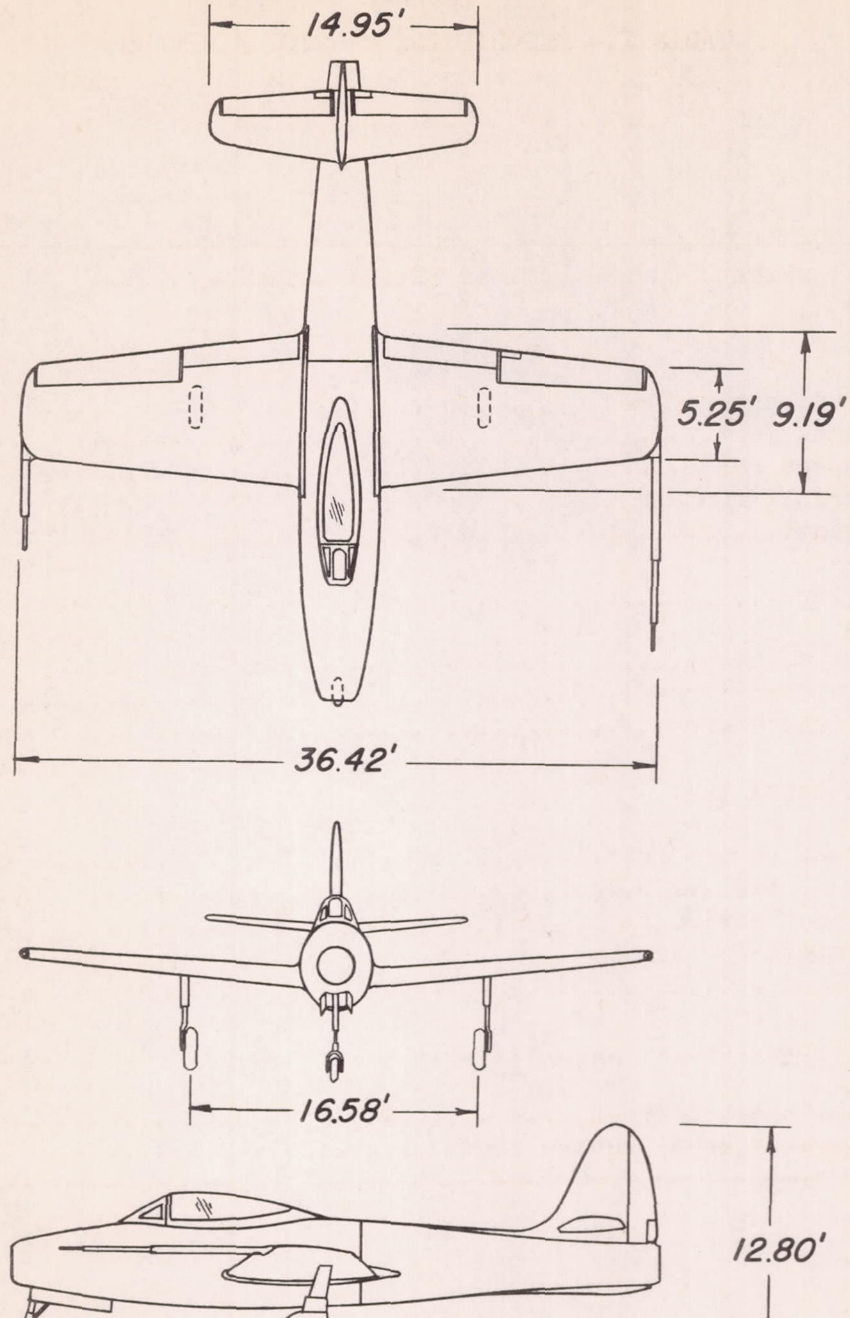

Figure 1.- Three-view drawing of test airplane.

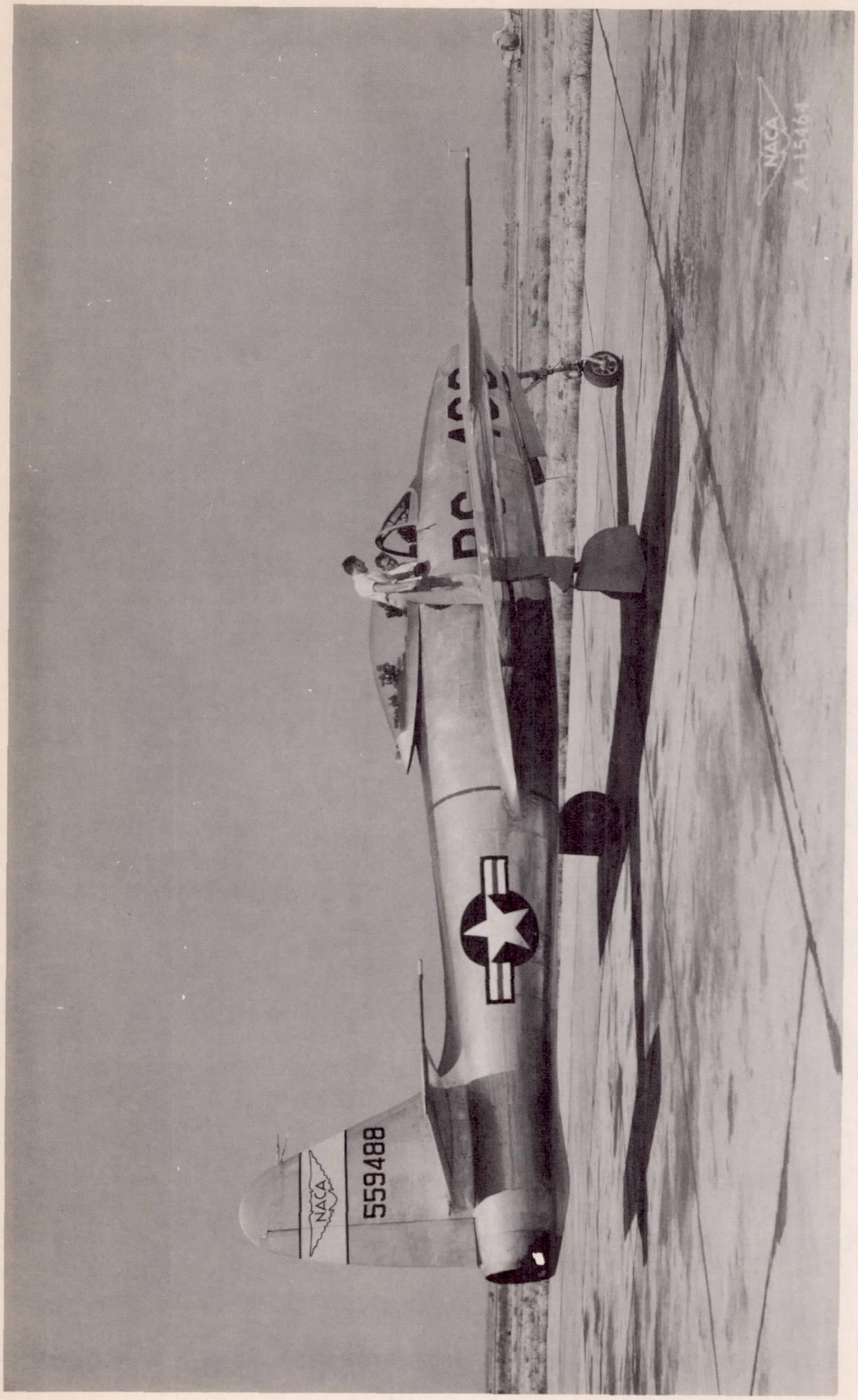

Figure 2.- Three-quarter rear view of test airplane.

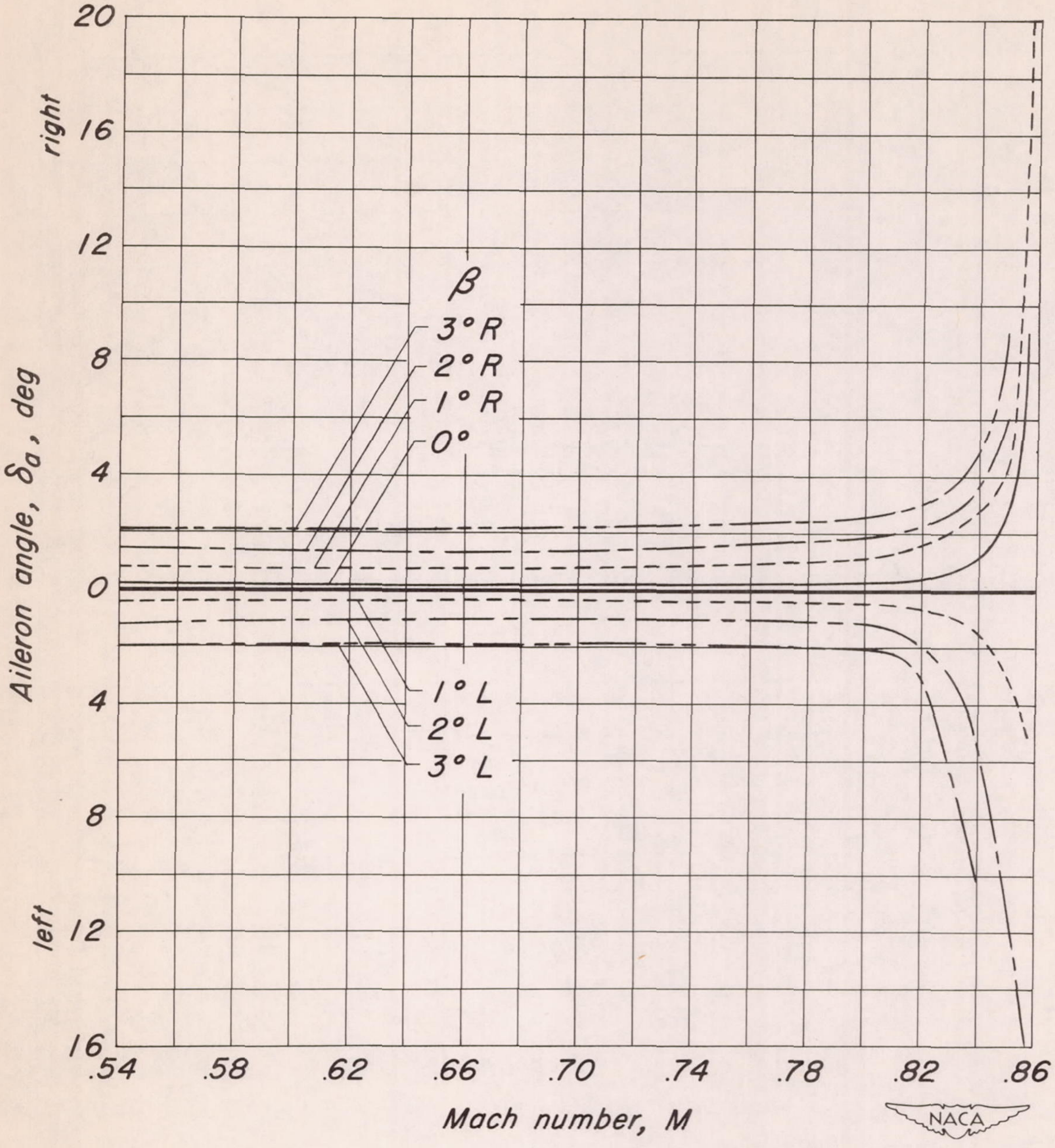

Figure 3.– Variation of aileron angle with Mach number in steady straight flight for various constant values of sideslip angle.

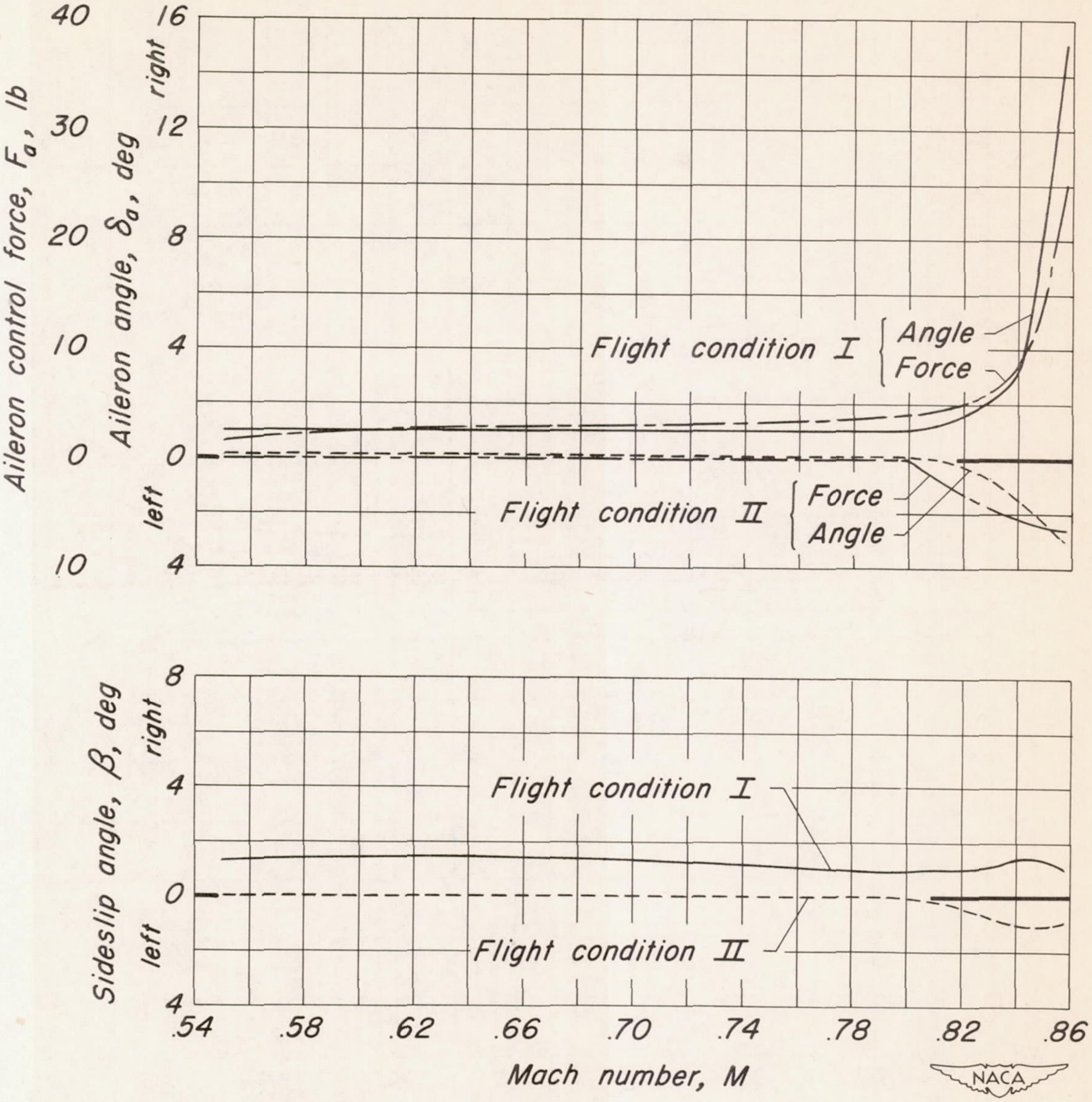

Figure 4.- Variation with Mach number of aileron angle, aileron-control force, and sideslip angle for steady wings-level flight at 35,000 feet.

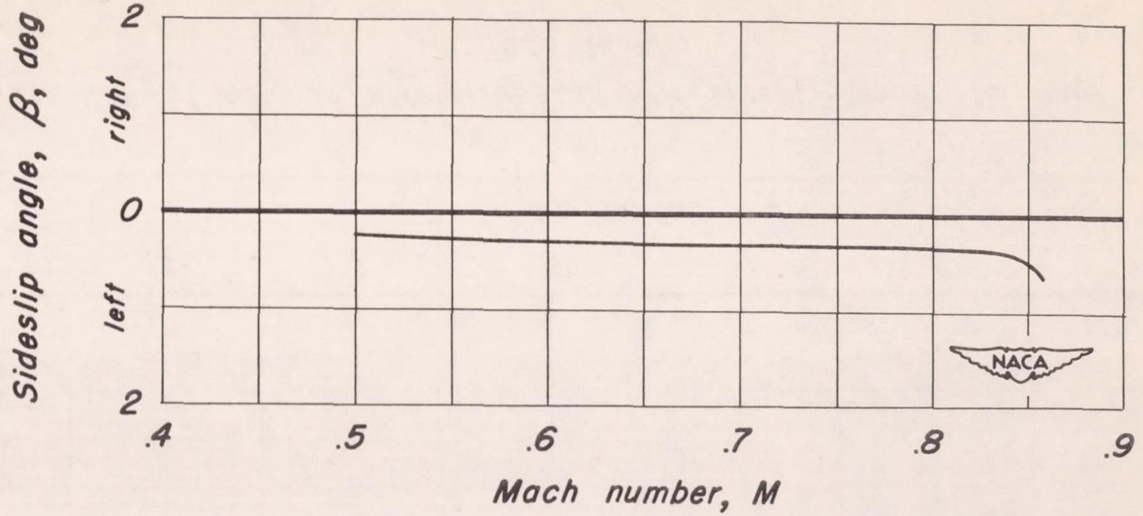

Figure 5.- Variation with Mach number of sideslip angle required to produce lateral balance without the use of aileron deflection.

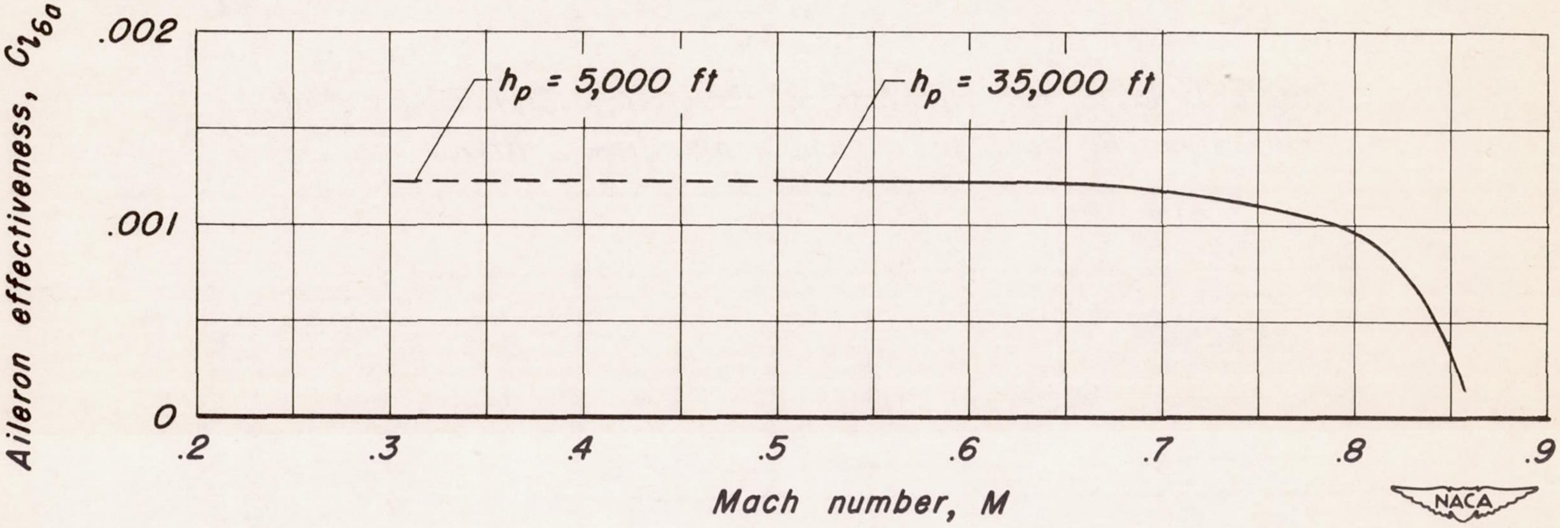

Figure 6.– Variation of aileron effectiveness with Mach number for high and low altitude tests.

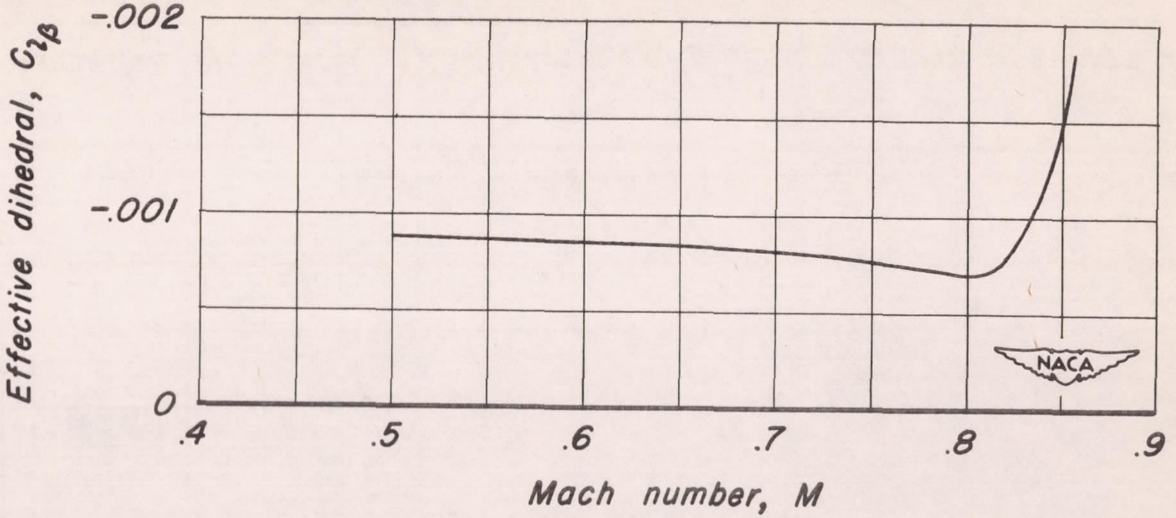

Figure 7.- Variation of effective dihedral with Mach number.

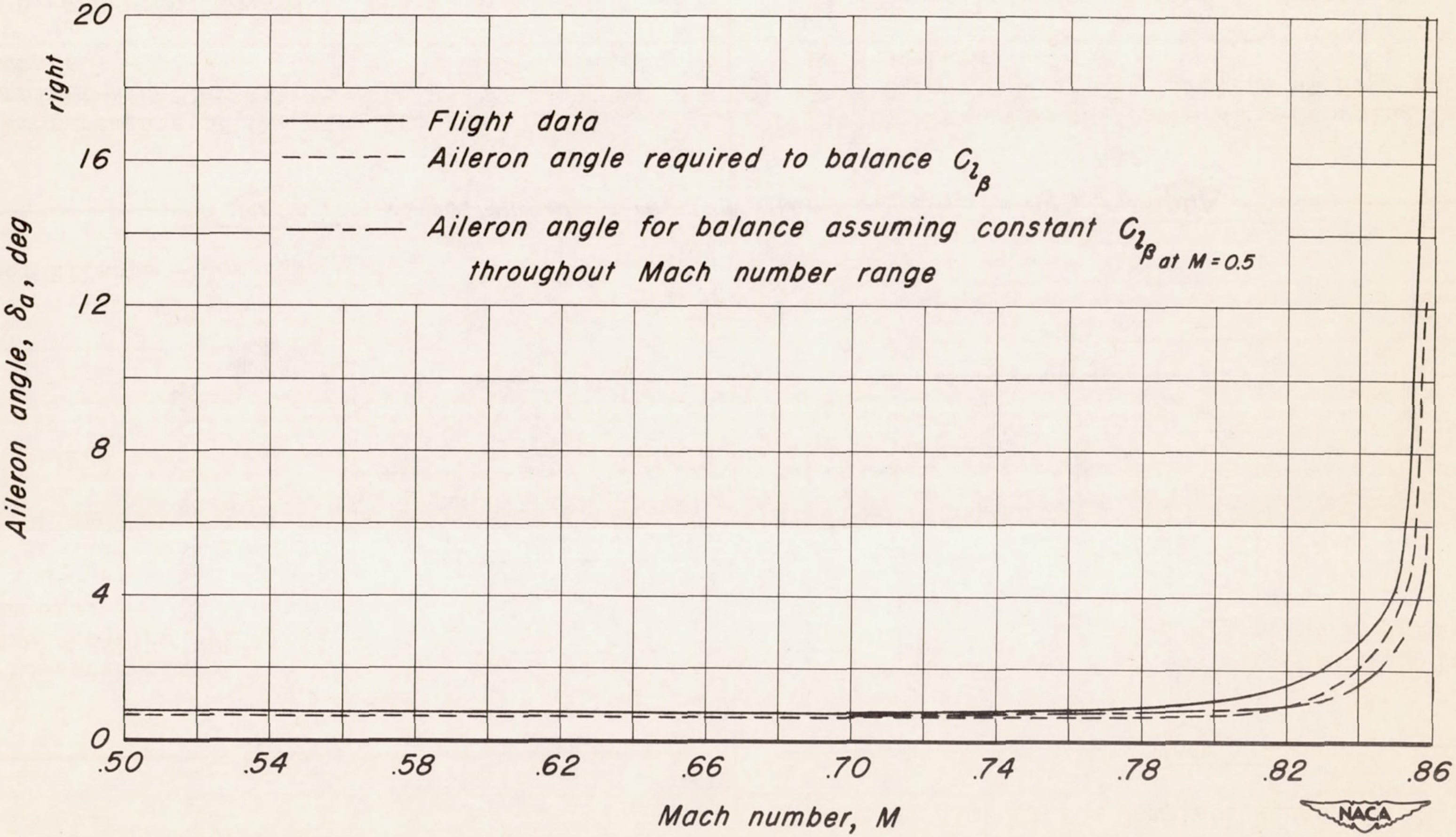

Figure 8.– Variation with Mach number of aileron angle required for balance in steady straight flight at 1° right sideslip angle.