RM L55L16a

NACA

RESEARCH MEMORANDUM

THE USE OF THE HORIZONTAL TAIL FOR ROLL CONTROL

By John P. Campbell

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

February 8, 1956
Declassified February 10, 1959

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

THE USE OF THE HORIZONTAL TAIL FOR ROLL CONTROL

By John P. Campbell

SUMMARY

A summary has been made of the data recently obtained by the National Advisory Committee for Aeronautics on the use of differential horizontal-tail incidence for roll control. In general, the results appear to be fairly promising even though most of the data were obtained with configurations that were not especially designed for the use of such a control. The results indicate that a tail roll control might be satisfactory if the tail is made relatively large to provide adequate effectiveness without excessive deflections, if the airplane is designed so that the longitudinal trim requirements for the tail are minimized so as to avoid interaction of roll and pitch controls, and if the horizontal tail is positioned vertically to avoid excessive favorable or adverse yawing moments.

INTRODUCTION

Because of the serious problems involved in the use of controls on the thin, flexible wings of high-speed airplanes, some designers have considered the possibility of using differential horizontal-tail incidence for roll control. During the last two or three years, the National Advisory Committee for Aeronautics has obtained a limited amount of data on controls of this type. (See refs. 1 to 5.) Since most of these data were obtained by adding a few tests to test programs laid out for other purposes, very few systematic results have been obtained, and the different sets of data are generally unrelated. It is the purpose of this report to summarize and, wherever possible, to correlate these data. Comparisons with conventional aileron control will be given in some cases.

SYMBOLS

b	wing span
$\bar{c}$	mean aerodynamic chord
C_L	lift coefficient

C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qS}$
$C_{l_\delta} = \frac{dC_l}{d\delta}$	
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS}$
$C_{m_{i_t}} = \frac{dC_m}{di_t}$	
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qS}$
$C_{n_\delta} = \frac{dC_n}{d\delta}$	
i_t	tail incidence
i_w	wing incidence
l	longitudinal distance from center of gravity to calculated center of pressure of horizontal tail
M	Mach number
$\frac{pb}{2V}$	wing-tip helix angle
q	dynamic pressure
S	wing area
y	lateral distance from center of gravity to calculated center of pressure of horizontal tail
α	angle of attack
δ	total roll-control deflection

RESULTS AND DISCUSSION

Effect of Mach Number

A summary of most of the available data for the clean condition at 0° angle of attack is shown in figure 1 as a plot of the roll-control parameter C_{l_δ} against Mach number. At low subsonic speeds the value of C_{l_δ} varies from about 0.0004 for the two lower configurations with swept and highly tapered tails to a value of about 0.0006 for the model with a high-aspect-ratio unswept tail. These values are only one-third to one-half as large as values of C_{l_δ} for conventional ailerons at low Mach numbers. Two sets of data are shown for the transonic speed range. The lower set of data, which was obtained in the Langley 16-foot transonic tunnel, shows no appreciable variation of C_{l_δ} between Mach numbers of 0.8 and 1.05. The upper set of data, which was obtained with a Pilotless Aircraft Research Division rocket model with a horizontal tail that was relatively large compared with the wing area, shows a slight increase in C_{l_δ} at a Mach number of about 1.2 and then shows a progressive decrease in effectiveness with increasing Mach number because of the decreasing lift-curve slope of the tail. The same general variation of C_{l_δ} with Mach number is shown by the two sets of data for the supersonic Mach numbers from 1.4 to 2.0 obtained in the Langley 4- by 4-foot supersonic pressure tunnel (shown by solid circles connected by lines). In this speed range, ailerons on stiff wings produce about the same value of C_{l_δ} as shown herein for the horizontal tail, but since there will usually be more control deflection available for the ailerons, they will provide the more powerful control - assuming that the wing is fairly stiff.

Effect of Wing Aeroelasticity

Figure 2 shows how the controls might compare if the wing were not stiff. Plots of $\frac{pb/2V}{\delta}$ against Mach number are shown for tail and aileron controls with stiff and flexible wings. The tail data were taken from reference 2 and the aileron data from reference 6. The term $\frac{pb/2V}{\delta}$ expresses the overall rolling effectiveness and is equal to C_{l_δ} divided by the damping-in-roll parameter C_{l_p}. The left plot shows that, for the tail roll control with the stiff wing, there is essentially no variation in rolling effectiveness over the Mach number range covered in the tests, which indicates that the variations of C_{l_δ} and C_{l_p} with Mach number are identical. For the model with the flexible wing, the rolling effectiveness was greater because of the reduced damping in roll provided by the wing.

Now for the aileron control, the situation is reversed. Going from the stiff wing to the flexible wing causes a large reduction in rolling effectiveness which leads to control reversal at some Mach numbers for this particular case. Since the flexible wings used in these tests are generally representative of current design practice, it appears, on the basis of these data, that a tail control might well be superior in some cases to aileron control at supersonic speeds.

Effect of Angle of Attack

Rolling moments.- The results of figures 1 and 2 are only for 0° angle of attack. Figure 3 shows the variation of C_{l_δ} with angle of attack for four Mach numbers for three of the configurations of figure 1. For comparison, there are also shown typical aileron control data for each Mach number. For the subsonic Mach numbers, the variation of C_{l_δ} with angle of attack is not very great for the tail control. For the aileron control, however, the effectiveness drops off rapidly with increasing angle of attack so that at the high angles of attack the values of C_{l_δ} are about the same as those for the tail control. For the case of a Mach number of 1.00, both the controls maintain most of their effectiveness up to the highest angles of attack covered in the tests. For a Mach number of 1.61, the results are quite different from the subsonic cases. The two controls have about the same effectiveness at the lower angles of attack, but at the higher angles of attack the aileron effectiveness increases while the tail-control effectiveness decreases. It should be pointed out that these results were obtained on wind-tunnel models with essentially rigid wings.

Yawing moments.- The yawing-moment data for the same cases are presented in figure 4 in the form of the parameter $\frac{C_{n_\delta}}{C_{l_\delta}}$, the ratio of the yawing moment to the rolling moment produced by control deflection. The aileron data show for all Mach numbers either zero moment or a small positive or favorable yawing moment at 0° angle of attack and an increasingly large negative or adverse yawing moment with increasing angle of attack. For the tail control, at Mach numbers up to 1.00, there are extremely large favorable yawing moments which decrease with increasing angle of attack but remain positive over the angle-of-attack range tested. These large yawing moments, which pilots would probably consider objectionable, are caused by loads on the vertical tail induced by the differentially deflected horizontal-tail surfaces. For the supersonic case, the tail roll control produces smaller, favorable yawing moments at low angles of attack and adverse yawing moments at high angles of attack. The carryover of load from the horizontal tail to the vertical tail is apparently much less in this case than at the subsonic speeds.

All these data were obtained with configurations having low horizontal tails. The next figure shows that the vertical position of the horizontal tail has a pronounced effect on these yawing moments.

Effect of Tail Position on Yawing Moments

The results of figure 5 were obtained at low speed with a model having low, intermediate, and high horizontal-tail positions. For the low position, the large positive values of $\frac{C_{n_\delta}}{C_{l_\delta}}$ are similar to those shown in figure 4 for the subsonic speeds. For the high position, very large negative or adverse yawing moments were obtained; whereas for the intermediate position, the moments were relatively small. The explanation for these results is that the load induced on the vertical tail by the horizontal tail varies both in magnitude and direction with tail position. It appears from these data that the designer might be able to adjust the yawing moments produced by a tail roll control to a satisfactory value by proper positioning of the horizontal tail, assuming, of course, that other considerations, such as the pitch-up problem, permit this to be done. In this connection, it might be pointed out that if a ventral fin is used on the airplane for high-speed stability, the yawing moments for a low tail position would be smaller - more like those shown in figure 5 for the intermediate position. If the yawing moments cannot be adjusted to a satisfactory value by positioning the tail, it might be necessary to adjust them by linking the rudder in with the tail roll control.

Interaction of Roll and Pitch Control

Figure 6 provides some information on one of the problems that usually comes to mind when a tail control is considered, that is, the problem of interaction of roll and pitch control. First, consider the effect of roll control on pitching moments shown in the left plot. The pitching moments are shown for 0° and -15° stabilizer settings (the solid lines); for these same stabilizer settings, $\pm 15^\circ$ roll control is superimposed on the pitch control (the dashed lines). The significant result herein is that for the angles of attack at which the model is trimmed longitudinally there is essentially no effect of the roll control on the pitch control. In the right plot the variation of roll control C_{l_δ} with angle of attack is shown for two different settings of the stabilizer, 0 and -15°. At low angles of attack, the effectiveness with -15° incidence is much less than that for 0° because one of the surfaces is stalled; but at high angles of attack, where this negative incidence is required for longitudinal trim, the roll control is better with the -15° incidence, apparently because this incidence tends to keep the tail unstalled at the high angles of attack.

The results shown in figure 6 illustrate the conditions which tend to make the control interaction problem less serious in some cases than might be expected at first glance but they should not lead to the conclusion that there will be no interaction problems in other cases. For other configurations or other flight conditions in which large tail loads are required for longitudinal trim, a serious problem might exist. For example, this same model in the landing condition has a control interaction problem that is shown in the next figure.

Effect of Flaps

The effect of flaps on the tail roll control is shown in figure 7. Values of C_{l_δ} and $\frac{C_{n_\delta}}{C_{l_\delta}}$ are plotted against lift coefficient for two configurations. The data on the left side of the figure, which are for the model shown in figure 6, show that there is less control effectiveness for the landing configuration at all lift coefficients. Apparently, the change in tail angle of attack produced by flap deflection and by the 7° wing incidence used for landing keeps one of the tail surfaces stalled at all times when the stabilizer trim of -15° and the roll-control deflection of $\pm 15^\circ$ are applied simultaneously.

For the configuration on the right side of figure 7 for which the wing incidence was kept at 0° and only -6° stabilizer deflection was required for trim, deflection of the flaps actually led to better control than with flaps retracted at the higher lift coefficients.

For both models, the values of the yawing-moment parameter $\frac{C_{n_\delta}}{C_{l_\delta}}$ for the clean configuration were increased by flap deflection mainly because of the reduction in C_{l_δ}. Results shown in figure 5 indicate that these yawing moments would be quite different for an intermediate or high horizontal-tail position.

Comparison of Measured and Estimated C_{l_δ}

Figure 8 shows a comparison of measured and estimated values of C_{l_δ} for most of the cases shown in figure 1 for the clean condition at 0° angle of attack. In estimating C_{l_δ}, values of $C_{m_{i_t}}$ (the pitching moment due to stabilizer incidence) obtained from force-test data for the particular model were used as shown in the formula at the top of figure 8. The factor of 2 in the formula is required to account for the fact that i_t in $C_{m_{i_t}}$ refers to deflection of both surfaces, whereas δ in C_{l_δ} refers to deflection of one surface. The term $\left(\frac{y}{l}\right)_{tail}$, the ratio of the lateral to the longitudinal distance from the center of gravity to the calculated center of pressure of the tail, and the term $\left(\frac{\bar{c}}{b}\right)_{wing}$ convert the pitching-moment parameter into a rolling-moment parameter.

For the two sets of supersonic test data in figure 8 (solid symbols connected by dashed lines) the agreement is fairly good, but for all the subsonic data the measured values of $C_{l_{\delta}}$ are only about 0.7 to 0.8 times as large as the estimated values. Two factors are apparently responsible for this difference between the measured and estimated values of $C_{l_{\delta}}$ for the subsonic cases. First, the load on the vertical tail which produces a large favorable yawing moment for the low-tail configurations of figures 1 and 4 also produces an adverse rolling moment which is not accounted for in the formula of figure 8. Second, with the differentially deflected horizontal-tail surfaces there is a spreading of the load from one surface to the other across the bottom of the fuselage which causes an inboard shift of the lateral center of pressure (decreased value of y). One reason that the factor of 0.7 or 0.8 does not seem to apply to the supersonic cases is probably that there is much less carry-over of the load from one surface to another at supersonic speeds, as pointed out previously in connection with figure 4.

For a high horizontal-tail position, the load induced on the vertical tail produces an adverse yawing moment (fig. 5) and a favorable rolling moment. The rolling effectiveness at subsonic speeds with a high tail position should therefore be slightly greater than that with a low tail position.

CONCLUDING REMARKS

In summary, the results presented in this report for the tail roll control appear to be fairly promising even though most of the data were obtained with configurations that were not especially designed for the use of such a control. The results indicate that a tail roll control might be satisfactory if (1) the tail is made relatively large to provide adequate effectiveness without excessive deflections, (2) the airplane is designed so that the longitudinal trim requirements for the tail are minimized so as to avoid interaction of roll and pitch controls, and (3) the horizontal tail is positioned vertically to avoid excessive favorable or adverse yawing moments. In many cases it might not prove feasible to use the horizontal tail as the primary roll control, but in these cases the tail control will still warrant consideration as an auxiliary control to supplement the effectiveness of ailerons that are unsatisfactory in some flight conditions.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 2, 1955.

REFERENCES

1. Koenig, David G.: Tests in the Ames 40- by 80-Foot Wind Tunnel of an Airplane Configuration With an Aspect Ratio 3 Triangular Wing and an All-Movable Horizontal Tail - Longitudinal and Lateral Characteristics. NACA RM A52L15, 1953.

2. English, Roland D.: Free-Flight Investigation, Including Some Effects of Wing Aeroelasticity, of the Rolling Effectiveness of an All-Movable Horizontal Tail With Differential Incidence at Mach Numbers From 0.6 to 1.5. NACA RM L54K30, 1954.

3. Tinling, Bruce E., and Karpen, A. V.: The Effects of Trailing-Edge Flaps on the Subsonic Aerodynamic Characteristics of an Airplane Model Having a Triangular Wing of Aspect Ratio 3. NACA RM A54L07, 1955.

4. Critzos, Chris C.: Lateral-Control Investigation at Transonic Speeds of Differentially Deflected Horizontal-Tail Surfaces for a Configuration Having a 6-Percent-Thick 45° Sweptback Wing. NACA RM L55I26, 1955.

5. Savage, Howard F., and Tinling, Bruce E.: The Static Lateral and Directional Subsonic Aerodynamic Characteristics of an Airplane Model Having a Triangular Wing of Aspect Ratio 3. NACA RM A55B11, 1955.

6. Schult, Eugene D., Strass, H. Kurt, and Fields, E. M.: Free-Flight Measurements of Some Effects of Aileron Span, Chord, and Deflection and of Wing Flexibility on the Rolling Effectiveness of Ailerons on Sweptback Wings at Mach Numbers Between 0.8 and 1.6. NACA RM L51K16, 1952.

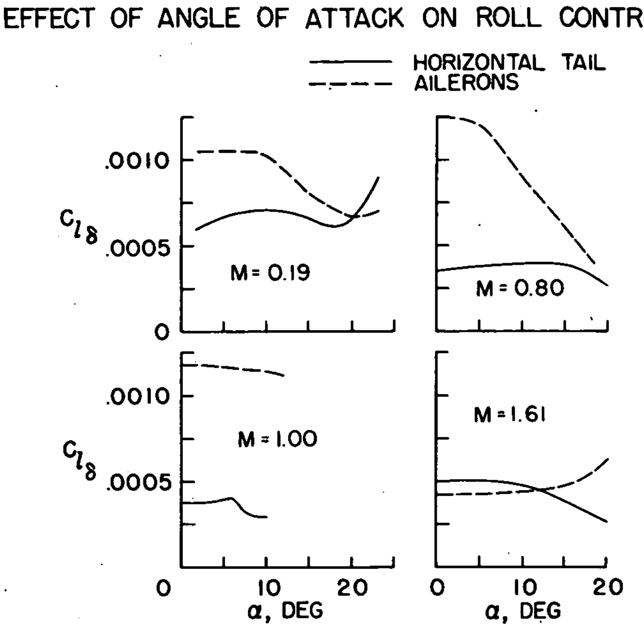

Figure 3

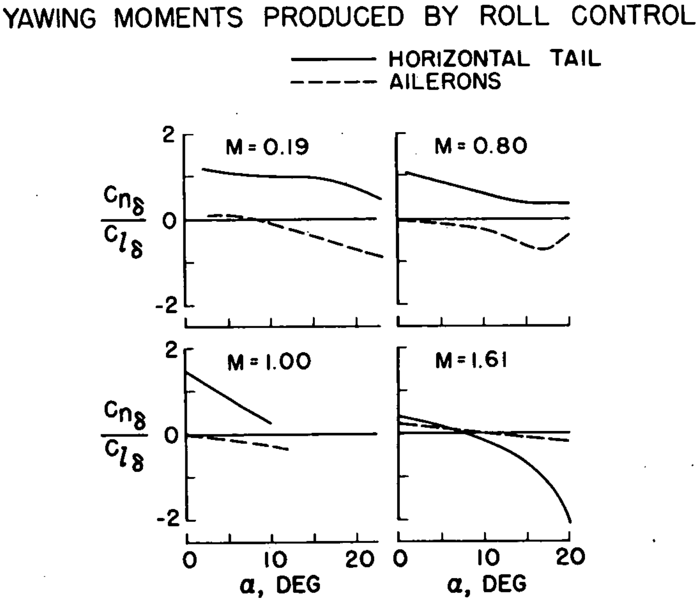

Figure 4

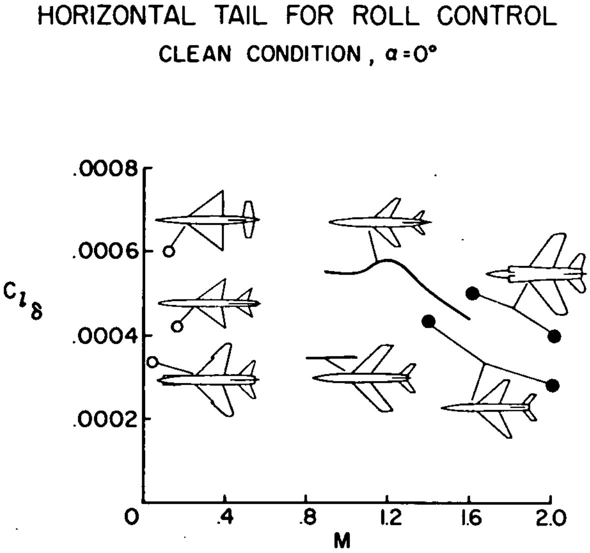

Figure 1

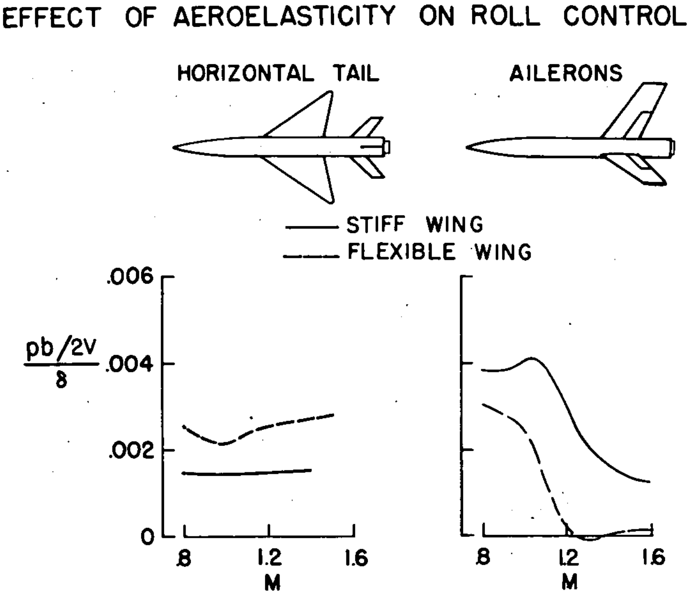

Figure 2

EFFECT OF TAIL POSITION ON YAWING MOMENTS

LOW-SPEED DATA; CLEAN CONDITION; $i_t = 0°$

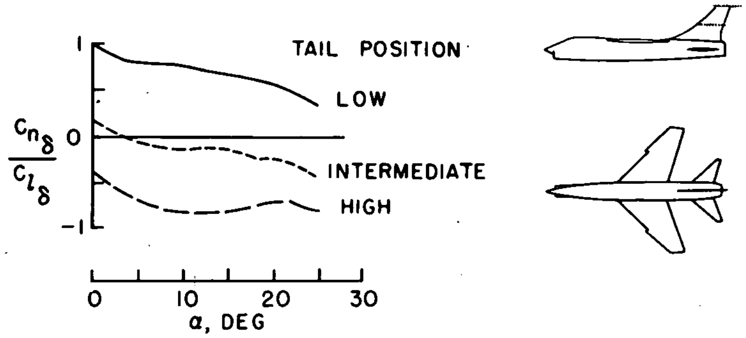

Figure 5

INTERACTION OF ROLL AND PITCH CONTROL

CLEAN CONDITION; LOW-SPEED DATA

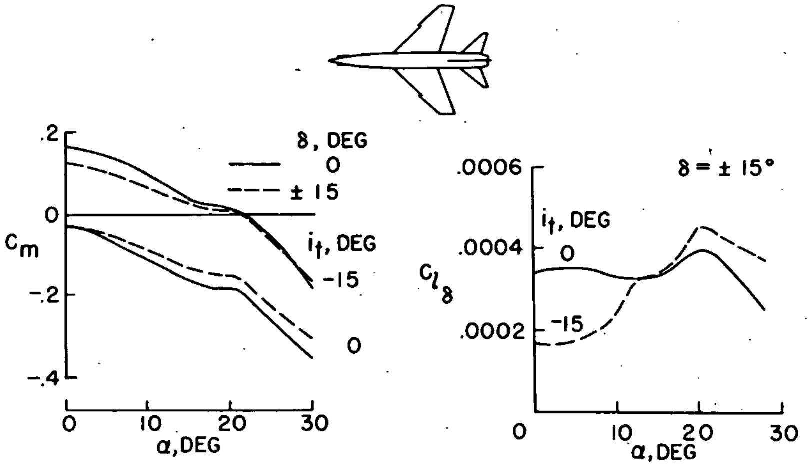

Figure 6

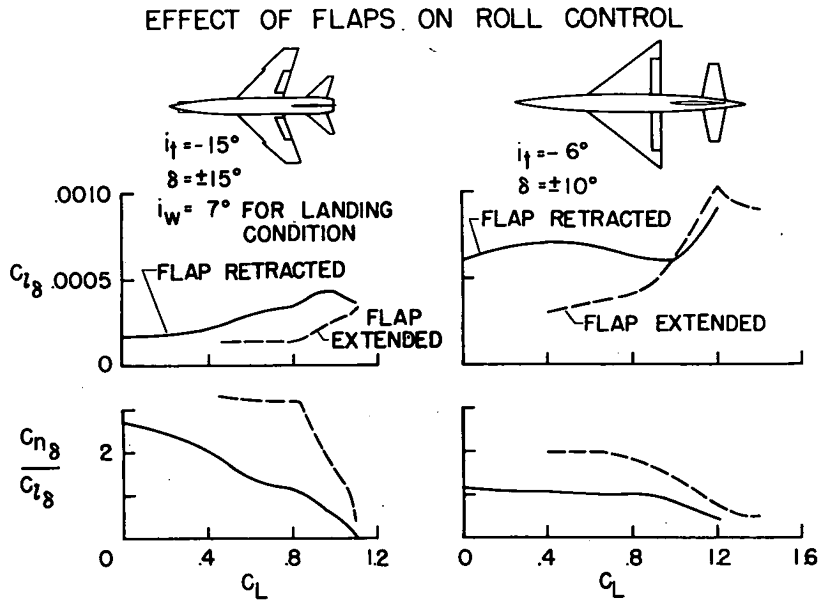

Figure 7

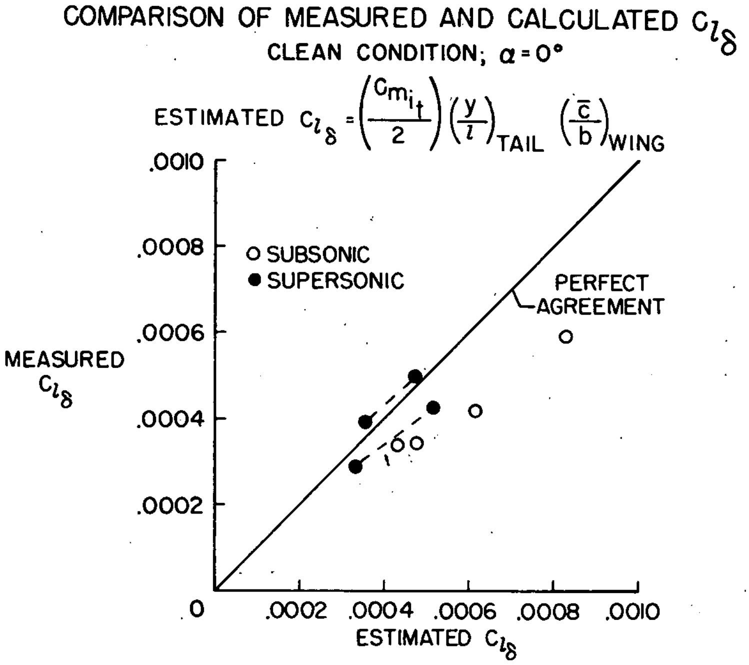

Figure 8

NACA - Langley Field, Va.