TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COMPARISON OF VEE-TYPE AND CONVENTIONAL TAIL SURFACES IN COMBINATION WITH FUSELAGE AND WING IN THE VARIABLE-DENSITY TUNNEL

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SUMMARY

The pitching and the yawing moments of a vee-type and a conventional type of tail surface were measured. The tests were made in the presence of a fuselage and a wing-fuselage combination in such a way as to determine the moments contributed by the tail surfaces. The results showed that the vee-type tail tested, with a dihedral angle of 35.3°, was about 71 percent as effective in pitch as the conventional tail and had a yawing-moment to pitching-moment ratio of 0.3. The conventional tail, the panels of which were all congruent to those of the vee-type tail, had a yawing-moment to pitching-moment ratio of 0.48. These ratios are in fair agreement with values calculated by methods shown in this and previous reports. The values of the measured moments were reduced from 15 to 25 percent of the calculated value by fuselage interference.

INTRODUCTION

A vee-type of tail surface consists essentially of two panels forming an angle less than 180°; that is, it is a horizontal tail surface with dihedral. Such a tail surface might replace a "conventional" three-panel surface consisting of a vertical fin and two horizontal surfaces placed end to end. The vee-type tail has been used (reference 1), but little quantitative information on its performance has been published. Important data required for design are the rate of change of pitching moment with angle of attack and the rate of change of yawing moment with angle of sideslip.

In order to obtain results for comparison, a vee-type and a conventional type of tail surface were tested in the variable-density wind tunnel to determine the rates of change of moments. The tail surfaces were tested with a fuselage and with a wing-fuselage combination. A dihedral angle of 35.3° was used; the value was determined by a very approximate calculation as the angle that would give a rate of change of yawing moment with angle of sideslip equal to half the rate of change of pitching moment with angle of attack. This ratio of rates will be called in this paper the "moment" ratio. The value is arbitrary and was selected because the conventional tail had yawing moments that were about half the pitching moments.

The slopes of the curves of pitching moment against angle of attack for the vee-type tail surface and for the conventional tail surface were obtained for the fuselage-tail combination and the wing-fuselage-tail combination. The slopes of the curves of yawing moment against angle of sideslip for the two tail surfaces were obtained only for the fuselage-tail combination. The wing and fuselage interference was determined for both tail surfaces. The interference results are an extension of the wing-fuselage-tail interference tests reported in reference 2.

A method of calculating the characteristics of a vee-type tail is presented and a comparison of the calculated characteristics is made with the measured characteristics obtained in the tests.

APPARATUS AND MODELS

The tests were made in the variable-density wind tunnel, which is described in reference 3.

The complete model of the wing, the fuselage, and the vee-type tail is shown in figure 1. The wing-fuselage arrangement is the same as combination 306 of reference 2, that is, a high-wing position with tapered fillets. The wing has a taper ratio of 2:1, an aspect ratio of 6, an area of 150 square inches, and no sweepback. The section varies from NACA 0018 at the root to NACA 0009 at the tip. The fuselage-tail combinations are shown in figure 2(a) and figure 2(b). Both types of tail surface are composed of tail panels of the shape shown in figure 2(c). The two tail surfaces tested are therefore not equivalent aerodynamically because the conventional tail surface had 1½ times as much wetted area as the vee-type tail and had a span 1.23 times greater than the vee-type tail.

TESTS

Measurements of lift, drag, and pitching moment were made for each of the combinations and partial combinations through an angle-of-attack range from below the angle-of-zero lift to beyond the stall. Yawing moments were measured on the pitching-moment balance by rotating the model through 90° about the longitudinal axis. These measurements were made only on the fuselage-tail combinations. All the tests were made at an "effective" Reynolds number of approximately 8,000,000.

RESULTS

Drag and moment polars for the complete model with the vee-type tail are shown in figure 3. Comparable data from reference 2 for the same models with no tail surface and with a conventional horizontal tail surface are also shown. (The absence of a vertical surface on the complete model with the conventional tail was a matter of experimental convenience and is assumed to have a negligible effect on the comparison of the pitching moments of the vee-type and the conventional tail. The wingless model with conventional tail surfaces, of course, included the fin.)

The results for the fuselage-tail combinations are expressed as moment increments due to the tail, taken about the same point as for the complete model (F on fig. 2(b)). All moment coefficients presented in this report are based on an area of 150 square inches and a mean chord of 5 inches. The chord, instead of the span, was used as the reference length for yawing moments in order to compare yawing and pitching moments by simply taking the ratio of the coefficients. The moment increments due to the tail surfaces are shown in figures 4, 5, and 6 and are obtained by deducting the moments of the fuselage alone from the moments of the fuselage-tail combinations. This method eliminates the necessity of tare measurements.

A comparison of the pitching moments of the vee-type with the conventional tail surface in the presence of the fuselage is shown in figure 4. A similar comparison with the wing present is shown in figure 5. The data for the wing present are plotted against the angle of attack at the tail, $\alpha_t = \alpha - \epsilon$, where α is the angle of attack and ϵ is the downwash angle. The downwash values for the same wing-fuselage combination and the same horizontal tail surface, determined in reference 2, were used here for ϵ. These values of the downwash were used in obtaining the effective angle of attack for both tail surfaces of the wing-fuselage combinations. Because the downwash values used were obtained from measurements on the model with the horizontal tail, it might be expected that the pair of curves showing the pitching moment due to the tail plotted against the effective angle of attack of the tail would show better agreement for the conventional tail surface than for the vee-type tail surface. As may be seen from figure 5, the curves that show the variation of C_{m_t} with $\alpha - \epsilon$ show better agreement for the conventional tail surface.

The comparison of the variation of C_{n_t} with angle of sideslip β for the two types of tail surface is shown in figure 6.

The principal aerodynamic characteristics of the wing alone, the wing-fuselage combination alone, and the two arrangements with the conventional tail surfaces are given in reference 2.

DISCUSSION OF RESULTS

Comparison of Pitching Moments of Vee-Type and Conventional Tail

It is of interest to compare the ratio of the pitching moment of the vee-type tail with that of the conventional tail, measured with and without the wing. The second column of table I gives the slopes of the curves of pitching moments of the tail surface plotted against total lift for the complete model. The third column gives the slopes of the curves of pitching moments plotted against angle of attack for the models consisting of fuselage and tail. The ratio of the two numbers in the second column is 0.73; the corresponding ratio in the third column is 0.71. The agreement is not so good for higher angles of attack, owing to the different manner in which these slopes change as the angle of attack is increased. (See fig. 5.)

Wake Effects

The tail factor, η_t, is defined as the ratio of the moment increment due to the addition of the tail surface to a fuselage to the moment that would be produced by the tail surface in the absence of the fuselage. The values of η_t for various tail surfaces presented in the following table are based on calculated values for the moment produced by the tail surface alone.

Kind of tail surface	η_t
Conventional tail in pitch	0.79
Vee-type tail in pitch	.85
Conventional tail in yaw	.85
Vee-type tail in yaw	.74

The pitching moment of the conventional tail in pitch can be easily calculated from the well-known theory of the elliptical monoplane wing, which has been well established by experiment. The pitching moment of the vee-type tail in pitch and sideslip (which depends, of course, on the lift and the lateral force developed by a wing of a large dihedral) is calculated in a later part of this report. The yawing moment of the conventional tail in sideslip was calculated by the method of reference 4. The tail factor is of the order of 80 to 90 percent for all the tail surfaces.

The wing wake, as determined by calculating the wake position, had no effect on the horizontal tail and a negligible effect on the vee-type tail.

CALCULATION OF THEORETICAL LIFT AND LATERAL FORCE ON A WING WITH DIHEDRAL

The following symbols are used in the report:

C_L' lift coefficient normal to each wing panel

L' lift normal to each wing panel

C_L resultant lift coefficient

C_Y lateral-force coefficient

α angle of attack

α_{eff} effective angle of attack on each wing panel

β angle of sideslip

γ dihedral angle

$C_{m_t} = \frac{M}{qcS}$ pitching-moment coefficient due to tail

$C_{n_t} = \frac{N}{qcS}$ yawing-moment coefficient due to tail

C and V used as subscripts refer to the conventional and the vee-type tail, respectively.

From figure 7, if α is small,

$$\alpha_{eff} = \alpha \cos \gamma$$

Also

$$C_L = C_L' \cos \gamma$$

Therefore

$$\frac{dC_L}{d\alpha} = \frac{dC_L}{d\alpha_{eff}} \times \frac{d\alpha_{eff}}{d\alpha} = \frac{dC_L'}{d\alpha_{eff}} \cos^2 \gamma$$

Assume

$$\left(\frac{dC_L'}{d\alpha_{eff}}\right)_V \doteq \left(\frac{dC_L}{d\alpha}\right)_C$$

Therefore

$$\left(\frac{dC_L}{d\alpha}\right)_V = \left(\frac{dC_L}{d\alpha}\right)_C \cos^2 \gamma$$

Then

$$\frac{\left(\frac{dC_{m_t}}{d\alpha}\right)_V}{\left(\frac{dC_{m_t}}{d\alpha}\right)_C} = \frac{\left(\frac{dC_L}{d\alpha}\right)_V}{\left(\frac{dC_L}{d\alpha}\right)_C} = \cos^2 \gamma$$

because the tail arms are equal and the area of the vee-type tail is equal to the area of the horizontal surfaces of the conventional tail.

If a vee-type wing is subjected to sideslip, the effective angle of attack is increased on one panel and decreased by an equal amount on the other panel. If the angle of attack of the wing as a whole is zero, as in these tests, the lifts on each panel will be equal and opposite, as shown in figure 8.

The span loading will be assumed to be equal to that of the same wing without dihedral but with a sudden twist at the center that makes the angles of attack on both panels equal and opposite. This angle of attack will be taken to be the effective angle of attack of the vee-type wing, which is, if β is small,

$$\alpha_{eff} = \beta \sin \gamma$$

The load distribution for a wing with unit angle-of-attack change from root to tip (produced, for example, by a full-span aileron of constant chord ratio) is given in reference 5 for wings of three different taper ratios and three different aspect ratios. The net lift on one panel due to equal and opposite angles of attack on both panels was found for the case of taper ratio 2:1 and extrapolated to an aspect ratio of 4.5. The results were:

$$\frac{dC_L'}{d\alpha_{eff}} = 0.049$$

Since

$$C_Y = C_L' \sin \gamma$$

and

$$\alpha_{eff} = \beta \sin \gamma$$

$$\frac{dC_Y}{d\beta} = \frac{dC_Y}{d\alpha_{eff}} \times \frac{d\alpha_{eff}}{d\beta} = \frac{dC_L'}{d\alpha_{eff}} \sin^2 \gamma = 0.049 \sin^2 \gamma$$

Therefore

$$\frac{\left(\frac{dC_{n_t}}{d\beta}\right)_V}{\left(\frac{dC_{m_t}}{d\alpha}\right)_C} = \frac{\left(\frac{dC_Y}{d\beta}\right)_V}{\left(\frac{dC_L}{d\alpha}\right)_C} = \frac{\frac{dC_L'}{d\alpha_{eff}} \sin^2 \gamma}{\left(\frac{dC_L}{d\alpha}\right)_C} = \frac{0.049}{0.071} \sin^2 \gamma$$

and

$$\frac{\left(\frac{dN}{d\beta}\right)_V}{\left(\frac{dM}{d\alpha}\right)_V} = \frac{\left(\frac{dC_Y}{d\beta}\right)_V}{\left(\frac{dC_L}{d\alpha}\right)_V} = \frac{0.049}{0.071} \tan^2 \gamma = 0.69 \tan^2 \gamma$$

In figure 9 is shown the variation of lift-force slope $dC_L/d\alpha$ and of lateral-force slope dC_Y/dB with dihedral angle, as calculated by the foregoing formulas. The ratio of the slopes of the yawing moment-angle of sideslip curve to the pitching moment-angle of pitch curve is given on the same figure. This moment ratio is the same as the ratio of $dC_Y/d\beta$ to $dC_L/d\alpha$ because both coefficients are based on the same area.

The points on figures 9 show that the measured ratio of yawing to pitching moment is 10 percent lower than the calculated value at the one dihedral angle for which test data are available. The actual values of the slope of lift-angle of attack and lateral force-angle of sideslip curves are from 15 to 25 percent less than the calculated values, the discrepancy being attributed to fuselage interference.

Another way of expressing the comparison is to give the ratio of all moment-curve slopes to the slope of the curve of pitching moment against angle of attack for the conventional tail. These ratios are given in the last two columns of table I. Fair agreement is evident in all cases.

A method of calculating the end-plate effect of the horizontal tail surface on the vertical tail surface is given in reference 4. The calculated values of the ratio of yawing moment to pitching moment of the conventional tail are in fair agreement with measured values as shown in table I.

CONCLUSIONS

The following data apply to a vee-type tail surface with a dihedral angle of 35.3° and to a conventional tail surface, the panels of which were congruent to those of the vee-type tail.

The ratio of yawing moment to pitching moment of the vee-type tail surface was 0.3.

The ratio of yawing moment to pitching moment of the conventional tail surface was 0.48.

The ratio of pitching moment of the vee-type tail to the pitching moment of the conventional tail was 0.71.

The simple method presented in this report of calculating the yawing-moment to pitching-moment ratio gave a value 10 percent higher than the measured value.

The presence of a fuselage reduced the measured moments from 15 to 25 percent of the values calculated without fuselage interference.

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3. Jacobs, Eastman N., and Abbott, Ira H.: The N.A.C.A. Variable-Density Wind Tunnel. Rep. No. 416, NACA, 1932.

4. Katzoff, S., and Mutterperl, William: The End-Plate Effect of a Horizontal-Tail Surface on a Vertical-Tail Surface. T.N. No. 797, NACA, 1941.

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TABLE I

TAIL-MOMENT SLOPES AND THEIR RATIOS WITH RESPECT TO CONVENTIONAL TAIL IN PITCH

[All moment coefficients based on area of 150 sq in. and chord of 5 in.]

Kind of tail surface	Wing fuselage and tail	Fuselage and tail (per deg)		Ratio of slope to $dC_{m_t}/d\alpha$ of conventional tail	
	$\left(\frac{dC_{m_t}}{dC_L}\right)_{C_L=0}$	$\left(\frac{dC_{m_t}}{d\alpha}\right)_{\alpha=0}$	$\left(\frac{dC_{n_t}}{d\beta}\right)_{\beta=0}$	Measured	Calculated
Conventional tail in pitch -------	-0.165	-0.0262		1.00	1.00
Vee-type tail in pitch ----	-.121	-.0186		.71	.67
Conventional tail in yaw -			-0.0127	.48	[a].45
Vee-type tail in yaw ------			-.0056	.21	.23

[a]Based on data of reference 4.

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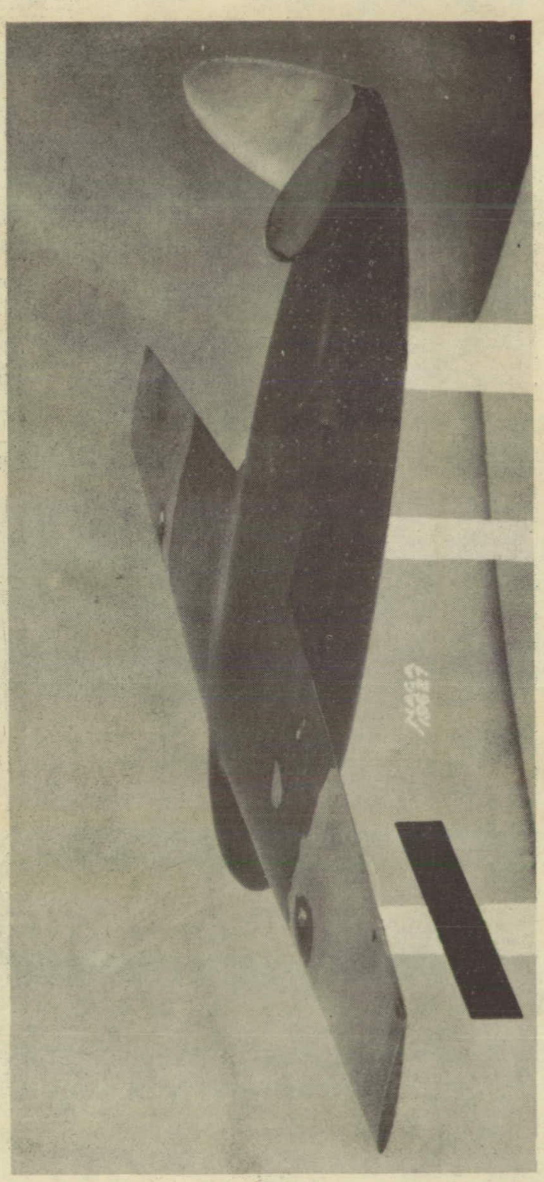

Figure 1.- Model of the wing, the fuselage, and the vee-type tail.

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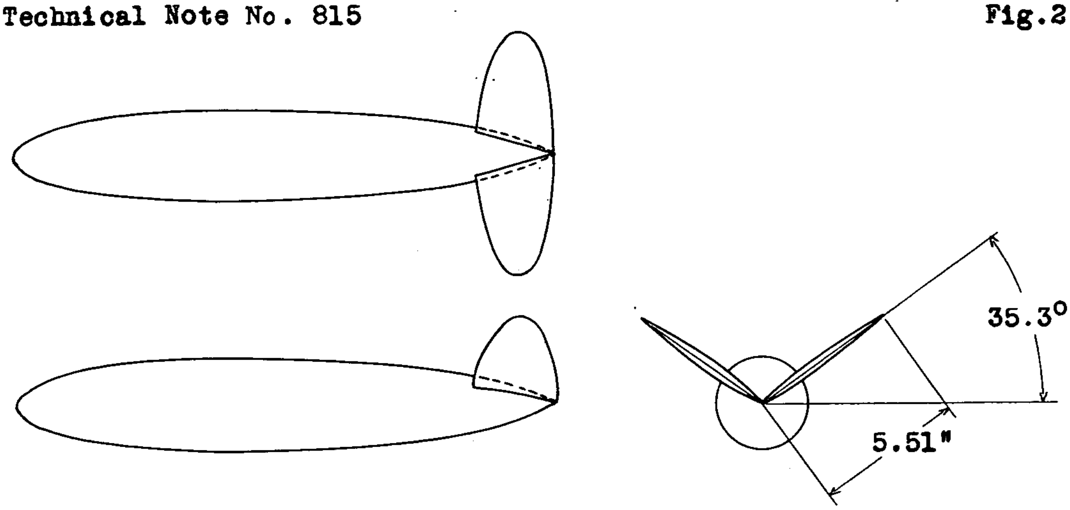
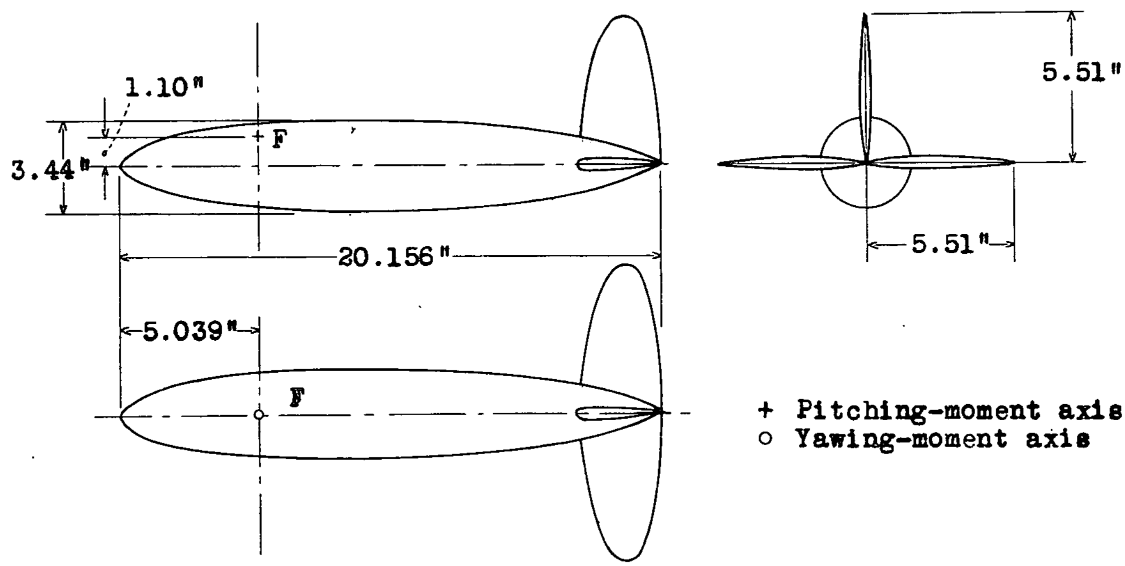
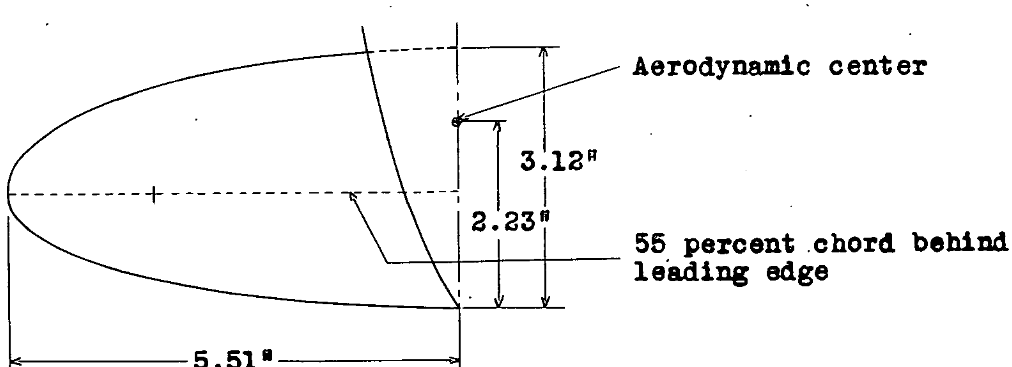


(a) Vee-type tail and fuselage.



(b) Conventional tail and fuselage.



(c) Plan form of tail panel used in tail surfaces (NACA 0009 section; panel area, 13.5 sq in., including 2.04 sq in. in fuselage).

Figure 2.- Fuselage-tail combinations.

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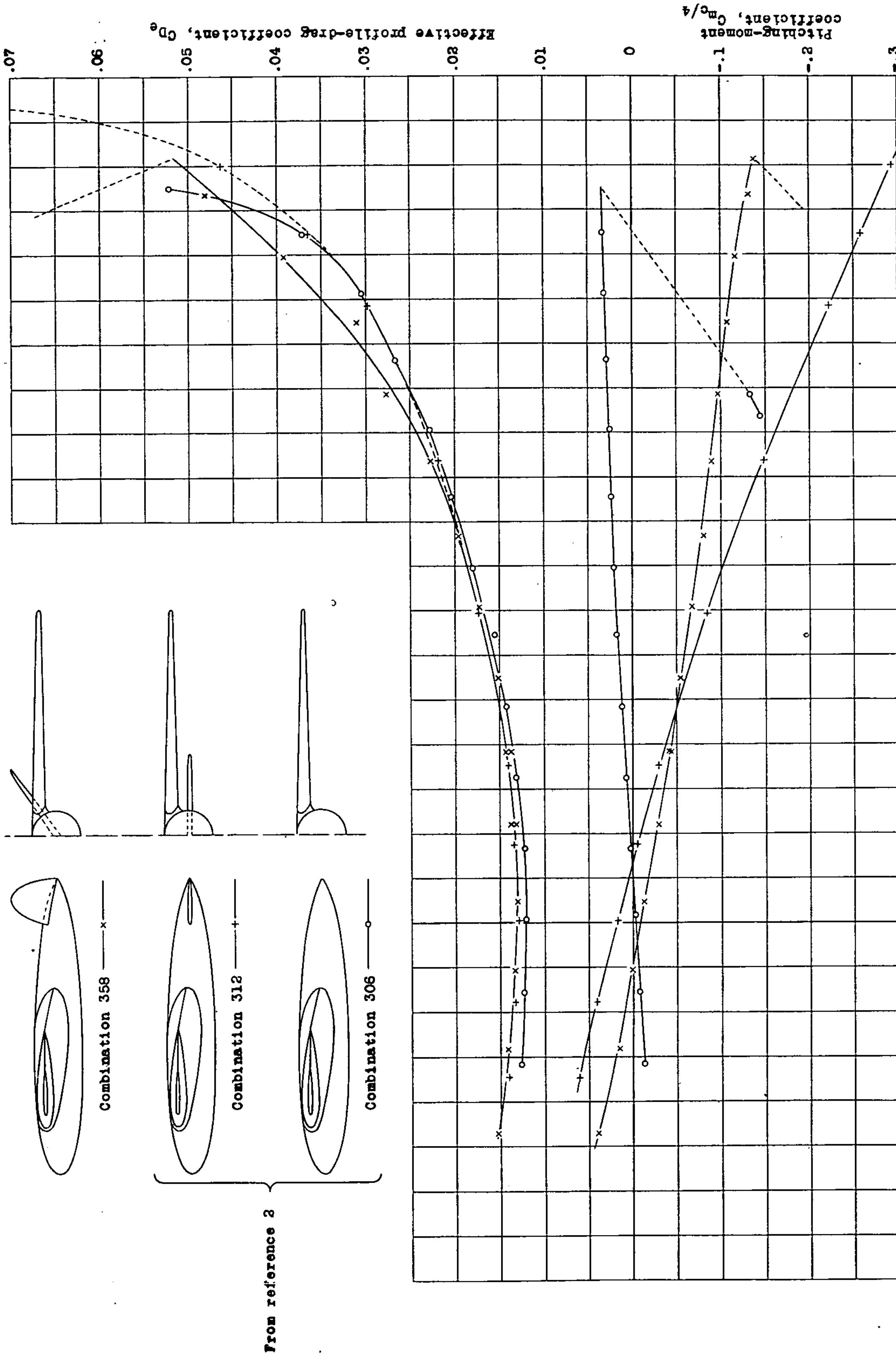

Figure 3.- Characteristics of high-wing combinations with various tail surfaces. Tapered NACA 0018-09 airfoil and round fuselage.

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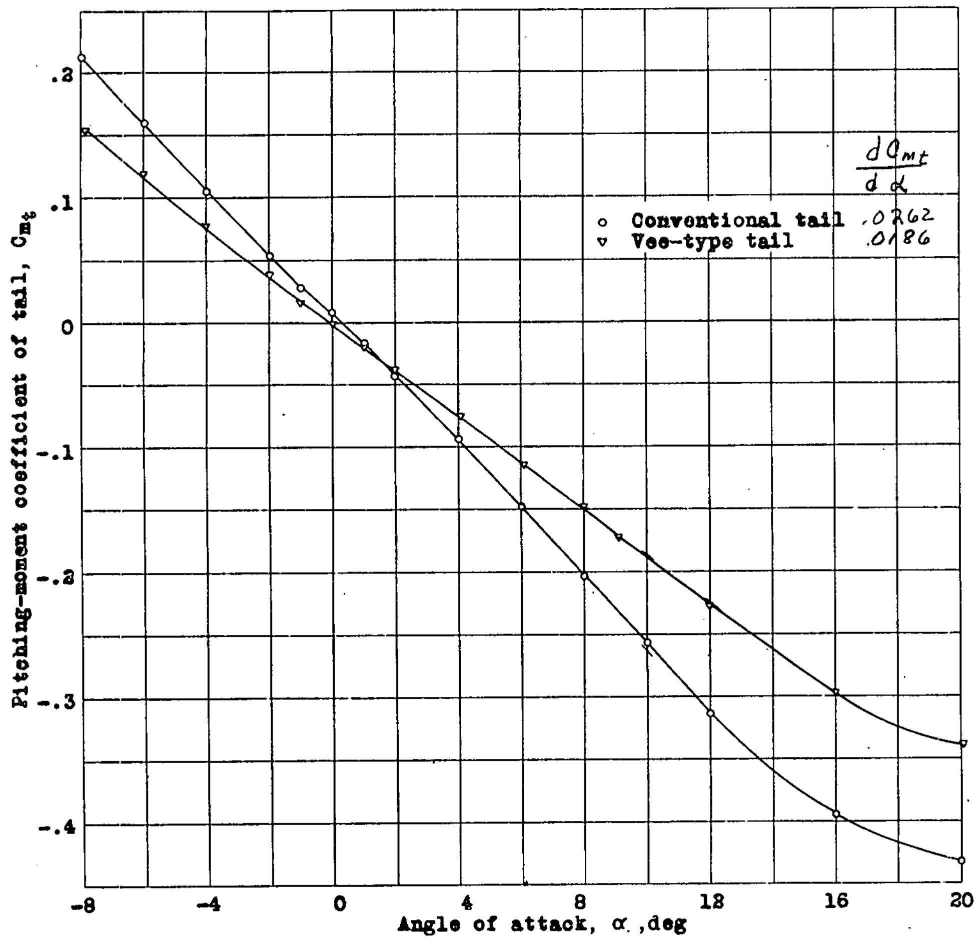

Figure 4.- Comparison of pitching moments of conventional and vee-type tail surfaces in presence of fuselage.

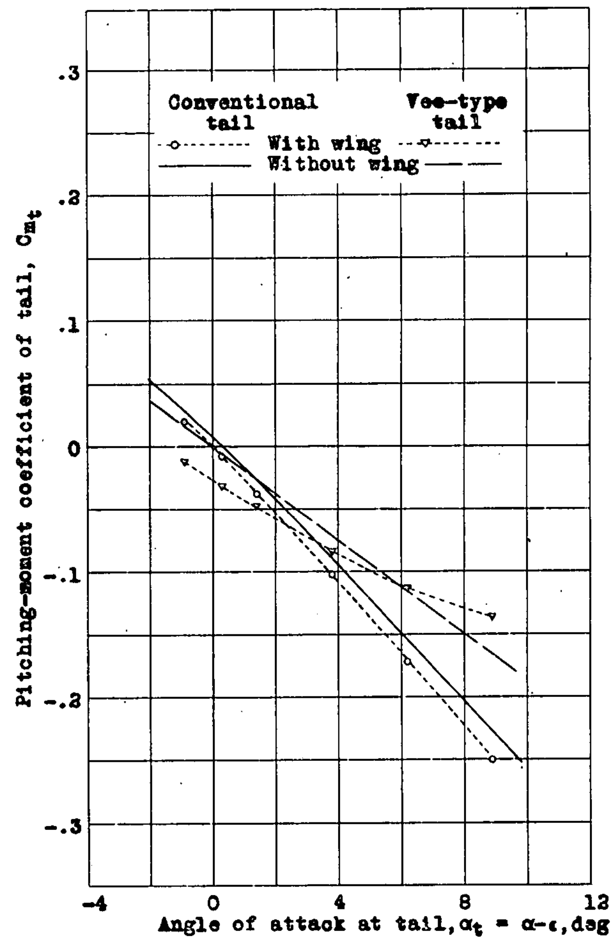

Figure 5.- Pitching moments of conventional and vee-type tail surfaces in presence of fuselage with and without wing. (Downwash values taken from reference 2.)

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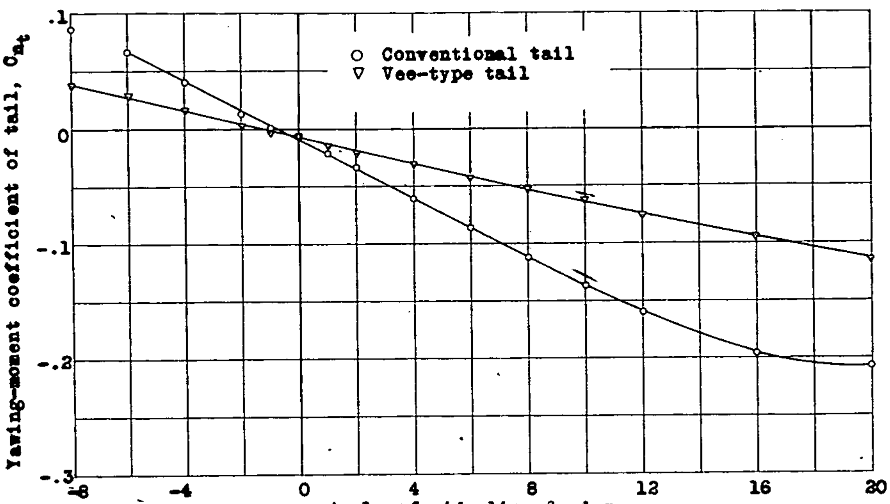

Figure 6.- Comparison of yawing moments of conventional and vee-type tail surfaces in presence of fuselage.(C_{n_t} based on wing chord).

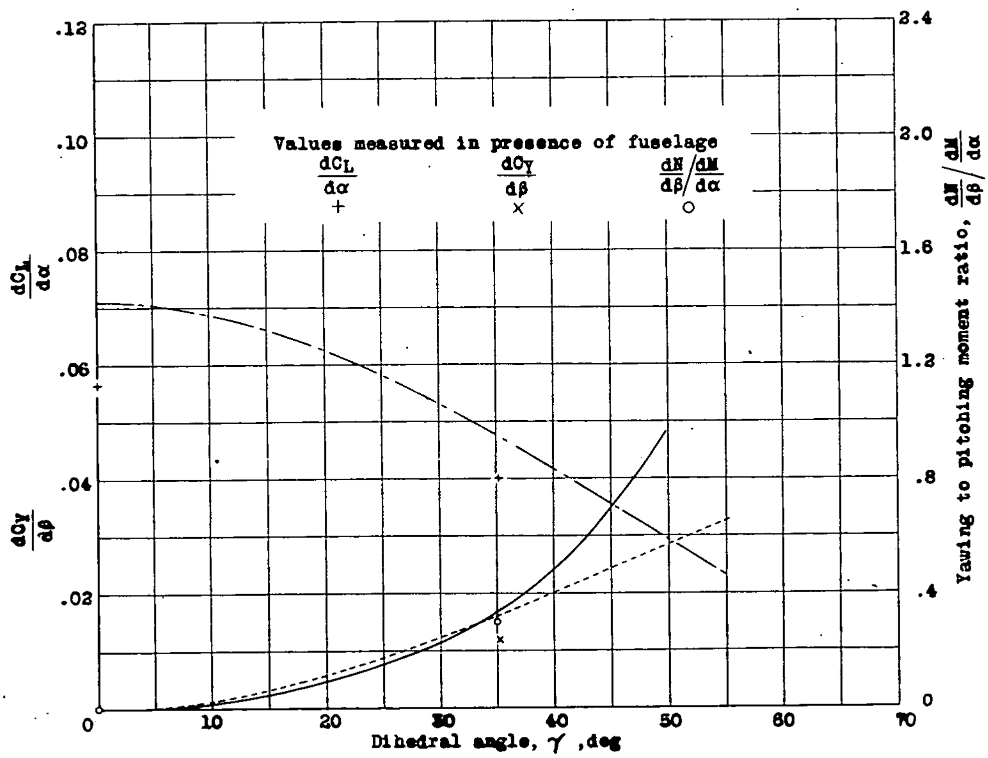

Figure 9.- Variation of lift and lateral-force curve slopes,and moment ratio with dihedral of a vee-type tail.

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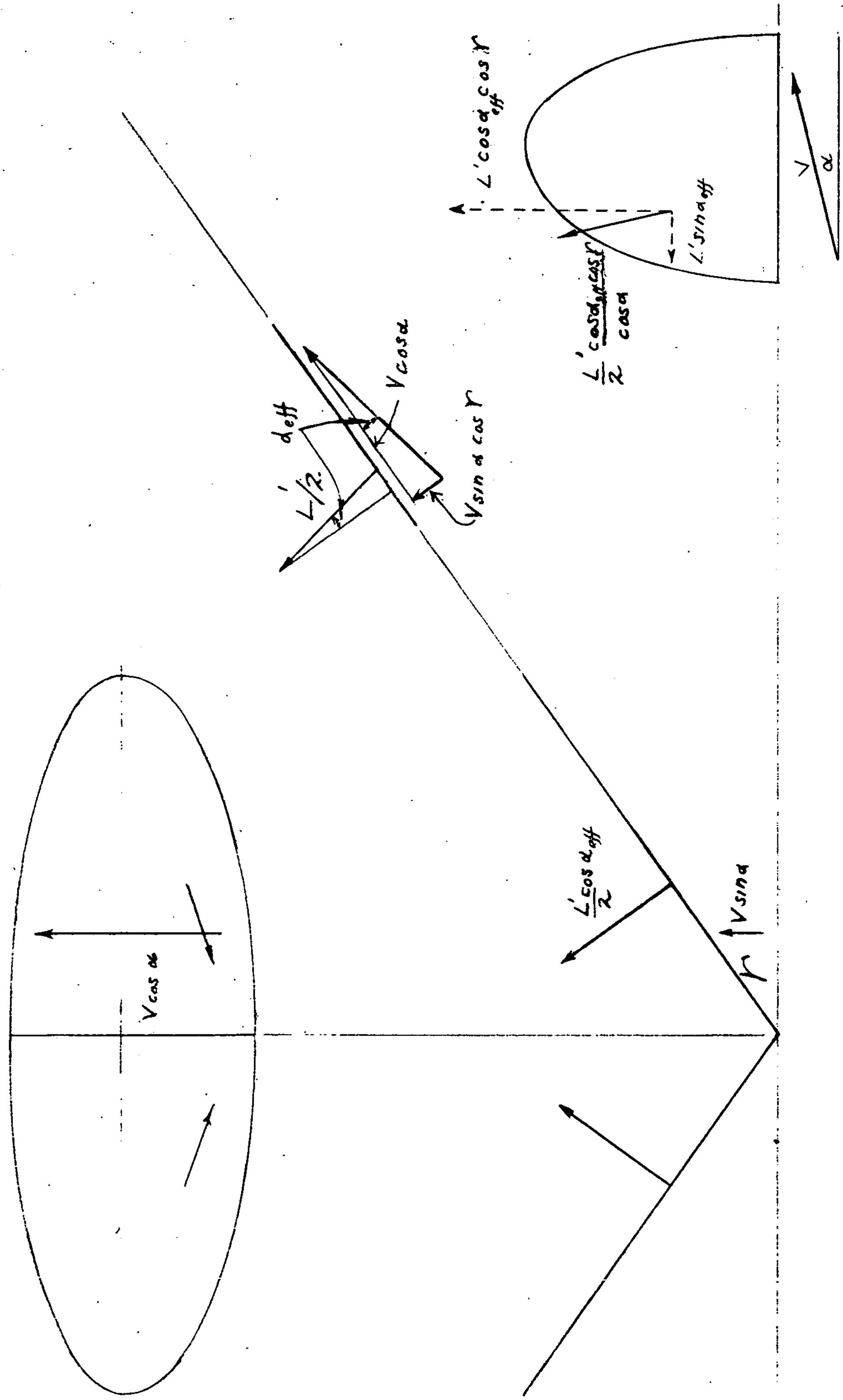

Figure 7.- Relation between velocity, V, and lift, L', vectors on vee-type tail with large dihedral in pitch.

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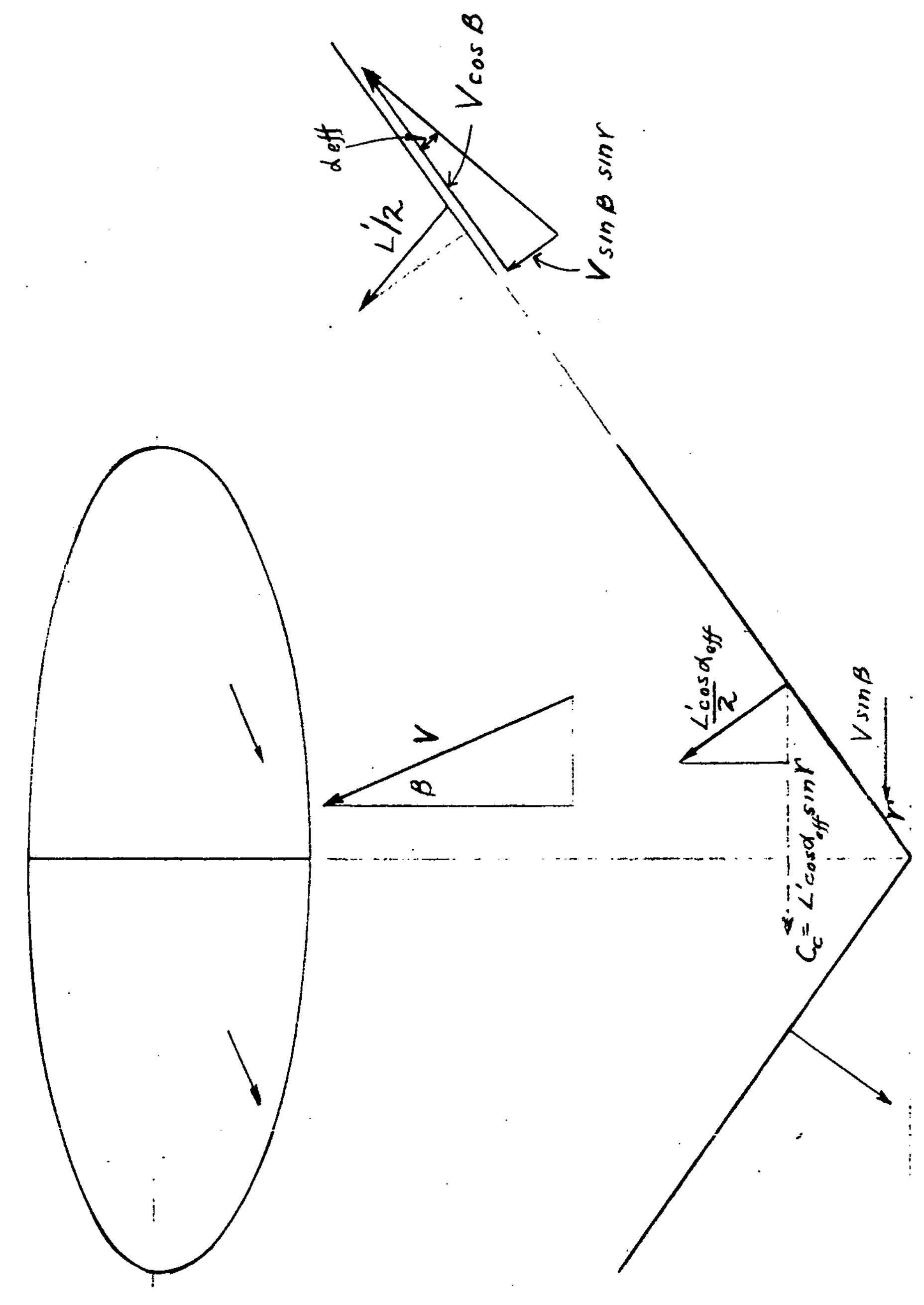

Figure 8.- Relation between velocity, V, and lift, L', vectors on vee-type tail with large dihedral in yaw.