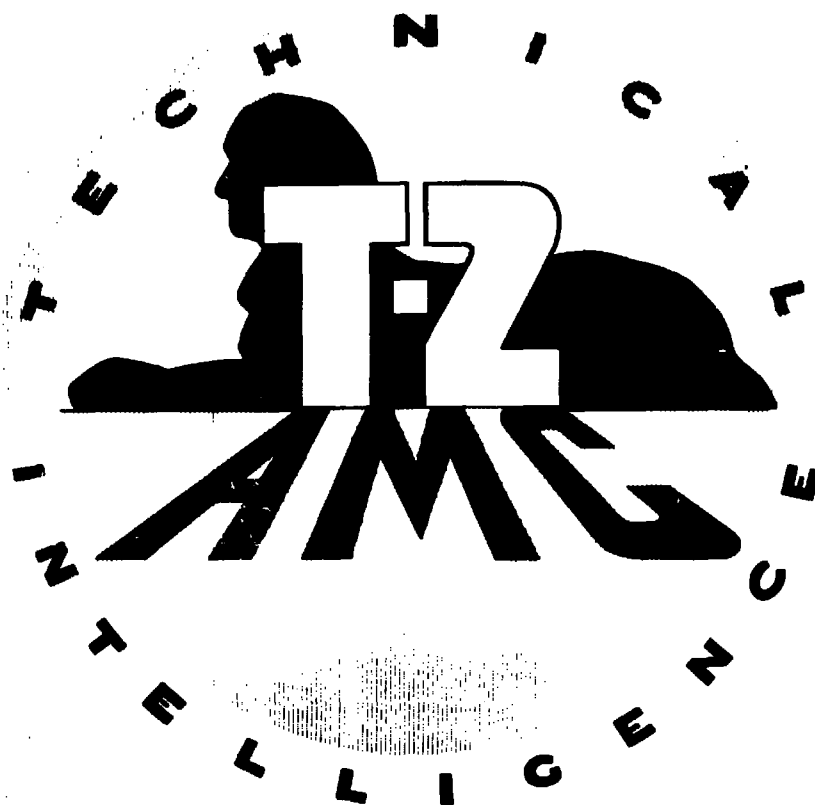| AD NUMBER	
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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ATI No. 8091

No. 815

COMPARISON OF VEE-TYPE AND CONVENTIONAL TAIL

SURFACES IN COMBINATION WITH FUSELAGE

AND WING IN THE VARIABLE-DENSITY TUNNEL

By Harry Greenberg
Langley Memorial Aeronautical Laboratory

Washington
July 1941

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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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 mo-
ments 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 tun-
nel, 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 aero-
dynamically 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 meas-
ured on the pitching-moment balance by rotating the model
through 90° about the longitudinal axis. These measure-
ments 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 experi-
mental convenience and is assumed to have a negligible ef-
fect 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 (Y 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 fuse-
lage alone from the moments of the fuselage-tail combina-
tions. 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 fuse-
lage and tail. The ratio of the two numbers in the second
column is 0.73; the corresponding ratio in the third col-
umn 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 sur-
face 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 sur-
faces.

The wing wake, as determined by calculating the wake
position, had no effect on the horizontal tail and a neg-
ligible 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

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

$C_{n_t} = \dfrac{N}{qcS}$ 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

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

Therefore

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

Then

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

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

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

and

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

In figure 9 is shown the variation of lift-force
slope $dC_L/d\alpha$ and of lateral-force slope $dC_Y/d\beta$ 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 calcu-
lating 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.

Langley Memorial Aeronautical Laboratory,
     National Advisory Committee for Aeronautics,
          Langley Field, Va.

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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 $\left(\dfrac{dC_{m_t}}{dC_L}\right)_{C_L=0}$	Fuselage and tail (per deg)		Ratio of slope to $dC_{m_t}/d\alpha$ of conventional tail	
		$\left(\dfrac{dC_{m_t}}{d\alpha}\right)_{\alpha=0}$	$\left(\dfrac{dC_{n_t}}{d\beta}\right)_{\beta=0}$	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.
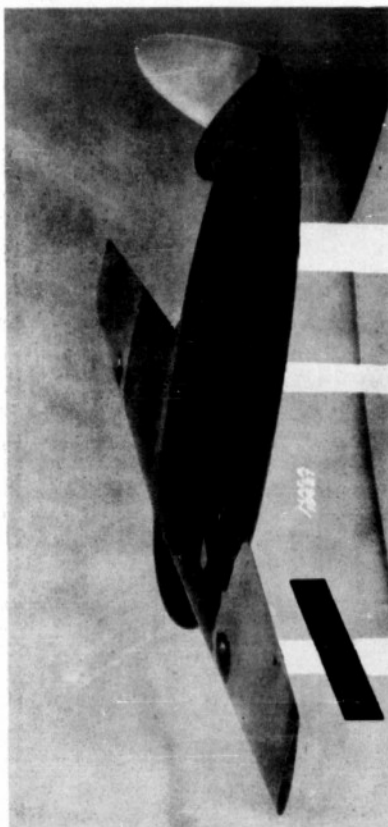
Figure 1.- Model of the wing, the fuselage, and the vee-type tail.

Fig.2
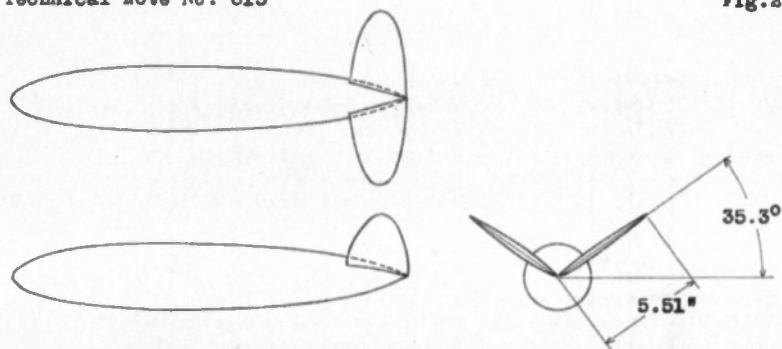
(a) Vee-type tail and fuselage.

35.3°

5.51"

1.10"

3.44"

F

20.156"

5.039"

F

5.51"

5.51"

+ Pitching-moment axis
○ Yawing-moment axis
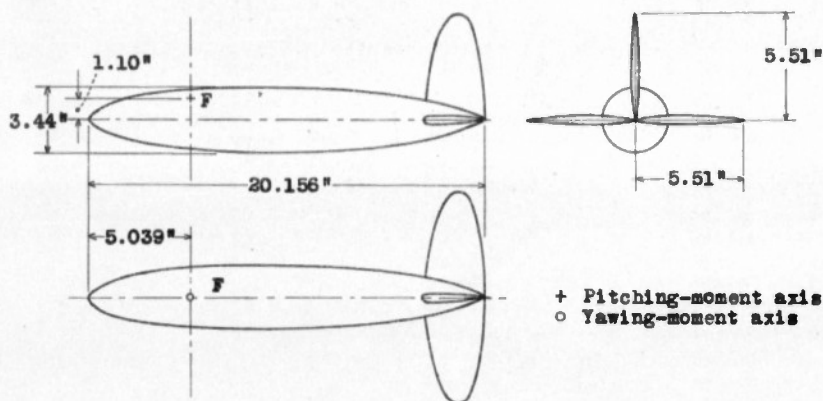
(b) Conventional tail and fuselage.

Aerodynamic center

3.12"

2.23"

55 percent chord behind
leading edge

5.51"
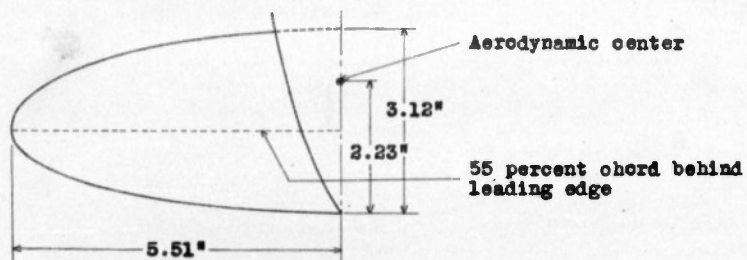
(c) Plan form of tail panel used in tail surfaces
(NACA 0009 section;panel area,13.5 sq in., in-
cluding 2.04 sq in. in fuselage).

Figure 3.- Fuselage-tail combinations.

Fig.3

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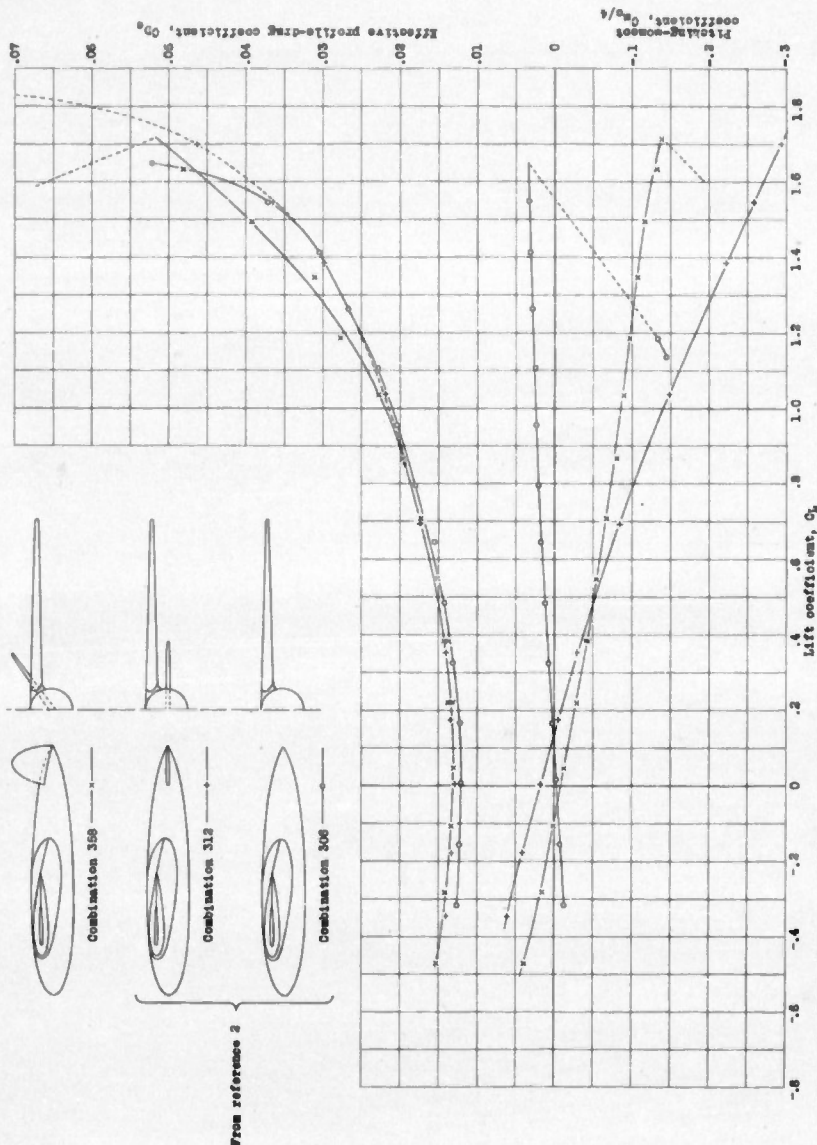
Figure 3.- Characteristics of high-wing combinations with various tail surfaces. Tapered NACA 0018-09 airfoil and round fuselage.

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Figure 5.- Pitching moments of conventional and vee-type tail surfaces in presence of fuselage with and without wing. (Downwash values taken from reference 3.)

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

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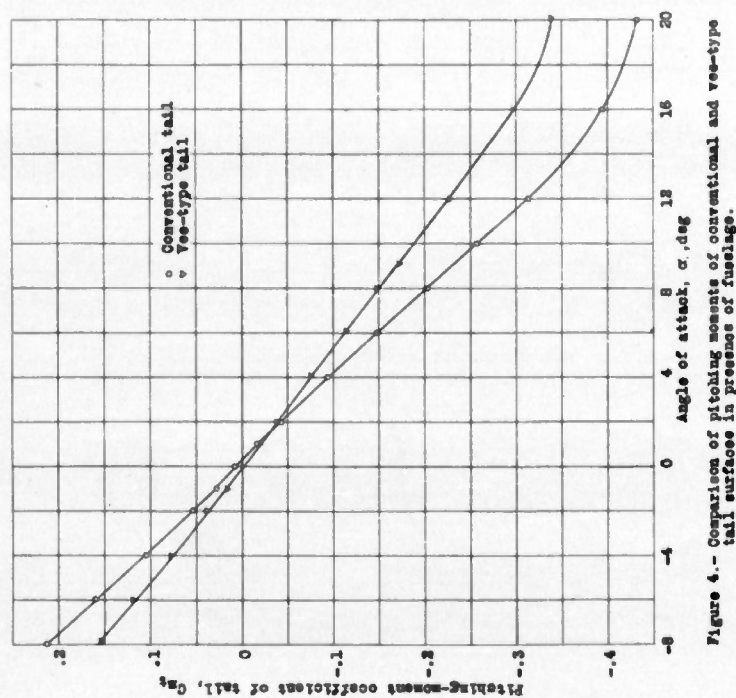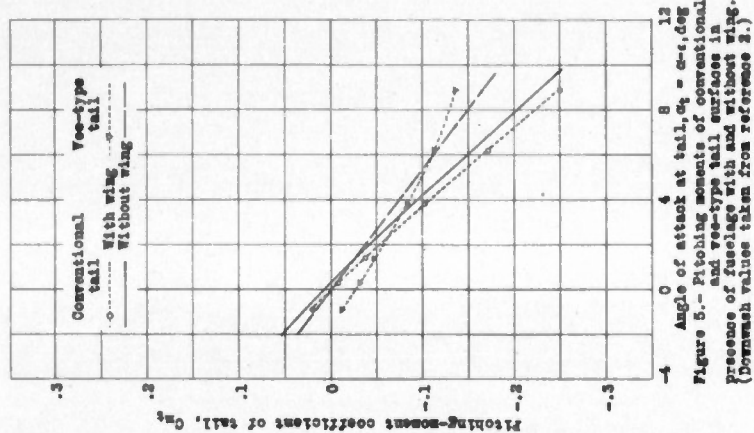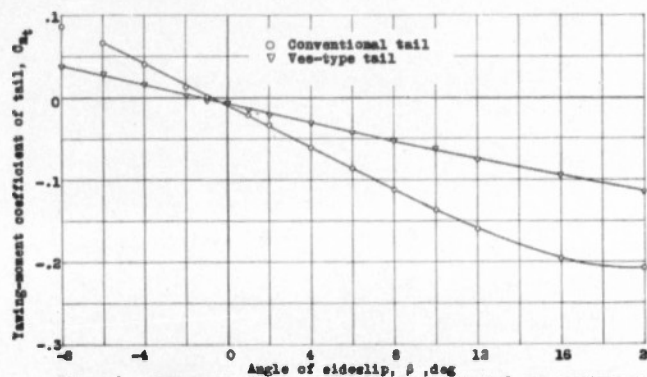
Figure 8.- Comparison of yawing moments of conventional and vee-type tail
surfaces in presence of fuselage.(C_{n_t} based on wing chord).
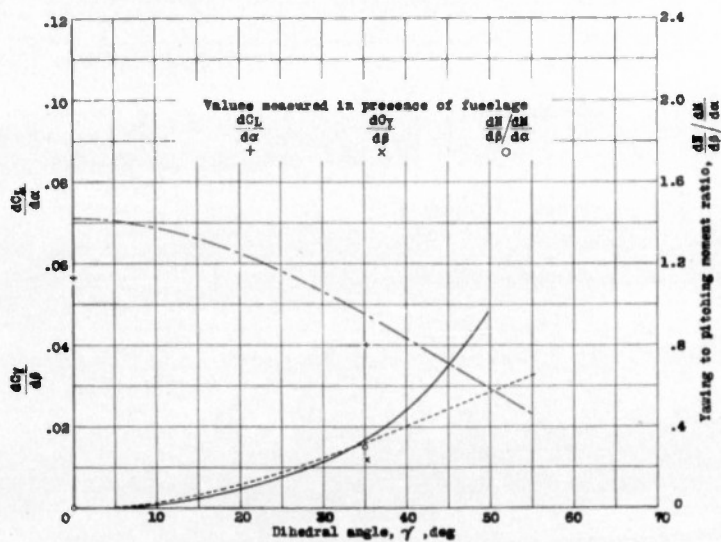
Figure 9.- Variation of lift and lateral-force curve slopes,and moment
ratio with dihedral of a vee-type tail.

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Fig. 7

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

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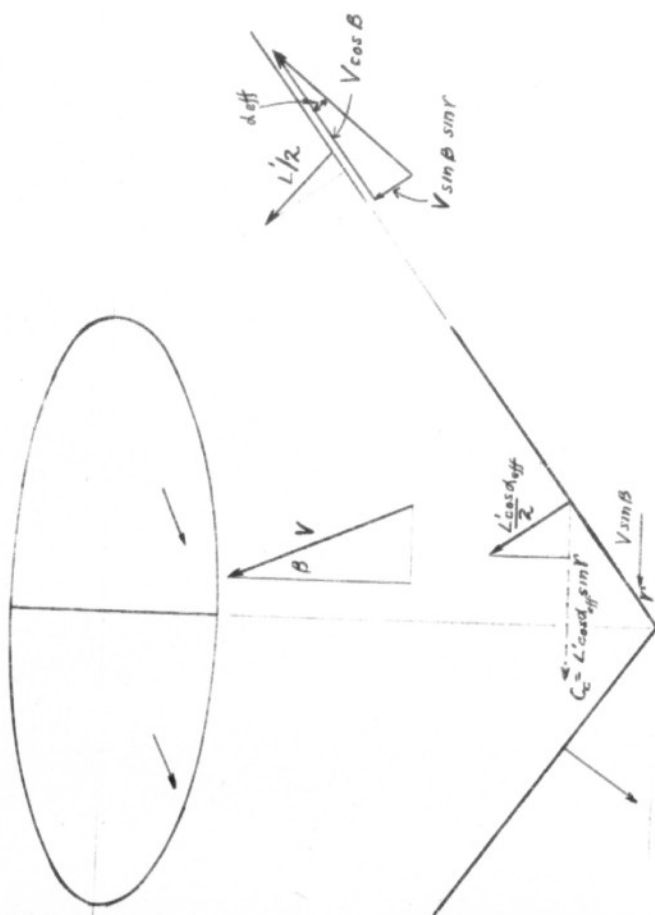
Figure 8.— Relation between velocity, V, and lift, L', vectors on vee-type tail with large dihedral in yaw.

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