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LOW-SPEED STATIC LATERAL AND ROLLING
STABILITY CHARACTERISTICS OF A SERIES OF
CONFIGURATIONS COMPOSED OF INTERSECTING
TRIANGULAR PLAN-FORM SURFACES

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SUMMARY

The static lateral and rolling stability derivatives of a series of cruciform, inverted T-, V-, and Y-configurations composed of low-aspect-ratio triangular surfaces have been obtained at low speed in the 6-foot-diameter rolling-flow test section of the Langley stability tunnel. These derivatives are presented as functions of the geometry of the models, and for two configurations (a planar wing and an inverted T), as functions of angle of attack. Where possible, comparisons have been made to indicate the extent of agreement between experiment and existing theory. In general, the sideslip derivatives showed better agreement between theory and experiment than the rolling derivatives.

INTRODUCTION

With the trend of modern high-speed aircraft, particularly missiles, toward the use of tail configurations incorporating surfaces of small aspect ratio, a number of theoretical papers have been published on the determination of the stability characteristics of this type of configuration (refs. 1 to 6). Although most of these papers are concerned primarily with supersonic flow, some, which are based on slender-body theory (i.e., thin wings of extremely low aspect ratio and slender bodies), are applicable to subsonic speeds. The theoretical stability characteristics for some tail configurations have been verified experimentally; however, only meager or no experimental data exist for a range of V-, Y-, and cruciform-tail configurations, particularly at low speeds.

The purpose of the present investigation was to obtain experimental data on V-, Y-, and cruciform tails and to compare the data where practical with existing slender-body theory. It should be kept in mind that the slender-body theory treats the case in which the surface carries a finite load at the trailing edge; whereas for the low-speed experimental
conditions used in this investigation, the trailing edge carries no load. Therefore, the theoretical and experimental curves should be compared for trends and not for absolute values.

SYMBOLS

The symbols used in this paper are referred to the stability system of axes with the origin of the axes located at two-thirds of the model root chord. Positive directions of forces, moments, and displacements about the stability axes are shown in figure 1.

\[ \begin{array}{ll}
  b & \text{span, ft} \\
  S & \text{area, sq ft} \\
  c_r & \text{root chord, ft} \\
  D & \text{diameter of circle swept by surface, ft} \\
  F_Y & \text{lateral force} \\
  M_X & \text{rolling moment} \\
  M_Z & \text{yawing moment} \\
  q & \text{dynamic pressure, lb/sq ft} \\
  V & \text{free-stream velocity, ft/sec} \\
  x/c_r & \text{longitudinal location of lateral-force center of pressure in percent of root chord} \\
  \alpha & \text{angle of attack, deg} \\
  \beta & \text{angle of sideslip, deg} \\
  \Gamma & \text{dihedral angle, deg} \\
  \phi & \text{rolling angular velocity, radians/sec} \\
  C_Y & \text{lateral-force coefficient, } \frac{\text{Lateral force}}{qS}
\end{array} \]
\[(C_y)_{TT} = \frac{\text{Lateral force}}{q(Area \text{ of vertical surface})}\]

\[(C_y)_{CT} = \frac{\text{Lateral force}}{q(Total \text{ area of vertical surfaces})}\]

\[(C_y)_{VT} = \frac{\text{Lateral force}}{2q(Area \text{ of one surface of V-configuration})}\]

\[(C_y)_{YT} = \frac{\text{Lateral force}}{2q(Area \text{ of one surface of V-portion of configuration})}\]

\[C_n \quad \text{yawing-moment coefficient, } \frac{\text{Yawing moment}}{qSb}\]

\[(C_n)_{TT} = \frac{\text{Yawing moment}}{q(Area \text{ of vertical surface})(Span \text{ of vertical surface})}\]

\[(C_n)_{CT} = \frac{\text{Yawing moment}}{q(Total \text{ area of vertical surfaces})(Total \text{ span of vertical surfaces})}\]

\[(C_n)_{VT} = \frac{\text{Yawing moment}}{4q(Area \text{ of one surface of V-configuration})(Span \text{ of one surface of V-configuration})}\]

\[(C_n)_{YT} = \frac{\text{Yawing moment}}{4q(Area \text{ of one surface of V-portion of configuration})(Span \text{ of one surface of V-portion of configuration})}\]

\[C_l \quad \text{rolling-moment coefficient, } \frac{\text{Rolling moment}}{qSb}\]

\[(C_l)_{TT} = \frac{\text{Rolling moment}}{q(Area \text{ of vertical surface})(Span \text{ of vertical surface})}\]
$$(C_l)_{CT} = \frac{\text{Rolling moment}}{q(\text{Total area of vertical surfaces})(\text{Total span of vertical surfaces})}$$

$$(C_l)_{VT} = \frac{\text{Rolling moment}}{h q(\text{Area of one surface of V-configuration})(\text{Span of one surface of V-configuration})}$$

$$(C_l)_{YT} = \frac{\text{Rolling moment}}{h q(\text{Area of one surface of V-portion of configuration})(\text{Span of one surface of V-portion of configuration})}$$

$$\frac{p_b}{2V} \quad \text{path helix angle, radians}$$

$$\left(\frac{p_b}{2V}\right)_{TT} = \frac{p}{2V} \quad (\text{Span of vertical surface})$$

$$\left(\frac{p_b}{2V}\right)_{CT} = \frac{p}{2V} \quad (\text{Total span of vertical surfaces})$$

$$\left(\frac{p_b}{2V}\right)_{VT} = \frac{p}{2V} \quad (\text{Twice span of one surface of V-configuration})$$

$$\left(\frac{p_b}{2V}\right)_{YT} = \frac{p}{2V} \quad (\text{Twice span of one surface of V-portion of configuration})$$

$$C_{\beta \gamma} = \frac{\partial C_{\gamma}}{\partial \beta} \quad \text{per degree}$$

$$C_{\beta \Phi} = \frac{\partial C_{\Phi}}{\partial \beta} \quad \text{per degree}$$

$$C_{\beta \tau} = \frac{\partial C_{\tau}}{\partial \beta} \quad \text{per degree}$$
MODELS AND TESTS

The models used in this investigation were assembled of plywood half-delta surfaces having rounded leading edges and tapered trailing edges. (See fig. 2(a).) The surfaces had root chords of 4.12 feet and semispans ranging from 0.375 to 1.375 feet.

The various configurations were obtained by clamping the surfaces to a mounting rod slightly less in diameter than the thickness of the plywood. The intersections between surfaces were then sealed. The models were assembled in such a manner that the apexes of all surfaces were coincident and their trailing edges were in a plane normal to the line of intersection. The line of intersection coincided with the root chords of
the surfaces. The complete range of configurations is indicated in figures 2(b) and 2(c), and two of the configurations tested in this investigation are shown in figure 3.

The models were mounted on a single strut support system with the mounting point at two-thirds of the root chord measured from the apex of the model. All models were mounted upright as indicated in figures 2(b), 2(c), and 3(a) with the exception of the Y-configurations which were tested in an inverted position as shown in figure 3(b). Forces and moments were measured by a six-component balance system.

The tests were made in the 6-foot-diameter rolling-flow test section of the Langley stability tunnel at a dynamic pressure of 39.7 pounds per square foot, which corresponds to a Mach number of 0.164 and a Reynolds number of approximately \( 4.8 \times 10^6 \) based on the root chord of the surfaces of 4.12 feet.

Sideslip data were obtained for values of sideslip angle \( \beta \) equal to 0°, \( \pm 2^\circ \), and \( \pm 5^\circ \). Rolling-stability data were obtained by using values of \( \frac{\gamma}{2V} \) of 0, \( \pm 0.005 \), \( \pm 0.010 \), and \( \pm 0.015 \) radian per foot of span. In most cases, the angle of attack was set at 0°; however, two configurations - the 3-foot-span planar surface and the inverted T-configuration, having a horizontal-surface span equal to 1.5 feet and a ratio of horizontal-surface span to vertical-surface span \( \frac{b_H}{b_V} \) equal to 1 - were tested at angles of attack up to 26°.

In order to determine the effect of thickness on the lift-curve slope of the surfaces, two delta wings having the same sweep angle of the leading edge of 84.8° and having thicknesses of \( \frac{3}{8} \) inch and \( \frac{3}{4} \) inch were tested through an angle-of-attack range. It was felt that a comparison of the results obtained from these two wings would give an indication of the validity of eliminating thickness effects as a factor in comparing the results obtained using the \( \frac{3}{4} \)-inch-thick surfaces with the slender-body theoretical results wherein the surfaces are assumed to have zero thickness. The effects of thickness for the surfaces tested were found to be small.

Corrections have been applied for jet-boundary effects on angles of attack and sideslip according to the method presented in reference 7. Tare corrections have been applied to the rolling-flow data of the cruciform configurations in an attempt to eliminate the effect of the cutout in the lower vertical surface necessitated by the method of mounting the models.

It is possible for a slight misalignment of the roll axis of the tunnel flow to produce increments of the side-force derivative \( C_{y_p} \) as evidenced in the results for the cruciform configuration \( \left( \frac{b_H}{b_V} = 1.00 \right) \) at 0° angle of attack and for the planar configuration at 0° angle of attack. No attempt has been made to correct for this effect.
RESULTS AND DISCUSSION

Sideslip Characteristics

Cruciform configurations. - The measured sideslip characteristics for the cruciform configurations are shown in figure 4 as curves of the derivatives $C_{Y\beta}$, $C_{n\beta}$, and $C_{l\beta}$ plotted against the ratio of horizontal span to vertical span $b_H/b_V$ for several values of the ratio of the lower span to the upper span of the vertical surface $b_{V_l}/b_{V_u}$.

The experimental results show that, for the inverted T-arrangement ($b_{V_l}/b_{V_u} = 0$), the derivatives $C_{Y\beta}$ and $C_{n\beta}$ increased negatively almost linearly with the ratio $b_H/b_V$ until a value of $b_H/b_V$ of about 1.0 was reached. Further increases in the ratio caused little change in $C_{n\beta}$, whereas the negative slope of $C_{Y\beta}$ was slightly decreased. The derivative $C_{l\beta}$ remained nearly constant until the ratio of horizontal-surface span to vertical-surface span of 1.0 was reached; then it decreased with further increase in $b_H/b_V$. The effects of horizontal-tail span indicated herein for the inverted T-configurations, usually referred to as end-plate effects, are qualitatively the same as those shown by the theoretical and experimental data of reference 8 and the theoretical analysis of reference 9 even though these references are concerned with aspect ratios and sweep angles very different from those of the present investigation. Equations presented in reference 4 are directly applicable to the inverted T-configurations and were used to obtain the variation of $C_{Y\beta}$ and $C_{l\beta}$ with $b_H/b_V$. The results are presented in figure 4 for comparison with the experimental data. The agreement between theory and experiment is good for both $C_{Y\beta}$ and $C_{l\beta}$.

The effect of varying the vertical position of the horizontal surface (increasing $b_{V_l}/b_{V_u}$) was to decrease the end-plate effect on $C_{Y\beta}$ and $C_{l\beta}$ for all ratios of $b_H/b_V$. The results also indicate that the rate of change of end-plate effect with increasing $b_{V_l}/b_{V_u}$ was very great when the horizontal surface was near the base of the vertical surface ($b_{V_l}/b_{V_u} = 0$), but became negligible as the horizontal surface neared the center of the vertical surface ($b_{V_l}/b_{V_u} = 1.0$). These effects are consistent with those of reference 8.
The effects of variation of angle of attack on the sideslip derivatives for a planar delta wing and an inverted T-configuration are presented in figure 5. Below an angle of attack of approximately 6°, the sideslip derivatives $C_{\beta y}$ and $C_{n\beta}$ were nearly equal to zero for the planar configuration. This and the variation of $C_{\beta y}$ up to an angle of attack of approximately 16° are in agreement with the theory of reference 5. The addition of a vertical surface on top of the planar configuration produced negative increments of all three derivatives at 0° angle of attack. A comparison of the data of figures 5(a) and 5(b) shows that the negative increment in the case of $C_{n\beta}$ decreased considerably as the angle of attack was increased.

**V-configurations.** The measured sideslip characteristics of the V-configurations (see fig. 2(b)) are shown in figure 6 as curves of $C_{\beta y}$, $C_{n\beta}$, and $C_{\beta \beta}$ plotted against dihedral angle. The results indicated a nearly linear increase in the negative values of $C_{\beta y}$ and $C_{n\beta}$ for the range of dihedral angle from 15° to 60°. Between dihedral angles of 0° and 15°, $C_{\beta y}$ and $C_{n\beta}$ showed only slight negative increases. The variation of $C_{\beta \beta}$ with increasing dihedral angle from 0° to 60° was nearly linear and negative. This variation of $C_{\beta \beta}$ is in good agreement with the results of reference 5 in the range of small dihedral angles for which this theory is applicable.

**Y-configurations.** The addition of vertical members to the bottom of the 45° dihedral-angle V-configuration, forming a Y-configuration, produced negative increments in $C_{\beta y}$ and $C_{n\beta}$ which increased as the ratio $b/V/D$ was increased. (See fig. 7.) Increasing the span of the vertical surface of the Y-configuration caused little change in $C_{\beta \beta}$ for $b/V/D$ ratios up to about 0.4. Further increases in $b/V/D$ caused $C_{\beta \beta}$ to become less negative.

Centers of pressure. Figure 8 presents the longitudinal location of the lateral-force centers of pressure for the various configurations tested. All configurations tested are in fairly good agreement with slender-body theory except the planar delta surface at angles of attack other than zero.

**Steady Rolling Characteristics**

**Cruciform configurations.** The measured steady rolling characteristics for the cruciform configurations are shown in figure 9 as curves of the
derivatives $C_{xp}$, $C_{np}$, and $C_{zp}$ plotted against the ratio of horizontal span to vertical span $b_H/b_V$ for several values of the ratio of the lower span to the upper span of the vertical surface $b_V/b_V'$. 

The experimental results indicated, in general, a decrease in the negative values of $C_{xp}$ for increases in the span of the horizontal surface. The rolling derivative $C_{zp}$ exhibited an increase in negative values with increased horizontal span. No definite trend was indicated in $C_{np}$.

The effect of varying the vertical location of the horizontal member (increasing $b_V/b_{V'}$) was to decrease the negative values of $C_{xp}$ and $C_{zp}$ for all ratios of horizontal-surface span to vertical-surface span $b_H/b_V$. The theoretical results of reference 4 for $C_{zp}$ are in good agreement with the experimental results when the horizontal surface is not at the base of the vertical surface. The theory overestimates values for $C_{xp}$ and $C_{zp}$ for the inverted T-configurations.

The effects of variation in angle of attack on the steady rolling stability derivatives for a planar delta and an inverted T-configuration are presented in figure 10. For the planar delta configuration, there is not very good agreement between the theoretical curves of $C_{xp}$ and $C_{np}$ calculated by reference 5 and the experimental results, and there is only fair agreement between the corresponding theoretical and experimental values of $C_{zp}$. The reason for this lack of agreement is not known; however, it is possible that the full theoretical edge suction was not realized experimentally. This factor is the source of the $C_{yp}$ and $C_{np}$ derivatives and may make $C_{zp}$ appreciably different from the theoretical results.

Some additional tests made in conjunction with this investigation indicated that the upwash of the support strut caused an increment of $C_{yp}$ about equal to the amount that the experimental curve of figure 10(a) is displaced from the origin at zero angle of attack.

V-configurations.- The rolling derivatives $C_{yp}$, $C_{np}$, and $C_{zp}$ for the V-configurations are shown plotted against dihedral angle in figure 11. Up to a dihedral angle of approximately $45^\circ$, the most obvious effect of dihedral angle was the negative increase in $C_{yp}$, which was associated with the increase in the projected lateral area of the surfaces. Above a dihedral angle of $45^\circ$, the interference between the two semispans tended
to disrupt the trend of $C_{yp}$ and caused the slope of $C_{yp}$ against $\Gamma$
to become less negative and to go positive for dihedral angles above $75^\circ$.
The variation of the experimental derivative $C_{np}$ with dihedral angle
was about half of that predicted by theory up to a dihedral angle of $45^\circ$.
From a dihedral angle of $45^\circ$ to approximately $75^\circ$, $C_{np}$ remained nearly
constant, and at $90^\circ$, it decreased slightly from the value at $75^\circ$. The
derivative $C_{lp}$ was roughly constant at about -0.1 from $0^\circ$ to $60^\circ$ of
dihedral, but it decreased thereafter, becoming about one-half the value
at the origin for $90^\circ$ of dihedral. These experimental results are not
in good agreement with the theory of reference 4 for $C_{yp}$ and $C_{lp}$ but
are in fair agreement with that of reference 5 for $C_{yp}$ up to dihedral
angles of about $15^\circ$ and for $C_{lp}$ up to dihedral angles of about $60^\circ$.
This difference between theoretical and experimental results may be attrib-
utable to a difference in edge suction as mentioned previously in connec-
tion with the results for the planar wing at an angle of attack.

**Y-configurations.** - The effect of variation of the span of a vertical
member added to the bottom of a $45^\circ$ dihedral-angle V-configuration on
the steady rolling derivatives $C_{yp}$, $C_{np}$, and $C_{lp}$ is shown in figure 12.
The effect of the addition of small vertical spans, $bV/D$ less than 0.2,
was to increase the negative value of $C_{yp}$. As the vertical member became
larger, however, $C_{yp}$ became less negative and finally went positive in
the region of $bV/D = 0.6$. The value of the rolling derivative $C_{lp}$
increased only slightly up to $bV/D = 0.4$. Beyond this point $C_{lp}$ became
appreciably more negative, being at $bV/D = 0.6$ about twice the value at
the origin. The derivative $C_{np}$ was small and little affected by the
addition of the lower surface for the range investigated. Agreement
between the theoretical results of reference 4 and experiment is not good
for $C_{yp}$, $C_{np}$, and $C_{lp}$.

**Centers of pressure.** - Figure 13 presents the longitudinal location
of the lateral-force centers of pressure for the various configurations
tested in rolling flow. The agreement between the theoretical centers
of pressure of references 4 and 5 and the experimental centers of pres-
sure is good to fair for all zero-angle-of-attack cases covered except
for the cruciform arrangements having the horizontal surface located in
the center of the vertical surface. The planar delta and inverted
T-configurations that were tested through a range of angle of attack
experienced a loss in side force as the angle of attack was increased
which, when combined with the yawing-moment couple existing, gave large
movements of the center of pressure toward the apex. In such cases, the comparison of theoretical and experimental $C_{np}$ values as in figure 10(a) is of more significance as a measure of the agreement between theory and experiment.

From $0^\circ$ to $6^\circ$ angle of attack, the inverted T-configuration center of pressure is in good agreement with the theory of reference 4. The agreement between theoretical and experimental centers of pressure in this same angle-of-attack range for the planar delta wing is not very good.

CONCLUDING REMARKS

The static lateral and rolling stability derivatives of a series of cruciform, inverted T-, V-, and Y-configurations composed of low-aspect-ratio triangular surfaces have been obtained at low speed in the 6-foot-diameter rolling-flow test section of the Langley stability tunnel. These derivatives are presented as functions of the geometry of the models, and, for two configurations (a planar wing and an inverted T), as functions of angle of attack. These configurations were tested in order to obtain data for comparison with the results of theoretical studies, and where possible, comparisons were made to indicate the extent of agreement between theory and experiment. In general, the sideslip derivatives showed better agreement between theory and experiment than the rolling derivatives, and the derivatives that depended upon the aerodynamic load acting normal to the surface (rolling moment) showed better agreement with theory than the derivatives depending upon edge suction (side force and yawing moment).

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REFERENCES


Figure 1.- Stability system of axes. Arrows indicate positive directions of forces, moments, and displacements applied to the model.
Figure 2.- Sketch of model surfaces and configurations used in investigation. All dimensions are in feet unless otherwise specified.
Figure 2.- Continued.

(b) Cross sections of configurations at trailing edges.
(c) Cross sections of inverted T- and cruciform configurations at trailing edges.

Figure 2. Concluded.
Figure 3.- Representative configurations.
Figure 4.—Effect of ratio of lower to upper vertical span on the sideslip derivatives for a series of cruciform configurations. $b_V = 1.5$ feet; $S_V = 3.09$ square feet.
Figure 5.— Effect of change of angle of attack on the sideslip derivatives of two representative configurations.

(a) Planar configuration. Aspect ratio, 1.476. Nondimensionalized with respect to
\( b_H = 3.0 \) feet and \( S_H = 6.18 \) square feet.

(b) Inverted T-configuration. Ratio of horizontal span to vertical span, 1.0; aspect
ratio of horizontal surface, 0.728. Nondimensionalized with respect to \( b_H = 1.5 \) feet
and \( S_H = 3.09 \) square feet.
Figure 6.- Effect of change of dihedral angle on the sideslip derivatives for a delta configuration of aspect ratio 1.456. $b = 3.0$ feet; $S = 6.18$ square feet.

Figure 7.- Effect of change of ratio of the vertical span to the diameter of the circle swept by the other two spans on the sideslip derivatives for a series of Y-configurations. $b = 3.0$ feet; $S = 6.18$ square feet.
(a) Cruciform and inverted T-configurations.

(b) Delta and inverted T-configurations through angle-of-attack range.

Figure 8.- Location of lateral-force center of pressure for the various configurations tested in sideslip.
Figure 8.- Concluded.

(c) V- and Y-configurations. $\alpha = 0^\circ$. 
Figure 9.- Effect of ratio of lower to upper vertical span on the rolling derivatives of a series of cruciform configurations. \(b_Y = 1.5 \text{ feet} ; S_Y = 3.09 \text{ square feet}\).
(a) Planar configuration. Aspect ratio, 1.456. Nondimensionalized with respect to
horizontal span to vertical span, 1.0; aspect ratio of horizontal surface, 0.728. Nondimensionalized with respect to $b_H = 3.0$ feet and $S_H = 6.18$ square feet.

(b) Inverted T-configuration. Ratio of horizontal span to vertical span, 1.0; aspect ratio of horizontal surface, 0.728. Nondimensionalized with respect to $b_H = 1.5$ feet and $S_H = 3.09$ square feet.

Figure 10.- Effect of change of angle of attack on the rolling derivatives of two representative configurations.
Figure 11. - Effect of change of dihedral angle on the rolling derivatives for a delta configuration of aspect ratio 1.456. \( b = 3.0 \) feet; \( S = 6.18 \) square feet.
Figure 12.- Effect of change of ratio of the vertical span to the diameter of the circle swept by the other two spans on the rolling derivatives for a series of Y-configurations.
(a) Cruciform and inverted T-configurations.  

\[ \frac{b_w}{b_v} \]

- 0
- 0.33
- 0.50
- 1.00
- Ref. 4 (TN2955)

(b) Delta and inverted T-configurations through angle-of-attack range.

Figure 13.- Location of lateral-force center of pressure for the various configurations tested in rolling flow.