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A PRELIMINARY STUDY OF THE PROBLEM OF DESIGNING HIGH-SPEED AIRPLANES WITH SATISFACTORY INHERENT DAMPING OF THE DUTCH ROLL OSCILLATION By John P. Campbell and Marion O. McKinney, Jr.

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#### SUMMARY

Considerable interest has recently been shown in means of obtaining satisfactory stability of the Dutch roll oscillation for modern high-performance airplanes without resort to complicated artificial stabilizing devices. One approach to this problem is to lay out the airplane in the earliest stages of design so that it will have the greatest practicable inherent stability of the lateral oscillation. The present paper presents some preliminary results of a theoretical analysis to determine the design features that appear most promising in providing adequate inherent stability. These preliminary results cover the case of fighter airplanes at subsonic speeds.

The investigation indicated that it is possible to design fighter airplanes to have substantially better inherent stability than most current designs. Since the use of low-aspect-ratio sweptback wings is largely responsible for poor Dutch roll stability, it is important to design the airplane with the maximum aspect ratio and minimum sweep that will permit attainment of the desired performance. The radius of gyration in roll should be kept as low as possible and the nose-up inclination of the principal longitudinal axis of inertia should be made as great as practicable.

#### INTRODUCTION

The problem of obtaining satisfactory stability of the Dutch roll oscillation is especially difficult for jet-propelled swept-wing airplanes designed for operation at high speeds and altitudes. The present trend is toward the use of artificial stabilizing devices to provide satisfactory stability since it is usually not possible to modify an existing airplane to provide satisfactory inherent stability.

One of the fundamental reasons for the poor inherent stability seems to be that very little consideration is given to dynamic stability in the early stages of design. That is, the basic design of the airplane is determined from other considerations and attempts are made later to improve the dynamic stability by the minor changes in configuration which are then permissible in the design. If such a procedure is continued, all airplanes of this type will probably require artificial stabilizing devices. The armed services and some airplane manufacturers are becoming increasingly concerned over the necessity for using these devices which increase the weight, complexity, and cost of the airplanes. The fact that the use of these devices increases the maintenance problem has been of particular concern to the services.

This concern has led to an increasing interest in means of obtaining satisfactory stability without resort to complicated artificial stabilizing devices. Various methods for accomplishing this aim have been proposed, the most fundamental and perhaps the most promising of which is to alter present design procedures to the extent of giving much more consideration in the early stages of design to features which will lead to better dynamic stability. A study is being made by the National Advisory Committee for Aeronautics to determine the design features which appear most promising in this respect. Some preliminary results of this investigation are included in the present paper which covers the case of fighter airplanes at subsonic speeds. The period and damping are the only characteristics of the Dutch roll oscillation considered in detail in the present paper.

As a preliminary to the investigation of means of providing inherent stability, a study of the basic causes of the poor stability of modern high-performance fighter airplanes was made. This study included consideration of the effects of increasing relative density and use of sweepback and low aspect ratio. Since the effects of sweep and aspect ratio have not been fully understood because no systematic investigation of their effects had been made, the effects of these factors were analyzed in considerable detail. The results of this analysis are also included in this paper.

## SYMBOLS

All forces and moments are referred to the stability system of axes which is defined in figure 1.

W weight of airplane, lb

m mass of airplane, slugs

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S
           wing area, sq ft
ъ
           wing span, ft
Z
           tail length (longitudinal distance from center of pressure of
             the vertical tail to the center of gravity), ft
           tail height (vertical distance from center of pressure of the
\mathbf{z}
             vertical tail to the center of gravity), ft
Α
           aspect ratio
Λ
           sweepback of wing-quarter-chord line, deg
λ
           taper ratio
Γ
           geometric dihedral angle, deg
V
           true airspeed, ft/sec
           equivalent lateral velocity, ft/sec
v_e
М
           Mach number
h
           pressure altitude, ft
{\bf k}_{\rm X_{\rm O}}
           radius of gyration about principal longitudinal axis of
             inertia, ft
           radius of gyration about principal normal axis of inertia, ft
K_{X_O} = k_{X_O} / b
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$$K_{Z_O} = k_{Z_O}/b$$

$$K_{\rm X}$$
 radius-of-gyration factor about X-axis,  $\sqrt{K_{\rm X_o}^2 \cos^2\eta + K_{\rm Z_o}^2 \sin^2\eta}$   $K_{\rm Z}$  radius-of-gyration factor about Z-axis,  $\sqrt{K_{\rm Z_o}^2 \cos^2\eta + K_{\rm X_o}^2 \sin^2\eta}$   $K_{\rm XZ}$  product-of-inertia factor,  $\left(K_{\rm Z_o}^2 - K_{\rm X_o}^2\right) \sin\eta \cos\eta$ 

μ relative-density factor, m/ρSb

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\eta angle of attack of principal longitudinal axis of inertia, deg
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 $\varepsilon$  angle between principal longitudinal axis of inertia and longitudinal body axis, deg

α angle of attack of longitudinal body axis, deg

 $\emptyset$  angle of bank, radians

w angle of yaw, radians

 $\beta$  angle of sideslip, radians

iw wing incidence, deg

ρ air density, slugs/cu ft

p rolling velocity, radians/sec

r yawing velocity, radians/sec

q dynamic pressure, lb/sq ft

P period of lateral oscillation, sec

 $T_{1/2}$  time to damp to one-half amplitude, sec

Y lateral force, 1b

L rolling moment, ft-lb

N yawing moment, ft-lb

C<sub>I.</sub> lift coefficient, Lift/qS

Cy lateral-force coefficient, Y/qS

C<sub>1</sub> rolling-moment coefficient, L/qSb

 $C_n$  yawing-moment coefficient, N/qSb

$$c^{A^{\beta}} = \frac{9^{\beta}}{9c^{A}}$$

$$C_{l_{\beta}} = \frac{\partial c_{l}}{\partial \beta}$$

$$C_{n_{\beta}} = \frac{\partial C_{n}}{\partial \beta}$$

$$cA^{b} = \frac{9\left(\frac{5\Lambda}{bp}\right)}{9c^{\Lambda}}$$

$$C_{l_p} = \frac{\partial C_l}{\partial \left(\frac{pb}{2V}\right)}$$

$$C_{n_p} = \frac{\partial C_n}{\partial \left(\frac{pb}{2V}\right)}$$

$$C^{A} = \frac{9\left(\frac{5A}{Lp}\right)}{9C^{A}}$$

$$C_{l_r} = \frac{\partial C_l}{\partial \left(\frac{rb}{2V}\right)}$$

$$C^{\mathbf{n^L}} = \frac{9(\frac{5\Lambda}{Lp})}{9C^{\mathbf{u}}}$$

## METHOD OF ANALYSIS

The period and time to damp to one-half amplitude of the lateral oscillation were the only characteristics of the lateral motion that were considered in the present analysis. These quantities were calculated by the method presented in reference 1. The period and damping requirements from the Air Force and Navy flying-qualities specifications of references 2 and 3 were used as a basis for evaluating the results.

## Basic Configurations Studied

In the study of the fundamental causes of the poor stability of modern high-performance airplanes, five basic configurations were considered:

Configuration	Sweepback, deg	Aspect ratio
1	0	6.0
2	.30	4.5
3	45	3.0
4	60	1.5
5	. 0	3.0

These configurations are illustrated by sketches in figure 2 and details of the dimensional and mass characteristics are given in table I. Configurations 2 to 4 were obtained by sweeping back the wings of configuration 1 with appropriate modifications to the tips. In sweeping the wings, the quarter-chord point of the mean aerodynamic chord was kept in the same longitudinal position relative to the body. Although these configurations are part of a systematic family, they are in general typical of present and proposed designs. Configuration 5 was chosen because it represents another trend in the design of high-speed airplanes and because it provides interesting comparisons with two of the other configurations. Comparison of configurations 1 and 5 shows the effect of aspect ratio at 0° sweep and comparison of configurations 3 and 5 shows the effect of sweep at aspect ratio 3. The size of the airplanes was chosen so that the span of the moderately swept wings was representative of that of current fighter airplanes with swept wings.

All the configurations were assumed to have the same fuselage except for minor modifications necessary to accommodate the different tail designs. The size and shape of the fuselage were selected as being representative of many current designs.

The vertical tails for the various configurations had the same value of  $\text{C}_{Y_\beta}$  . At  $\text{O}^\text{O}$  angle of attack, the center of pressure of  $^\beta tail$ 

the tail for all configurations was the same distance behind and above the center of gravity, which was located at the quarter-chord point of the mean aerodynamic chord. All the configurations were assumed to have a wing loading of 50 pounds per square foot. The principal longitudinal axis of inertia was assumed to be inclined 20 nose down relative to the longitudinal fuselage axis. These values were selected as being representative of those of current fighter airplanes.

The approximate magnitudes of the radii of gyration for various sweep angles were first determined by averaging the values for a number of current designs. A systematic variation of the radii of gyration with sweep that was in general agreement with these actual values was then set up. This systematic variation which is shown in figure 3 was based on the assumption that the weight distribution along the wing panels remained constant as the sweep of the panels was varied. The assumed weight distribution of the panels was determined from the average weight distribution of several current swept-wing fighter airplanes for which detailed weight data were available.

## Flight Conditions

The calculations for both the basic and modified configurations were made for four conditions:

Condition	h, ft	M	$\mathtt{c}_\mathtt{L}$
(a)	0	0.75	0.06
(b)	0	•27	.46 ·
(c)	0	.204	.80
(a)	50,000	<b>.</b> 75	.46

Conditions (a) and (d) were chosen to show the stability at a high subsonic speed at sea level and at an altitude of 50,000 feet and to show the effect of altitude at a constant Mach number. A Mach number of 0.75 was chosen for these conditions since that was considered about the highest value at which subsonic stability derivatives could be expected to apply for all configurations without compressibility corrections. Condition (b) was chosen for direct comparison with condition (d) to show the effect of altitude at constant lift coefficient where the stability derivatives would be the same. Condition (c) was chosen to show the stability at moderately high lift coefficients with flaps retracted. The lift coefficient of 0.80 used for condition (c) was assumed to represent the highest lift coefficient at which the theoretical variations of the different stability derivatives with lift

coefficient were still valid. Above this lift coefficient, flow changes over the wing, fuselage, and tail surfaces often cause the stability derivatives to be greatly different from their theoretical values. For airplanes with thin, highly swept wings or with roughness on the wings, these flow changes might actually occur at lift coefficients below 0.80, but for the purpose of this generalized study it was assumed that the stability derivatives of all configurations would follow theoretical trends up to this lift coefficient. Comparison of conditions (a) to (c) shows the effect of lift coefficient at constant altitude.

All the calculations were made for the condition of level flight at 1 g normal acceleration.

#### Estimation of Derivatives

The estimation of the stability derivatives used in the calculations was based on the methods presented in reference 1. Plots showing the variation of the derivatives with sweepback and aspect ratio are shown in figures 4 to 6 for the complete airplanes and for the vertical-tail-off condition. The derivatives for the complete basic configurations are also listed in table II. In some cases, particularly for the wing-fuselage combinations, the estimations were based on experimental data and require some explanation.

Sideslip derivatives. The value of  $C_{Y_{\beta}}$  for the vertical-tail-off condition was assumed to be constant at a value of -0.229 per radian  $\left( ^{C_{Y_{\beta}}} = -0.00^{l_{1}} \right)$  per degree for all configurations and flight conditions on the basis of experimental data for a number of designs. These data showed no consistent trend for the variation of this factor with sweep-back or lift coefficient. As pointed out previously, the vertical tails for all the configurations were designed to give the same value of  $C_{Y_{\beta}}$ . Since there was assumed to be no variation of  $C_{Y_{\beta}}$  with angle of attack, the value of  $C_{Y_{\beta}}$  for the complete airplane was the same for all configurations and flight conditions.

Since the configurations were laid out as midwing designs, the value of  $c_{l_{\beta}}$  was assumed to be simply the value of  $c_{l_{\beta}}$  wing This value and the value of  $c_{l_{\beta}}$  were determined from the charts and formulas presented in reference 1.

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On the basis of experimental data the value of the factor  ${}^{b}C_{n_{\beta}}$  for the vertical-tail-off condition was assumed to be constant for all configurations and flight conditions. The magnitude of  ${}^{c}C_{n_{\beta}}$  tail off therefore varied inversely with wing span. The value of  ${}^{c}C_{n_{\beta}}$  was calculated from the value of  ${}^{c}C_{\gamma}$  by means of the formula given in reference 1.

Rolling derivatives. The rolling derivatives  $C_{Y}$ ,  $C_{l}$ , and  $C_{n}$  p p p p were determined by the methods described in reference 1 except that  $C_{l}$  was assumed to be constant over the lift-coefficient range at pwing the value given by reference 1 for the zero-lift condition.

Yawing derivatives. - The value of Cyrtail off was assumed to be zero for all configurations and conditions since experimental data for many wings and wing-fuselage combinations had shown no consistent variation of  $C_{Y_{\infty}}$  with configuration or lift coefficient. The value was calculated from the formula presented in reference 1. The values of  $C_{l_{\pi}}$  were determined by the method of reference 1. A constant value of the factor  $b^2C_{n_r}$  for the tail-off condition was assumed for all configurations and flight conditions on the basis of experimental data on a number of configurations so that the magnitude Cnrtail off of varied inversely with the square of the wing span. These experimental data did not show consistent trends in the variation with configuration or lift coefficient and, since the value of is small compared with the value for the complete airplane, the assumption of a constant value of  $b^2C_{n_n}$  seemed reasonable. The value of  $C_{n_r}$ tail was calculated from the equation given in reference 1.

#### LIMITATIONS OF ANALYSIS

This paper presents some preliminary results of a study of the possibility of designing airplanes to have satisfactory inherent dynamic

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lateral stability. As pointed out previously, these preliminary results cover only the case of fighter airplanes at subsonic speeds and cover only the period and damping of the lateral oscillation. The calculated period and damping of the oscillation for the basic and modified configurations are compared with the Air Force and Navy period and damping requirements. The authors realize that these requirements are not adequate in some cases and that other factors, such as the ratio of roll to yaw, should be considered in a comprehensive analysis. Although these additional factors are not considered in detail in this preliminary analysis they are discussed briefly with regard to the effects of some of the mass and aerodynamic parameters.

A few comments are required on the applicability of the calculated data presented in this paper to actual airplanes of similar configuration before these results are discussed in detail. The reader should bear in mind that small changes in some of the important stability derivatives can have a significant effect on dynamic stability and that such changes might result unpredictably from apparently minor changes in design. These calculations are intended to show the general trends in the effects of the various design factors covered and are not intended for use in predicting the stability of specific airplane designs which are superficially similar to these configurations.

One reason that the stability of these hypothetical configurations might be very different from the stability of actual airplanes is that the theoretical values of the wing contributions to the stability derivatives were assumed to be accurate for the entire range of lift coefficients covered by the calculations ( $C_L = 0.06$  to 0.80). Actually, this assumption may be far from correct at the higher lift coefficients for airplanes of practical construction, particularly for those having thin, highly swept wings. There is evidence from experimental data on such designs that the values of the derivatives  $C_{l_{\beta}}$ ,  $C_{n_{p}}$ , and  $C_{l_{r}}$  may diverge from the theoretical variation with lift coefficient at moderate lift coefficients ( $C_L$  near 0.4) and be greatly different — perhaps even have a different sign — at a lift coefficient of 0.8.

## RESULTS AND DISCUSSION

Causes of Inadequate Dutch Roll Stability

The causes of the poor dynamic lateral stability of modern high-performance fighter airplanes must be established before a reasonable approach can be made to the problem of designing such airplanes to have satisfactory inherent stability. The first part of the present analysis therefore treats the stability of the series of basic

configurations which are representative of present-day airplane designs with emphasis on the determination of the reasons that the dynamic lateral stability of these airplanes is generally worse than that of World War II fighter airplanes which had lower relative density, less sweep, and higher aspect ratio. The results of the calculations made for this part of the analysis are presented in tables II and III and figures 7 to 9.

Effect of sweepback and aspect ratio. The data of figure 7 show that at the low lift coefficient ( $C_L=0.06$ ) the period and damping were about the same for all the configurations. At the higher lift coefficients, however, the damping became worse and the period became shorter as the sweepback was increased and the aspect ratio reduced simultaneously in the manner representative of present-day design practice (configurations 1 to 4). Comparison of the data for configurations 1, 3, and 5 shows that both of these factors were responsible for this reduction in stability. There was some reduction in stability when the aspect ratio alone was reduced (configurations 1 and 5) and there was a greater reduction when sweepback alone was increased (configurations 3 and 5).

Examination of figures 3 to 6 gives some indication of the causes of the detrimental effects of increasing sweepback and reducing aspect ratio on dynamic stability. These figures show that, of the mass parameters and stability derivatives which generally have an important effect on dynamic stability, the values of  $\mu$ ,  $K_X$ ,  $K_Z$ ,  $C_{l_B}$ ,  $C_{l_D}$ , and  $C_{\mathbf{n}_{\mathcal{D}}}$  are changed in the adverse direction by sweepback for configurations 1 to 4, whereas the values of  $C_{n_{\beta}}$  and  $C_{n_{\mathbf{r}}}$  are changed in the favorable direction. These figures also show that the same effects are caused, but to a lesser degree, by a reduction in aspect ratio (configurations 1 and 5). The changes in the mass parameters and  $C_{n_{\rm R}}$ and  $C_{n_{_{\boldsymbol{r}}}}$  are almost entirely caused by the reduction in the span on which the nondimensional form of these factors is based; the changes in  $\mathtt{C}_{l_{\mathtt{D}}}$  are caused by the change in aspect ratio; the changes in  $\mathtt{C}_{\mathtt{n}_{\mathtt{D}}}$ caused by the changes in sweep and in the span on which the coefficient is based; and the changes in  $Cl_{R}$  are caused by the change in sweep, aspect ratio, and the span on which the coefficient is based.

Effect of mass parameters and individual stability derivatives.-Figure 8 and table III present the results of calculations made to determine whether the mass parameters or any of the stability derivatives discussed in the preceding paragraph were predominantly responsible for the decrease in stability as sweepback was increased and aspect ratio reduced. These calculations were made for only the high-aspect-ratio,

unswept and the  $45^{\circ}$  swept-wing configurations (configurations 1 and 3). Although only one flight condition was considered ( $C_{L} = 0.46$ ; h = 0 feet), the results obtained are believed to be indicative, at least at moderate and high lift coefficients, of the effect of independently changing the mass parameters or the individual stability derivatives for one of these configurations to the values for the other configuration. The results of these calculations show that, when either the mass parameters or one of the stability derivatives  $C_{l_p}$ ,  $C_{l_p}$ , or  $C_{n_p}$  for configuration 3 was changed to the value for configuration 1, the stability of configuration 3 became almost as good as that of configuration 1. When the value of one of these factors for configuration 1 was changed to the value for configuration 3, the stability did not generally become much worse. It is clearly evident from these results that it is very difficult to generalize on the effects of these stability parameters. No one factor is the cause of the reduction in stability as the sweep is increased and aspect ratio reduced. Changes in any one of several derivatives, however, resulted in substantial improvements in the stability of the swept-wing configuration.

Some of the data in figure 8 can be used to illustrate why the elimination of the propeller makes the stability of jet airplanes worse than that of propeller-driven airplanes. Experimental data have shown that the propeller provides a substantial increase in damping in yaw  $-c_{n_{\mathbf{r}}}$  and, in many cases, a reduction in static directional stability  $c_{n_{\boldsymbol{\beta}}}$ . The results of figure 8 show that for the unswept configuration both of these changes provide an improvement in the period-damping relationship (that is, a reduction in time to damp and an increase in period).

Effect of relative-density factor. - The relative-density factor of modern high-performance fighter airplanes is generally greater than that of older types because of increases in wing loading and operational altitude and because of the use of low-aspect-ratio wings. The effect of increasing the relative-density factor on stability can be seen in figure 7 by a comparison of the sea-level and altitude conditions. These results show that an increase in altitude had a detrimental effect on the stability of all configurations when compared at a constant Mach number (M = 0.75). An increase in altitude at a constant lift coefficient also had a detrimental effect for all configurations except configuration 4 where the airplane was unstable at sea level. This effect of increasing µ for a configuration which is unstable would generally be expected since an airplane is neutrally stable when the relative-density factor is infinite. This result is illustrated in figure 9. Figure 9(a) which was taken from the data of table II shows that neutral stability is approached as  $\mu$  is increased. The data are presented in terms of

 $\frac{1}{T_{1/2}}$  and  $\frac{1}{\sqrt{\mu}}$  since  $\frac{1}{T_{1/2}}$  is a direct measure of damping and since for a one-degree-of-freedom oscillation the value of  $\frac{1}{T_{1/2}}$  would vary directly with the value of  $\frac{1}{\sqrt{\mu}}$ . The three-degree-of-freedom data of figure 9(a) appear as straight lines since only two points (the end points of these lines) were available from the calculations. These end points were taken from the 0- and 50,000-foot-altitude conditions at a lift coefficient 0.46. The fact that  $\frac{1}{T_{1/2}}$  does not necessarily vary directly with  $\frac{1}{\sqrt{\mu}}$  for a three-degree-of-freedom motion, however, is illustrated in figure 9(b) where the variation is shown for an extended range of  $\mu$  for configurations 1 and 4 and for another configuration indicated as airplane A. The results for airplane A were included to show that this nonlinear variation of  $\frac{1}{T_{1/2}}$  with  $\frac{1}{\sqrt{\mu}}$ , which shows up for configuration 4 only when values of  $\mu$  below the normal range are considered, can occur in the range of normal values of  $\mu$  for some airplanes.

# Means of Improving Dutch Roll Stability

On the basis of the preceding results regarding the causes of inadequate Dutch roll stability, an analysis has been carried out to determine means of improving this stability.

Factors that can be changed .- If it is assumed that the wing loading is determined from performance considerations, there are three mass factors that can be changed to improve dynamic lateral stability the inclination of the principal axis of inertia, the radius of gyration in roll, and the radius of gyration in yaw. An increase in the noseupward inclination of the principal axis of inertia increases the beneficial effect of the product of inertia as described in references 4 and 5. A reduction in the radius of gyration in roll is beneficial, particularly when the principal axis is inclined nose upward. Changing the radius of gyration in yaw might or might not have a beneficial effect on the stability depending upon many related factors, the inclination of the principal axis of inertia in particular. If the principal axis is inclined nose up relative to the stability axis, increasing the radius of gyration in yaw might be beneficial since the favorable product-of-inertia effect would tend to offset the normally adverse effect of increasing the radius of gyration.

Five of the aerodynamic stability derivatives generally have an important effect on dynamic lateral stability:  $C_{l_{\beta}}$ ,  $C_{n_{\beta}}$ ,  $C_{l_{p}}$ ,  $C_{n_{p}}$ ,  ${\rm C}_{\rm n_r}.$  The derivative  ${\rm C}_{\it l_{\rm B}}$  can easily be changed independently of the others by varying the geometric dihedral. The derivatives  $Cl_n$ and  $C_{n_n}$ , however, cannot be changed appreciably by geometric changes other than major changes in the wing plan form. The two derivatives and  $C_{n_r}$  can be changed simultaneously by varying the size of  $^{\mathrm{C}}\mathbf{n}_{\mathsf{B}}$ the vertical tail but they cannot conveniently be varied an appreciable amount independently of each other. The changes in stability that result from varying these derivatives simultaneously by changing the tail size tend to offset each other. An increase in tail size increases  $-C_{n_n}$  and thereby increases the damping but the accompanying increase in  $C_{n_{\mathsf{R}}}$  reduces the period. On a plot such as figure 7, this simultaneous reduction in time to damp and period tends to shift a point parallel to the period-damping boundary given by the flying-qualities requirements for periods greater than 2 seconds. The effect of changing the size of the vertical tail should be studied for any particular design, however, since it offers possibilities for improving stability in some cases.

Modifications considered. In the study of means of improving the Dutch roll stability of modern high-speed fighter airplanes, configurations 3 and 5 were chosen as basic configurations from which to work since they were considered representative of proposed high-speed designs. Five modifications to each of these basic airplanes were considered:

- (1)  $K_{X_{\odot}}$  reduced to 0.65 times the basic value
- (2)  $K_{\mathrm{Z}_{\mathrm{O}}}$  increased to 1.41 times the basic value
- (3)  $K_{Z_0}$  increased and  $K_{X_0}$  reduced simultaneously to 1.25 and 0.65 times the basic values, respectively
- (4) iw changed from 0° to -5°
- (5)  $\Gamma$  adjusted to give zero  $C_{l_{\beta}}$  at a lift coefficient of 0.06

These changes were considered separately and in various combinations. The modifications should not be considered as practicable changes that can be made to improve the stability of an existing airplane. They are intended only to show what factors should be considered in the early design stages and to illustrate the improvements in inherent stability

that can be obtained by designing for stability. The results of the calculations made for this part of the analysis are presented in table IV and figures 10 and 11.

Effect of radii of gyration.— The designer is concerned with the radii of gyration about axes which are fixed in the airplane and approximately coincide with the body and wing axes. For this reason the modified configurations were established by changing the radius-of-gyration factors about the principal axes of inertia  $K_{X_{\rm O}}$  and  $K_{Z_{\rm O}}$ . The radii of gyration used in equations of motion in stability work, however, are usually referred to the stability axes. The effects of the changes in  $K_{X_{\rm O}}$  and  $K_{Z_{\rm O}}$  are therefore analyzed in terms of the effects of  $K_{\rm X}$ ,  $K_{\rm Z}$ , and  $K_{\rm XZ}$ .

The magnitudes of the changes in  $K_{\hbox{\scriptsize X}_{\tiny O}}$  and  $K_{\hbox{\scriptsize Z}_{\tiny O}}$  assumed for the modified configurations were determined from the following considerations. In order to obtain the maximum beneficial effect from the inertia changes, the value of  $K_{X_{\bigcirc}}$  was made as small as practicable. A study of moments of inertia of a number of current and proposed designs indicated that a value of  $K_{X_0}$  of 0.0100 (0.65 times the basic value of 0.0154) was probably the minimum value that could be obtained on a practical airplane. The determination of the value of  $K_{Z_{\mathcal{O}}}$  for the modified configuration was not so straightforward because the direction in which  ${
m K}_{{
m Z}_{
m O}}$  should be changed to give a beneficial effect is not always the Since increasing  $\mbox{ K}_{\mbox{\scriptsize Z}_{\mbox{\scriptsize O}}}$  is generally beneficial from an overall standpoint, however, only increases were considered in this analysis. Since there is no definite maximum value to which  $K_{\mathbb{Z}_{O}}$  can be increased, two relatively large values (1.25 and 1.41 times the basic value) were chosen to illustrate the effect of varying  $K_{\mathbb{Z}_0}$ . These values are in line with the general trend toward increased  $\ensuremath{\mathrm{K}}_{\ensuremath{\mathrm{Z}}_{\ensuremath{\mathrm{O}}}}$  which results from the use of very long fuselages in the latest designs.

A reduction in the radius-of-gyration factor in roll  $K_{X_O}$  improved the stability in almost every case for both configurations 3 and 5 as shown in figures 10 and 11. The only exceptions were the two cases in which  $K_{X_O}$  was reduced for the basic configurations at a lift coefficient of 0.06. In these cases the principal axis was inclined nose down relative to the stability axes so that the effect of the product of inertia was unfavorable, and evidently the adverse effect of increasing the product-of-inertia factor was greater than the favorable effect of reducing  $K_X$ .

There was no consistent effect of increasing the radius-of-gyration factor in yaw  $K_{Z_O}$  alone either for configuration 3 or configuration 5. As shown in figures 10 and 11 there was generally an adverse effect of increasing  $K_{Z_O}$  for the low lift coefficients and a favorable effect at the high lift coefficients. This result can be explained by the following reasoning: At low angles of attack the increase in the product-of-inertia factor  $K_{XZ}$  which resulted from an increase in  $K_{Z_O}$  caused either a small favorable or unfavorable effect depending on the inclination of the principal axis, but in neither case did this effect offset the adverse effect of increasing the value of  $K_Z$ . At high angles of attack the effect of the product-of-inertia factor was always favorable and was generally greater than the adverse effect of the greater value of  $K_Z$ .

When  $K_{X_O}$  was reduced and  $K_{Z_O}$  was increased simultaneously, the stability at the moderate and high angles of attack was even better than it was when  $K_{X_O}$  was reduced by itself. At the low angle of attack, however, the stability was worse than it was for the basic configuration or the configuration with reduced  $K_{X_O}$ . This result is illustrated in figures 10 and 11 for both configurations 3 and 5. This simultaneous change in both the radii of gyration seems somewhat better than a reduction in  $K_{X_O}$  alone since it is more effective for the high-altitude condition and since the adverse effect on the stability at the low angle of attack can be counteracted by other means as is shown subsequently.

Effect of inclination of principal axis .- There are a number of ways that the inclination of the principal axis relative to the stability axis can be changed by changing the design of an airplane. A simple change in wing incidence was the method considered in the present analysis. The sketch of figure 12 illustrates another way in which it can be done. This figure shows the profile of a configuration in which the weight in the rear of the airplane is kept as low as practicable. The engine is located low in the rear of the airplane behind an underslung inlet and the horizontal tail is mounted low at the rear of the fuselage. forward part of the fuselage is located as high as possible without increasing the frontal area of the fuselage. The midsection of the fuselage has a narrow oval cross section about the same width as the engine so that this distribution of the weight in the fuselage can be accomplished without increasing the frontal area of the fuselage. profile of configuration 3, which is representative of a current trend in design, is shown in figure 12 for comparison. The modified design would have a principal-axis inclination  $\epsilon$  of 2° or 3° nose up relative to the wing chord instead of 2° or 3° nose down as would be the case for

an airplane of the type represented by configuration 3. This would give a change in the inclination of the principal axis of inertia of about 5° which is the same as would be obtained with the simple 5° change in wing incidence assumed in the calculations for the modified configurations. The method of changing the inclination in this analysis is not important except that it indicates how the tail contributions to the stability derivatives were changed.

The results presented in figures 10 and 11 show that the use of  $5^{\circ}$  negative wing incidence to increase the nose-up inclination of the principal axis had either a favorable effect or no significant effect on the lateral stability for all the radius-of-gyration and dihedral conditions covered in the calculations. The favorable effect of negative wing incidence was particularly significant at the low-lift-coefficient condition ( $C_L = 0.06$ ) where it made all the conditions satisfactory which were otherwise marginal or unsatisfactory.

Effect of dihedral.- The amount of negative geometric dihedral covered in the calculations was limited to the amount required to give zero effective dihedral ( $Cl_{\beta}=0$ ) at the low-lift-coefficient condition since the use of greater negative geometric dihedral would probably make the airplane uncomfortable to fly at the low angles of attack where the effective dihedral would be negative.

The effect of negative geometric dihedral is shown by figures 10 and 11 to vary from a slight favorable effect to no significant effect at the moderate and high lift coefficients. In many of these cases the use of negative dihedral caused the time to damp to increase but, because of the accompanying increase in period, the stability did not appear to become less satisfactory with respect to the flying-qualities damping requirement indicated by the boundaries in figures 10 and 11. At the low lift coefficients the use of negative geometric dihedral had a favorable effect when the wing incidence was 0° and an adverse effect when the wing incidence was -5°. The conditions under which varying the dihedral can be expected to have a favorable effect on stability can be determined from the expression

$$c_{n_p} - 2c_L K_Z^2 - c_{l_p} \frac{K_{XZ}}{K_X^2}$$

Negative values of this quantity indicate that the use of negative geometric dihedral will reduce the time to damp for the oscillation. This test will not work in every case, however, since its derivation involved a number of simplifications and generalizations. Examination of the expression shows that the sum of the first two terms will almost always be negative since  $C_{n_p}$  is usually negative and  $-2C_LK_Z^2$  is

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always negative. Since  $C_{lp}$  is always negative for practical flight conditions and  $K_\chi^2$  is always positive, the sign of the third term will always be the same as the sign of  $K_{\chi Z}$ . When  $K_{\chi Z}$  is positive and of relatively large magnitude (that is, when the principal axis of inertia is inclined nose up relative to the flight path) and the value of  $K_\chi$  is low, the third term will have a large positive value which will usually mean that the effect of using negative dihedral will be unfavorable. Since these mass characteristics (large positive value of  $K_{\chi Z}$ , and small value of  $K_\chi$ ) are desirable from the standpoint of oscillatory stability, the use of negative dihedral may be unfavorable for a design in which the mass characteristics have been made as favorable as possible. The effect of dihedral angle, however, should be studied for each particular airplane configuration.

Effect of modifications on roll-to-yaw ratio and control.- It has been fairly well established that a pilot's opinion of the acceptability of a lateral oscillation is influenced by the ratio of roll to yaw which has been expressed in terms of  $\phi/\psi$ ,  $\phi/\beta$ , and  $\phi/v_e$  by various investigators. Although no definite requirement has been generally accepted, it seems evident that increasing the ratio of roll to yaw makes the lateral oscillation more objectionable. Some of the modifications covered in the present study which improved the stability from the standpoint of the present Air Force and Navy flying-qualities requirement would have an adverse effect from the standpoint of rollto-yaw ratio. Either reductions in the rolling radius of gyration Kx or increases in the yawing radius of gyration  $K_{\mathbb{Z}_{0}}$  would increase the ratio of roll to yaw. On the other hand, the use of negative geometric dihedral would reduce the ratio of roll to yaw. Whether or not reasonable changes in the radii of gyration or dihedral would have a large effect on the flying qualities because of their effect on the ratio of roll to yaw is a subject for further study.

Another factor to be considered is the effect of the modifications on the adverse yaw caused by a rolling acceleration and consequently on the adverse rolling moments caused by the adverse yaw. An increase in the nose-upward inclination of the principal axes will cause an increase in the adverse yaw in rolls.

## Application of Results to Actual Airplanes

The foregoing analysis has brought out a number of factors that should be considered in designing an airplane so that it will have the best inherent stability that it is practicable to obtain. Some of these factors will probably conflict with factors that appear desirable

from some other standpoint. It is up to the designer in any particular case, then, to weigh all the facts and decide on the relative merits of these design features for his particular application. The application of the results of the analysis to the problem of designing airplanes so that they will have satisfactory inherent dynamic lateral stability is discussed in the following paragraphs.

Wing plan form. One of the principal facts brought out by this analysis is that the use of low-aspect-ratio and sweptback wings has a very detrimental effect on dynamic lateral stability. Within the limits permitted by high-speed performance requirements, the use of unswept wings of higher aspect ratio (about 6) is very desirable. The next most desirable wings appear to be an unswept wing of low aspect ratio similar to that of configuration 5 or a wing of moderate sweep similar to that of configuration 2.

Radii of gyration.- It also appears highly desirable to keep the radius-of-gyration factor in roll  $K_{X_O}$  as low as possible. This feature appears particularly important if a highly swept wing is used. For example, it appeared to be impossible to make configuration 3 satisfactory unless  $K_{X_O}$  were reduced. The use of a longer fuselage to accommodate items normally located in the wings might be slightly beneficial if the principal axis of inertia is inclined nose up relative to the flight path.

Inclination of principal axis of inertia. The inclination of the principal axis of inertia is also a very important factor, particularly for obtaining satisfactory stability at low angles of attack. For this reason the use of high horizontal tails and vertical tails located on a boom over the jet exit are definitely undesirable from the standpoint of dynamic stability. Every effort should be made to design the airplane to take advantage of the large favorable effect of a more nose-up inclination of the principal axis by designing the airplane so that the weight forward is located high and the weight rearward is located low relative to the wing chord plane.

Dihedral and tail area. The use of a reasonable amount of negative geometric dihedral would probably not have a large effect on the dynamic lateral stability but this modification should be considered since it may improve the stability in some cases and may also be helpful by reducing the adverse rolling moments which result from adverse yaw in an aileron roll. The effect of dihedral should be investigated for each airplane design. Similarly the effect of vertical-tail area is not immediately obvious and should be investigated for each particular design in an effort to determine the optimum size from considerations of both stability and control.

### CONCLUSIONS

On the basis of the present theoretical analysis to determine the design features that appear most promising in providing inherent Dutch roll stability, the following conclusions were drawn for the case of fighter airplanes at subsonic speeds:

- l. The stability of the Dutch roll oscillation of modern highspeed fighter airplanes is less satisfactory than that of older types of fighter airplanes such as those used in World War II because of the use of low-aspect-ratio sweptback wings and because of the higher wing loadings and operating altitudes. The unfavorable effect of the use of low-aspect-ratio sweptback wings was caused mainly by the increase in the relative density  $\mu$ , the effective dihedral  $-\text{C}_{l_{\beta}}$ , and the yawing moment due to rolling  $-\text{C}_{n_p}$ , and the decrease in the damping in roll  $-\text{C}_{l_p}$  which resulted from the change from the older type of unswept wings of higher aspect ratio.
- 2. It is possible to design high-performance fighter airplanes to have substantially better inherent stability of the Dutch roll oscillation than that of most current fighter designs. It is important to design the airplane with the maximum aspect ratio and minimum sweep that will permit attainment of the desired performance. For a given configuration the radius of gyration in roll should be kept as low as possible and the nose-up inclination of the principal longitudinal axis of inertia should be made as great as practicable. The optimum dihedral angle and vertical-tail area should be selected on the basis of a study of the stability and control of the particular airplane design.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 19, 1953.

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TABLE I

DIMENSIONAL AND MASS CHARACTERISTICS

OF BASIC CONFIGURATIONS

Configuration	1	2	3	14	5
Wing:					
Λ, deg	0	30	45	60	0
Α	6.0	4.5	3.0	1.5	3.0
λ	0.5	0.5	0.5	0.5	0.5
b, ft	50.0	43.4	35.4	25.0	35.4
S, sq ft	417	417	417	417	417
Vertical tail:					
Λ, deg	0	30	45	60	0
Α	1.64	1.50	1.36	1.17	1.64
λ	0.5	0.5	0.5	0:5	0.5
S, sq ft	45.5	50.1	55.0	64.1	45.5
(1) <sub>α=0</sub> 0, ft	24.5	24.5	24.5	24.5	24.5
(z) <sub>α=0</sub> 0, ft	7.2	7.2	7.2	7.2	7.2
Mass charac- teristics:					
W, lb	20,833	20,833	20,833	20,833	20,833
W/S, lb/sq ft	50	50	50	50	50
(μ) <sub>h=0</sub>	13.0	15.0	18.4	26.0	18.4
к <sub>хо</sub>	0.1400	0.1448	0.1540	0.1768	0.1540
к <sub>го</sub>	0.243	0.272	0.320	0.435	0.318
€, deg	-2	<b>-</b> 2	-2	<b>-</b> 2	<b>-</b> 2

TABLE II

CONDITIONS FOR WHICH CALCULATIONS WERE MADE, DERIVATIVES USED IN CALCULATIONS,

AND RESULTS OF CALCULATIONS FOR BASIC CONFIGURATIONS

[ = 0°; 1 = 0

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	Oscillatory mode	T1/2,	1.455 3.626 4.008 10.919	1.514 4.695. 6.345 19.960	1.500 8.559 35.587 71.472	1.568 -9.218 -4.151	1.418 4.141 5.291 12.746
Results	0sc11	P,	1.637 4.347 5.480 4.594	1.625 3.960 4.488 4.275	1.538 3.383 3.541 3.692	1.466 2.616 2.381 2.842	1.532 3.775 4.453 4.021
Resi	Aperiodic mode	T <sub>1</sub> /2'	0.1015 .284 .376 .713	. 134 . 364 . 472 . 890	.207 .511 .628 1.212	.439 .745 .817 1.775	.1975 .532 .680 1.320
	Aperi	T <sub>1/2</sub> ,	863 -40.1 -17.0 -101.5	212 110 122 280	78.6 19.0 15.8 48.4	20.0 7.8 7.9 20.0	119.0 243 -127 620
		$c_{\mathbf{n_r}}$	-0.1288 -1335 -1383 -1335	1634 1686 1740 1686	2557 2689 2757 2689	5246 5531 5531	2557 2689 2757 2689
		$c_{l_{m{r}}}$	0.0444 .1163 .1775	.0533 .1227 .1799	.0745 .1303 .1766	.1343 .1317 .1441 .1317	.0743 .1280 4171. 1280
		$^{ m C}_{ m r}$	0.2323 .2370 .2417 .2370	.2607 .2654 .2702 .2654	.3271 .3365 .3413 .3365	.4693 .4835 .4835 .4835	.3271 .3365 .3413 .3365
lvatives		e d	-0.0046 0.2323 C 0358 .2370 0622 .2417 0358 .2370	0075 0567 0990 0567	0128 0978 1712	0343 2655 4639 2655	0070 0530 0919
Aerodynamic derivatives		C,D	-0.4116 4098 4096 4098	3323 3299 3301 3299	2338 2301 2325 2301	1266 1448 1224	2489 2452 2462
lerodyn		$^{C_{Y}}_{\mathbf{p}}$	0.0116 .0905 .1569	. 2679 . 4666 . 2679	.0559 .4275 .7425 .4275	.0883 .6765 1.1763 .6765	.0227 .1703 .2981
,		n <sub>n</sub>	0.0805 .0829 .0853	.0881 .0904 .0928	0211. 1168 11911.	.1613 .1684 .1684 .1684	.1120 .1168 .1191 .1161
		C <sub>1</sub> B	-0.0332 0269 0231 0269	0444 0799 1088	0574 1200 1728 1200	0837 1880 3149 1880	0497 0594 0671
		$r_{ m fg}$	-0.4660 4660 4660	0991*- 0991*- 0991*-	099† 099† 099†	0991 - 0991 - 0991 -	0994:- 0994:-
re		KXZ	\$200° \$0\$00° \$200° \$200°	00110 .00395 .00816	00138 .00806 .01580	00110 .02720 .04850	00149 .00673 .01340
Mass parameters	c	$\kappa_{\rm Z}^-$	0.0592 .0591 .0585	.0738 .0735 .0725	.1025 .1017 .0992	.1890 .1842 .1723 .1842	.1012 .1006 .0988 .1006
Мавв р	c	Kx_	0.0196 .0197 .0203	.0210 .0213 .0223	.0237 .0245 .0270 .0245	.0313 .0366 .7740.	.0237 .0243 .0261
		1	13 13 13 85	15 15 15 98	18.4 18.4 18.4 120.5	26 26 26 170.5	18.4 18.4 18.4 120.5
,		deg	-1.29 3.41 7.41 3.41	-1.18 4.30 8.96 4.30	5.94 5.94 11.80 5.94	42 10.10 19.05 10.10	-1.09 4.98 10.13
tions	_	deg.	0.71 5.41 9.41 5.41	.06 6.30 4.30 6.30 8.96 8.96 6.30 4.30	.06 1.03 .46 7.94 .80 13.80 .46 7.94	.06 1.5842 .46 12.10 10.10 .80 21.05 19.05 .46 12.10 10.10	.06 .91 -1.09 .46 6.98 4.98 .80 12.13 10.13 .46 6.98 4.98
condi		r <sub>J</sub>	90.0 94. 98. 94.	90. 94. 98. 94.	90. 94. 98. 94.		90 94 94 94
Flight conditions		×	0.06 27.046 20.08.09.09.09.09.09.09.09.00.00.00.00.00.00.	.27. .204 .204	.75 .27 .204	.27. .27. .20. .75.	.27. .204 .204
		<b>:</b> ₹	50,000	0 0 50,000	0 0 0 50,000	0 0 50,000	0 0 0 50,000
	4		0 6.0	30 4.5	45 3.0	60 1.5	0 3.0
	deg		0	30	54	9	0
	Configu- ration		1	a	£,	η	2

TABLE III

CONDITIONS FOR WHICH CALCULATIONS WERE MADE, DERIVATIVES USED IN CALCULATIONS, AND RESULTS OF CALCULATIONS TO DETERMINE EFFECTS OF MASS PARAMETERS

AND INDIVIDUAL STABILITY DERIVATIVES

_	_				_	ź	Mean nemerators	orotom.	_			•	<b>lerodyns</b>	Aerodynamic derivatives	[vatives					NEBUT CS	60.1	
		Flight	t con	conditions	n	-													Aperi	Aperiodic	Oscillatory mode	llatory mode
from basic configuration deg deg h,	deg h	×	$^{ m C}_{ m L}$	α, deg	deg	э.	ж <sup>х</sup> 2	к <sub>2</sub> 2	KXZ	$^{\mathrm{c}_{\mathbf{Y}_{\boldsymbol{\beta}}}}$	g to	ng.	$\mathbf{q}^{\mathbf{r}}$	c, p	n <sub>d</sub>	C.	C <sub>l</sub> r	o <sup>L</sup>	T1/2, sec	T1/2, T1/2, sec sec	p,	T <sub>1/2</sub> , sec
Derivatives changed one at a time to the values for configuration 3 0 Derivatives changed are underlined.	0	0 0.27	0.46	46.70 14.00 14.00 14.00	20.00.00.00.00.00.00.00.00.00.00.00.00.0	1 41	0.0157 0.0197 0.0197 0.0197 0.0197	.0591 .0591 .0591 .0591 .0591	0.00806 0.00234 0.00234 0.00234 0.00234 0.00234	099† - 0.4660 099† - 1.4660 099† - 1.4660 099† - 1.4660	-0.0269 -0.0269 -0269 -0269 -0269	0.0829 .0829 .1168 .0829 .0829	0.0905 .0905 .0905 .0905 .0905	-0.4098 -0.4098 -1.098 -1.2301 -1.098	-0.0358 -0.0358 -0.0358 -0.0358	0.2370 .2370 .2370 .2370 .2370	0.1163 1.163 1.163 1.163 1.163	-0.1335 1335 1335 1335 2689	-41.6 45.8 -33.4 -24.1 -30.3	0.340 .277 .283 .482 .324	4.681 3.986 3.695 4.287 4.646 4.397	4.604 4.713 3.596 4.048 6.369 2.169
Derivatives changed one at a time to the values for configuration 1.0 Derivatives changed are underlined.	0	, č	, i	7.41 7.94 7.94 7.94 7.94	2.8.8.9.9. 1.8.9.9.9.9.	13 18.4 18.4 18.4 18.4 18.4	.0197 .0245 .0245 .0245 .0245	20591 7101. 7101. 7101. 7101.	4 £200. 20806. 20806. 20806. 20806.								.1303 .1303 .1303 .1303 .1303				3.280 3.873 3.716 3.479 3.503 3.357	5.067 3.679 11.786 3.817 4.424 51.649
Long Con	0 0	0 0	0 0	0 0 0.27 0.46	0 0 0.27 0.46	0 0 0.27 0.46	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 6.41 3.41 13 11 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 8.41 6.71 6.71 6.71 13 1.41 6.71 6.7	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 6.41 3.41 13 11 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 8.41 6.71 6.71 6.71 13 1.41 6.71 6.7	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 6.41 3.41 13 11 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 8.41 6.71 6.71 6.71 13 1.41 6.71 6.7	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 6.41 3.41 13 11 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 8.41 6.71 6.71 6.71 13 1.41 6.71 6.7	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 6.41 3.41 13 11 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 8.41 6.71 6.71 6.71 13 1.41 6.71 6.7	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 6.41 3.41 13 11 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 8.41 6.71 6.71 6.71 13 1.41 6.71 6.7	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 5.41 3.41 13 11 13 6.41 3.41 13 11 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 3.41 13 8.41 6.71 6.71 6.71 13 1.41 6.71 6.7	0 0 0 0.27 0.46 5.41 3.41 13 5.41 3.41 13 5.41 3.41 13 5.41 3.41 13 5.41 3.41 13 6.41 3.41 13 7.41 3.41 13 7.41 3.41 13 7.41 5.41 3.41 13 7.41 5.41 3.41 13 7.41 5.41 13.41 13 7.41 5.41 18.11 13 7.41 7.41 7.41 7.41 13 7.41 7.41 7.41 7.41 7.41 13 7.41 7.41 7.41 7.41 7.41 7.41 7.41 7.41	0 0 0 0.27 0.465 5.41 3.41 13 0.1017 0.0006 0.04660 0.0269 0.0629 0.0905 0.0406 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0905 0.0406 0.0209 0.0905	0 0 0 0.27 0.465 5.41 3.41 13 0.1017 0.0006 0.04660 0.0269 0.0629 0.0905 0.0406 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0905 0.0406 0.0209 0.0905	0 0 0 0.27 0.465 5.41 3.41 13 0.1017 0.0006 0.04660 0.0269 0.0629 0.0905 0.0406 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0905 0.0406 0.0209 0.0905	0 0 0 0.27 0.465 5.41 3.41 13 0.1017 0.0006 0.04660 0.0269 0.0629 0.0905 0.0406 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0406 0.0629 0.0905 0.0905 0.0406 0.0209 0.0905	0 0 0 0.27 0.46 5.41 13.41 13 0.197 0.0806 0.04660 0.0269 0.0809 0.0905 0.0959 0.0558 0.0103 0.1103 5.41 13.41 13 0.097 0.0591 0.0806 0.0269 0.0809 0.0905 0.0959 0.0558 0.0103 0.1103 5.41 13.41 13 0.097 0.091 0.0024 0.4660 0.0269 0.0829 0.0905 0.4098 0.0378 0.1163 0.097 0.0591 0.0024 0.4660 0.0269 0.0829 0.0905 0.4098 0.0378 0.1163 0.097 0.0991 0.0991 0.0294 0.4660 0.0269 0.0829 0.0905 0.4098 0.0378 0.1163 0.097 0.0991 0.0024 0.4660 0.0269 0.0829 0.0905 0.4098 0.0378 0.1163 0.097 0.0991	0 0 0 0.27 0.465 5.94 18.4 1 0.0245 0.1017 0.0366 0.0466 0.0869 0.0965 0.4098 0.0358 0.2370 0.1153 -1135	7.94 5.94 18.4 0.0245 0.1017 0.0386 0.04660 0.0859 0.0905 0.0408 0.0358 0.2370 0.1103 -0.1357 0.1103 0.1357 0.1103 0.1357 0.1103 0.1357 0.1103 0.1357 0.1103 0.1357 0.1103 0.1357 0.1103 0.1357 0.1103 0.1357 0.1103 0.1357 0.1051 0.00234 0.0005 0.0005 0.0008 0.0358 0.2370 0.1103 0.1357 0.133 0.137 0.0591 0.00234 0.0005 0.0005 0.0008 0.0358 0.2370 0.1103 0.1357 0.133 0.137 0.0591 0.00234 0.0005 0.0005 0.0008	7.94 5.94 18.4 0.0245 0.1017 0.0366 0.4666 0.0269 0.0369 0.03758 0.2370 0.135 -1335 -1335 -1335 0.2370 0.135 0.2185 0.2370 0.135 0.135 0.135 0.241 0.0371 0.0371 0.0371 0.0269 0.0269 0.0255 0.0256 0.0259 0.0255 0.0256 0.0259 0.0255 0.0256 0.0259 0.0255 0.0256 0.0259 0.0255 0.0256 0.0259 0.0255 0.0256 0.0259 0.0255 0.0259 0.0259 0.0255 0.0259 0.0255 0.0259 0.0259 0.0255 0.0255 0.

CONDITIONS FOR WHICH CALCULATIONS WERE MADE, DERIVATIVES USED IN CALCULATIONS, AND RESULTS TABLE IV

OF CALCULATIONS FOR DETERMINING MEANS OF IMPROVING DUTCH ROLL STABILITY

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			[E.	1ght c	Flight conditions	suo		Мазя	Mass perameters	ters				Ae	rodyna	Aerodynamic derivatives	vatives					Results	8	
		L.				<del> </del>	<u> </u>		ļ	ļ				,		,					Aperiodic mode		Oscillatory mode	llatory
coniiguracion	g an	g an		E	J <sub>O</sub>	deg de	deg deg	×	. K2	, KXZ		Cr.	c, 2	h E	Ş.	Sa,	<sup>2</sup> tg.	r.	r S	r L	T <sub>1/2</sub> ,	T <sub>1/2</sub> ,	P,	T <sub>1</sub> /2'
Reduced 14	-5	<u>بر</u> ه	0 0 50,000	0.75.0 79. 20%.	0.06 6. .46 12. .80 18. .46 12.	8.83	4.03 18 10.94 18 16.80 18 10.94 120	18.4 0.0241 18.4 .0265 18.4 .0303 120.5 .0265	65 .0997 03 .0957 65 .0959	0	1	-0.1660 -0 -1660 - -1660 - -1660 -	-0.0458 0 1250 1926 1250	0.1166 0.0946 .1191 .5362 .1191 .9110		-0.2305 2318 2384 2318	-0.0347 0.3366 1331 .3412 2158 .3412 1331 .3412	0.3366 .3412 .3412 .3412	0.0587 1294 1893 1294	-0.2690 2750 2750 2750	96.2 19.2 16.2 16.2	0.226 .566 .679 1.387	1.438 3.033 3.142 3.102	1.126 4.638 11.434 14.664
Reduced F	0	-5.4	0 0 50,000	55. 405. 57.	20.06 1.08 1.08 1.08 1.08	1.03 7.94 13.80 11.94 7.94 5.	97 18 5.94 18 5.94 18 5.94 120	18.4 .0237 18.4 .0245 18.4 .0270 120.5 .0245		<u>'</u>			0 0626 1154 0626	.1120 .1168 .1191	.0559 .4275 .425 .4275	2338 2301 2325 2301	0128 0978 1712 0978	.3271 .3365 .3413 .3365	.0745 .1303 .1766 .1303	2557 2689 2757 2689	-57.0 161.0 31.0 -2510	.218 1.537 .549 3.660 .660 3.865 1.320 3.766	3.660 3.865 3.865 3.766	1.242 4.927 11.908 20.515
Reduced 1 <sub>w</sub> and Γ	-5-	-4-3 50	0 0 50,000	.27 .204 .75	.06 6. .46 12. .80 18. .46 12.	£8.53	4.03 10.94 16.80 16.80 10.94	18.4 .0241 18.4 .0265 18.4 .0303 120.5 .0265	11 .1021 65 .0997 03 .0959 65 .0997		.00500 .01470 .021801	4660 4660 4660 4660	0 0792 1468 0792	.1168 .1911 .1911 .1911	.0946 .5362 .9110 .5362	2305 2318 2384 2318	0347 1331 2158 1331	.3366 .3412 .3412 .3412	.0587 .1294 .1893	2690 2750 2750 2750	-71.5 47.8 23.5 121.5	.223 .585 .698 1.440	1.499 3.274 3.367 3.337	1.146 3.880 8.446 11.485
Reduced K <sub>Xo</sub>	0	0	0 0 50,000	.75 .27 .204 .75	.06 1. .46 7. .80 13.	8846	97 18 5.94 18 11.80 18 5.94 120	18.4 .0100 18.4 .0110 18.4 .0139 120.5 .0110		-			0574 1200 1728 1200	.1120 .1168 .1191 .1168	.0559 .4275 .7425 .4275	2338 2301 2325 2301	0128 0978 1712	.3271 .3365 .3413 .3365	.0745 .1303 .1766 .1303	2557 2689 2757 2689	78.7 19.2 15.9 49.0	.089 .278 .432	1.517 2.989 2.799 2.929	2.331 1.907 5.352
Reduced 1 $_{ m W}$ and $K_{ m X_O}$	÷	0	000,000	.75 .204 .75	.06 .46 .12 .80 .18 .16 .12	.03 4.03 .94 10.94 .80 16.80 .94 10.94	.03 18.4 .94 18.4 .80 18.4 .94 120.5	.4 .0105 40133 .4 .0177 .5 .0133	33 .0992 77 .0948 33 .0992				-,0458 -,1250 -,1926 -,1250	.1168 .1191 .1191 .1191	.0946 .5362 .9110 .5362	2305 2318 2384 2318	0347 1331 2158 1331	.3366 .3412 .3412 .3412	.0587 .1294 .1893 .1294	2690 2750 2750	96.3 19.4 16.4 16.4	.100 .353 .535 .992	1.420 2.536 2.322 2.375	.854 1.232 1.319 2.724
Reduced $\Gamma$ and $K_{X_{\mathcal{O}}}$	0	F5.4 50	50,000	.27 .204 .75	.06 1.66 13. 1.60 13.	89.83	5.94 18. 5.94 18. 5.94 120	18.4 .0100 18.4 .0110 18.4 .0139 120.5 .0110	00 .1025 10 .1015 39 .0986 10 .1015	1		4660 4660 4660 4660	0626 1154 0626	.1120 .1168 .1194 .1168	.0559 .4275 .7425 .7227	2338 2301 2325 2301	0128 0974 1712 0974	.3271 .3365 .3413 .3365	.0745 .1303 .1766 .1303	2557 2689 2757 2689	-56.8 161.5 31.4 -2520.0	.092 .273 .418	1.537 3.388 3.190 3.326	1.225 2.420 1.985 5.943
Reduced 14, F, and Kx <sub>O</sub>	-5	-4.3	0 0 50,000	.75 .20 .20 .75	.06 .46 .80 .80 .18. .16	8484	4.03 10.94 16.30 18.4 10.94 120.5	.4 .0105 4 .0133 .4 .0177 .5 .0133	. 1021 33 . 0992 77 . 0948 33 . 0992			4660 0 4660 4660	0 0792 1469 0792	1911. 1911. 1911.	.0946 .5362 .9110 .5362	2305 2318 2384 2318	0347 1331 2158 1331	.3366 .3412 .3412 .3412	.0587 .1294 .1893 .1294	2690 2750 2750	-71.5 48.2 23.9 123.0	.094 1.503 .330 2.875 .520 2.569 .940 2.681	2.875 2.875 2.569 2.681	1.085 1.373 1.350 2.911

TABLE IV. Continued

CONDITIONS FOR WHICH CALCULATIONS WERE MADE, DERIVATIVES USED IN CALCULATIONS, AND RESULTS OF CALCULATIONS FOR DETERMINING MEANS OF IMPROVING DUTCH ROLL STABILLTY

(a) Basic configuration 3 ( $\Lambda = 45^{\circ}$ ; A = 3).- Concluded

			je,	Flight conditions	cond1t	tions		Σ	lass per	Mass parameters	_				Aerodyn	Aerodynamic derivatives	ivatives			-		Results		
Changes from basic	ş ţ.	Γ, deg	ģ		<del></del>	8	-		0	o.								,	. ,		Aperiodic		Oscillatory mode	llatory
configuration	)		ť	×	r,	deg	deg	1	אַל	<sup>K</sup> 2 <sup>-</sup>	, xz	$^{\mathrm{C}}_{\mathbf{Y}_{\mathbf{B}}}$	д <sub>г</sub> о	n e	Ş.	c,	P.	J.	$c_1$	u,	T <sub>1</sub> /2'	T <sub>1/2</sub> ,	P,	T <sub>1</sub> /2'
Increased $K_{Z_{\mathcal{O}}}$	0	0	000,000	0.75 27. 408. 75.	3.06 .86 .87	1.03 7.94 13.80 7.94	-0.97 5.94 5.94 5.94	18.4 0 18.4 18.4 18.4	0.0238 0 .0255 .0311	.2000 .1981 .1926	-0.00290 .01820 .03530	-0.4660 4660 4660 4660	-0.0574 1200 1728 1200	0.1120 1.1168 1.1191 1.1168	0.0559 .4275 .7425 .4275	-0.2338 2301 2325 2301	-0.0128 0978 1712 0978	0.3271 .3365 .3413 .3455	0.0745 .1303 .1766 .1303	-0.2557 2689 2757 2689	80.5 ( 23.4 21.1 59.6	0.206 .551 .734 1.325	2.129 4.088 3.957 4.232	2.808 11.036 14.720 94.121
Reduced $\mathbf{1_{4}}$ and $\mathbf{1_{20}}$	-5-	0	000,000	.75 .204 .75	.06 1.08 1.08 1.04	6.03 12.94 18.80 14.91	10.94 16.80 16.80 10.94	18.4 18.4 18.4 120.5	.0246 .0300 .0384 .0300	.1991 .1937 .1853	.01240 .03290 .04880 .03290	-,4660 -,4660 -,4660 -,4660	0458 1250 1926 1250	1168 1911. 1911.	.0946 .5362 .9110 .5362	2305 2318 2384 2318	0347 1331 2158 1331	.3366 .3412 .3412 .3412	.0587 .1294 .1893 .1294	2690 2750 2750	98.3 23.4 60.0	.238 .682 .874 .874	.939 .376 .376	1.417 3.825 5.610 10.059
Reduced $\Gamma$ and increased $K_{Z_{O}}$	٥	-5.4	000,000	7.5. 40%. 57.	90. 1. 1. 1. 1. 1. 1. 1.	1.03 7.94 13.80 7.94	5.94 5.94 5.94 5.94	18.4 18.4 18.4 120.5	.0238 .0255 .0311	.2000 .1981 .1926 .1981	00290 .01820 .03530	4660 4660 4660 4660	0 0626 1154 0626	.1120 .1168 .1191	.0559 .4275 .7425 .4275	2338 2301 2325 2301	0128 0978 1712 0978	.3271 .3365 .3413 .3365	.0745 .1303 .1766 .1303	2557 2689 2757 2689	-57.0 187.5 40.5	.219 .573 .750 11.385	2.143 4.617 4.138 4.745	1.909 7.101 10.512 32.167
Reduced $1_{\mathbf{V}}$ and $\Gamma$ and increased $K_{Z_{\mathbf{O}}}$	<u>ب</u>	-4.3	0 0 50,000	.75 .20 ¥0≤.	.06 .80 .10 .10 .10 .10 .10 .10	6.03 12.94 18.80 12.94	4.03 10.94 16.80 10.94	18.4 18.4 18.4 120.5	.0246 .0300 .0384 .0300	.1991 .1937 .1853 .1937	.01240 .03290 .04880 .03290	-, 4660 -, 4660 -, 4660 -, 4660	0 0792 1460 0792	.1168 .1191 .1191	.0946 .5362 .9110 .5362	2305 2318 2384 2318	0347 1331 2158 1331	.3366 .3412 .3412 .3412	.0587 .1294 .1893 .1294	2690 2750 2750	-72.0 56.1 30.8 144.5	.225 .665 .876 1.720	2.082 3.919 3.692 3.915	1.704 3.794 5.354 9.811
Increased $K_{Z_{\mathbf{O}}}$ and reduced $K_{X_{\mathbf{O}}}$	0	0	0 0 50,000	.75 .204 .204 .75	.06 .80 .46	1.03 7.94 13.80 7.94	5.94 5.94 11.80 5.94	18.4 18.4 18.4 120.5	.0100 .0116 .0163 .0116	.1600 .1576 .1539 .1576	00254 .01550 .03020	4660 4660 4660 4660	0574 1200 1728 1200	0211. 1911. 1911.	.0559 .4275 .7425 .4275	2338 2301 2325 2301	0128 0978 1712 0978	.3271 .3365 .3413 .3365	.0745 .1303 .1766	2557 2689 2757 2689	79.8 21.8 19.1 55.5	.089 .295 .500 .839	1.879 3.414 2.989 3.209	2.409 2.180 1.571 4.068
Reduced $\mathbf{1_{Y}}$ , $\mathbf{1_{DCPeased}}$ $\mathbf{K_{Z_O}}$ , and $\mathbf{reduced}$ $\mathbf{K_{X_O}}$	-5-	0	0 0 50,000	55: 48: 57:	.06 .80 .104.	6.03 12.94 18.80 18.94	4.03 10.94 16.80 10.94	18.4 18.4 18.4 120.5	.0108 .0154 .0225 .0154	.1593 .1546 .1475 .1546	.01040 .02790 .02150	0994 0994 0994	0458 1250 1926 1250	.1168 1911. 1911.	.0946 .5362 .9110 .5362	2305 2318 2384 2318	0347 1331 2158 1331	.3366 .3412 .3412 .3412	.0587 .1294 .1893 .1294	2690 2750 2750	97.5 21.9 19.4 56.0	.101 .415 2.799 .670 2.408 1.248 2.506	1.75 2.799 2.408	.975 1.064 1.127 2.292
Reduced $\Gamma$ , increased $K_{Z_O}$ , and reduced $K_{X_O}$	0	4.6-	0 0 50,000	.27 .204 .75	.06 .80 .46	1.03 7.94 13.80 7.94	5.94 11.80 5.94	18.4 18.4 18.4 120.5	.0100 .0116 .0163 .0116	.1600 .1576 .1539 .1576	00254 .01550 .03020		0 0626 1154 0626	0211. 8311. 1911.	.0559 .1275 .7425 .7275	2338 2301 2325 2301	0128 0978 1712 0978	.3271 .3365 .3413 .3365	.0745 .1303 .1766 .1303	2557 2689 2757 2689	-56.9 177.0 37.0 -2760	35888	3.985 3.495 3.779	1.648 2.558 1.720 4.851
Reduced $i_{\mathbf{y}}$ and $\Gamma$ , increased $K_{\mathbf{Z_O}}$ , and reduced $K_{\mathbf{X_C}}$	5-	-4-3	00,00	.75 .27 .204 .75	.06 .80 .164 .164	6.03 12.94 18.80 12.94	4.03 10.94 16.80 10.94	18.4 18.4 18.4 120.5	.0108 .0154 .0225 .0154	.1593 .1546 .1475 .1546	.01040 .02790 .04150		0 0792 1460 0792	8911. 1911. 1911.	.0946 .5362 .9110 .5362	2305 2318 2384 2318	0347 1331 2158 1331	3366.	.0587 1294 1294 1294	2690 2750 2750	-71.5 53.4 28.1 136.2		1.873 3.281 2.701 2.891	1.426 1.249 1.163 2.459

TABLE IV.- Continued
CONDITIONS FOR WHICH CALCULATIONS WERE MADE, DERIVATIVES USED IN CALCULATIONS, AND RESULTS
OF CALCULATIONS FOR DETERMINING MEANS OF IMPROVING DUTCH FOLL STABILLIT

(b) Basic configuration  $5 (\Lambda = 0^{\circ}; \Lambda = 3)$ 

				1ght	Flight conditions	lone		Z.	ass par	Mass parameters	,,,			-	Aerodyne	Aerodynamic derivatives	ivatives				į	Results		
Changes from basic	, å	L.,	ء.				ء ۔		·												Aperiodic mode		Oscillatory mode	llatory mode
configuration	geg	geb	îť	×	Ţ,	deg	deg	<b>1</b>	χ,	K <sub>Z</sub> <sup>c</sup>	KXZ	Ç.	g <sub>1</sub>	်ရှိ ရ	λ. Ta	d.	Sq.	, t	r,	7. 1.	T <sub>1/2</sub> , sec	T <sub>1/2</sub> , sec	P,	${ m T}_{1/2},$ sec
Reduced 14	-5	0	000,05	0.75 .27 .204 .75	3.06 .46 .80 .46	5.91 11.98 17.13 11.98	3.91 9.98 15.13 9.98	18.4 18.4 18.4 120.5	0.0241 0.0290 0290 0290	0.1008 0.0989 0.0959 0.0989	0.00526 .01320 .01950	-0.4660 4660 4660 4660	-0.0350 0440 0524	0.1157 .1193 .1197 .1193	0.0516 .2006 .3270 .2006	-0.2455 -2462 -2492 -2462	-0.0275 0753 1131 0753	0.3340 .3416 .3424 .3424	3.0550 .1064 .1503	-0.2665 2760 2770	182.0 -52.1 -59.7 -1116.0	0.212 .569 .762 1.480	1.456 3.612 4.289 3.610	1.112 3.009 3.803 7.806
Reduced I	0	4	0 0 50,000	.75 .27 .204 .75	94. 94. 98.	.91 6.98 12.13 6.98	-1.09 4.98 10.13 4.98	18.4 18.4 18.4 120.5	.0237 .0243 .0261 .0243	.1012 .1006 .0988 .1006	00149 .00673 .01340	099† 099† 099†	0 	.1120 .1168 .1191	.0227 .1703 .2981 .1703	2489 2462 2452 2452	0070 0530 0919 0530	.3271 .3365 .3413 .3365	.0743 .1280 .1714 .1280	2557 2689 2757 2689	-60.9 -17.0 -12.4 -13.0	.205 .558 .712 1.403	1.528 4.029 4.906 4.059	1.234 3.171 3.882 8.496
Reduced 14 and I	-5	-2.8	000,005	.75 .204 .75	.06 .80 .16 .16	5.91 11.98 17.13 11.98	3.91 9.98 15.13 9.98	18.4 18.4 18.4 120.5	.0241 .0260 .0290	.1008 .0989 .0959	.00526 .01320 .01950	099† 099† 099†	0 0090 0174 0090	.1157 .1193 .1197 .1193	.0516 .2006 .3270 .2006	2455 2462 2492 2462	0275 0753 1131 0753	.3340 .3416 .3424 .3424	.0550 .1064 .1503	2665 2760 2770 2760	-81.1 -21.5 -15.4 -54.4	.210 .585 .760 1.485	1.498 3.865 4.659 3.860	1.147 2.800 3.384 7.221
Reduced KX <sub>O</sub>	0	0	000,03	.75 .27 .204 .75	.06 .80 .80	.91 6.98 12.13 6.98	-1.09 4.98 10.13 4.98	18.4 18.4 18.4 120.5	.0100 .0107 .0128	.1012 .1005 .0948 .1005	00180 .00790. .01570	099† 099† 099†	1650 1790 1790	.1120 .1168 .1191 .1168	.0227 .1703 .2981 .1703	2489 2452 2462 2452	0070 0530 0919 0530	1.3271 1.3365 1.3413 1.3365	.0743 .1280 .1714 .1280	2557 2689 2757 2689	118.5 242.0 -128.0 620.0	.084 .249 .356 .356	.249 3.594 356 4.062 675 3.484	1.512 2.491 2.125 5.121
Reduced 14 and KX <sub>O</sub>	<u>-</u> -5	0	0 0 50,000	.75 .27 .204 .75	.06 .46 .80 1	5.91 11.98 17.13 11.98	3.91 9.98 15.13 9.98 12	18.4 18.4 18.4 18.4	.0104 .0127 .0162	.0984 .0950 .0950	.00620 .01560 .02290 .01560	099†'- 099†'- 099†'-	0440 0440 0524	.1157 .1193 .1197	.0516 .2006 .3270 .2006	2455 2462 2492 2462	0275 0753 1131 0753	.3340 .3416 .3424 .3424	.0550 .1064 .1503	2665 2760 2770	182.0 -4550.0 -69.5 -1140.0	.091 .276 .414 .838	1,449 3,433 3,861 3,116	.903 1.589 1.491 2.850
Reduced $\Gamma$ and $K_{X_{\mathcal{O}}}$	0	7-	0 0 50,000	.75 .27 .204 .75	90.	.91 6.98 12.13	-1.09 4.98 10.13 4.98	18.4 18.4 18.4 120.5	.0100 .0107 .0128	.1012 .1005 .0984 .1005	00180 .00790 .01570		0 0097 4710	.1120 .1168 .1191	.0227 .1703 .2981 .1703	2489 2452 2462 2452	0070 0530 0919 0530	.3271 .3365 .3413 .345	.0743 .1280 .1714 .1280	2557 2689 2757 2689	-60.7 -16.8 -12.2 -42.5	.086 .244 .333 .639	1.527 3.998 4.756 3.941	1.218 2.629 2.428 6.025
Reduced $1_V$ , $\Gamma$ , and $K_{X_{\mathcal{O}}}$	-5	-2.8	000,03	75. 408. 75.	96. 1. 68. 1. 64.	5.91 11.98 17.13 11.98	3.91 9.98 15.13 9.98	18.4 18.4 18.4 120.5	.0104 .0127 .0162	.1008 .0984 .0950	.00620 .01560 .02290 .01560	099† 099† 099†	0 0090 0174 0090	7211. 1193 1197 1193	.0516 .2006 .3270 .2006	2455 2462 2492 2462	0275 0753 1131 0753	.3340 .3416 .3424 .3416	.0550 .1064 .1503	2665 2760 2770 2760	-86.3 -21.2 -15.3 -54.0	.088 .256 .372 .735	.088 1.502 .256 3.813 .372 4.440 .735 3.581	1.096 1.971 1.775 3.631

1,456 2,289 1,862 3,420

-81.1 .088 1.885 -22.4 .261 4.677 -17.0 .384 5.267 -56.8 .798 4.246

184.0 .092 1.808 1.078 1.650 -498.0 .292'4.104 1.650 -80.0 .449 4.411 1.425 -1242.0 .975 3.508 2.512

1.654 3.338 2.795 6.666

-60.7 .087 1.917 1-14.4 1.938 3-13.4 .334 5.707 2-14.0 6.884 4.887

CONDITIONS FOR WHICH  OF CALCULL  The conditions  Fight conditions  Conditions	CONDITIONS FOR WHICH CALCULATIONS FOR THICH CALCULATIONS FOR CALCULATIONS FOR THICH CALCULATIONS FOR CALCULA	CONDITIONS FOR WHICH CALCULATIONS WERE Note of the configurety of calculations for december of calculat	TABLE 1  CONDITIONS FOR WHICH CALCULATIONS WERE MADE, MADE, T. 1ght conditions of calculations	TABLE IV Comcludations of CALCULATIONS WERE MAJE, DEFLIVATIVES  T. CALCULATIONS FOR WHICH CALCULATIONS WERE MAJE, DEFLIVATIVES  O C. 2204  O C. 77  O C. 2204	TABLE IV. Concluded  CONDITIONS FOR WHICH CALCULATIONS WERR MADE, DERIVATIVES USED IN  deg	Third IV. Compliance for validations were made, defining the conditions for calculations were made, defining the conditions for calculators for definitions and the conditions for calculators for definitions and the conditions for calculators for definitions for definiti	TABLE IV. Concluded  Characteristics of the conditions of the configurations were made with the conditions of the conditions of the configurations of the conditions of the configurations of the conditions of th	TABLE IV. Concluded  CONDITIONS FOR WHICH CALCULATIONS WERE MAINE, DESTVORTIVES USED IN CALCULATIONS, AND F. C.	TABLE IV. Concluded  Transmiss for Macchanisms were were were and the configurations of	There contitions to which examines are morning using Maria IV. Correlated  F. F. R. C. L. dee G. S. L. 19 S. R. C. C. D. C. D. C. C. C. C. C. D. C. D. C. C. D. C. D. S. C. D. S. C. D. S. C. D. D. C. D. C. D. D. C. D. C. D. C. D. D. C. D. C. D. D. C. D. C. D. D. D. C. D. D. D. C. D. D. D. C. D. D. D. C. D. D. D. C. D. D. C. D. D. C. D. D. C. D. D. D. D. C. D. D. D. C. D. D. D. C. D. D. D. C. D. D. D. D. C. D. D. D. D. D. D. C. D.	Third IV. Concluded The Challestone Name And Description Date to Challestone And Name Intervention of the Challestone And Name Intervention And Name In	TABLE 11 Concluded  CONCILIONS FOR WINCH CALCULATIONS WERE MURE, BEST-VETTERS HERD IN CALCULATIONS, AND RESULTS:  (b) Basic confiling to the confiling transfer of the confi				Changes Iw, from basic deg	configuration	Increased K, 0	Reduced 1 $_{\mathbf{v}}$ and -5 increased $K_{\mathbf{Z}_o}$	Reduced $\Gamma$ and 0 increased $K_{Z_{\mathbf{O}}}$	Reduced 1 and 7 -5 and 1ncreased $K_{Z_0}$	Increased K.o and 0 reduced K.o	Reduced i.v., increased $K_{Z_O}$ , and -5 reduced $K_{X_O}$	Reduced $\Gamma$ , increased $K_{Z_{\mathcal{O}}}$ , and 0 reduced $K_{X_{\mathcal{O}}}$	Reduced in and $\Gamma$ , increased $K_{Z_O}$ , and $^-5$ reduced $K_{X_C}$
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TABLE IV Concluded  (b) Basic configuration 5 (A = 0°); A = 3) Concluded  Asse parameters  Mass parameters  -1.09   18.4   0.0238   0.1999   -0.00340   -0.4660   -0.0497   0.1120   0.184   0.0250   1.194   0.0250   0.1947   0.0010   -0.4660   -0.0497   0.1120   0.1961	TABLE IV. 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		### CONTIGURED	### AMERIE MADE, FOR DETERMITHING ME.   Constiguration 5   Constitution 5   Consti	### TABLE IV. Comeluad AMIDONS WERE MADB, DERIVATIVES FOR DETERMINING WEARS OF 14PR (1978)  #### Configuration 5 (A = 0°), A = 0°, A =	### TABLE IV Comcluded AMINONS WERR MADE, DERIVATIVES USED IN FOR DETERMINING MEANS OF IMPROVING DUTY CONTIGURATION OF IMPR	### TABLE IV. Concluded AMTONS WERE MADE, DERIVATIVES USED IN CALCUL FOR DETERMINING MEANS OF IMPROVING DITCH FOLL  ##################################	### CAPIE IV. Comcluded  FOR DETERMINION MEANS OF IMPROVING INTCH FOLLS TRABIL  CC CONTIGURATION OF AN S   X = 0.0   A = 3). CONCLUDED  #### CAPICON OF THE PROVING INTCH FOLL STABIL  ### CAPICON OF THE PROVING INT	TABLE IV. Comcluded AMTONS WERE MADE, DERIVATIVES USED IN CALCULATIONS, AND FOR DETERMINING MEANS OF IMPROVING DUTCH ROLL STABILITY FOR DETERMINING MEANS OF IMPROVING DUTCH ROLL STABILITY CC CONTIGURATION 5 (A = 0°, A = 3) CONCLUDED CC50 1987 0.02340 -0.4660 -0.0497 0.1120 0.0227 -0.24 CC50 1987 0.03340 -0.4660 -0.0497 0.1139 0.0227 -0.24 CC50 1987 0.03340 -0.4660 -0.0440 0.1193 0.0227 -0.24 CC50 1987 0.03040 -0.4660 -0.0374 0.1193 0.0227 -0.24 CC50 1987 0.03040 -0.4660 -0.0374 0.1193 0.0227 -0.24 CC50 1987 0.03050 -0.4660 -0.0490 0.1193 0.0227 -0.24 CC50 1987 0.03050 -0.4660 -0.0374 0.1193 0.006 -0.24 CC60 0.0107 0.0524 0.0375 0.0365 -0.4660 -0.0440 0.193 0.006 -0.24 CC60 0.0105 0.0375 -0.4660 -0.0440 0.193 0.006 0.024 CC60 0.0105 0.0375 -0.4660 -0.0440 0.193 0.006 0.024 CC60 0.0105 0.0375 0.0460 0.0374 0.193 0.006 0.024 CC60 0.0105 0.0375 0.0460 0.0374 0.193 0.006 0.024 CC60 0.0105 0.0375 0.0560 0.0440 0.193 0.0560 0.024 CC60 0.0105 0.0375 0.0560 0.0374 0.193 0.0560 0.0375 CC60 0.0105 0.0375 0.0560 0.0375 0.0374 0.0374 0.0374 0.0576 0.0375 CC60 0.0105 0.0375 0.0460 0.0074 0.193 0.0560 0.0375 CC60 0.0105 0.0375 0.0460 0.0074 0.193 0.0560 0.0375 CC60 0.0105 0.05760 0.0460 0.0077 0.193 0.0576 0.0375 CC60 0.0105 0.05760 0.0470 0.193 0.0576 0.0375 CC60 0.0105 0.0375 0.0375 0.0377 0.0375 CC60 0.0077 0.0077 0.0077 0.0077 0.00	TABLE IV. Comcluded ANTIONS WERE MADE, DERIVATIVES USED IN CALCULATIONS, AND RESULTS FOR DEFERMINING MEANS OF IMPROVING DITCH ROLL STABILLITY  (c configuration 5 % = 0°; A = 3) Concluded  Ex. 2	POR DETERMENTION WARN OF INCRONING DITCH ROLL STABILLITY  CROSS DISTANCELLION 5 (A = 0°), A = 3) CONCLIMATIONS, AND RESULTS  For DETERMENTION MEANS OF INCROVING DITCH ROLL STABILLITY  CROSS DISPAYS OF SOUR CONTROL DITCH ROLL STABILLITY  Asse partameters  Ky² K²² Kx² C'y C'p	POR DETERMINING MEANS OF IMPROVING DITCH ROLL STABILITY  FOR DETERMINING MEANS OF IMPROVING DITCH ROLL STABILITY  FOR DETERMINING MEANS OF IMPROVING DITCH ROLL STABILITY  C CONTIGURATION 5 Å. = 0°2, Å = 3) Concluded  Asse parameters  K½	The different lands are the proving different lands are different lands. And results are noted being used to the proving different lands of the office of the lands of the		ATIONS		   	ı	18.4 18.4 18.4 120.5		18.4 18.4 18.4 120.5	18.4 18.4 18.4 120.5			18.4 18.4 18.4 120.5	18.4 18.4 18.4
### WERE IV. Concluded  #### WAIR, 1V. Concluded  ##################################	7. C.	CV <sub>p</sub> A = 3) Concluded  CV <sub>p</sub> C <sub>1</sub> B C <sub>1</sub> C <sub>2</sub> C <sub>2</sub> C <sub>3</sub> C <sub>3</sub> C <sub>4</sub> C <sub>4</sub> C <sub>4</sub> C <sub>4</sub> C <sub>5</sub> C <sub>4</sub> C <sub>5</sub> C <sub>5</sub> C <sub>4</sub> C <sub>5</sub>	C16   C16   C17	CHECULATIONS, AND RESULTES  CIT POLL STABILITY  Mcluded  CD CYP C1P C1P C1P C1P C1P C1P C1P C1P C1P C1	AND RESULTS  C1p  C1p  C1p  C2p  C2p  C2p  C2p  C3p  C3p  C3p  C3	### derivatives    C_n	Part	C <sub>1</sub> r C <sub>1</sub> r T <sub>1</sub> /2° con the control of the control	Apertal mood of the control of the c	Aperial Book    T. 1/2    Book    Book	Aperite and a part of the part				Resi	odic le	T //	0.1	23.	2000	9,9,9,3	30.	0, 0, 1, 2,	8 4 2 2	38. 27.

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121.0 0.195 2.140 280.0 .535 4.860 6-162.2 .718 5.402 6720.0 1.345 4.945 80

sec

 $r_{1/2}$ ,

Oscillatory

Aperiodic

Results

1.467 3.518 4.065 8.275

185.0 .220 1.995 -524.0 .625 4.569 -87.0 .835 5.107 -1310.0 1.660 4.476

1.912 4.760 5.404 13.074

-60.8 .206 2.143 -18.0 .557 5.488 -14.4 .729 6.346 -45.5 1.410 5.539 11

1.727 3.666 4.014 8.741

.210 2.096 .603 5.141 .810 5.834 1.580 5.065

2.265 2.863 2.165 4.732

120.0 .085 1.894 2 268.0 .252 4.290 2 -149.0 .368 4.675 2 681.0 .718 4.055

29

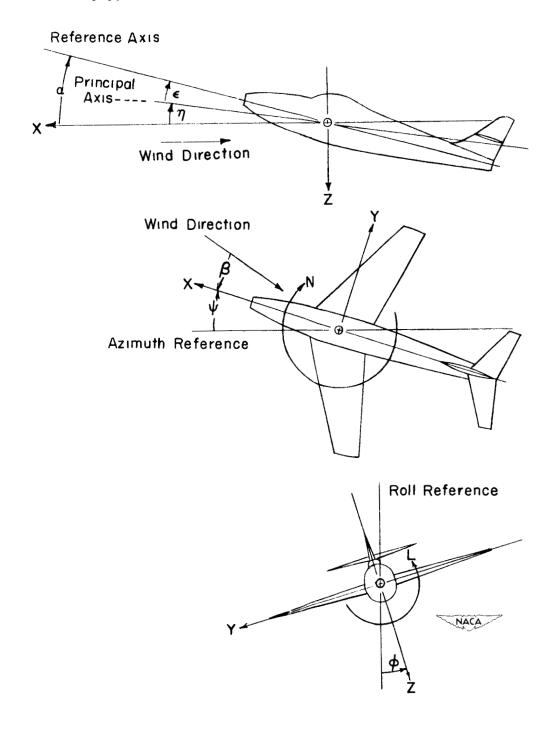


Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and angles. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. At a constant angle of attack, these axes are fixed in the airplane.

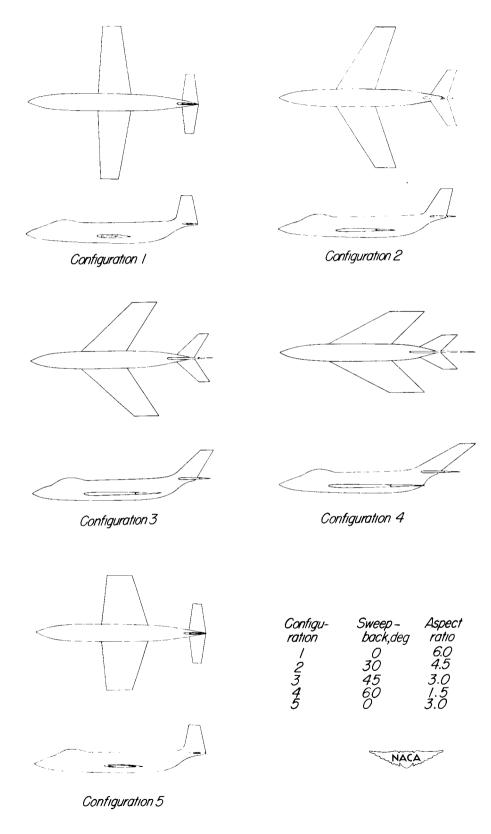
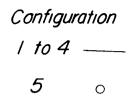


Figure 2.- Basic configurations for which calculations were made.



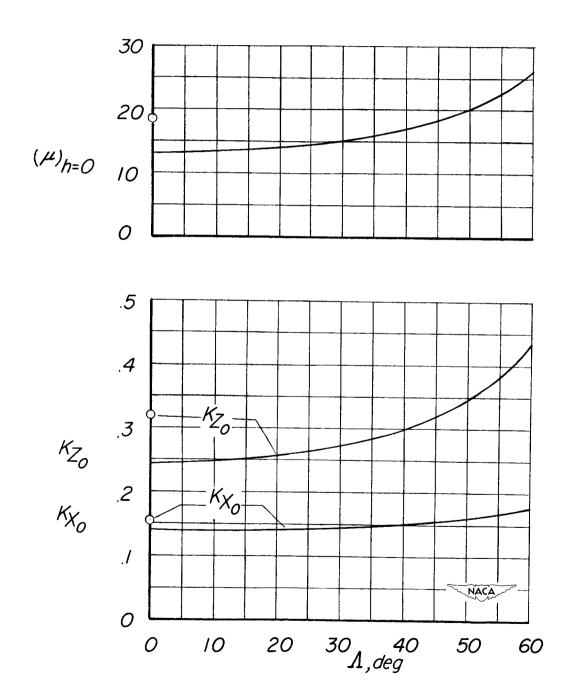


Figure 3.- Variation of mass parameters with sweepback.

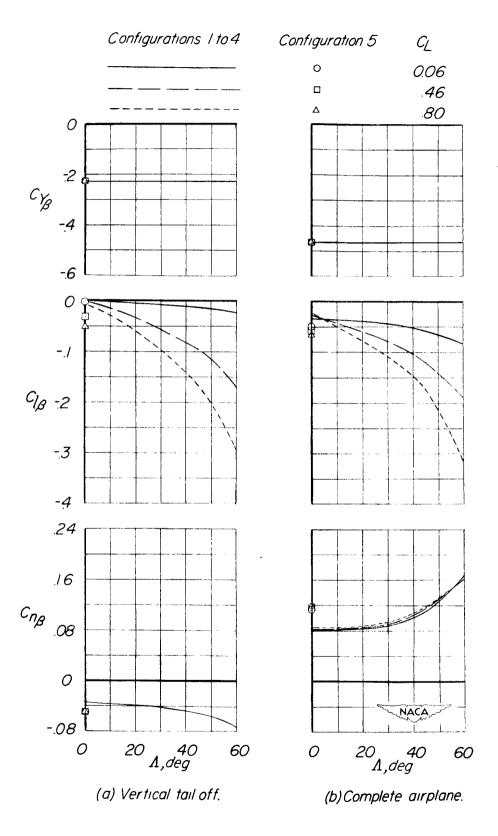


Figure 4.- Variation of sideslip stability derivatives with sweepback and lift coefficient.

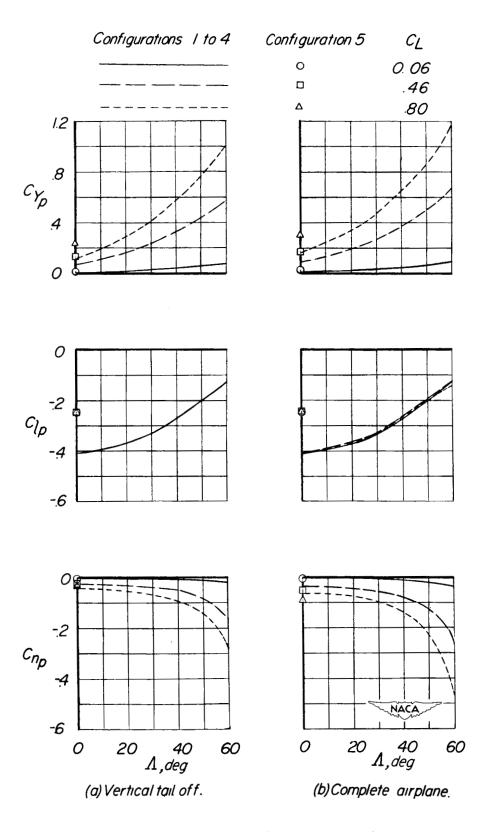


Figure 5.- Variation of rolling stability derivatives with sweepback and lift coefficient.

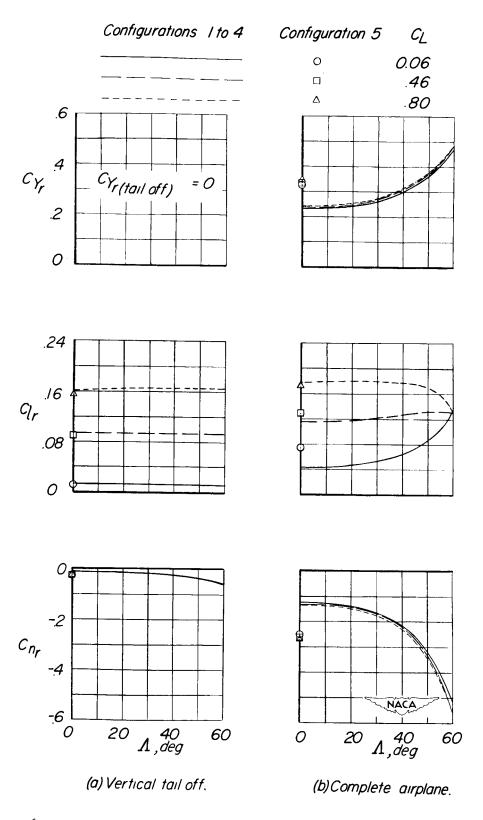


Figure 6.- Variation of yawing stability derivatives with sweepback and lift coefficient.

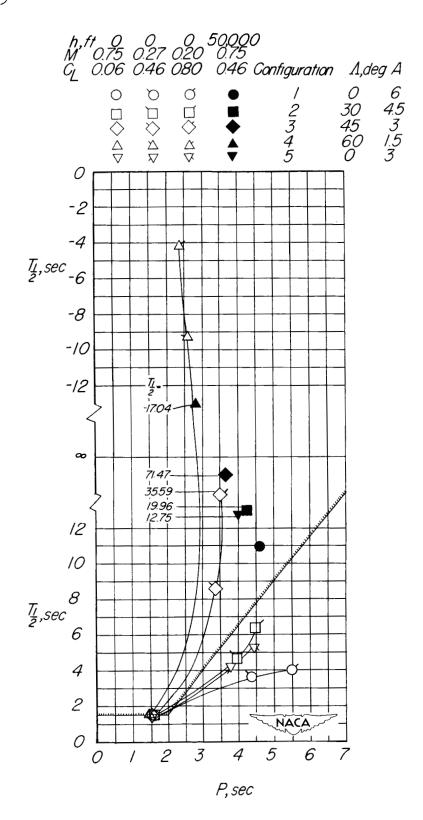
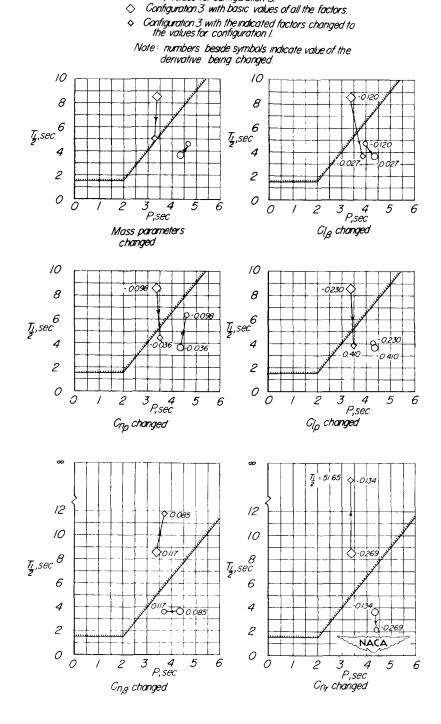


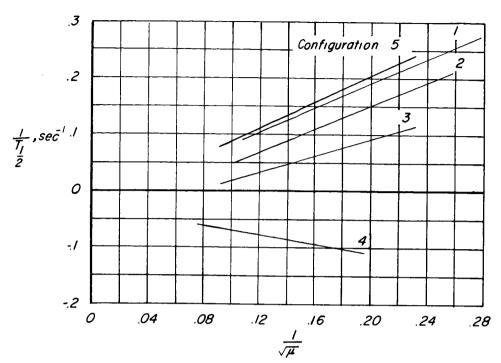
Figure 7.- Stability of basic configurations. Hatched boundary is period-damping requirement of references 2 and 3.



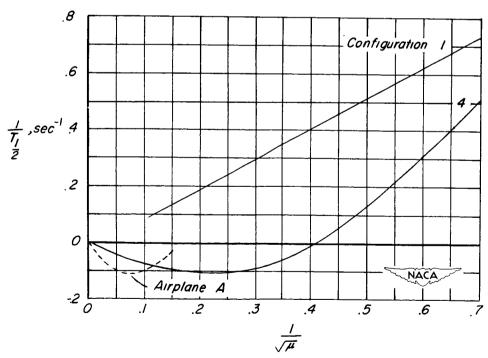
Configuration I with basic values of all the factors.
 Configuration I with the indicated factors changed to

the values for configuration 3.

Figure 8.- Effect of the differences in mass parameters and individual stability derivatives on stability of configurations 1 and 3.  $C_L$  = 0.46; h = 0 feet.



(a) Basic configurations. Data taken from table  $\Pi$  for altitudes of O and 50,000 feet.



(b) Configurations I and 4 for an extended range of  $\mu$ , and an actual airplane for altitudes from sea level to infinity.

Figure 9.- Variation of damping with relative-density factor.  $C_{\rm L}$  = 0.46.

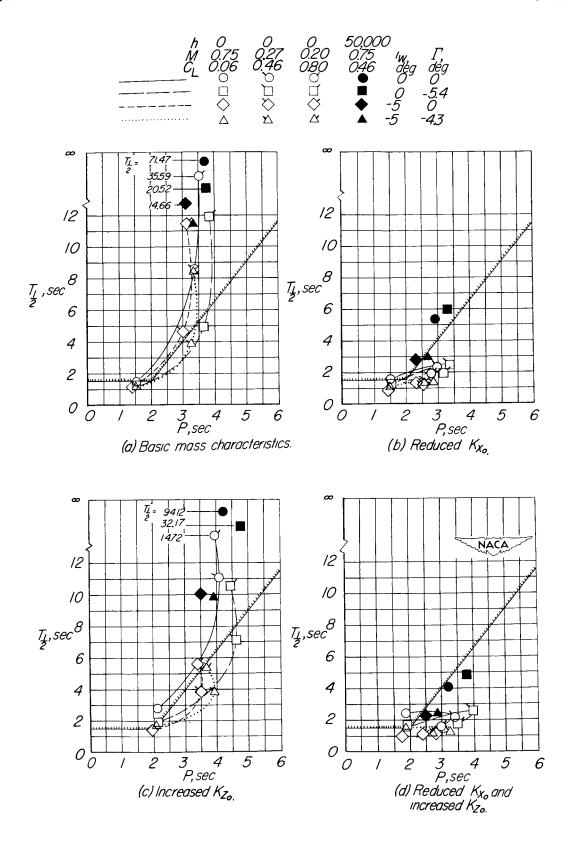


Figure 10.- Stability of modified configuration derived from configuration 3.

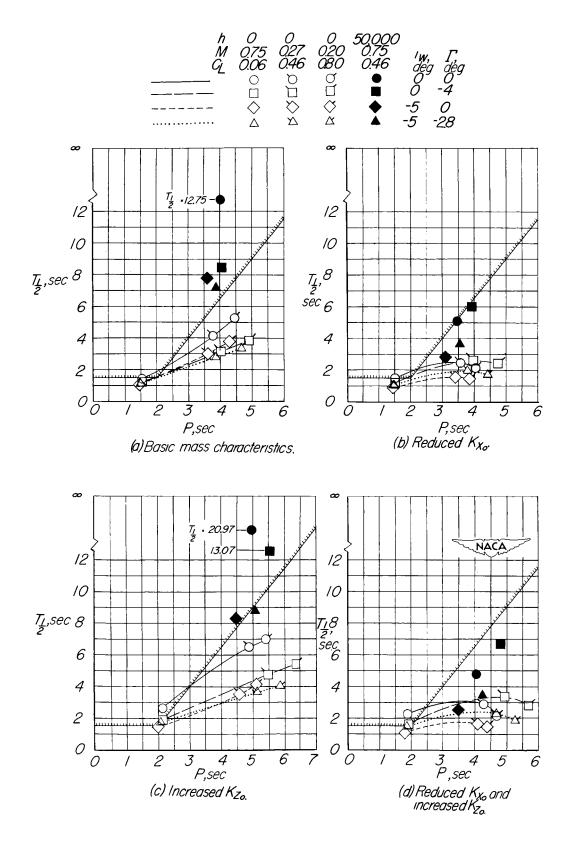
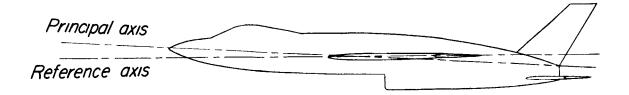
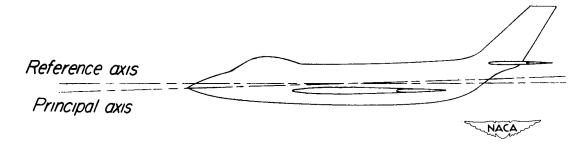


Figure 11.- Stability of modified configuration derived from configuration 5.



(a) Modified design.



(b) Configuration 3.

Figure 12.- Illustration of profile of an airplane designed to have positive inclination of the principal longitudinal axis of inertia and comparison with profile of configuration 3 which is representative of many designs.