STUDIES OF SOME EFFECTS OF AIRPLANE CONFIGURATION ON THE RESPONSE TO LONGITUDINAL CONTROL IN LANDING APPROACHES

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STUDIES OF SOME EFFECTS OF AIRPLANE CONFIGURATION ON THE RESPONSE TO LONGITUDINAL CONTROL IN LANDING APPROACHES

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SUMMARY

The investigation reported in this paper was undertaken to see if there are inherent differences in the response of the flight path angle to control movements between swept wing airplanes having no horizontal tail and using trailing edge flaps for longitudinal control and conventional airplanes, which are known to have satisfactory response characteristics. Particular emphasis is placed on the final few seconds of the landing approach.

This study shows that the only difference in the short-time response of the flight path between the two types of airplanes is in a time lag in the flight path angle response of the swept wing airplanes. This time lag was found to result from two factors, first a relatively small value of the parameter

$$\left(\frac{VC_{L_\alpha}}{2\mu\bar{c}}\right)\left(\frac{V^2C_{m_{\delta_e}}}{2\mu k_y^2}\right)\Delta\delta_e$$

which is a measure of the effectiveness of the control in changing the flight path angle, and second a relatively large value of the parameter

$$\left(\frac{VC_{L_{\delta_e}}}{2\mu\bar{c}}\right)\Delta\dot{\delta}_e$$

which is a measure of the amount of undesirable change in lift accompanying the control deflection required to change the angle of attack. It had been suspected that the relatively large change in drag with angle of attack, of low-aspect-ratio swept wing airplanes having no horizontal tails would be an important factor in the flight path angle response but this was found not to be the case for the short time intervals under consideration.

The importance of the differences found in the response characteristics between the two types of airplanes studied can only be evaluated by flight experience. Other factors such as range of vision, control feel, the pilots' reaction to the relatively large nose up attitudes of the low aspect ratio swept wing airplanes and psychological influences associated with new type airplanes may be of equal or greater importance.

INTRODUCTION

With the demand for high-speed flight, airplane configurations have changed appreciably and necessary compromises have led to some flight difficulties particularly at low speeds. One such difficulty was reported in reference 1 for free-flying airplane models having low aspect ratio wings and no horizontal tails. The models responded uncertainly to elevator control movements particularly when flying beyond the angle of attack of maximum L/D ratio. It was felt that troubles may be encountered on similar airplanes at low speeds particularly in landing approaches where small height corrections may be needed. A theoretical investigation of the responses to longitudinal control of airplanes having low aspect ratio wings and no horizontal tails, therefore, was undertaken at the NACA's Langley Aeronautical Laboratory to evaluate the effects of aerodynamic differences between this type of airplane and other more conventional airplanes which are known to have satisfactory response characteristics in landing approaches.

Other factors such as the range of vision, control feel, pilots' reaction to the relatively large nose up attitude of low aspect swept wing airplanes, and psychological influences associated with new type airplanes also may have considerable influence on pilots' opinions regarding the landing approach characteristics of such airplanes. The theoretical investigation, however, was made without regard to any such possible psychological influences.

Motions in response to longitudinal control movements were computed, on an analog computer, for two swept-wing airplanes having no horizontal tails and for a conventional airplane which was known to have good height control in landing approaches.

SYMBOLS AND COEFFICIENTS

The longitudinal motions presented herein were calculated about the stability axes.

S	wing area, sq ft
$\bar{c}$	mean aerodynamic chord, ft
W	weight of airplane
m	mass of airplane, slugs (W/g)
k_y	radius of gyration about Y-body axis, ft
ρ	air density, slugs per cu ft

μ	airplane relative-density coefficient $\frac{m}{\rho S\bar{c}}$
V	velocity, ft per sec
g	acceleration due to gravity, 32.2 ft/sec^2
L	lift, pounds
D	drag, pounds
M	pitching moment, ft-pounds
C_L	lift coefficient $\frac{L}{\frac{1}{2}\rho V^2 S}$
C_D	drag coefficient $\frac{D}{\frac{1}{2}\rho V^2 S}$
C_m	pitching-moment coefficient $\frac{M}{\frac{1}{2}\rho V^2 S\bar{c}}$
C_{L_o}	lift coefficient at $\alpha = 0^\circ$ with an elevator deflection which would be required to trim at landing approach speed
C_{m_o}	pitching-moment coefficient at $\alpha = 0^\circ$ with an elevator deflection which would be required to trim at landing approach speed
T	thrust, pounds
Z	height, ft ($\int_0^t V \sin\gamma \, dt$)
α	angle of attack, deg ($\alpha = \theta - \gamma$)
γ	flight-path angle, deg
θ	angle of pitch, deg
δ_e	elevator deflection, deg
ΔZ	increment of height from trimmed condition
$\Delta\alpha$	increment of angle of attack from trimmed condition
Δ	increment of flight-path angle from trimmed condition

$\Delta\theta$	increment of angle of pitch from trimmed condition
ΔV	increment of velocity from trimmed condition
$\Delta\delta_e$	increment of elevator deflection from trimmed condition
$\dot{\theta}$ or q	pitching angular velocity, radians per sec
V	rate of change of velocity V with time

$C_{L_{\delta_e}} = \dfrac{\partial C_L}{\partial \delta_e}$, per deg

$C_{D_{\delta_e}} = \dfrac{\partial C_D}{\partial \delta_e}$, per deg

$C_{m_{\delta_e}} = \dfrac{\partial C_m}{\partial \delta_e}$, per deg

$C_{L_\alpha} = \dfrac{\partial C_L}{\partial \alpha}$, per deg

$C_{D(\alpha)}$ coefficient of drag as a nonlinear function of α

$C_{m_\alpha} = \dfrac{\partial C_m}{\partial \alpha}$, per deg

$C_{m_q} = \dfrac{\partial C_m}{\partial \frac{q\bar{c}}{2V}}$

AIRPLANES INVESTIGATED

The airplanes for which motion calculations were made are referred to herein as airplanes A, B, and C. Airplane A is a conventional straight wing airplane which has good response characteristics in the landing approach. Airplane B is a swept-wing airplane having no horizontal tail and airplane C, which also has no horizontal tail, is an airplane generally similar to airplane B but having a lower aspect ratio and different mass characteristics. Pertinent

aerodynamic, mass, and dimensional information on airplanes A, B, and C are given in Table I.

PROCEDURE

For this investigation, the three longitudinal equations of motion were used in the analog computer

$$\dot{V} = -\frac{V^2}{2\mu\bar{c}}\left(C_{D(\alpha)} + C_{D_{\delta_e}}\delta_e\right) - g\sin\gamma + \frac{T}{m}\cos\alpha \qquad (1a)$$

$$\dot{\gamma} = \frac{V}{2\mu\bar{c}}\left(C_{L_\alpha}\alpha + C_{L_0} + C_{L_{\delta_e}}\delta_e\right) - g\cos\gamma + \frac{T}{m}\sin\alpha \qquad (1b)$$

$$\ddot{\theta} = \frac{V^2}{2\mu k_y^2}\left(C_{m_\alpha}\alpha + C_{m_0} + C_{m_{\delta_e}}\delta_e\right) + \frac{V}{4\mu k_y^2} C_{m_q}\bar{c}\,\dot{\theta} \qquad (1c)$$

The equations were not linearized in that the thrust and gravitational forces were introduced in their nonlinear form. The lift, drag, and pitching-moment coefficients were introduced as functions of angle of attack and of elevator deflection. All of the airplanes were trimmed in level flight at 110 knots (185.8 ft/sec) at the beginning of the motions and the slopes of the lift and pitching-moment coefficients with angle of attack were taken in the vicinity of the angle of attack for trimmed flight at 110 knots. The drag coefficient $(C_{D(\alpha)})$ was introduced as a nonlinear function of angle of attack. The lift, drag, and pitching-moment coefficients, as functions of elevator deflection, were introduced as linear functions of δ_e, the slopes were taken as mean values between the elevator deflection for trim and the maximum up-elevator deflection. The elevator deflections and therefore the values of $C_{L_{\delta_e}} \delta_e$, $C_{D_{\delta_e}} \delta_e$, and $C_{m_{\delta_e}} \delta_e$ were introduced as step functions. The thrust and the airplane damping derivative, C_{m_q}, were held constant for any given calculation.

In order to evaluate the response to longitudinal control for the three airplanes, the following procedure was used. As previously mentioned, the three airplanes were initially trimmed in steady level flight at a landing approach speed of 110 knots. The initial trim values are given in table II. A disturbance from this condition was initiated by deflecting the elevator down and holding it down for a short time (2 seconds) after which an attempt to stop the ensuing descent was made by deflecting the elevator full-up. The amount of down-elevator deflection used initially for airplane A, resulted in a loss of altitude that might be desired for a final height correction during an approach, approximately 10 feet. For comparison purposes, it was desired to make the initial pushover flight paths the same for airplanes B and C as for airplane A, so that when the final up-elevator deflection was used in an attempt to stop the descent all three airplanes would be in approximately the same flight condition. This was attempted by deflecting the elevators down on airplanes B and C an amount which would result in approximately the same initial rate of change of normal acceleration for all three airplanes. The amount the elevator was deflected down from the initial trim deflection for all three airplanes is given in Table III. As previously mentioned, the

elevator on each airplane was deflected full-up after the initial pushover motion. The maximum full-up elevator was used in that it would give the maximum acceleration in pitch, possible on each airplane, and any other correction by use of up elevator would be proportional to that given by full-up elevator. It is realized that the use of full-up elevator and of step input functions does not simulate the actual conditions used by a pilot, but it was felt that the method does reveal any difference in response due to inherent differences in stability and control characteristics that exist between airplanes A, B, and C. In order that the airplanes would not trim at an angle of attack beyond maximum lift, the elevator was returned after a given time, from full up to a deflection that would trim the airplanes at maximum lift.

SIMPLIFIED ANALYTICAL CONSIDERATIONS

The calculations performed in this paper, as previously noted, are based on the three longitudinal equations of motion and are accurate to the extent of the completeness and accuracy of the aerodynamic data used. Short-period oscillation in longitudinal motions may be studied, within required accuracy, by consideration of only 2 degrees of freedom, assuming the velocity to be constant. It is possible, therefore, that factors pertinent to short-time responses to longitudinal control movement also may be obtained from consideration of only 2 degrees of freedom. These degrees of freedom are expressed in the equations of the pitching and normal accelerations given previously as equations (1-b) and 1-c). It can be shown that changes in the gravitational and thrust forces in equation (1-b) are of only secondary importance and, if neglected, the equations when simplified to changes from the initial trimmed conditions may be solved simultaneously for the flight-path angle γ, a pertinent parameter to changes in height, when the change in height may be expressed as

$$\Delta Z = \int_0^t V \sin \gamma \, dt \qquad (2)$$

The solution for γ gives the following result

$$\gamma = \frac{V C_{L_{\delta_e}}}{2\mu \bar{c}}\left(\frac{a}{b} + \frac{\lambda_2^2 e^{\lambda_1 t} - \lambda_1^2 e^{\lambda_2 t}}{b\sqrt{a^2-4b}}\right)\Delta\delta_e$$

$$+\left(\frac{V C_{L_{\delta_e}}}{2\mu \bar{c}}\right)\left(\frac{V^2 C_{m_\alpha}}{2\mu k_y^2}\right)\left[\frac{\lambda_2^2 e^{\lambda_1 t} - \lambda_1^2 e^{\lambda_2 t}}{b^2\sqrt{a^2-4b}} - \left(\frac{t}{b} - \frac{a}{b^2}\right)\right]\Delta\delta_e$$

$$-\left(\frac{V C_{L_\alpha}}{2\mu \bar{c}}\right)\left(\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2}\right)\left[\frac{\lambda_2^2 e^{\lambda_1 t} - \lambda_1^2 e^{\lambda_2 t}}{b^2\sqrt{a^2-4b}} - \left(\frac{t}{b} - \frac{a}{b^2}\right)\right]\Delta\delta_e \qquad (3)$$

where

$$a = \left(\frac{V C_{L_\alpha}}{2\mu \bar{c}} - \frac{V C_{m_q} \bar{c}}{4\mu k_y^2}\right)$$

$$b = -\left(\frac{V^2 C_{L_\alpha} C_{m_q}}{8\mu^2 k_y^2} + \frac{V^2 C_{m_\alpha}}{2\mu k_y^2}\right)$$

$$\lambda_1 = -\frac{a}{2} - \frac{\sqrt{a^2-4b}}{2}$$

and

$$\lambda_2 = -\frac{a}{2} + \frac{\sqrt{a^2-4b}}{2}$$

If the velocity is constant as assumed in this simplified solution, γ as expressed in equation (3) is of prime importance to an understanding of factors pertinent to the short-time longitudinal responses of airplanes. If the lift due to elevator deflection, $C_{L_{\delta_e}}$, was zero, then γ, all its derivatives, and any height changes would be proportional to the factor

$$\left(\frac{V C_{L_\alpha}}{2\mu \bar{c}}\right)\left(\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2}\right)\Delta\delta_e$$

The down-elevator deflections required for airplanes B and C to obtain the same rate of change of normal acceleration in the initial push over, previously discussed, were based on making this parameter the same as for airplane A.

Another factor which may have important influence on the motion is the change in lift due to elevator deflection ($C_{L_{\delta_e}}$) where an up elevator deflection causes an immediate loss in lift proportional to the deflection. It should be noted that for a short coupled airplane such as airplanes B and C, which have no horizontal tails, a much larger change in lift is required in order to get a given pitching moment than is required on a conventional airplane with a horizontal tail.

RESULTS AND DISCUSSION

Comparison of Airplanes A, B, and C

A fundamental comparison of the results of all three airplanes is given in figure 1. Here the maximum available full-up elevator was used on each airplane to stop the descent following the initial push-over. In figure (1-a) is shown the change in height obtained and the elevator control movements used. The initial flight paths in the pushover were about the same as was desired although airplanes B and C required about 2 1/3 and 1 1/3 times as much increment in down elevator, respectively, as did airplane A to accomplish this (see Table III). Corrective action by the use of full-available-up elevator was attempted after the elevator was held down for 2 seconds. The amount of the increment of up elevator available on airplane B was a little more than one-half of that of airplane A, whereas the amount of the increment of up elevator available on airplane C was about three-fourths of that of airplane A. After a short period of time the elevators of airplanes A and C were moved down so as not to trim above maximum lift whereas full-up elevator on airplane B trimmed the airplane at about maximum lift.

All three airplanes responded to the up-elevator deflection in that the descent was stopped and the lost height was regained. It took approximately twice as much time, however, for airplane B to stop its descent or to regain its lost height after up-elevator movement as it does for airplane A. In addition, airplane B lost about 50 percent more height and traveled some 180 feet further before the descent was stopped than did airplane A. It is possible that a pilot may become aware of such differences when making height correction in short-time periods. Further, presuming the airplanes were retrimmed at the bottom

of the descents, the 6-foot increment in height between them could represent as much as say 100 feet in the touchdown point such an increment might be of concern. Airplane C responded more quickly than did airplane B but not as quickly as airplane A.

Figure 1-b shows the variations of angle of attack and angle of pitch for the motions just discussed. Of primary importance in changing height is of course the lift and how fast it can be changed. The angle of attack of airplane A changes at a rate about twice as fast as does airplane B. Because of the difference in wing loading and C_{L_α}, airplane A changed its normal acceleration about 3 times as fast as did airplane B and it is this acceleration which the pilot feels. What the pilot does is to pitch the airplane and what he sees is the motion of the horizon. The rate of change of the pitch angle for airplane A is also about twice as great as that of airplane B. These differences, account for the differences in response as measured by the height changes previously discussed. Here also the results for airplane C fall between those for the other two airplanes. Although not shown here, because the values of angle of pitch presented are increments from the trimmed values, the initial trimmed pitch or attitude angles of airplane A was about 4° whereas that for airplane B was well over 20° and that for airplane C was about 16°. Such differences in attitudes may influence a pilots' feelings with regard to an airplanes characteristics.

Effect of Increasing Total Elevator Effectiveness

In order to demonstrate reasons for these differences in height response, the total elevator effectiveness of airplanes B and C was increased to approximately that of airplane A by making the total elevator effectiveness parameter,

$$\left(\frac{C_{L_\alpha}}{2\mu \bar{c}}\right)\left(\frac{C_{m_{\delta_e}}}{2\mu K_Y^2}\right)\Delta\delta_e ,$$

previously discussed, the same for all airplanes. The total elevator effectiveness as used herein refers to the effectiveness of the elevator in causing an initial rate of change of flight path angle neglecting the effect of the change in lift due to elevator deflection. Making this parameter the same is done arbitrarily by assuming the factor to be increased by increasing the full-up elevator deflections, based on the same slopes of the pitching moment with elevator deflection previously used. The maximum full-up elevator deflection of airplane B was increased from -30° to about -74°, whereas for airplane C the deflection was increased from -20° to about -30°. It was realized that the increase in elevator deflection on airplane B was excessively large and beyond the linear range of $C_{m_{\delta_e}}$.

The results of calculations with the total elevator effectiveness, the same for all three airplanes are shown on figure 2. Here there is a great deal of improvement in the response of airplane B, figure 2-a, the time for the airplane to respond to up-elevator deflection is now only slightly larger than that of airplane A and the increment in height between them has been reduced to only about 2 feet. There was only slight improvement in airplane C, but, of course, less improvement and less correction was required.

The variations of the angle of attack and angle of pitch are shown in figure 2-b. Here the rate of change of angle of attack, as indicated by its slope with time, are more nearly the same for airplane B as for airplane A than before. Similarly airplane B pitched much more rapidly than before when only its normal full-up elevator was used. The changes on airplane C are only slight in that the required change in elevator deflection was much less extreme.

Effect of Eliminating the Lift Due to Elevator Deflection

The lift due to elevator deflection is a force in opposition to the desired force. This force is larger on short-coupled airplanes, such as airplanes B and C, than on conventional airplanes, as was previously discussed. It was reasoned that eliminating this factor may show some improvement on the height responses of airplanes B and C. The results of calculations with this force neglected and with the total elevator effectiveness increased in amounts as previously discussed are shown in figure 3.

The height changes and control deflections are shown on figure 3-a. The response of airplanes B and C now compare favorably with those for airplane A. The improvement due to neglecting the lift due to elevator deflection was greatest for airplane C.

The time to respond to the up-elevator movement, that is, the time to stop the descent are all about the same although the actual changes in height are somewhat different.

The variations in the angle of attack and pitch angle with time for airplanes B and C, figure 3-b, are also quite similar to that of airplane A, accounting at least in part for the similarity in height response just discussed. Thus the differences in short-time responses to elevator control for two widely different types of airplanes, airplane A representing conventional straight-wing types, and airplanes B and C representing swept-wing types having no horizontal tails, are primarily the results of differences in total elevator effectiveness and the increment of lift due to elevator deflection.

Effects of Other Parameters

It has been reasoned that other parameters than those previously discussed also may influence the short-time responses of the airplanes. It was felt that the great differences in the L/D ratios of airplane A and airplanes B and C could effect the results in that airplanes B andC would tend to trim in much steeper glide path angles following the up elevator movement, (see reference 1). A comparison of the L/D ratios of airplanes A, B, and C is shown on figure 4. Airplanes B and C have much smaller L/D ratios for the landing conditions but of even more importance the variations of L/D with angle of attack from the trimmed angle of attack are much larger than for airplane A. The results previously discussed, however, indicate that these differences in L/D ratio do not influence the short-time responses, primarily because there was no appreciable variation in the velocity during the short times. The effect of the increased drag causing the larger variations in L/D on airplanes B and C, is to reduce the velocity more rapidly on airplanes B and C than on airplane A. This is primarily a long period effect, however, and may be expected to effect only the changes in height after long periods. Figure 5 shows the relatively long time variations of height for airplanes A, B, and C with the airplanes in the same conditions previously shown in figure 3. The total elevator effectiveness of airplane B and C were increased and the lift due to elevator deflection was eliminated for airplanes B and C for the calculations of figure 5, as they were in figure 3. The change in height for the first 4 seconds

in figure 5 is the same as that shown on figure 3. From this time until the end of the motion shown, there is developed a great differences in the height for the three airplanes, airplane A gaining the most altitude. All airplanes appear to be in a long period or phugoid motion and at the end of the motion shown are descending because of the increased drag at the angle of attack of maximum lift. Airplane C having the least L/D ratio is descending most rapidly.

Other parameters which may be considered as important to the motion are the stability derivatives C_{m_α} and C_{m_q}. The effects of increasing the value of the damping derivative, C_{m_q}, on airplane B was studied but the results are not shown here. Increasing the value of C_{m_q} did not appreciably influence the time at which the descent, following the push over and then pull up, was checked. The primary effect was to reduce the rate of change of the pitch angle and angle of attack and thus in the push over and subsequent pull up the height changes were reduced, with increasing C_{m_q}.

No specific calculations were made to determine the effect of changes in the static stability derivative, C_{m_α}. From the simplified analytical considerations, previously discussed, however, the parameter in which C_{m_α} is dominate (assuming the lift due to elevator deflection, $C_{L_{\delta_e}} = 0$), is

$$\left(\frac{V^2 C_{L_\alpha} C_{m_q}}{8\mu^2 k_y^2} + \frac{V^2 C_{m_\alpha}}{2\mu k_y^2}\right)$$

The values of these parameters for airplanes A, B, and C are nearly the same. The motions for all three airplanes were also nearly the same when the total elevator effectiveness of airplanes B and C were increased to that of airplane A and the lift due to control deflection, $C_{L_{\delta_e}}$, was eliminated. It may be reasoned, however, that reducing the static stability, C_{m_α}, would allow an airplane to pitch faster, increase its angle of attack faster, and thus to respond more quickly to elevator deflection. Increasing C_{m_α} would, of course, have the opposite effect.

General Discussion

Examination of some of the parameters which are involved in longitudinal motions may give an understanding of the results just shown. Some of these parameters for airplanes B and C are compared relatively to those of airplane A in Table IV. From the simplified analytical consideration, it is indicated that these parameters are indicative, comparatively, of the motion to be expected at the time of control movement. The parameter $\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2}$ indicates the effectiveness of the elevator on the rate of changing the angle of the pitch. Airplanes B and C were less effective than airplane A. The parameter $\frac{V C_{L_\alpha}}{2\mu \bar{c}}$

indicates the ability when pitched, to change lift and therefore the normal acceleration and flight path. This parameter was smallest for airplanes B and had about the same value for airplanes A and C. The product of these parameters and the available elevator deflection (called the total elevator effectiveness) for airplanes B and C was about $\frac{1}{4}$ and $\frac{2}{3}$, respectively, of that of airplane A. This indicates why the impractically large increase in up-elevator deflection, previously referred to was required for airplane B.

The parameter $\frac{V C_{L_{\delta_e}} \Delta\delta_e}{2\mu\bar{c}}$ (Table III) of course indicates the change in normal acceleration due to control deflection. Considering the up-elevator deflections available, this parameter is about the same for airplanes A and B. The value for airplane C was about $2\frac{1}{3}$ times as great as for either of the other airplanes.

In general the time it takes an airplane of a specific configuration to respond in height, for a given elevator deflection, depends on the rate at which it can change its flight-path angle. It has been shown that, for a short period motion, the rate of changing the flight-path angle depends mainly on the magnitude of the weight, moment of inertia (I_y), $C_{m_{\delta_e}}$, C_{L_α}, $C_{L_{\delta_e}}$, and $\Delta\delta_e$. An increase in weight, I_y, or $C_{L_{\delta_e}}$, or a decrease in C_{L_α}, $C_{m_{\delta_e}}$, or $\Delta\delta_e$ will tend to decrease the airplanes' ability to quickly respond in height.

CONCLUDING REMARKS

The investigation reported in this paper was undertaken to see if there are inherent differences in the response of the flight path angle to control movements between swept wing airplanes having no horizontal tail and using trailing edge flaps for longitudinal control and conventional airplanes, which are known to have satisfactory response characteristics. Particular emphasis is placed on the final few seconds of the landing approach.

This study shows that the only difference in the short-time response of the flight path between the two types of airplanes is in a time lag in the flight path angle response of the swept wing airplanes. This time lag was found to result from two factors, first a relatively small value of the parameter

$$\left(\frac{VC_{L_\alpha}}{2\mu\bar{c}}\right)\left(\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2}\right) \Delta\delta_e$$

which is a measure of the effectiveness of the control in changing the flight path angle, and second a relatively large value of the parameter

$$\left(\frac{V C_{L_{\delta_e}}}{2\mu\bar{c}}\right) \Delta\delta_e$$

which is a measure of the amount of undesirable change in lift accompanying the control deflection required to change the angle of attack. It had been suspected that the relatively large change in drag with angle of attack, of low-aspect-ratio swept wing airplanes having no horizontal tails would be an important factor in the flight path angle response but this was found not to be the case for the short time intervals under consideration.

The importance of the differences found in the response characteristics between the two types of airplanes studied can only be evaluated by flight experience. Other factors such as range of vision, control feel, the pilots' reaction to the relatively large nose up attitudes of the low aspect ratio swept wing airplanes and psychological influences associated with new type airplanes may be of equal or greater importance.

REFERENCE

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TABLE I.- MASS, DIMENSIONAL AND AERODYNAMIC PARAMETERS

[Aerodynamic parameters for airplanes B and C generally given relative to those for airplane A]

Airplane	$\frac{W}{S}$	$\frac{k_y}{\bar{c}}$	$\frac{C_{m_q}}{(C_{m_q})_A}$	$\frac{C_{m_{\delta_e}}}{(C_{m_{\delta_e}})_A}$	$\frac{C_{L_{\delta_e}}}{(C_{L_{\delta_e}})_A}$	$\frac{C_{D_{\delta_e}}}{(C_{D_{\delta_e}})_A}$	$\frac{C_{m_\alpha}}{(C_{m_\alpha})_A}$	$\frac{C_{L_\alpha}}{(C_{L_\alpha})_A}$	$\frac{C_{L_{trim}}}{C_{L_{max}}}$
A	49.1	0.99	------	------	------	------	------	------	0.63
B	42.7	.57	0.12	0.29	1.71	1.61	0.65	0.62	.79
C	26.1	.46	.04	.18	1.50	1.70	.39	.57	.65

TABLE II.- INITIAL TRIM VALUES FOR STEADY LEVEL FLIGHT AT 185.8 ft/sec (110 KNOTS)

Airplane	α, deg	γ, deg	θ, deg	T, lb	δ_e, deg
A	4.40	0	4.40	2,642	5.0 (1.5° up stabilizer)
B	21.85	0	21.85	4,770	-20.0
C	15.97	0	15.97	2,781	-1.5 (30° up trimmer)

TABLE III.- ELEVATOR DEFLECTIONS USED AND COMPARISON OF RESULTING PARAMETERS AFFECTING LONGITUDINAL MOTION

[Parameters for airplanes B and C given relative to those for airplane A]

Airplane	Push-down $\Delta\delta_e$, deg (From trim elevator deflection)	Pull-up $\Delta\delta_e$, deg (From push-down elevator deflection)	$\frac{\Delta\delta_e}{(\Delta\delta_e)_A}$ (for pull-up)	[a] $\frac{\frac{V^2 C_{m_{\delta_e}} \Delta\delta_e}{2\mu k_y^2} \frac{VC_{L_\alpha}}{2\mu\bar{c}}}{\left(\frac{V^2 C_{m_{\delta_e}} \Delta\delta_e}{2\mu k_y^2} \cdot \frac{VC_{L_\alpha}}{2\mu\bar{c}}\right)_A}$	[b] $\frac{\frac{VC_{L_{\delta_e}} \Delta\delta_e}{2\mu\bar{c}}}{\left(\frac{VC_{L_{\delta_e}} \Delta\delta_e}{2\mu\bar{c}}\right)_A}$
Original elevator deflection					
A	1.86	-24.86	----	------	-----
B	[c] 4.33	-14.33	.58	.25	1.14
C	[c] 2.45	-20.95	.84	.64	2.37
Increased up-elevator deflection					
B	[c] 4.33	[c] -57.81	2.33	1.00	-----
C	[c] 2.45	[c] -32.71	1.32	1.00	-----

[a]Parameter indicates total available elevator effectiveness in causing a rate of change of flight-path angle (neglecting change in lift due to elevator deflection).

[b]Parameter indicates change in lift due to elevator deflection.

[c]These $\Delta\delta_e$ values resulted in the initial increment of $\ddot{\gamma}$ being approximately the same as for airplane A (neglecting change in lift due to elevator deflection).

TABLE IV.- COMPARISON OF PARAMETERS AFFECTING LONGITUDINAL MOTION

[Parameters for airplanes B and C given relative to those for airplane A]

Airplanes	$\dfrac{\frac{1}{2\mu k_y^2}}{\left(\frac{1}{2\mu k_y^2}\right)_A}$	$\dfrac{C_{m_{\delta_e}}}{\left(C_{m_{\delta_e}}\right)_A}$	(a) $\dfrac{\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2}}{\left(\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2}\right)_A}$	$\dfrac{\frac{1}{2\mu \bar{c}}}{\left(\frac{1}{2\mu \bar{c}}\right)_A}$	$\dfrac{C_{L_{\delta_e}}}{\left(C_{L_{\delta_e}}\right)_A}$	(b) $\dfrac{\frac{VC_{L_{\delta_e}}}{2\mu \bar{c}}}{\left(\frac{VC_{L_{\delta_e}}}{2\mu \bar{c}}\right)_A}$	$\dfrac{C_{L_\alpha}}{\left(C_{L_\alpha}\right)_A}$	$\dfrac{\frac{VC_{L_\alpha}}{2\mu \bar{c}}}{\left(\frac{VC_{L_\alpha}}{2\mu \bar{c}}\right)_A}$	(c) $\dfrac{\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2} \Big/ \frac{VC_{L_\alpha}}{2\mu \bar{c}}}{\left(\frac{V^2 C_{m_{\delta_e}}}{2\mu k_y^2} \Big/ \frac{VC_{L_\alpha}}{2\mu \bar{c}}\right)_A}$
B	2.06	.29	.60	1.15	1.71	1.97	.62	.71	.43
C	3.94	.18	.71	1.88	1.50	2.82	.57	1.07	.76

[a]Parameter indicates elevator effectiveness in causing a rate of change of pitch angle.

[b]Parameter indicates change in lift due to elevator deflection.

[c]Parameter indicates elevator effectiveness in causing a rate of change of flight-path angle (neglecting change in lift due to elevator deflection).

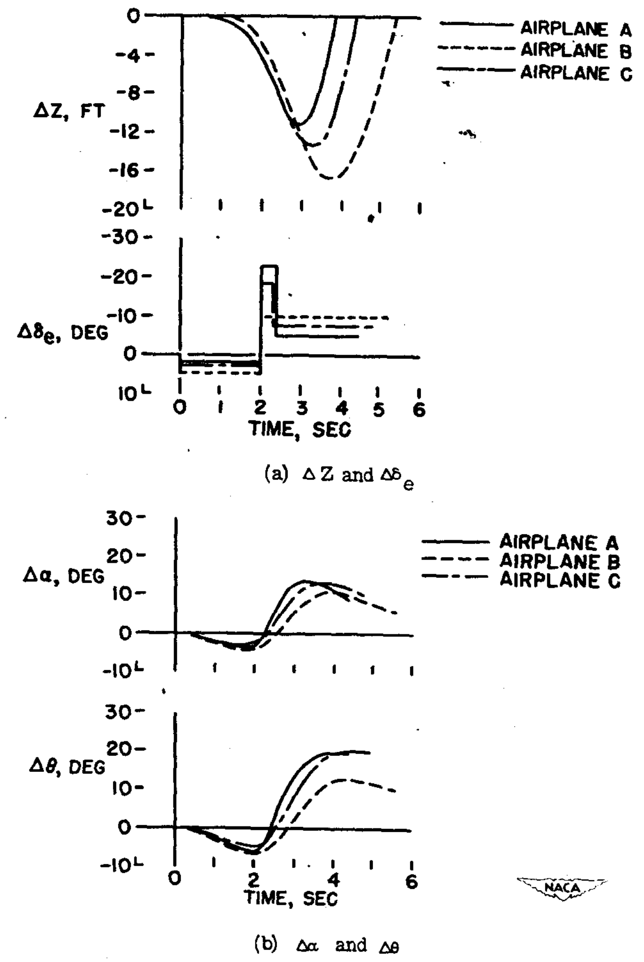
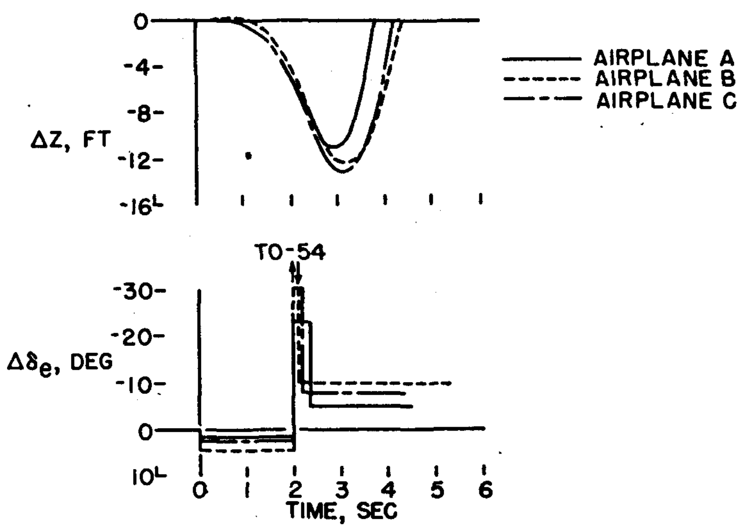
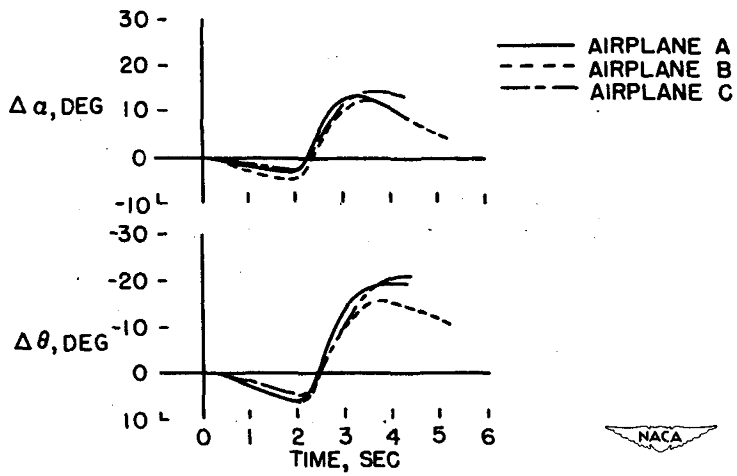


Figure 1.- Comparison of short time responses of airplanes A, B, and C with available up-elevator deflection.

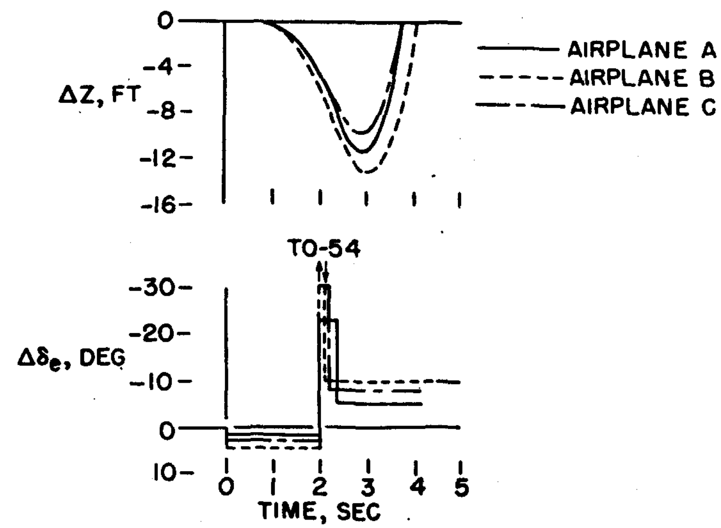


(a) ΔZ and $\Delta\delta_e$

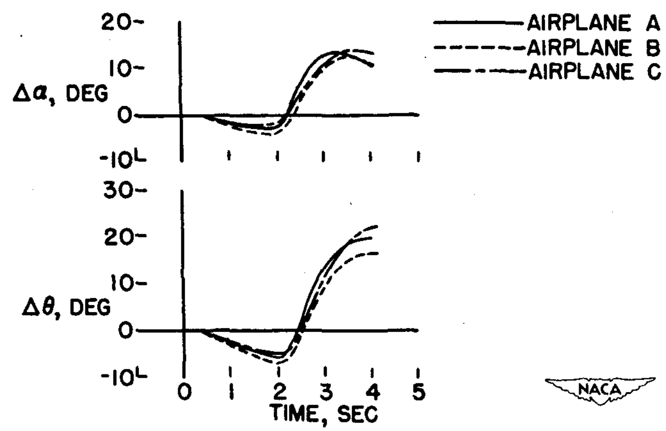


(b) $\Delta\alpha$ and $\Delta\theta$

Figure 2.- Comparison of short time responses of airplanes A, B, and C. Airplanes B and C with increased up-elevator deflection.



(a) ΔZ and $\Delta\delta_e$



(b) $\Delta\alpha$ and $\Delta\theta$

Figure 3.- Comparison of short time responses of airplanes A, B, and C. Airplanes B and C with increased up-elevator deflections and the change in lift due to elevator deflection eliminated.

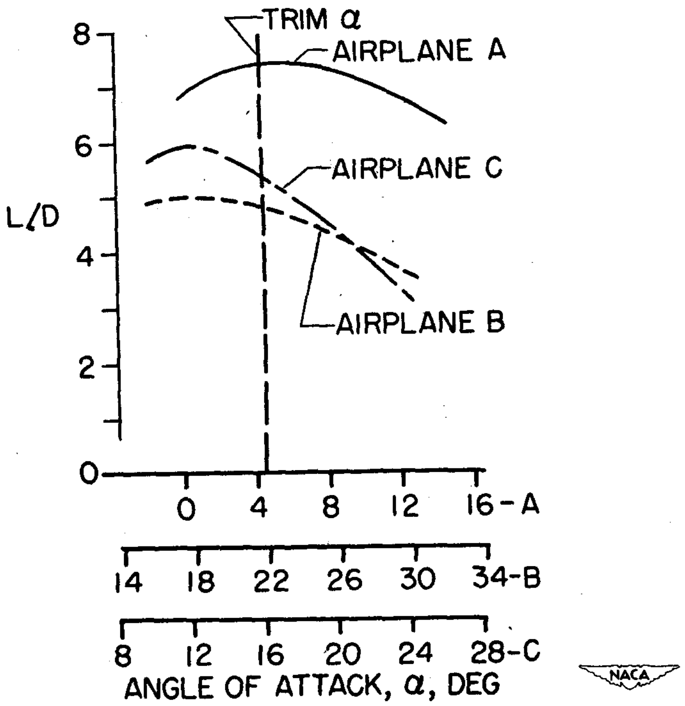


Figure 4.- Variations of lift-to-drag ratio with angle of attack for airplanes A, B, and C.

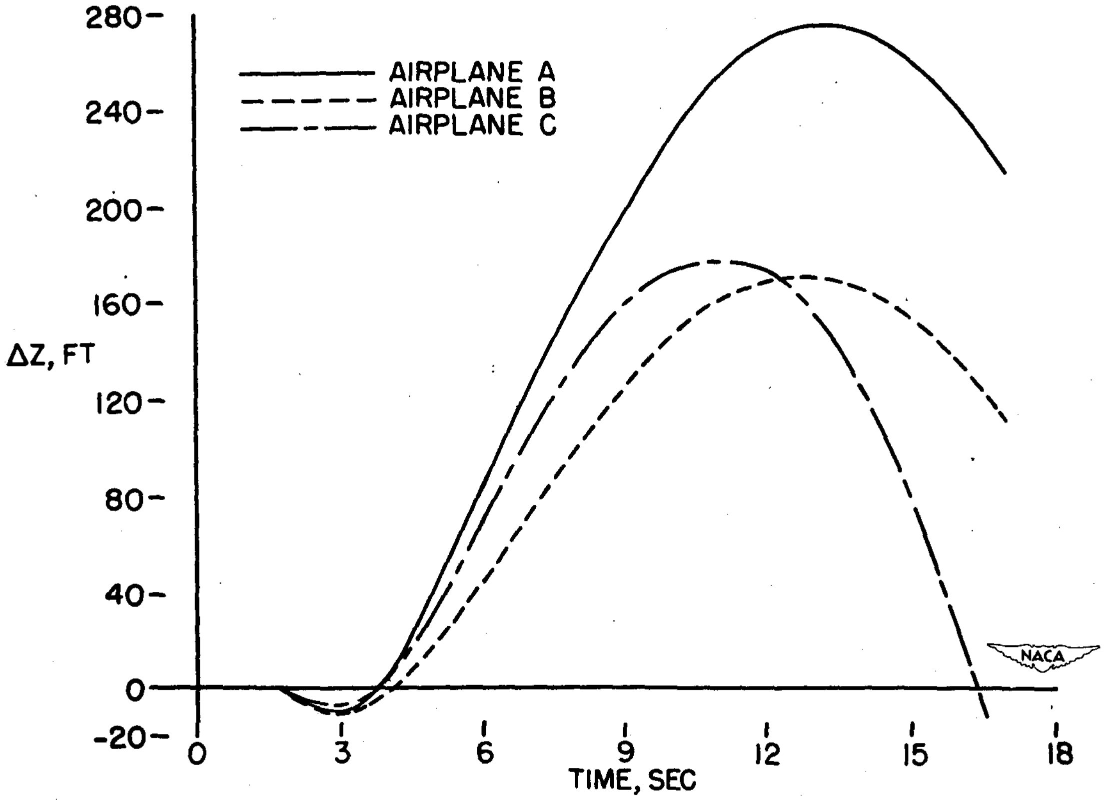


Figure 5.- Comparison of the change in height for long time periods of airplanes A, B, and C. Airplanes B and C with increased up-elevator deflections and the change in lift due to elevator deflection eliminated.