NASA - Langley

DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF PARAWINGS

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INTRODUCTION

Recently, the Langley Research Center has conducted several investigations to determine the dynamic stability and control characteristics of models employing the parawing concept. These investigations have consisted of free-flight model tests conducted in the Langley full-scale tunnel and outdoors using the drop-model technique with uncontrolled and radio-controlled models.

The models used in the dynamic stability studies have varied from small-scale, simple research configurations to large-scale, inflatable configurations similar to those currently being considered for recovery system applications. Control for most of the model flight tests was obtained from the center-of-gravity-shift control system but a few tests were made in which other methods of control were evaluated. This paper presents a brief summary of the dynamic stability and control information obtained in these tests and includes the results of related analytical studies and force test investigations.

LONGITUDINAL STABILITY CHARACTERISTICS

Some static longitudinal stability information obtained in recent force test investigations of parawings are presented in figures 1 to 3. Basic pitching moment data for a parawing configuration having a low center of gravity position is presented in figure 1 for an angle-of-attack range of the keel from -10° to 50°. These data show static longitudinal stability over most of the positive angle-of-attack range with an increase in static stability above the stall. For some parawings, longitudinal instability or pitch-up has occurred near the stall. In the low positive angle-of-attack range, parawing configurations have been found to have very low static stability and instability at low negative angles of attack This static instability, either at low or high angles of attack can lead to dynamic stability problems. One problem of this type is a tendency toward an end over end tumbling motion which may occur under some conditions of flight. Some static force test information related to the tumbling problem is presented in figure 2.

The data of figure 2 show static pitching moment characteristics over a 360° angle-of-attack range for a parawing configuration with low center of gravity together with similar data for a conventional delta wing configuration with the center of gravity in the plane of the wing. Notice the near 0° and, of course, 360° angle of attack (which also corresponds to 0°) both configurations have a stable trim point. In the case of the conventional wing, a disturbance which pitches the wing away from its trim point is opposed by large restoring moments which are symmetrical at positive or negative angles of attack. In the case of the parawing, however, there is a region of static longitudinal instability at low negative angles of attack and large differences in the magnitude of the positive and negative pitching moments over the angle-of-attack range. The static instability at low negative angles of attack is related to the reversal in the fabric as the wing pitches through zero angle of attack. The large asymmetry in the positive and negative pitching moments is related to the low center-of-gravity offset. A parawing configuration which pitches downward through its trim point to low negative angles of attack will encounter the region of static longitudinal instability and will therefore tend to pitch downward to even higher negative angles of attack. If the pitching motion is great enough to overcome the restoring moments in the first half of the cycle, then the pitching motion will continue with energy being fed into the system as the configuration seeks its stable trim point near 0° angle of attack. This energy acts as a driving force which tends to pitch the configuration through its stable trim point and into the region of static instability. From these results it can be seen how a steady nose-down tumbling motion could be established for a configuration of this type. It should be pointed out, however, that predictions of a tumbling motion cannot be made based on static data alone. There are other factors, such as damping in pitch and mass and inertia characteristics which must be considered in determining stable and unstable boundaries in a dynamic stability problem of this type. It should also be pointed out that the data presented in figure 2 apply to configurations having rigid connections between the center of gravity or payload and the parawing and therefore are not directly applicable to recovery systems where flexible risers are involved unless the risers are in tension.

Presented in figure 3 is the low subsonic parawing data from the previous figure together with data at a Mach number of 4.5 for the micrometeoroid parawing configuration. It is interesting to note the general similarity in the static pitching characteristics for the two cases in that the Mach number 4.5 data show static instability at low negative angles of attack and unsymmetrical pitching moment variations over the angle-of-attack range. Based on these data it would appear that the micrometeoroid configuration may have tumbling problems similar to those encountered with the low subsonic models. Analysis made by the 7 x 10-foot tunnels branch has indicated that the build-up in dynamic pressure which occurs when this configuration enters the atmosphere acts to prevent tumbling but there are critical conditions in this speed range where tumbling may occur.

LATERAL STABILITY CHARACTERISTICS

To date, the dynamic lateral stability characteristics of parawings have been found to be generally satisfactory. Presented in figure 4 are some static and dynamic lateral stability derivatives which were measured for a parawing configuration at various center of gravity locations below the parawing keel. Presented in this figure are the static lateral stability derivatives C_{n_β} and C_{l_β}, the yawing derivatives $C_{n_r} - C_{n_{\dot\beta}}$ and $C_{l_r} + C_{l_{\dot\beta}}$, the rolling derivatives C_{n_p} and C_{l_p}, and the ratio of yawing inertia to rolling inertia I_Z/I_X. Some significant changes in these derivatives as the center of gravity was lowered (that is, increasing Z/b) are the increases in directional stability and positive dihedral effect, the increase in damping in roll, and the decrease in the radio of I_Z/I_X. The effect of the changes in these derivatives on the calculated Dutch roll damping is presented in figure 5. Plotted in figure 5 is the calculated Dutch roll damping, $1/c_{1/2}$ (one over cycles to damp to one-half amplitude), against Z/b. Although the data show that the damping for the configuration with the low center of gravity ($Z/b = .5$) is only about one-fourth of the value for the configuration with the center of gravity on the keel ($Z/b = 0$), the damping is still considered good for the low center-of-gravity condition. Reducing the geometric dihedral by 18°, which has been suggested as a possible means of improving lateral control (as will be discussed later), increased the damping for this condition. It should be pointed out that the values of damping shown here do not take into account the effects of bodies beneath the parawing. In cases where large destabilizing bodies are used, the Dutch roll damping could possibly be reduced down into the unstable region.

CONTROL CHARACTERISTICS

As was pointed out in the INTRODUCTION, control for most parawing flight tests to date was obtained from the center-of-gravity-shift control system. Longitudinally, this control system has been found to be generally effective but in some cases large stick forces and unstable stick force gradients have been encountered. Presented in figure 6 are calculated data which show the variation in longitudinal stick force with lift coefficient for a control system of this type using several different riser arrangements. These results, which were presented by Hewes at the Apollo Conference last year, show unstable stick force gradients and indicate that the gradients can be altered appreciably by changing the riser lengths and attachment points. Analysis indicates that the stick force gradients could have been made stable in these cases by proper arrangement of the risers. It is, of course, desirable to have the stick force gradient stable from handling qualities considerations and to keep the gradients low from control power requirements.

In the analysis of this type of control system it was found that the significant factor involved in determing the stick force characteristics was the C_{m_o} of the wing. Some information to illustrate this point is presented in figure 7. On the left side of this figure is a plot of the pitching moment coefficient (referred to the parawing keel) against lift coefficient and, on the right side, is a plot of C_{m_o} against stick force gradient. The data presented are for the Ryan Flex-Wing configuration and for an inflatable parawing of the type being considered for recovery system applications. In the case of the Ryan Flex-Wing, it was found that at moderate lift coefficients this configuration had positive values of C_{m_o} which produced a high stable stick force gradient. In order to reduce the stick forces in this case, the gradient was lowered by reducing C_{m_o} through trailing-edge modifications to the wing so that in the final arrangement the stick forces were in a more tolerable region. Based on these data, it appears that parawings for recovery systems, which have been found to have negative values of C_{m_o}, will have high unstable stick force gradients unless some means is used to reduce these values of C_{m_o}, either by changes in the wing itself or by changes in the rigging as mentioned earlier.

From the lateral control standpoint, there has been some indication of possible problems in the use of the center-of-gravity-shift control system. An equation for calculating the net rolling moment produced by this type of control system is presented in figure 8. This equation is $C_{l_{net}} = C_L \sin \phi \; Z/b \; (1 - -C_{l_\beta} / C_{n_\beta} \; L/D)$. The $C_L \sin \phi \; Z/b$ term in this equation is derived from the fact that when the wing is banked, the lift vector is tilted and has a component which produces a rolling moment about the center of gravity through the moment arm Z/b. The term $(1 - -C_{l_\beta}/C_{n_\beta}\ L/D)$ is called the rolling effectiveness factor and is derived from the fact that the lift component which produces roll is rearward of the center of gravity and also produces an adverse yawing moment through the arm X/b. When the sideslip angle resulting from this adverse yawing moment is taken into account, it can be shown that the favorable rolling moment produced by the lift vector is reduced through the effective dihedral parameter C . For configurations having high ratios of $-C_{l_\beta}/C_{n_\beta}$ and low values of L/D, the rolling effectiveness term becomes small and therefore the net rolling moment produced in such ases is reduced. Presented in figure 9 are some data showing the effect of leading-edge thickness on these parameters. Plotted in this figure are values of C_{n_β}, $-C_{l_\beta}$, L/D and the rolling effectiveness factor $(1 - -C_{l_\beta}/C_{n_\beta}\ L/D)$ for a parawing with a leading edge thickness of 1.5 percent of the keel and another having a leading edge thickness of 7 percent of the keel. These results indicate that the rolling moment produced by banking the wing is reduced by about 50 percent at moderate lift coefficients for either wing and that the rolling effectiveness for the wing with the thin leading edges decreases rapidly with increasing lift coefficient and approaches zero near maximum lift coefficient. It is significant to note that for the thick leading-edge configuration, which is representative of inflatable parawings now being considered for recovery systems, there is an increase in effectiveness with increasing lift coefficient.

In discussing lateral control characteristics, another factor which must be considered is that of lateral hinge moments. Some indication of the lateral hinge moment characteristics involved in the center-of-gravity-shift control system was obtained in the force test investigation of the Ryan Flex-Wing airplane. Some of the results obtained in this investigation are presented in figure 10. Plotted in this figure is rolling moment coefficient against roll hinge moment coefficient. The horizontal dashed line plotted in this figure represents the value of C_l required to produce a pb/2V of 0.09 based on a value of damping in roll of -.15. This value of pb/2V is the minimum value specified in the handling qualities requirements for a light liaison airplane. It is presented here merely to establish a reference for purposes of comparison and is not intended to imply that this value of pb/2V is a valid specification for parawing applications. For recovery system applications, a smaller value may well prove to be acceptable. Considerably more research and flight experience will be required to establish the proper criterion for this case. The solid circle at the lower right, which represents measured data, shows that 5^{o} of wing bank produces only about one-third of the rolling effectiveness required by the pb/2V = .09 criterion. The stick force corresponding to the hinge moment for this condition was about 70 pounds. Analysis indicated that reducing $C_{l\beta}$ by using 18^{o} negative geometric dihedral angle of the wing would improve the rolling effectiveness and reduce the hinge moments. It was also estimated that increasing Z/b up to 0.5, which is a value representative of parawing recovery systems, would substantially increase the rolling moments without increasing the hinge moments.

Because of the problems that have been encountered with the center-of-gravity-shift control system, some attention has recently been given to other methods of control for parawings. Presented in figure 11 are some of the alternative control methods that have been proposed. These methods are:

1. Trailing edge bolt rope. In this control system the tension is increased or decreased in a cable in the parawing trailing edge to provide pitch or roll control.

2. Trailing edge risers. In this control system risers are attached to the parawing trailing edge and pulled down or released to provide control.

3. Hinged leading-edge or keel members. In this control system hinges are placed in the wing leading edges or keel and the aft portion of these members deflected for control.

4. Auxiliary surfaces. This control system is concerned primarily with surfaces placed at the rear of the wing to provide directional control.

Some promising results have been obtained with a wing-tip control system in tests in the Langley full-scale tunnel with the Ryan Flex-Wing airplane. In order to show how these results compare with those for the center-of-gravity-shift control system, data for both types of control are presented in figure 12. Plotted in this figure are the data for the wing bank control system from figure 10 for comparison purposes. Also plotted are measured data for 5° and 10° deflection of the aft 25-percent of the wing leading edges for control. These results show that with about 7° deflection of the wing tips a $pb/2V$ of .09 could be produced with a hinge moment coefficient considerably less than that produced by banking the wing. The stick force corresponding to the hinge moment for 7° deflection of the wing tip was about 30 pounds on the Ryan Flex-Wing airplane.

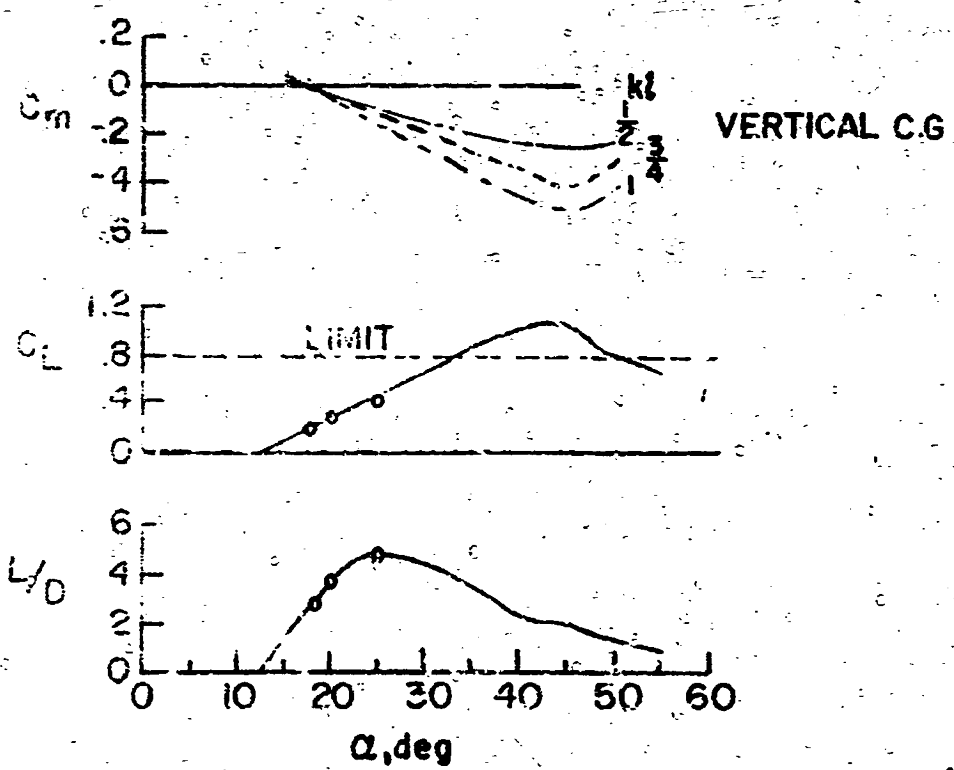
SUMMARY

1. Parawing configurations generally have satisfactory dynamic longitudinal stability characteristics in the normal operational angle-of-attack range but there may be problems at extreme angles of attack (either high or low) because of static longitudinal instability.

2. Laterally, parawing configurations generally have satisfactory dynamic stability characteristics.

3. From the control standpoint, the use of the center-of-gravity-shift control system may be generally satisfactory for recovery systems applications but this type of control system may introduce some stick-force problems and may become inadequate for configurations having high ratios of dihedral effect to directional stability and low values of L/D.

STATIC AERODYNAMIC CHARACTERISTICS OF PARAWING (BASIC Λ=45°, DEPLOYED Λ=55°)



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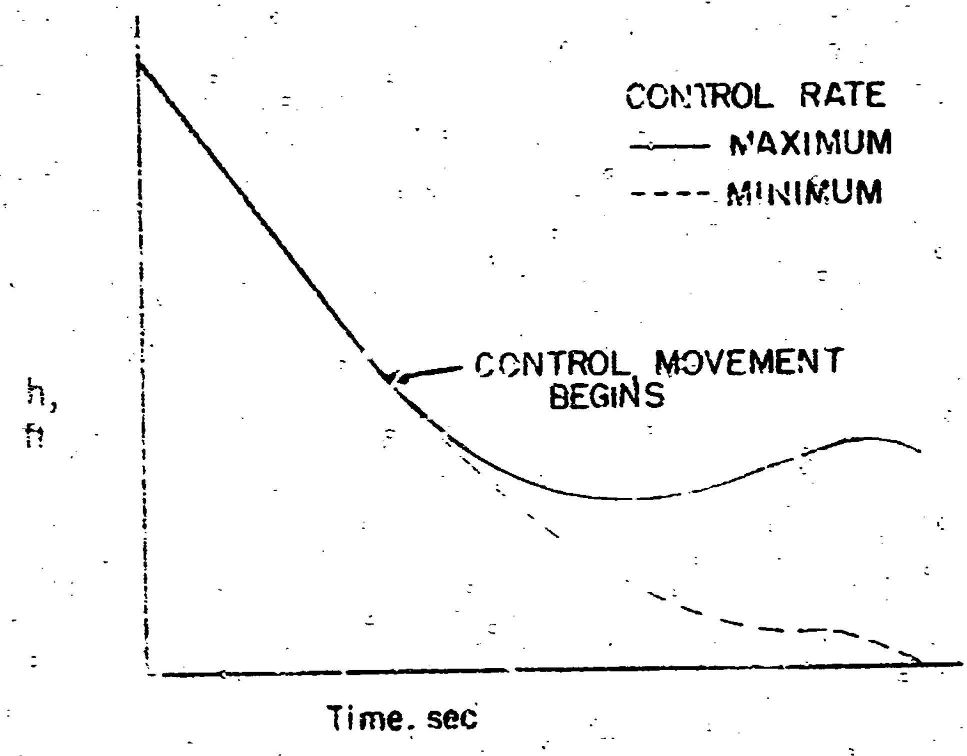
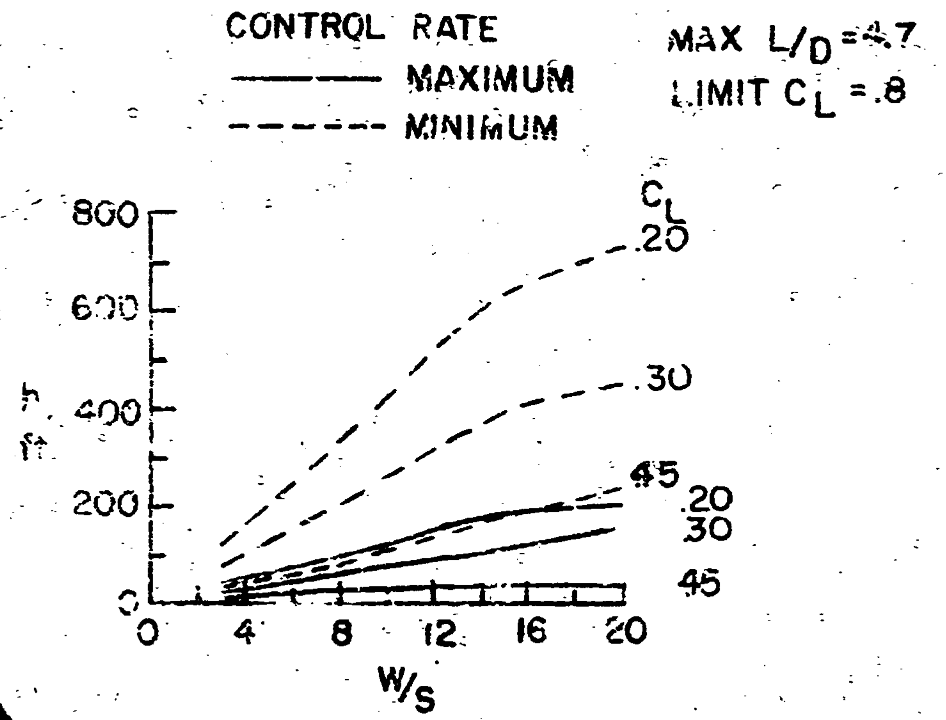
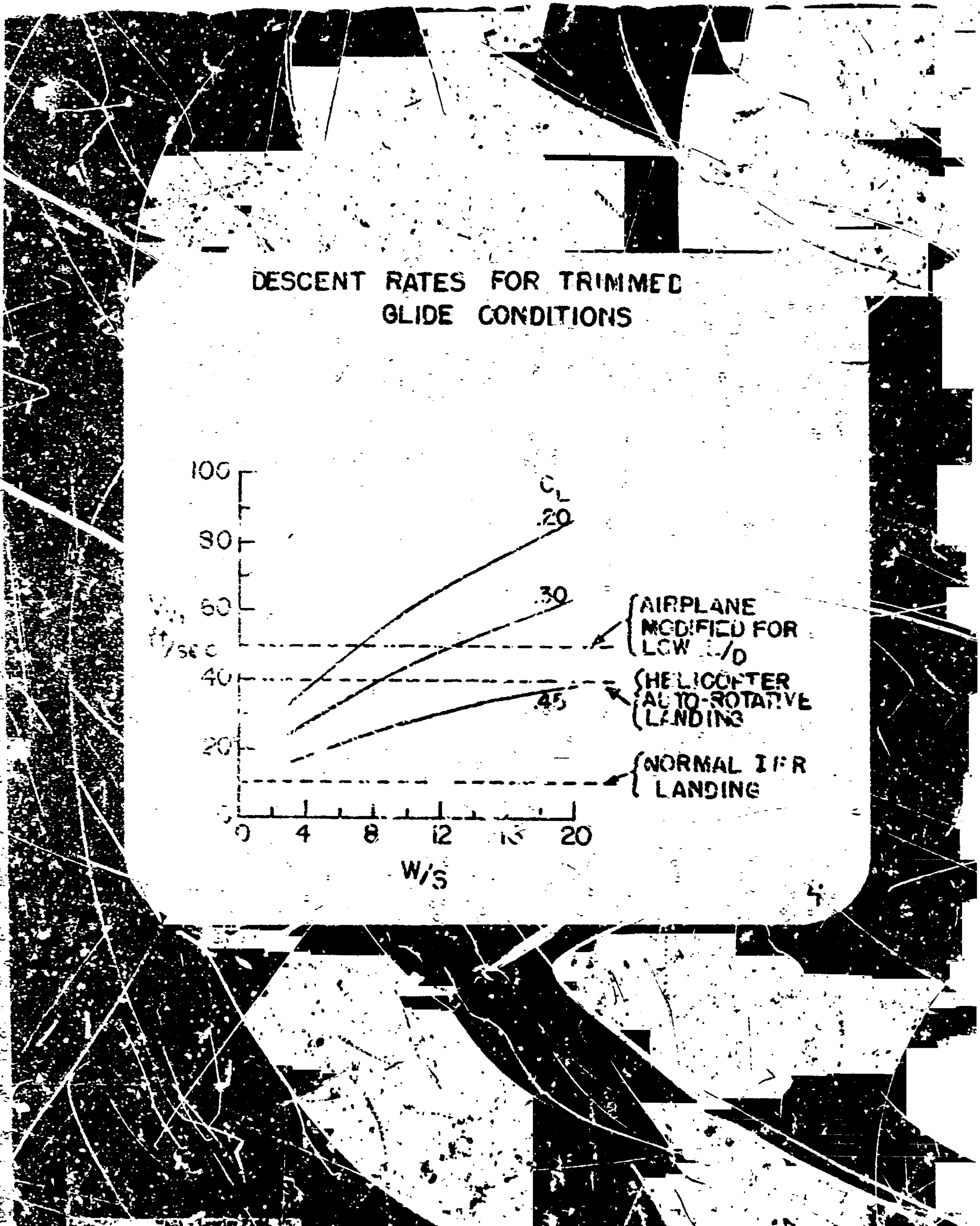
FLARE MANEUVER



ALTITUDE USED DURING FLARE





DESCENT RATES FOR TRIMMED GLIDE CONDITIONS
100
80
60
40
20
0
0
4
8
12
20
W/S
C_L
.20
.30
.45
AIRPLANE MODIFIED FOR
HELICOPTER
LANDING
NORMAL
LANDING