

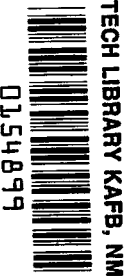
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STALLING AND TUMBLING OF A RADIO-CONTROLLED PARAWING AIRPLANE MODEL

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STALLING AND TUMBLING OF A RADIO-CONTROLLED
PARAWING AIRPLANE MODEL

By Charles E. Libbey and Joseph L. Johnson, Jr.

SUMMARY

A free-flight investigation of a radio-controlled parawing model has been made to determine the dynamic stability and control characteristics over a large angle-of-attack range with emphasis on studies of post-stall dynamic behavior. The model consisted basically of a rectangular platform fuselage with a pylon structure which supported the parawing overhead and was powered by a pusher propeller located at the rear of the platform.

The results of the investigation showed that the model had dynamic longitudinal and lateral stability and was controllable in the normal operating range of angle of attack, although there was a decrease in lateral control effectiveness as the angle of attack was increased. In gentle stalls the model showed no tendency toward roll-off and no spin-like motion was encountered. Recoveries from such stalls could be effected readily by proper use of the pitch control. After whip stalls, however, the model could develop an extremely violent dynamic longitudinal instability in the form of a nose-down, end-over-end tumbling motion. This tumbling motion appeared to be caused by the low position of the center of gravity relative to the wing and by the reversal in the direction that the parawing fabric billowed when the model pitched down to negative angles of attack. It was found that at times tumbling could be avoided and the model could be recovered from violent stalls by the use of corrective pitch control provided this control was applied soon enough and provided the pitching angular momentum was not allowed to become excessive.

One-degree-of-freedom dynamic tests in pitch and static wind-tunnel force tests were made of the parawing alone to aid in the interpretation of the flight tests.

INTRODUCTION

The National Aeronautics and Space Administration is conducting a general investigation to provide some basic information on configurations employing the parawing concept. (For example, see refs. 1 to 3.) As part of this general study, an outdoor, radio-controlled flight-test investigation has been conducted by the Langley Research Center of a parawing model. The model consisted

basically of a rectangular platform fuselage with a pylon structure which supported the parawing overhead. The vehicle was powered by a pusher propeller located at the rear of the fuselage platform and had a cockpit windscreen located at the front. Control was obtained by rolling and pitching the wing with respect to the fuselage platform. A model generally similar in design to the vehicle of the present investigation was flight tested in the Langley full-scale tunnel over the normal operating angle-of-attack range and into the stalled range; the results of this investigation are reported in reference 4. The present flight-test investigation was made primarily to extend the work of reference 4 to include dynamic stability studies in the angle-of-attack regions beyond the normal operational boundaries, for example, into the regions which might be inadvertently encountered in recovering from a stalled attitude.

The present investigation consisted of radio-controlled flight tests to determine the dynamic stability and control characteristics of the model over a large angle-of-attack range with emphasis on studies of dynamic behavior in post-stall and stall recovery conditions. In addition to the flight tests, a few wind-tunnel tests were made to obtain some basic information for use in correlation with the flight-test results. The wind-tunnel tests included static-force tests over an angle-of-attack range of 360° and, also, one-degree-of-freedom dynamic tests in which a parawing was mounted on a support assembly which allowed 360° of freedom in pitch about a fixed axis.

SYMBOLS

The pitching-moment data are referred to the center-of-gravity position shown in figure 1. The pitching-moment coefficient is based on the area of the flat planform of the wing (45° sweepback).

C_D	drag coefficient, D/qS
C_L	lift coefficient, L/qS
C_m	pitching-moment coefficient, M_y/qSk
D	drag, lb
k	keel of parawing, ft
L	lift, lb
M_y	pitching moment, ft-lb
q	dynamic pressure, $\rho V^2/2$, lb/sq ft
S	wing area, sq ft, based on flat planform of wing
V	airspeed, ft/sec

α_{keel} angle of attack of wing keel
 ρ air density, slugs/cu ft

MODEL AND TEST EQUIPMENT

A three-view drawing and a photograph of the flight-test model are shown in figures 1 and 2, respectively. The wing was constructed from acrylic-coated 1.2-ounce-per-square-yard nylon ripstop fabric over an aluminum-alloy-tubing framework. The fabric material was essentially nonporous and very flexible as well as being very light. It was cut to a 45° sweepback modified delta planform and had casings sewn at the leading edges and the root chord to accept the structural members. The two leading edges and the keel were each 5 feet long and were joined at the forward end. A spreader bar was used between the two leading edges and joined to the keel to maintain the leading edges at a 50° sweepback angle regardless of the various loads imposed on the structure during maneuvering flight.

The fuselage consisted of a rectangular planform flat plate and a pylon structure used to support the parawing. A universal joint at the top of the pylon allowed the wing to pitch and roll relative to the fuselage. This wing pivot point was approximately 44 percent of the keel length back from the nose. The radio receiver, batteries, servomechanisms, and a single-cylinder two-cycle gasoline engine driving a pusher propeller were mounted on the flat-plate fuselage. The weight of the model was approximately $11\frac{3}{4}$ pounds.

Pitch control was achieved by a push rod attached to the wing keel forward of the pivot point and to a servomechanism on the fuselage. Roll control was achieved by two flexible cables attached to the wing spreader bar, one on each side of the pivot point, and to a second servomechanism. Engine speed was controlled by an exhaust throttle linked to a third servomechanism. Closing the throttle and thus increasing the back pressure in the cylinder caused the engine to run more slowly.

A six-channel radio receiver was used to control the servomechanisms. Two channels each were used for pitch, roll, and engine-speed control. The pitch and roll control servos were self-neutralizing and of the "bang-bang" type; that is, when a signal was given, they moved rapidly to their full travel in the direction indicated by the signal and stayed at full travel until the cessation of the signal, at which time the servos automatically returned to their neutral positions. The engine control servo was of the positionable type; that is, when a signal was received, it traveled at a slow rate in the direction indicated until either the cessation of the signal or until a limit switch was activated. With no signal, the servo remained wherever it had stopped.

The flight tests were made by utilizing the outdoor, radio-controlled free-flight technique with powered models. This technique for testing powered models is a very simple one and is essentially the same as that used by model airplane

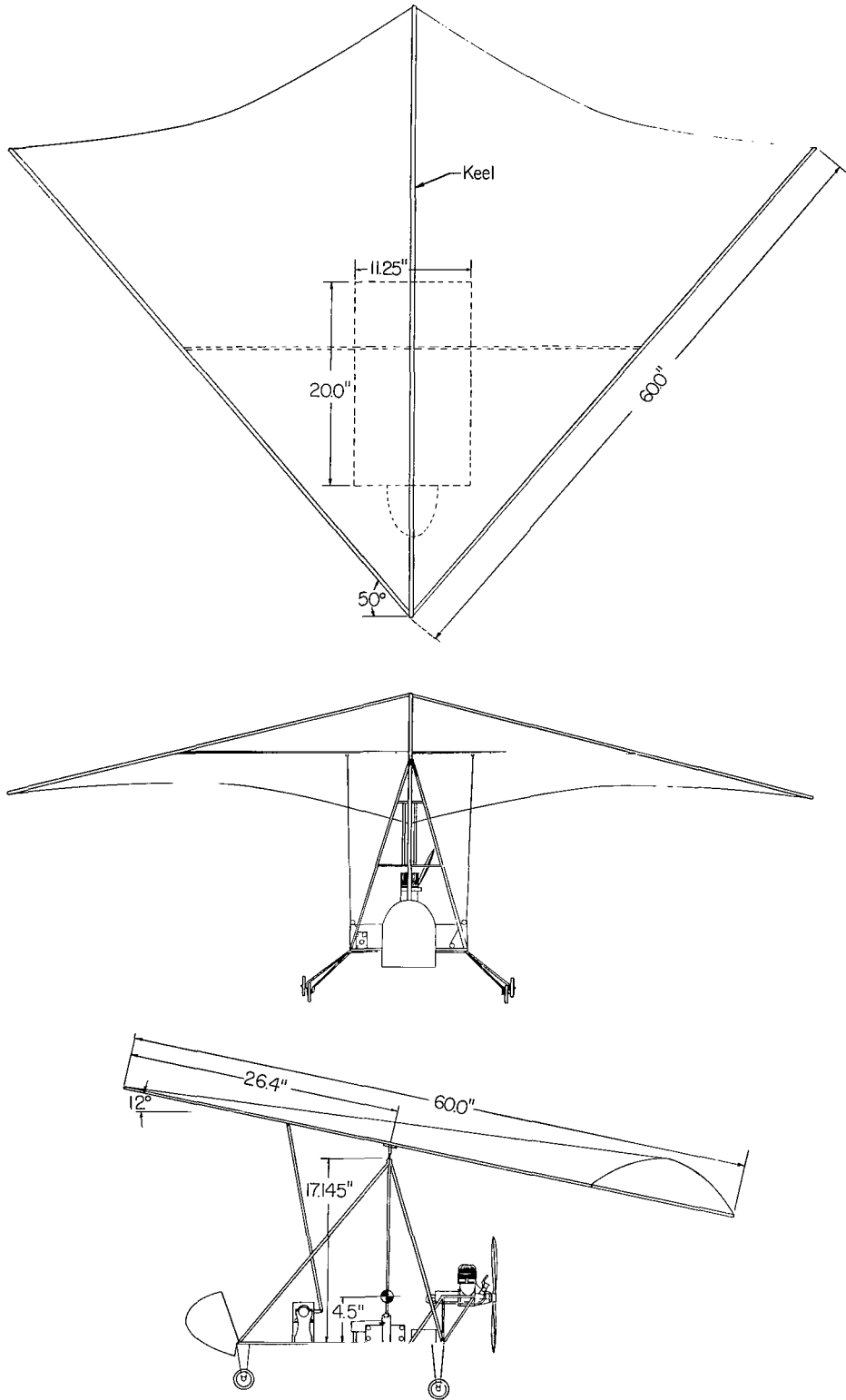


Figure 1.- Three-view drawing of the model used in the investigation.

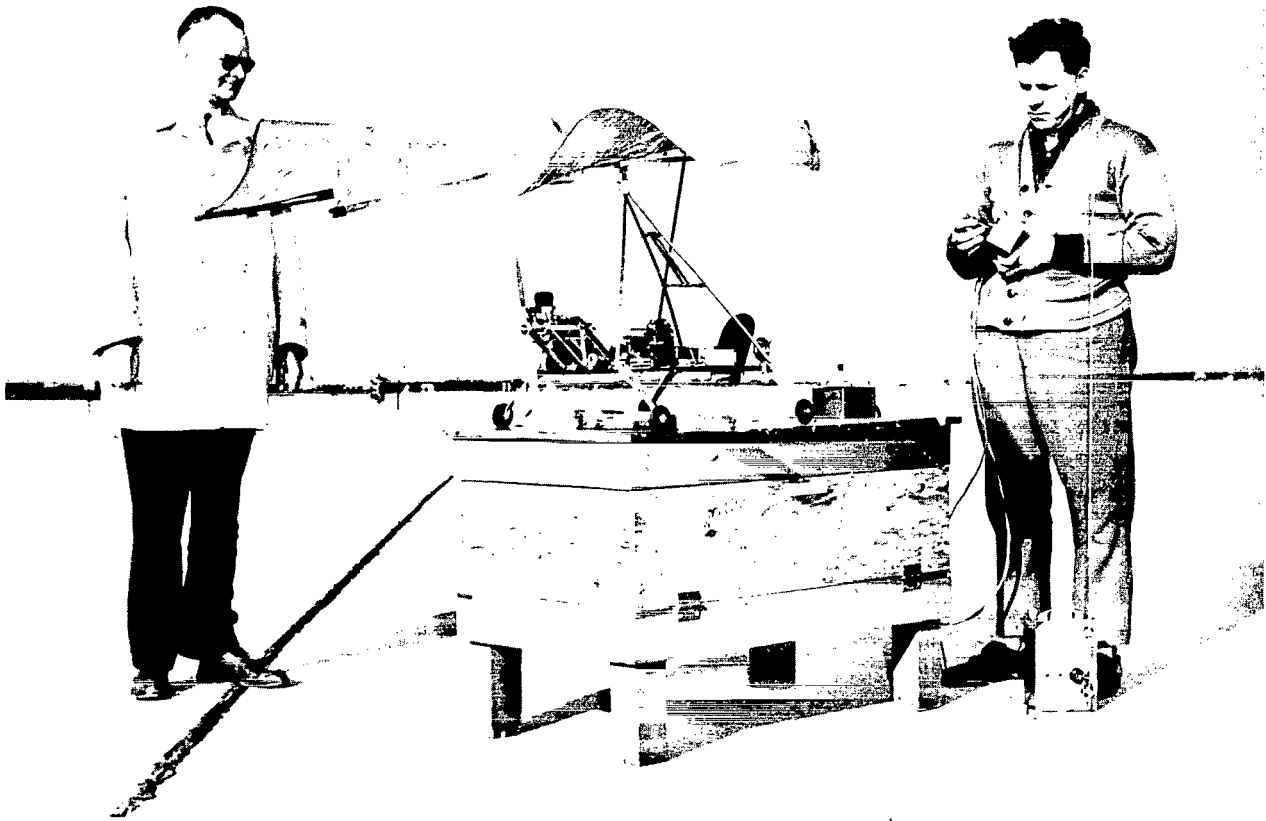


Figure 2.- Radio-controlled flight-test model.

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hobbyists. The flight-test procedure consisted of take-offs, climbs to test altitude, and a series of level flights and maneuvers to evaluate the handling qualities and stability and control characteristics of the model. A more detailed description of this radio control technique and related radio control work is given in references 3 and 5.

A photograph of the test setup used in the free-to-pitch wind-tunnel tests is presented in figure 3. In this setup the parawing alone was mounted on its side so that it was free to pitch around a vertical axle which was located at the same position relative to the wing as was the center of gravity of the complete model.

Static wind-tunnel tests were made in a low-speed tunnel having a 12-foot octagonal test section at the Langley Research Center. A simplified parawing configuration was tested on a sting-mounted force-test setup and static forces and moments were measured by using a strain-gage balance.

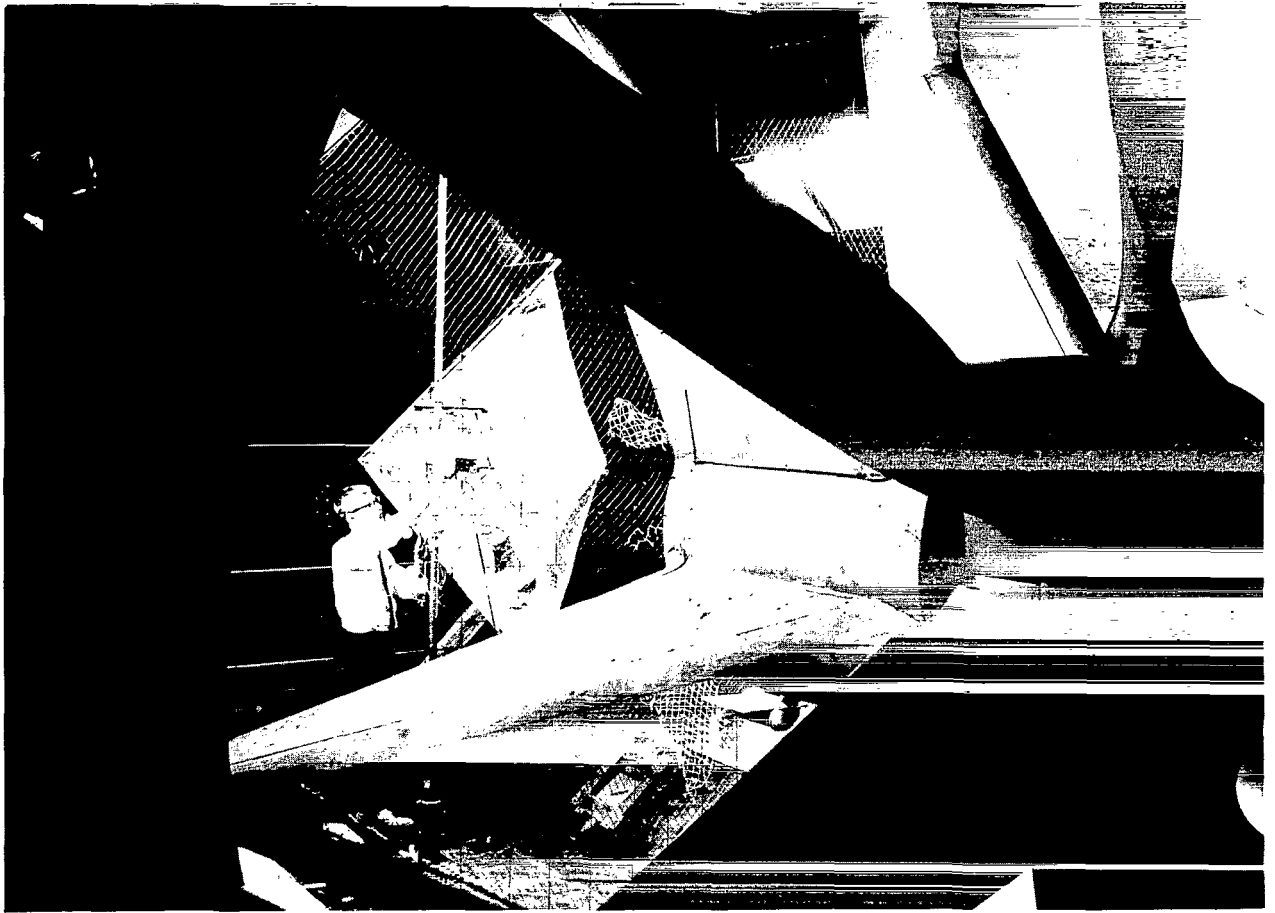


Figure 3.- Model parawing used for one-degree-of-freedom wind-tunnel tests. L-61-7830

TESTS

The flight-test portion of the investigation consisted of a series of flights at different power settings, during which the model was subjected to various control inputs to determine qualitatively its stability and control response. The model was flown at progressively lower power settings and higher lift coefficients until it stalled. After the model had stalled, various control manipulations were applied to determine their effect on the post-stall motions and stall recovery.

The center of gravity was located approximately 48 percent of the keel length back from the nose and approximately 25 percent of the keel length below the keel with controls neutral. With pitch control neutral, the wing incidence angle was 12° with respect to the engine thrust line. Back stick changed the wing incidence angle to 30° and forward stick changed the incidence angle to 4° . Roll control rotated the wing approximately $\pm 15^{\circ}$ from its neutral position.

Evaluation of the flight characteristics was based solely on the opinion of the control operators and observers. No quantitative data were obtained because of the exploratory nature of the test program. The qualitative data obtained consist of motion-picture records of the flight tests taken from ground-based cameras.

One-degree-of-freedom dynamic tests in pitch and static wind-tunnel force tests were made of the parawing-alone configuration to obtain some basic information for use in interpretation of the flight-test results. The free-to-pitch wind-tunnel tests were made by observing the response of the simplified parawing configuration after disturbances in pitch were introduced. The model was mounted to a vertical support assembly as shown in figure 3 so that the pitching motions could be studied under closely controlled conditions over an angle-of-attack range of 360° . The static wind-tunnel force tests were made over an angle-of-attack range from 0° to 360° to measure lift, drag, and pitching-moment characteristics of the configuration.

RESULTS AND DISCUSSION

Flight Tests

A motion-picture film supplement covering flight tests of the model has been prepared and is available on loan. A request card form and a description of the film will be found on the page with the abstract cards.

The model was longitudinally and laterally stable and could be maneuvered satisfactorily over most of the normal operating angle-of-attack range by using center-of-gravity shift as the only means for control. It was found, however, that the lateral control effectiveness of this system decreased at low angles of attack where the fabric was luffing and also decreased at high angles of attack near the stall. These results at high angles of attack are generally similar to those reported in the flight-test investigation reported in reference 4.

In gentle stalls the model motions were fairly mild and easily controlled. There was little or no tendency toward roll-off at the stall and no spin-like motion was encountered. In fact the model did not spin even when the pilot attempted to initiate a spin after a stall by holding back stick and applying full roll control.

Recovery from the stall could be accomplished easily by use of the pitch control. In order to effect such recoveries, the pitch control was returned to neutral and the model would nose down and pick up speed in a dive. After it had picked up some speed, back stick could then be applied to effect a recovery from the dive and reestablish normal level flight.

During one test flight, there was a sudden and unexpected loss of power while the model was being flown at a relatively large nose-up attitude and

large angle of attack, and an abrupt stall resulted. At the time the model was stalled all controls were neutralized and the model pitched down as it had been doing for previous gentle stalls with little or no observed rolling or yawing motions. However, when the model reached the vertical nose-down attitude it still had some nose-down pitching velocity. Therefore, the model continued to rotate past the vertical into an inverted attitude. At that time the billowing of the fabric reversed and the model appeared to increase its rate of rotation so that as it reached an erect level attitude again there was sufficient momentum to prevent it from stopping at its trimmed condition and a forward end-over-end tumbling motion developed. Various control manipulations were applied as the model was tumbling in an effort to stop the motion and regain normal flight: (1) back stick was held for several turns, (2) forward stick was held for several more turns, (3) right stick was applied for several turns, and (4) back stick and right stick were applied simultaneously for several turns. None of the control inputs appeared to have any effect on the tumbling motion. The model completed approximately 20 to 25 turns before it crashed.

As a result of this unexpected tumbling motion encountered after a stall, further tests were conducted in an effort to reproduce and study further the tumbling motion. The tests showed that the motion could be encountered as a result of a whip stall. After the model was tumbling, the controls were ineffective to stop the motion and recovery to normal flight was not possible. Also, during the tumbling motion, severe loads were encountered on the spreader bar which, in some cases, caused it to fail in bending after two or three turns. Recovery to normal flight after a whip stall was possible if the model did not pitch down so far as to become vertical. If the pitching velocity became zero before the model reached a vertical attitude, the application of back stick caused the model to pull out of the dive and a level-flight condition was then easily reestablished.

It should be pointed out that for these recoveries no consideration was given to the stick forces involved. When the model results are applied to a full-size aircraft, it is important that the stick forces be considered, since it has been shown (ref. 6) that the longitudinal stick forces in such a machine were unstable and can become large under conditions of flight similar to those encountered during a recovery from a stall.

Free-to-Pitch Wind-Tunnel Tests

The free-to-pitch wind-tunnel tests were conducted to provide some further insight into the tumbling motion. It was found that, as expected, the parawing trimmed at about the proper angle of attack for the center-of-gravity position represented by the pitch pivot axis. In this connection, it was also found that the model would trim in the low negative angle-of-attack range if it was rotated very slowly to this attitude. If the model pitched into this range with appreciable pitching angular momentum, however, it would not trim but, instead, would continue to rotate to higher negative angles of attack.

The general procedure followed in these tests was first to place the model at its trimmed attitude in normal operational angle of attack (a keel angle of attack of about 25°). The model was then displaced to angles of attack higher than the stall and released. It was observed that the wing pitched downward through its trim point into the low-angle-of-attack region in much the same manner observed in the free-flight tests after a stall occurred. Although the nose-down pitching angular velocity was noticed to decrease somewhat as the model neared the 0° angle-of-attack condition, this motion did not stop and, as negative angles of attack were reached the billowing of the fabric reversed and the angular velocity increased. At an angle of attack of about 180° , it was observed that the fabric abruptly returned to its original shape; and, as the model pitched toward its original trim point, there appeared to be considerable angular momentum developed in the system. This momentum drove the model through the trim point faster than on its first pass and the model continued into another cycle at an increased rate of rotation. After this cycle, the model continued its tumbling motion at about a steady rate.

Force Tests

Some static longitudinal stability information related to the tumbling problem encountered with this parawing model is presented in figure 4. The

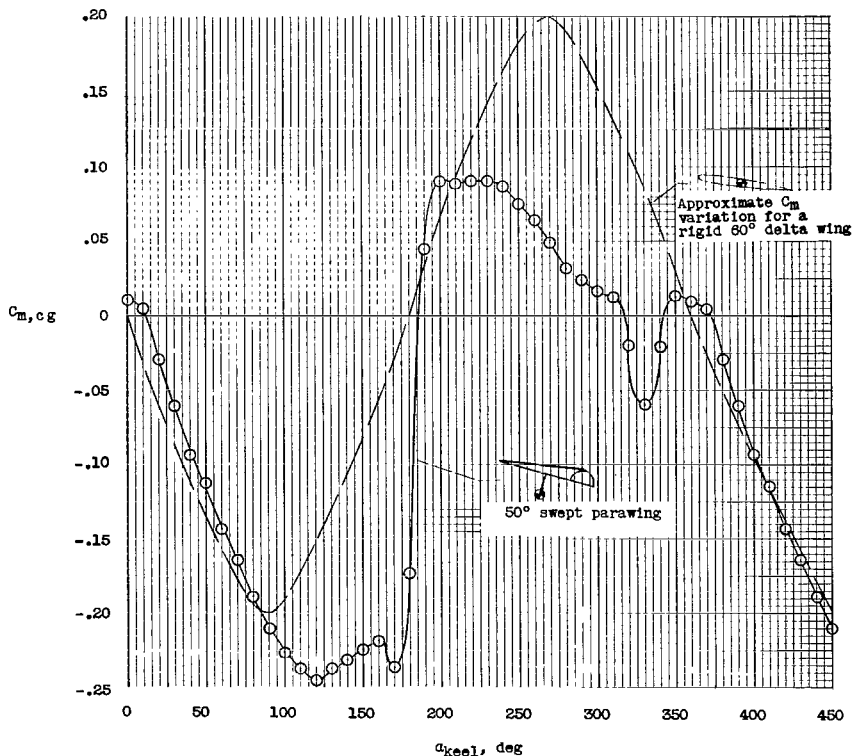
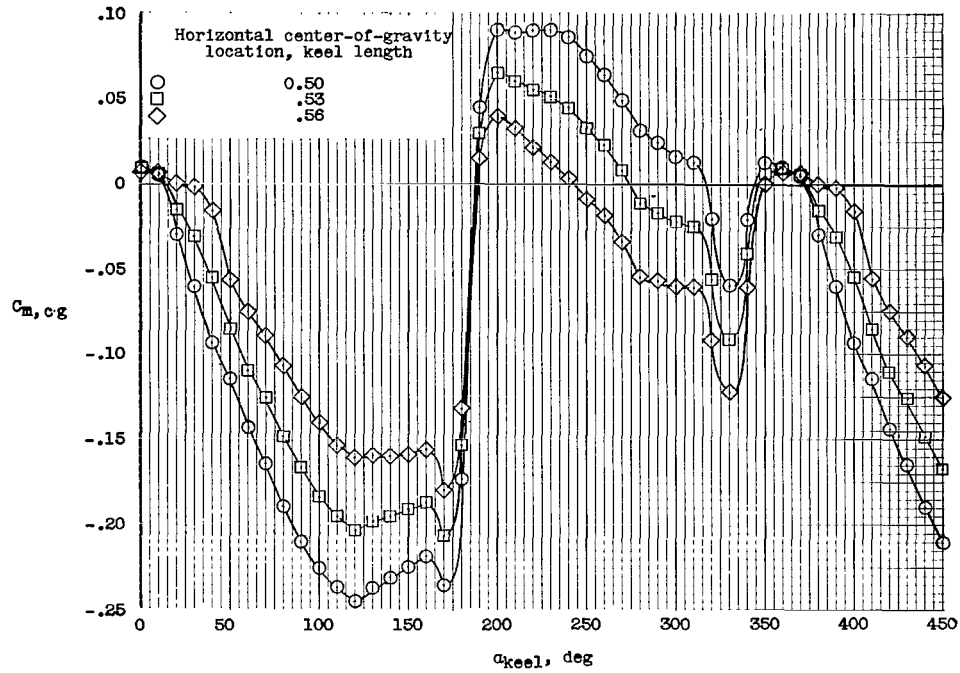


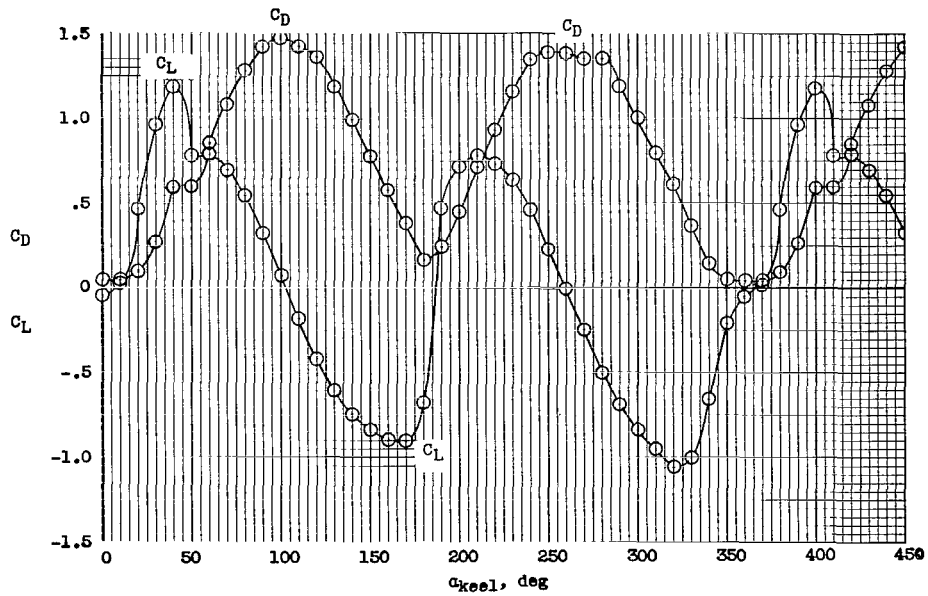
Figure 4.- Comparison of the static pitching-moment characteristics of a parawing and a rigid delta wing over an angle-of-attack range of 360° .

data of figure 4 show static pitching-moment characteristics over an angle-of-attack range of 360° for a parawing with low center-of-gravity position together with similar data for a conventional, rigid, delta-wing configuration with the center of gravity in the plane of the wing. The data show that near an angle of attack of 0° and of 360° both configurations are stable and trimmed. 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 caused by the fabric reversal in conjunction with the low center-of-gravity position and large differences in the magnitude of the positive and negative pitching moments over the angle-of-attack range. It is this combination of static instability and asymmetry in the pitching moments which appears to be significant in establishing a steady tumbling motion for parawing configurations. For example, 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. It is interesting to note the trim point indicated by the static data (fig. 4) at low negative angles of attack and to relate this information to the results of the one-degree-of-freedom pitching tests where this trim point was first discovered experimentally. If the pitching motion is strong enough to overcome both the damping in pitch and the positive restoring moments in the angle-of-attack range from 300° to 180° , the pitching motion will continue, energy being fed into the system by the larger negative pitching moments in the angle-of-attack range from 180° to 0° . It is thus possible for a steady nose-down tumbling motion to 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, mass and inertia characteristics, and the variation in airspeed or dynamic pressure which must be considered in determining stable and unstable boundaries in a dynamic stability problem of this type.

Presented in figure 5 are parawing lift, drag, and pitching-moment data to show the effect of forward and rearward center-of-gravity shift on the pitching-moment characteristics of the model over an angle-of-attack range of 360° . The three pitching-moment curves shown can be considered to represent the pitching-moment characteristics for three different control positions for the center-of-gravity-shift control system - stick forward (curve with circular symbols), stick neutral (curve with square symbols), and stick back (curve with diamond symbols). In the normal operating angle-of-attack range (approximately 20° to 40°), it is seen that forward stick (forward center-of-gravity shift) increases static longitudinal stability and rearward stick (rearward center-of-gravity shift) decreases stability. The stick-rearward or up-control condition has more static instability in the low negative angle-of-attack region (330° to 360°) and almost all negative moments over the entire angle-of-attack range (0° to 360°). On the basis of these data, it would appear that the stick-rearward condition has variations in pitching-moment characteristics which would allow a steady tumbling motion to develop much more readily than in the case of the stick-forward condition. Such a conclusion cannot be definitely drawn, however, since in flight tests it was found that the use of up-control



(a) Pitching-moment characteristics.



(b) Lift and drag characteristics.

Figure 5.- Effect of horizontal shift in center-of-gravity position on the static pitching-moment characteristics of a parawing. Vertical center-of-gravity position at 0.25 keel length perpendicularly below keel.

was effective at times in recovering from the forward pitching motion encountered from a whip-stall condition. Such items as the amount of control, time of control application, and angular pitching velocity would be very important factors in determining whether a particular configuration could be prevented from entering a steady tumbling motion by use of corrective control in recovery attempts from a stalled attitude.

SUMMARY OF RESULTS

The results of a free-flight investigation of a radio-controlled parawing model to determine its dynamic stability and control characteristics over a large angle-of-attack range with emphasis on post-stall behavior may be summarized as follows:

1. The model was found to have dynamic longitudinal and lateral stability and was controllable in the normal operating range of angle of attack, although there was a decrease in lateral control effectiveness as the angle of attack was increased.

2. In gentle stalls the model exhibited no roll-off tendencies and no spin-like motions were encountered in the flight tests. Recoveries from such gentle stalls could be accomplished readily by proper use of the pitch control.

3. After whip stalls, the model was found to have extremely violent dynamic longitudinal instability in the form of a nose-down, end-over-end tumbling motion. This tumbling motion appeared to be caused by the low position of the center of gravity relative to the wing and by the reversal in parawing fabric when the model pitched down to negative angles of attack.

4. It was found that at times tumbling could be avoided and recoveries from violent stalls could be effected by use of the pitch control, provided this control was applied soon enough and the pitching angular momentum had not become excessive.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 6, 1964.

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