



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

STABILITY AND CONTROL FLIGHT TESTS OF A 0.13-SCALE MODEL
OF THE CONSOLIDATED-VULTEE XFY-1 AIRPLANE IN
TAKE-OFFS, LANDINGS, AND HOVERING FLIGHT

TED No. NACA DE 368

By Powell M. Lovell, Jr., Charles C. Smith, Jr.,
and Robert H. Kirby

SUMMARY

An investigation is being conducted to determine the dynamic stability and control characteristics of a 0.13-scale flying model of the Consolidated-Vultee XFY-1 vertically rising airplane. This paper presents the results of flight tests to determine the stability and control characteristics of the model in hovering, take-offs, and landings. Most of the tests were made in still air but a few tests were made to determine the behavior of the model in gusty winds at translational speeds up to 40 knots full scale.

In hovering flight, the model had unstable pitching and yawing oscillations but could be controlled smoothly and easily despite its lack of stability. Very little adverse effect of ground proximity on control was evident in hovering flight near the ground. Unrestrained take-offs and landings could therefore be made easily in still air. Tethered landings could be made satisfactorily with twin lines (one attached to each wing tip) or with four lines (one attached to the tip of each wing and vertical tail). Landings with a single tethering line attached to either the rear of the fuselage or near the center of gravity were unsatisfactory. At low forward translational speeds in gusty air, the model seemed reasonably stable and easy to fly except that it became difficult to control the yawing motions when the speed exceeded a value of about 30 knots (full scale).

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, an investigation is being conducted to determine the dynamic stability and control characteristics of a 0.13-scale flying model of the Consolidated-Vultee XFY-1 vertically rising airplane. This airplane has a modified triangular wing and modified triangular vertical tail surfaces mounted symmetrically above and below the fuselage, and has no horizontal tail. It has a large dual-rotating propeller and sufficient power to take off and land vertically. Control is provided by flap-type elevons and rudders operating in the propeller slipstream.

The results of an investigation with a somewhat similar model are covered in reference 1. This model was a simplified version of the XFY-1, which was similar with regard to the plan form of the wing and tail surfaces and with regard to the size and location of the propellers. The investigation with this simplified model was a preliminary measure to obtain an indication of the control characteristics of the XFY-1 airplane long before an exact scale model could be built and a detailed investigation completed. Some results of a series of flight tests on a more conventional vertically rising airplane configuration are presented in references 2 to 4.

The present paper gives the results of the first phase of the dynamic stability and control investigation of the XFY-1 model. Included in this phase of the investigation were: hovering tests at considerable height above and near the ground, take-offs, unrestrained landings, and tethered landings using several different tethering techniques. All of these tests were made in still air. The model behavior at low translational speeds in gusty winds was also investigated.

The results of the investigation were obtained primarily from the pilots' observations. In some cases, however, time histories of the motions of the model were prepared from motion-picture records of the flights to aid in the study of some particular phase of the model behavior.

NOMENCLATURE AND SYMBOLS

In general, the model is considered as a conventional airplane in a vertical attitude. The controls and motions are referred to in conventional terms relative to the body system of axes; that is, the rudders on the vertical tails produce yaw about the normal (Z) axis, differential deflection of the elevons on the wings produces roll about the longitudinal (X) axis, simultaneous up or down deflection of the elevons produces

pitch about the spanwise (Y) axis. Figure 1 shows the axes and the positive directions of the linear and angular displacements.

The definitions of the symbols used in the present paper are as follows:

z	displacement along Z-axis, ft
y	displacement along Y-axis, ft
θ	angle of pitch, deg
ϕ	angle of bank, deg
$\dot{\phi}$	rolling velocity, deg/sec
ψ	angle of yaw, deg
δ_a	total differential deflection of the elevons, deg
\bar{c}	mean aerodynamic chord
X	fuselage axis
Y	spanwise axis
Z	normal axis
I_x	moment of inertia about fuselage axis, slug-ft ²
I_y	moment of inertia about spanwise axis, slug-ft ²
I_z	moment of inertia about normal axis, slug-ft ²

APPARATUS AND MODEL

The investigation was conducted in the return passage of the Langley full-scale tunnel using the test setup illustrated in figure 2. This test setup was the same as that used during the previous vertically rising airplane model flight tests described in references 1 to 4 except that the flight cable did not trail down from the model and that the autopilot with the string for a reference was eliminated entirely. In the present setup the cable, which consisted of wires and plastic tubes supplying the electric power for the motor and solenoids and air for the servomechanisms, was suspended from above and attached to the safety rope

about 15 feet above the model. From this point down to the model, the cable and safety rope were taped together. Instead of the displacement-type roll autopilot which used a string for a reference, a rate-gyro roll damper with a manual control override was used during this investigation for roll stabilization.

A photograph of the model is shown in figure 3 and a sketch showing some of the more important dimensions is presented in figure 4. The model had a modified-triangular wing and modified-triangular vertical tail surfaces mounted symmetrically above and below the fuselage and an eight-blade, dual-rotating, fixed-pitch propeller (two four-blade elements in tandem) powered by a 5-horsepower variable-frequency electric motor. Geometric characteristics are presented in detail in table I. The model does not represent the final configuration of the airplane since it was constructed before the final design revisions were made. Moreover, the model was not exactly a 0.13-scale model of the original design in all respects since it was designed from some rather small drawings and some slight inaccuracies occurred in obtaining dimensions. It is believed, however, that the differences between the model and the final airplane configuration are not great enough to alter appreciably the results presented in this paper.

The center of gravity was at the design location, 0.15 mean aerodynamic chord and 5.0 inches (full scale) above the thrust line. The weight and moments of inertia of the model scaled up to full scale were within 10 percent of the calculated values for the airplane as shown in the following table:

	Model (scaled up)	Airplane
Weight, lb	16,000	16,250
I_x , slug-ft ²	10,900	12,016
I_y , slug-ft ²	25,100	23,361
I_z , slug-ft ²	29,000	30,647

Maneuvering was accomplished by means of flap-type elevons and rudders operating in the propeller slipstream. These controls were remotely operated by the pilots and were deflected by flicker-type (full-on, full-off) pneumatic servomechanisms which were controlled by electric solenoids. Three separate pilots were used to control the model in pitch, roll, and yaw in order that they might give careful attention to studying the motions of the model about each of the axes. For convenience in most of the flights the rolling motions of the model were controlled automatically by a rate-gyro damping device with a manual override but for some of the flights the rolling motions were controlled manually.

The damping device slowed the rolling motions of the model but did not produce stability of position. Since unavoidable out-of-trim rolling moments were always present it was necessary for the pilot to use the manual override to reorient the model with respect to his position.

TESTS

The investigation covered in the present paper consisted entirely of flight tests of the model. Stability, controllability, and general flight behavior were determined in various cases, either qualitatively from the pilots' observations or quantitatively from motion-picture records of the flights. General flight behavior is a term used to describe the over-all flight characteristics of a model and indicates the ease with which the model can be flown. In effect, the general flight behavior is much the same as the pilots' opinion of the flying qualities of an airplane and indicates whether stability and controllability are adequate and properly proportioned.

Hovering flight at altitude.- Hovering flight tests were made in still air at a considerable height above the ground to determine the basic stability and control characteristics of the model. For all of these flights it was possible to obtain the pilots' opinion of the stability, controllability, and general flight behavior of the model. In some of the flights, quantitative indications of the stability were obtained by taking motion-picture records of the uncontrolled pitching and yawing oscillations. In some other flights, quantitative data on the controllability of the model were obtained by making motion-picture records to show the ability of the pilot to stop the pitching and yawing oscillations after they had been allowed to build up. Since a rate-gyro roll damper was used for convenience in flying the model in most of the tests, these flights provided some incidental information on the effect of a roll damper.

Hovering flight near the ground.- Hovering flight tests were also made near the ground to determine the effect of the proximity of the ground on the flight behavior of the model. During these flights the model was flown with the trailing edge of the wing about 12 inches above the ground. This height was maintained to the best of the power operator's ability. Actually the model dropped so low at times that the landing gear touched the ground and it rose so high at times that the trailing edge of the wing was considerably more than 12 inches above the ground.

Take-offs and landings.- Flight tests were made in still air to determine the behavior of the model in unrestrained take-offs and landings. Vertical take-offs were accomplished by rapidly increasing the speed of the propellers until the model took off. These take-offs were not as

rapid as those described in references 2 and 3 because the motor-generator set could not supply as much excess power as was used in the previous tests. Unrestrained landings were made by decreasing the speed of the propellers so that the model descended slowly until the landing gear was about 12 inches above the ground. At this point the power was cut off completely and the model dropped to the ground.

Sketches are presented in figure 5 to illustrate the tethered landing techniques covered in this investigation. For all tethered landings the power operator applied a little excess thrust and the model was pulled to the ground with the tethering lines. For the technique shown in figure 5(a), a single line was attached to the rear of the fuselage on the thrust line. In the technique shown in figure 5(b), a single line was attached to the surface of the fuselage slightly rearward of the center of gravity. In order to keep the tethering line clear of the model, the model was pulled sideways as well as down. Figure 5(c) shows the technique in which a tethering line was attached to each wing tip. These lines passed through rings on the ground farther apart than the attachment points on the model to provide stability of both position and attitude. Two different longitudinal attachment points were covered in these tests - one point located about 2 inches behind the front of the gun pods and the other at the elevon hinge line. In the fourth technique (see fig. 5(d)), the lines were attached to the tips of the wings and vertical tails near the control hinge lines. These lines also passed through rings on the ground that were farther apart than the attachment points on the model.

Translational flights in gusty air.- A few tests were made in the return passage of the Langley full-scale tunnel with the tunnel running in order to study the behavior of the model at low forward translational speeds and in gusty air. The tests covered a range of average translational speeds from 17 to 42 knots (full scale). For these tests the air was very rough as is indicated in figure 6. This figure shows the variation of dynamic pressure with time for a number of different average airspeeds over the range of speeds covered in the tests. These data indicate that at the higher airspeeds the dynamic pressure changed so rapidly that at times it varied as much as ± 40 percent of the average value within 1 or 2 seconds.

RESULTS AND DISCUSSION

The results of the present investigation are illustrated more graphically by motion pictures of the flights of the model than is possible in a written presentation. For this reason a motion-picture film supplement to this paper has been prepared and is available on loan from NACA Headquarters, Washington, D. C.

Hovering Flight at Altitude

Time histories of the uncontrolled pitching and yawing motions are presented in figures 7 and 8, respectively. These time histories are not symmetrical about the horizontal axis because the model could not be trimmed perfectly. Since the control surfaces were not trimmed perfectly and the propellers caused large random fluctuations in moments, the model moved away from the center of the test area and its motion was superimposed on the motion caused by the out-of-trim moments. A study of the moment fluctuations caused by the propellers on another model is presented in reference 3.

Time histories presented in figures 7 and 8 show that the model had unstable pitching and yawing oscillations. The periods of these oscillations were about 3.5 and 4.0 seconds, respectively, which correspond to periods of about 10 and 11 seconds for the full-scale airplane.

The stability of the XFY-1 model was markedly different from that of the simplified model of reference 1 with respect to the stability of the yawing motions. The XFY-1 model had an unstable yawing oscillation, whereas the yawing motions of the simplified model were predominantly aperiodic and about neutrally stable. This difference probably resulted mainly from the aerodynamic effects of the fuselage. The larger fuselage of the XFY-1 probably blanketed the center portion of the vertical tail. The resulting reduction in tail effectiveness as well as the increase in the direct moments on the fuselage tended to produce oscillatory instability. There were also some differences in the pitching motions of the two models which were probably also caused by the differences in the fuselages. The pitching oscillations of the XFY-1 appeared more unstable than those of the simplified model and the angular motion for the XFY-1 model appeared to be greater in proportion to the translational motion.

The model responded quickly to a control deflection and could be flown smoothly and easily in spite of its lack of stability. It could be maneuvered quickly and easily to various positions in the test area as desired and could be stopped with very little overshoot and no evidence of a tendency to overcontrol. As a further demonstration of the controllability of the model, the pilot at times allowed the pitching and yawing oscillations to build up and then applied the controls to stop them. Data of figures 9 and 10, which present several time histories of these tests, indicate that the pilot could stop the oscillations and return the model to a near vertical attitude in less than 1/2 cycle. The fact that the model did not return to zero displacement is not significant since the pilot was not making an effort to stop the model over a particular spot or to return it to zero displacement. In stopping these oscillations, the pilot had no tendency to overcontrol and reinforce the oscillation as is sometimes the case of the Dutch-roll oscillation

of conventional airplanes. The ease with which the pilot could stop the oscillations can probably be attributed largely to the fact that the periods of the oscillations were fairly long.

As pointed out previously, some flights were made with only manual control in roll. In these flights it was found that the model could be controlled in roll fairly easily despite the fluctuations of propeller torque, which appeared as abrupt changes in trim occurring at fairly long intervals. For convenience, most of the flights were made with the roll damper operating. In these flights it was very easy for the pilot to fly the model in roll because it rolled very slowly as a result of the out-of-trim moments and he had to give a control only occasionally to keep the model oriented in roll with respect to his position. The gearing of the roll damper was such that the differential movement of the elevons in response to the rate of roll $\delta_a/\dot{\phi}$ was 4.8 degrees per degree per second.

The model had neutral vertical-position stability but had positive rate-of-climb stability because of the pronounced inverse variation of the thrust of propellers with axial speed. This rate-of-climb stability tended to offset the effect of the time lag in the thrust control so that the model could be maintained at a given height fairly easily.

Hovering Flight Near the Ground

The model became only slightly more difficult to fly as it neared the ground and it was fairly easy to maneuver the model and to keep it hovering within a foot of the ground over a spot for a considerable length of time and to make recoveries even when the model tilted to a fairly large angle. Such behavior of the model when hovering near the ground was quite different from the behavior observed during the investigation of reference 1 in which it was observed that the simplified model became considerably more difficult to fly as the tail surfaces approached the ground. Although some of this difference in behavior near the ground might have been caused by the previously mentioned differences in the stability and control characteristics between the two models, it is believed that most of the differences can be attributed to the change in flight cable arrangement. The trailing cable used in the previous investigation probably caused the erratic behavior near the ground which was not evident in the present investigation. The trailing cable was fairly heavy and bulky and undoubtedly exerted a rather large force on the tail of the model when it was dragged over the ground as a result of translational movement of the model. This force produced a destabilizing moment as the model moved sideways. Further large forces on the tail of the model might have been produced as a result of the slipstream blowing the flight cable around in an erratic manner. The change to the overhead flight cable arrangement in the present investigation was made because such an effect of the trailing cable had been

suspected. With this revised setup there was no more effect of the flight cable when hovering near the ground than when hovering at altitude and the behavior of the model seemed almost as good during flights near the ground.

Take-Offs and Landings

Unrestrained take-offs and landings.- Unrestrained take-offs and landings were easy to perform because the model responded quickly to a control deflection and could be maneuvered fairly easily when near the ground. The model could almost always be landed within one-half a span of a selected point on the ground. In most of the take-offs the model moved sideways, sometimes as much as one-half a span, as it left the ground. This motion is quite evident in the film supplement to this report. The pilot could, however, easily stop this sideways motion and right the model. This behavior is believed to be a characteristic of the model and is not necessarily a characteristic of the full-scale airplane. One cause of this sideways motion is believed to be the fact that the pilot had no warning of any out-of-trim moments before the model took off because the model had no spring in the landing gear. This lack of landing-gear spring also caused the take-offs to come as a surprise to the pilot since the model did not rise at all until the thrust actually exceeded the weight. A secondary reason that the sideways motion was particularly noticeable with this model is that the motor-generator set could not supply much excess power so the model could not take-off rapidly.

In order to obtain some indication of how the model landings represented those of the full-scale airplane with regard to rate of descent, a few time histories of the vertical height during several representative landings of the model were obtained from motion-picture records. In these tests the object was not to make either very gentle or very fast landings but was to make reasonably smooth landings on a selected spot. The records of these landings (see fig. 11) show that in some landings the rate of descent was reasonably constant at a value of about 2 feet per second (full scale) for the entire descent from a height of about 50 feet (full scale) to the touchdown; whereas in one of the landings shown, the descent was checked before the touchdown but the rate of descent at the time of touchdown was still about 2 feet per second. It appeared, therefore, that it was possible to make very gentle landings even with the poor power control used in the model. With the tethered landing techniques discussed in the following paragraphs the model could probably be pulled down at any desired rate of descent.

Tethered landings with single line attached to rear of fuselage.- When the model was pulled down to the ground with a single line attached

to the rear of the fuselage the landings were unsatisfactory because the model diverged as it approached the ground as was the case in similar tests described in reference 2. This divergence occurred because the line introduced a severe instability of angle of pitch or yaw with horizontal displacement. When the model was disturbed and moved in the Y or Z direction, the line caused the model to yaw or pitch in the direction of the displacement. This yaw or pitch produced a force which caused the model to continue to move in the direction of displacement. When the model was near the ground and displaced sufficiently far horizontally, the controls were not powerful enough to pitch or yaw the model to an erect attitude with the tail restrained by the tethering line. Once the model started to diverge, it was impossible to effect a recovery unless the line was released and the tension eliminated.

Tethered landings with a single line attached to the side of the fuselage.- The use of a single line attached to the side of the fuselage at a longitudinal location slightly behind the center of gravity made the model difficult to fly and the landings were very poor. The model seemed to have a tendency to make the tethering line go slack as it moved sideways and the line sometimes became tangled with the wing or vertical tail. The troubles encountered with this technique may have resulted partly from the fact that there was not enough excess power available to put much tension in the line.

Tethered landings with two lines.- When the model was tethered with lines attached either to the forward or to the rearward ends of the gun pods, landings were fairly easy to perform but were sometimes rough. The yawing motion was easily controlled because it was stabilized by the tethering lines, in fact, for most of these landings no rudder control was necessary. The pitching motion, however, was more difficult to control because the model had to be flown directly over the tethering line attachment points on the ground. The lines produced pitching moments which were stabilizing with angle of pitch but destabilizing with displacement in the Z-direction. The pilot could not, therefore, allow any appreciable movement of the model away from a position directly above the attachment points of the tethering lines. This type of flying was more difficult than flying with no tethering lines because the pilot was required to give control for even very slight displacements. In flying the model unrestrained the pilot was not usually concerned with small displacements and could concentrate on keeping the model in a vertical attitude so that its sideways motions were mild. Most of the roughness encountered in the tethered landings resulted from the poor behavior in pitch which was similar to that obtained with a single tethering line attached to the rear of the fuselage. If the model happened to pitch abruptly as a result of the instability or a control deflection just as it was about to touch down, one of the relatively rigid landing gears usually hit sharply and caused the model to bounce violently. This behavior would not have appeared as undesirable if the

model had had a shock-absorbing landing gear. Since the model had greater unstable pitching moments when the tethering lines were attached to the rearward ends of the gun pods, the landings made with this configuration were more difficult than when the tethering lines were attached to the forward ends of the gun pods.

Tethered landings with four lines.- Tethered landings made with lines attached to the tip of each wing and vertical tail were easy to perform and were smoother than with any of the other tethering techniques. During several of these landings the model appeared completely stable and would fly for quite long periods of time with no control being given by the pilot. This stability resulted from the fact that the lines passed through rings on the ground that were farther apart than the attachment points on the model. In this configuration the lines produced stable variations of pitching and yawing moments with sideways displacement from the trimmed position.

Translational Flight in Gusty Air

At low translational speeds the model was somewhat more difficult to fly in pitch and yaw than it was when hovering in still air. This increased difficulty in flying the model seemed to result from the gustiness of the wind instead of the fact that the model was in translational flight. In fact, the air was so gusty that it was impossible to make any definite observations about the stability in pitch or yaw. The model was definitely easier to fly in roll in translational flight because the translational velocity eliminated the fluctuations in trim resulting from changes in propeller torque. The model appeared to have stability in bank about its body axis; that is, it seemed to have a definite tendency to fly with its belly into the wind.

As the translational velocity was increased above 30 knots (full scale) the model became more difficult to fly in yaw. It appeared that in these conditions the model had an aperiodic divergence which the pilot was unable to stop if he allowed it to develop very far. This result seems to be in agreement with the results of some preliminary force tests made by the Consolidated-Vultee Aircraft Corporation which indicated directional instability in this angle-of-attack range.

The variation of angle of attack with translational speed obtained in the tests is shown in figure 12. These angles of attack are averages read from motion-picture records of each flight at times when the model appeared to be in a steady flight condition. This variation of angle of attack with speed does not, of course, represent that of the full-scale airplane very accurately because of the high drag of the model which resulted from the propeller guard and flight cable and from the low scale of the tests.

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CONCLUDING REMARKS

The following results were obtained from flight tests of a 0.13-scale model of the Consolidated-Vultee XFY-1 vertically rising airplane in take-offs, landings, and hovering flight.

1. In hovering flight the model had unstable pitching and yawing oscillations but could be controlled smoothly and easily despite its lack of stability.

2. The behavior of the model was almost as good when hovering near the ground as when hovering at a considerable height above the ground. Unrestrained take-offs and landings were therefore easy to perform.

3. Satisfactory tethered landings could be made using either twin lines (one attached to each wing tip) or four lines (one attached to the tip of each wing and vertical tail), the better landings being obtained with the four-line technique.

4. At low forward translational speeds in gusty air the model seemed reasonably stable and easy to fly except that it became difficult to control the yawing motions when the speed exceeded a value of about 30 knots (full scale).

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\bar{c}	mean aerodynamic chord
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I_x	moment of inertia about fuselage axis, slug-ft ²
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I_x , slug-ft ²	10,900	12,016
I_y , slug-ft ²	25,100	23,361
I_z , slug-ft ²	29,000	30,647

Maneuvering was accomplished by means of flap-type elevons and rudders operating in the propeller slipstream. These controls were remotely operated by the pilots and were deflected by flicker-type (full-on, full-off) pneumatic servomechanisms which were controlled by electric solenoids. Three separate pilots were used to control the model in pitch, roll, and yaw in order that they might give careful attention to studying the motions of the model about each of the axes. For convenience in most of the flights the rolling motions of the model were controlled automatically by a rate-gyro damping device with a manual override but for some of the flights the rolling motions were controlled manually.

The damping device slowed the rolling motions of the model but did not produce stability of position. Since unavoidable out-of-trim rolling moments were always present it was necessary for the pilot to use the manual override to reorient the model with respect to his position.

TESTS

The investigation covered in the present paper consisted entirely of flight tests of the model. Stability, controllability, and general flight behavior were determined in various cases, either qualitatively from the pilots' observations or quantitatively from motion-picture records of the flights. General flight behavior is a term used to describe the over-all flight characteristics of a model and indicates the ease with which the model can be flown. In effect, the general flight behavior is much the same as the pilots' opinion of the flying qualities of an airplane and indicates whether stability and controllability are adequate and properly proportioned.

Hovering flight at altitude.- Hovering flight tests were made in still air at a considerable height above the ground to determine the basic stability and control characteristics of the model. For all of these flights it was possible to obtain the pilots' opinion of the stability, controllability, and general flight behavior of the model. In some of the flights, quantitative indications of the stability were obtained by taking motion-picture records of the uncontrolled pitching and yawing oscillations. In some other flights, quantitative data on the controllability of the model were obtained by making motion-picture records to show the ability of the pilot to stop the pitching and yawing oscillations after they had been allowed to build up. Since a rate-gyro roll damper was used for convenience in flying the model in most of the tests, these flights provided some incidental information on the effect of a roll damper.

Hovering flight near the ground.- Hovering flight tests were also made near the ground to determine the effect of the proximity of the ground on the flight behavior of the model. During these flights the model was flown with the trailing edge of the wing about 12 inches above the ground. This height was maintained to the best of the power operator's ability. Actually the model dropped so low at times that the landing gear touched the ground and it rose so high at times that the trailing edge of the wing was considerably more than 12 inches above the ground.

Take-offs and landings.- Flight tests were made in still air to determine the behavior of the model in unrestrained take-offs and landings. Vertical take-offs were accomplished by rapidly increasing the speed of the propellers until the model took off. These take-offs were not as

rapid as those described in references 2 and 3 because the motor-generator set could not supply as much excess power as was used in the previous tests. Unrestrained landings were made by decreasing the speed of the propellers so that the model descended slowly until the landing gear was about 12 inches above the ground. At this point the power was cut off completely and the model dropped to the ground.

Sketches are presented in figure 5 to illustrate the tethered landing techniques covered in this investigation. For all tethered landings the power operator applied a little excess thrust and the model was pulled to the ground with the tethering lines. For the technique shown in figure 5(a), a single line was attached to the rear of the fuselage on the thrust line. In the technique shown in figure 5(b), a single line was attached to the surface of the fuselage slightly rearward of the center of gravity. In order to keep the tethering line clear of the model, the model was pulled sideways as well as down. Figure 5(c) shows the technique in which a tethering line was attached to each wing tip. These lines passed through rings on the ground farther apart than the attachment points on the model to provide stability of both position and attitude. Two different longitudinal attachment points were covered in these tests - one point located about 2 inches behind the front of the gun pods and the other at the elevon hinge line. In the fourth technique (see fig. 5(d)), the lines were attached to the tips of the wings and vertical tails near the control hinge lines. These lines also passed through rings on the ground that were farther apart than the attachment points on the model.

Translational flights in gusty air.- A few tests were made in the return passage of the Langley full-scale tunnel with the tunnel running in order to study the behavior of the model at low forward translational speeds and in gusty air. The tests covered a range of average translational speeds from 17 to 42 knots (full scale). For these tests the air was very rough as is indicated in figure 6. This figure shows the variation of dynamic pressure with time for a number of different average airspeeds over the range of speeds covered in the tests. These data indicate that at the higher airspeeds the dynamic pressure changed so rapidly that at times it varied as much as ± 40 percent of the average value within 1 or 2 seconds.

RESULTS AND DISCUSSION

The results of the present investigation are illustrated more graphically by motion pictures of the flights of the model than is possible in a written presentation. For this reason a motion-picture film supplement to this paper has been prepared and is available on loan from NACA Headquarters, Washington, D. C.

Hovering Flight at Altitude

Time histories of the uncontrolled pitching and yawing motions are presented in figures 7 and 8, respectively. These time histories are not symmetrical about the horizontal axis because the model could not be trimmed perfectly. Since the control surfaces were not trimmed perfectly and the propellers caused large random fluctuations in moments, the model moved away from the center of the test area and its motion was superimposed on the motion caused by the out-of-trim moments. A study of the moment fluctuations caused by the propellers on another model is presented in reference 3.

Time histories presented in figures 7 and 8 show that the model had unstable pitching and yawing oscillations. The periods of these oscillations were about 3.5 and 4.0 seconds, respectively, which correspond to periods of about 10 and 11 seconds for the full-scale airplane.

The stability of the XFY-1 model was markedly different from that of the simplified model of reference 1 with respect to the stability of the yawing motions. The XFY-1 model had an unstable yawing oscillation, whereas the yawing motions of the simplified model were predominantly aperiodic and about neutrally stable. This difference probably resulted mainly from the aerodynamic effects of the fuselage. The larger fuselage of the XFY-1 probably blanketed the center portion of the vertical tail. The resulting reduction in tail effectiveness as well as the increase in the direct moments on the fuselage tended to produce oscillatory instability. There were also some differences in the pitching motions of the two models which were probably also caused by the differences in the fuselages. The pitching oscillations of the XFY-1 appeared more unstable than those of the simplified model and the angular motion for the XFY-1 model appeared to be greater in proportion to the translational motion.

The model responded quickly to a control deflection and could be flown smoothly and easily in spite of its lack of stability. It could be maneuvered quickly and easily to various positions in the test area as desired and could be stopped with very little overshoot and no evidence of a tendency to overcontrol. As a further demonstration of the controllability of the model, the pilot at times allowed the pitching and yawing oscillations to build up and then applied the controls to stop them. Data of figures 9 and 10, which present several time histories of these tests, indicate that the pilot could stop the oscillations and return the model to a near vertical attitude in less than 1/2 cycle. The fact that the model did not return to zero displacement is not significant since the pilot was not making an effort to stop the model over a particular spot or to return it to zero displacement. In stopping these oscillations, the pilot had no tendency to overcontrol and reinforce the oscillation as is sometimes the case of the Dutch-roll oscillation

of conventional airplanes. The ease with which the pilot could stop the oscillations can probably be attributed largely to the fact that the periods of the oscillations were fairly long.

As pointed out previously, some flights were made with only manual control in roll. In these flights it was found that the model could be controlled in roll fairly easily despite the fluctuations of propeller torque, which appeared as abrupt changes in trim occurring at fairly long intervals. For convenience, most of the flights were made with the roll damper operating. In these flights it was very easy for the pilot to fly the model in roll because it rolled very slowly as a result of the out-of-trim moments and he had to give a control only occasionally to keep the model oriented in roll with respect to his position. The gearing of the roll damper was such that the differential movement of the elevons in response to the rate of roll $\delta_a/\dot{\phi}$ was 4.8 degrees per degree per second.

The model had neutral vertical-position stability but had positive rate-of-climb stability because of the pronounced inverse variation of the thrust of propellers with axial speed. This rate-of-climb stability tended to offset the effect of the time lag in the thrust control so that the model could be maintained at a given height fairly easily.

Hovering Flight Near the Ground

The model became only slightly more difficult to fly as it neared the ground and it was fairly easy to maneuver the model and to keep it hovering within a foot of the ground over a spot for a considerable length of time and to make recoveries even when the model tilted to a fairly large angle. Such behavior of the model when hovering near the ground was quite different from the behavior observed during the investigation of reference 1 in which it was observed that the simplified model became considerably more difficult to fly as the tail surfaces approached the ground. Although some of this difference in behavior near the ground might have been caused by the previously mentioned differences in the stability and control characteristics between the two models, it is believed that most of the differences can be attributed to the change in flight cable arrangement. The trailing cable used in the previous investigation probably caused the erratic behavior near the ground which was not evident in the present investigation. The trailing cable was fairly heavy and bulky and undoubtedly exerted a rather large force on the tail of the model when it was dragged over the ground as a result of translational movement of the model. This force produced a destabilizing moment as the model moved sideways. Further large forces on the tail of the model might have been produced as a result of the slipstream blowing the flight cable around in an erratic manner. The change to the overhead flight cable arrangement in the present investigation was made because such an effect of the trailing cable had been

suspected. With this revised setup there was no more effect of the flight cable when hovering near the ground than when hovering at altitude and the behavior of the model seemed almost as good during flights near the ground.

Take-Offs and Landings

Unrestrained take-offs and landings.- Unrestrained take-offs and landings were easy to perform because the model responded quickly to a control deflection and could be maneuvered fairly easily when near the ground. The model could almost always be landed within one-half a span of a selected point on the ground. In most of the take-offs the model moved sideways, sometimes as much as one-half a span, as it left the ground. This motion is quite evident in the film supplement to this report. The pilot could, however, easily stop this sideways motion and right the model. This behavior is believed to be a characteristic of the model and is not necessarily a characteristic of the full-scale airplane. One cause of this sideways motion is believed to be the fact that the pilot had no warning of any out-of-trim moments before the model took off because the model had no spring in the landing gear. This lack of landing-gear spring also caused the take-offs to come as a surprise to the pilot since the model did not rise at all until the thrust actually exceeded the weight. A secondary reason that the sideways motion was particularly noticeable with this model is that the motor-generator set could not supply much excess power so the model could not take-off rapidly.

In order to obtain some indication of how the model landings represented those of the full-scale airplane with regard to rate of descent, a few time histories of the vertical height during several representative landings of the model were obtained from motion-picture records. In these tests the object was not to make either very gentle or very fast landings but was to make reasonably smooth landings on a selected spot. The records of these landings (see fig. 11) show that in some landings the rate of descent was reasonably constant at a value of about 2 feet per second (full scale) for the entire descent from a height of about 50 feet (full scale) to the touchdown; whereas in one of the landings shown, the descent was checked before the touchdown but the rate of descent at the time of touchdown was still about 2 feet per second. It appeared, therefore, that it was possible to make very gentle landings even with the poor power control used in the model. With the tethered landing techniques discussed in the following paragraphs the model could probably be pulled down at any desired rate of descent.

Tethered landings with single line attached to rear of fuselage.- When the model was pulled down to the ground with a single line attached

to the rear of the fuselage the landings were unsatisfactory because the model diverged as it approached the ground as was the case in similar tests described in reference 2. This divergence occurred because the line introduced a severe instability of angle of pitch or yaw with horizontal displacement. When the model was disturbed and moved in the Y or Z direction, the line caused the model to yaw or pitch in the direction of the displacement. This yaw or pitch produced a force which caused the model to continue to move in the direction of displacement. When the model was near the ground and displaced sufficiently far horizontally, the controls were not powerful enough to pitch or yaw the model to an erect attitude with the tail restrained by the tethering line. Once the model started to diverge, it was impossible to effect a recovery unless the line was released and the tension eliminated.

Tethered landings with a single line attached to the side of the fuselage.- The use of a single line attached to the side of the fuselage at a longitudinal location slightly behind the center of gravity made the model difficult to fly and the landings were very poor. The model seemed to have a tendency to make the tethering line go slack as it moved sideways and the line sometimes became tangled with the wing or vertical tail. The troubles encountered with this technique may have resulted partly from the fact that there was not enough excess power available to put much tension in the line.

Tethered landings with two lines.- When the model was tethered with lines attached either to the forward or to the rearward ends of the gun pods, landings were fairly easy to perform but were sometimes rough. The yawing motion was easily controlled because it was stabilized by the tethering lines, in fact, for most of these landings no rudder control was necessary. The pitching motion, however, was more difficult to control because the model had to be flown directly over the tethering line attachment points on the ground. The lines produced pitching moments which were stabilizing with angle of pitch but destabilizing with displacement in the Z-direction. The pilot could not, therefore, allow any appreciable movement of the model away from a position directly above the attachment points of the tethering lines. This type of flying was more difficult than flying with no tethering lines because the pilot was required to give control for even very slight displacements. In flying the model unrestrained the pilot was not usually concerned with small displacements and could concentrate on keeping the model in a vertical attitude so that its sideways motions were mild. Most of the roughness encountered in the tethered landings resulted from the poor behavior in pitch which was similar to that obtained with a single tethering line attached to the rear of the fuselage. If the model happened to pitch abruptly as a result of the instability or a control deflection just as it was about to touch down, one of the relatively rigid landing gears usually hit sharply and caused the model to bounce violently. This behavior would not have appeared as undesirable if the

model had had a shock-absorbing landing gear. Since the model had greater unstable pitching moments when the tethering lines were attached to the rearward ends of the gun pods, the landings made with this configuration were more difficult than when the tethering lines were attached to the forward ends of the gun pods.

Tethered landings with four lines.- Tethered landings made with lines attached to the tip of each wing and vertical tail were easy to perform and were smoother than with any of the other tethering techniques. During several of these landings the model appeared completely stable and flew for quite long periods of time with no control being given by the pilot. This stability resulted from the fact that the lines passed through rings on the ground that were farther apart than the attachment points on the model. In this configuration the lines produced stable variations of pitching and yawing moments with sideways displacement from the trimmed position.

Translational Flight in Gusty Air

At low translational speeds the model was somewhat more difficult to fly in pitch and yaw than it was when hovering in still air. This increased difficulty in flying the model seemed to result from the gustiness of the wind instead of the fact that the model was in translational flight. In fact, the air was so gusty that it was impossible to make any definite observations about the stability in pitch or yaw. The model was definitely easier to fly in roll in translational flight because the translational velocity eliminated the fluctuations in trim resulting from changes in propeller torque. The model appeared to have stability in bank about its body axis; that is, it seemed to have a definite tendency to fly with its belly into the wind.

As the translational velocity was increased above 30 knots (full scale) the model became more difficult to fly in yaw. It appeared that in these conditions the model had an aperiodic divergence which the pilot was unable to stop if he allowed it to develop very far. This result seems to be in agreement with the results of some preliminary force tests made by the Consolidated-Vultee Aircraft Corporation which indicated directional instability in this angle-of-attack range.

The variation of angle of attack with translational speed obtained in the tests is shown in figure 12. These angles of attack are averages read from motion-picture records of each flight at times when the model appeared to be in a steady flight condition. This variation of angle of attack with speed does not, of course, represent that of the full-scale airplane very accurately because of the high drag of the model which resulted from the propeller guard and flight cable and from the low scale of the tests.

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CONCLUDING REMARKS

The following results were obtained from flight tests of a 0.13-scale model of the Consolidated-Vultee XFY-1 vertically rising airplane in take-offs, landings, and hovering flight.

1. In hovering flight the model had unstable pitching and yawing oscillations but could be controlled smoothly and easily despite its lack of stability.

2. The behavior of the model was almost as good when hovering near the ground as when hovering at a considerable height above the ground. Unrestrained take-offs and landings were therefore easy to perform.

3. Satisfactory tethered landings could be made using either twin lines (one attached to each wing tip) or four lines (one attached to the tip of each wing and vertical tail), the better landings being obtained with the four-line technique.

4. At low forward translational speeds in gusty air the model seemed reasonably stable and easy to fly except that it became difficult to control the yawing motions when the speed exceeded a value of about 30 knots (full scale).

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1. Lovell, Powell M., Jr., Bates, William R., and Smith, Charles C., Jr.:
Dynamic Stability and Control Characteristics of a Delta-Wing Vertically Rising Airplane Model in Take-Offs, Landings, and Hovering Flight. NACA RM L51H13a, 1951.
2. Bates, William R., Lovell, Powell M., Jr., and Smith, Charles C., Jr.:
Additional Studies of the Stability and Controllability of an Unswept-Wing Vertically Rising Airplane Model in Hovering Flight Including Studies of Various Tethered Landing Techniques. NACA RM L51I07a, 1951.
3. Smith, Charles C., Jr., Lovell, Powell M., Jr., and Bates, William R.:
Effect of the Proximity of the Ground on the Stability and Control Characteristics of a Vertically Rising Airplane Model in the Hovering Condition. NACA RM L51G05, 1951.
4. Bates, William R., Lovell, Powell M., Jr., and Smith, Charles C., Jr.:
Dynamic Stability and Control Characteristics of a Vertically Rising Airplane Model in Hovering Flight. NACA RM L50J16, 1951.

TABLE I.- GEOMETRIC CHARACTERISTICS OF THE MODEL

Weight, lb	34.00
Wing (modified triangular plan form):	
Sweepback, deg	55
Airfoil section	NACA 63-009 modified
Aspect ratio	1.90
Taper ratio (root to theoretical tip)	5.23
Area (total to center line), sq in.	818.95
Span (theoretical), in.	39.49
Mean aerodynamic chord, in.	23.94
Span of elevon (each), in.	15.37
Chord of elevon, in.	2.92
Dihedral angle, deg	0
Over-all length of model, in.	49.40
Fuselage length, in.	45.40
Vertical tails (modified triangular plan form):	
Sweepback, deg	40
Airfoil section	NACA 63-009 modified
Aspect ratio	3.18
Taper ratio (root to theoretical tip)	3.15
Area (total to center line), sq in.	379.88
Span, in.	34.73
Mean aerodynamic chord, in.	13.07
Span of top rudder, in.	14.13
Span of bottom rudder, in.	11.13
Chord of rudders, in.	2.85
Propellers (eight-blade dual-rotating):	
Diameter, in.	23.85
Hamilton Standard design, drawing number	3155-6-1.5
Solidity, one blade	0.0475
Gap, in.	3.00



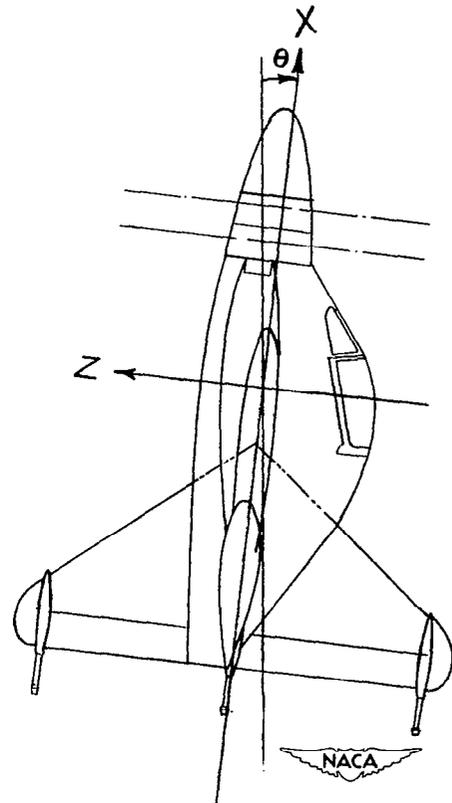
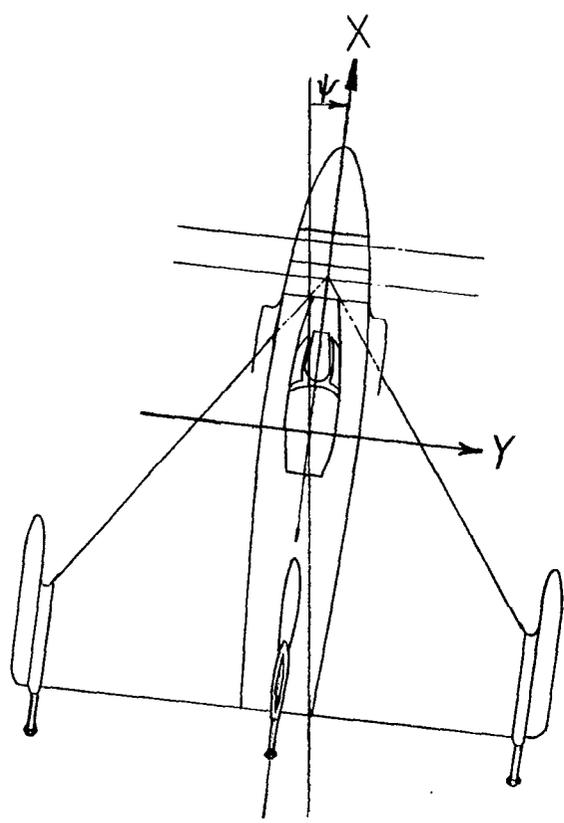
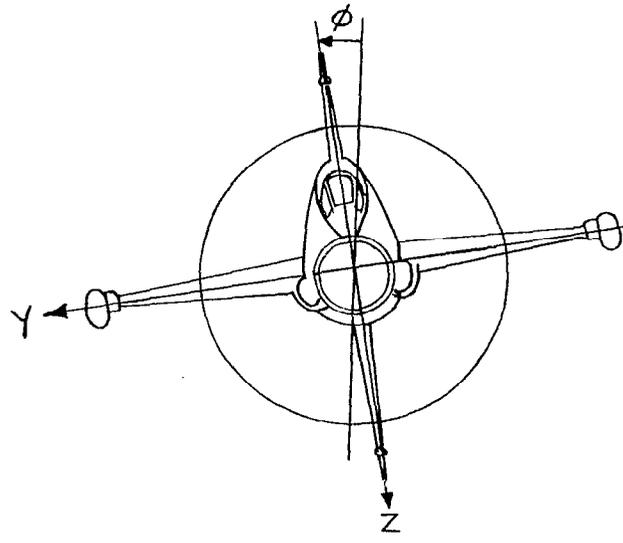


Figure 1.- The body system of axes. Arrows indicate positive directions of linear and angular displacements.

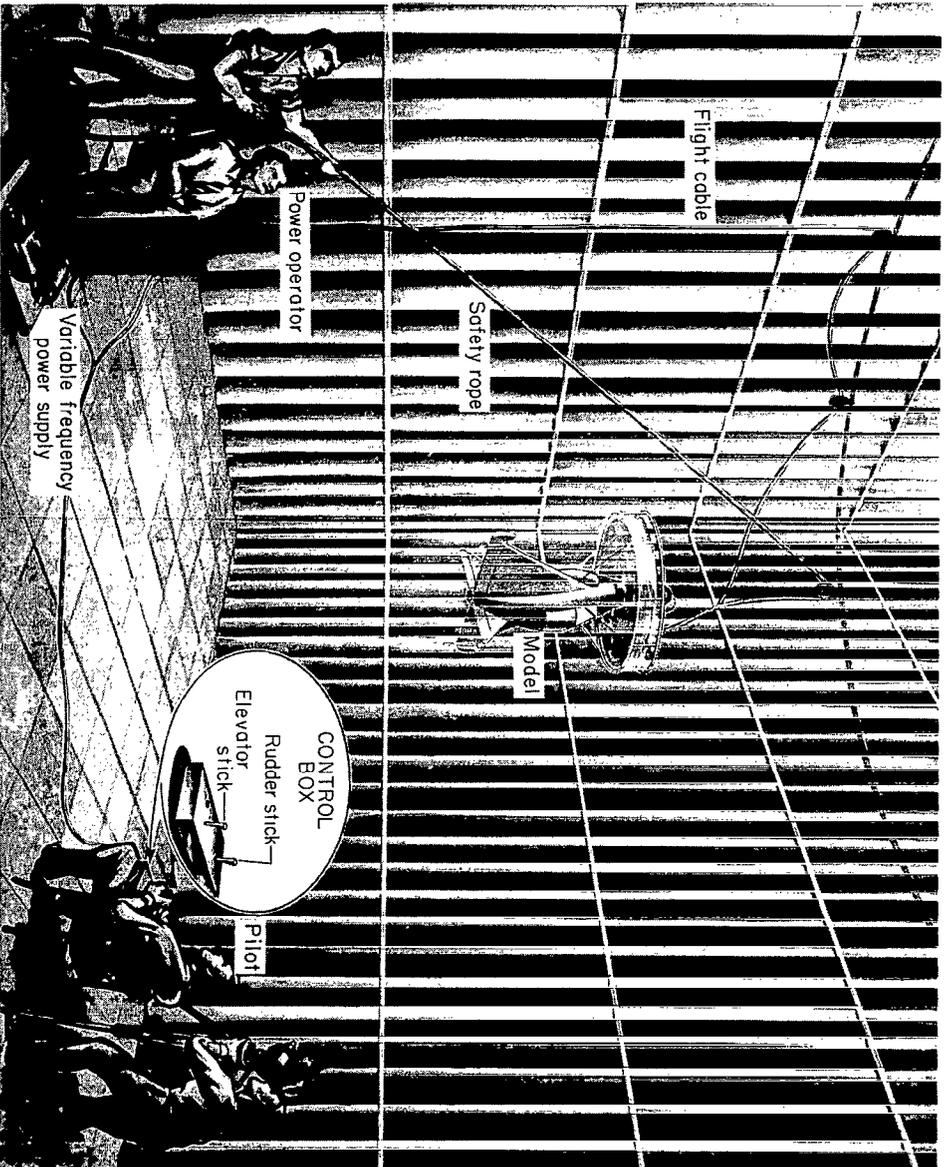


Figure 2.- Sketch of test setup used in return passage of Langley full-scale tunnel.

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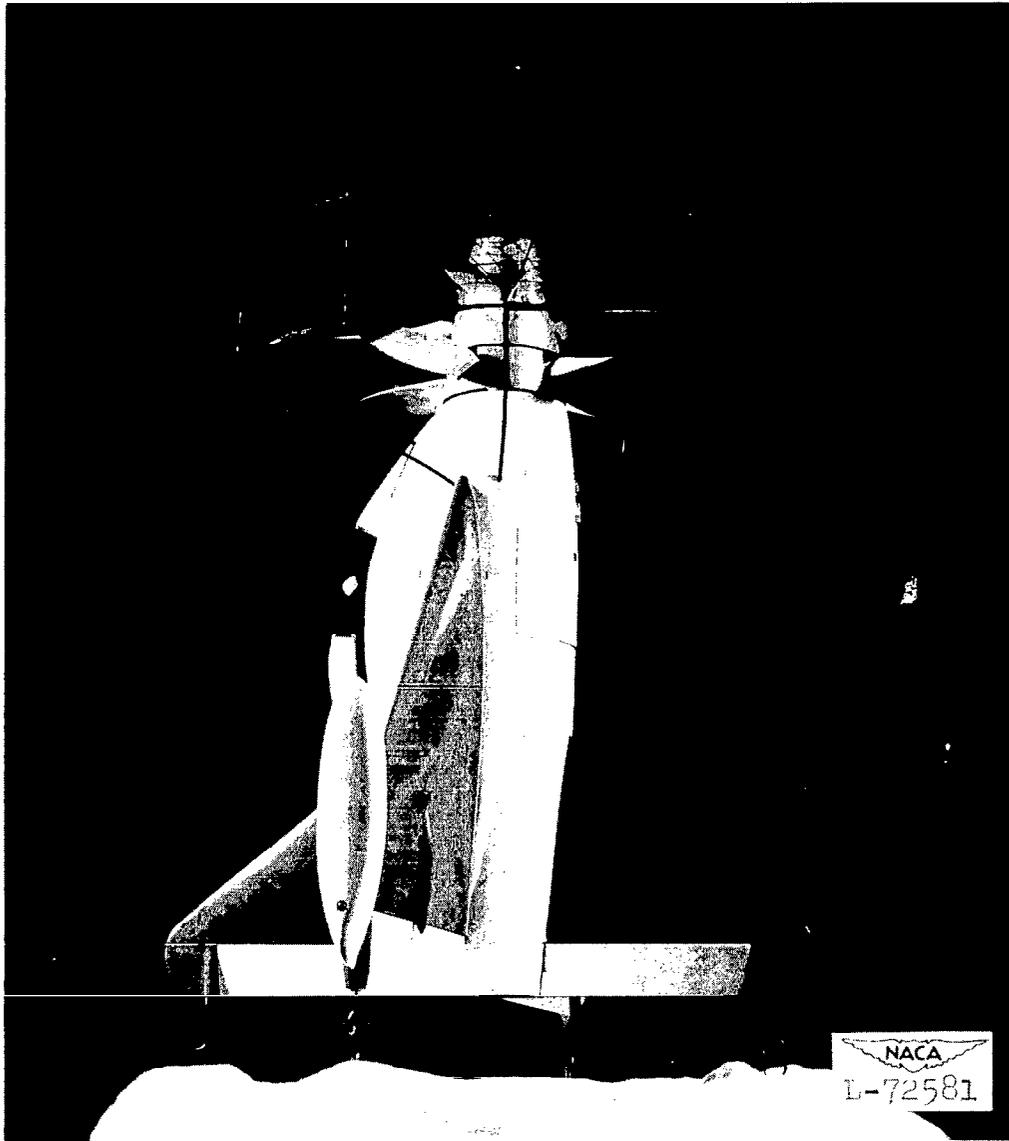


Figure 3.- Photograph of XFY-1 model showing propeller guard.

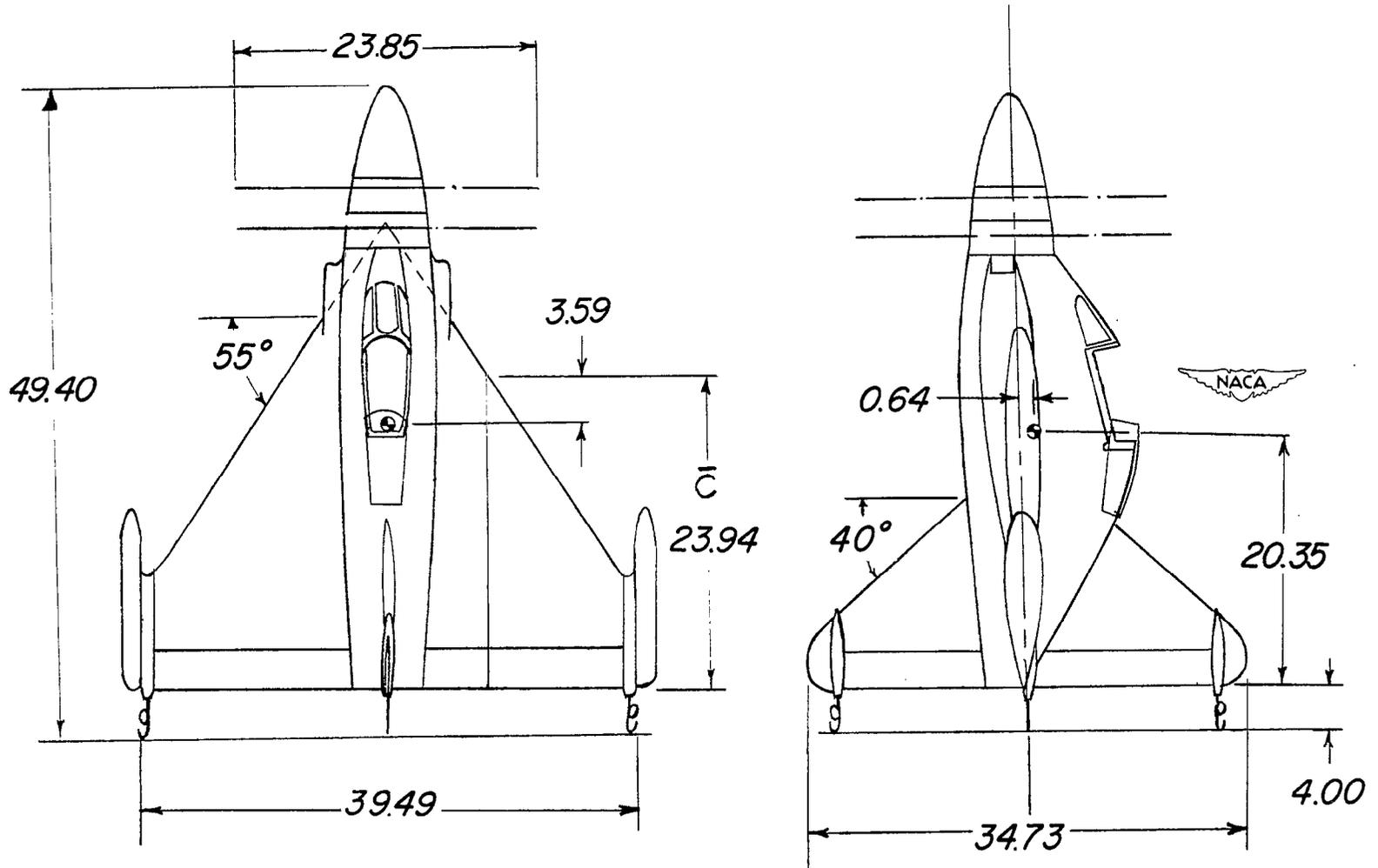
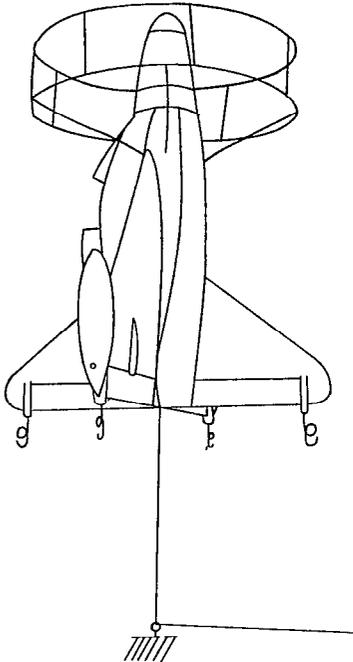
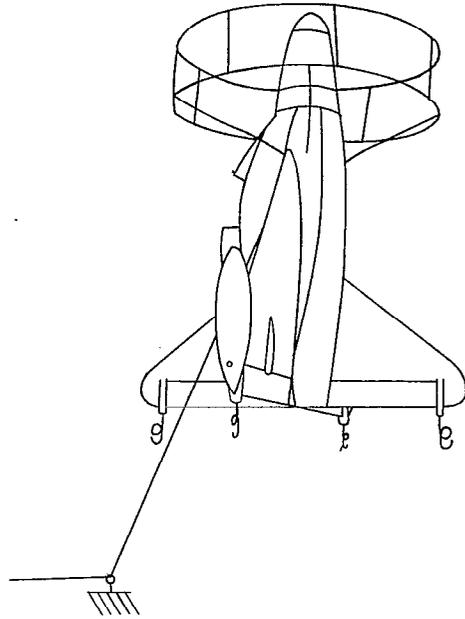


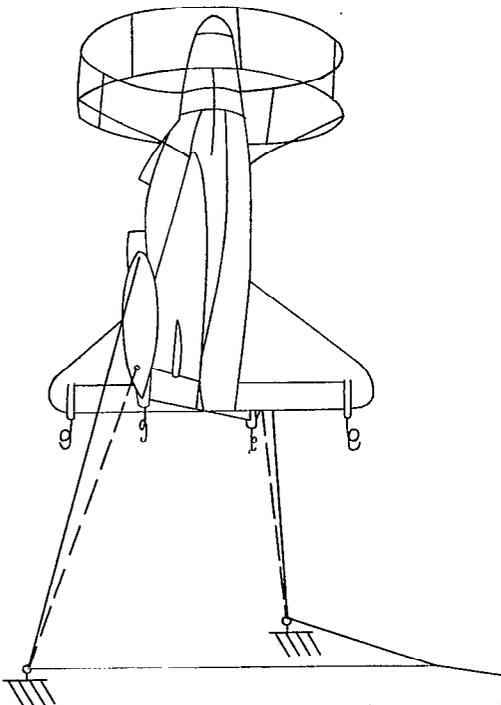
Figure 4.- The XFY-1 vertically rising airplane model. All dimensions are in inches.



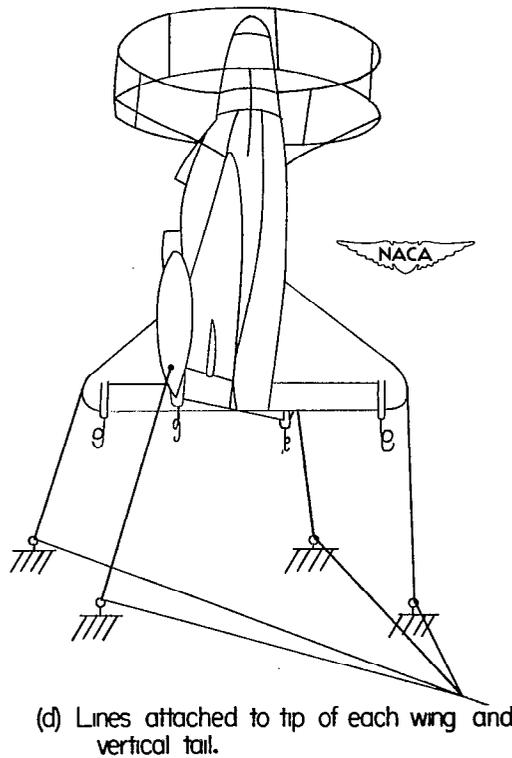
(a) Single line attached to rear of fuselage.



(b) Single line attached to side of fuselage.



(c) Lines attached to either forward or rearward ends of gun pods.



(d) Lines attached to tip of each wing and vertical tail.

Figure 5.- Tethering techniques used for landings.

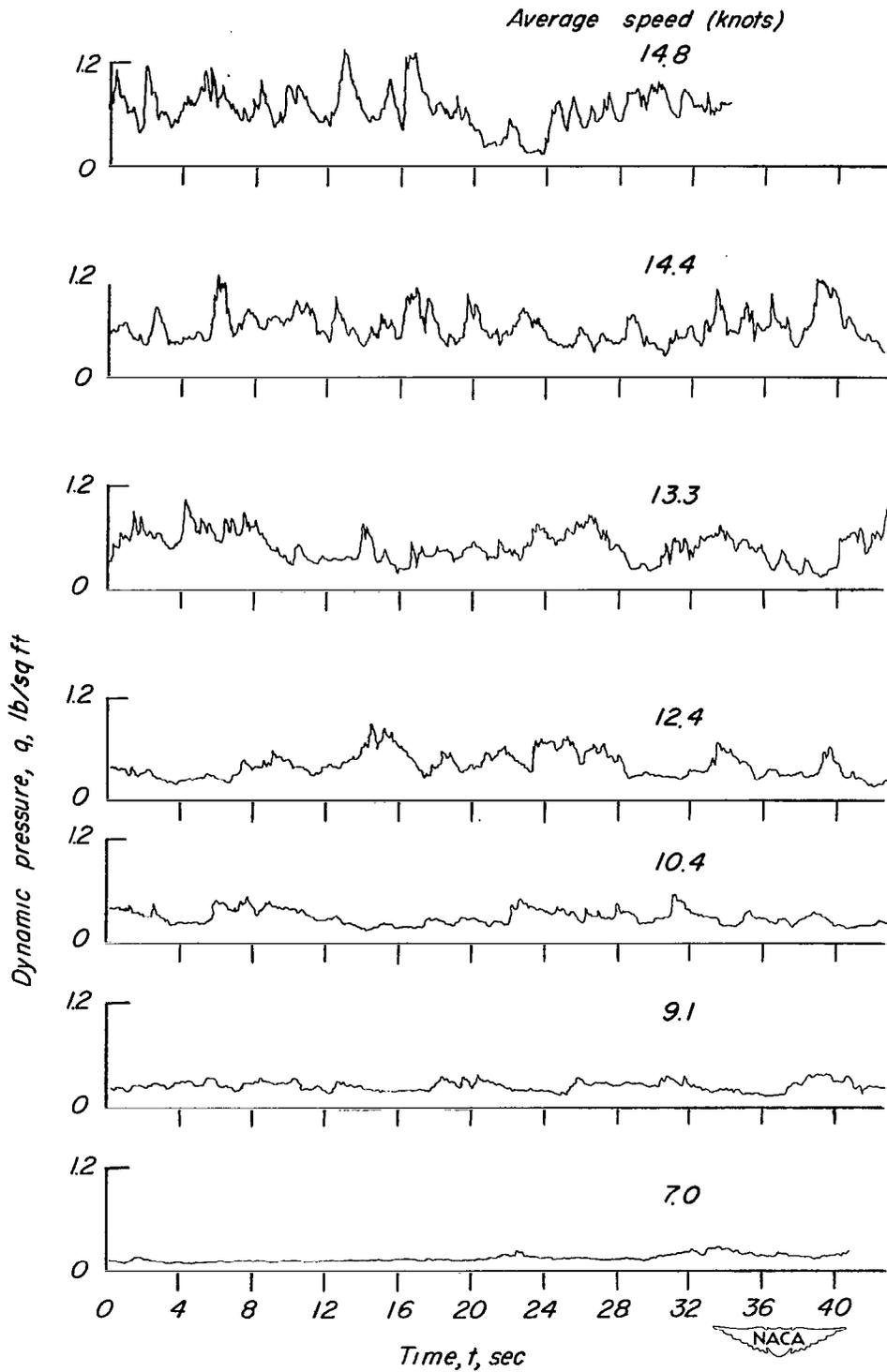


Figure 6.- The variation of dynamic pressure with time in the return passage of the Langley full-scale tunnel.

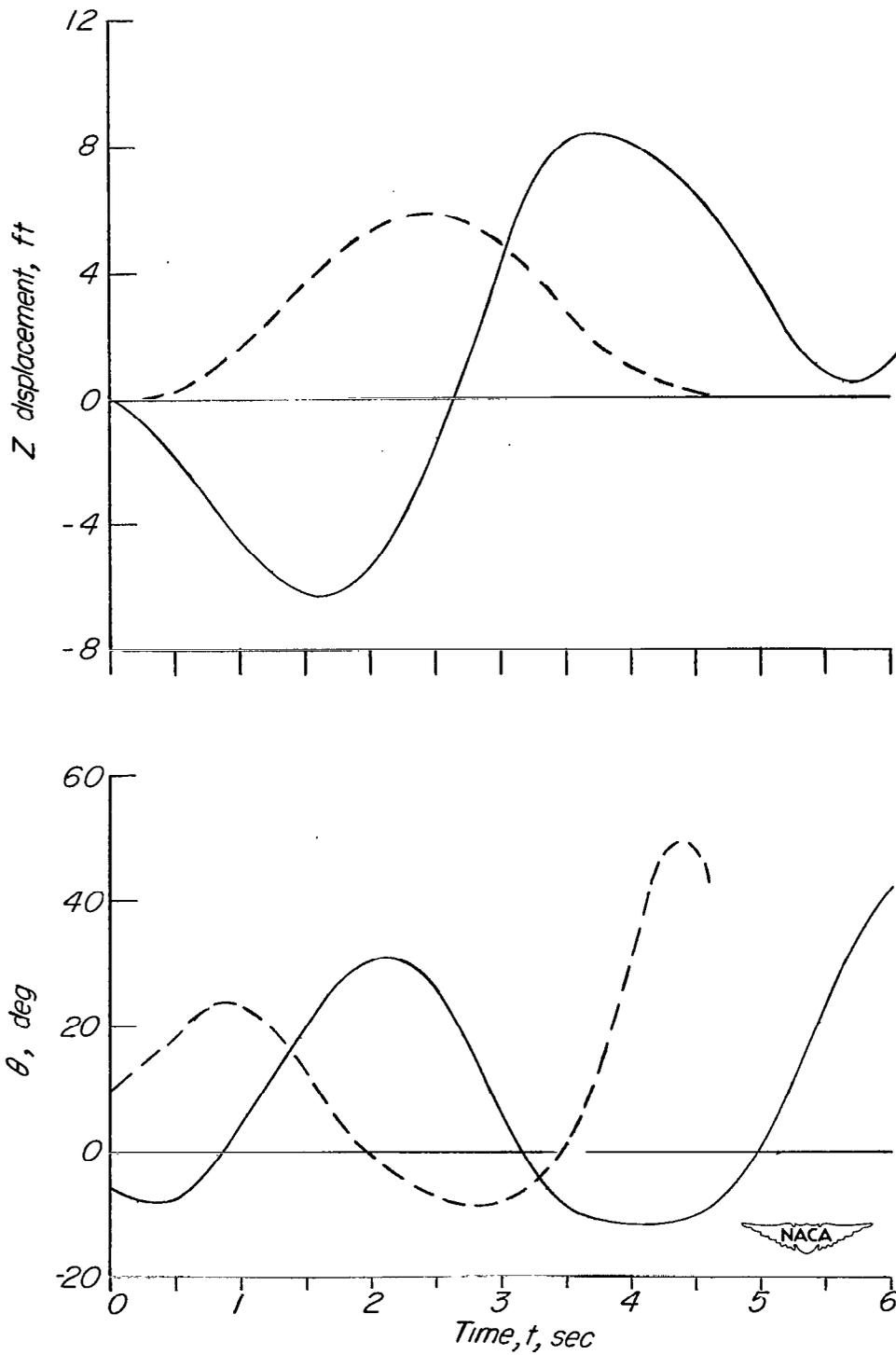


Figure 7.- The uncontrolled pitching motions of the model in hovering flight for two runs.

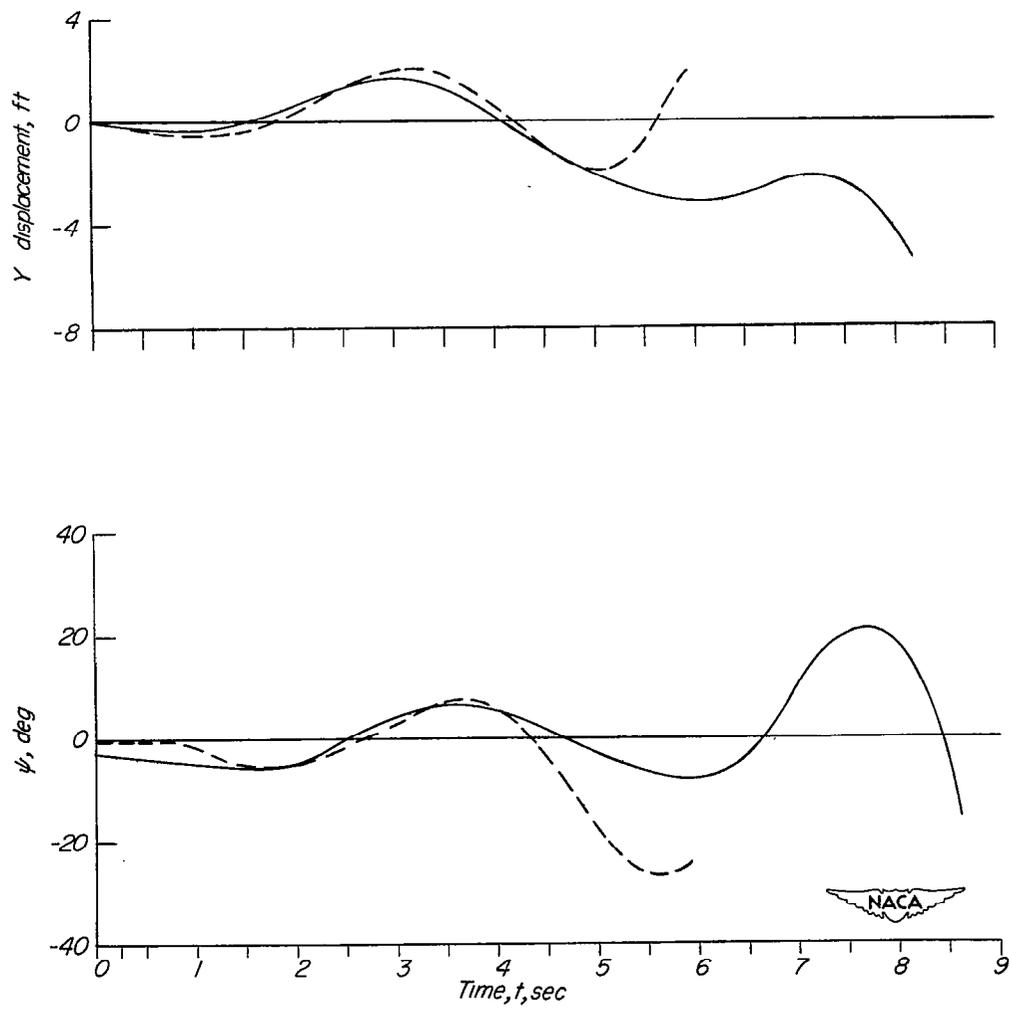


Figure 8.- The uncontrolled yawing motions of the model in hovering flight for two runs.

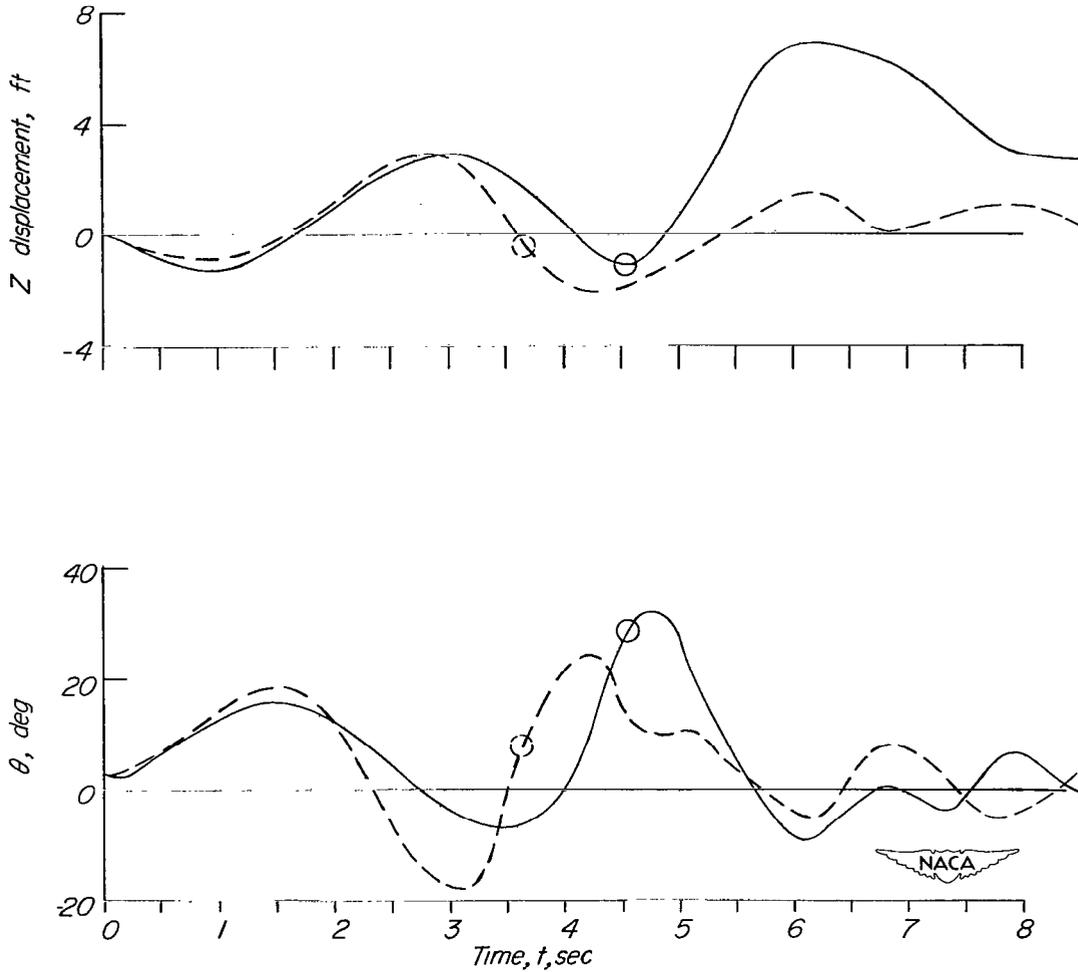


Figure 9.- Flight records showing the ability of the pilot to stop the pitching oscillation. The circular symbols indicate the time at which the pilot began using controls to stop the oscillation.

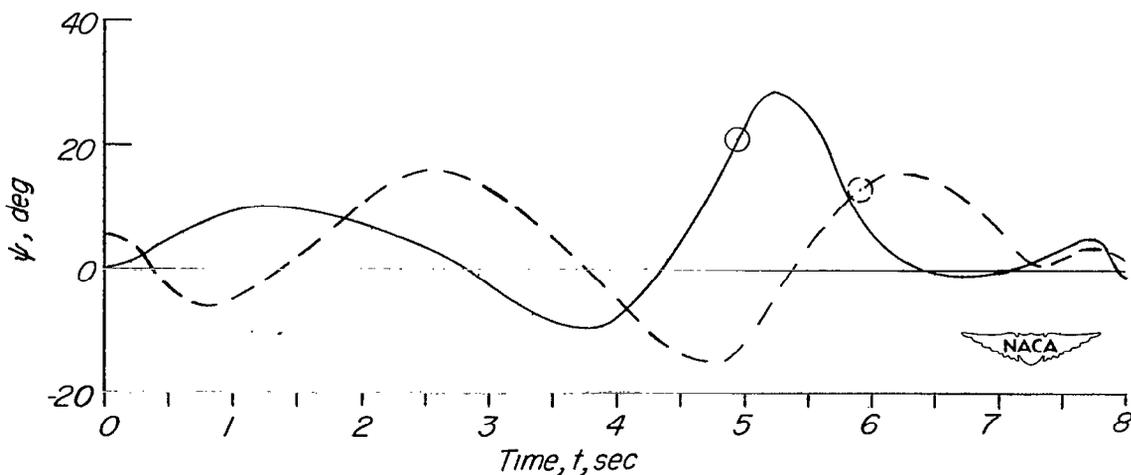
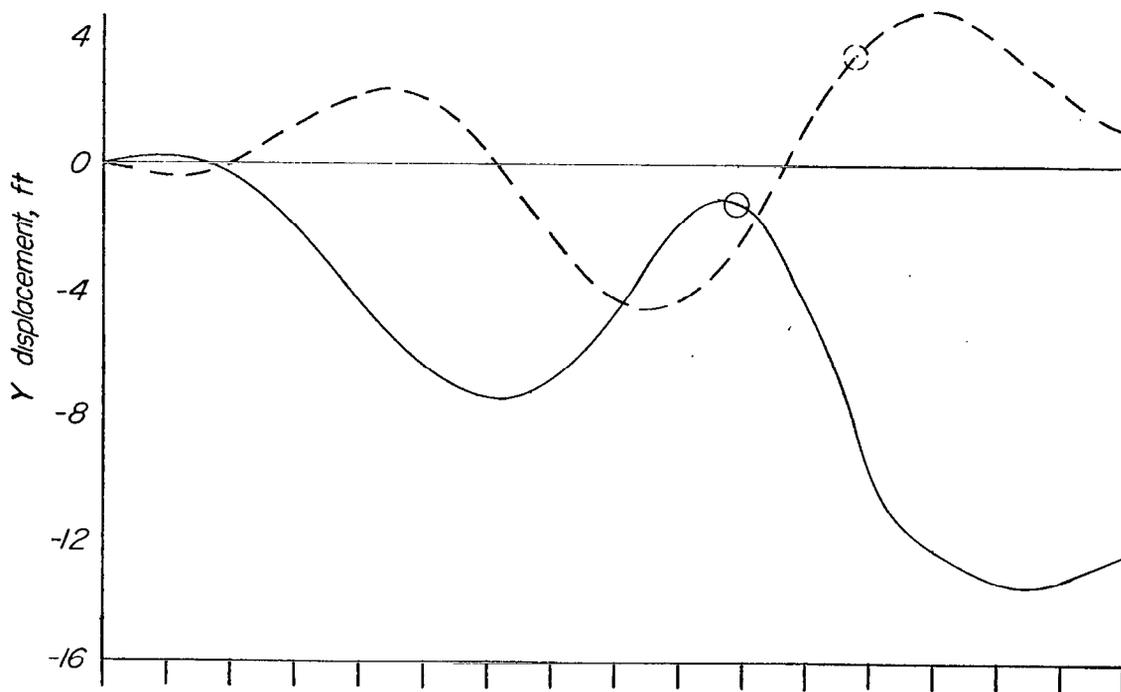


Figure 10.- Flight records showing the ability of the pilot to stop the yawing oscillation. The circular symbols indicate the time at which the pilot began using the controls to stop the oscillation.



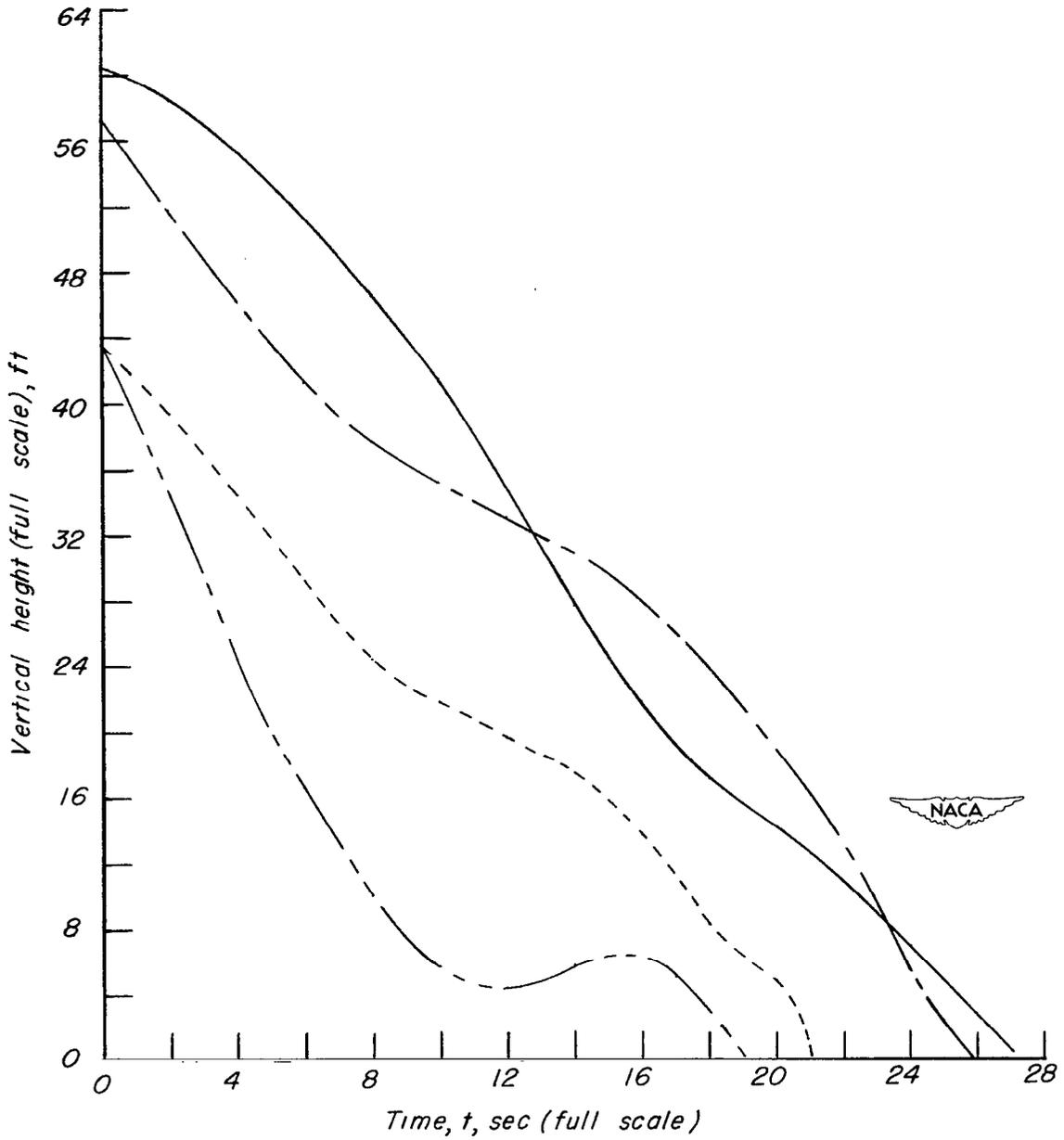


Figure 11.- Time histories of descent in unrestrained landings.

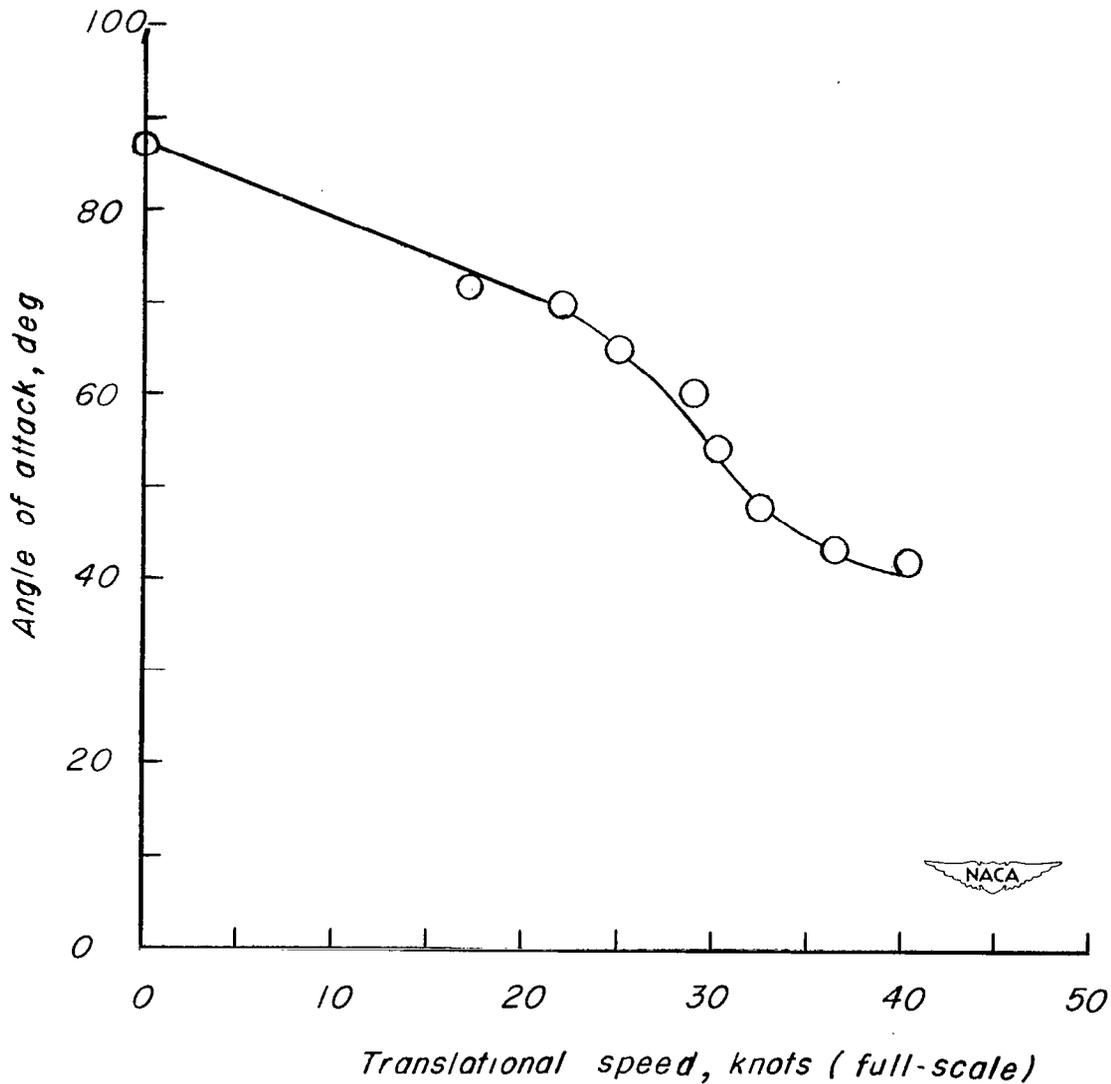


Figure 12.- The variation of angle of attack with forward translational speed.

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