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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3440

HOVERING FLIGHT TESTS OF A FOUR-ENGINE-TRANSPORT VERTICAL TAKE-OFF AIRPLANE MODEL UTILIZING A LARGE FLAP AND EXTENSIBLE VANES FOR REDIRECTING THE PROPELLER SLIPSTREAM

By Louis P. Tosti and Edwin E. Davenport

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Washington
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SUMMARY

An investigation of the take-off, landing, and hovering-flight characteristics of a four-engine-transport, vertical take-off airplane has been conducted with a remotely controlled free-flight model. The model had four propellers distributed along the wing with thrust axes parallel to the fuselage axis. In order to produce direct lift for hovering flight, the propeller slipstream was deflected downward about 70° by a full-span 65-percent-chord flap deflected 90° and eight extensible vanes arranged above the wing in a cascade relation.

Flying the model without the use of artificial damping in pitch was difficult for the pilot because of a violently unstable pitching oscillation. This oscillation could be stabilized by the use of a rate-sensitive artificial damper which also made the pitching motions easy to control. The rolling motion was slightly divergent but was fairly easy to control. Although the pilot could generally maintain control of the model in yaw, the yaw control was considered undesirably weak. The stability and control characteristics of the model when hovering near the ground appeared to be as good as those obtained when hovering at a considerable height above the ground. Vertical take-offs and landings could be performed satisfactorily, although, when trimmed for hovering flight well above the ground, the model had a slight tendency to move forward as it took off or neared the ground on landing. Some difficulty was experienced in controlling the vertical motions of the model, because there was apparently very little damping of these motions.

INTRODUCTION

For some types of vertical take-off airplanes, particularly transports, it is desirable to have the fuselage as near horizontal as possible

to facilitate loading and handling of passengers. One configuration which has been proposed to accomplish this aim is a reasonably conventional airplane with wing flaps and possibly auxiliary vanes to turn the propeller slipstream downward to provide direct lift for hovering flight. In order to determine whether such an airplane was feasible from the stability and control standpoint, hovering flight tests of a simplified test vehicle were made by the Langley free-flight tunnel section and are reported in reference 1. Inasmuch as these tests indicated that the stability and control characteristics of an airplane of this type could be fairly satisfactory in hovering flight, research on this general configuration has been expanded.

A model has been built for use in a test program to extend the flight tests to cover the transition between hovering and normal forward flight. This model has a wing system which can turn the slipstream about 70° with reasonable efficiency and can be retracted to form a simple monoplane wing. The model is intended primarily for study of the stability and control characteristics in transition between hovering and normal forward flight. Preliminary tests have been made, however, to check the stability and flight characteristics in take-offs, landings, and hovering flight. The results of these preliminary tests are presented herein.

The flying model used in the present investigation had four propellers with thrust axes parallel to the fuselage axis and distributed along the wing span so that the turning vanes and most of the wing were immersed in the slipstream. The wing had a full-span plain flap of about 65 percent chord which was deflected about 90° for hovering flight. The trailing portion of the flap was hinged as a control flap and had a chord of 25 percent of the mean aerodynamic chord. For hovering flight, eight evenly spaced 90° turning vanes were located above the wing in a cascade relation to turn the slipstream downward (approximately 70°) to produce direct lift for hovering flight. For a few preliminary flights the model was also equipped with eight additional turning vanes located below the wing in a cascade relation. These lower vanes, however, were removed for most of the tests to simplify the configuration after the preliminary tests had indicated that the performance of the model was reasonably satisfactory without the lower vanes. The model was designed so that the flap and vanes would retract to form a conventional monoplane configuration for forward flight. Control was provided by moving the right and left control flaps differentially for yaw control and together for pitch control and by varying the total pitch of the two outboard propellers differentially for roll control.

The investigation consisted entirely of flight tests and included hovering flight at a considerable height above the ground, hovering flights close to the ground to determine the effects of the ground, vertical take-offs, and landings. The stability and controllability were determined from visual observation, the pilots' impressions of the flying qualities of the model, and also from motion-picture and control-position records of the flight tests.

Some additional research has been undertaken by the Langley 7- by 10-Foot Tunnel Branch to study the aerodynamic characteristics of other wing systems that are capable of turning the propeller slipstream through large angles and of being folded to form a clean wing for forward flight by a simple retraction system. This work, the first results of which are published in references 2 to 4, consisted of force tests in forward flight as well as in the hovering condition.

SYMBOLS

The motions of the model are referred to the body system of axes. Figure 1 shows these axes and the positive direction of the forces, moments, and angular displacements. For simplicity in reducing the records, linear displacements in time histories of the model motions are presented with reference to horizontal and vertical space axes.

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

$\bar{c}$ mean aerodynamic chord

θ angle of pitch of thrust axis relative to horizontal, deg

$\dot{\theta}$ pitching velocity, deg/sec

ψ angle of yaw, deg

ϕ angle of roll, deg

δ_f deflection of control flap for pitch control, deg

L rolling moment, ft-lb

M pitching moment, ft-lb

N yawing moment, ft-lb

I_X moment of inertia about X-axis, slug-ft^2

I_Y moment of inertia about Y-axis, slug-ft^2

I_Z moment of inertia about Z-axis, slug-ft^2

X longitudinal force, positive forward, lb

Y lateral force, positive to right, lb

Z normal force, positive downward, lb

APPARATUS AND MODEL

Some of the flight tests were conducted in the large room used by the Langley free-flight tunnel section for flight tests of models in the hovering condition. Other tests were conducted outdoors because the test room was not available at the time. These outdoor tests were conducted in a clearing in a dense woods in order to provide protection from the normal outdoor winds and gusts. The test setup used in all the tests is illustrated in figure 2, and the test technique is described in detail in reference 1.

Photographs of the model are shown in figures 3(a) and 3(b). In these figures the model is shown with auxiliary vanes below as well as above the wing. The lower vanes were removed for most of the tests to simplify the configuration after preliminary tests had indicated that the performance of the model was reasonably satisfactory without these additional vanes. In order to accomplish transition from hovering to forward flight, the model was designed so that, as the main wing flap rotates from 90° to 0°, the cascade of auxiliary vanes rotates 45° to a position perpendicular to the wing chord; the cascade of vanes then folds outwardly as a parallelogram setup to nest in a recess in the wing. The model is then a conventional monoplane configuration for forward flight as shown by the photograph in figure 4. This retraction system was selected on the basis of being mechanically simple for a small-scale dynamic model and not on the basis of being an optimum arrangement for a full-scale airplane. A three-view drawing of the model with the lower vanes removed is presented in figure 5, and the geometric characteristics of the model are presented in table I. A detailed sketch of a section of the model wing and the upper and lower vanes is presented in figure 6. The model was powered by a 10-horsepower electric motor which turned four two-blade propellers having their thrust axes parallel to the fuselage axis. The direction of rotation of the propellers is indicated in figure 5. Blade-form curves for the propeller are given in figure 7.

Control was obtained by moving the left- and right-trailing-edge 25-percent-chord flaps differentially for yaw control and together for pitch control and by varying the total pitch of the two outboard propellers differentially for roll control. The control surfaces were deflected by flicker-type (full-on or off) pneumatic actuators which were remotely operated by the pilots. These manually operated servomechanisms gave approximately the following control deflections:

Pitch control, deg	±9
Yaw control (each flap), deg	±12
Outboard propeller blades (each propeller blade), deg	±3

These actuators were equipped with integrating-type trimmers which trimmed the controls a small amount in the direction that the controls were moved each time a control movement was applied. With actuators of this type, the model became accurately trimmed after flying a short time in a given

flight condition. Separate pilots were used to control the model in pitch, roll, and yaw since it has been found that, if a single pilot operates all three controls, he is so busy controlling the model that he has difficulty ascertaining the true stability and control characteristics of the model about its various axes.

A rate-sensitive artificial stabilizing device was used in some of the tests to increase the damping of the pitching motions. This device (called a pitch damper) consisted of a rate gyroscope which, in response to rate of pitch, provided signals to a proportional control actuator which moved the control to oppose the pitching motion. This proportional control actuator was connected to the flicker actuator so that their outputs were superimposed. The maximum additional pitch deflection that could be provided by the pitch damper was $\pm 9^{\circ}$.

TESTS

The tests included hovering flight at a considerable height above the ground, hovering flight near the ground, and vertical take-offs and landings. The stability and controllability of the model were determined from the pilots' observations and opinions of the behavior of the model, from the study of motion-picture records of the flight tests, and from time-history plots of the motions of the model read from the motion-picture records. The flight-test techniques used in the present investigation were similar to those used in the investigation of the simplified test vehicle which are described in detail in reference 1. The investigation of the effects of artificial stabilizing devices in the present series of tests was much less detailed than that reported in reference 1 because it was felt that these effects had been covered adequately in the previous work. For the tests in which the pitch damper was used, the value of the reponse parameter of the damper $\frac{d\delta_f}{d\dot{\theta}}$ was about 0.7. This value was obtained by calibrating the damper on a rocking table.

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 the National Advisory Committee for Aeronautics, Washington, D. C.

In general, the results of the hovering flight tests indicated that the behavior of the model was similar to that of the simplified test vehicle covered by reference 1; that is, controlling the model in pitch was very difficult because of a violently unstable pitching oscillation, but this oscillation could be stabilized with a pitch damper. The behavior of the model with the pitch damper was fairly satisfactory in that take-offs and landings could be made and the model could be controlled fairly easily in hovering flight. All the results presented herein are for the configuration with the lower vanes removed except those presented in the section entitled "Preliminary Tests With Lower Vanes Installed."

Hovering Flight at Altitude

Pitching.- The flight tests showed that the model had a violently unstable pitching oscillation. This oscillation is shown in the time histories of the uncontrolled pitching motions presented in figure 8(a). These time histories show that the oscillation was a combination of pitching and longitudinal translation. The model seemed to have a very pronounced tendency to pitch nose-up if it moved forward or to pitch nose-down if it moved backward. It also had a tendency to move forward if it pitched nose-down or to move rearward if it pitched nose-up. These two force and moment variations are statically stabilizing. For example, if the model noses down, it starts to move forward and this forward movement causes it to pitch nose upward which tends to right the model and stop its forward motion. The phase relation of these motions, which appear to be stabilizing from static considerations, can be such as to produce an unstable oscillation if there is insufficient damping in pitch and insufficient damping of longitudinal translation. Evidently these damping factors were too small in proportion to the static stability parameters for this model.

In spite of this violently unstable oscillation, the model could be controlled in pitch by careful use of the pitch control. This fact is illustrated in figure 8(b) by time histories of the pitching and longitudinal motions of the model in controlled flight. For this record the pilot was attempting to fly the model as smoothly as possible. The fact that the model was pitching through a rather large range of angles despite his efforts to control it is evident from the figure. The present model was somewhat easier to control, however, than the cascade-wing model of reference 1. This slight difference may have resulted partly from the larger size and corresponding slower motions of the present model. A full-scale airplane could probably be flown considerably more smoothly than either model because the angular velocities of the airplane would be much lower than those of the models and because the pilot could sense the movements of the airplane more quickly and apply the proper amount of corrective control more exactly than was possible with the models.

Whether the behavior of a full-scale airplane would be considered tolerable cannot be definitely ascertained from the model tests, but the behavior of the model was considered unacceptable in comparison with that of other flying models. Such a condition might be considered barely acceptable for an airplane, however, if it were only an emergency condition encountered in the event of autopilot failure.

The pitch damper was used on the model as a means of improving its stability by increasing its damping in pitch. Time histories of the model motions with the damper operating are presented in figure 9 for both controlled and uncontrolled flight. With the value of gearing used in these tests $\left(\frac{d\delta_f}{d\dot{\theta}} = 0.7\right)$, the pitching oscillation was completely stable. For this condition the model would fly for indefinite periods of time without the use of any manual pitch control by the pilot. This result is illustrated in figure 9(a) by the time history of the uncontrolled pitching and longitudinal motions of the model. The model, of course, had no stability of position and consequently wandered around somewhat in response to gusts or disturbances introduced by the safety cable. The motions of the model in controlled flight with the pitch damper operating are plotted in figure 9(b). These records illustrate the fact that the model can be flown very smoothly with this value of the damper response factor.

Yawing.- The observations of the yaw pilot indicated that, in general, the yaw control was weak. This condition was particularly evident when random disturbances due to gusts or random air currents caused the model to diverge in yaw despite the application of full opposite yaw control. In one short series of flights it was noticed that the yaw control was considerably improved. It was later found that the main flap had been inadvertently set at an angle of about 85° instead of the 90° for which the flap was designed. This result may indicate a means of improving the yaw control.

There was no stability of yaw position because there was no static restoring moment in yaw. Continuous use of yaw control was therefore required to prevent yawing as a result of the random disturbances on the model. It is important to maintain a constant heading when flying the model because the model must be properly oriented with respect to the remote pilots in order for them to control the model effectively. Some yawing was caused by the roll control that was somewhat troublesome to the yaw pilot because of the weak yaw control.

Rolling.- The uncontrolled rolling motions of the model appeared to be an aperiodic (not oscillatory) divergence involving lateral translation as well as rolling. These uncontrolled motions are illustrated in figure 10. It is difficult to tell whether such a motion is a true

aperiodic divergence or simply the result of an out-of-trim rolling moment. The pilot's opinion, after he had made many attempts to record the uncontrolled motion after trimming the model as carefully as possible, was that this divergent motion actually indicated the instability of the model. As mentioned previously, the model was generally in fairly good trim since it was equipped with integrating-type trimmers which changed the trim a small amount in the direction that the control was deflected every time the pilot applied his flicker-type control. With this system the model becomes trimmed very accurately a short time after take-off.

The pilot could control the rolling motions of the model despite the tendency toward a roll divergence. The uncontrolled rolling motions presented in figure 10 are as smooth as those generally obtained with other free-flying models with flicker-type controls.

There was a considerable effect of the use of the yaw control on the rolling motions of the model. The use of right yaw control caused a rolling motion to the right and the use of left yaw control caused a rolling motion to the left. This cross-coupling effect was somewhat troublesome to the roll pilot, but he could usually fly the model steadily in roll despite the fact that the yaw pilot applied the yaw control frequently. In some cases trouble was experienced, however, when the model had an unusually strong tendency to diverge in yaw because of gusts or random air currents. In these cases the yaw pilot was forced to hold full yaw control for long periods of time and the model then tended to diverge in roll despite the efforts of the roll pilot to prevent the rolling. For example, if the model tended to diverge to the left in yaw, the yaw pilot held full right yaw control and the model rolled off to the right against full left roll control. A few tests with increased deflection on the roll control indicated that these divergences generally could be prevented but that the increased travel made the model more difficult to fly smoothly for normal steady flight.

Vertical motions.- The vertical motions of the model were fairly difficult to control. Part of this difficulty was caused by the lag in the power-control system in which it was necessary to accelerate or decelerate several heavy-duty components of the motor-generator power-supply unit before the model motor speed changed. When operated from the same motor-generator set, the vertical motions of the present model, however, were more difficult to control than those of the models with the propeller-shaft axis vertical. Evidently, the present model has less damping of the vertical motions than a model with the propeller-shaft axis vertical; the latter model is known to have considerable damping because of the pronounced inverse variation of the thrust of a propeller with axial velocity.

Hovering Flight Near the Ground

The model appeared to have as good stability and control characteristics when hovering near the ground as those obtained when hovering at a considerable height above the ground. All flights near the ground were made with the pitch damper operating with a gearing ratio $\frac{d\delta_f}{d\dot{\theta}}$ of 0.7 which was found to make the model completely stable in pitch when hovering well above the ground. It was necessary to fly the model continuously when hovering near the ground because any small angular motions tended to make the model lose altitude and touch the ground. The stability of the model could not be studied, therefore, by observing the uncontrolled motions. From the general ease of maintaining steady flight, however, it appeared that the stability was as good when the model was hovering near the ground as that obtained when hovering at altitude. There was no noticeable adverse effect of ground proximity on the effectiveness of any of the controls. There was a tendency for the model to move forward as it neared the ground. It was necessary therefore to increase the angle of pitch of the model by the use of up-elevator trim as the model neared the ground. A time history of the longitudinal motions of the model when hovering near the ground is given in figure 11. The pitching motions shown in this figure are not as smooth as those shown in figure 9(b) for a comparable condition with the model hovering well above the ground. This difference does not indicate that the model was more difficult to fly but resulted from the change in trim as it neared the ground. Figure 11 shows that as the model descended the pilot had to apply nose-up control very frequently in order to prevent it from moving forward and to effect the required nose-up change in trim with the self-trimming flicker-control actuators.

Take-Offs and Landings

At take-off with the horizontal tail in the original position at zero incidence, the tail tended to rise and the model moved forward rapidly before it left the ground. This motion may have resulted from a lift force on the rear part of the fuselage caused by the outward flow of the slipstream along the ground and possibly by an upflow over the fuselage behind the wing. The existence of such an upflow has been noticed in subsequent tuft tests of the model in the presence of the ground with the fuselage removed. In an effort to keep the tail down, the horizontal tail was set at about 35° negative incidence with 35° up-elevator and was moved to the low position indicated in figure 5 so that it would be in the flow of the slipstream along the ground. This change effectively eliminated the tendency for the tail to rise and the model to move forward in take-off.

With the tail in the low position, take-offs and landings were easy to perform. Time histories of three take-offs and two landings are shown in figures 12 and 13, respectively. When trimmed for hovering flight well above the ground, the model had a tendency to move forward as it took off or as it neared the ground on landing. This type of ground effect was also noticed on the cascade-wing model of reference 1. The close proximity to the ground caused a decrease in the angle through which the slipstream was turned; thus, the model was caused to move forward because of the forward tilt of the resultant force vector unless the angle of pitch was increased to compensate for the change in direction of the resultant force vector. The tendency for the model to move forward on take-offs and landings would probably be less troublesome to the pilot of a full-scale airplane than to the pilot of the model because he would have a proportional pitch-control system rather than the flicker-control system used on the model.

Preliminary Tests With Lower Vanes Installed

The results of a few preliminary flight tests of the model with the lower vanes installed indicated that the stability and control characteristics for this configuration were approximately the same as for the configuration without these vanes below the wing. These tests covered only the case of hovering at a considerable height above the ground and did not include any detailed study of stability and control characteristics. The results were based only on the pilots' impressions of the behavior of the model in controlled flight.

It was found in these preliminary tests that the model hovered with the fuselage at an angle of pitch of about 15° from the horizontal. Since an angle of 20° was considered acceptable for the model, and since later tests showed that the model could be hovered at an angle of about 20° without the lower vanes, these vanes were removed to reduce the mechanical complication involved in retracting them for normal forward flight. The complete hovering, take-off, and landing test programs were therefore made with the lower vanes removed.

Since it was not the purpose of the model or tests to suggest that the wing system used on the model be used for a full-scale airplane, no attempt was made to reduce the angle of pitch of the fuselage as far as possible. The preliminary tests with the lower vanes installed, however, suggest that, if a wing of this general type (large wing and flap with a number of small auxiliary vanes) is used, the use of vanes below the wing will reduce the fuselage angle. Reference 1 contains force-test data which indicate that the propeller slipstream can be turned 90° to give hovering flight at 0° pitch angle if both upper and lower vanes are used and if a suitable airfoil section is used instead of the curved plates used on the present model. Such vanes, however, would be considerably thicker than those of the present model and would be more difficult to retract for forward flight. A reduction in the fuselage angle might also

be obtained by the use of as much positive wing incidence as can be tolerated from consideration of other flight conditions. As pointed out previously an extensive force-test program aimed at developing a simple wing system that will turn the propeller slipstream efficiently through large angles is being conducted by the Langley 7- by 10-Foot Tunnel Branch, and some of the results of this work are published in references 2 to 4.

SUMMARY OF RESULTS

The following results were obtained from take-off, landing, and hovering flight tests of a four-engine-transport, vertical take-off, airplane model utilizing a large flap and extensible vanes for redirecting the propeller slipstream:

1. Flying the model without the use of artificial damping in pitch was difficult for the pilot because of a violently unstable pitching oscillation.

2. The pitching oscillation could be stabilized by the use of a rate-sensitive artificial damper which also made the pitching motions easy to control.

3. The rolling motion was slightly divergent but was fairly easy to control.

4. Although the pilot could generally maintain control of the model in yaw, the yaw control was considered undesirably weak.

5. The stability and control characteristics of the model appeared to be as good when hovering near the ground as those obtained when hovering at a considerable height above the ground.

6. Vertical take-offs and landings could be performed satisfactorily, although, when trimmed for hovering flight well above the ground, the model had a slight tendency to move forward as it took off or neared the ground on landing.

7. Some difficulty was experienced in controlling the vertical motions of the model, because there was apparently very little damping of these motions.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 15, 1955.

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1. McKinney, Marion O., Tosti, Louis P., and Davenport, Edwin E.: Dynamic Stability and Control Characteristics of a Cascade-Wing Vertically Rising Airplane Model in Take-Offs, Landings, and Hovering Flight. NACA TN 3198, 1954.

2. Kuhn, Richard E., and Draper, John W.: An Investigation of a Wing-Propeller Configuration Employing Large-Chord Plain Flaps and Large-Diameter Propellers for Low-Speed Flight and Vertical Take-Off. NACA TN 3307, 1954.

3. Kuhn, Richard E., and Draper, John W.: Investigation of Effectiveness of Large-Chord Slotted Flaps in Deflecting Propeller Slipstreams Downward for Vertical Take-Off and Low-Speed Flight. NACA TN 3364, 1955.

4. Draper, John W., and Kuhn, Richard E.: Some Effects of Propeller Operation and Location on Ability of a Wing With Plain Flaps To Deflect Propeller Slipstreams Downward for Vertical Take-Off. NACA TN 3360, 1955.

TABLE I.- GEOMETRIC CHARACTERISTICS OF MODEL

Weight, lb	51.0
I_X, slug-ft^2	3.96
I_Y, slug-ft^2	1.95
I_Z, slug-ft^2	5.59
Fuselage length, in.	84.8
Propellers (two blades each):	
Diameter, in.	20
Solidity (each propeller)	0.079
Design (see NACA Rep. 237)	Modified NACA Propeller A
Wing:	
Sweepback (leading edge), deg	0
Airfoil section	NACA 0018
Aspect ratio	7.13
Tip chord, in.	10.8
Root chord (at center line), in.	15.0
Taper ratio	0.72
Area (total to center line), sq in.	1186.8
Span, in.	92
Mean aerodynamic chord, in.	13.03
Control-flap hinge line, percent chord	75
Dihedral angle, deg	0
Vertical tail:	
Sweepback (leading edge), deg	5.0
Airfoil section	NACA 0009
Aspect ratio	1.94
Tip chord, in.	7.54
Root chord (at center line), in.	11.12
Taper ratio	0.68
Area (total to center line - excluding dorsal area), sq in.	169.1
Span, in.	18.125
Mean aerodynamic chord, in.	9.45
Rudder (hinge line perpendicular to fuselage center line):	
Tip chord, in.	2.5
Root chord, in.	4.05
Span, in.	14.03

Horizontal tail:	High position	Low position
Sweepback (leading edge), deg	7.3	7.3
Airfoil section	NACA 0009	NACA 0009
Aspect ratio	5.81	6.17
Tip chord, in.	4.6	4.6
Root chord (at center line), in.	8.3	8.62
Taper ratio	0.55	0.53
Area (total to center line), sq in.	241.9	269.4
Span, in.	37.5	40.75
Mean aerodynamic chord, in.	6.62	6.81
Elevator (hinge line perpendicular to fuselage center line):		
Tip chord, in.	2.13	2.13
Root chord, in.	3.30	3.30
Span (each) in.	16.94	16.94

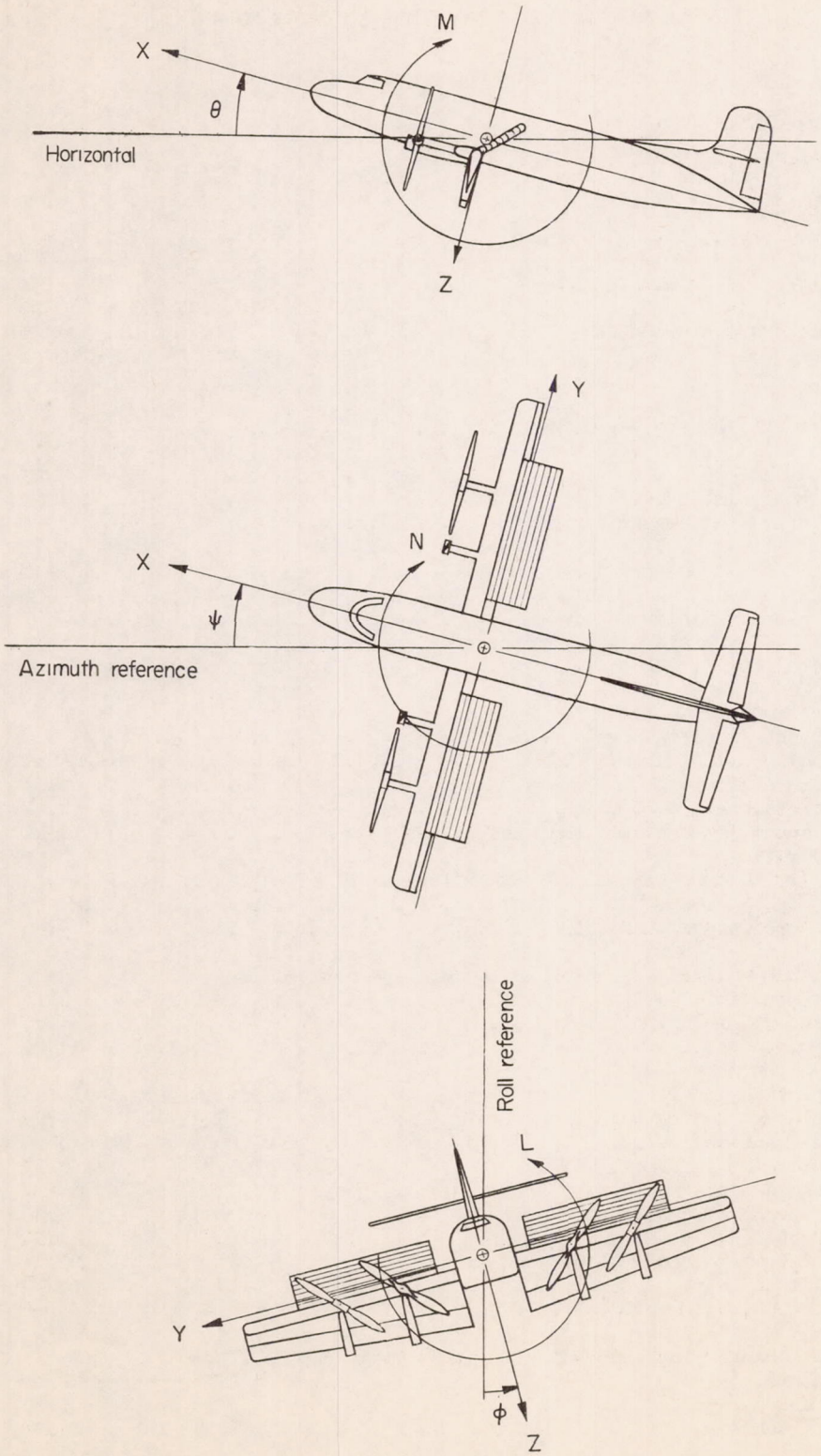


Figure 1.- The body system of axes. Arrows indicate positive directions of forces, moments, and angular displacements.

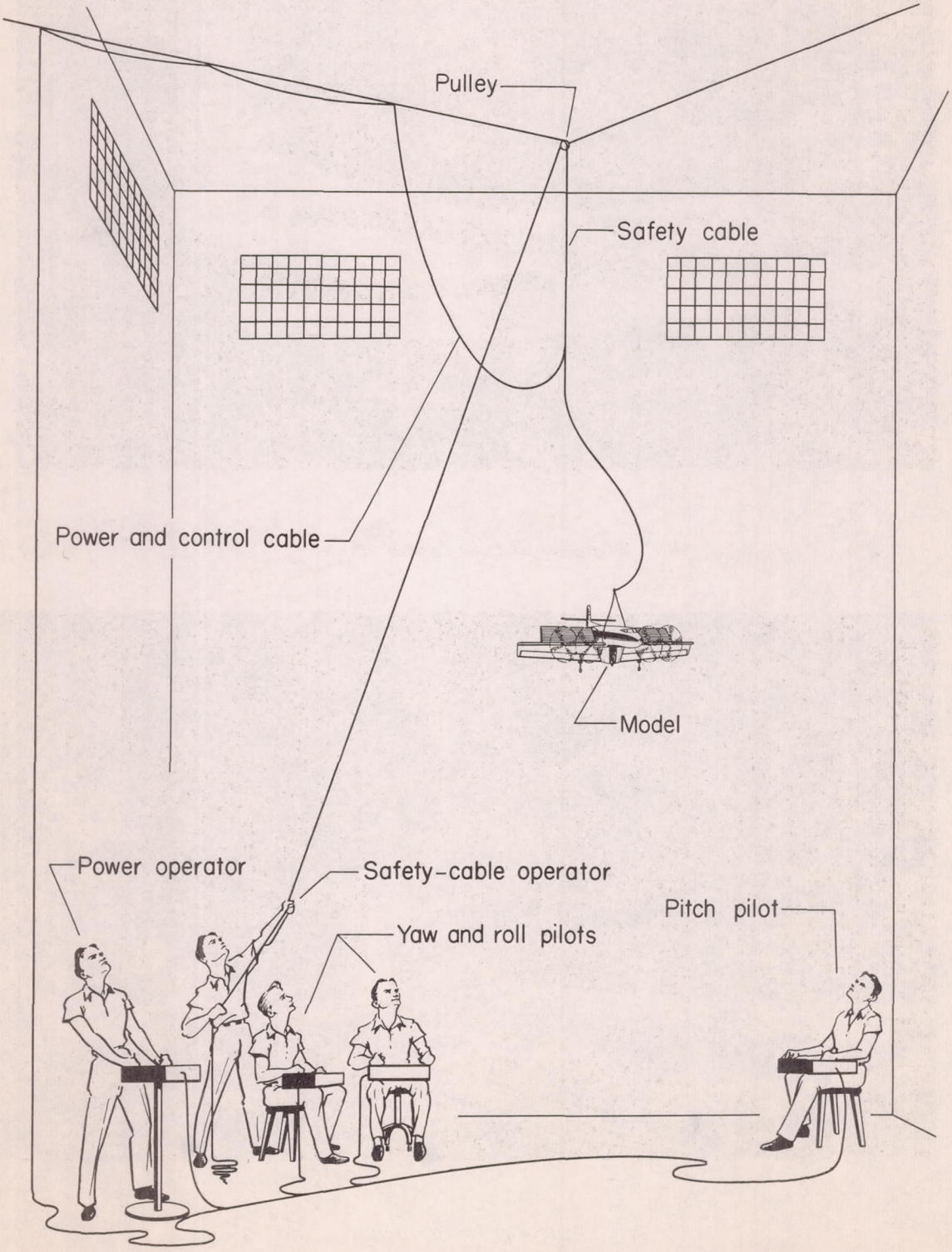
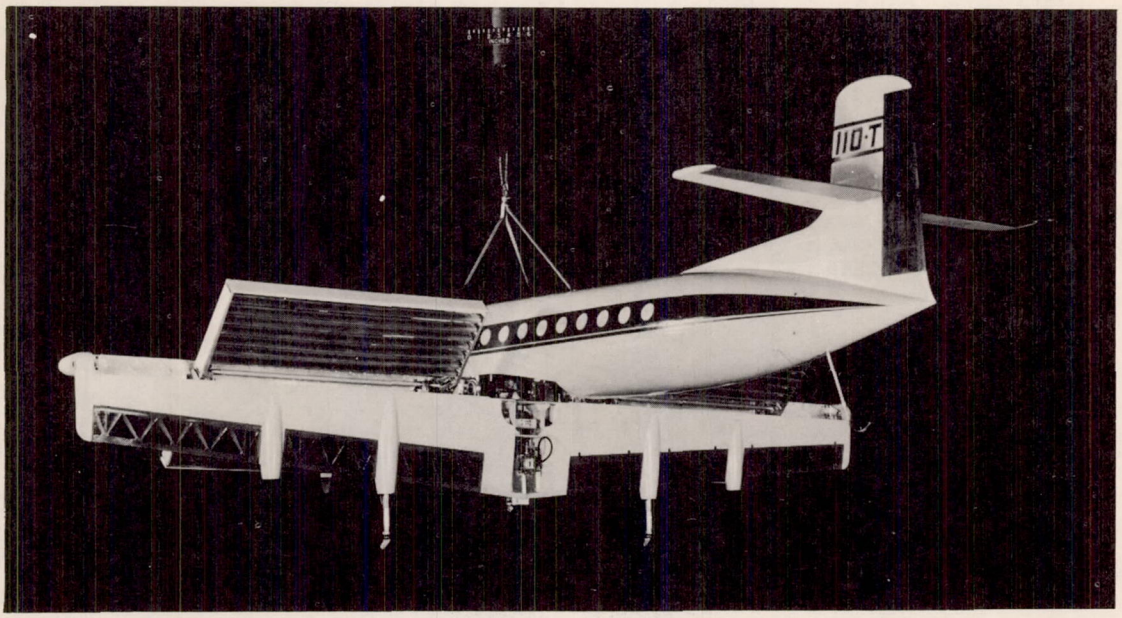


Figure 2.- Indoor test setup used in flight testing hovering models.



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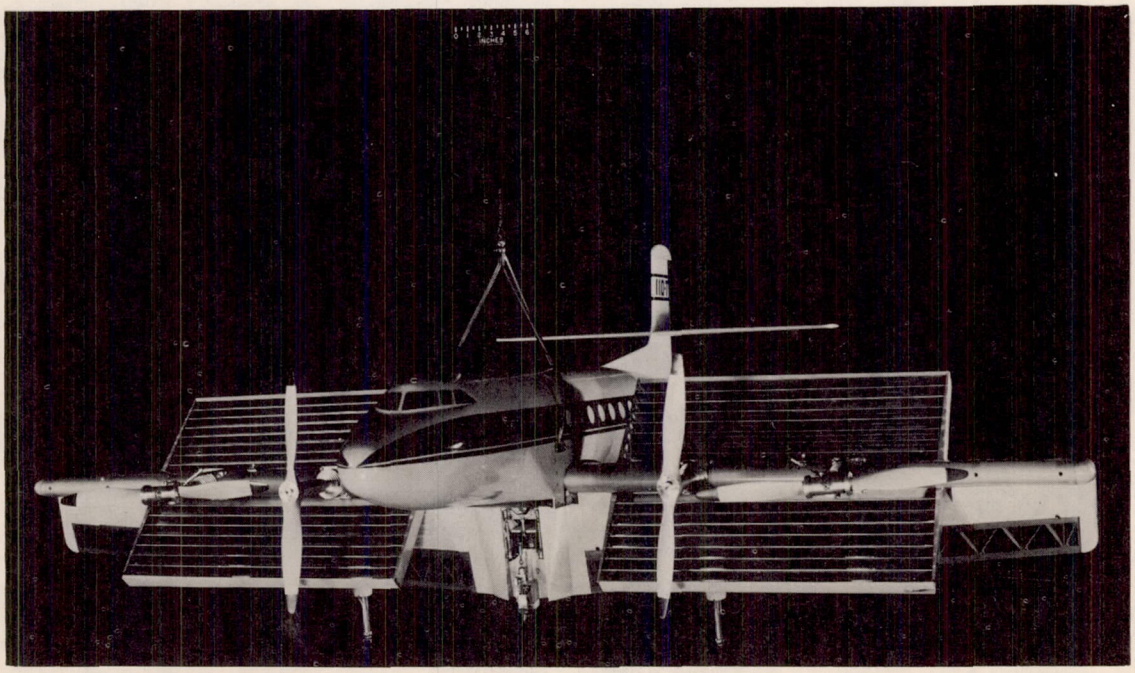
(a) Three-quarter rear view.



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(b) Three-quarter front view.

Figure 3.- Photographs of the model in the hovering configuration with lower vanes installed.

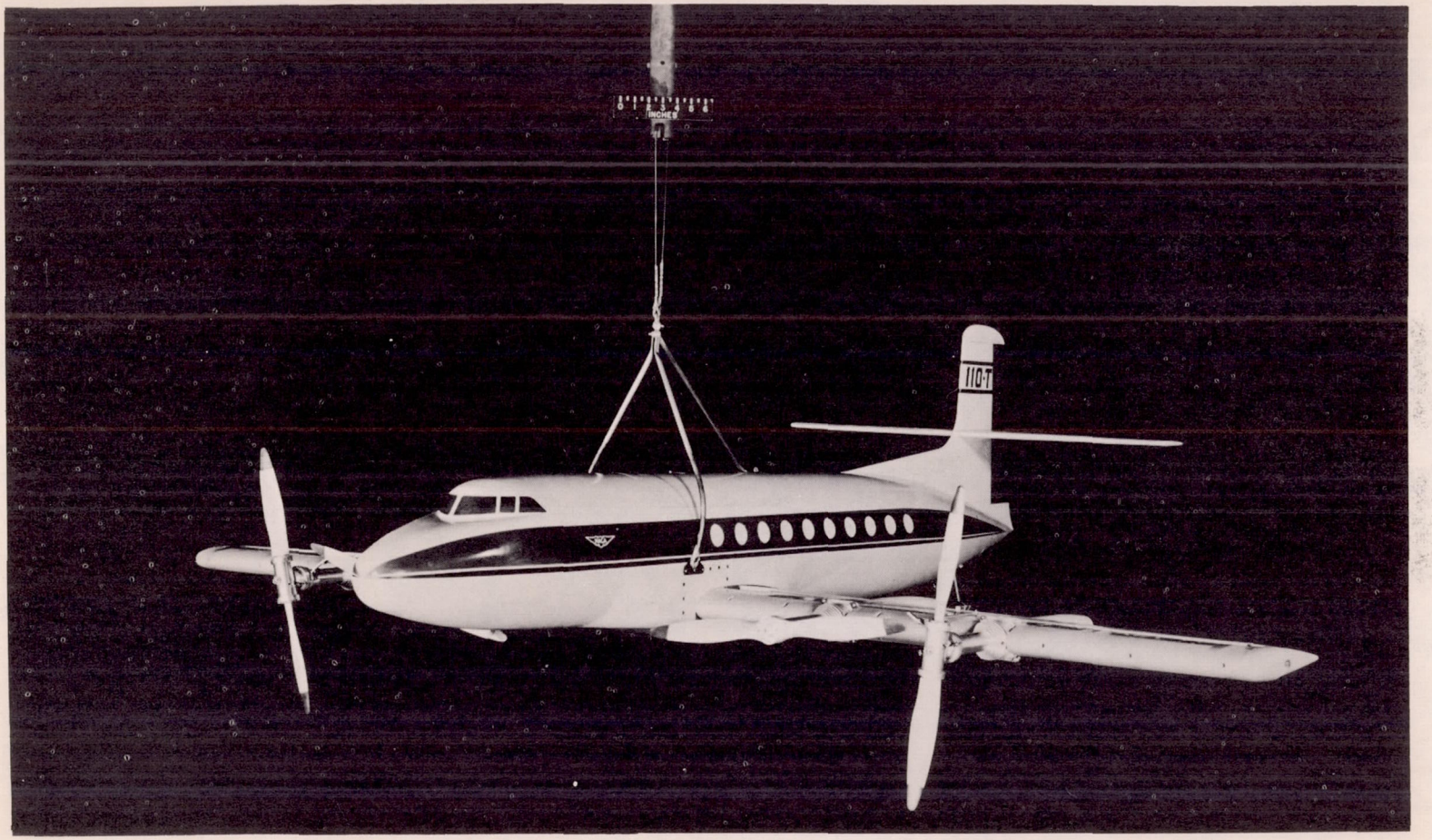

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Figure 4.- Photograph of the model in the forward-flight configuration.

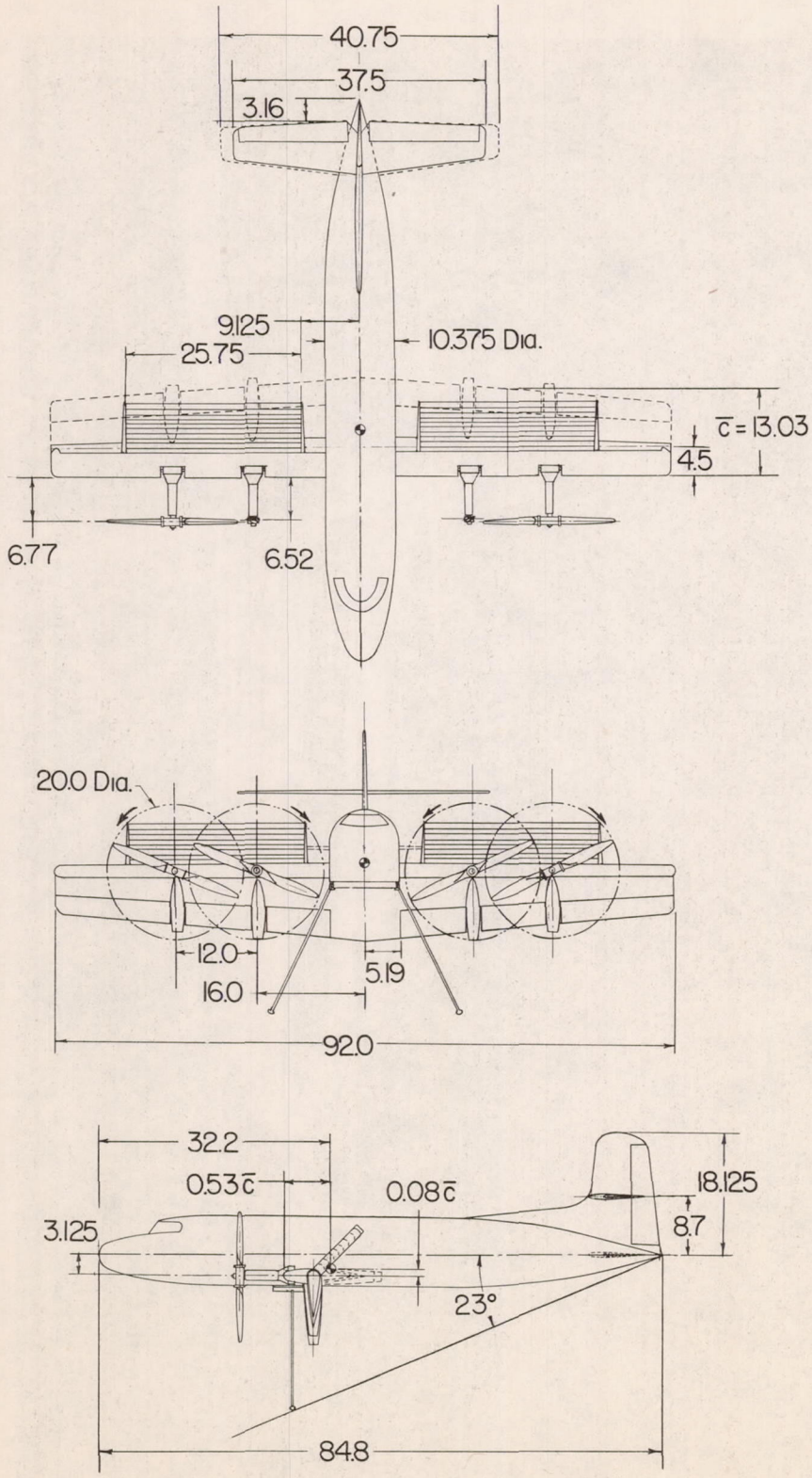


Figure 5.- Three-view sketch of the model with lower vanes removed. All dimensions are in inches.

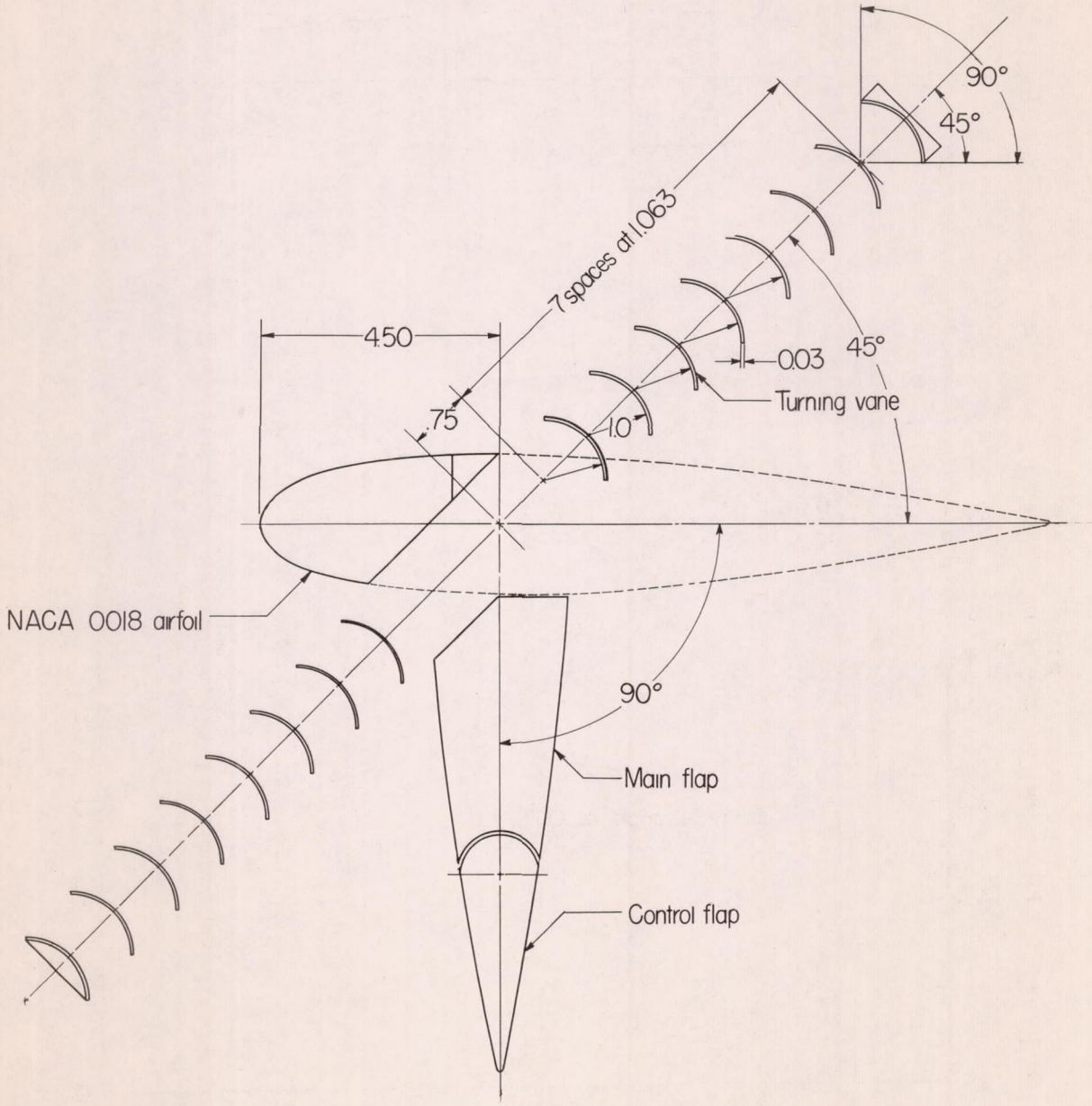


Figure 6.- Cross-sectional details of wing showing both the upper and lower sets of vanes. All dimensions are in inches.

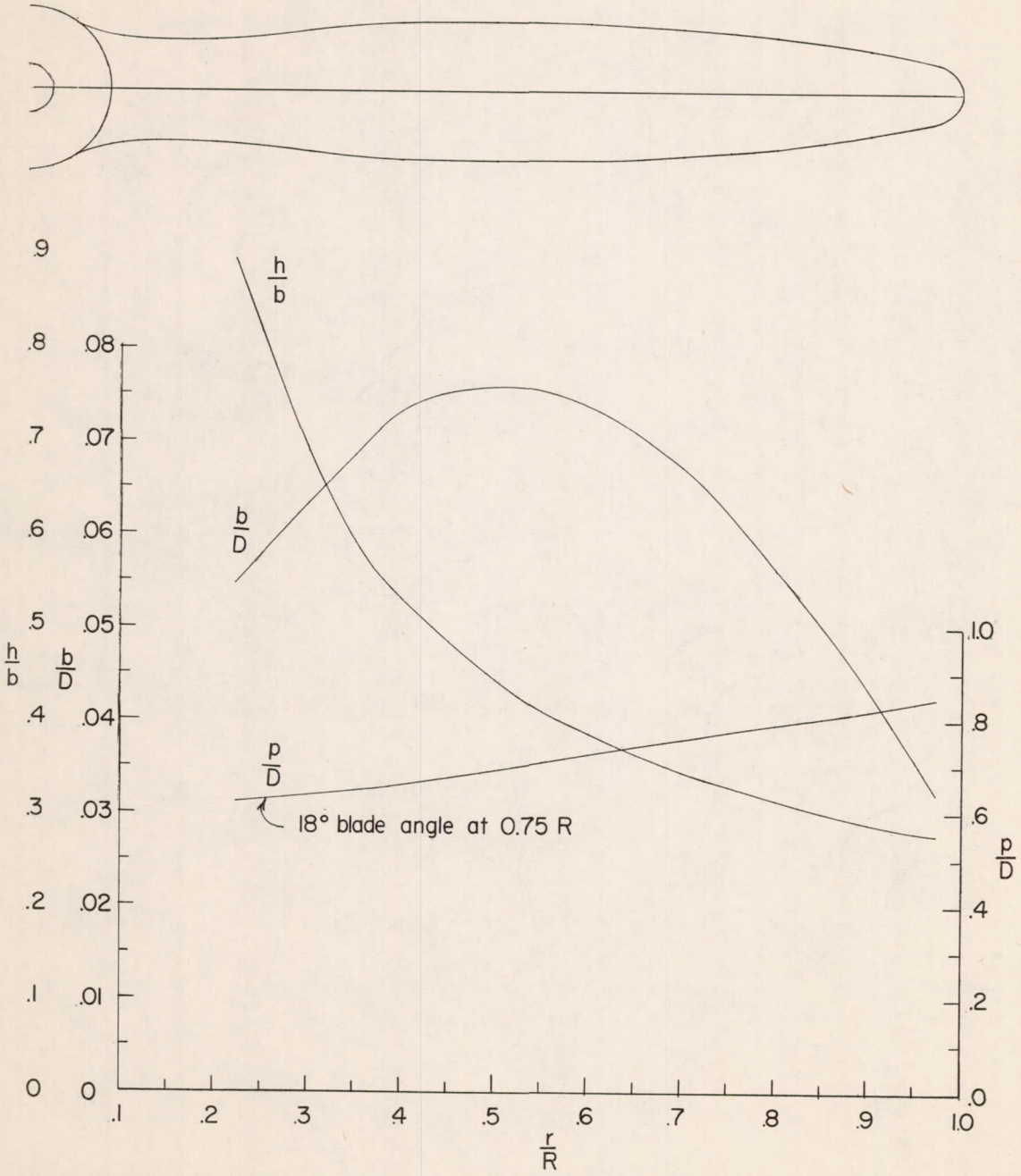
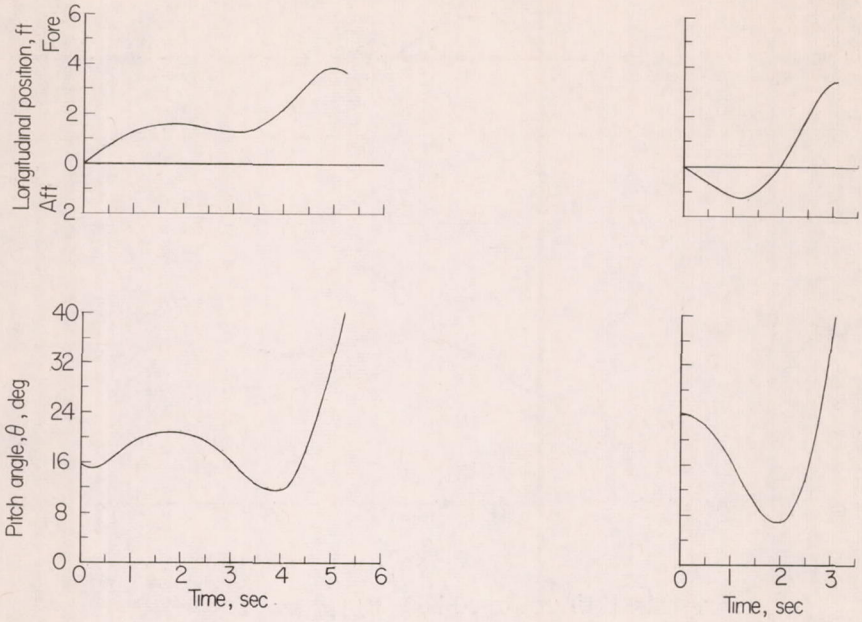
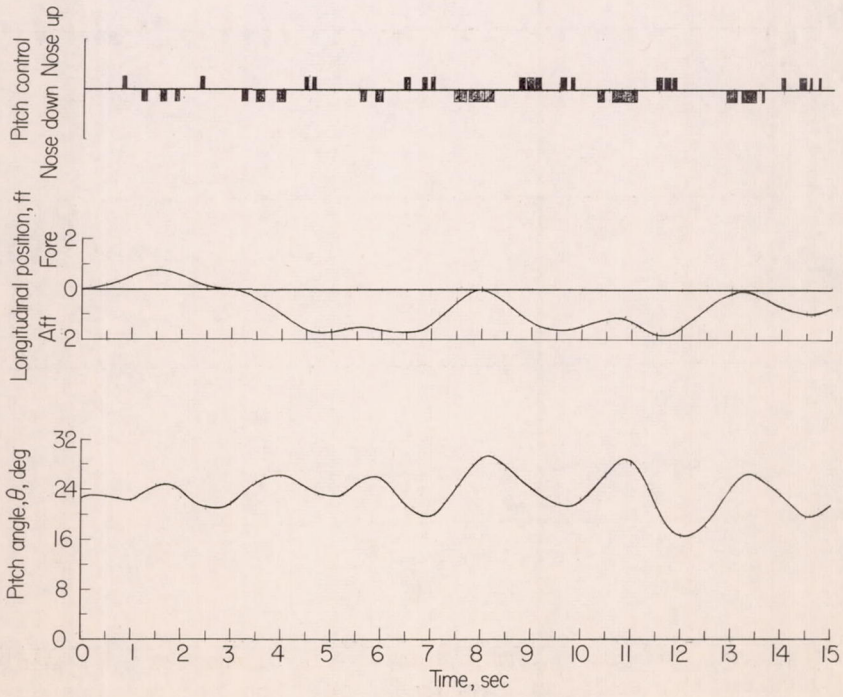


Figure 7.- Blade-form curves. Symbols are: D, diameter; R, radius; r, station radius; b, section chord; h, section thickness; p, geometric pitch ($p = 2\pi r \tan \beta$); β, section blade angle.

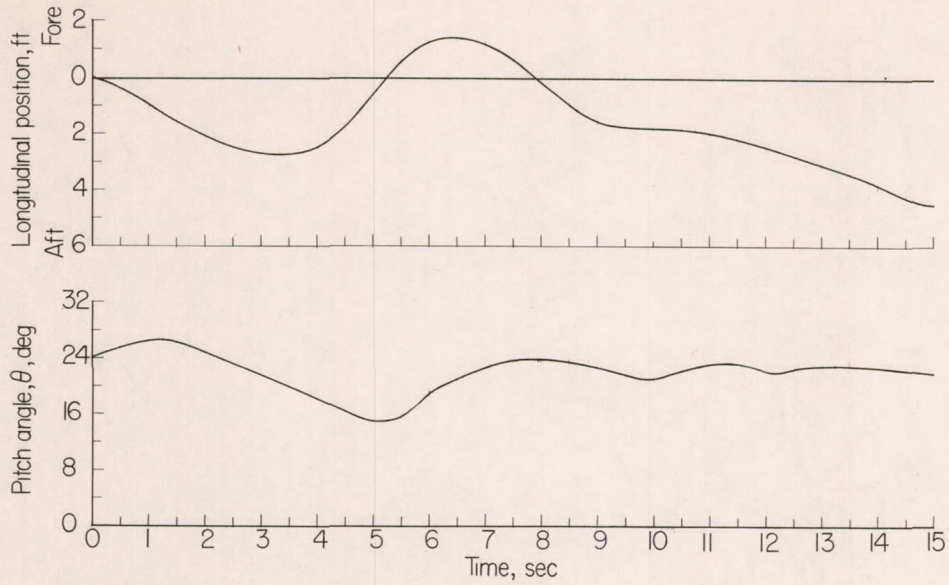


(a) Uncontrolled flight.

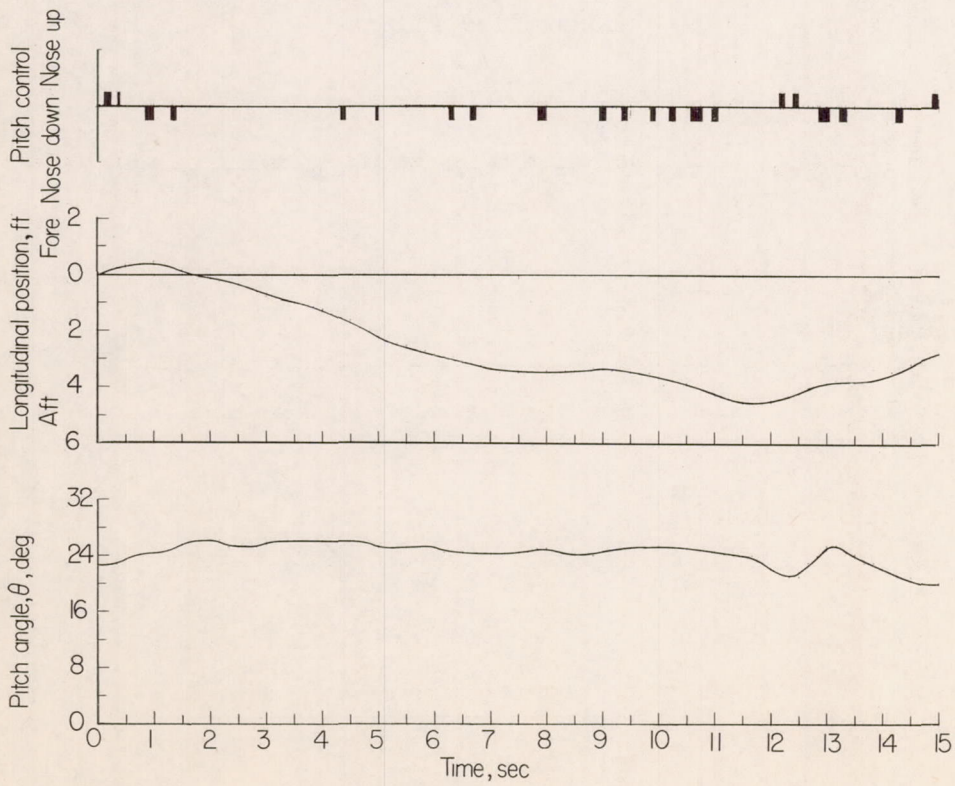


(b) Controlled flight.

Figure 8.- Pitching motions of the model without pitch damper.

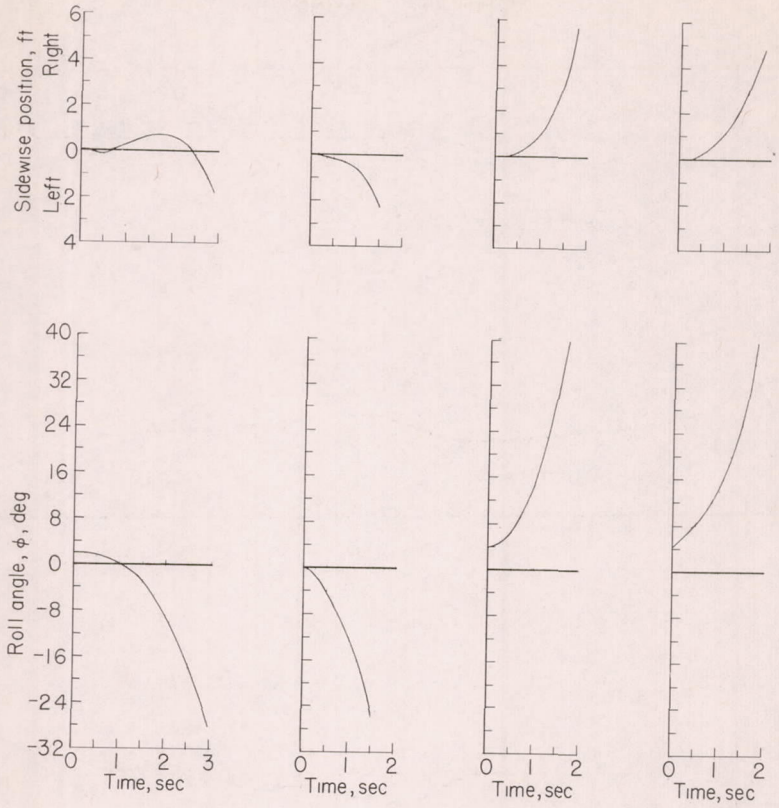


(a) Uncontrolled flight.

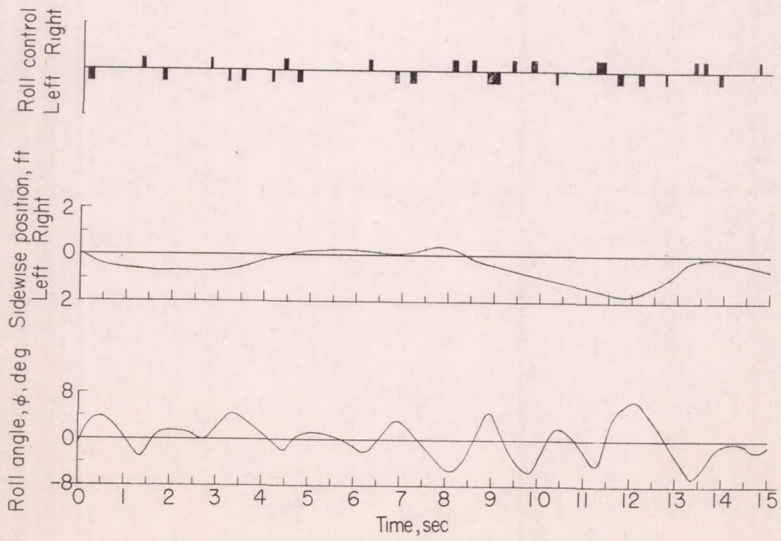


(b) Controlled flight.

Figure 9.- Pitching motions of the model with pitch damper. $\frac{d\delta_f}{d\dot{\theta}} = 0.7$.



(a) Uncontrolled flight.



(b) Controlled flight.

Figure 10.- Rolling motions of the model.

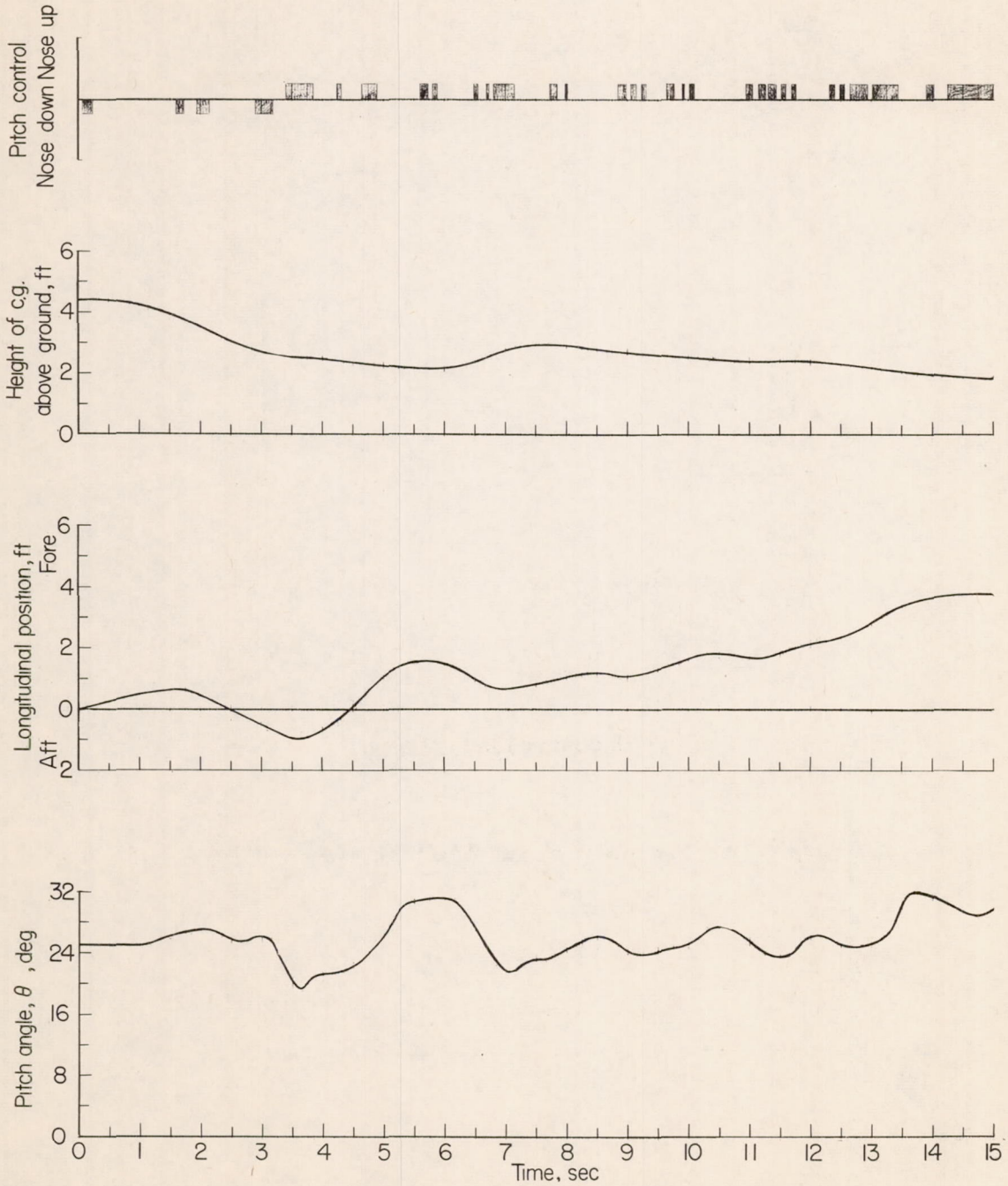


Figure 11.- Controlled flight near the ground with pitch damper. $\frac{d\delta_f}{d\dot{\theta}} = 0.7$.

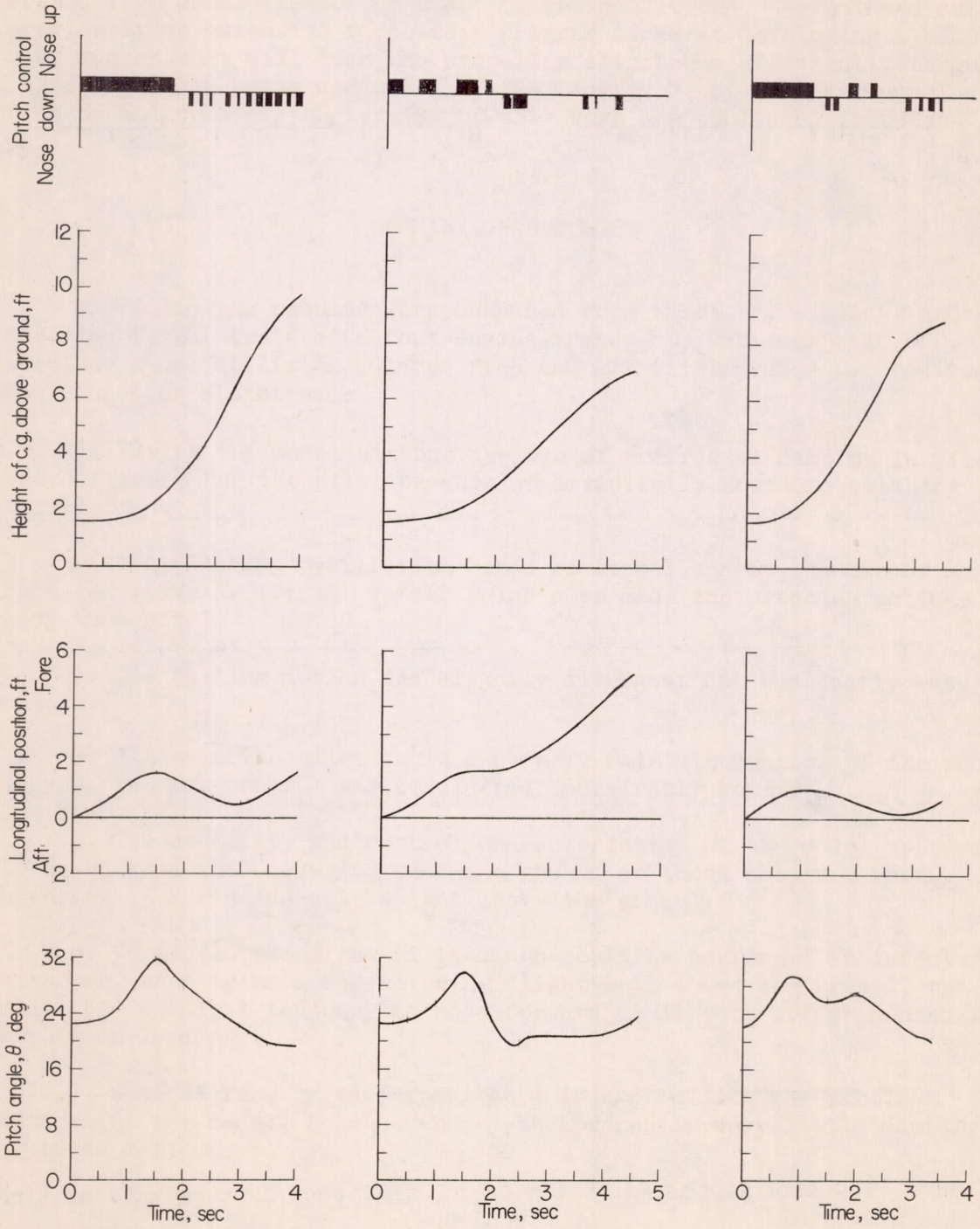


Figure 12.- Time histories of take-offs.

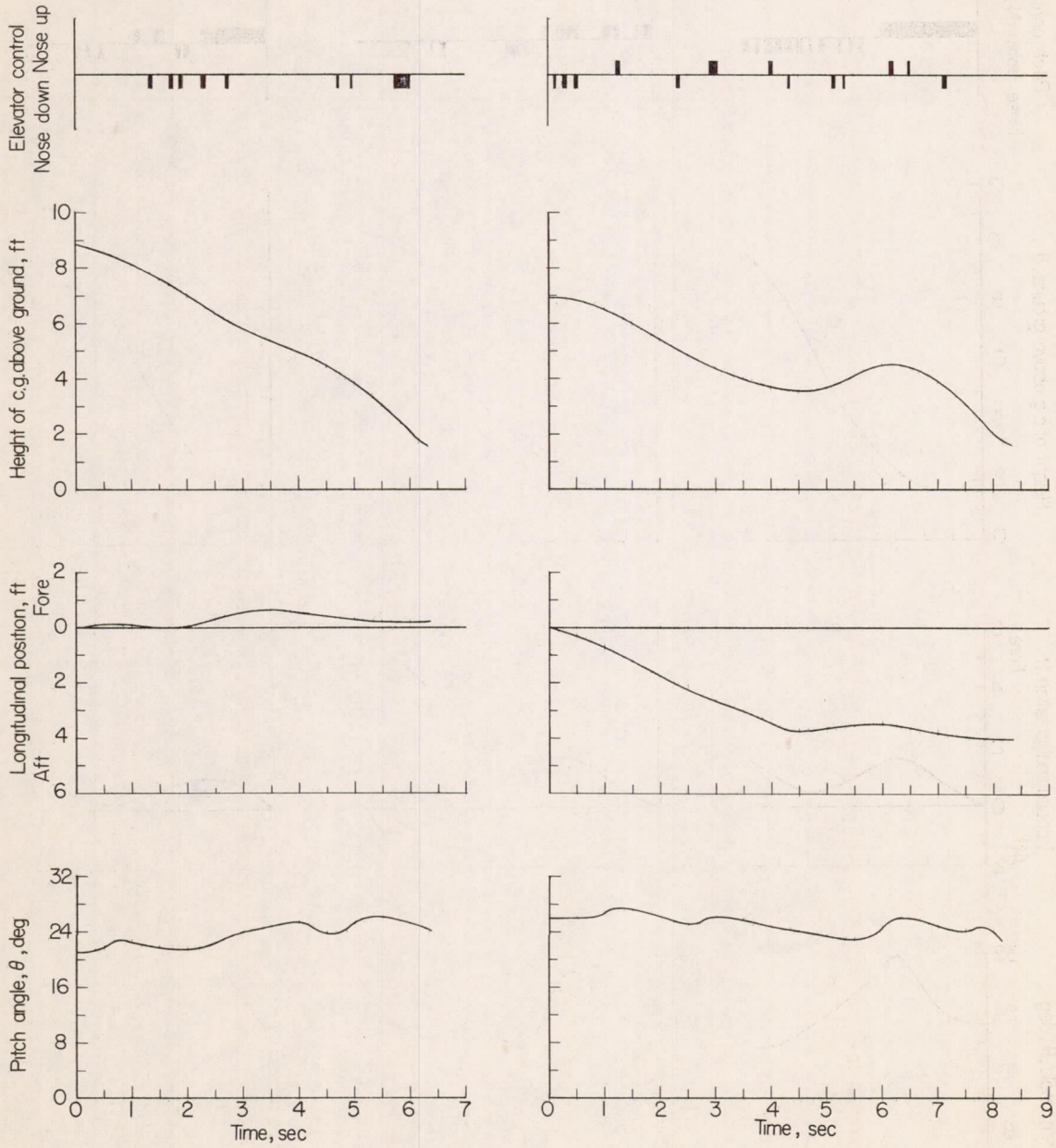


Figure 13.- Time histories of landings. (All records terminate at time of touchdown.)