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RESEARCH MEMORANDUM

DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A DELTA-WING VERTICALLY RISING AIRPLANE MODEL IN TAKE-OFFS, LANDINGS, AND HOVERING FLIGHT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A DELTA-WING VERTICALLY RISING AIRPLANE MODEL IN TAKE-OFFS, LANDINGS, AND HOVERING FLIGHT

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SUMMARY

An investigation has been conducted by means of tests of a flying model in still air to determine the dynamic stability and control characteristics of a delta-wing vertically rising airplane in the take-off, landing, and hovering phases of flight. The model had a dual-rotating propeller in a tractor arrangement, a modified triangular wing, and modified triangular vertical tail surfaces mounted symmetrically above and below the fuselage, but had no horizontal tail. Control was provided by elevons and rudders operating in the propeller slipstream.

The uncontrolled pitching motion consisted of an unstable oscillation which was more unstable with a rearward than with the normal center-of-gravity location. The period of this pitching oscillation for a fighter airplane would be about 8 or 10 seconds. The uncontrolled yawing motions were predominantly aperiodic and were about neutrally stable. The controls operating in the slipstream were powerful enough to enable the pilot to fly the model smoothly and easily in hovering flight at altitude in spite of its lack of stability. The response of the model to controls became less satisfactory as the model neared the ground but satisfactory take-offs and landings in a tail-down attitude could be performed without much difficulty by flying the model quickly through the range of heights for which this ground effect occurred.

INTRODUCTION

An investigation has been conducted to determine the stability and control characteristics of a delta-wing vertically rising airplane model

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in the take-off, landing, and hovering phases of flight. This investigation was conducted in the facility used by the free-flight-tunnel section for flight testing hovering models by the trailing-cable technique (reference 1).

The flying model used in the investigation was a horizontal-tailless design which had a modified triangular wing and modified triangular vertical-tail surfaces mounted symmetrically above and below the fuselage. It had a large dual-rotating propeller and sufficient power to take-off and land vertically. Control was provided by flap-type elevons and rudders operating in the propeller slipstream.

The investigation consisted of hovering flight tests made with the center of gravity located at 15 percent of the mean aerodynamic chord. These tests included flights at a considerable height above the ground, flights at low altitudes to determine the effects of the ground, and take-offs and landings. Some tests were also made with the center of gravity located at 25 percent of the mean aerodynamic chord to determine the effect of center-of-gravity location on the stability and control characteristics of the model. The stability, controllability, and general flight behavior were determined from motion-picture records, from visual observation of the flight tests, and from the pilot's impressions of the flying qualities of the model.

NOMENCLATURE AND SYMBOLS

The special nomenclature and terminology used herein for discussing the vertically rising airplane model and its behavior in hovering flight has been explained in reference 1. 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 forces and moments and angular displacements.

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

z displacement along Z-axis, feet

θ angle of pitch, degrees

ϕ angle of bank, degrees

ψ angle of yaw, degrees

APPARATUS AND MODEL

The investigation was conducted in the facility used by the free-flight-tunnel section for flight testing hovering models by the trailing-cable technique. A complete description of this facility and its operation is given in reference 1.

The model was a horizontal-tailless design as shown by the photograph of figure 2 and the sketch of figure 3. The model had a modified triangular wing and modified triangular vertical-tail surfaces mounted symmetrically above and below the fuselage and also had an eight-blade, dual-rotating, fixed-pitch propeller (two 4-blade elements in a tractor arrangement) powered by a 5-horsepower variable-frequency electric motor. The speed of the motor was changed to vary the thrust. The geometric characteristics are presented in detail in table I.

The model was maneuvered by means of flap-type elevons and rudders operating in the propeller slipstream. The differential deflections of the elevons were controlled automatically by a displacement autopilot which kept the model oriented in roll with respect to the pilot's position. This autopilot is discussed in some detail in reference 1. The model was controlled in pitch and yaw with the elevons and rudders which were remotely controlled by the pilot. These remotely operated controls were deflected by flicker-type (full on, full off) pneumatic servomechanisms which were controlled by electric solenoids.

The power for the motor and electric solenoids and the air for the servomechanisms were supplied through wires and plastic tubes which trailed from the tail of the model.

TESTS

Flight tests which were made with the center of gravity located at 15 percent of the mean aerodynamic chord included hovering flights at a considerable height above the ground, flights at low altitudes to determine the effects of the proximity of the ground, and take-offs and landings. Some hovering flights were also made at the higher altitudes with the center of gravity located at 25 percent of the mean aerodynamic chord to determine the effect of center-of-gravity location on the stability and control characteristics of the model. No tests were made to simulate rough air or flight near ground obstructions.

The stability, controllability, and general flight behavior were determined from motion-picture records, from visual observation of the flight tests, and from the pilot's impressions of the flying qualities of the model. General flight behavior is a term used to describe the over-all flying characteristics of a model and indicates the ease with which a model can be flown. In effect, the general flight behavior is much the same as the pilot's opinion of the flying qualities of an airplane and indicates whether stability and controllability are properly proportioned.

Vertical take-offs were made by rapidly increasing the speed of the propellers until the model took off. These take-offs were rather abrupt and the model generally climbed to a height of about 10 feet before the power operator adjusted the power for steady hovering flight.

Tail-down landings were made by decreasing the speed of the propellers so that the model descended slowly until the landing gear was about 1 foot above the ground. At this point the power was cut off completely and the model dropped to the ground.

During the hovering flights with the tail near the ground, the model was flown with the trailing edge of the control surfaces 12 to 18 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 control surfaces were several feet above the ground. The flight behavior of the model was judged, however, only when the control surfaces were about 12 to 18 inches above the ground.

Some preliminary force tests were made to determine the center-of-gravity locations which would result in satisfactory static longitudinal stability in the normal, unstalled, level-flight condition.

RESULTS AND DISCUSSION

The results of the preliminary force tests (not presented herein) indicated that, with a center-of-gravity location of 15 percent of the mean aerodynamic chord, the model would have a reasonable degree of stability of angle of attack over the range of angles of attack covered in the force tests (0° to 34°). This center-of-gravity location was, therefore, considered as the normal location and was used in most of the flight tests.

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

Some results of a series of flight tests on a more conventional vertically rising airplane configuration are presented in references 1 and 2. These results may be of interest to the reader for comparison with the results of the present tests.

Hovering Flight at Altitude

Time histories of the uncontrolled pitching motions for the two center-of-gravity locations are presented in figure 4. 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 characteristic motion was superimposed on the motion caused by the out-of-trim moments. A study of the moment fluctuations caused by the propellers is presented in reference 2.

The time histories of figure 4 show that the model had an unstable pitching oscillation for both center-of-gravity locations and that this oscillation was more unstable for the rearward than for the normal location. The periods of the oscillations for the normal and rearward center-of-gravity locations are 3.6 and 2.9, respectively. If the model is considered as a $\frac{1}{8}$-scale model of an airplane, these values would be 10.2 and 8.2 seconds, respectively, for the airplane.

The observations of the pilot indicated that the uncontrolled yawing motions were predominantly aperiodic and were about neutrally stable for both center-of-gravity locations. For conditions of near neutral stability motion-picture records of aperiodic motions of the model were difficult to analyze because the motions were easily masked by out-of-trim motions caused by propeller-moment variations and imperfectly trimmed control surfaces. For this reason no time histories of the uncontrolled yawing motions are presented.

The elevon and rudder control appeared powerful since the model responded quickly to control deflection and could be flown smoothly and easily in spite of its lack of stability. In order to demonstrate the controllability of the model, the pilot at times allowed the pitching oscillation to build up and then applied controls to stop it. The data of figure 5, 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 about one-fourth of a cycle. 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 oscillation can probably be attributed largely to the fact that the period of the oscillation was fairly long.

The model did not have vertical-position stability but did have 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 Near the Ground

The model became more difficult to fly as it neared the ground. The pilot found that it was considerably more difficult to keep the model in an erect attitude and to keep it over a spot when hovering near the ground than when hovering well above the ground. It was possible to keep the model hovering low over a spot on the ground for a short time, but eventually the behavior would become erratic and the model would move off in spite of the efforts of the pilot to keep it over the spot. This adverse effect of the ground on the flight behavior of the model resulted from a reduction in response of the model to controls and probably from an increase in sensitivity of the model to disturbances such as the propeller-force fluctuations. Analysis based on the data presented in reference 2 indicates that the reduction in slipstream velocity over the rear part of the model as it nears the ground causes a reduction in static-control effectiveness and in damping in pitch and yaw. Such a reduction in damping would cause the model to be more sensitive to disturbances but would not necessarily cause an increase in the response of the model to the controls because the static-control effectiveness would probably be reduced more rapidly than the damping as the model approaches the ground. In fact, the flight tests showed that the response of the model to the controls was actually reduced considerably.

A full-scale airplane should be easier to fly than the model, however, because the angular velocities of the airplane would be much lower than those of the model and the pilot could sense the movements of the airplane and apply the proper amount of corrective control more exactly than was possible with the model.

Take-Offs and Landings

Take-offs and landings with the model in a tail-down attitude were not difficult to perform. In fact, take-offs were easy because the model quickly went through the range of heights for which the ground could affect the flight behavior. Landings were somewhat more difficult, however, because the model was required to fly near the ground for longer periods of time. This difficulty was particularly noticeable when attempts were being made to land the model on a spot because then it was brought down more slowly and was required to fly longer at heights for which the ground effect on controllability was pronounced.

CONCLUSIONS

The following conclusions were made from take-off, landing, and hovering-flight tests of a delta-wing vertically rising airplane model in still air:

1. The uncontrolled pitching motions consisted of an unstable oscillation which was more unstable with the rearward than with the forward center-of-gravity location.

2. The uncontrolled yawing motions were predominantly aperiodic and were about neutrally stable for both center-of-gravity locations.

3. In hovering flight at altitude the controls were powerful enough to enable the pilot to fly the model smoothly and easily in spite of its lack of stability.

4. The model was more difficult to fly when hovering near the ground than when hovering at a considerable height above the ground.

5. Take-offs were easy to perform because the model passed quickly through the range of heights for which the ground could affect the flight behavior. Landings, although slightly more difficult than take-offs, were also easily performed.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., August 14, 1951

REFERENCES

1. 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.

2. Smith, Charles C., Jr., Lovell, Powell M., Jr., and Bates, William R.: The 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.

TABLE I

GEOMETRIC CHARACTERISTICS OF THE MODEL

Weight, lb	32.75
Wing (modified triangular plan form):	
Sweepback, deg	55
Flat-plate section (0.5 thick)	
Aspect ratio	1.91
Taper ratio	0.20
Area, sq in.	874.8
Span, in.	40.90
Mean aerodynamic chord, in.	21.23
Span of elevon (each)	17.45
Chord of elevon	3.00
Moment arm, distance from 0.25 mean aerodynamic chord to hinge line of elevon, in.	12.92
Over-all length of model, in.	44.58
Fuselage:	
Length, in.	23.00
Diameter, in.	6.00
Vertical tails (modified triangular plan form):	
Sweepback, deg	40
Flat-plate section (0.25 thick)	
Aspect ratio	2.58
Taper ratio	0.314
Area, sq in. (both tails)	374.6
Span, in.	31.10
Mean aerodynamic chord, in.	11.33
Span of rudder, in.	12.55
Chord of rudder, in.	3.00
Moment arm, distance from 0.25 mean aerodynamic chord to hinge line of rudder, in.	12.92
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
Moment arm, distance from 0.25 mean aerodynamic chord to center of gap between propellers, in.	22.40

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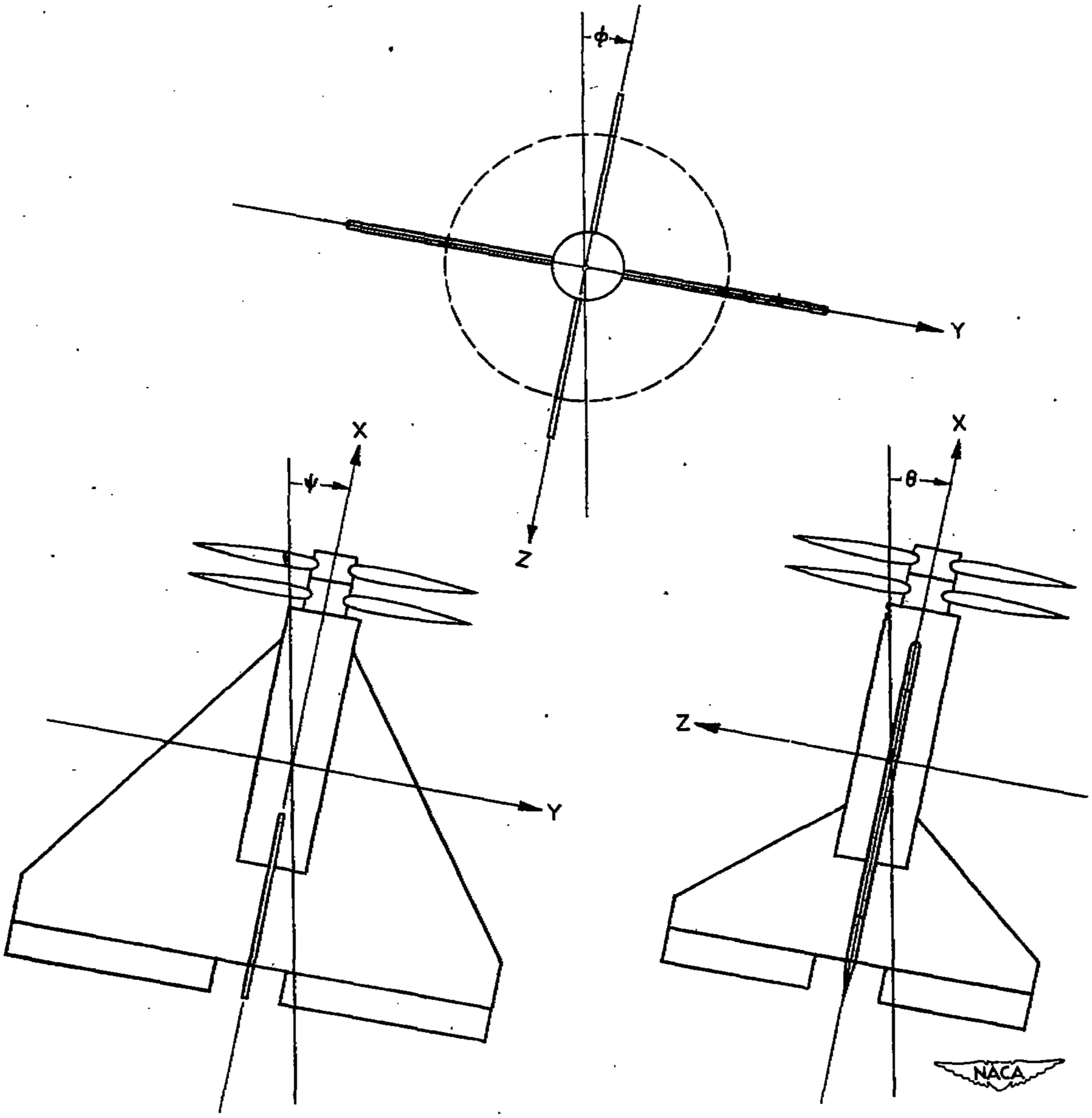

Figure 1.- The body system of axes. Arrows indicate positive directions of forces, moments, and angular displacements.

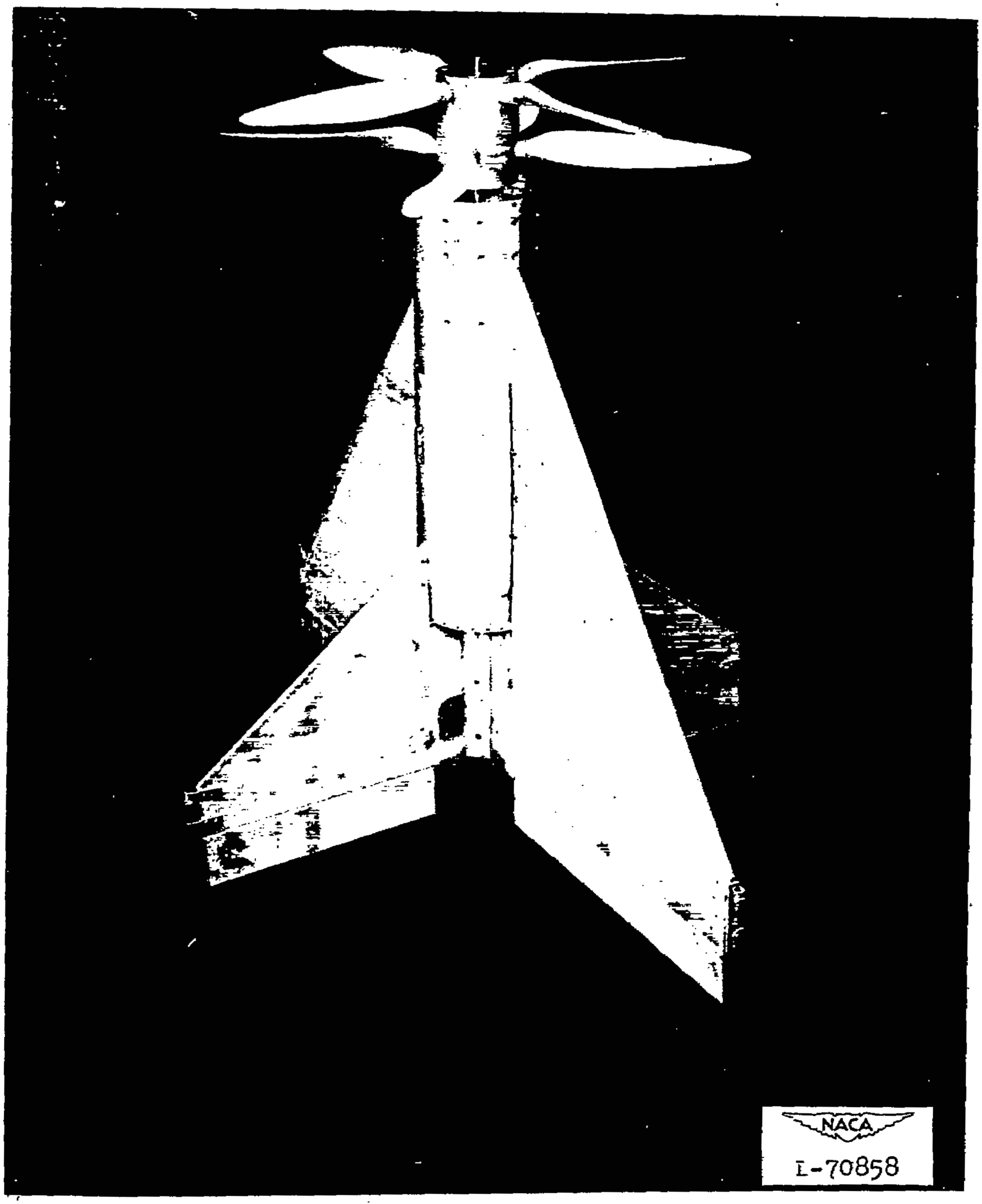

Figure 2.- Photograph of the vertically rising model.

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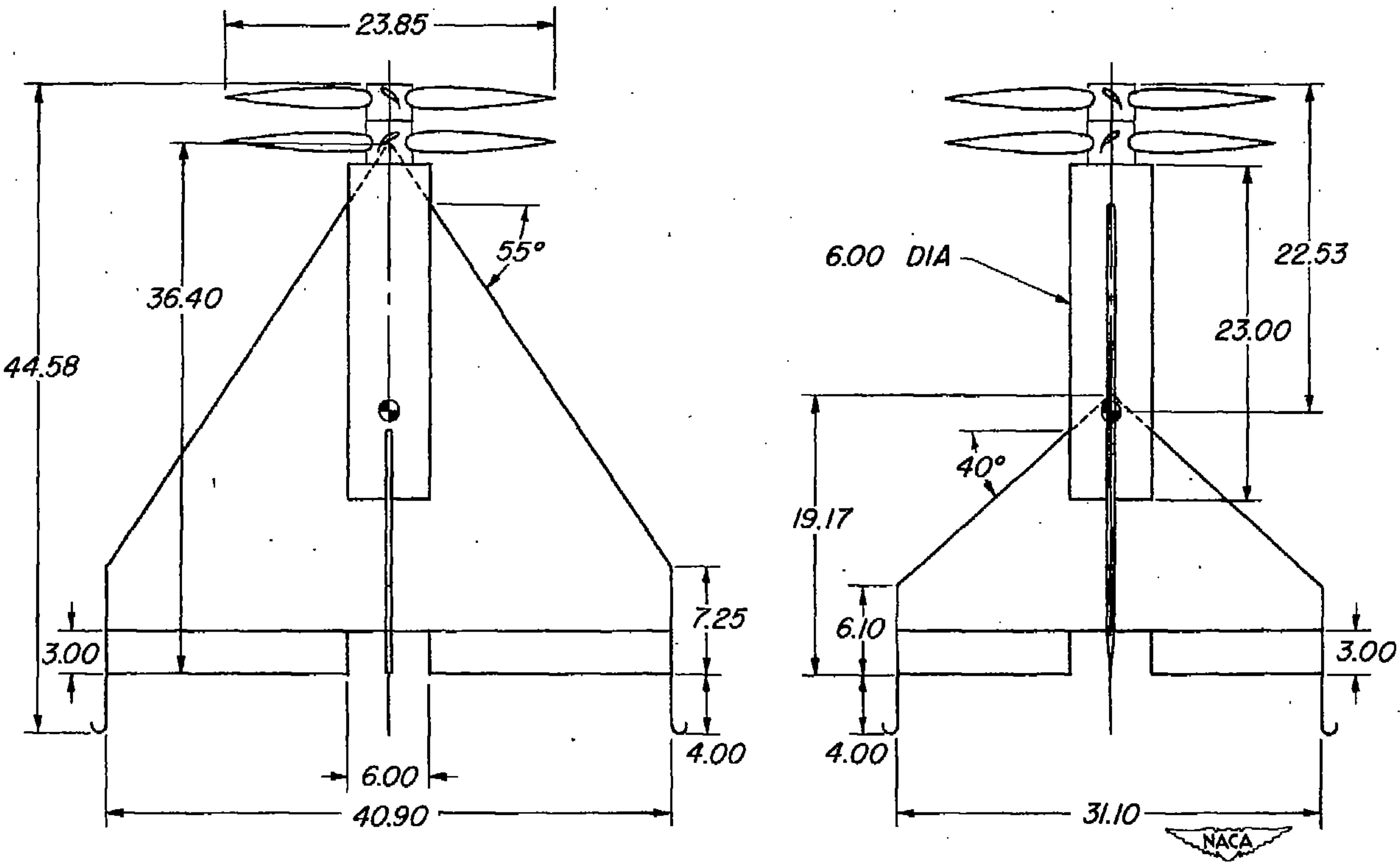
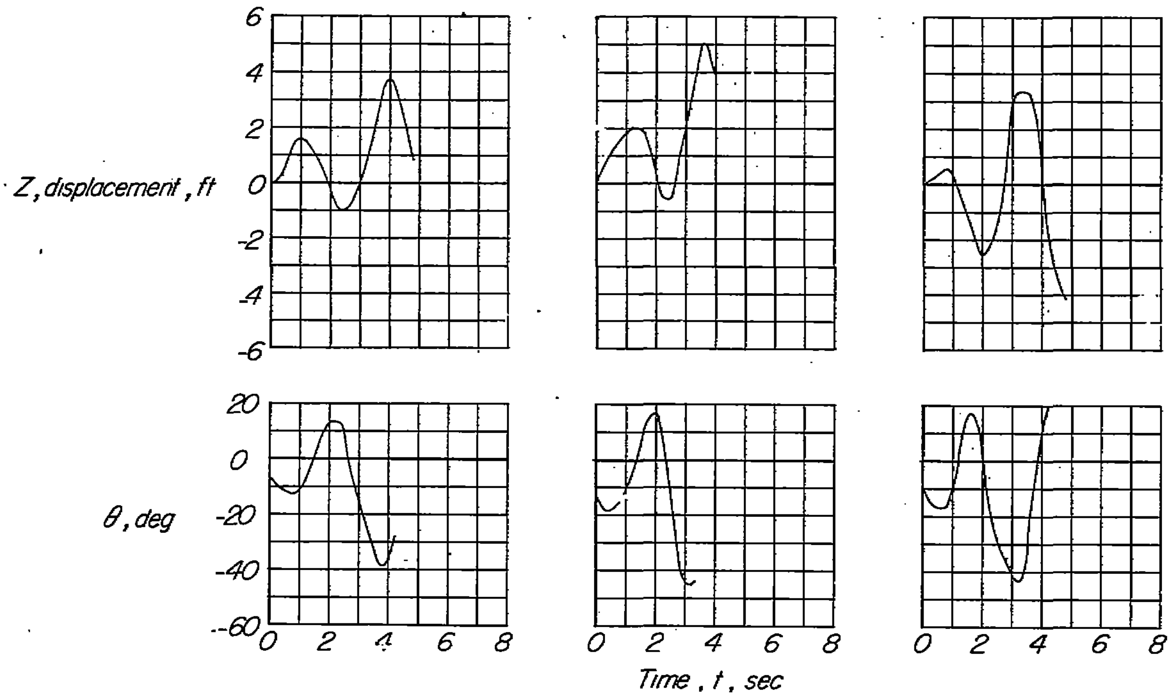
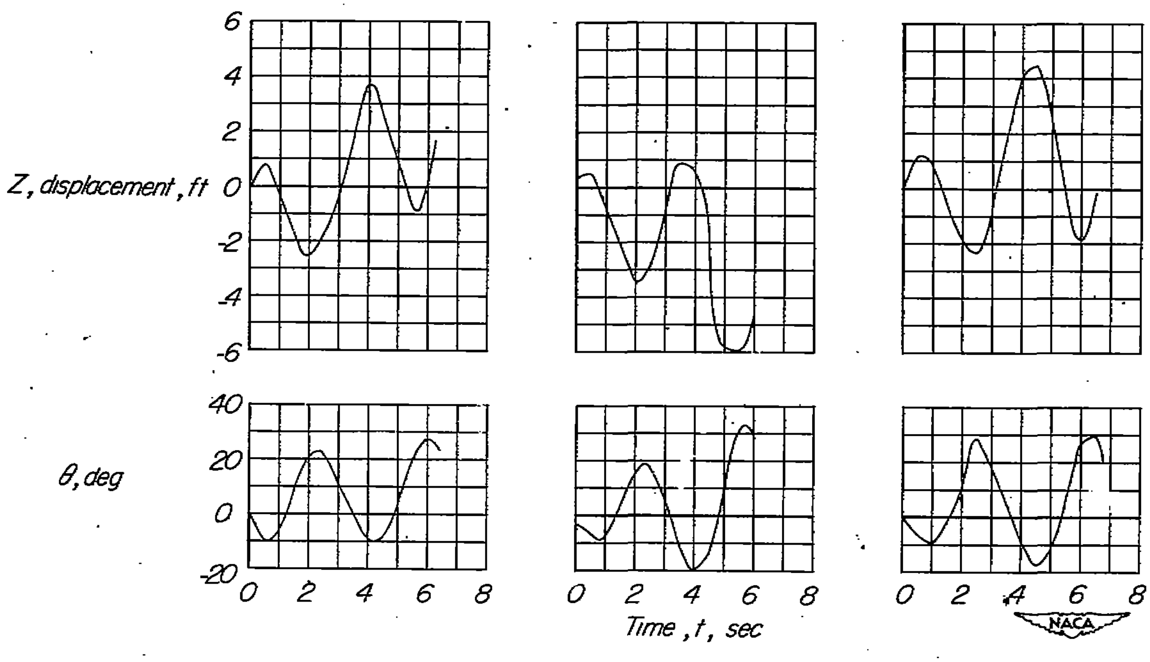


Figure 3.- Delta-wing vertically rising airplane model. All dimensions are in inches.



(a) Rearward (0.25c̄) center of gravity.



(b) Forward (0.15c̄) center of gravity.

Figure 4.- Uncontrolled pitching motions of the model.

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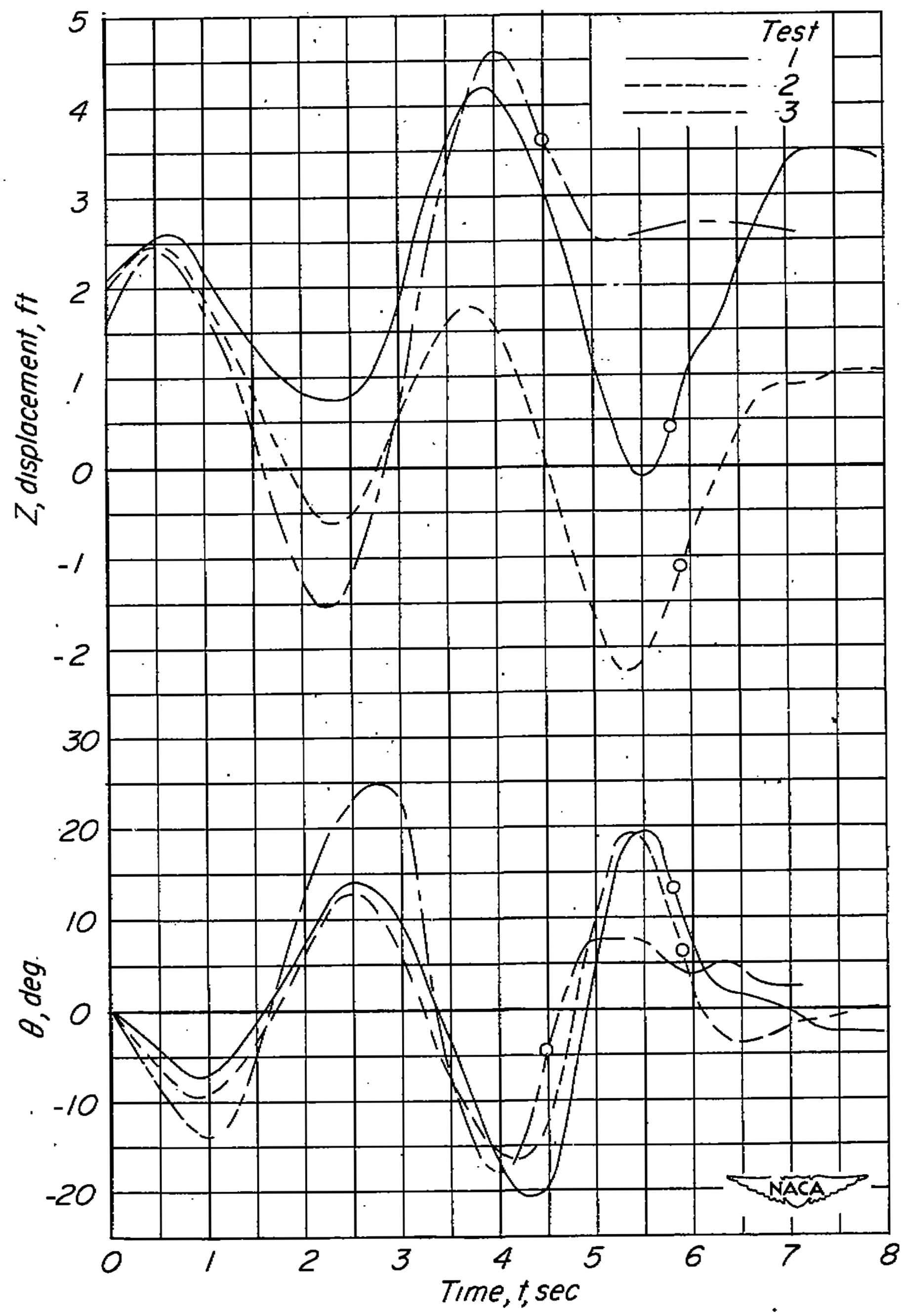

Figure 5.- Flight records showing the ability of the pilot to stop the pitching oscillation. The circular symbols indicate the time at w'ich the pilot began using the controls to stop the oscillation. (Center-of-gravity location, 0.15c̄.)

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