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TECHNICAL NOTE

D-946

RAPID-TRANSITION TESTS OF A 1/4-SCALE MODEL OF THE VZ-2 TILT-WING AIRCRAFT

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Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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RAPID-TRANSITION TESTS OF A 1/4-SCALE MODEL OF THE VZ-2 TILT-WING AIRCRAFT

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SUMMARY

An investigation of the longitudinal stability and control characteristics of a 1/4-scale model of the VZ-2 tilt-wing vertical-take-off-and-landing aircraft during rapid transitions has been made on the Langley control-line facility. Only the longitudinal characteristics were studied because with the control-line technique the other phases of the model motion are partially restrained.

The rapid transitions from hovering to forward flight could be performed easily at any of the accelerations attempted; whereas, the transitions from forward flight to hovering were generally accompanied by a strong noseup pitching moment which at times was uncontrollable because of an inadequate amount of available pitch control. The model was more difficult to control during rapid decelerations than during slow decelerations and was also more difficult to control for rearward center-of-gravity conditions than for forward ones.

INTRODUCTION

Investigations are being conducted on the VZ-2 (Vertol 76) VTOL aircraft and models of this aircraft at the Langley Research Center to provide aerodynamic, handling qualities, and loads information on tilt-wing VTOL aircraft. The results of a number of the test programs completed to date are reported in references 1 to 5. The present investigation was made with a 1/4-scale model of the VZ-2 aircraft to provide information on the longitudinal stability and control characteristics during rapid accelerating and decelerating transition flights. These tests were made on the Langley control-line facility and consisted of rapid transitions from hovering flight to normal unstalled forward flight and back to hovering flight at essentially constant altitude. With the use of the control-line technique, only the longitudinal stability and control characteristics can be studied because the other phases of the model motion are partially restrained.

APPARATUS AND TESTS

Model

The model used in the investigation was the 1/4-scale model of the VZ-2 tilt-wing VTOL aircraft, which was used in the flight and force-test investigations of references 1, 2, and 4. A three-view drawing of the model is shown in figure 1 and a photograph of the model is shown as figure 2. Table I gives the dimensional characteristics of the model. The model had two three-blade propellers with flapping hinges and was powered by a 6-horsepower electric motor which drove the propellers through shafting and right-angle gearboxes. The propeller blade angle was set at 12° and the speed of the motor was changed to vary the thrust of the propellers. The wing was pivoted at the 37-percent-chord station and was rotated between incidence angles of 3° and 86° during flight. In this investigation the model was tested with three center-of-gravity positions: 0.04 chord ahead of the wing pivot, directly below the pivot, and 0.03 chord behind the pivot. The center of gravity of the model is designated in terms of its position when the wing is at 86° incidence. As the wing was tilted down to 3° incidence the center of gravity moved forward approximately 5 percent chord. The weight of the model was 55.2 pounds.

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Longitudinal control was provided by an all-movable horizontal tail and a jet-reaction control in the rear of the fuselage. The two types of longitudinal control were deflected together by flicker-type (full on or full off) pneumatic actuators which were remotely operated by the pilot by means of solenoid-operated valves. The horizontal tail was set at an incidence angle of 2° for most of the tests and was deflected ±10° for control. The pitch jet was set to trim out the moments in hovering and gave control moments of about ±9.3 ft-lb. No roll or yaw control was required to fly since in control-line tests the rolling and yawing motions are restrained.

Test Equipment

The Langley control-line facility is illustrated in figure 3 and is described in detail in reference 6. Basically this equipment consists of a crane with a jib boom to provide an overhead support for the safety cable. The pilot and three operators ride in the cabs of the crane so that they will always face the model as it flies in a circle at the end of a single restraining line. The use of a single-restraining-line technique, which included a device which automatically kept the restraining line horizontal, is described as an alternate arrangement in reference 6. The crane is mounted on a pedestal in the middle of a large concrete apron located in a wooded area which serves as a windbreak. With this crane, transition flights can be made rapidly from hovering, to normal forward flight, and back to hovering, since the crane has high rates of acceleration and deceleration. Actually the crane can accelerate or decelerate rapidly enough to keep up with a 2g acceleration or deceleration of the model.

Test Technique

The test technique is best explained by describing a typical flight. The wing incidence of the model was set at 86° and a vertical take-off from the ground was made by 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. When the pilot had the model flying smoothly in hovering, he actuated a switch which tilted the wing down at a constant rate to a wing incidence of 3°. The rate of wing-incidence variation could be changed between flights by setting a different voltage on the wing incidence actuating motor. In hovering and transition the model power operator adjusts the model power in order to maintain the desired altitude (usually 15 feet above the ground). In transitions at a constant altitude the power variations, as well as the fuselage-angle variations, tend to affect the forward speed; therefore, the pilot controls the operation by requesting power changes from the power operator to establish an equilibrium condition at the fuselage angle or airspeed that the pilot decides to fly. The crane operator adjusts the rate of rotation of the crane so that the end of the jib is above the model at all times. The crane does not determine the desired flight speed of the model but merely follows the model and thus has virtually no effect on the model motions. In order to complete the transition tests, the reverse transition from normal unstalled forward flight to hovering is made and the model lands. During these slowdown transition tests the wing tilt is also operated at an approximately constant rate.

RESULTS AND DISCUSSION

Transitions From Hovering to Forward Flight

The rapid transitions from hovering to forward flight were found to be easy to perform. Time histories of three representative transitions are shown in figure 4. In these transitions the model was flown with an approximately constant rate of change of wing incidence of about 10^{o} per second. There was a tendency, as shown in these time histories, for the model to pitchup at the start of the transition, particularly for the more rearward center-of-gravity conditions. This pitchup tendency shows as an increase in fuselage angle in figure 4(a) where the pilot does not make a determined effort to control the pitch and shows in the use of large amounts of nose-down pitch control to prevent the pitchup in the flights shown in figures 4(b) and (c). This pitchup tendency did not seem to pose any problem other than to require a nose-down control for a short period of time or to cause a slight hesitation in the rate of buildup of forward speed. As the wing incidence continued to decrease the pitchup tendency was relieved. The accelerating transition was much easier to perform for any given center-of-gravity condition than the effective zero-acceleration transition had been in the flight tests in the Langley full-scale tunnel reported in reference 2. The difference in ease of performing the transition was largely a matter of longitudinal trim since in the accelerating condition the pitching moment required was low and well within the capabilities of the model control, whereas in zero-acceleration transitions the nose-up pitching moment was high and sometimes greater than the available nose-down control moment and the model frequently experienced a temporary loss of control and a pitchup. For example, the tests of reference 2 showed that the longitudinal control available in the zero-acceleration transition was inadequate for trim when the center of gravity was located at the wing pivot or 0.03 chord behind the pivot, conditions for which the model could be trimmed easily in the accelerating condition.

A quantitative picture of the longitudinal trim problem is shown in figure 5. This figure shows the pitching moments required for trim in transition as computed from the force-test data of reference 1 for power settings that gave 0g, 1/4g, and 1/2g acceleration at a fuselage angle of 0^{o} for each of the three different center-of-gravity positions for which the model was flown. The figure also shows the control moments available from the combination of pitch jet and 10^{o} of horizontal-tail deflection. These data show that for the zero-acceleration condition there is a sharp increase in nose-up pitching moment with increasing speed, up to a velocity of about 15 knots (wing incidence of 60^{o}), followed by a decrease in pitching moment with a further increase in forward speed. The data also show that there is a marked favorable effect of forward acceleration on the magnitude of the pitching moment required for trim and also on the variation of the pitching moment with speed.

The force-test data of figure 5 also correlate well with the wind-tunnel flight tests of reference 2 for the zero-acceleration condition in that they show that with the center of gravity 0.04 chord ahead of the pivot there was sufficient control available for trim with some margin left over for maneuvering; whereas, with the center of gravity located at the wing pivot, the model would be unflyable because there was no control margin left over for maneuvering, and with the center of gravity located 0.03 chord behind the wing pivot, there was not even enough control power available for trim at speeds from about 10 to 18 knots.

Transitions From Forward Flight to Hovering

Rapid transitions from forward flight to hovering were difficult to perform and were not so smooth as transitions from hovering to forward flight. In order to provide a suitable quantity of data for study of this rather difficult phase of operation a rather large number of time histories are presented (figs. 6 to 8). In these figures zero time is taken as the time at which the model reached zero forward velocity so that the time during the transition to hovering is expressed as negative time. Several records of each test condition are required to give a positive indication of the stability and control characteristics of the model in that condition. This is true because the transitions were performed by a human pilot and are consequently performed in a random and arbitrary manner so that no one record necessarily gives a good indication of the characteristics of the model.

In the decelerating transitions the model was flown at an approximately constant rate of change of wing incidence, of about 10° per second and the flight records show that the model made the transition from a normal forward flight speed of 30 to 35 knots to hovering in about 8 seconds. This is a very rapid transition and represents a severe test of the model. For example, the transitions made with the model represented transitions of the full-scale airplane in 16 seconds whereas the representative transition of the full-scale airplane shown in reference 3 covered a period of 60 seconds. It was found that the rapid transitions of the model could generally be performed satisfactorily with the center of gravity in the most forward of the three positions covered in the tests (0.04 chord ahead of the wing pivot). With the center of gravity in the most rearward position (0.03 chord behind the wing pivot), however, the pilot generally lost control of the model.

From a detailed inspection of the time histories of figures 6 to 8 it seems that, in a representative transition, the transition proceeded at a deceleration of about 1/8g to 1/4g with the model under control down to a speed of about 20 knots. At speeds slightly below this value the nose-up pitching moment of the model became slightly greater than the pitching moment available from control; the model then began an uncontrollable pitchup and the deceleration increased to about 1/2g. The angle of attack continued to increase to about 20° or 30° and the speed dropped off rapidly until at a speed of about 10 knots the nose-up pitching moment of the model dropped off to a value which was less than the control moment available and the pilot was generally able to recover control of the model after a few wild gyrations in pitch. As pointed out previously, the center-of-gravity location had some effect on the characteristics of the model during the transition. The behavior of the model was somewhat better than this average case for the forward center-of-gravity condition and somewhat worse for the rearward center-of-gravity condition.

Force-test data on the pitching-moment characteristics of the model during decelerating transitions have been recomputed from the data of reference 1 for the particular conditions of the control-line flight tests and are presented in figure 9. Inspection of this figure shows that there was an unfavorable effect of deceleration on the nose-down pitching moments required for trim just as was observed in the flight tests. The data of figure 9 also support the flight-test results in showing that the control power available was not adequate for trim at some intermediate speeds for the deceleration condition. The nose-up pitching moments indicated by the static force-test data were aggravated in the dynamic motions in flight
since, in a slowdown transition, a nose-up motion would tend to increase L
further the rate of deceleration which in turn would increase the nose-up 1
moment. An inadequate amount of available control would make the nose-up 6
motion uncontrollable as is shown in figures 7 and 8. 8
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CONCLUDING REMARKS

Results have been presented from an investigation of the longitudinal stability and control characteristics of a 1/4-scale model of the VZ-2 tilt-wing VTOL aircraft in rapid transitions from hovering to forward flight and back to hovering. Accelerating transitions were found to be easy to perform; whereas, decelerating transitions were difficult to perform. This difference was caused by the effect of forward acceleration on the pitching moments required for trim. In accelerating conditions, the pitching moment required was low and was well within the capabilities of the model control; whereas, in decelerating conditions, the nose-up pitching moment was greater than the available nose-down control moment and the model frequently experienced a temporary loss of control and a pitchup. This condition was more severe for rearward than for forward center-of-gravity conditions. This condition was also more severe for rapid decelerations than for slow decelerations.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., June 28, 1961.

REFERENCES

1. Newsom, William A., Jr., and Tosti, Louis P.: Force-Test Investigation of the Stability and Control Characteristics of a 1/4-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Aircraft. NASA MEMO 11-3-58L, 1959.

2. Tosti, Louis P.: Flight Investigation of the Stability and Control Characteristics of a 1/4-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Aircraft. NASA MEMO 11-4-58L, 1959.

3. Thomas, Lovic P. III: A Flight Study of the Conversion Maneuver of a Tilt-Wing VTOL Aircraft. NASA TN D-153, 1959.

4. Tosti, Louis P.: Aerodynamic Characteristics of a 1/4-Scale Model of a Tilt-Wing VTOL Aircraft at High Angles of Wing Incidence. NASA TN D-390, 1960.

5. Reeder, John P.: Handling Qualities Experience With Several VTOL Research Aircraft. NASA TN D-735, 1961.

6. Schade, Robert O.: Flight-Test Investigation on the Langley Control-Line Facility of a Model of a Propeller-Driven Tail-Sitter-Type Vertical-Take-Off Airplane With Delta Wing During Rapid Transitions. NACA TN 4070, 1957.

TABLE I.- GEOMETRIC CHARACTERISTICS OF THE MODEL

Propellers (3 blades each rotor):	
Diameter, in.	28.0
Solidity	0.24
Chord, in.	3.0
Wing:	
Pivot station, percent chord	37.0
Sweepback (leading edge), deg	0
Airfoil section	NACA 4415
Aspect ratio	5.42
Chord, in.	14.25
Taper ratio	1.0
Area, sq in.	1063.5
Span, in.	74.63
Dihedral angle, deg	0
Ailerons (each):	
Chord, in.	3.66
Span, in.	17.50
Hinge line, percent chord	74.1
Vertical tail:	
Sweepback (leading edge), deg	0
Airfoil section	NACA 0012
Aspect ratio	1.25
Chord, in.	12.0
Taper ratio	1.0
Area, sq in.	180.0
Span, in.	15.0
Rudder (hinge line perpendicular to fuselage center line):	
Chord, in.	3.75
Span, in.	15.0
Horizontal tail:	
Sweepback (leading edge), deg	0
Airfoil section	NACA 0012
Aspect ratio	3.10
Chord, in.	9.0
Center-section chord, in.	12.63
Area (including center body), sq in.	298.6
Span, in.	29.7
Dihedral angle, deg	0

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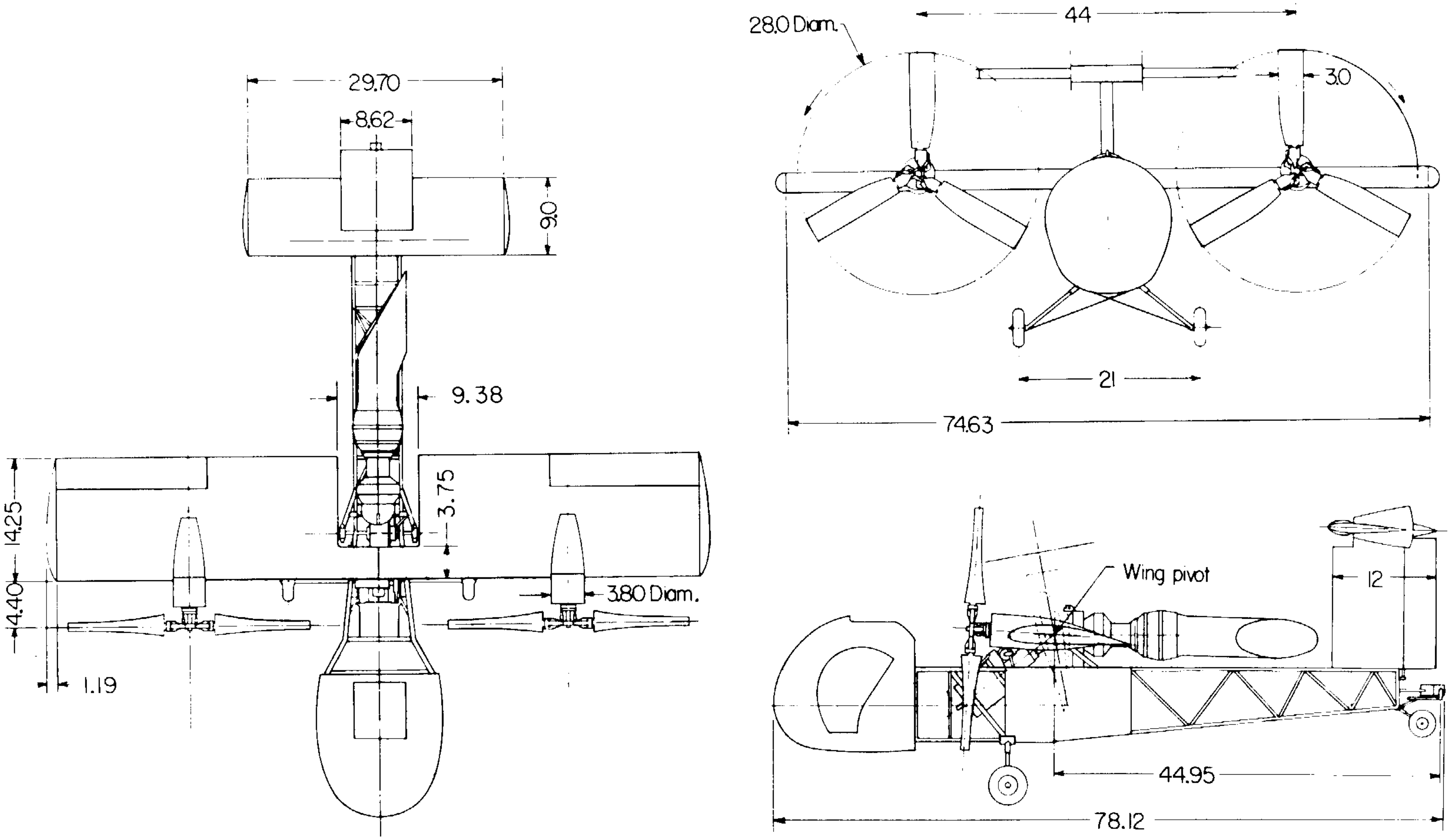

Figure 1.- Three-view sketch of model. All dimensions are in inches.

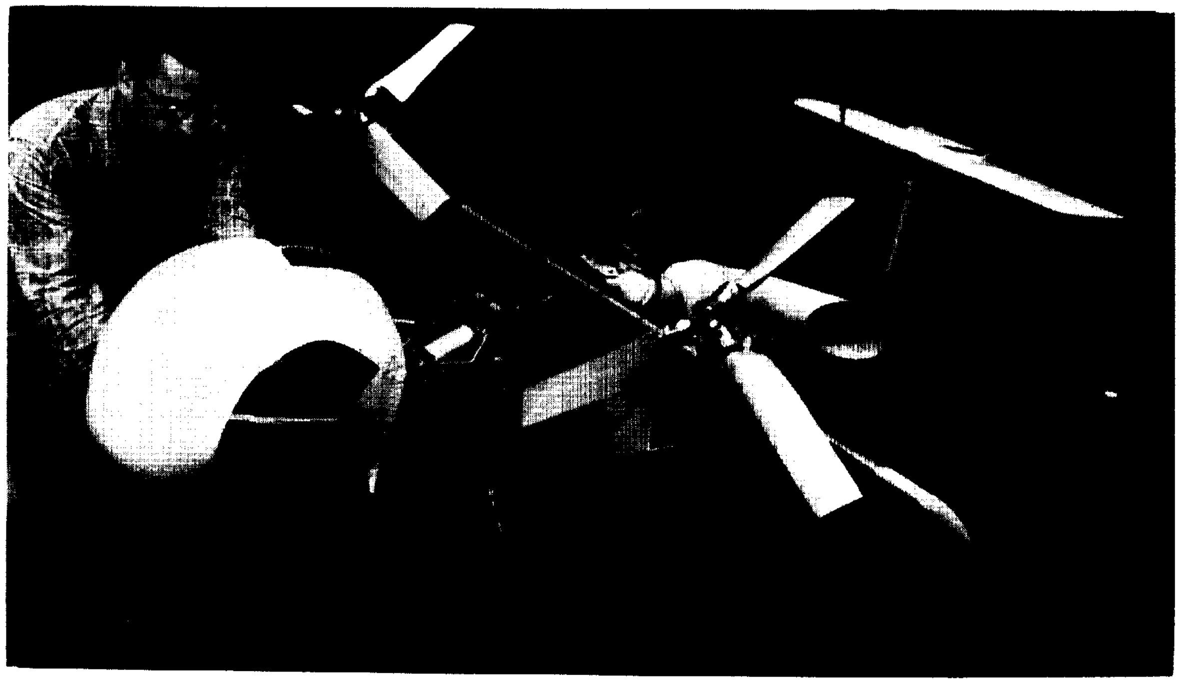

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Figure 2.- Photograph of the 1/4-scale model of the VZ-2 tilt-wing VTOL aircraft.

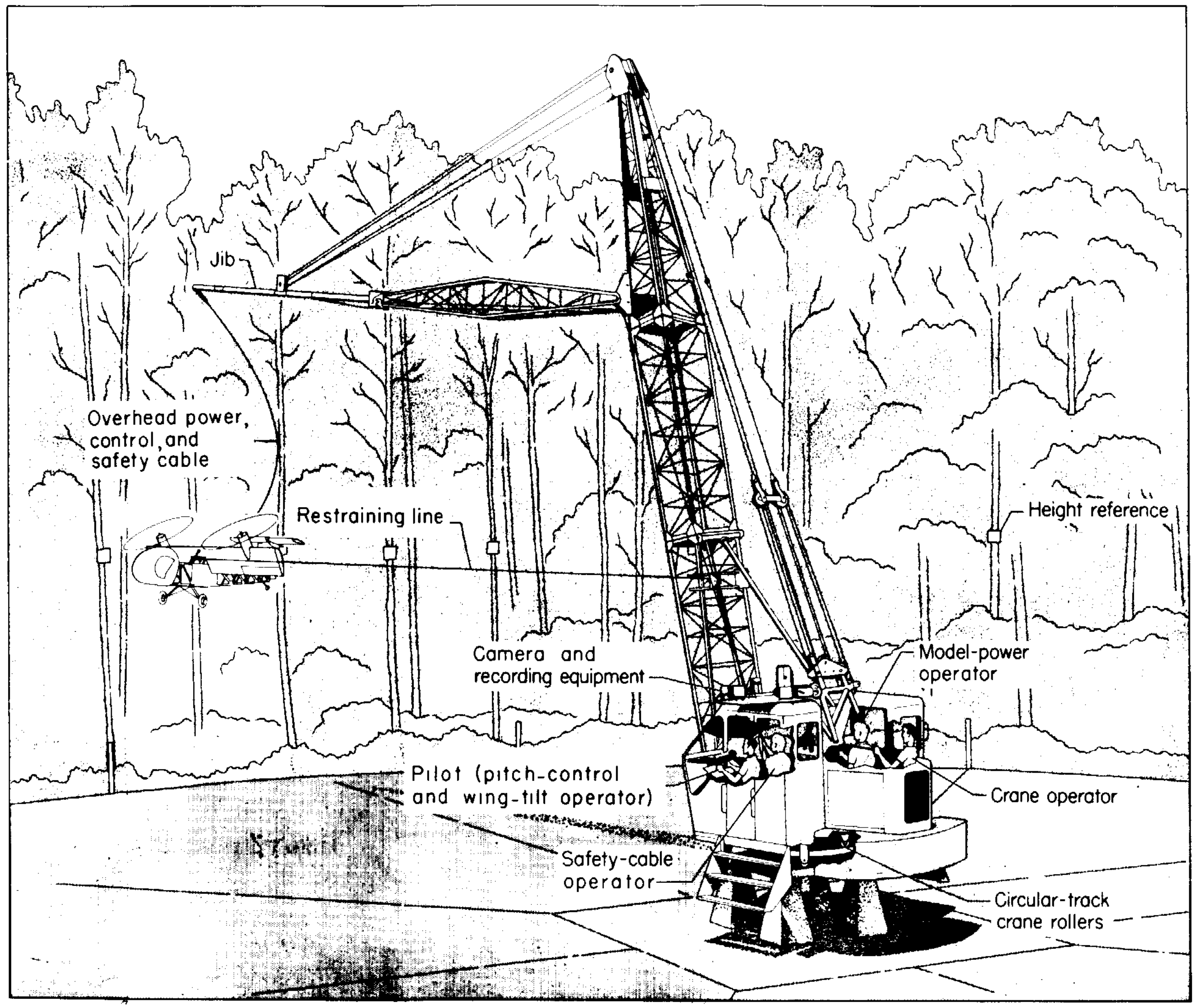
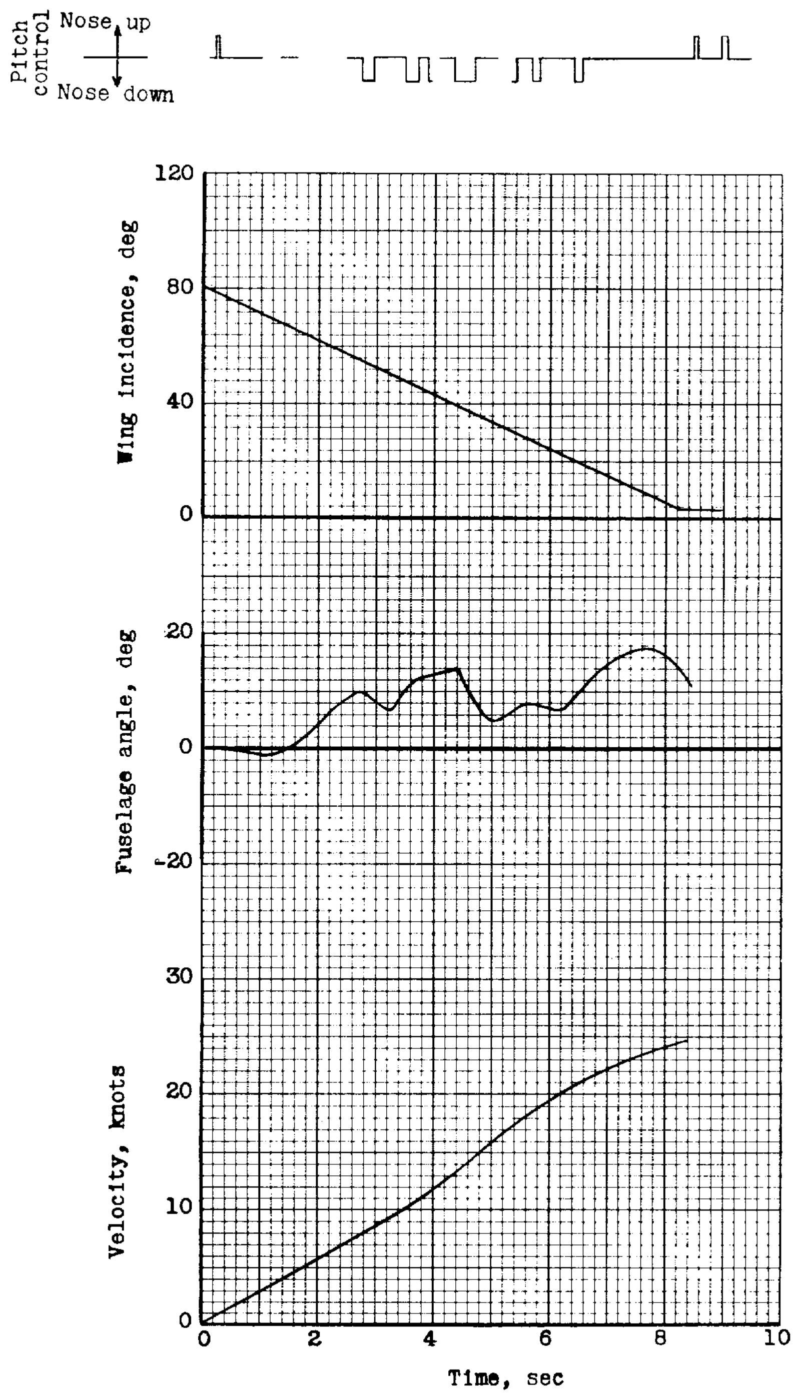


Figure 3.- Sketch of the test setup for transition flight tests on the Langley control-line facility.



(a) Flight 6; center of gravity 0.04 chord ahead of wing pivot.

Figure 4.- Pitching motions in transition from hovering to forward flight.

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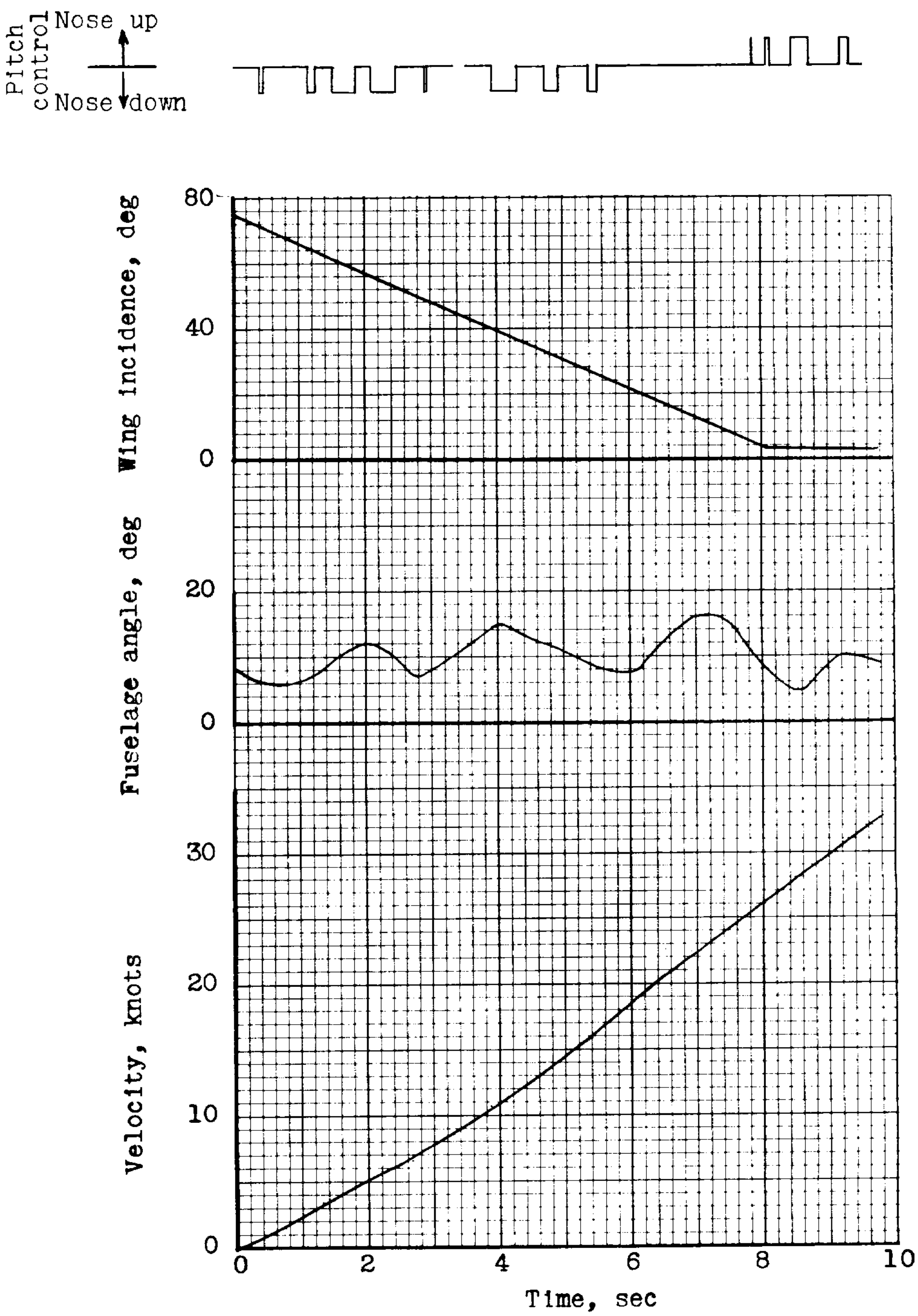
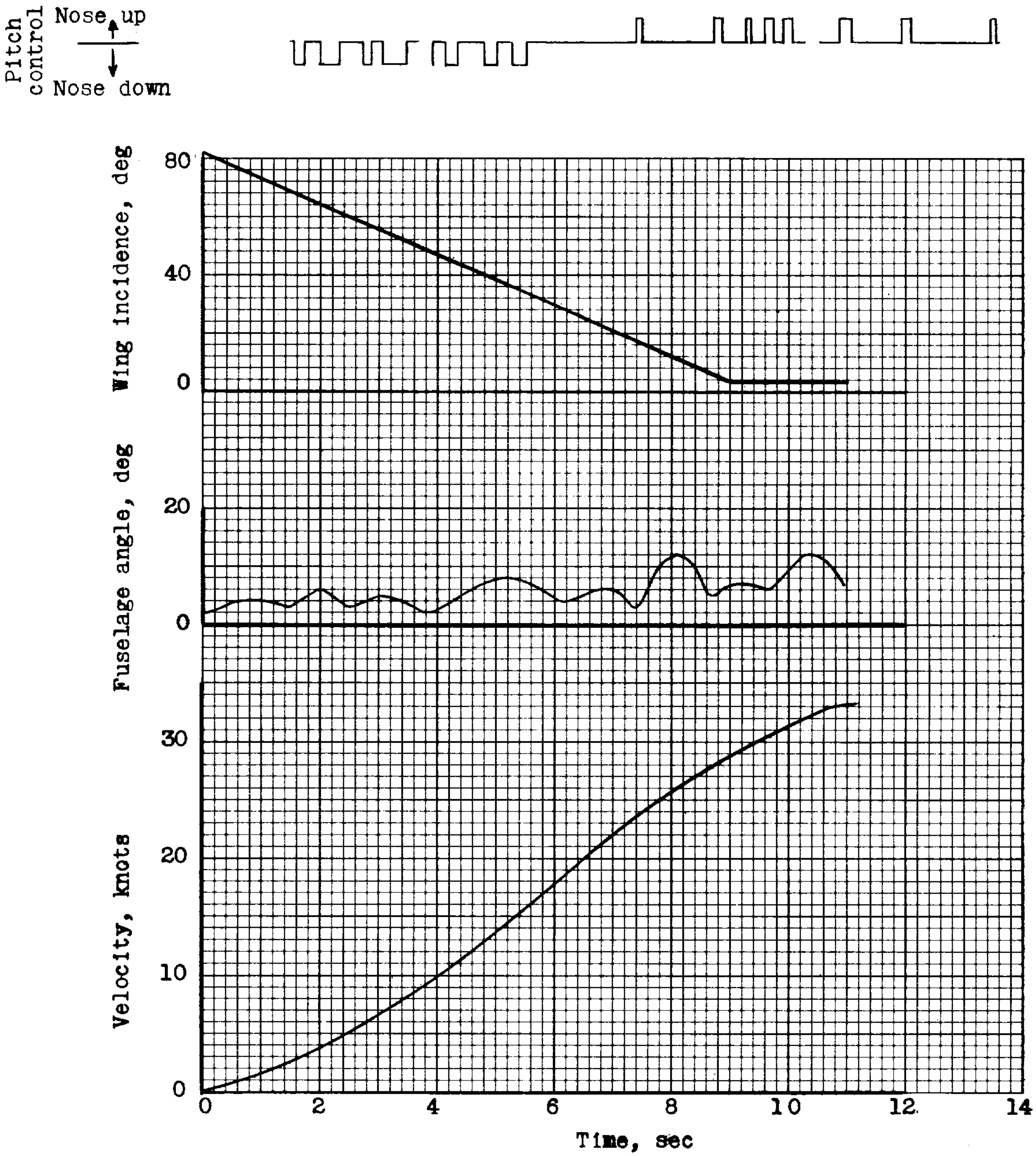


(b) Flight 9; center of gravity directly below wing pivot.

Figure 4.- Continued.



(c) Flight 16; center of gravity 0.03 chord behind wing pivot.

Figure 4.- Concluded.

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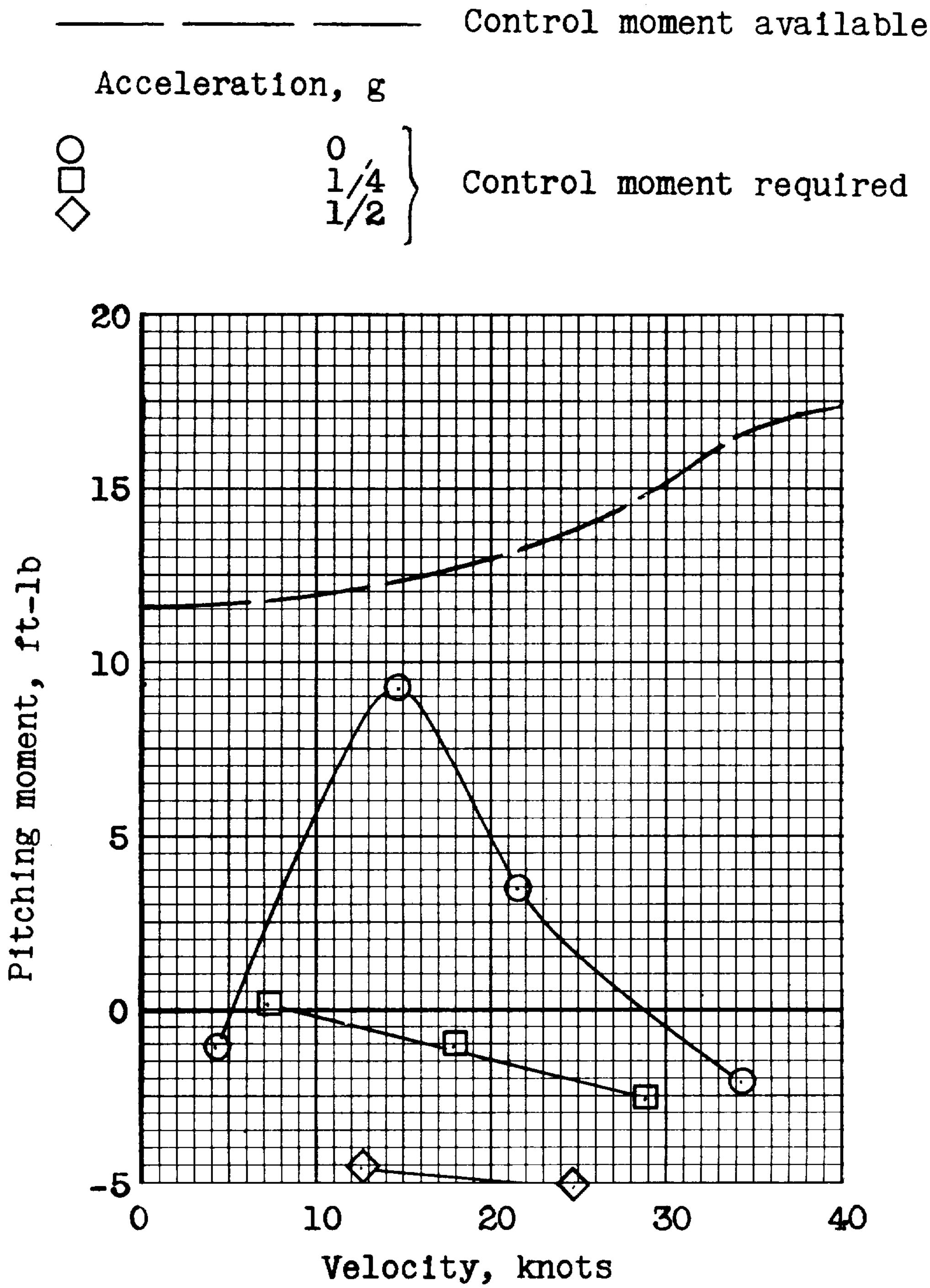
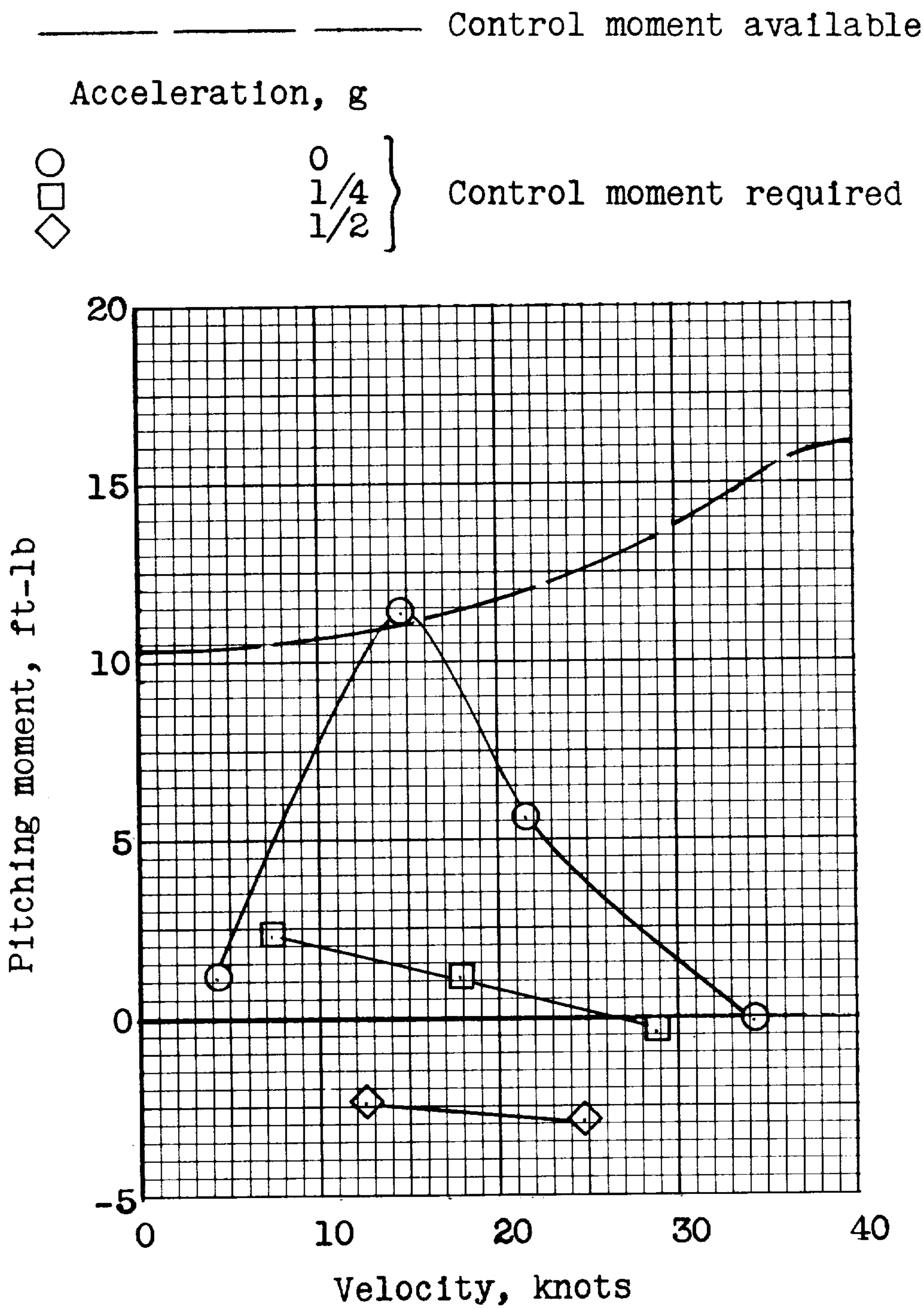


(a) Center of gravity 0.04 chord ahead of wing pivot.

Figure 5.- Longitudinal trim and control characteristics for 0g, 1/4g, and 1/2g acceleration.



(b) Center of gravity directly below wing pivot.

Figure 5.- Continued.

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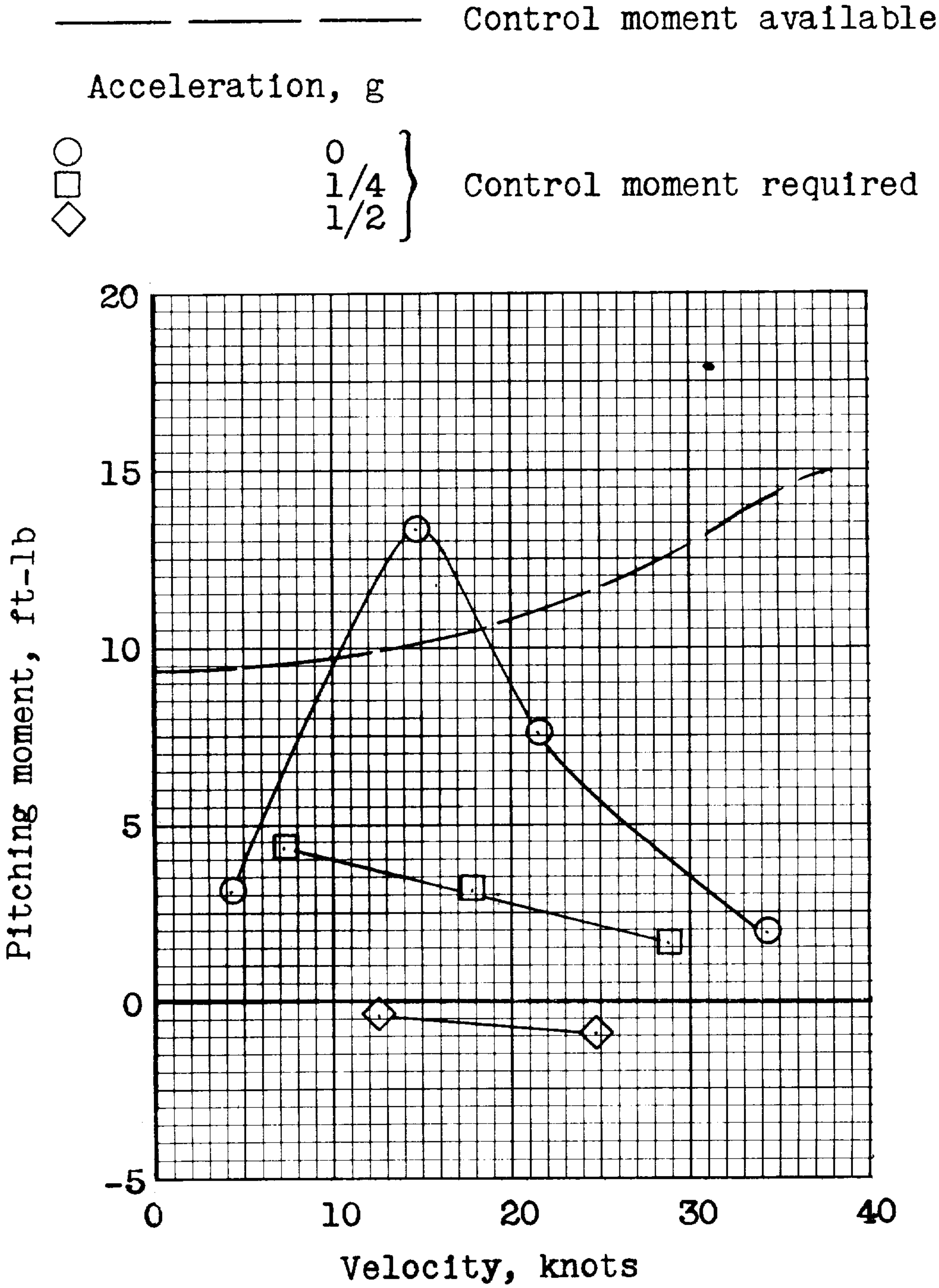
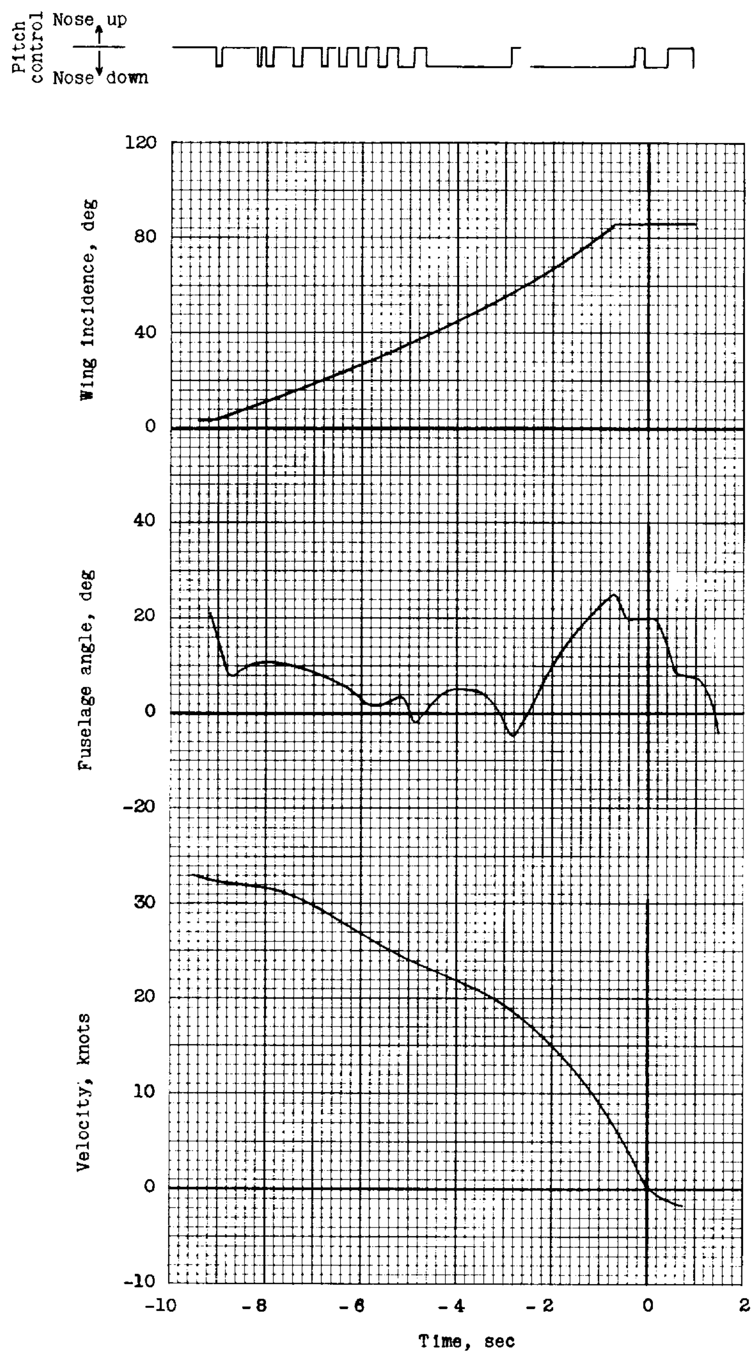


(c) Center of gravity 0.03 chord behind wing pivot.

Figure 5.- Concluded.



(a) Flight 1.

Figure 6.- Pitching motions in transitions from forward flight to hovering with center-of-gravity location 0.04 chord ahead of wing pivot.

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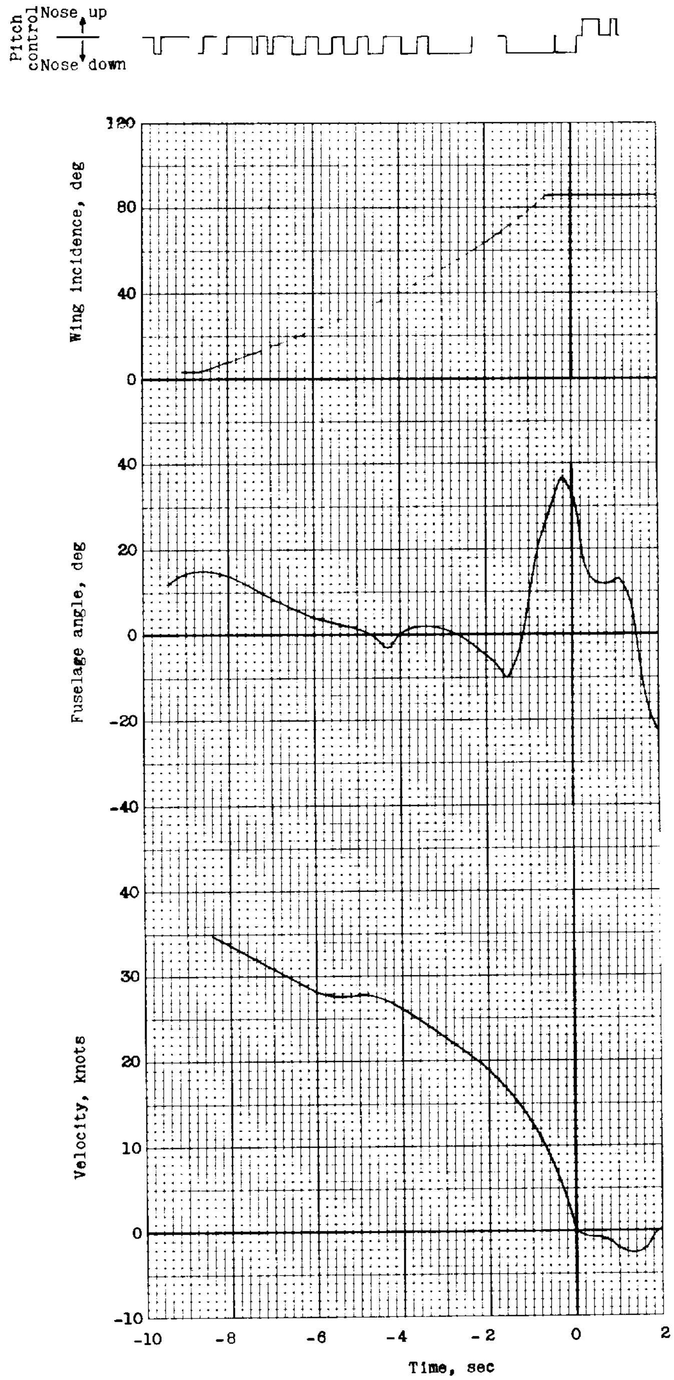
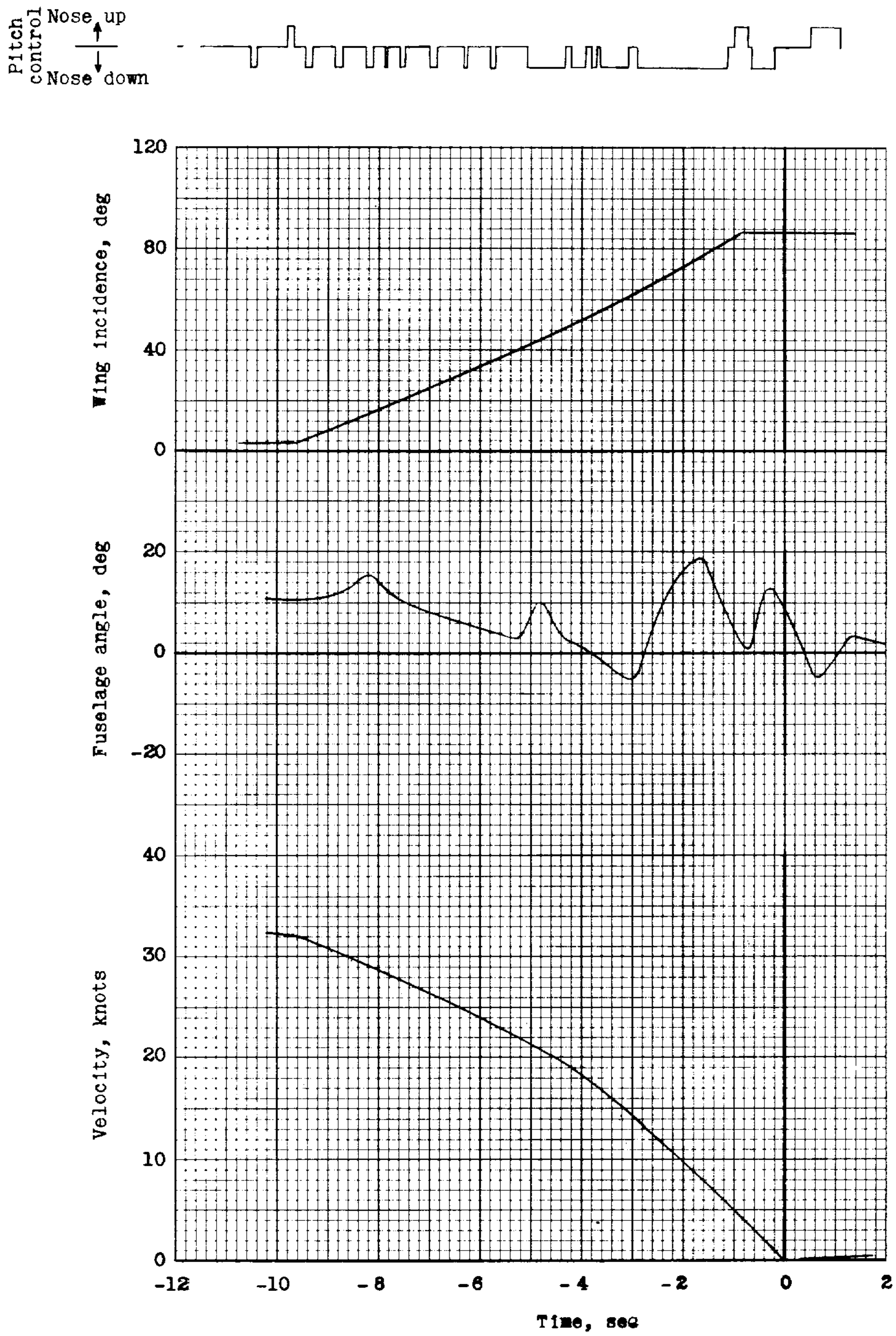


(b) Flight 2.

Figure 6.- Continued.



(c) Flight 3.

Figure 6.- Continued.

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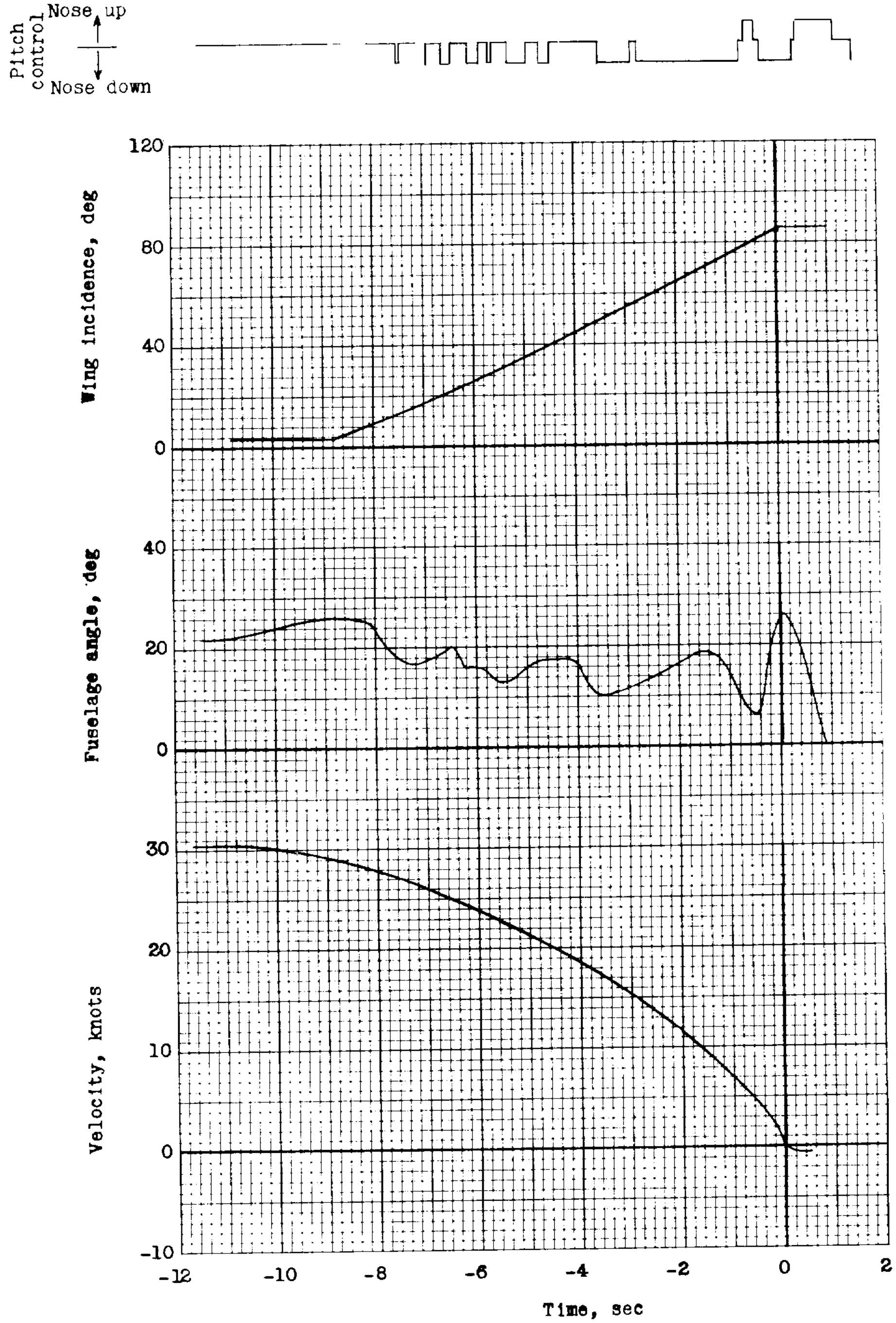

(d) Flight 4.

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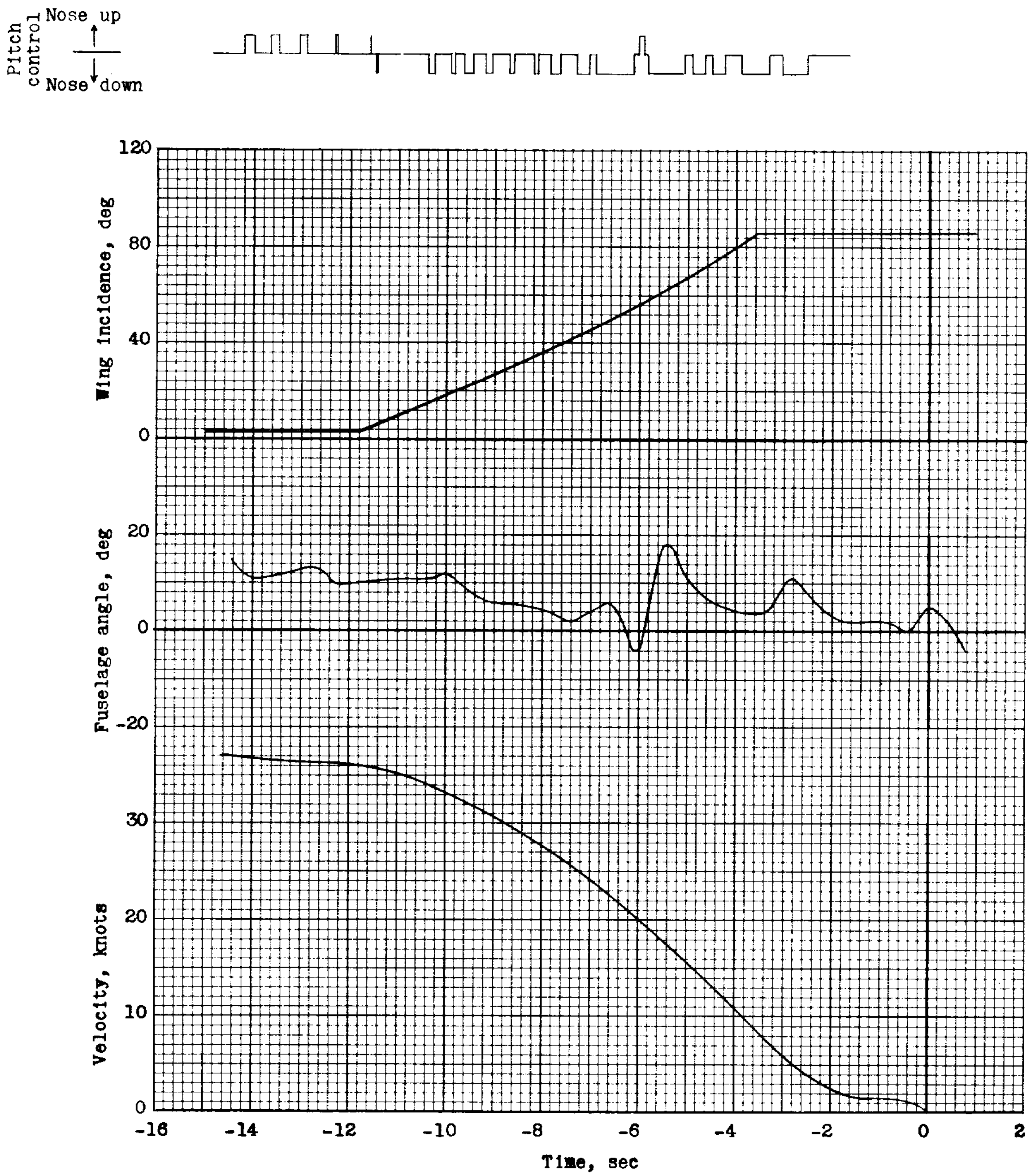

(e) Flight 5.

Figure 6.- Continued.

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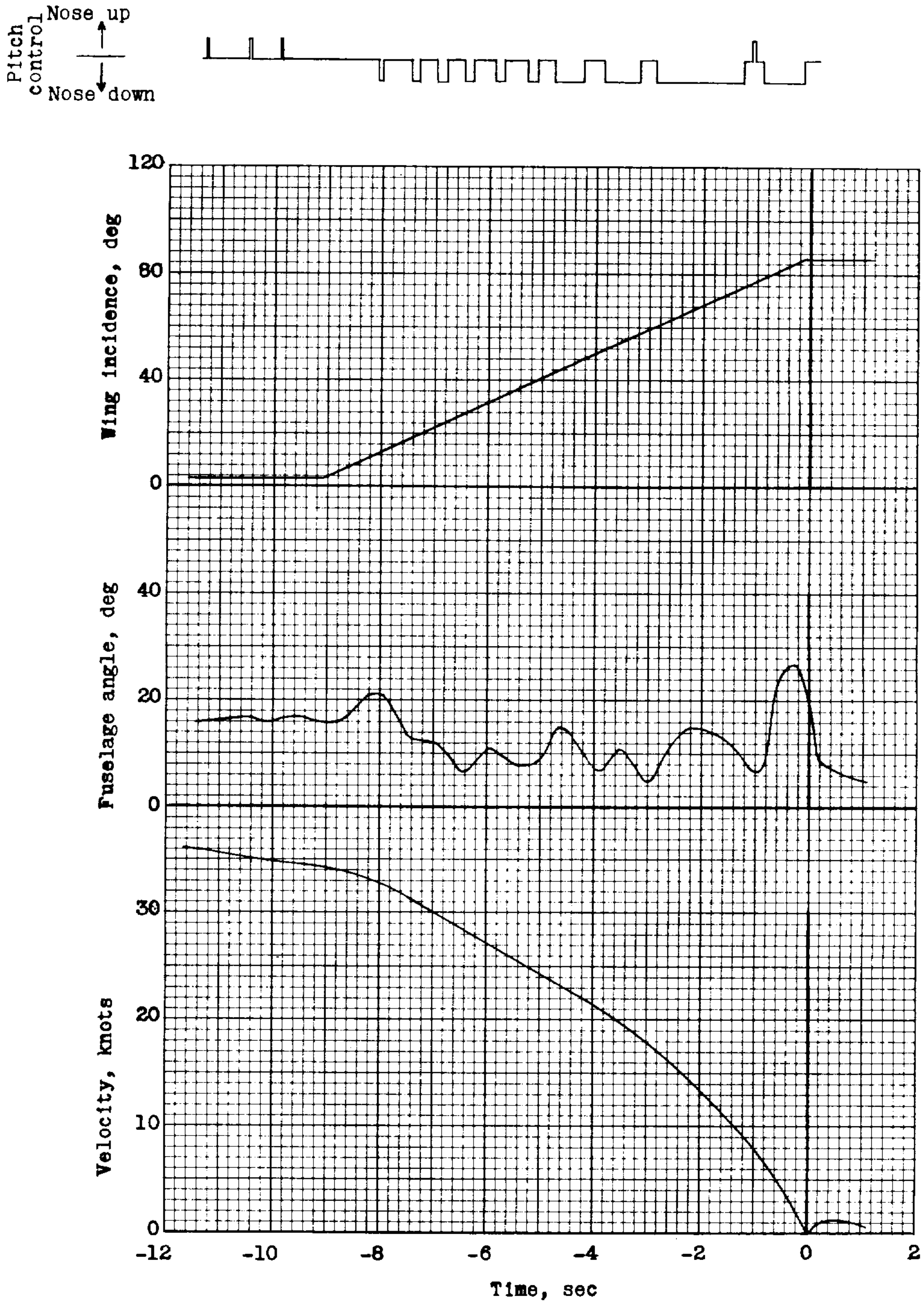
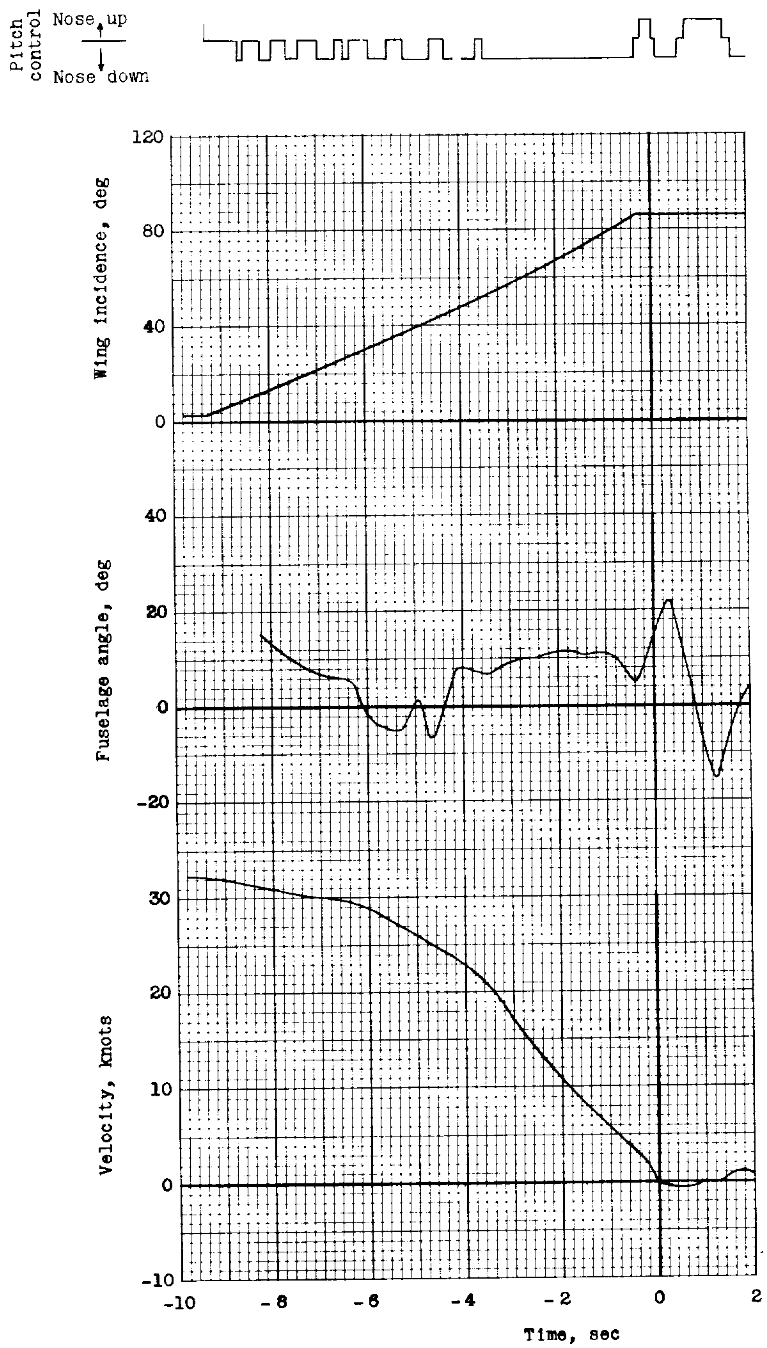


(f) Flight 6.

Figure 6.- Continued.



(g) Flight 7.

Figure 6.- Continued.

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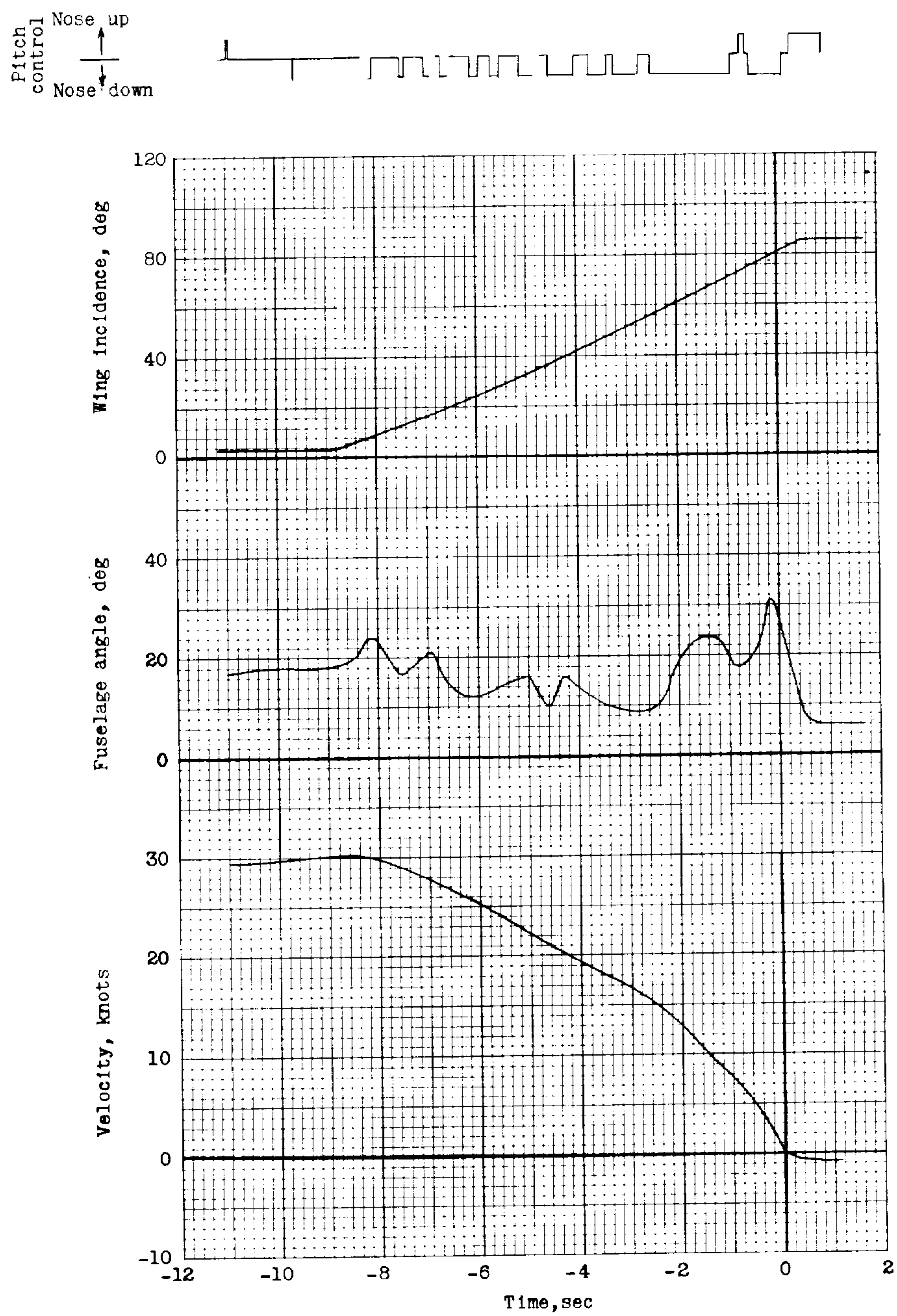
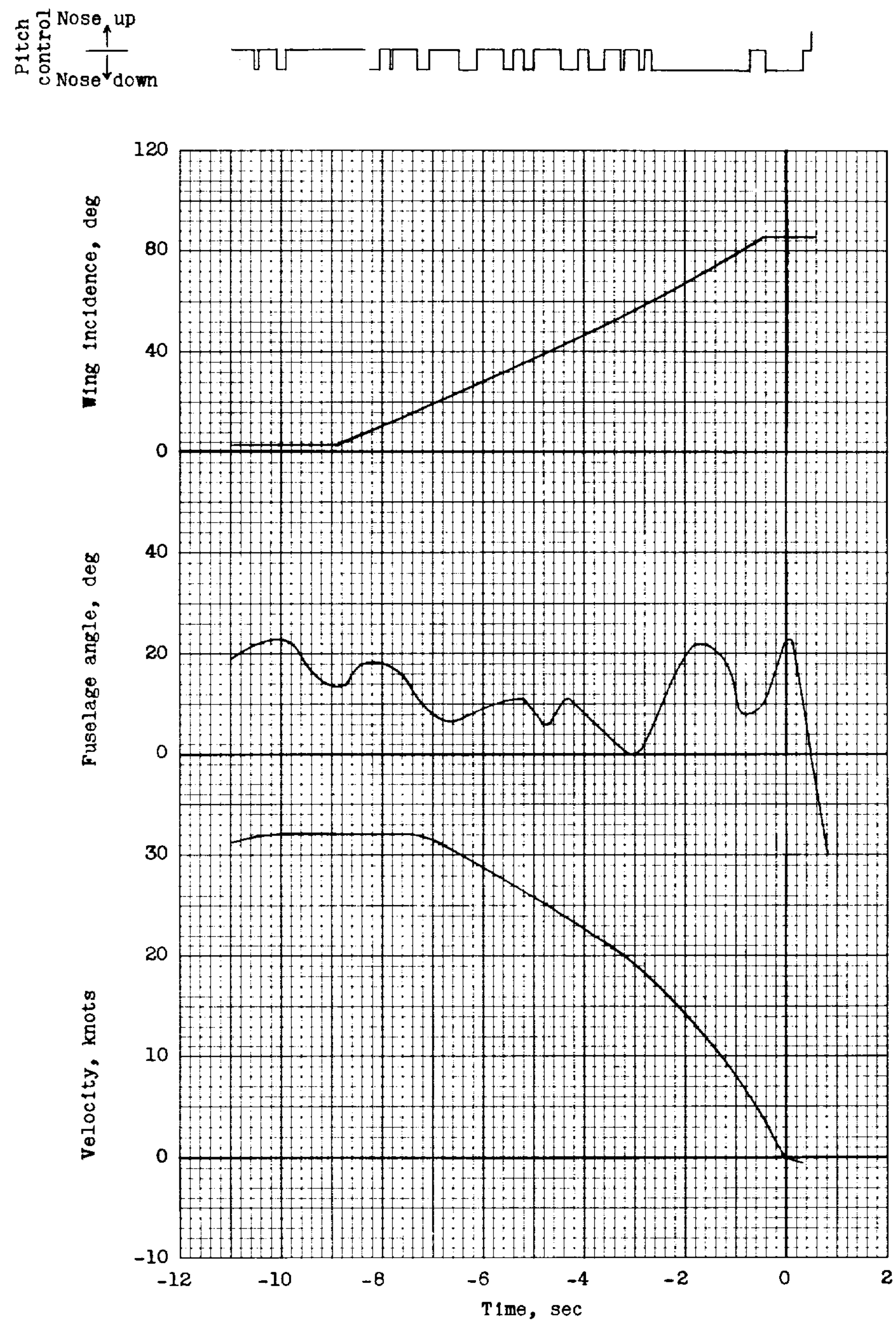


(h) Flight 8.

Figure 6.- Concluded.



(a) Flight 9.

Figure 7.- Pitching motions in transition from forward flight to hovering with center of gravity directly below wing pivot.

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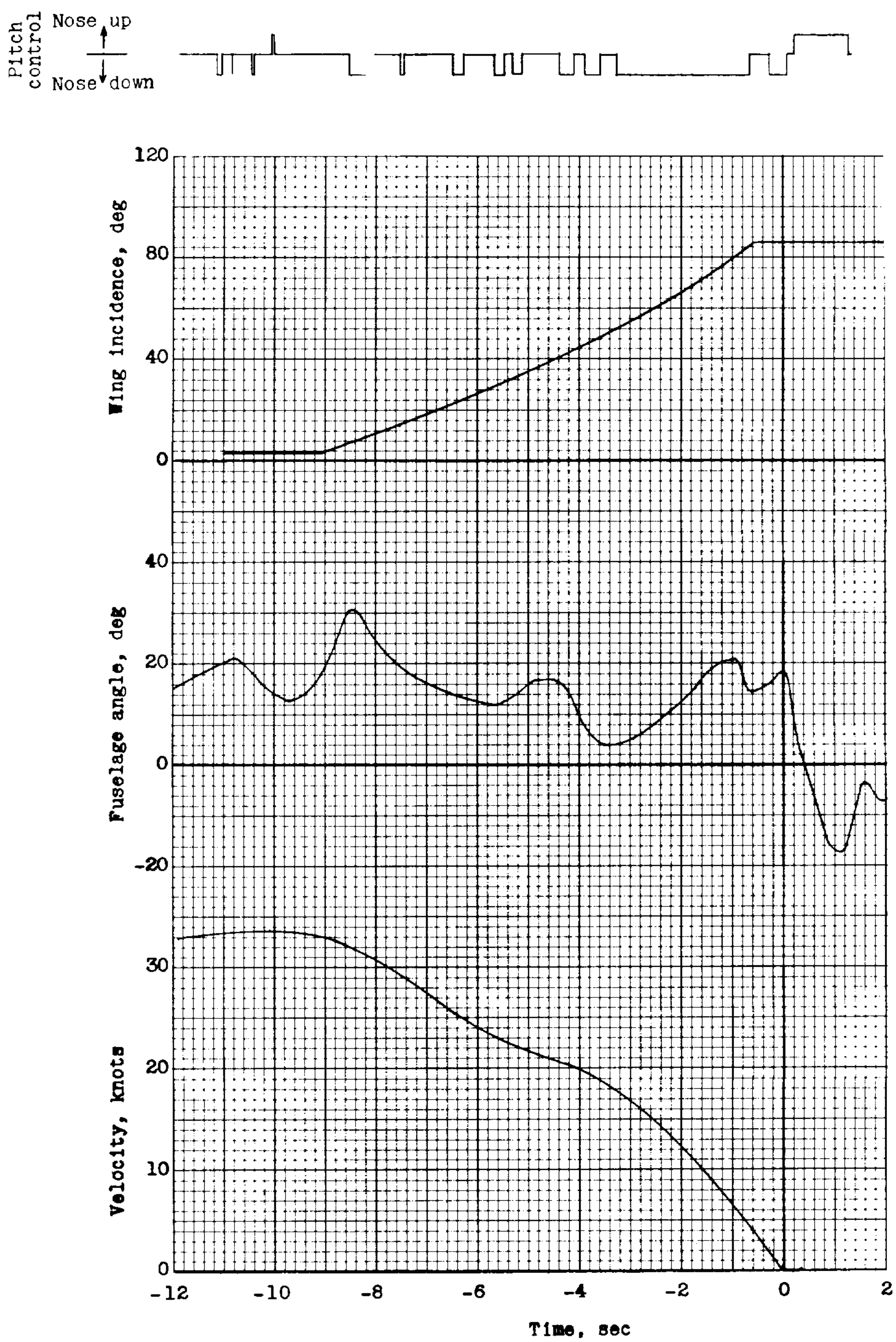
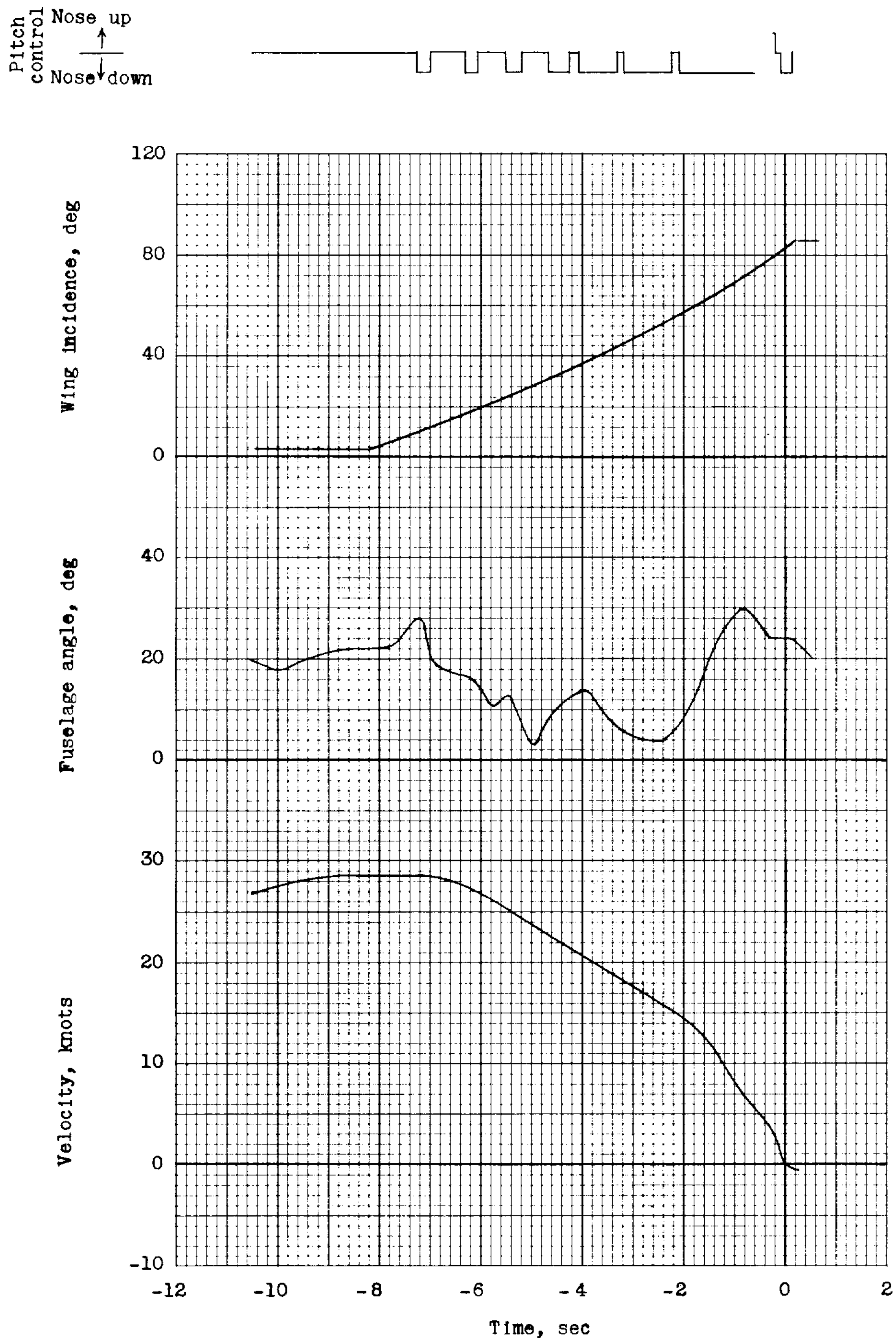


(b) Flight 10.

Figure 7.- Continued.



(c) Flight 11.

Figure 7.- Continued.

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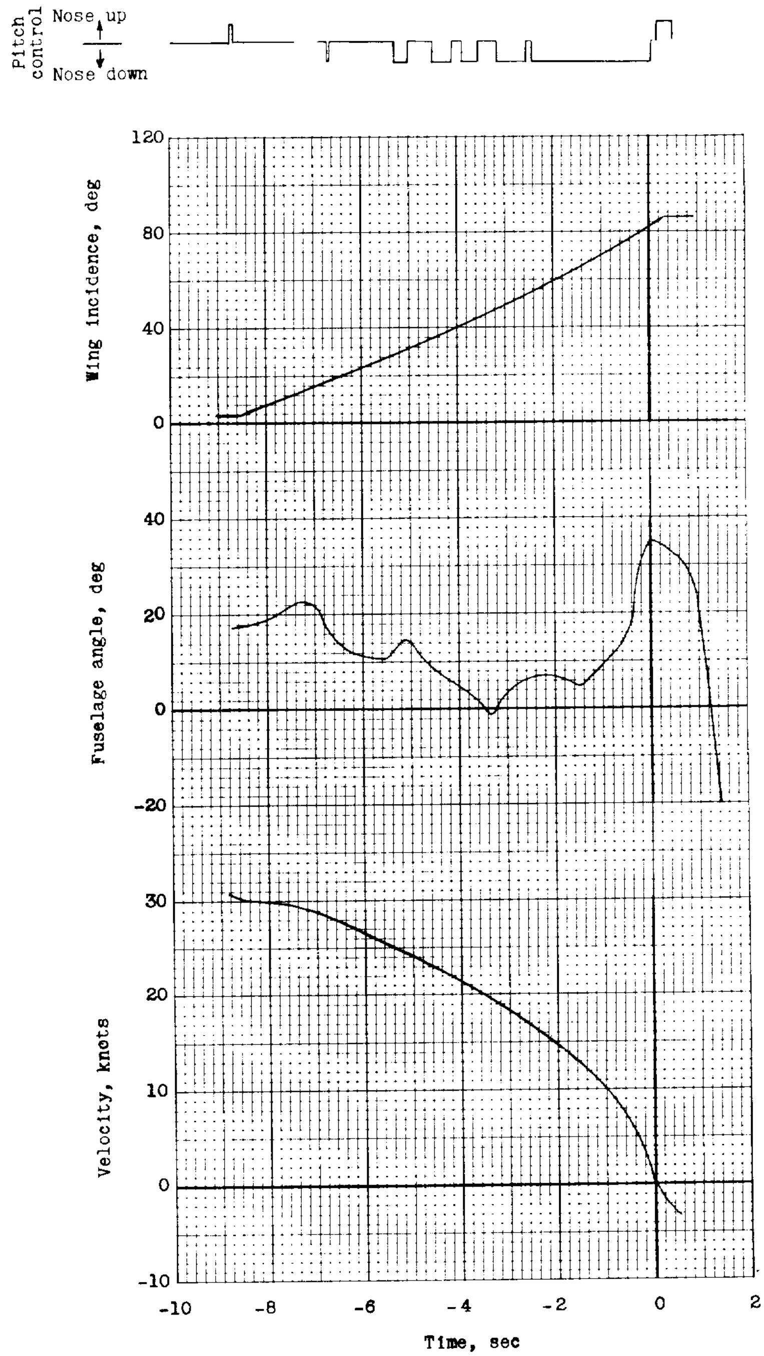

(d) Flight 12.

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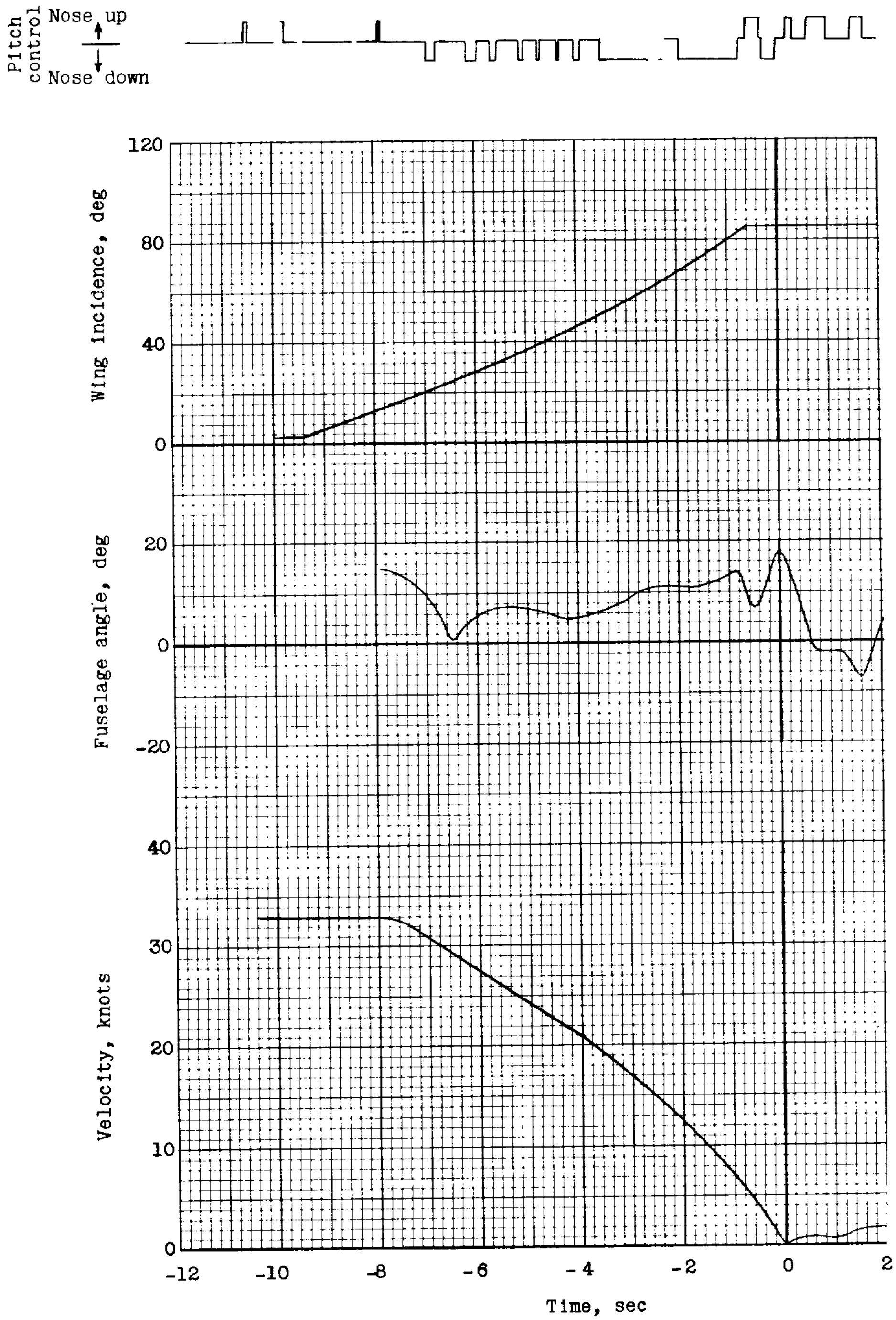

(e) Flight 13.

Figure 7.- Continued.

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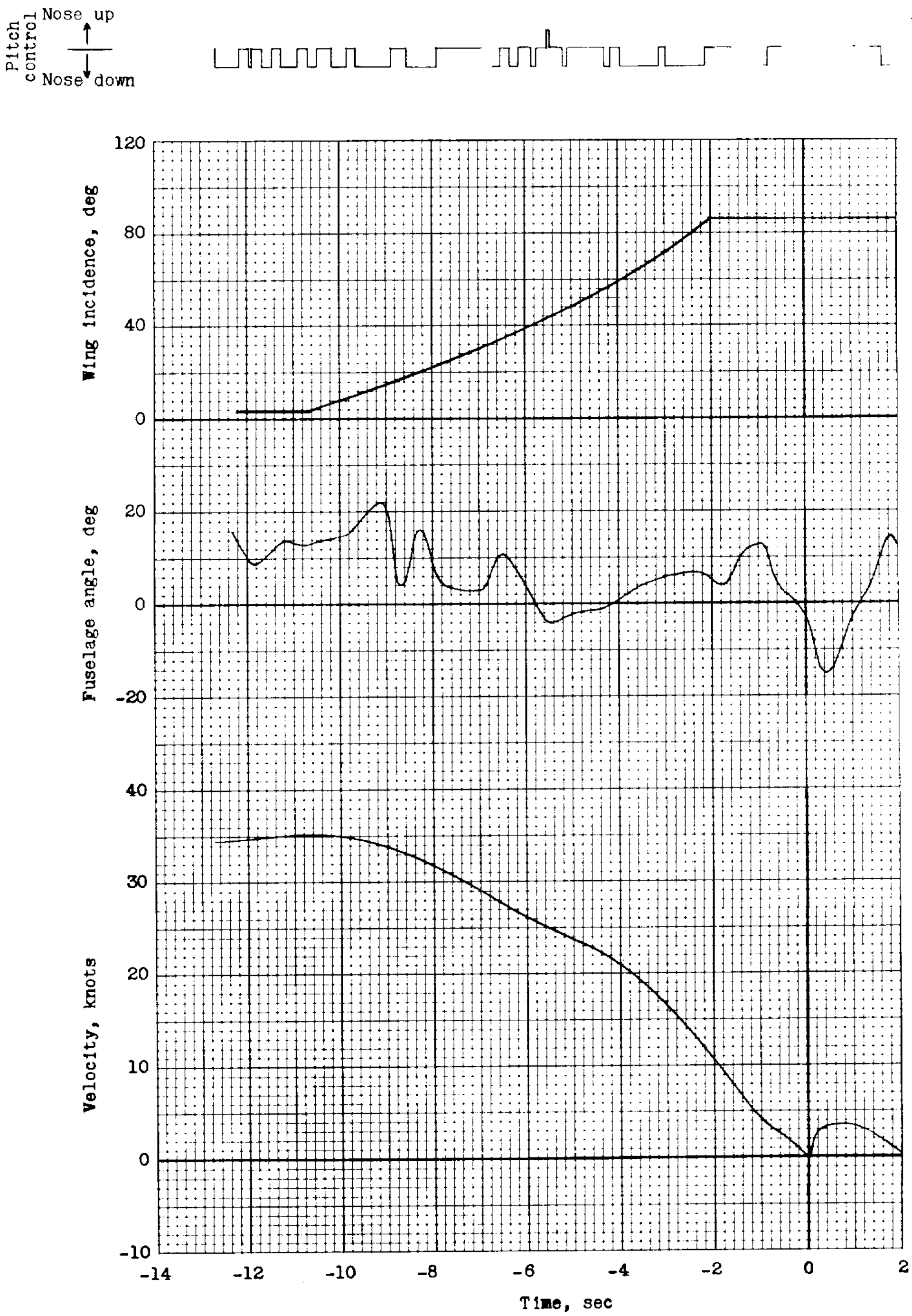

(f) Flight 14.

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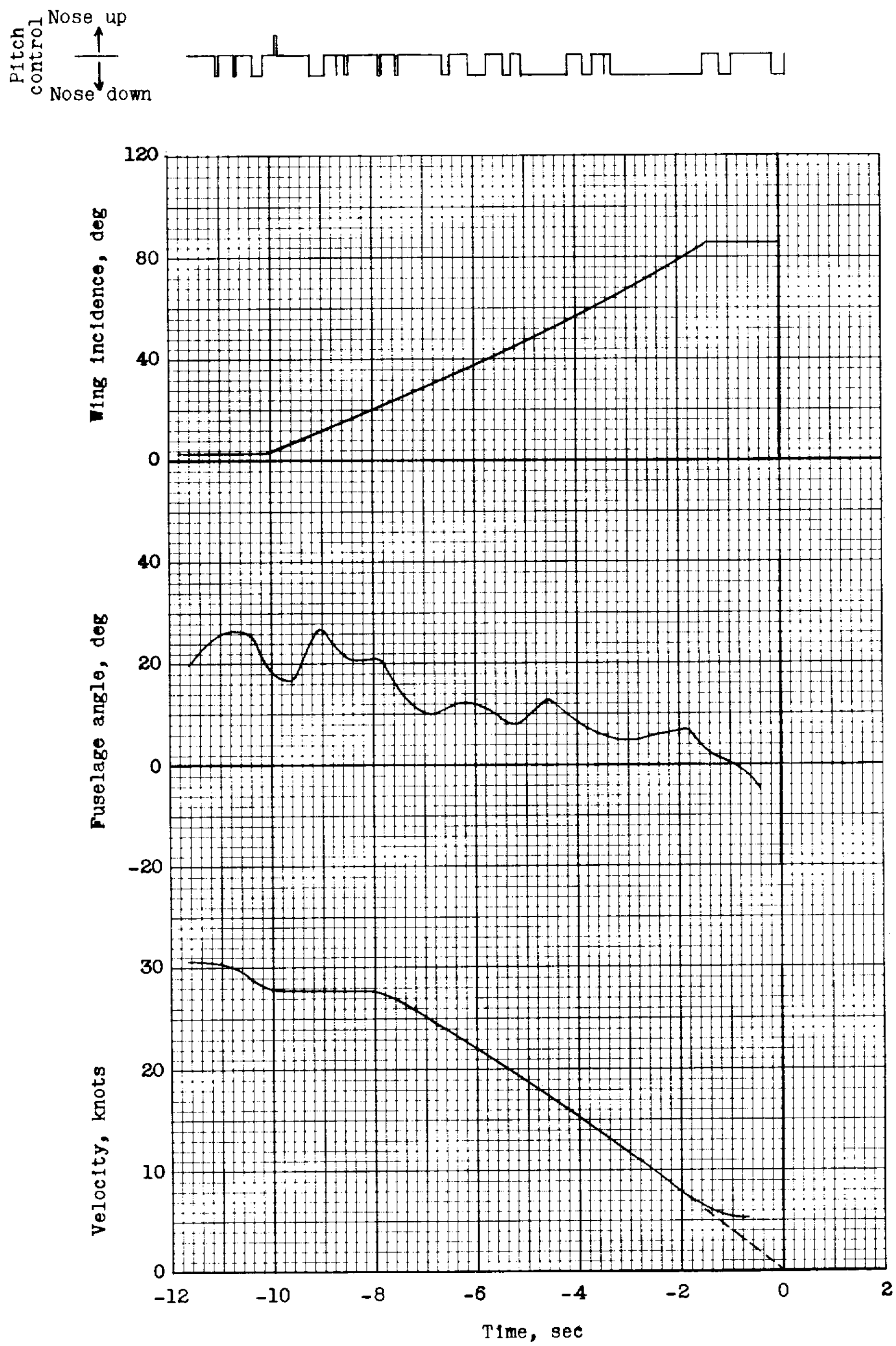

(g) Flight 15.

Figure 7.- Concluded.

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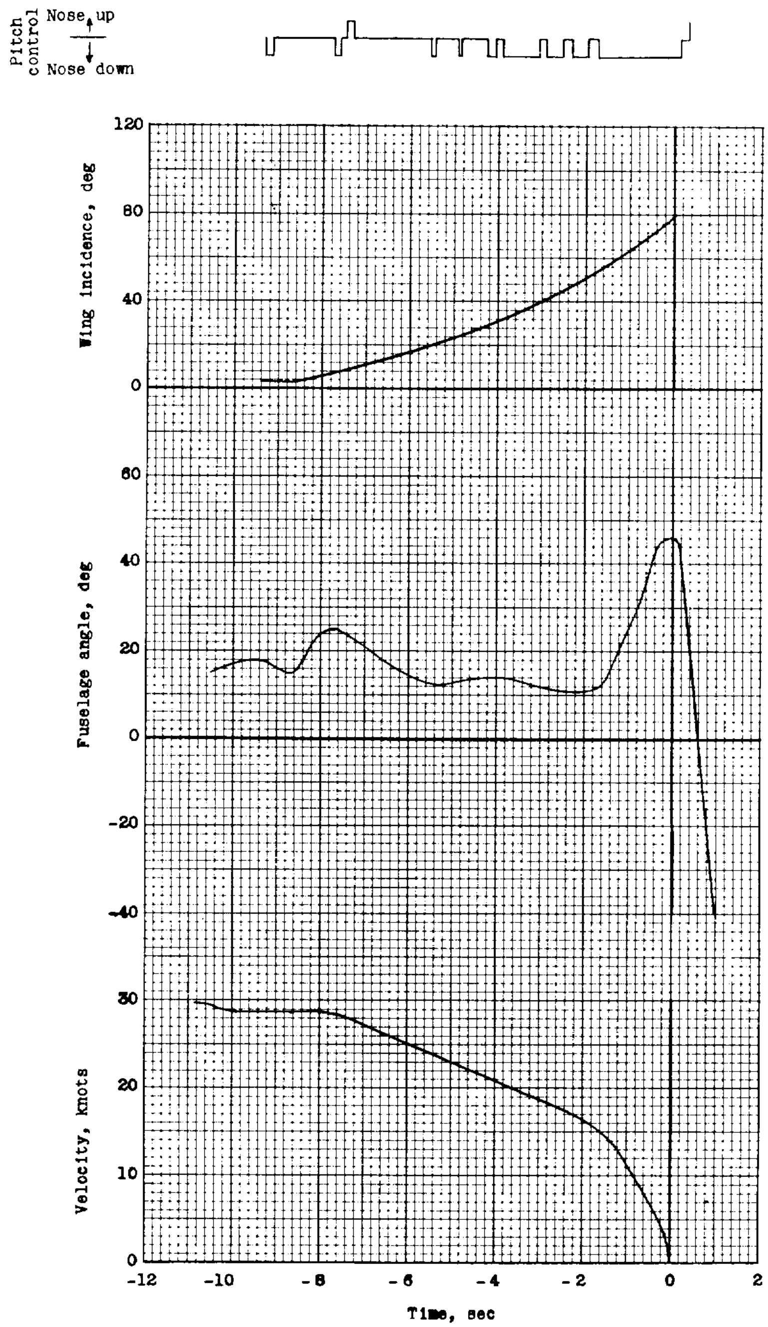
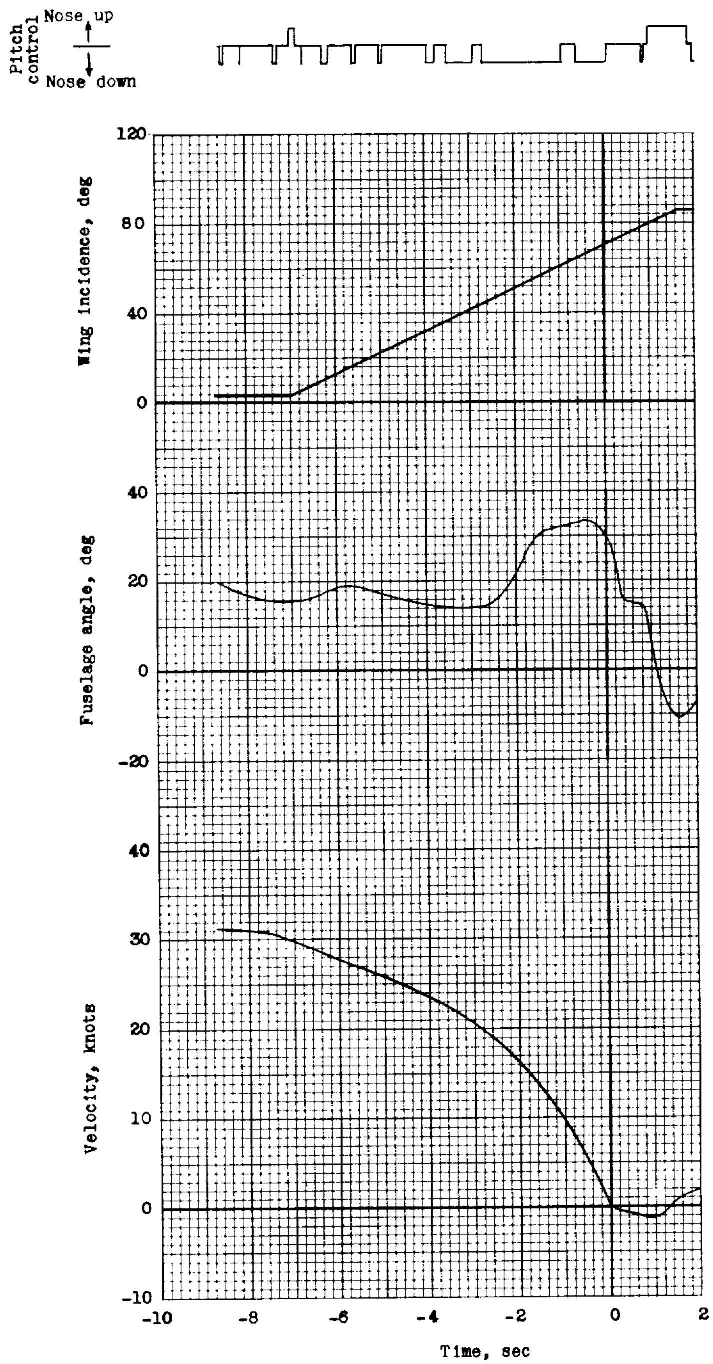


(a) Flight 16.

Figure 8.- Pitching motions in transition from forward flight to hovering with center of gravity 0.03 chord behind wing pivot.



(b) Flight 17.

Figure 8.- Concluded.

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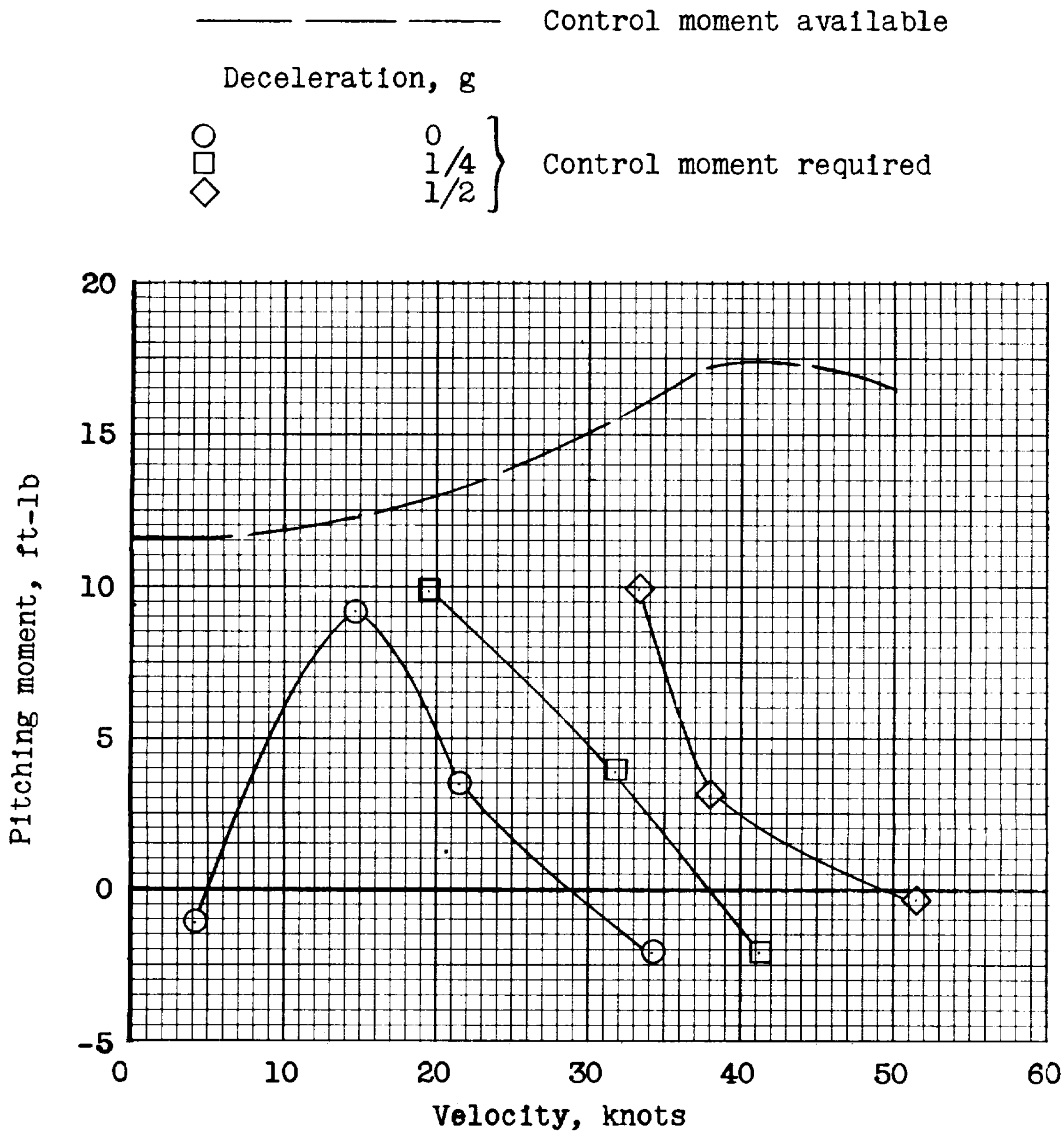
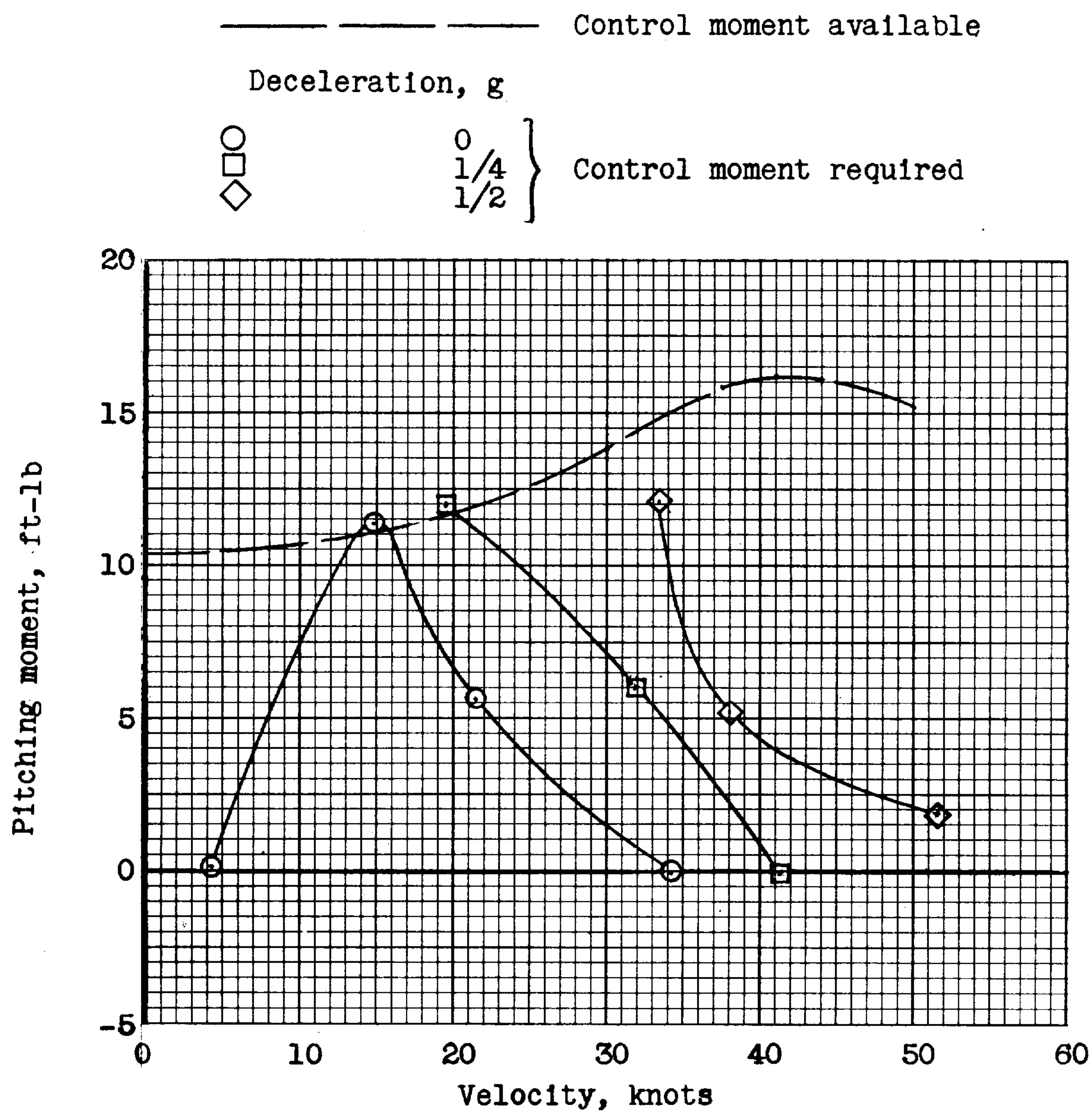


(a) Center of gravity 0.04 chord ahead of wing pivot.

Figure 9.- Longitudinal trim and control characteristics for 0g, 1/4g, and 1/2g decelerations.



(b) Center of gravity directly below wing pivot.

Figure 9.- Continued.

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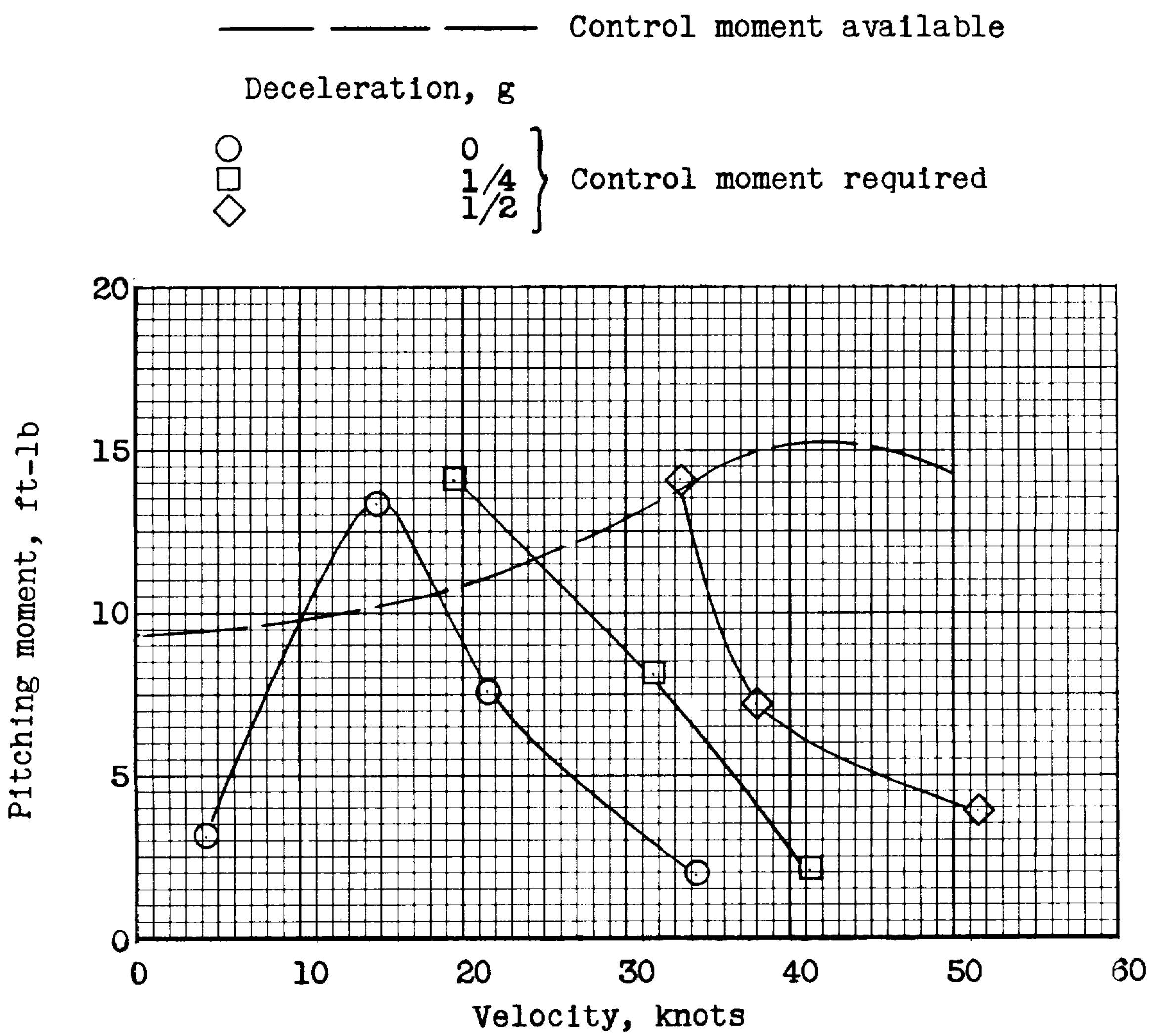

(c) Center of gravity 0.03 chord behind wing pivot.

Figure 9.- Concluded.

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National Aeronautics and Space Administration.
RAPID-TRANSITION TESTS OF A 1/4-SCALE MODEL OF THE VZ-2 TILT-WING AIRCRAFT. Louis P. Tosti. October 1961. 37p. OTS price, $1.00. (NASA TECHNICAL NOTE D-946)

An investigation of the longitudinal stability and control characteristics of a 1/4-scale model of the VZ-2 tilt-wing vertical-take-off-and-landing aircraft during rapid transitions has been made on the Langley control-line facility. The rapid transitions from hovering to forward flight could be performed easily at any of the accelerations attempted; whereas, the transitions from forward flight to hovering were generally accompanied by a strong nose-up pitching moment which at times was uncontrollable because of an inadequate amount of available pitch control.

Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-946

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