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# RESEARCH MEMORANDUM

## MEASUREMENTS OBTAINED DURING THE GLIDE-FLIGHT PROGRAM OF THE BELL X-2 RESEARCH AIRPLANE

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CLASSIFICATION CHANGED TO UNCLASSIFIED
AUTHORITY: NACA RESEARCH ABSTRACT NO. 128
DATE: JUNE 24, 1958
[redacted] WHL
[redacted]

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
July 30, 1953

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RESEARCH MEMORANDUM

# MEASUREMENTS OBTAINED DURING THE GLIDE-FLIGHT PROGRAM OF THE BELL X-2 RESEARCH AIRPLANE

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## SUMMARY

Results obtained during the glide-flight program of the Bell X-2 research airplane are presented. Landing characteristics and limited data evaluating static longitudinal stability at low speeds are included.

The data indicated positive static longitudinal stability in unaccelerated flight from indicated airspeeds of 152 to 178 miles per hour for the clean configuration, between 142 and 171 miles per hour with the flaps up and gear extended, and between 142 and 204 miles per hour with flaps and gear extended. A region of neutral stability, both stick fixed and stick free, was apparent between 178 and 192 miles per hour for the clean configuration. Data obtained during a turn made at an indicated airspeed of approximately 235 miles per hour with steadily increasing acceleration indicated positive stick-free and stick-fixed longitudinal stability. Stick force per unit normal acceleration was approximately 15 pounds.

Pilots' notes indicated that dynamic stability in each plane of reference was apparently positive with satisfactory damping for the speed range covered.

The main landing-skid surface area was enlarged 300 percent for flights 2 and 3 with a resulting improvement in landing characteristics. Average longitudinal deceleration during the ground run was decreased from 0.7 unit of acceleration for flight 1 to a value of 0.3 unit of acceleration for flights 2 and 3. Normal acceleration at the nose wheel was correspondingly reduced from 4 to 2.8 units of acceleration. The addition of inboard wing skids prevented rolling onto a wing tip during ground run.

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## INTRODUCTION

The Bell X-2 airplane is one of the experimental series of research airplanes currently being used in the joint Air Force—Navy—NACA high-speed flight research program. The X-2 was designed to investigate the supersonic characteristics of an airplane having a circular-arc airfoil. The airplane has several unconventional features among which are the circular-arc wing section profile, a skid-type main landing gear, a variable-thrust rocket engine, and all stainless-steel construction.

Prior to installing the rocket motor, three glide flights were performed by means of air launching to demonstrate the unconventional landing gear and to perform a brief investigation of the flight and handling characteristics at low speeds. Instrumentation was provided by NACA. Glide flights 1 and 2 were flown by the manufacturer. The third flight was made by an Air Force pilot for Air Force evaluation. The flights were conducted at Edwards Air Force Base, Calif.

Data obtained during the approach and landing of the first glide flight have been reported in reference 1. The purpose of this paper is to present the limited measurements of flying qualities, landing data, and pilots' comments obtained from the three glide flights.

## SYMBOLS

| | |
|---|---|
| $A_X$ | longitudinal acceleration, g units |
| $A_Y$ | lateral acceleration, g units |
| $A_Z$ | normal acceleration, g units |
| $C_{N_A}$ | airplane normal-force coefficient |
| $F_a$ | aileron stick force, lb |
| $F_e$ | elevator stick force, lb |
| $g$ | acceleration due to gravity, $ft/sec^2$ |
| $H$ | geometric altitude, ft |
| $h_p$ | pressure altitude, ft |
| $i_t$ | stabilizer incidence, deg |

[redacted]

| | |
|---|---|
| M.A.C. | mean aerodynamic chord, ft |
| $q$ | dynamic pressure, lb/sq ft |
| $s$ | horizontal distance to touchdown, ft |
| $V_i$ | indicated airspeed, mph |
| $V_v$ | vertical velocity, ft/sec |
| $\alpha$ | angle of attack, deg |
| $\beta$ | angle of sideslip, deg |
| $\delta_{a_T}$ | total aileron deflection, deg |
| $\delta_e$ | elevator deflection, deg |
| $\delta_{f_{TE}}$ | trailing-edge flap deflection, deg |
| $\dot{\theta}$ | pitching angular velocity, radians/sec |
| $\tau$ | relative elevator-stabilizer effectiveness, $di_t/d\delta_e$ |
| $\dot{\varphi}$ | rolling angular velocity, radians/sec |
| $\dot{\psi}$ | yawing angular velocity, radians/sec |

## AIRPLANE

The Bell X-2 is a low-wing single-place airplane designed for flight research at supersonic speeds. The wings are swept back 40° at the quarter chord and 10-percent-thick circular-arc airfoils normal to the quarter chord. Construction is entirely of stainless steel. For the flights described herein, lead weights were installed in place of the rocket motor to maintain design center of gravity and normal empty weight. A manual control system was employed. Aileron balancing tabs were used which had a deflection ratio of 1 to 1 with aileron deflection. Springs were installed in the elevator control system to produce artificial force variation in addition to the aerodynamic force. The geometric characteristics of the airplane are presented in table I and a three-view drawing is shown in figure 1. The leading-edge flaps were locked in the 15° down position for flights 1 and 3. The second glide

flight was made with the right leading-edge flap locked in the 15° down position and the left flap inadvertently in the up position.

The landing gear employed for glide flight 1 consisted of a main landing skid and nose wheel and wing-tip skids. For glide flights 2 and 3, the main skid was replaced with one of similar design but of increased surface area. In addition, two extensible stabilizing skids were installed under each wing at the midsemispan wing station. These inboard skids are retracted manually on the ground and are released electrically when the main skid and nose wheel are extended. A drawing of the airplane showing the landing-gear arrangement is presented as figure 2 and a photograph of the airplane in the normal ground attitude is shown as figure 3. Figure 4 shows photographs of the modified main skid and the left inboard wing skid extended.

## INSTRUMENTATION

The airplane was instrumented to record the following quantities on internal recording instruments:

Altitude
Airspeed
Normal, longitudinal, and transverse acceleration
Rolling angular velocity
Pitching angular velocity
Yawing angular velocity
Elevator angle
Aileron angle
Rudder angle
Stabilizer incidence
Flap angles
Elevator stick force
Aileron stick force
Angle of attack
Angle of sideslip

The rudder control position transmitter was inoperative during glide flights 2 and 3.

The three-component accelerometer is located 123 inches forward of the center of gravity of the airplane.

Angle of attack and stabilizer incidence are measured relative to the center line of the airplane. Elevator deflection is measured relative to the stabilizer. Aileron and elevator forces presented herein

include control-system friction forces of approximately 8 pounds. In addition, elevator forces include forces due to artificial "feel" springs. These springs provide approximately 1.3 pounds elevator stick force per degree of elevator stick movement. Askania phototheodolite cameras were employed to obtain time and position data in the approach and landing. A modified SCR 584 radar was employed to obtain the airplane landing pattern and to augment the Askania records. All internal records were synchronized by a common timer. Internal records were synchronized with the Askania cameras by radar timing.

## TESTS, RESULTS, AND DISCUSSION

In view of the fact that the total flying time for the three glide flights was only 26 minutes and that much of this time was consumed in pilot familiarization and in the landing pattern, an extensive evaluation of the low-speed handling characteristics of the airplane could not be obtained. However, the recorded data and pilots' comments were sufficient to evaluate some stability and control characteristics over limited ranges.

### Flight Data

Static-longitudinal-stability data in unaccelerated flight were obtained with the airplane in the clean configuration, with the landing gear extended, and with both flap and landing gear extended. Figure 5 presents the variation of elevator stick force and position required for trim with airspeed and normal-force coefficient. The speed range covered was from an indicated airspeed of 142 to 204 miles per hour with a $C_{N_A}$ range from 0.37 to 0.80. The data show that the airplane was stable in all configurations except for indicated airspeeds between 178 and 192 miles per hour in the clean condition where neutral stability both stick fixed and stick free, is indicated.

Data obtained during a turn performed at an indicated airspeed of approximately 235 miles per hour with the airplane in the clean configuration are presented in figure 6. A normal-force-coefficient range from 0.25 to 0.58 was covered. The stick-force and elevator-position variation indicate that the airplane is stable, both stick free and stick fixed, in this lift range. There is a decrease of apparent stability indicated at about $C_{N_A}$ of 0.31 by a change of the elevator-angle—angle-of-attack gradient. There was an increase of pitching rate at this $C_{N_A}$ but the pitching velocities were so low that the reduction

[redacted]

of stability was not noticed by the pilot. The control effectiveness $d\delta_e/dC_{N_A}$ in this turn decreased from a value of about 35° below $C_{N_A} = 0.31$ to a value of about 12° above $C_{N_A} = 0.31$. The stick force per g was fairly constant at a value of 15 pounds per g of which about $6\frac{1}{2}$ pounds per g results from the elevator feel springs.

The relative elevator-stabilizer effectiveness $\tau$ as obtained from trim points at several stabilizer settings is shown in figure 7. A value of $\tau = 0.4$ was obtained for elevator deflections ranging from 0.4° to 9.5° at an indicated airspeed of approximately 230 miles per hour.

No controlled maneuvers were attempted from which dynamic stability data could be evaluated. However, the Air Force pilot reported that longitudinal, directional, and lateral dynamic stability appeared positive, with satisfactory damping, in the speed range tested.

Flight 2 was made with the right nose flap locked in the 15° down position and the left nose flap inadvertently in the up position. The pilot commented that no appreciable asymmetry was observed during flight as a result of this configuration.

## Landing Data

The landing approach patterns, as recorded by radar, for glide flights 2 and 3 are shown as figures 8 and 9, respectively. The time ticks on the trajectories in figures 8 and 9 correspond to the abscissa times in figures 11 and 12, respectively. The landing flight paths as recorded by Askania phototheodolites are presented in figure 10. Time histories of the measured quantities during final approach, landing, and landing run are shown in figures 11 and 12. A summary of pertinent quantities obtained in the three landings is given in table II.

The winds at ground level for each flight were from 0 to 3 miles per hour from the northeast.

Glide flight 2.- The downwind leg of the landing pattern, shown in figure 8, was flown at approximately 240 miles per hour, indicated airspeed, with landing gear extended and trailing-edge flaps up. The turn onto the base leg was made at 7,000 feet, geometric altitude, at approximately 235 miles per hour at which time the trailing-edge flaps were lowered 29°. The flaps were lowered to 38° as the final approach was started at approximately 3,000 feet, geometric altitude, and 225 miles per hour, indicated airspeed. The speed in the approach was held nearly constant at approximately 230 miles per hour from time 0 to time 32 seconds. After time 32 seconds, the airspeed decreased more rapidly until

contact was made at an indicated airspeed of 169 miles per hour with a $C_{N_A}$ of 0.71, and a $V_V$ of -1.7 feet per second.

The flight path during final approach is shown in figure 10. The times indicated at various data points correspond to the time history of figure 11.

The second glide-flight landing was made at a higher indicated airspeed in order to reduce the angle of attack of touchdown and consequently reduce the pitch down resulting from the main skid contact. This, in combination with the decreased retarding force of the enlarged main skid reduced the resulting normal acceleration at the nose wheel to 2.7g as compared with 4.0g for flight 1. (See table II.)

The inboard wing skids held the airplane erect for the entire ground run. The modified main skid did not dig into the surface of the lake bed as did the original skid. The average longitudinal deceleration during ground run was approximately 0.3g as compared with approximately 0.7g for glide flight 1 using the original skid. The ground run distances for flights 1 and 2 were 1,010 feet and 3,340 feet, respectively.

Glide flight 3.-- The approach and landing of flight 3 was similar to that of flight 2 except that when the landing gear was lowered, the right inboard wing skid did not extend.

The geometric altitude of the downwind leg of the approach at the point opposite contact was 4,500 feet (fig. 9) at an indicated airspeed of 233 miles per hour. The airspeed was maintained fairly constant throughout the base leg and final approach until a geometric altitude of 300 feet was reached. The airspeed was then gradually reduced in the landing flare (figs. 10 and 12) until contact was made at an indicated airspeed of 185 miles per hour with a $C_{N_A}$ of 0.46, an angle of attack of 3.6°, and a $V_V$ of -1.5 feet per second. Although the indicated airspeed at contact was considerably higher than that of flight 2, the angle of attack was larger because flaps were not employed. The normal acceleration at the nose wheel was 2.8g. The landing impact released the right inboard wing skid permitting it to lock in the extended position and a normal ground run followed. The average longitudinal deceleration, as in flight 2, was approximately 0.3g. The ground run covered a distance of 3,713 feet.

Both pilots stated that the landing of the X-2 airplane is a simple and easy maneuver comparable to any modern fighter airplane. The Air Force pilot of flight 3 was of the opinion that the aileron effectiveness was excellent and that aileron control was available down to an indicated airspeed of 50 miles per hour during the landing run.

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Figure 13 is a rear-view photograph of the airplane showing the main skid, the two inboard wing skids, and the skid marks left on the surface of the dry lake bed at the termination of glide flight 3.

## CONCLUSIONS

The following conclusions were drawn from data evaluation and pilots' comments obtained during the glide-flight program of the Bell X-2 research airplane:

1. Static longitudinal stability in unaccelerated flight was positive for an indicated airspeed between 152 and 178 miles per hour for the clean configuration, between 142 and 171 miles per hour with the flaps up and gear extended, and between 142 and 204 miles per hour with flaps and gear extended. A region of neutral stability, both stick fixed and stick free, was apparent between 178 and 192 miles per hour for the clean condition.

2. Data obtained in a turn at an indicated airspeed of approximately 235 miles per hour indicated positive stick-free and stick-fixed longitudinal stability. Stick force per unit acceleration was approximately 15 pounds.

The remaining conclusions were taken from pilots' comments.

3. The longitudinal, lateral, and directional dynamic stability appeared to be positive with satisfactory damping qualities for the speed range covered.

4. With the modified landing gear, the landing of the X-2 airplane is a simple and easy maneuver.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 19, 1953.

Richard E. Day
Aeronautical Research Scientist

Approved: Hartley A. Soulé
Hartley A. Soulé
Assistant Director

[redacted]

## REFERENCE

1. Day, Richard E., and Stillwell, Wendell H.: First Landing of Bell X-2 Research Airplane. NACA RM L52I11, 1952.

[redacted]

TABLE I

PHYSICAL CHARACTERISTICS OF BELL X-2 AIRPLANE

| | |
|---|---|
| Wing: | |
| Area, sq ft | 260.4 |
| Span, ft | 32.3 |
| Aspect ratio | 4.0 |
| Taper ratio | 0.5 |
| Sweep at 0.25 chord, deg | 40.0 |
| Mean aerodynamic chord, ft | 8.379 |
| Location of mean aerodynamic chord, horizontal from fuselage center line, in. | 79.42 |
| Airfoil section | 10-percent-thick circular-arc |
| Incidence: | |
| Root, deg | 3.0 |
| Tip, deg | 3.0 |
| Dihedral, deg | 3.0 |
| Aileron: | |
| Area, sq ft | 10.8 |
| Travel, deg | ±17.0 |
| Flap, T.E.: | |
| Area (total), sq ft | 21.2 |
| Travel, deg | 45 |
| Flap, L.E.: | |
| Area (total), sq ft | 12.2 |
| Travel, deg | 15 |
| Horizontal tail: | |
| Area, sq ft | 43.7 |
| Span, ft | 12.8 |
| Aspect ratio | 3.75 |
| Sweep at 0.25 chord, deg | 40.0 |
| Airfoil section | NACA 65-008 |
| Elevator: | |
| Area, sq ft | 8.4 |
| Travel, deg: | |
| Up | 15 |
| Down | 10 |
| Stabilizer: | |
| Travel, deg: | |
| L.E. up | 7 |
| L.E. down | 10 |

[redacted]

TABLE I - Concluded

PHYSICAL CHARACTERISTICS OF BELL X-2 AIRPLANE

| | |
|---|---|
| Vertical tail: | |
| Area, excluding dorsal, sq ft | 38.6 |
| Sweep of leading edge, deg | 40.6 |
| Airfoil section: | |
| Root | NACA 27-010 |
| Tip | NACA 27-008 |
| Fuselage: | |
| Length, ft | 37.8 |
| Fineness ratio | 9.5 |
| Landing gear: | |
| Surface area of main skid, sq in. | 360 |
| Airplane weight, lb | 10,463 |
| Center-of-gravity location, percent M.A.C. | 23.66 |

TABLE II

SUMMARY OF PERTINENT QUANTITIES OBTAINED IN LANDINGS DURING THE GLIDE-FLIGHT PROGRAM OF THE BELL X-2 RESEARCH AIRPLANE

| | Quantities | Flight 1 | Flight 2 | Flight 3 |
|---|---|---|---|---|
| Geometric altitude, 50 ft | $V_i$, mph | ----- | 230 | 228 |
| | $V_v$, fps | ----- | -11 | -19 |
| | s, ft | ----- | 3640 | 4400 |
| | $C_{N_A}$ | ----- | 0.39 | 0.33 |
| Contact | $V_i$, mph | 142 | 169 | 185 |
| | $V_v$, fps | ----- | -1.7 | -1.5 |
| | $C_{N_A}$ | 0.77 | 0.71 | 0.46 |
| | $\alpha$, deg | 6.0 | 2.3 | 3.6 |
| | *$\delta_{f_{TE}}$, deg | 28 | 38 | 0 |
| Ground run | Average $A_X$, g | -0.67 | -0.30 | -0.30 |
| | Nose-wheel contact normal acceleration, g | 4.0 | 2.7 | 2.8 |
| | Distance, ft | 1010 | 3340 | 3713 |
| | Duration, sec | 10.0 | 28.4 | 29.6 |

*Leading-edge flaps were deflected 15° for flights 1 and 3; for flight 2 the right leading-edge flap was locked down 15° and the left leading-edge flap was inadvertently at 0°.

[redacted]

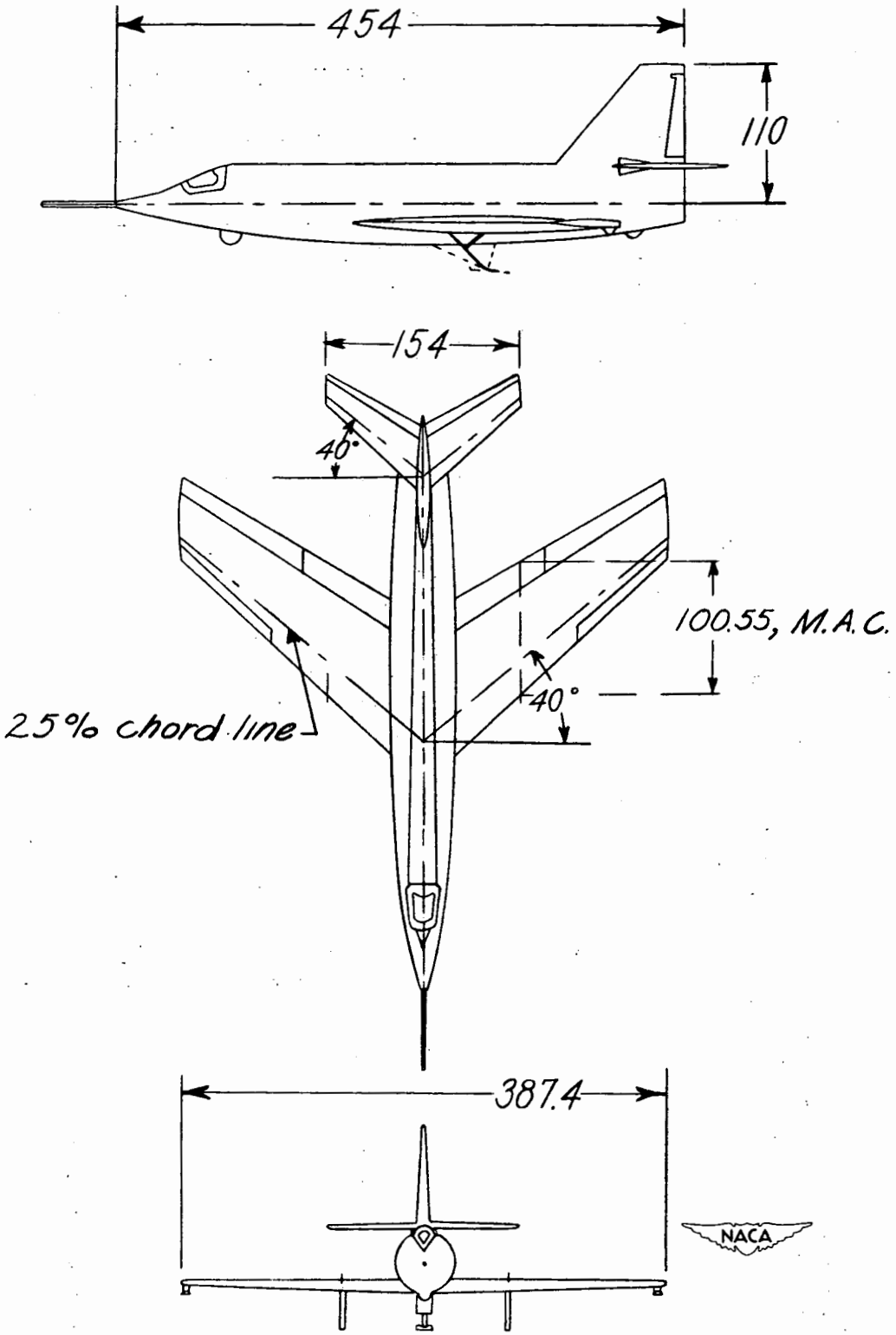



Figure 1.- Three-view drawing of the Bell X-2 research airplane. All linear dimensions are in inches.

[redacted]

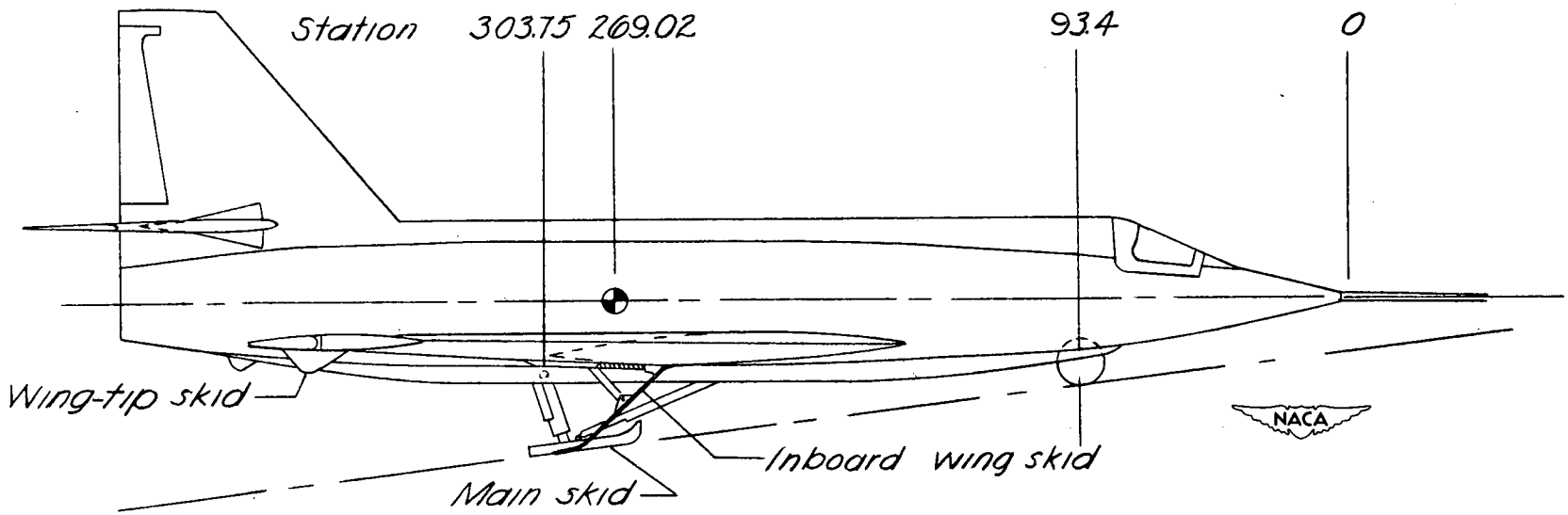
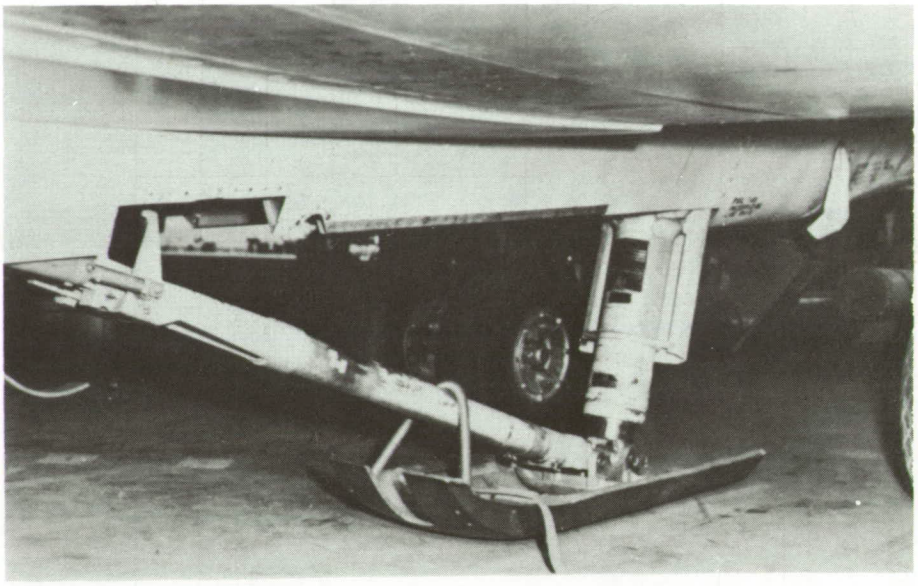



Figure 2.- Drawing showing the modified landing gear on the Bell X-2 research airplane.

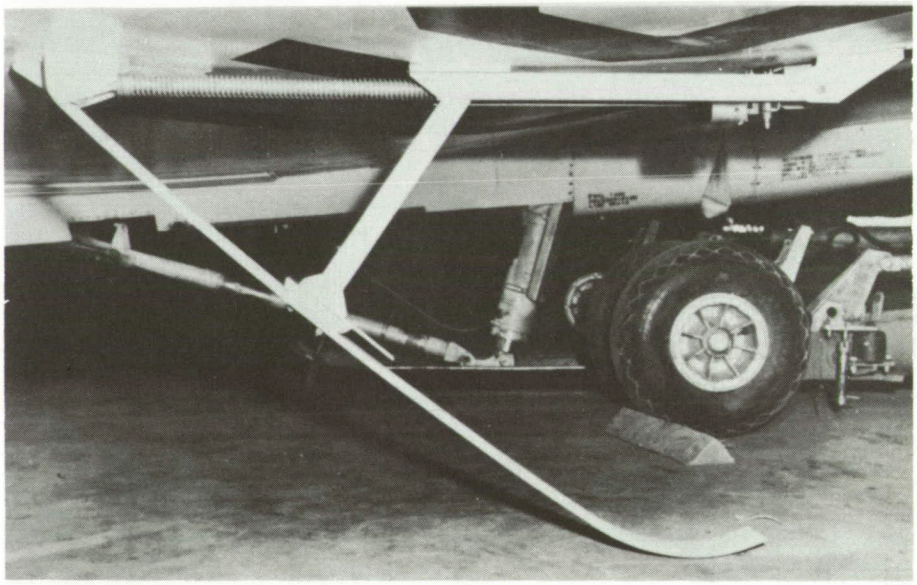



L-80237

Figure 3.- Photograph of the Bell X-2 research airplane in the normal ground attitude.



(a) Modified main landing skid.



(b) Extended inboard wing skid. L-80238

Figure 4.- Photographs of landing skids of Bell X-2 airplane. (The wheels appearing in these photographs are a part of the ground handling dolly.)

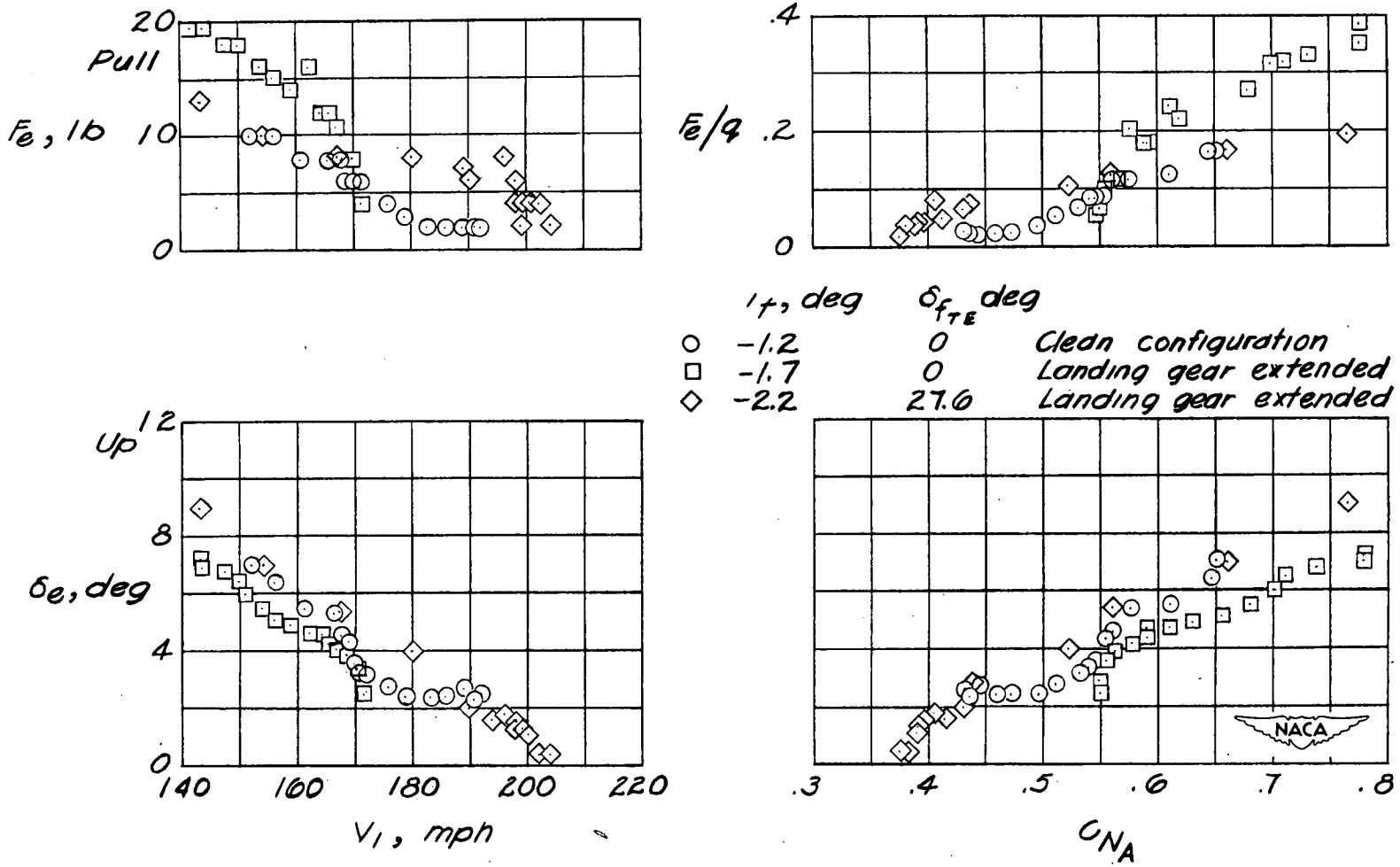



Figure 5.- Elevator stick force and elevator control position required for trim as a function of indicated airspeed and airplane normal-force coefficient as measured in approaches to unaccelerated stalls. Bell X-2 airplane.

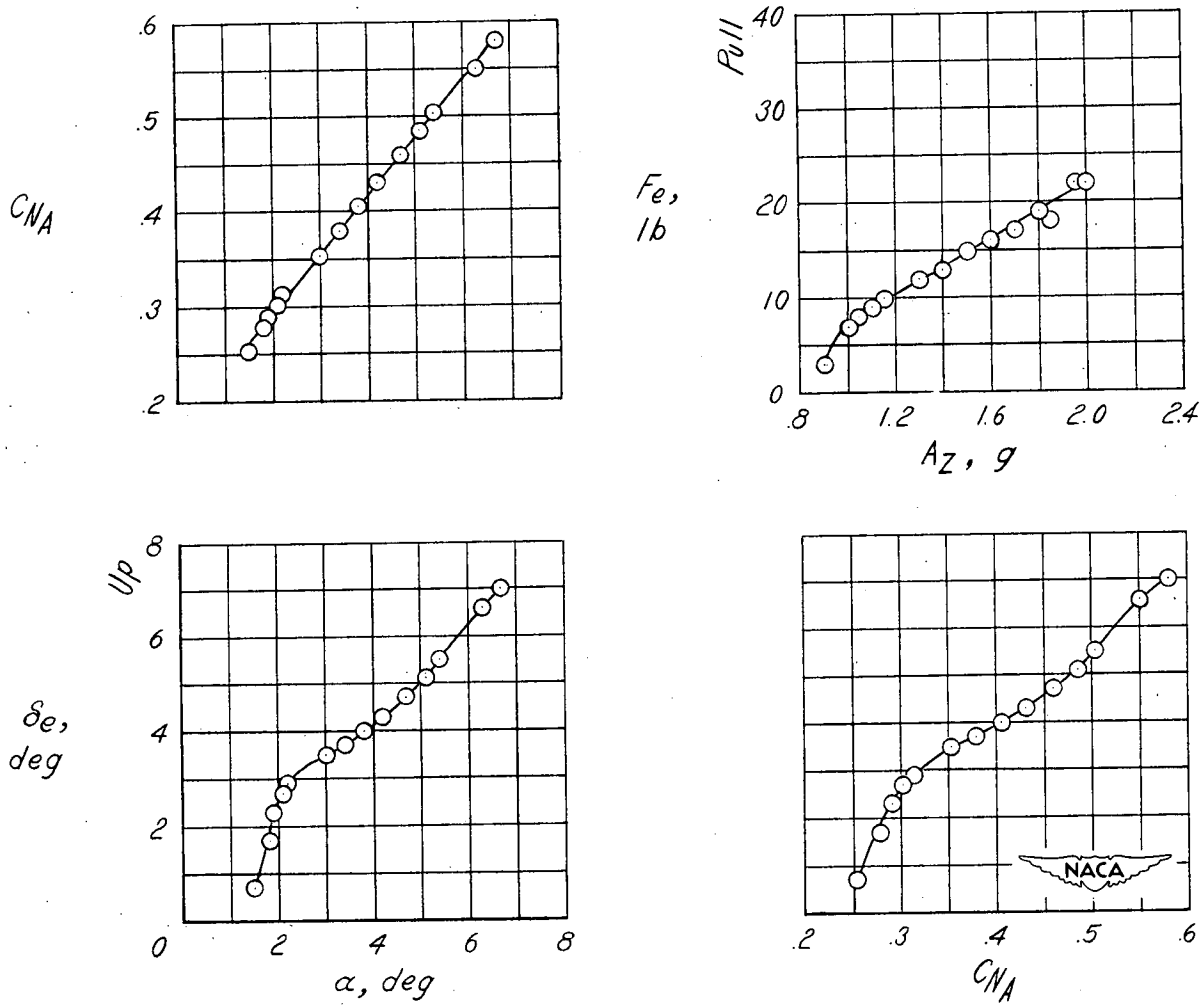



Figure 6.- Static longitudinal stability characteristics in accelerated flight of the Bell X-2 airplane in the clean condition. $V_i \approx 235$ mph; $i_t = -0.7°$.

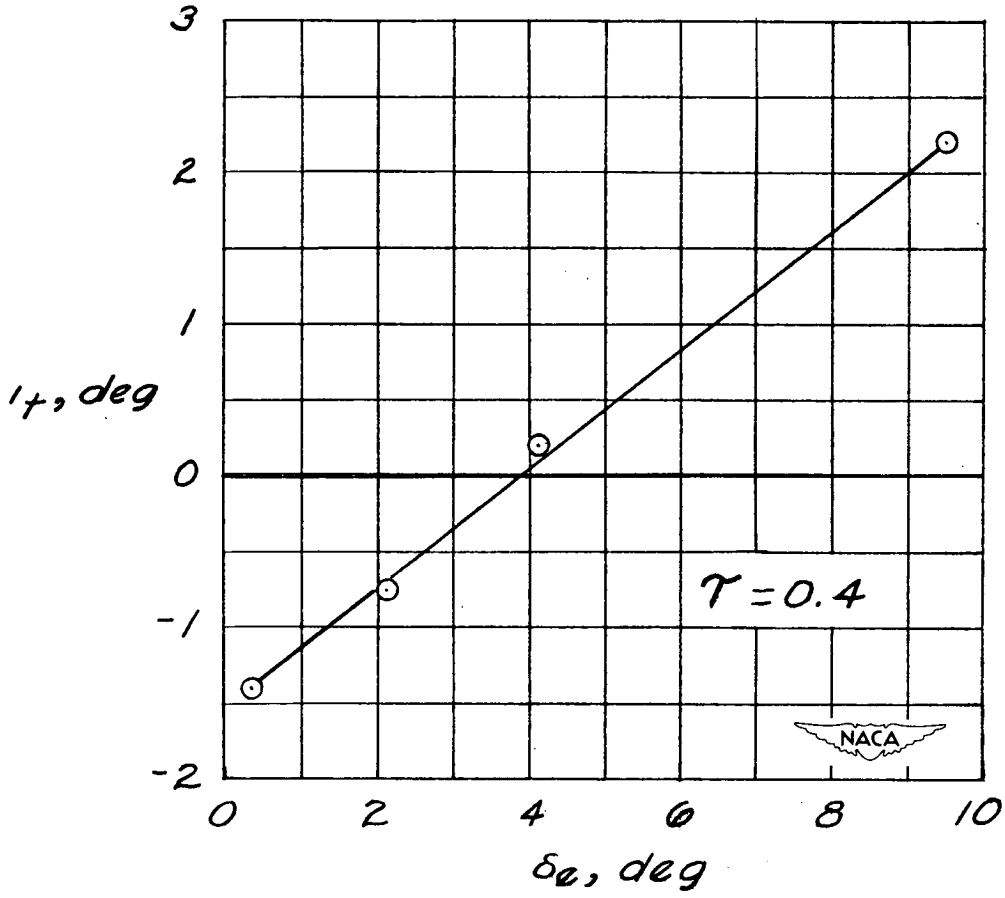



Figure 7.- Variation of elevator deflection required for trim with stabilizer incidence. Bell X-2 airplane. $\delta_{f_{TE}} = 0^\circ$; $V_i \approx 230$ mph; $C_{N_A} = 0.28$.

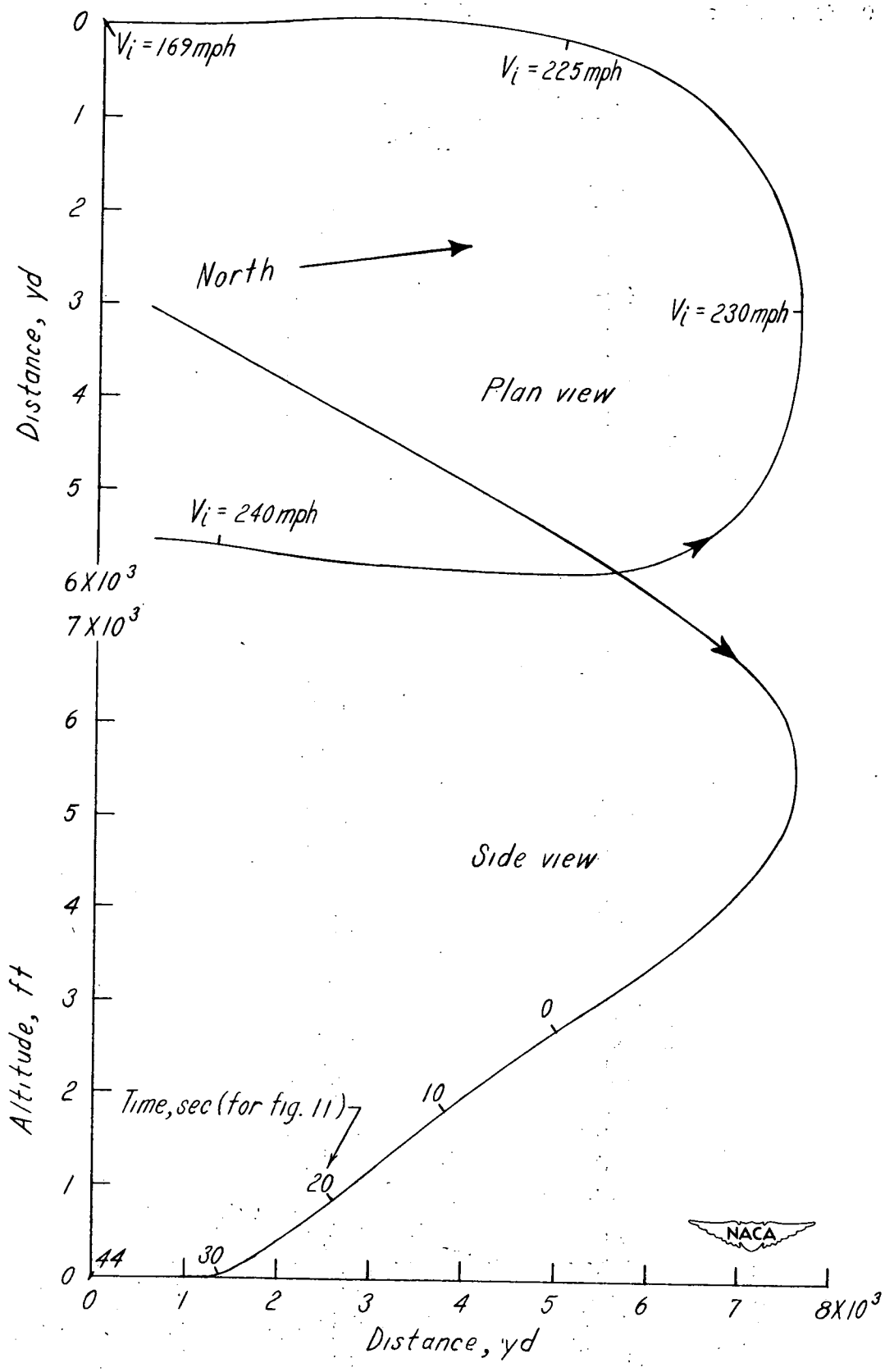



Figure 8.- Landing approach pattern as obtained by radar for glide flight 2 of the Bell X-2 research airplane.

[redacted]

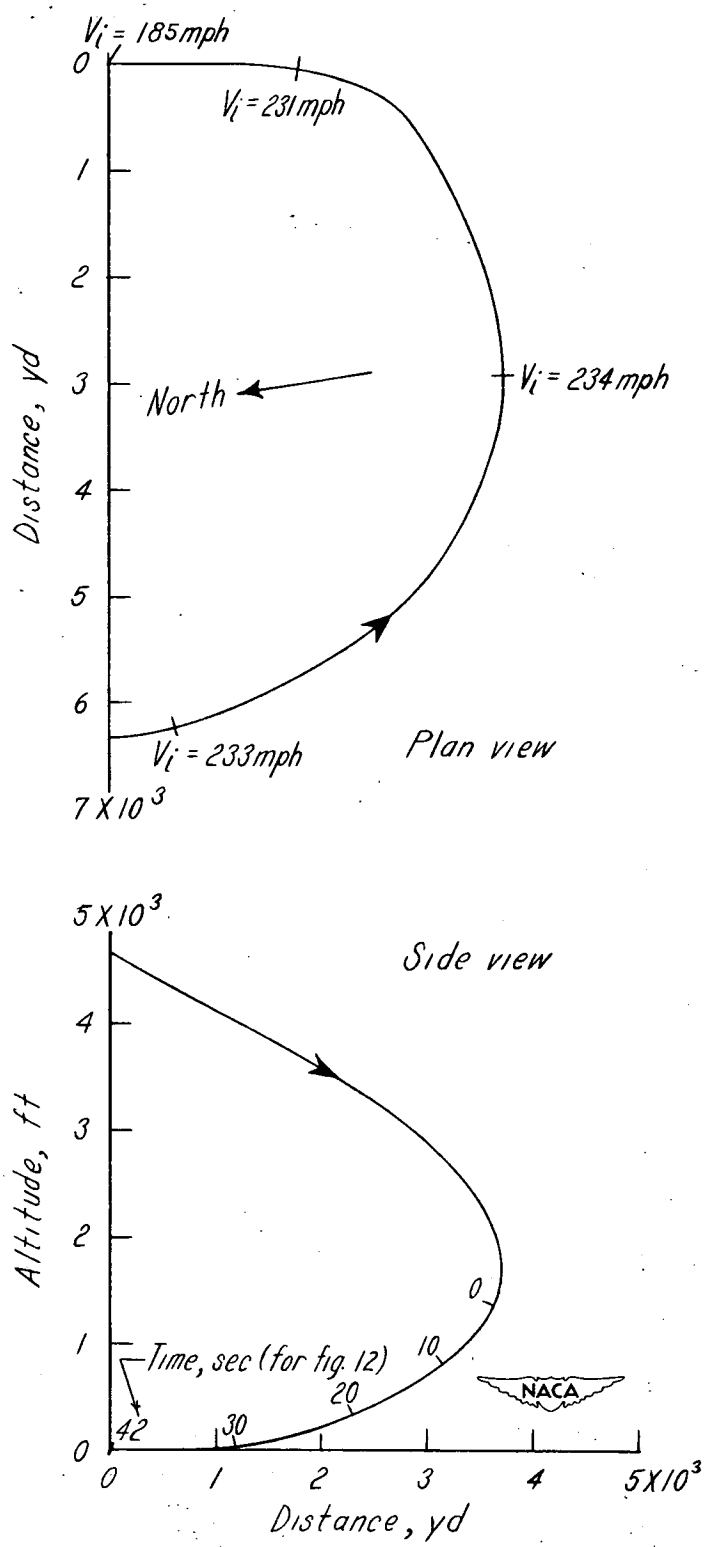



Figure 9.- Landing approach pattern as obtained by radar for glide flight 3 of the Bell X-2 research airplane.

[redacted]

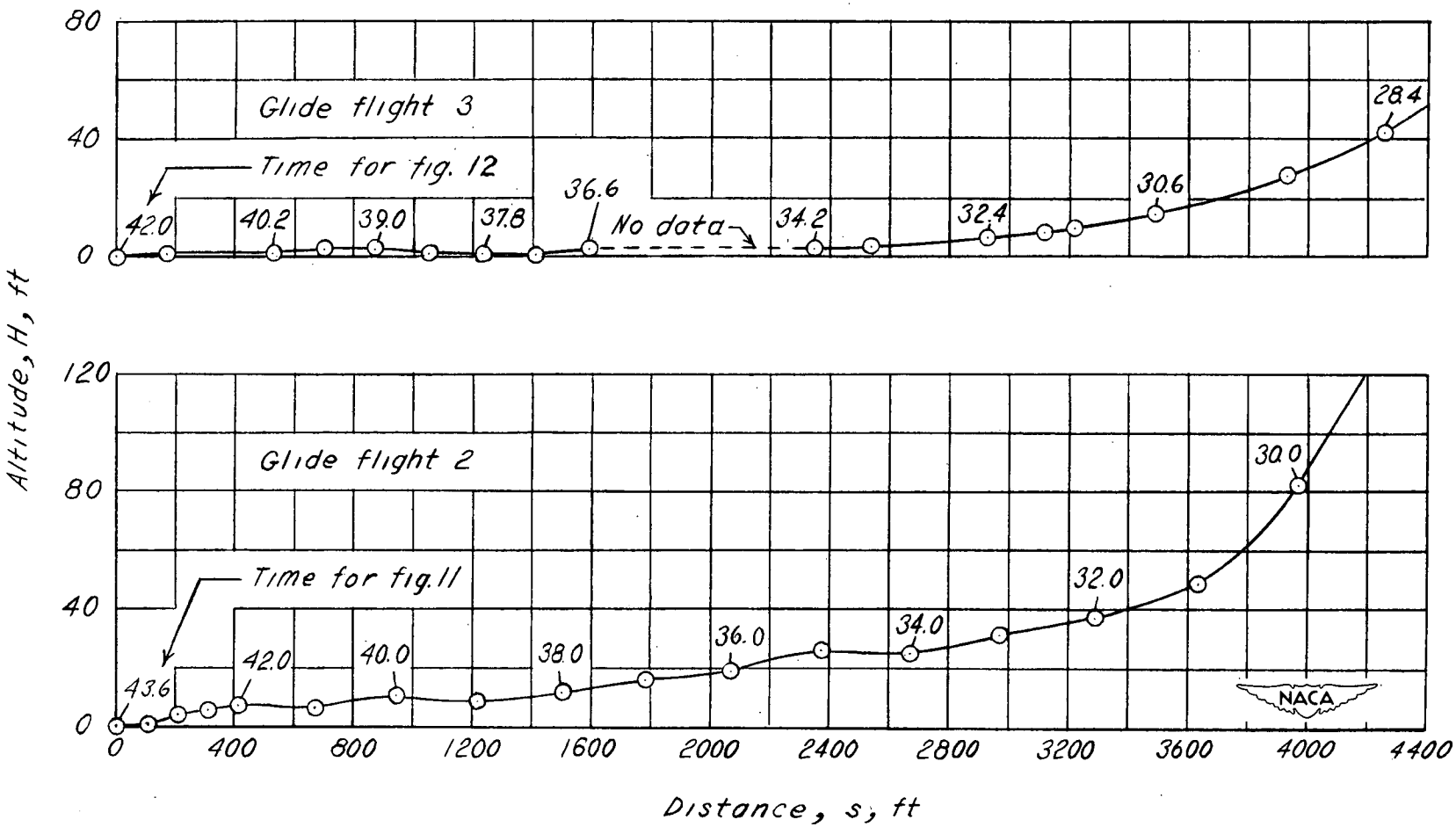



Figure 10.- Glide path during final approach to landing of glide flights 2 and 3. Bell X-2 airplane.

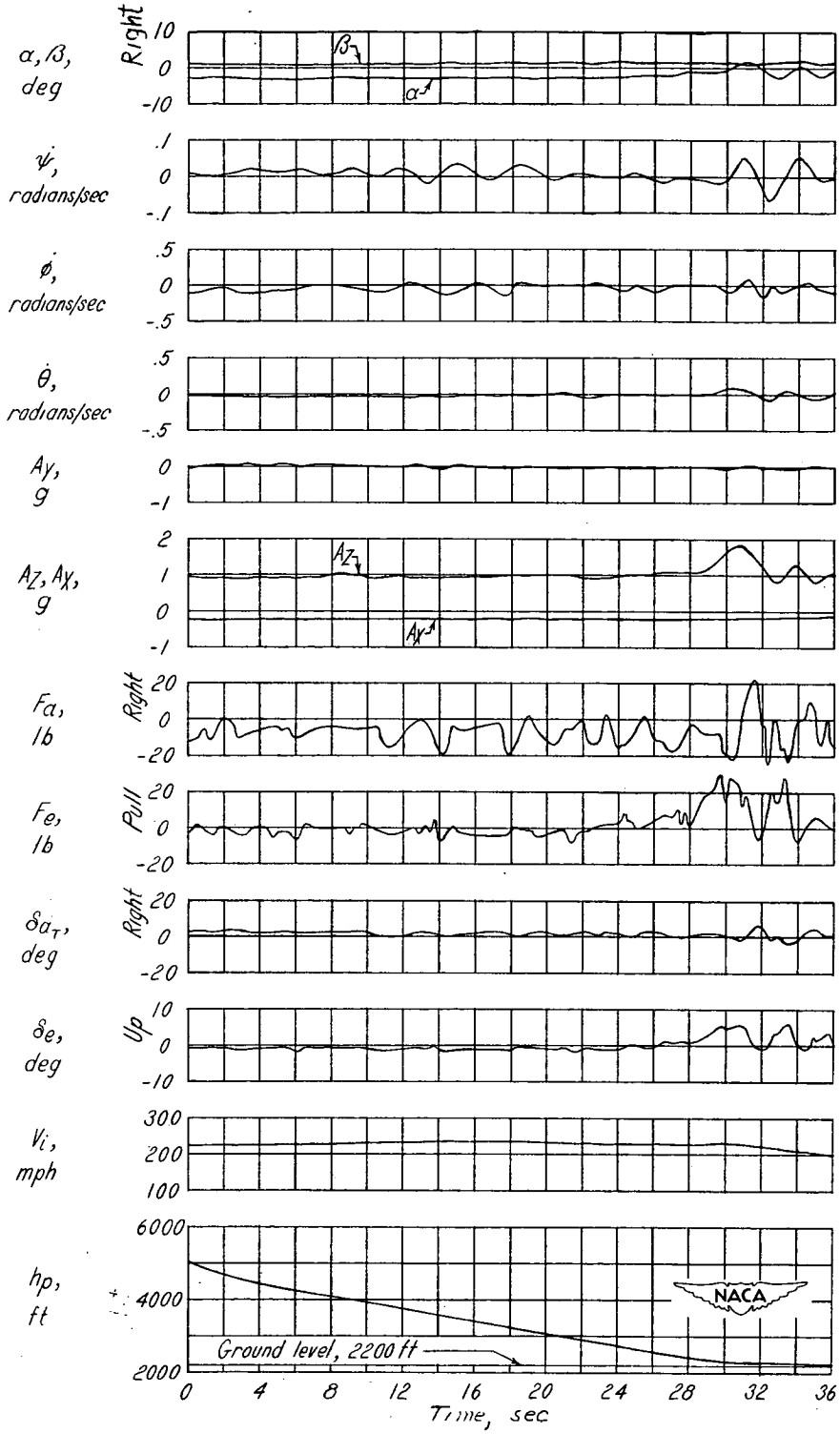



Figure 11.- Time history of landing of glide flight 2. Bell X-2 research airplane. $\delta f_{TE} = 38^{\circ}$; $i_t = -2.5^{\circ}$; weight = 10,463 lb.

[redacted]

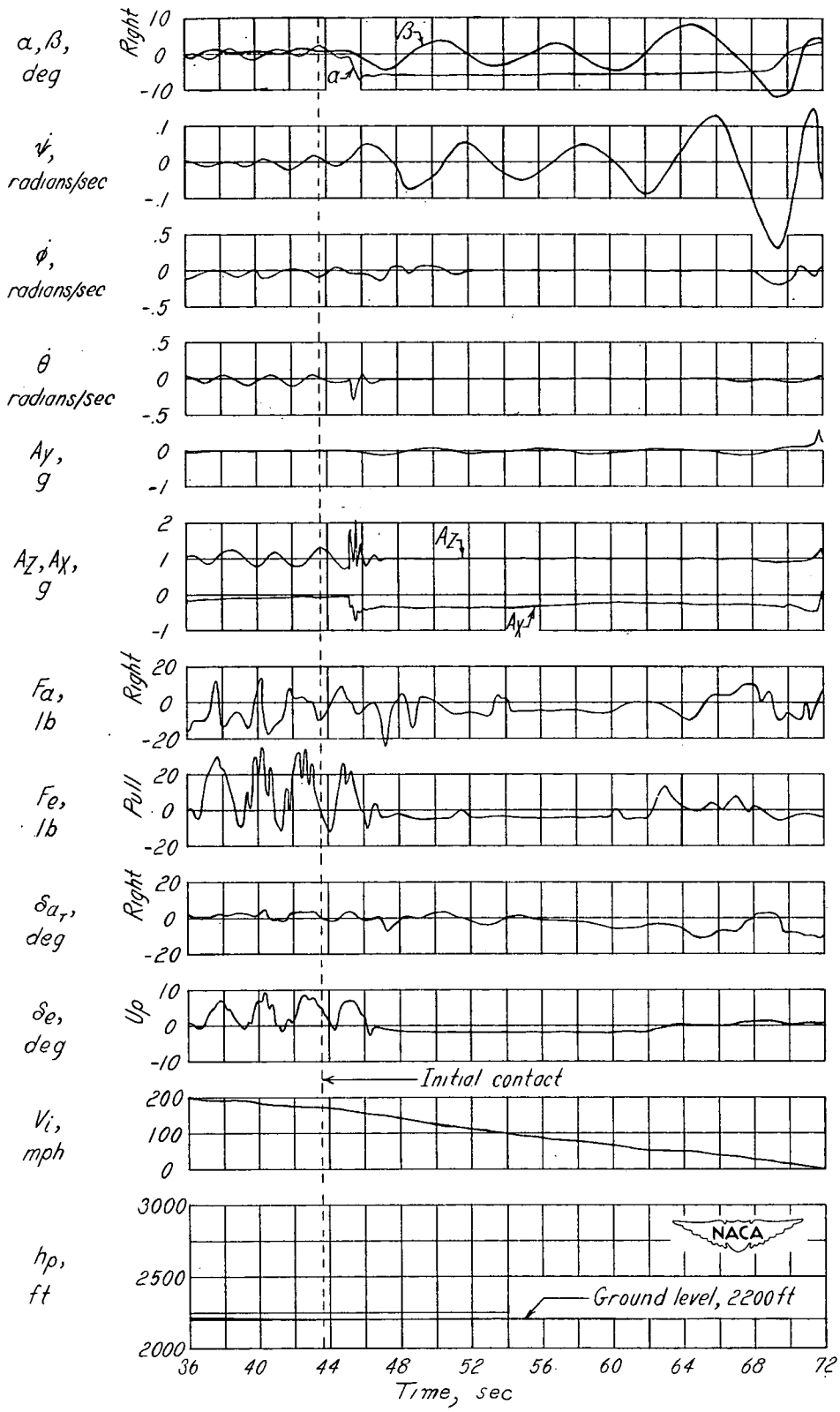



Figure 11.- Concluded.

[redacted]

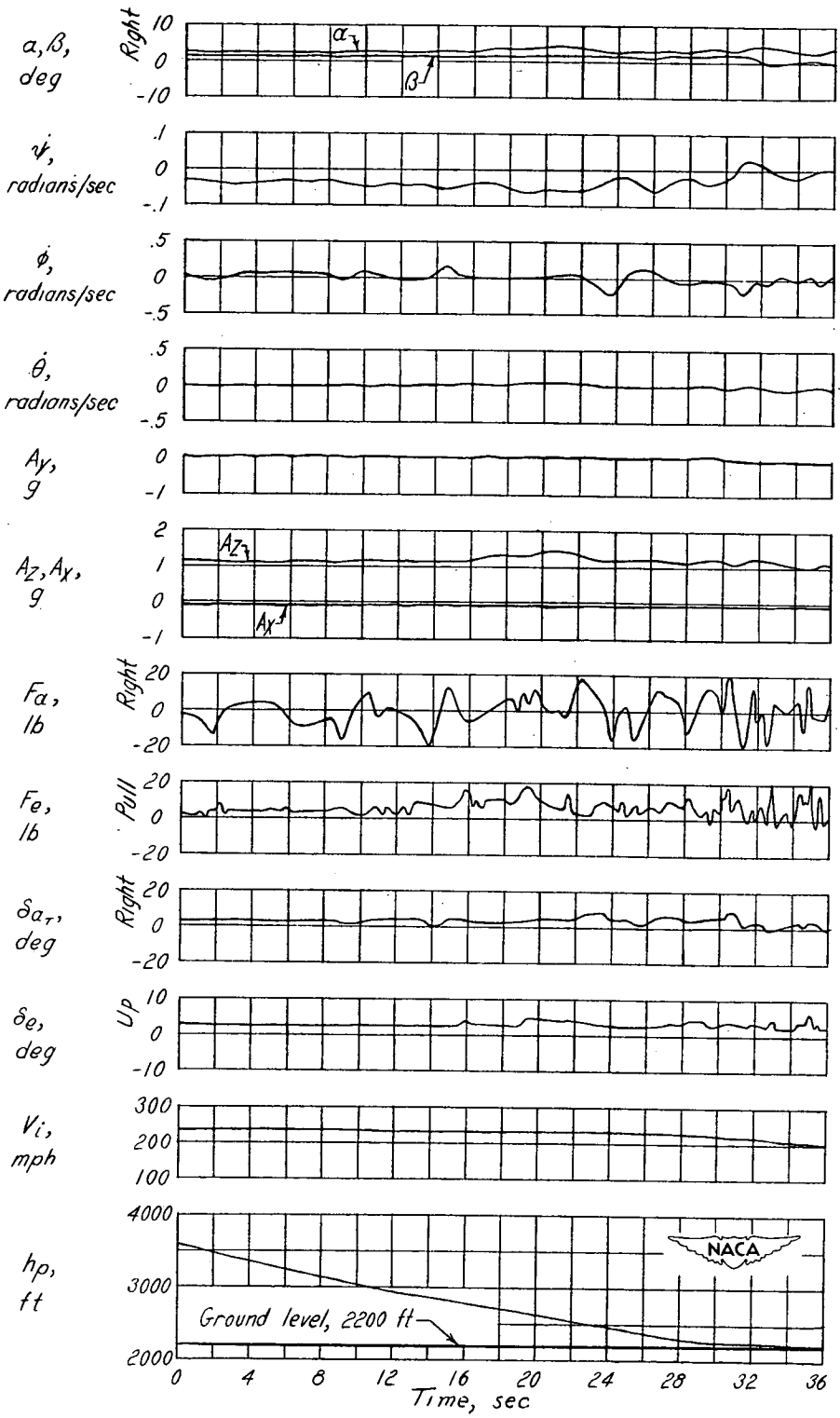



Figure 12.- Time history of landing of glide flight 3. Bell X-2 research airplane. $\delta_{f_{TE}} = 0^{\circ}$; $i_t = 0.7^{\circ}$; weight = 10,463 lb.

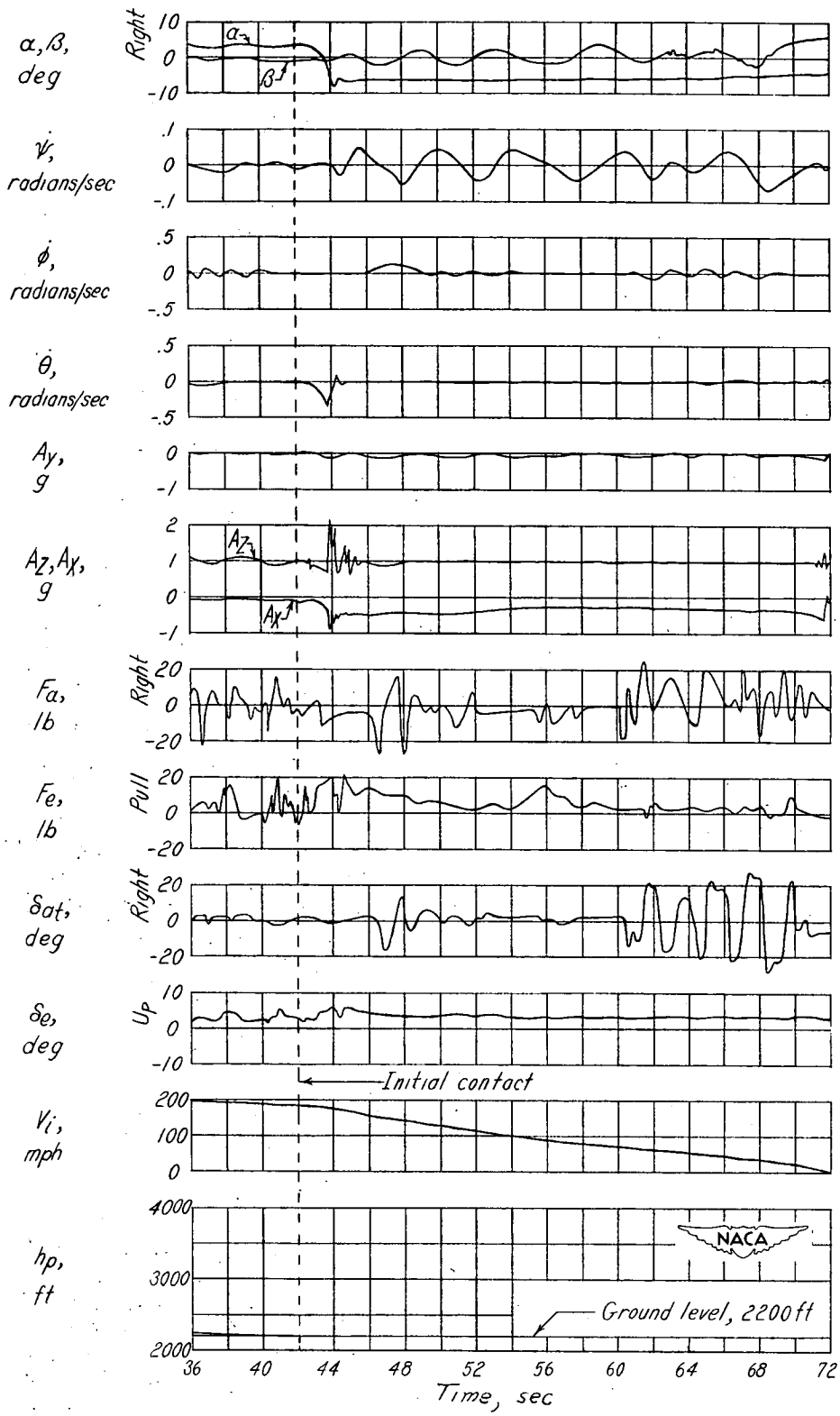



Figure 12.- Concluded.



L-80239

Figure 13.- Rear-view photograph of Bell X-2 airplane showing main skid, inboard wing skids, and skid marks left on the surface of the dry-lake bed.