NASA TM X-207

N-05
401

TECHNICAL MEMORANDUM

X-207

MEASUREMENTS OBTAINED DURING THE FIRST LANDING OF THE NORTH AMERICAN X-15 RESEARCH AIRPLANE

By James M. McKay

High-Speed Flight Station
Edwards, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON

October 1959
Declassified April 12, 1961

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-207

MEASUREMENTS OBTAINED DURING THE FIRST LANDING OF THE NORTH AMERICAN X-15 RESEARCH AIRPLANE*

By James M. McKay

SUMMARY

The first landing of the X-15 airplane was made at 8:43 a.m., June 8, 1959, on the hard surface of Rogers Dry Lake. One purpose of the first glide flight was to evaluate the effectiveness of the landing-gear system. Some results are presented of the landing-approach characteristics, the impact period, and the runout phase of the landing maneuver.

The results indicate that the touchdown was accomplished at a vertical velocity of 2.0 feet per second for the main gear and 13.5 feet per second for the nose gear. These vertical velocities were within the values of sinking speeds established by structural design limitations. However, permanent structural deformation occurred in the main-landing-gear system as a result of the landing, and a reevaluation of the gear is being made by the manufacturer.

The landing occurred at a true ground speed of 158 knots for main-gear touchdown at an angle of attack of 8.5°. The incremental acceleration at the main gear was 2.7g and 7.3g at the nose gear as a result of the landing. The incremental acceleration at the center of gravity of the airplane was 0.6g for the main-gear impact and 2.4g for the nose-gear impact. The incremental acceleration at the main gear as a result of the nose-gear impact was 4.8g.

The extreme rearward location of the main-gear skids appears to offer satisfactory directional stability characteristics during the runout phase of the landing. No evidence of nosewheel shimmy was indicated during the impact and runout phase of the landing despite the absence of a shimmy damper on the nose gear.

The maximum amount of skid wear as a result of the landing was on the order of 0.005 inch. No appreciable amount of tire wear was indicated for the dual, corotating nosewheels.

---

*Title, Unclassified.

INTRODUCTION

The approach and landing operation of unpowered rocket airplanes has always required considerable pilot concentration, but has usually been accomplished with a relatively conventional procedure. The X-15 airplane lands in a range of lift-drag ratio markedly lower than previous airplanes have used. Because of the high sinking speeds associated with the low lift-drag ratio of the X-15 airplane in the landing configuration, and because of other performance and operational requirements of the X-15, a landing-gear system was incorporated which would meet these requirements and would expend a minimum of airplane space and weight.

This paper presents preliminary data from the first landing and compares these data with some requirements of the landing-gear system.

SYMBOLS

a_l	center-of-gravity longitudinal acceleration, g units
a_n	center-of-gravity normal acceleration, g units
a_v	main- and nose-gear incremental vertical acceleration, g units
C_L	airplane lift coefficient
g	acceleration due to gravity, ft/sec^2
h	geometric altitude, ft
L/D	lift-drag ratio
q	pitching velocity, radians/sec
t	time, sec
V	true ground velocity, knots
V_i	indicated airspeed, knots
V_v	vertical velocity, ft/sec
α	angle of attack, deg

β angle of sideslip, deg

δ_h horizontal-tail deflection, deg

δ_s longitudinal side-located-stick position

AIRPLANE

The X-15 airplane (figs. 1 and 2) is an experimental research aircraft designed to explore the flight regime at hypersonic speeds up to 6,600 feet per second and altitudes up to 250,000 feet and above. The airplane was designed by North American Aviation, Inc., through the cooperative effort of the U. S. Air Force, the U. S. Navy, and the National Aeronautics and Space Administration. Physical characteristics of the airplane are given in table I and reference 1.

The landing-gear configuration is basically an arrangement consisting of a conventional dual-wheel nose gear located well forward and a main gear equipped with steel skids located under the tail. A schematic drawing of the main-landing-gear system is shown in figure 3(a), and a side view of the left main skid in the extended position is shown in figure 3(b). The nose gear is shown in figure 4 with the shock strut in the fully extended position. This particular nosewheel configuration was chosen to provide roll stability on the ground. The extreme rearward location of the main gear proved, from dynamic model tests, to provide more stability than with the main gear mounted close to the center of gravity of the airplane.

The cantilevered, Inconel strut legs and the drag braces of the main gear are attached to the fuselage by means of trunnion fittings, and the struts are attached to oleopneumatic-type shock absorbers which are installed within the fuselage. Each shock absorber has a total deflection of 2.577 inches and is serviced to an inflation pressure of 750 psi with the struts in an extended position. The two 6-inch-wide, 3-foot-long skids, fabricated from 4130 steel, are normalized and are universally mounted in two planes to allow for pitching and rolling motion, but are restrained from yawing to provide the necessary parallel alinement of the two skids. The drag braces are attached to the skid ahead of the main pivot joint to allow the nose of the skid to lift and improve the planing action.

Corotating, dual wheels were installed on the nose gear to prevent shimmy. The VII-type nose-gear tires are 18×4.4 in size with a rating of 8 ply. The tires are inflated to a pressure of 185 psi and have a rolling radius of 8 inches at this inflation pressure. The nosewheel shock strut is of the oleopneumatic type and has a total travel of 18 inches. The nose-gear shock strut is inflated to a pressure of 184 psi in the fully extended position.

INSTRUMENTATION

The following information pertinent to the landing investigation was recorded on NASA airborne recording instruments synchronized by a common timer:

Airspeed

Normal and longitudinal acceleration at airplane center of gravity

Vertical acceleration at nose of airplane close to nose-gear trunnion fitting

Vertical acceleration at tail of airplane directly above right main gear

Angle of attack

Angle of sideslip

Horizontal-tail position

Pitching velocity

Flap deflection

Airspeed was measured with an NASA pitot-static tube mounted on the end of the nose boom. Free-floating vanes also mounted on the nose boom were used to measure angles of attack and sideslip.

Askania Cine-Theodolite cameras and an Air Force Missile Test Center Model II tracking radar furnished photo coverage of the X-15 airplane from launch from the B-52 mother airplane to touchdown on the lakebed. Akeley phototheodolite cameras tracked the airplane from a height of approximately 80 feet above the runway through touchdown and final landing runout. From this photo coverage such information as landing coordinates, airplane altitude, flight-path velocity, vertical velocity at landing, and distance covered by the airplane along the runway was obtained.

TESTS

The first landing of the X-15 airplane was made at 8:43 a.m., June 8, 1959, on a designated strip 6.8 miles long on the hard lakebed of Rogers Dry Lake at Edwards Air Force Base, Calif. The landing was made in clear weather to the north with little or no wind over the lakebed. The outside air temperature at the time of the landing was 70.4° F. The touchdown weight of the airplane was 13,234 pounds, and the center of gravity in the landing configuration was 17.4 percent of the mean aerodynamic chord.

The airplane was flown by a North American Aviation experimental test pilot who had "flown" the first glide flight many times previously on an analog simulator and in flight-test programs using modified operational aircraft. The airplane was flown from launch to touchdown on the lakebed by using only the side-located-stick control. Escort airplanes accompanied the X-15 through the landing approach, touchdown, and runout phase of the landing on the lakebed and informed the pilot of airspeed and altitude during the approach and landing.

RESULTS AND DISCUSSION

A comprehensive discussion of the launch, low-speed, and landing-approach characteristics during the first glide flight of the X-15 airplane is presented in reference 1. To provide background information, however, some of the pertinent details of the approach to the actual landing are included herein.

The flight plan representing the geographical path of the X-15 airplane from launch to touchdown on the lakebed is shown in figure 5. The landing pattern of the first glide flight is shown in figure 6 in terms of distances away from the touchdown point, which is designated as 0 sec. The turn into the final segment of the approach was completed at an altitude of approximately 1,500 feet where the initial flare was started about 30 seconds before touchdown. The flap cycle was initiated at an altitude of approximately 700 feet, and the flaps were fully down at an altitude of about 200 feet. The landing gear was then lowered and was down and locked at an altitude of about 80 feet. The oscillations indicated in figure 7 at 18 seconds prior to touchdown became so severe and were of such magnitude that increased pilot concentration was required in performing the landing maneuver.

Figure 8 presents some values of lift-drag ratio obtained from the first landing. The values shown are for the landing configuration and are only for conditions in which the longitudinal pitching velocity resulting from the pitching oscillations encountered is a minimum. A plot of some values obtained from wind-tunnel tests is also shown for comparison. There appears to be a reasonable correlation between the flight and wind-tunnel values.

Some of the quantities measured during the landing are presented in figures 9 to 11 as a variation with time from impact. The data in figures 9 and 10 are presented for a period of several seconds prior to initial main-gear touchdown, the impact period, and for a small interval of time after nose-gear touchdown. The nose- and main-gear upper-mass accelerations at touchdown and during a short period of the ground run are shown in figure 11. It can be seen from these time histories that just prior to touchdown the airplane experienced an increase in angle of attack to approximately 12° (fig. 9(b)) as a result of the associated pitching oscillations. As a consequence, the forward speed reduced to approximately 158 knots true ground speed at touchdown (fig. 10). The angle of attack of the airplane was approximately 8.5° (fig. 9(c)) at the time of initial touchdown. Just prior to ground contact the center-of-gravity vertical acceleration was of the order of 1.4g and the vertical velocity at main-gear touchdown was approximately 2 feet per second.

An analysis of the accelerometer records (fig. 11) indicates an incremental acceleration of 2.7g for the main-gear touchdown measured in the airplane upper mass directly above the right main gear. The incremental acceleration as a result of the nose-gear touchdown measured at a position in the airplane upper mass next to the nose-gear trunnion fitting was 7.3g. The incremental acceleration at the main-gear-accelerometer position as a result of the nose-gear impact was 4.8g. The response at the center of gravity of the airplane due to main-gear impact (fig. 9(c)) was an incremental acceleration of 0.6g and 2.4g as a result of the nose-gear touchdown.

The airplane first contacted the lakebed on the left main skid as shown in figure 12 and table II. The second and final touchdown of the left main skid was made 15 feet down the runway from the initial skid mark. The right main skid first contacted the lakebed 24.6 feet down the runway from the initial left main-skid touchdown point. The right main skid then contacted and remained on the lakebed 37 feet down the runway from the initial left main-skid mark. The nose-gear touchdown occurred 0.52 second later at a vertical velocity of approximately 13.5 feet per second at a point 187 feet down the runway from the left main-gear initial skid mark. A closeup view of the nose-gear touchdown marks is shown in figure 13(a), and a diagram of the skid marks is shown in figure 13(b).

An inspection of the airplane after the landing indicated that damage had occurred in the main-landing-gear system to the bell-crank arm connecting the main-gear strut leg to the oleopneumatic shock strut.

The damage occurred in both the left and right main gears, with the greatest damage incurred by the right gear. The bell-crank arms experienced permanent deformation in bending, thus allowing the gear to spread beyond the maximum designed tread as indicated from measurements of the landing skid marks (fig. 12). As a result of the damage, a reevaluation of the main-landing-gear system is being made by the manufacturer.

Photographs of the main-gear skids and nosewheel marks on the lakebed are shown in figure 14(a) for a distance of approximately 300 feet from touchdown and in figure 14(b) toward the end of the landing run.

The skid marks shown in figure 14(b) indicate that toward the end of the runout phase of the landing the airplane veered to the right. It is believed that the nature of the damage to the main-landing-gear system allowed the airplane to assume this particular path. However, in spite of the damage to the main gear, the skid marks on the lakebed after the impact period indicated satisfactory directional stability characteristics. No evidence of nosewheel shimmy was indicated during the impact and runout phase of the landing (figs. 13(a) and 14(a)) despite the absence of a shimmy damper on the nose gear. Tests made previously by the NASA on the landing track at Langley Research Center during some high-speed ground runs with the X-15 nose gear without a shimmy damper had indicated the absence of shimmy. As a result, the shimmy damper was removed from the nose gear of the X-15 airplane prior to the first glide flight. The depth of the main- and nose-gear marks on the lakebed resulting from the impact and runout phase of the landing were too small in magnitude to be measured. A closeup view of a typical main-gear skid mark is shown in figure 14(c).

The maximum amount of skid wear as indicated from measurements taken before and after flight (table III) was on the order of 0.005 inch for both main-gear skids. This occurred in the vicinity of the trunnion fitting connecting the skid to the cantilevered strut leg. No appreciable amount of tire wear was indicated on the dual, corotating nosewheels after the landing (fig. 15(a)). Tire slippage resulting from the landing was 9/16 of an inch with respect to the wheel rim on the left nosewheel (fig. 15(b)). No apparent slippage of the tire was indicated for the right nosewheel.

Figure 16, prepared from unpublished data, presents the variation of vertical velocity with time for the X-15 nose gear as dictated by structural design limitations. The design limits are based on a minimum approach speed of 164 knots indicated at an airplane attitude angle of 6° and an overall airplane vertical velocity of 9 feet per second. At main-gear touchdown, the nose-gear vertical velocity increases to a value of 18 feet per second, at which time nose-gear touchdown occurs. The vertical velocity of the nose gear then reaches a value of zero in the time indicated on the design-limited envelope. If the overall airplane vertical velocity is less than the limit design value of 9 feet per second, the nose gear would also touch down at a vertical velocity less than its design limit of 18 feet per second, and, consequently, the time for the nose gear to touch down after main-gear impact would be greater. As can be seen from figure 16, the actual landing occurred at a vertical velocity of about 2 feet per second for the main gear. The nose-gear touchdown occurred 0.52 second later at a vertical velocity of about 13.5 feet per second.

CONCLUSIONS

The principal conclusions resulting from this preliminary evaluation of data obtained during the first landing of the X-15 airplane are:

1. The touchdown was accomplished at a vertical velocity of 2.0 feet per second for the main gear and 13.5 feet per second for the nose gear. These vertical velocities were within the values of sinking speeds established by structural design limitations. However, permanent structural deformation occurred in the main-landing-gear system as a result of the landing, and a reevaluation of the gear is being made by the manufacturer.

2. The landing occurred at a true ground speed of 158 knots for main-gear touchdown at an angle of attack of 8.5°. The incremental acceleration at the main gear was 2.7g and 7.3g at the nose gear as a result of the landing. The incremental acceleration at the center of gravity of the airplane was 0.6g for the main-gear impact and 2.4g for the nose-gear impact. The incremental acceleration at the main gear as a result of the nose-gear impact was 4.8g.

3. The extreme rearward location of the main-gear skids appears to offer satisfactory directional stability characteristics during the runout phase of the landing. No evidence of nosewheel shimmy was indicated during the impact and runout phase of the landing despite the absence of a shimmy damper on the nose gear.

4. The maximum amount of skid wear as a result of the landing was on the order of 0.005 inch. No appreciable amount of tire wear was indicated for the dual, corotating nosewheels.

High-Speed Flight Station,
National Aeronautics and Space Administration,
Edwards, Calif., September 18, 1959.

REFERENCE

1. Finch, Thomas W., and Matranga, Gene J.: Launch, Low-Speed, and Landing Characteristics Determined From the First Flight of the North American X-15 Research Airplane. NASA TM X-195, 1959.

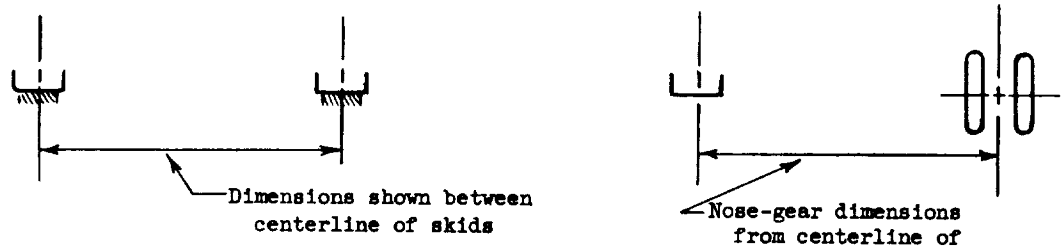
TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRPLANE

Wing:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 94.98 sq ft covered by fuselage), sq ft	200
Span, ft	22.36
Mean aerodynamic chord, ft	10.27
Root chord, ft	14.91
Tip chord, ft	2.98
Taper ratio	0.20
Aspect ratio	2.50
Sweep at 25-percent-chord line, deg	25.64
Incidence, deg	0
Dihedral, deg	0
Aerodynamic twist, deg	0
Flap -	
Type	Plain
Area (each), sq ft	8.30
Span (each), ft	4.50
Inboard chord, ft	2.61
Outboard chord, ft	1.08
Deflection, down, deg	40
Ratio flap chord to wing chord	0.22
Ratio total flap area to wing area	0.08
Ratio flap span to wing semispan	0.40
Trailing-edge angle, deg	5.67
Sweepback angle of hinge line, deg	0
Horizontal tail:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 63.29 sq ft covered by fuselage), sq ft	115.34
Span, ft	18.08
Mean aerodynamic chord, ft	7.05
Root chord, ft	10.22
Tip chord, ft	2.11
Taper ratio	0.21
Aspect ratio	2.83
Sweep at 25-percent-chord line, deg	45
Dihedral, deg	-15
Ratio horizontal-tail area to wing area	0.58
Movable surface area, sq ft	51.77
Deflection -	
Longitudinal, up, deg	15
Longitudinal, down, deg	35
Lateral differential (pilot authority), deg	±15
Lateral differential (autopilot authority), deg	±30
Control system	Irreversible hydraulic boost with artificial feel
Upper vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	40.91
Span, ft	4.58
Mean aerodynamic chord, ft	8.95
Root chord, ft	10.21
Tip chord, ft	7.56
Taper ratio	0.74
Aspect ratio	0.51
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.20
Movable surface area, sq ft	26.45
Deflection, deg	±7.50
Sweepback of hinge line, deg	0
Control system	Irreversible hydraulic boost with artificial feel

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRPLANE - Concluded

Lower vertical tail:		
Airfoil section	10° single wedge	
Total area, sq ft	34.41	
Span, ft	3.83	
Mean aerodynamic chord, ft	9.17	
Root chord, ft	10.21	
Tip chord, ft	8	
Taper ratio	0.78	
Aspect ratio	0.43	
Sweep at 25-percent-chord line, deg	23.41	
Ratio vertical-tail area to wing area	0.17	
Movable surface area, sq ft	19.95	
Deflection, deg	±7.50	
Sweepback of hinge line, deg	0	
Control system	Irreversible hydraulic boost with artificial feel	
Fuselage:		
Length, ft	50.75	
Maximum width, ft	7.33	
Maximum depth, ft	4.67	
Maximum depth over canopy, ft	4.97	
Side area (total), sq ft	215.66	
Fineness ratio	10.91	
Main landing gear:		
Type	Two (6 in. wide, 3 ft long) skids	
Shock strut	Oleopneumatic (inside fuselage)	
Strut-inflation pressure, psi	750 (fully extended)	
Shock-strut stroke, in.	2.577	
Tread distance, ft	8.83	
Nose landing gear:		
Tire type	VII	
Tire size	18 × 4.4	
Ply rating	8	
Rolling radius, in.	8	
Wheels	Dual, corotating	
Tire pressure, psi	185	
Shock strut	Oleopneumatic	
Strut-inflation pressure, psi	184 (fully extended)	
Shock-strut stroke, in.	18	
Airplane attitude:		
Oleo static	-2° 21'	
Oleo extended	-1° 20'	
Speed brake:		
Area (each), sq ft	5.57	
Span (each), ft	1.67	
Chord (each), ft	3.33	
Deflection, deg	35	
	Launch	**Landing**
Weight, lb	13,452	13,234
Center-of-gravity location, percent mean aerodynamic chord	18.1	17.4
Moments of inertia, slug-ft^2		
I_X	3,400	3,400
I_Y	79,000	77,900
I_Z	80,800	79,600

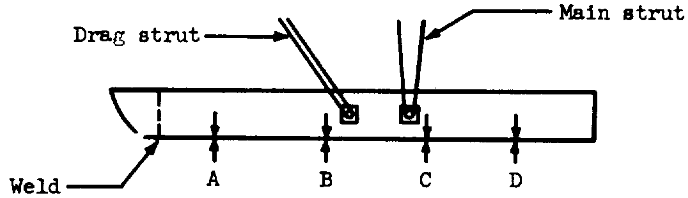
TABLE II.- LAKEBED SKID AND NOSEWHEEL MARKS



Maximum allowable tread = 9.17 ft

Distance down runway, ft	Tread, ft	Nose-gear dimensions, ft	Remarks
0	----	----	Initial touchdown, left skid
15.00	----	----	Final left-skid touchdown
24.50	7.42	----	Right-skid first touchdown
37.00	7.92	----	Final right-skid touchdown
43.83	8.31	----	
58.83	9.13	----	
73.83	9.48	----	
88.83	9.41	----	
103.83	9.00	----	
118.83	8.73	----	
133.83	8.48	----	
148.83	8.39	----	
163.83	8.58	----	
178.83	9.08	----	
187.00	Not measured	3.67	Nose-gear initial touchdown
193.83	9.63	Not measured	
199.75	Not measured	Not measured	Final nose-gear touchdown
208.83	10.04	4.19	
223.83	10.04	Not measured	
238.83	9.78	4.00	
253.83	9.50	3.08	
268.83	9.29	3.67	
283.83	9.25	3.71	
298.83	9.58	3.85	
313.83	9.58	4.00	
328.83	9.73	4.25	
343.83	9.71	4.25	
358.83	9.73	4.25	
373.83	9.67	4.25	
388.83	9.67	4.25	
403.83	9.69	4.33	
418.83	9.71	4.42	
433.83	9.73	4.46	
448.83	9.71	4.58	
463.83	9.78	4.58	
478.83	9.71	4.67	
493.83	9.69	4.75	

TABLE III.- SKID THICKNESS BEFORE AND AFTER LANDING



Preflight Measurements

Skid	A	B	C	D
Left	0.164	0.155	0.167	0.168
Right	.167	.165	.168	.164

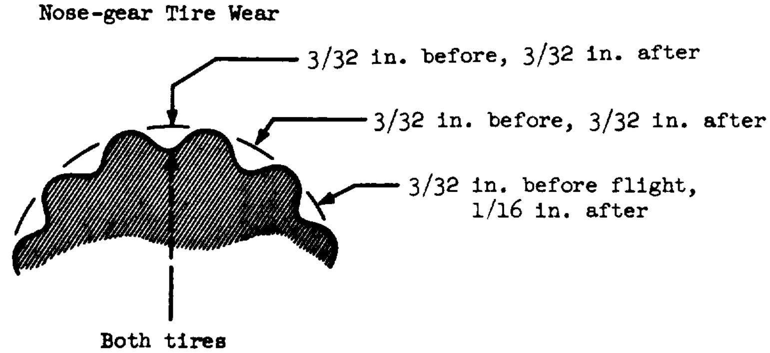
Postflight Measurements

Skid	A	B	C	D
Left	0.163	0.155	0.162	Measurement not dependable
Right	.165	.164	.163	.163

Wear

Skid	A	B	C	D
Left	0.001	0	0.005	---------
Right	.002	.001	.005	.001

Nose-gear Tire Wear



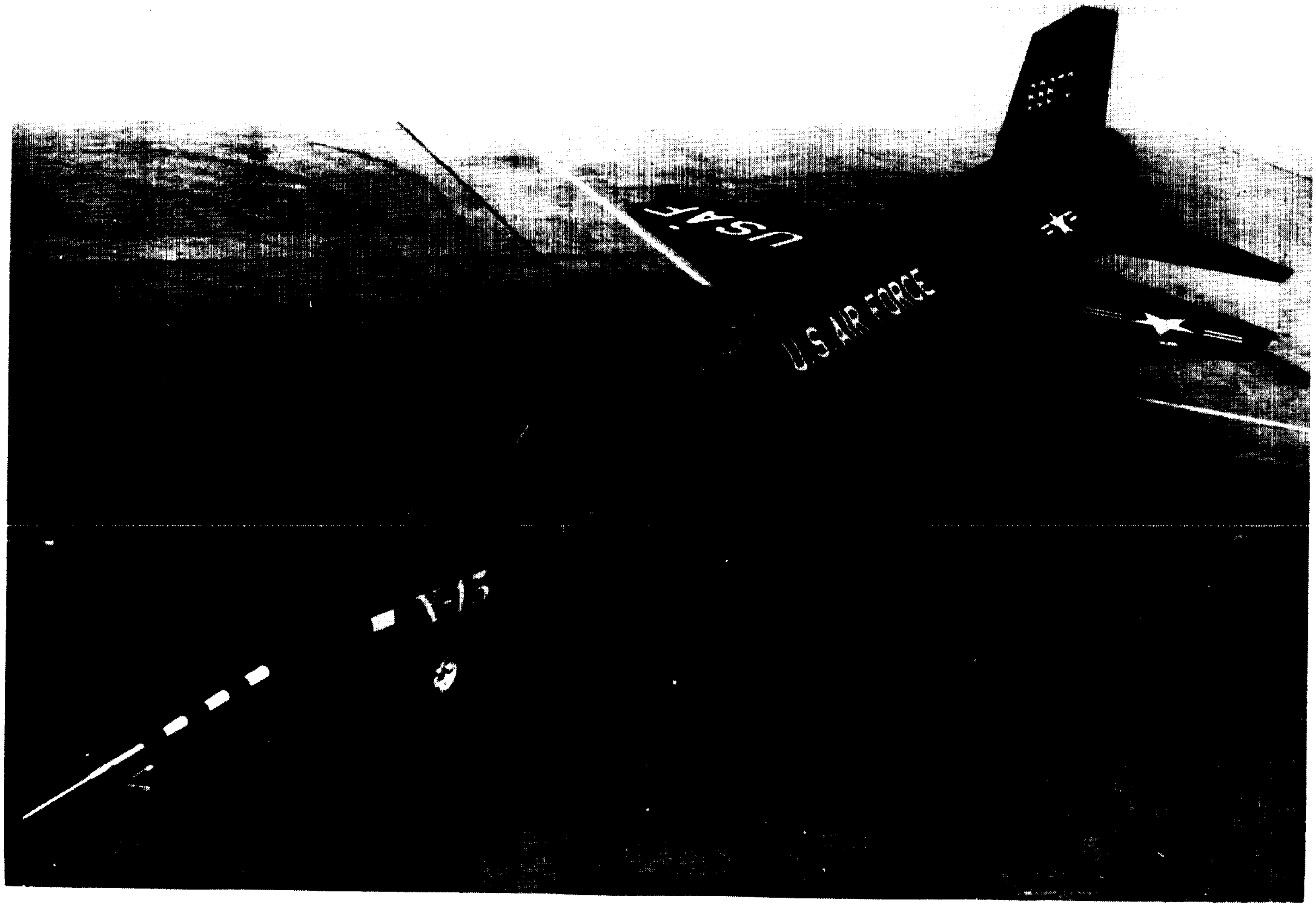


Figure 1.- X-15 airplane. E-4484

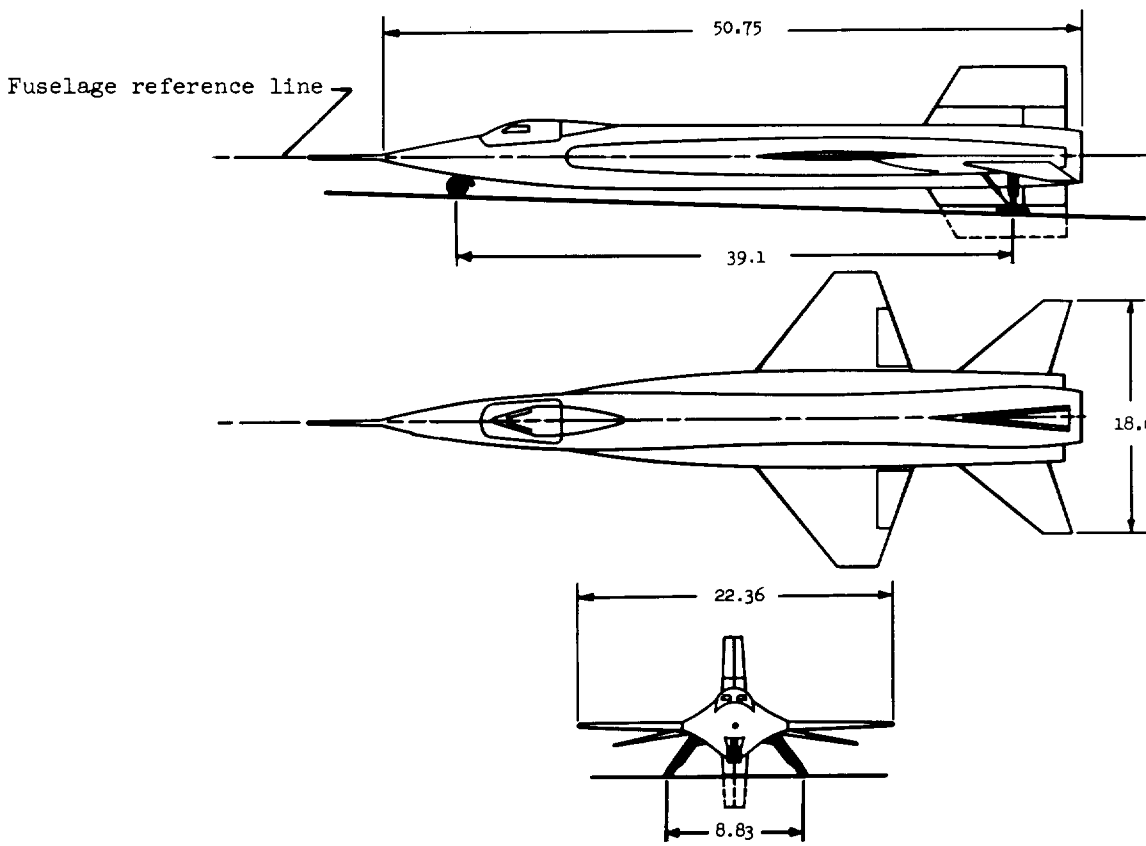
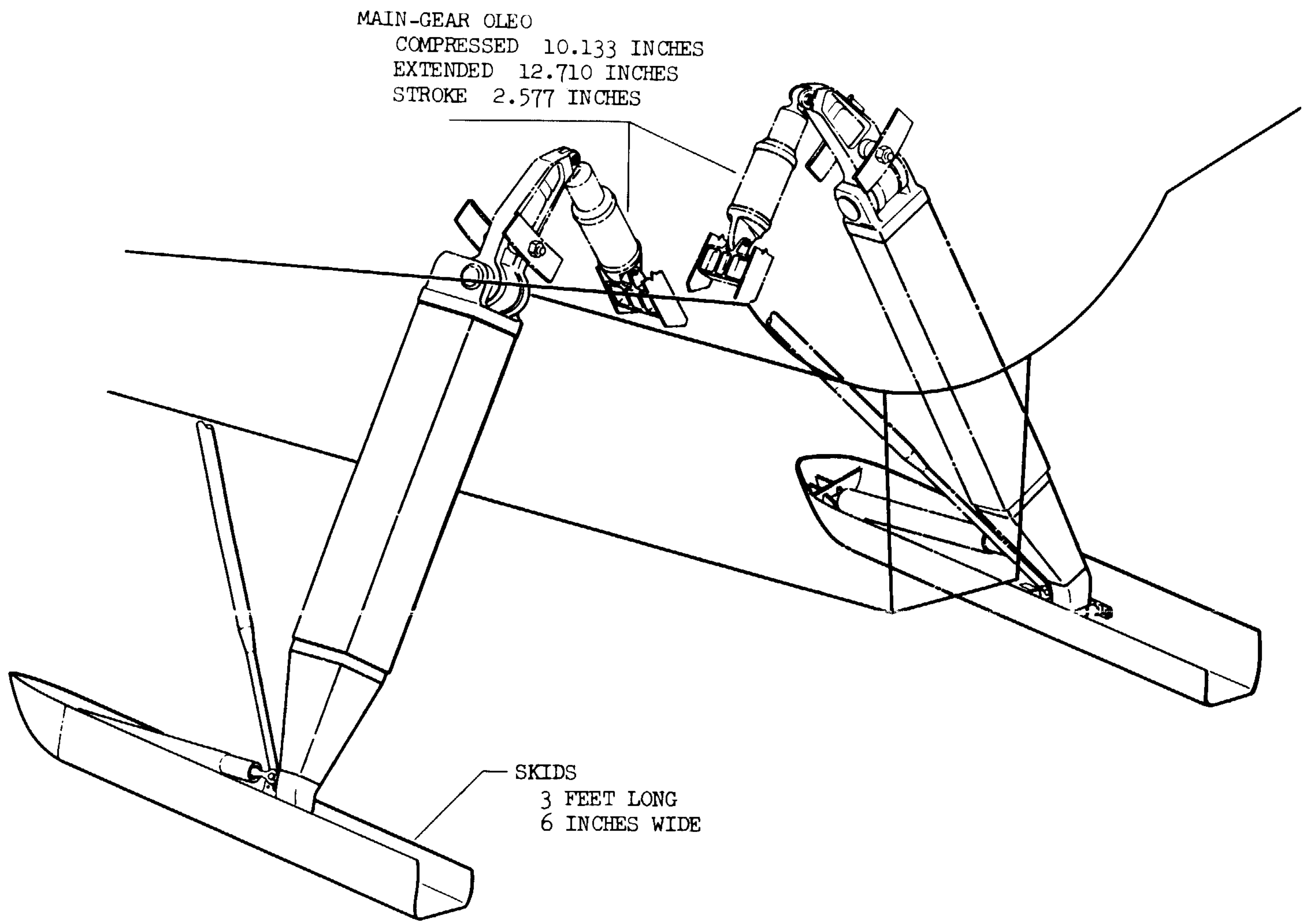


Figure 2.- Three-view drawing of the X-15 airplane. All dimensions in feet.

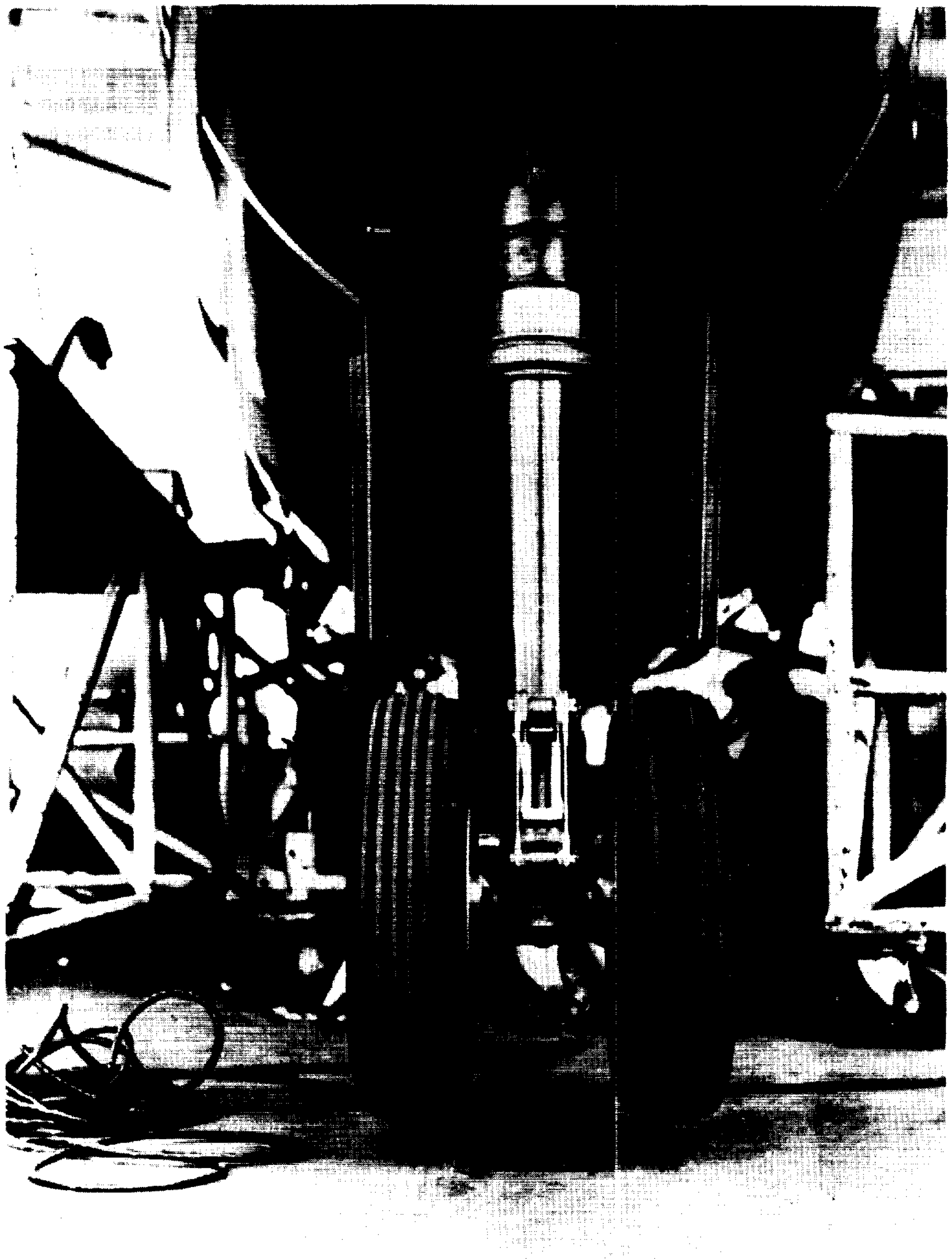


(a) Schematic drawing.

Figure 3.- X-15 main landing gear.

(b) Side view of left main skid in extended position. E-4679

Figure 3.- Concluded.



E-4689

Figure 4.- Front view of nose gear with shock strut in fully extended position.

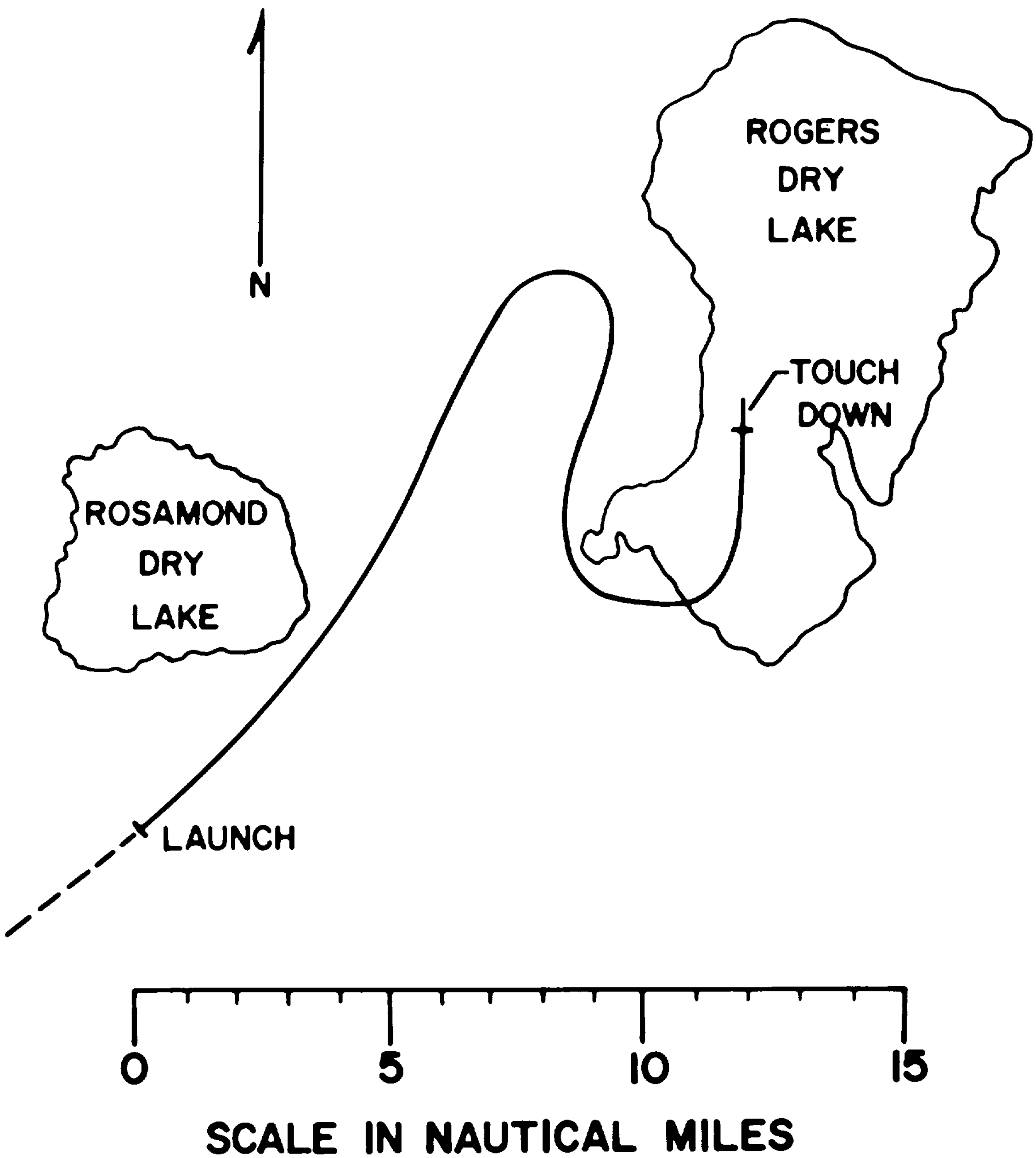


Figure 5.- General flight plan of the first X-15 flight.

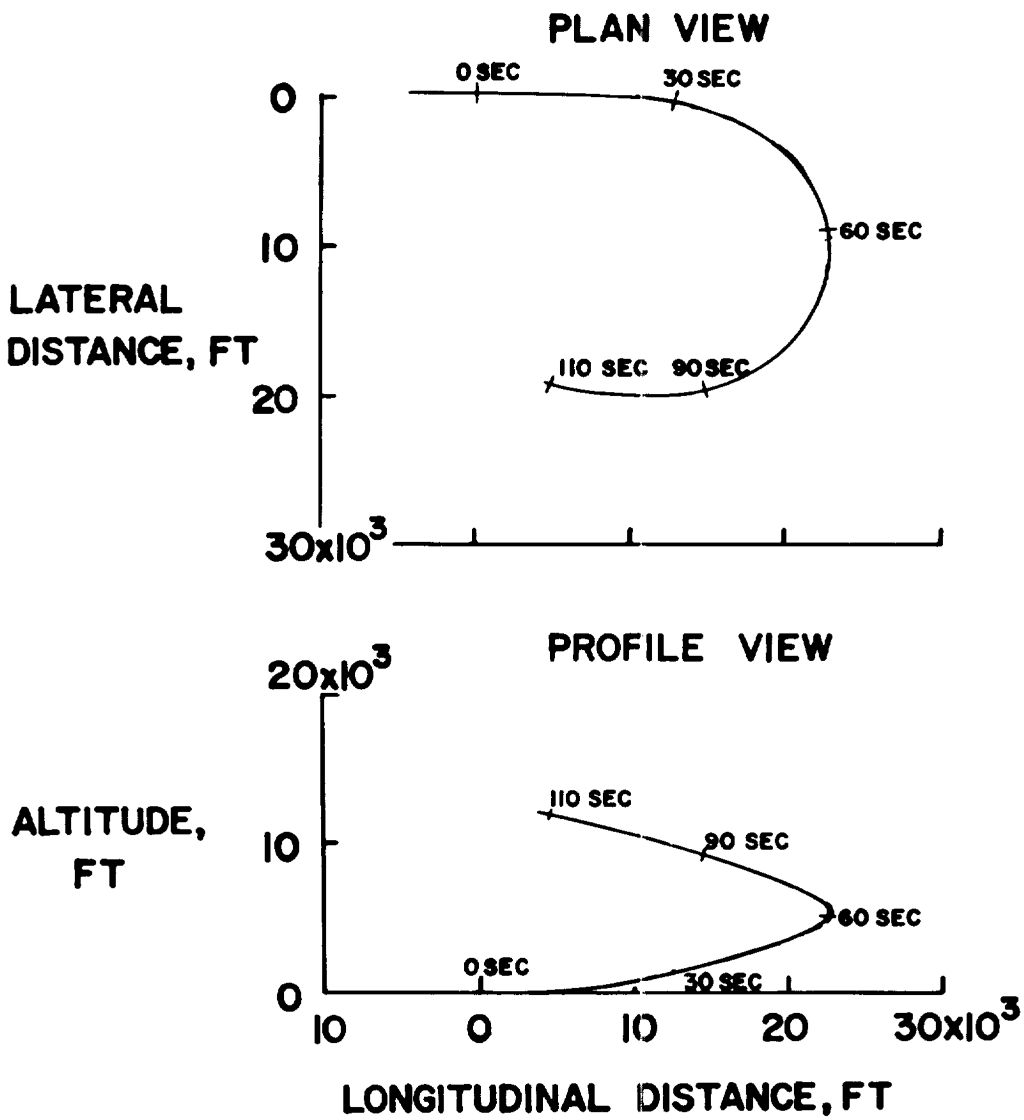


Figure 6.- Landing pattern of first X-15 glide flight.

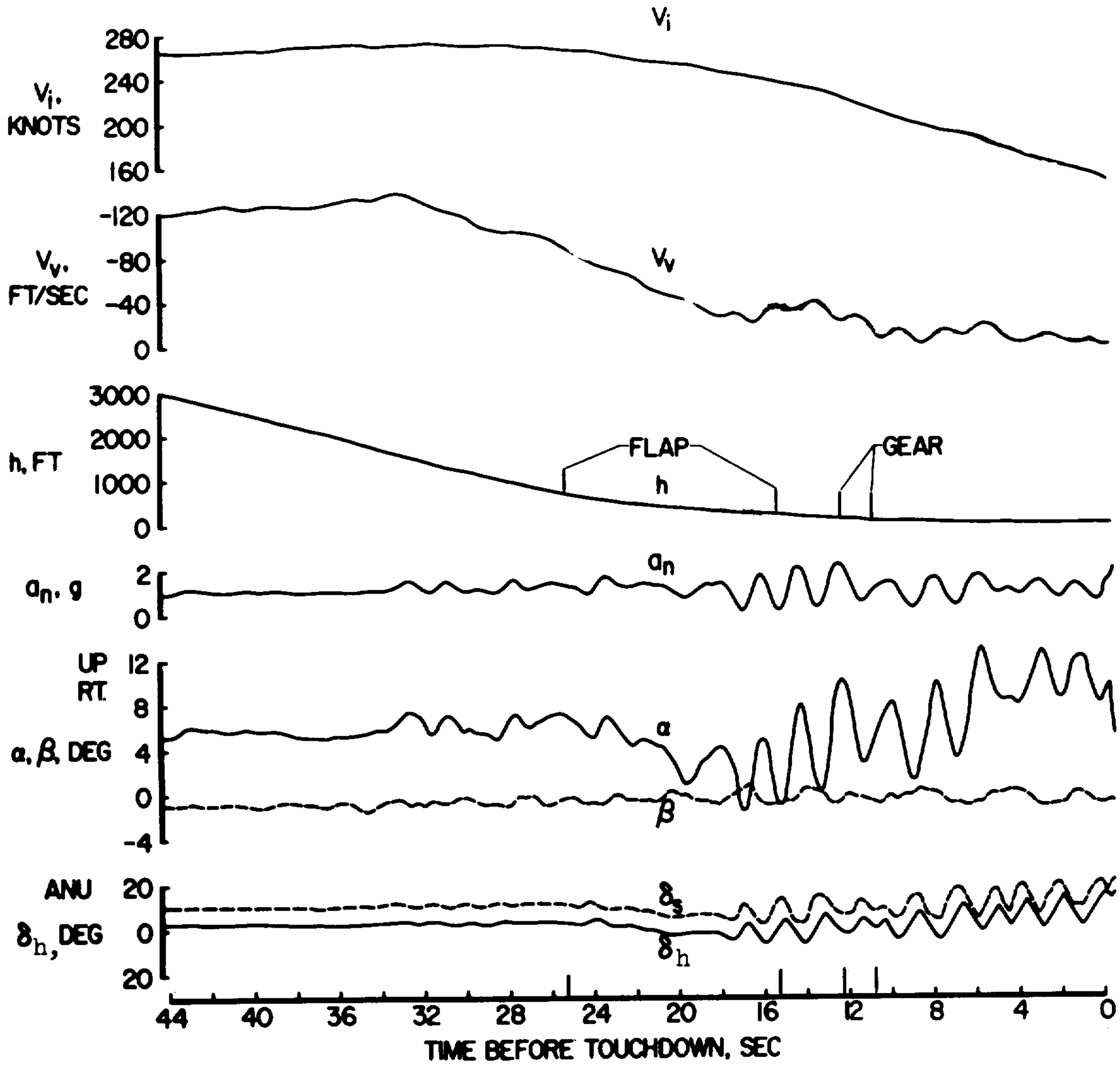


Figure 7.- Time history of the flare and touchdown.

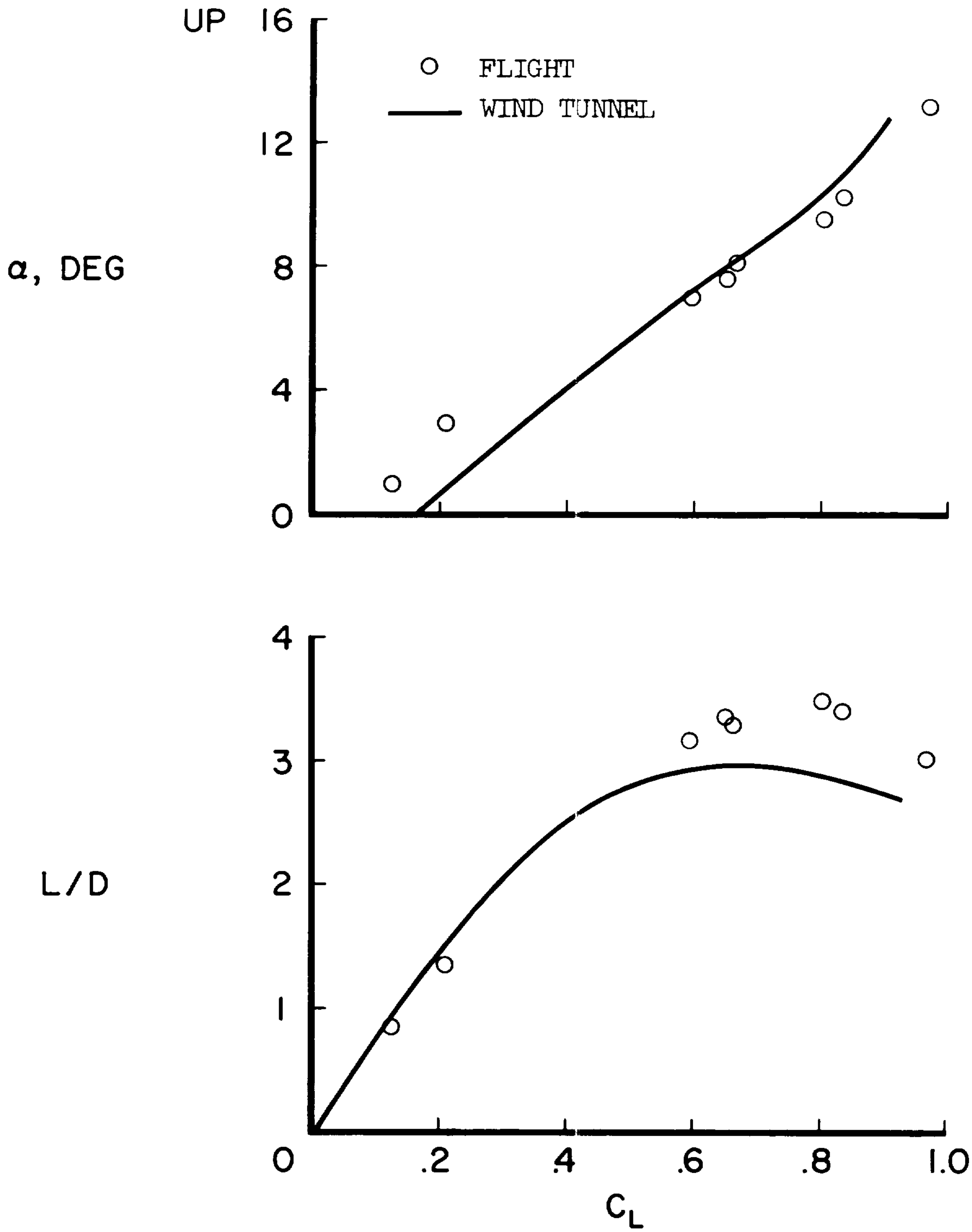
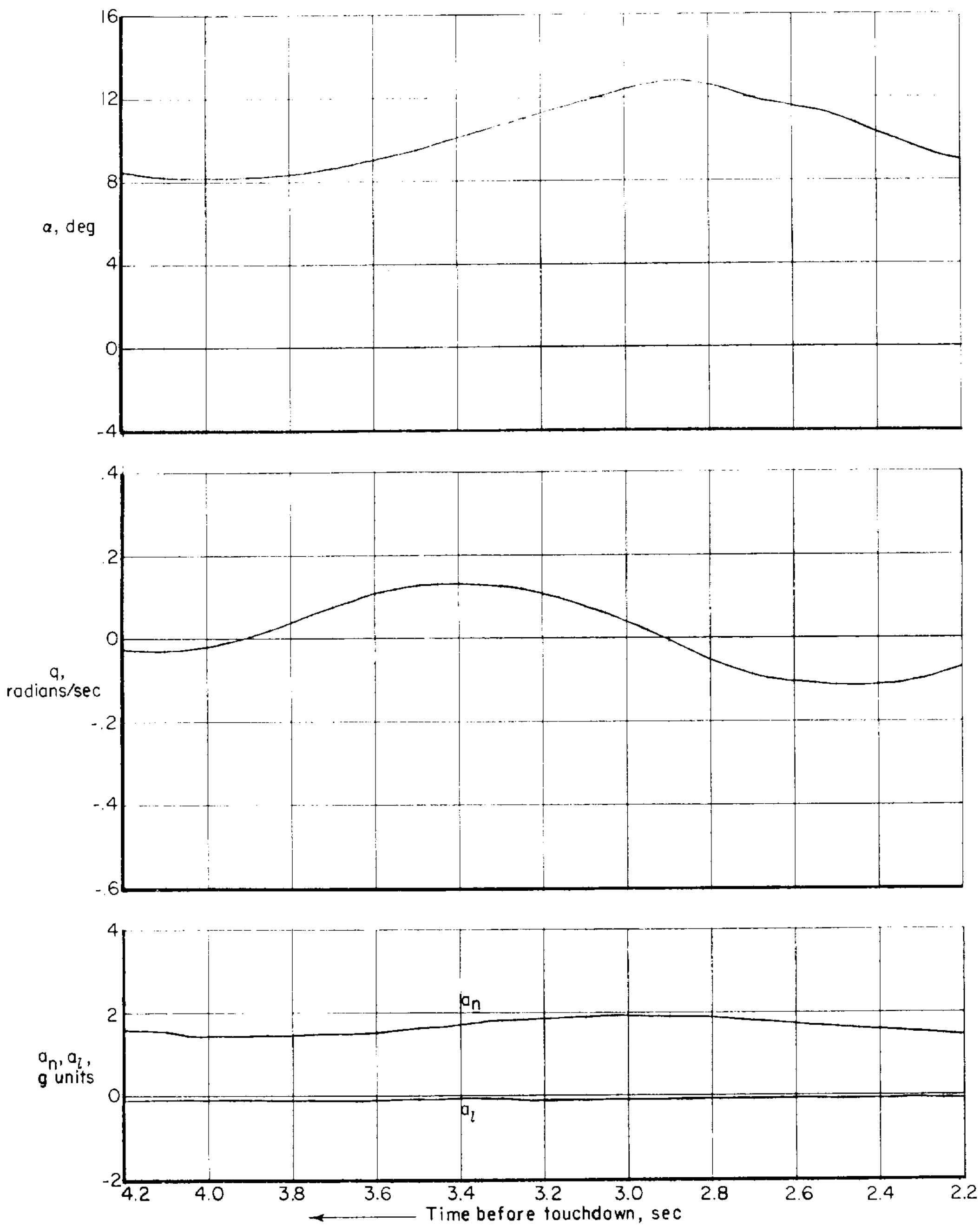
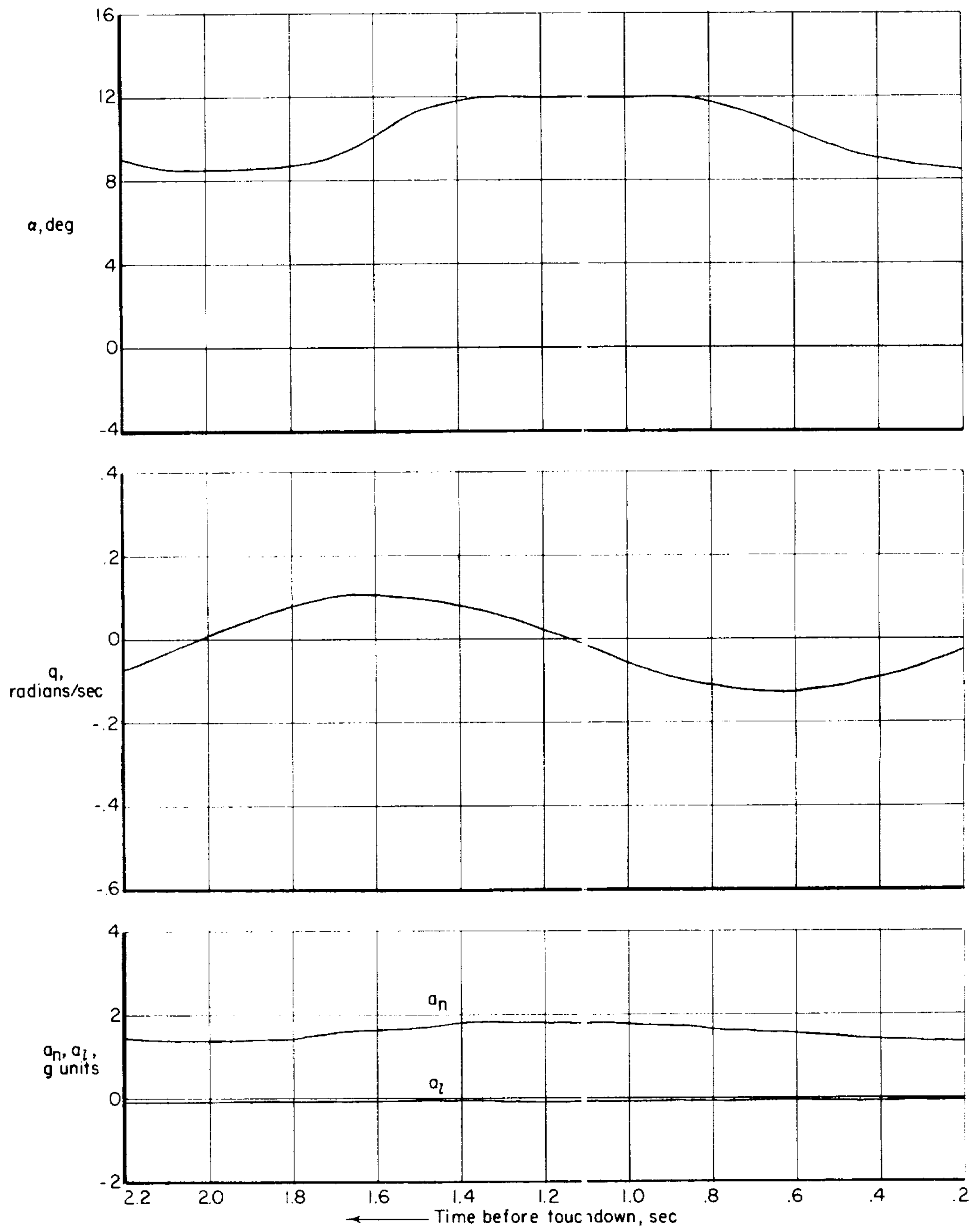


Figure 8.- Lift-drag ratio of the X-15 in the landing configuration.



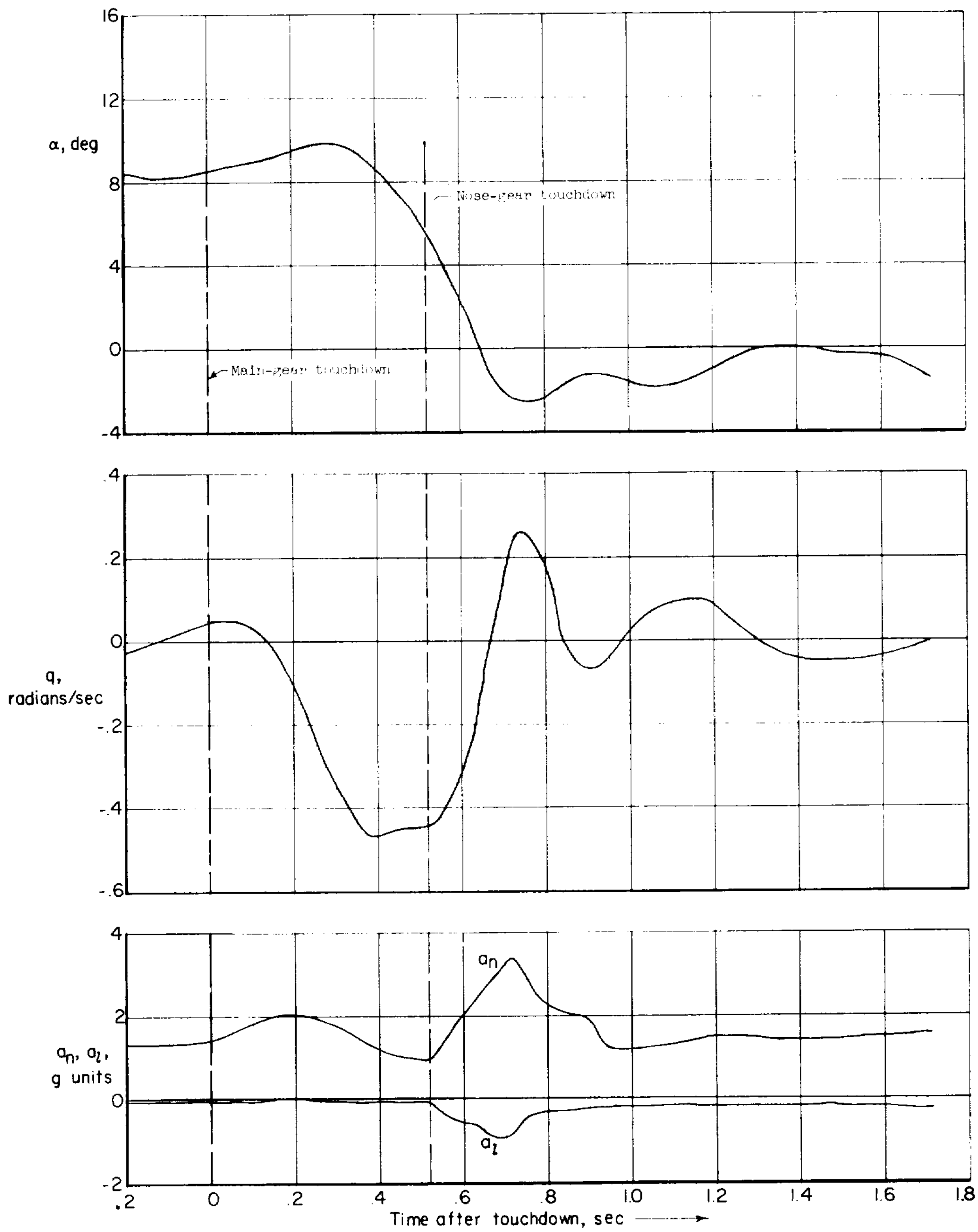
(a)

Figure 9.- Variation with time of angle of attack, pitching velocity, and center-of-gravity vertical and longitudinal acceleration during the first landing of the X-15 airplane.



(b)

Figure 9.- Continued.



(c)

Figure 9.- Concluded.

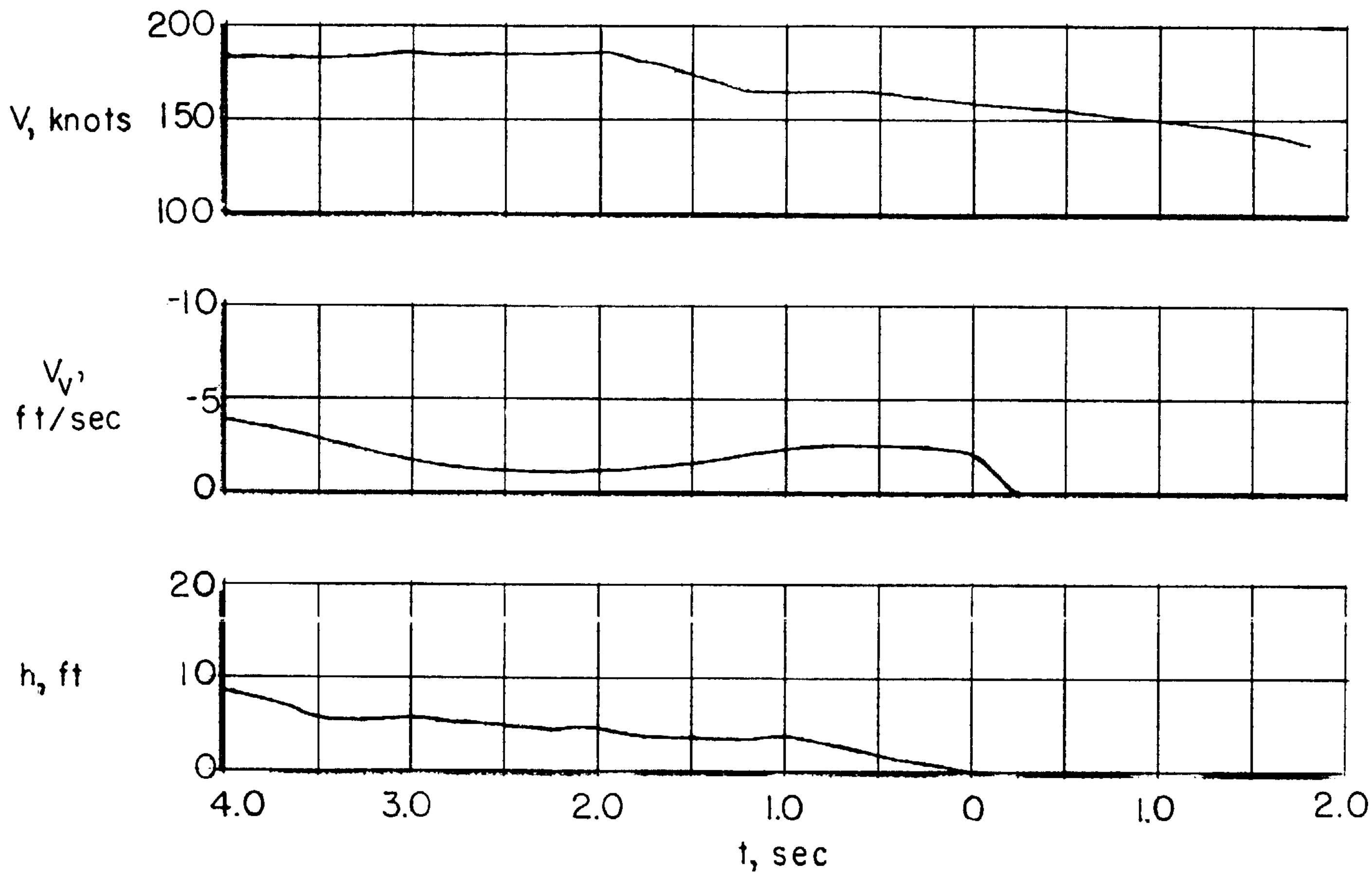


Figure 10.- Variation with time of forward speed, vertical velocity, and height above the ground during the first landing of the X-15 airplane.

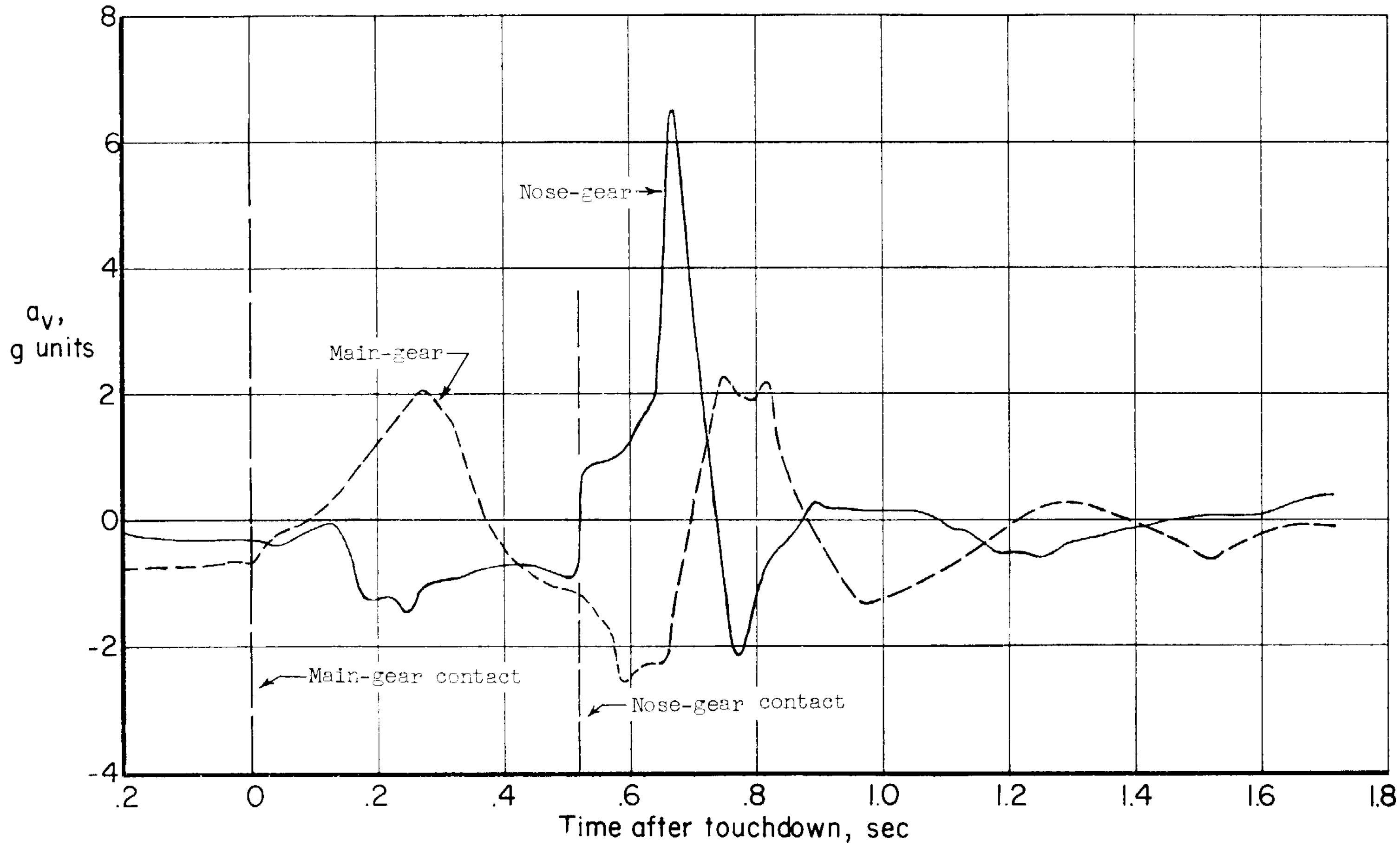


Figure 11.- Variation with time of nose- and main-gear upper-mass accelerations during the first landing of the X-15 airplane.

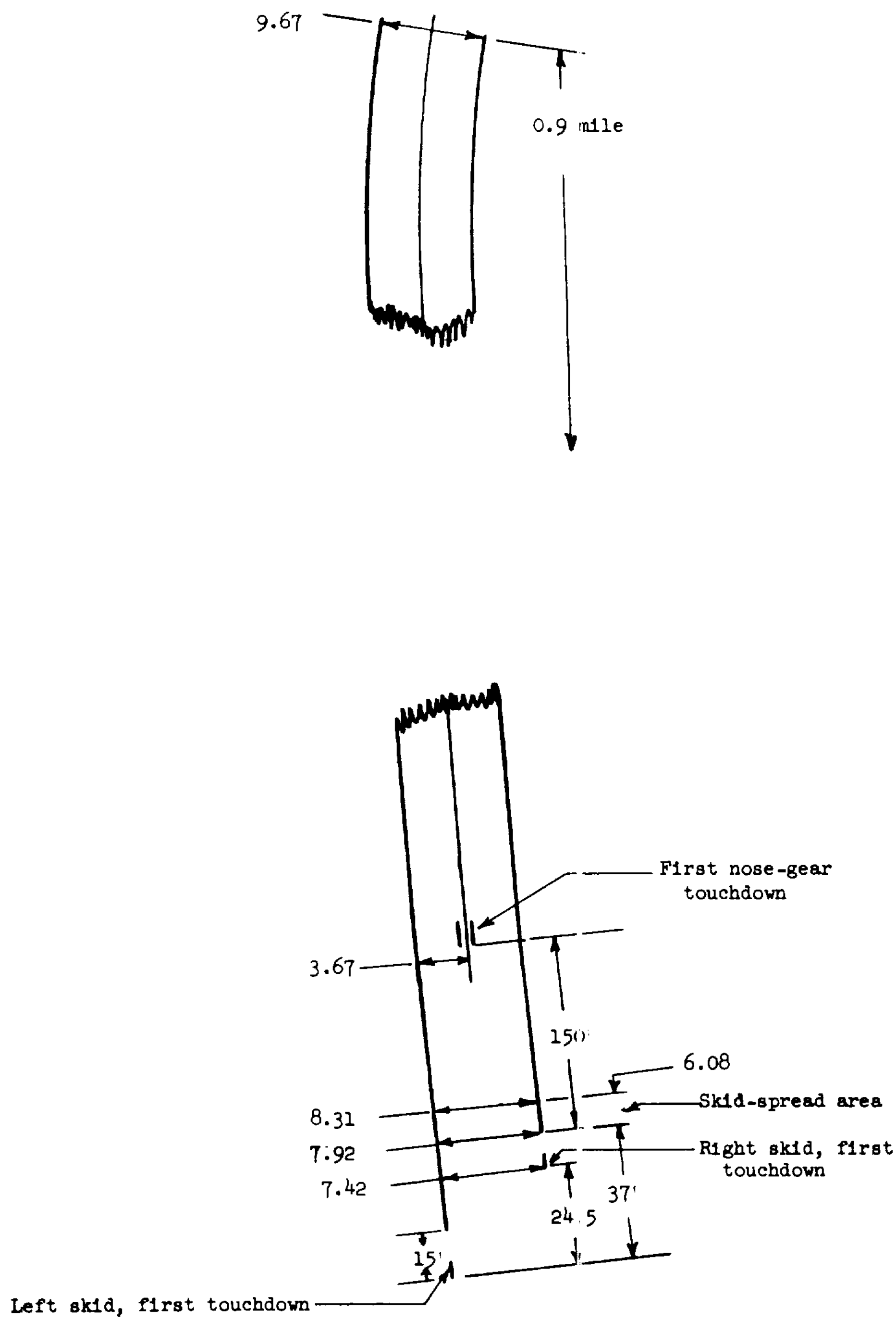
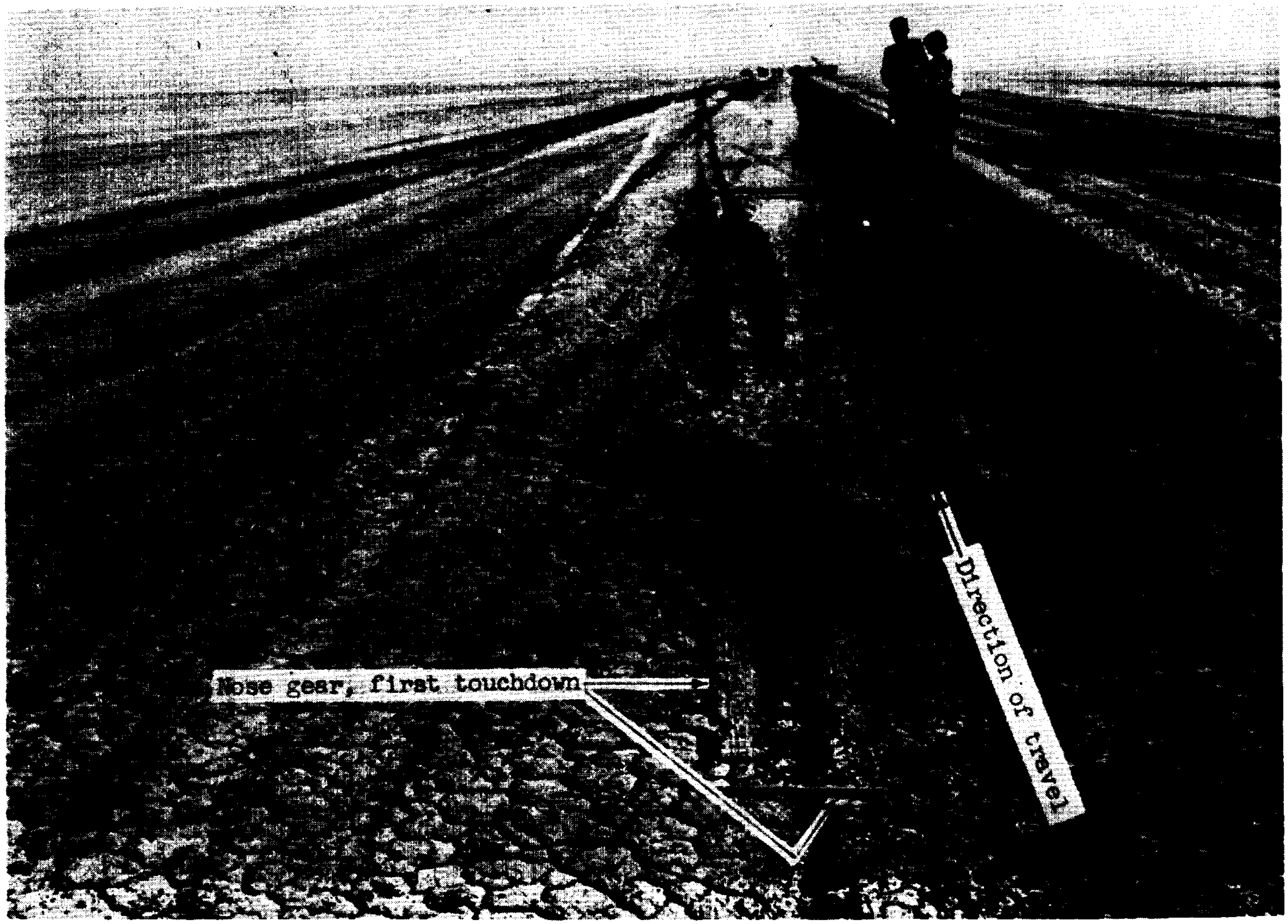
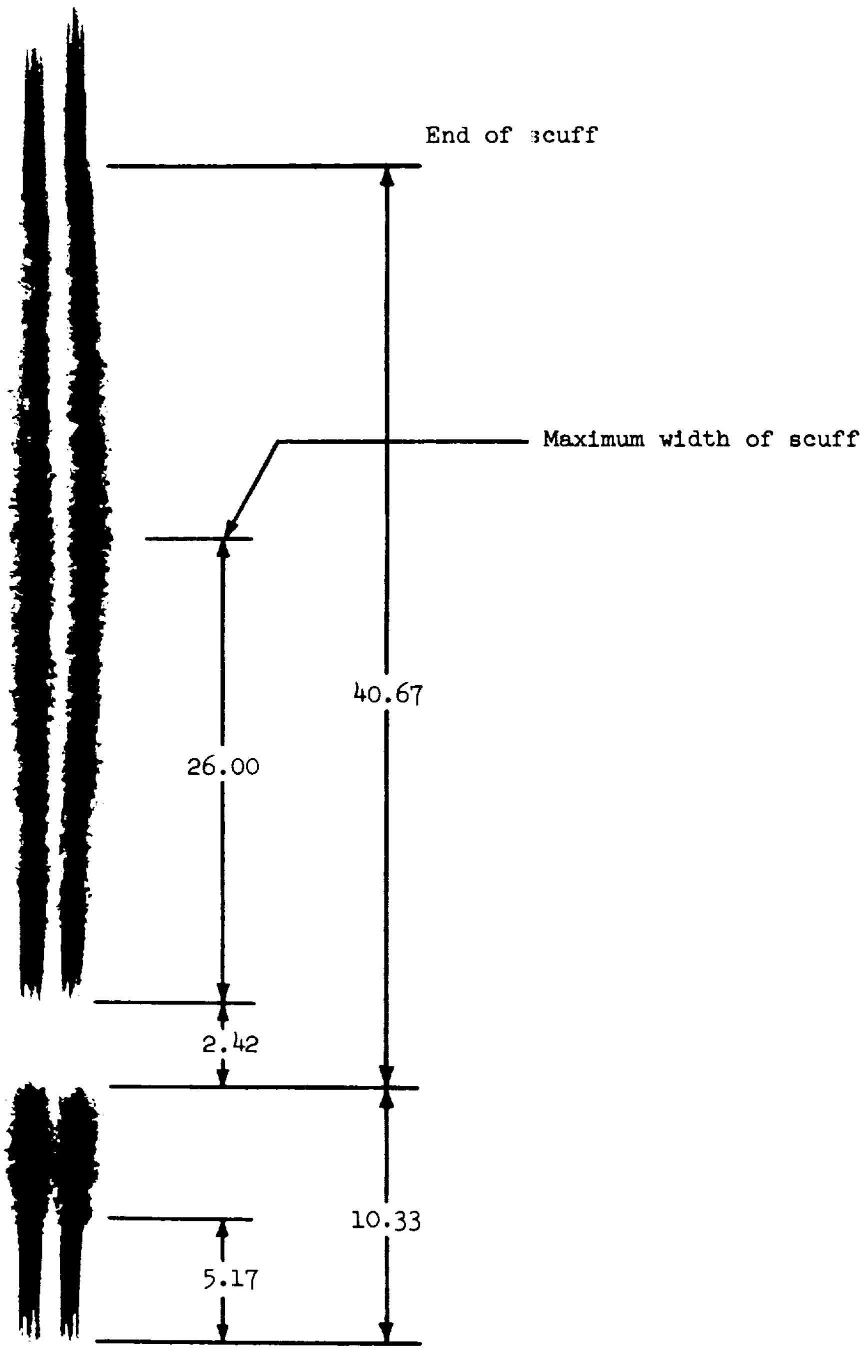


Figure 12.- Diagram of the X-15 main- and nose-gear skid marks on lakebed for the touchdown and runout phase of the first landing. All dimensions in feet.



(a) In direction of travel. E-4677

Figure 13.- Nose-gear touchdown initial skid marks.



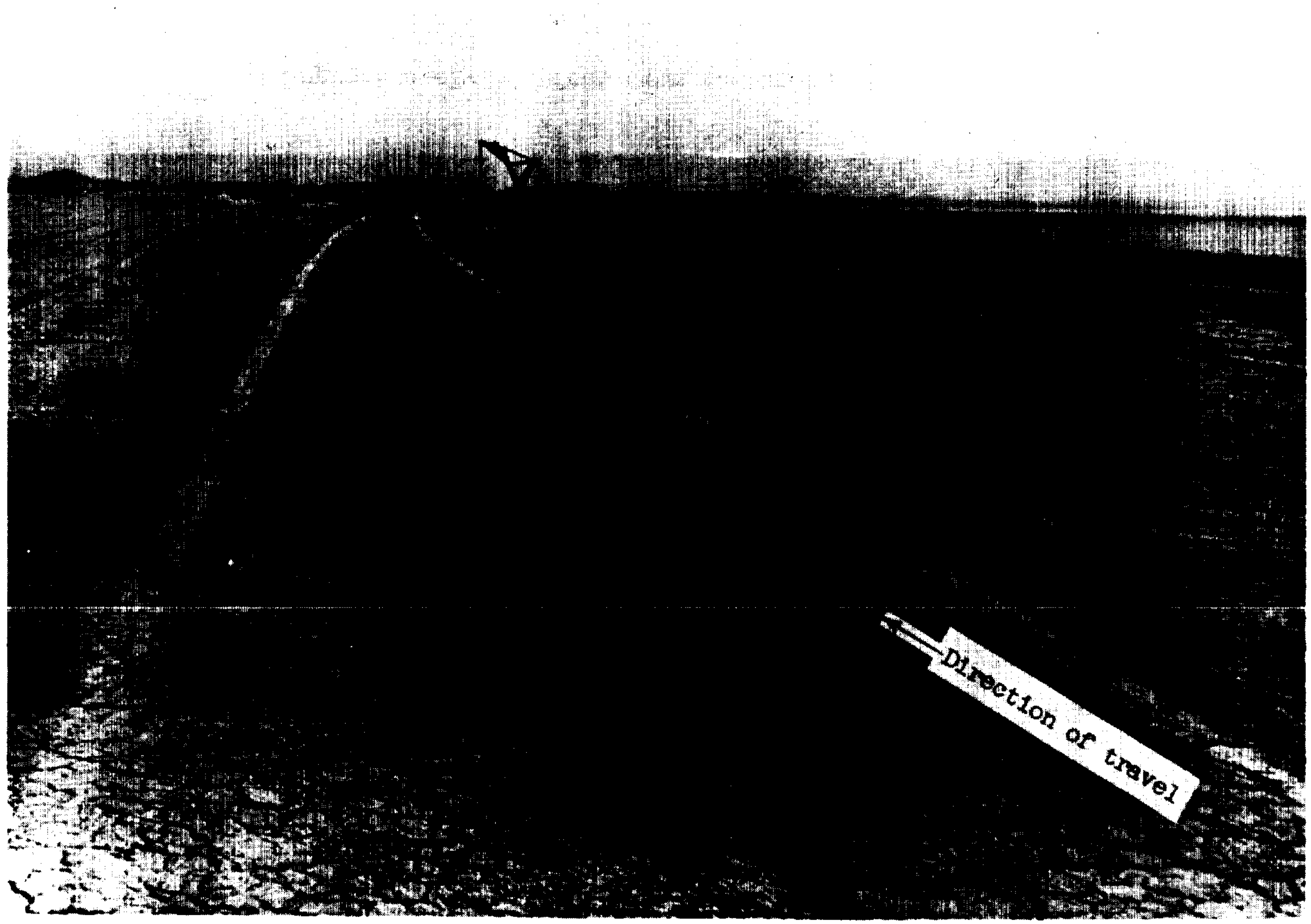
(b) Diagram of the X-15 nose-gear initial touchdown marks. All dimensions in feet.

Figure 13.- Concluded.

E-4667

(a) Approximately 300 feet from touchdown, looking rearward.

Figure 14.- Main- and nose-gear skid marks.



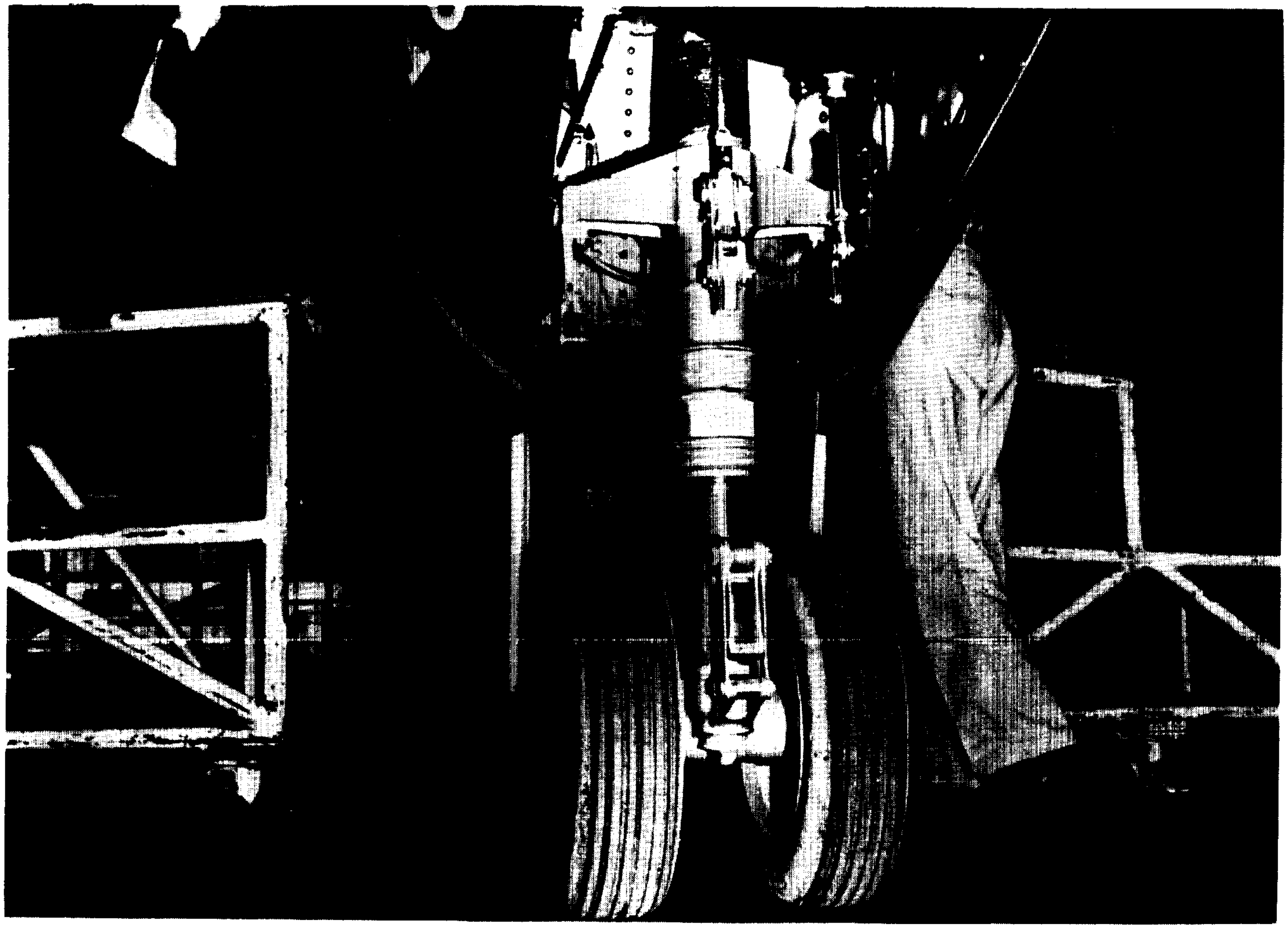
(b) Runout phase of the landing. E-4663

Figure 14.- Continued.

E-4668

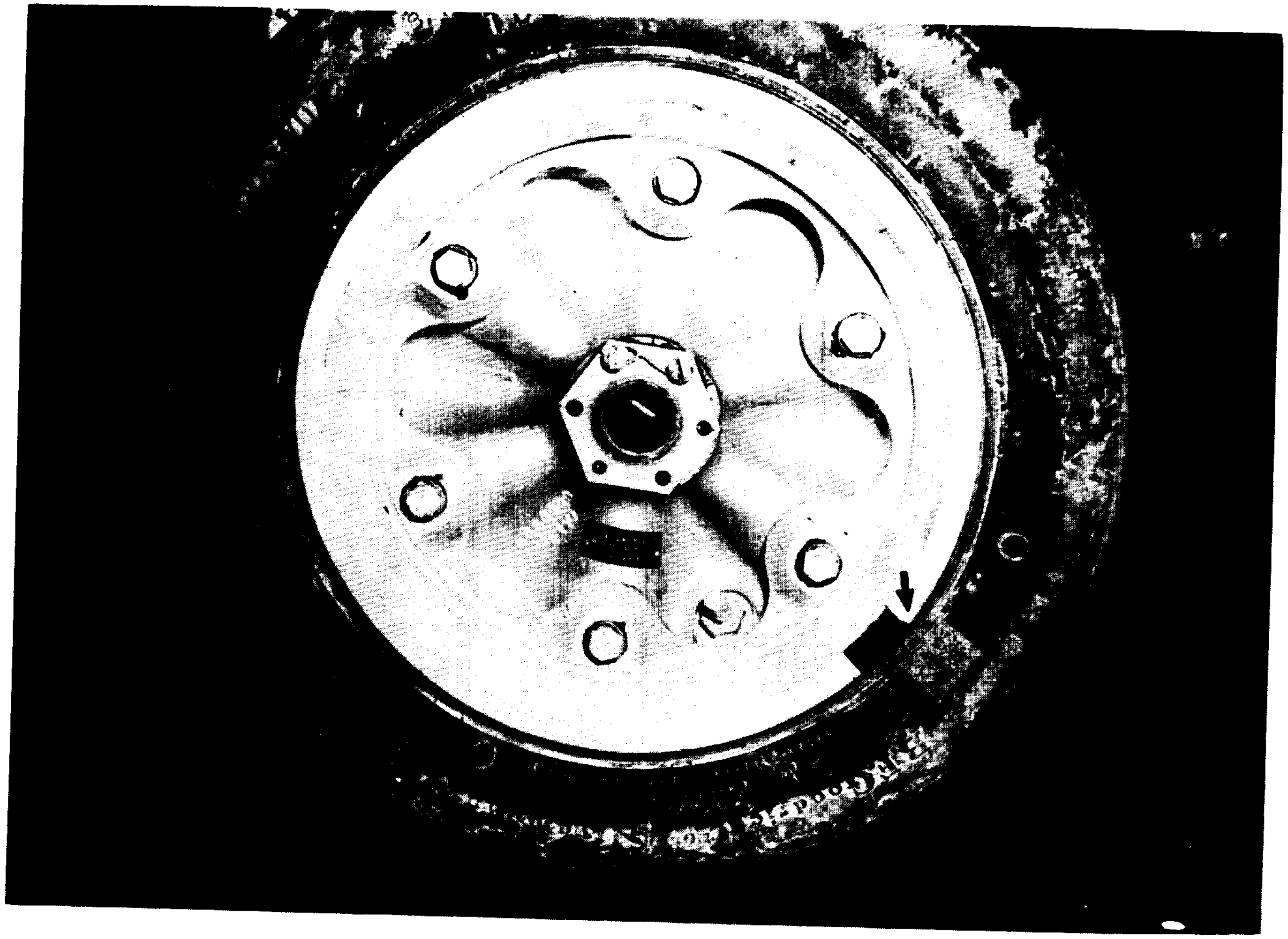
(c) Closeup view of typical main-gear skid mark, runout phase of the landing.

Figure 14.- Concluded.



(a) Shock strut in the static position. E-4687

Figure 15.- X-15 nose gear after the first landing.



E-4686

(b) Left nosewheel, with tire slippage indicated by arrow.

Figure 15.- Concluded.

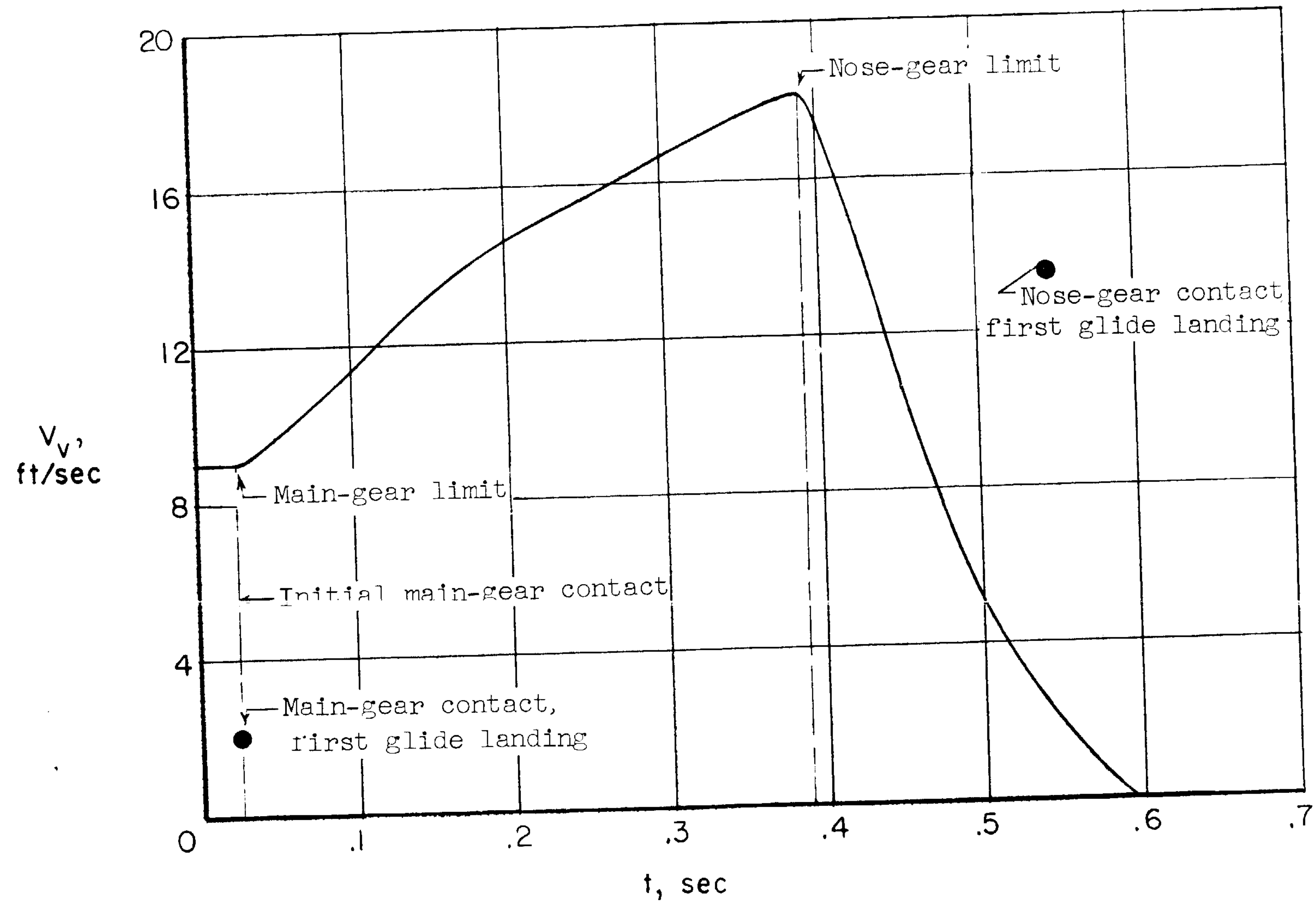


Figure 16.- X-15 design limit sinking speed for the main and nose gear. V_i = 164 knots; $\alpha = 6^\circ$; V_v = 9 ft/sec.