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RESEARCH MEMORANDUM

HIGH-SPEED LANDING LOADS MEASURED ON THE DOUGLAS X-3 RESEARCH AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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HIGH-SPEED LANDING LOADS MEASURED ON THE DOUGLAS X-3 RESEARCH AIRPLANE

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SUMMARY

Landing conditions and landing-gear loads on the Douglas X-3 research airplane were investigated during routine research flights. It was found that the X-3 airplane normally landed under power at indicated airspeeds from 106 to 145 percent of the stalling speed of 283 feet per second, with rates of descent from 2 to 5 feet per second. No correlation was found between forward velocity and sinking speed for the landing speed range investigated.

Normal landings were found to result in peak normal accelerations at the airplane center of gravity of 1.6g to 2.1g. Maximum axial loads in the main struts ranged from about 11.8 to 21.0 percent of the design ultimate load of 65,720 pounds. Maximum drag loads varied from 10.1 to 13.4 percent of the design ultimate value of 33,640 pounds. Wheel spin-up was essentially complete in from 0.2 to 0.3 second following initial touchdown, after which the drag loads were low. Side loads were generally low except in one landing where sideslipping was evident; the maximum side load was 31.9 percent of the design ultimate load of 16,600 pounds.

Data obtained near the end of a landing run as the airplane was turned off the runway indicated axial loads on one wheel up to 23.6 percent of design ultimate, which was higher than that of any landing impact loads encountered during these tests, together with side loads up to 18.1 percent of the design ultimate.

Nosewheel loads were measured during one landing. For this landing nosewheel axial loads up to 6.9 percent of ultimate were experienced, with nosewheel touchdown occurring about 24 seconds after the main-gear impact. The nosewheel drag loads were strongly influenced by spring-back of the strut, with maximum values reaching 14.9 percent of ultimate design load. Side loads for the nosewheel were negligible for this landing.

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INTRODUCTION

The trend in recent years toward higher wing loadings and reduced lift-to-drag ratios in high-performance airplanes has resulted in approach and landing conditions not previously experienced. The Douglas X-3 research airplane with a landing speed of over 200 knots is an example of an airplane of this type, and, therefore, the approach conditions and landing-gear loads on the X-3 airplane were considered to be of interest.

Some of the results pertaining to the approach and landing conditions of the X-3 airplane, along with approach and landing conditions of several other research airplanes, were reported in reference 1. The present paper presents representative results from measurements of landing-gear loads at ground contact obtained during a limited research investigation. Some approach- and landing-condition data supplementing that of reference 1 are also presented. These data were obtained during routine research flights of the X-3 airplane conducted by the NACA High-Speed Flight Station at Edwards, Calif.

SYMBOLS

a_n	airplane normal acceleration at center of gravity, g units
F_A	axial load in landing-gear strut, positive upward, lb
F_D	drag load normal to landing-gear strut, positive to the rear, lb
F_Y	side load normal to landing-gear strut, positive to the right, lb
g	acceleration due to gravity, ft/sec^2
h	airplane altitude above ground, ft
t	time, sec
V_f	forward velocity, ft/sec
V_v	vertical velocity, ft/sec

Subscript:

max	maximum

AIRPLANE

The Douglas X-3 is a single-place jet-powered research airplane having a low-aspect-ratio, tapered wing, with a wing loading of 105 pounds per square foot at the normal landing weight of 17,500 pounds. Leading-edge plain flaps with a deflection range of 30° and split trailing-edge flaps with 50° deflection are used. The control surfaces are operated through an irreversible hydraulic power system.

The tricycle landing gear is of conventional oleo-strut construction with Type VII Extra High Pressure tires, size 32 by 8.8, for the main gear and size 20 by 4.4 for the nose gear. The tire inflation pressure is 200 pounds per square inch. To prevent the tire tread from shedding because of the high rotational speeds developed by the wheels during takeoff and landing, the tread was removed by grinding to a thickness of about 1/8 inch (ref. 2).

A photograph of the airplane is shown in figure 1 and a three-view drawing in figure 2. Table I presents physical characteristics of the airplane pertinent to this investigation.

INSTRUMENTATION AND ACCURACY

Axial, drag, and side loads were measured by resistance-wire strain-gage bridges installed on each main-gear axle near the wheel and on the nose-gear strut above the axle. Figure 3 shows the approximate strain-gage locations on the landing gear. A static calibration was performed to determine the strain-gage-bridge responses to known loads. Axial loads were applied by lowering the airplane onto platform scales under the wheels. Drag and side loads were applied to steel plates resting on rollers which were placed under the wheels, using the friction between the plate and the tire to transfer load to the wheel. Since each bridge responded to all components of load, it was found necessary to derive load equations by using combined bridge responses. Based on the results of this calibration and the reading accuracies involved, the measured loads are estimated to be accurate to within ±200 pounds. The bridge responses were recorded on the airplane oscillograph.

Altitude data during the final approach were obtained by photographing the airplane through modified Askania phototheodolites located approximately 1/2 mile from the runway at a film rate of 5 frames per second. The accuracy of these data varied from ±0.2 to ±1.0 foot, depending primarily on the distance of the airplane from the cameras.

The recording airspeed system of the airplane, calibrated for position and instrument error, was used to obtain the forward velocity at landing. Wind velocities were negligible compared to the airplane velocity and were, therefore, neglected. The forward speed is estimated to be accurate to within ±15 feet per second. The speeds given in this paper are true airspeeds unless otherwise stated.

Airplane accelerations at landing were obtained from the NACA three-component recording accelerometer located near the airplane center of gravity. The normal acceleration is estimated to be accurate to within ±0.04g.

TESTS

All landings were made on a strip 300 feet wide and 7.5 miles long, marked out on the smooth, hard surface of Rogers Dry Lake at Edwards Air Force Base, Calif. The flights were made in clear weather with negligible winds. Air temperatures were estimated to be from 80° F to 100° F. The altitude of the dry lake is 2,280 feet above sea level.

The airplane was flown by Air Force and NACA test pilots with considerable experience in flight research. Although the pilots were aware that landing data were being obtained, no special techniques, speeds, or other restrictions were requested, nor were any flights made solely to obtain landing data. An escort airplane accompanied the X-3 on every flight, and its pilot assisted the X-3 pilot in landing by calling estimated altitudes over the radio. This procedure was used to supplement the limited visibility forward from the X-3 in the landing attitude. Therefore, as reported in reference 1, normal landings of the X-3 were characterized by long power approaches with gradual flareouts and low sinking speeds.

RESULTS AND DISCUSSION

The vertical-flight profiles just prior to touchdown for six typical flights of the X-3 are shown in figure 4. This figure presents time histories of airplane height above the ground obtained from the Askania phototheodolite data. Slopes taken from these plots indicate that sinking speed at touchdown for the X-3 was generally between 2 and 5 feet per second. These sinking speeds are low, compared with the design ultimate value of 14 feet per second (ref. 3). The forward velocity ranged from about 308 to 423 feet per second, with indicated airspeeds ranging from 106 to 145 percent of the stalling speed of 283 feet per second. For these tests, there is no apparent correlation between sinking speed and forward velocity.

Portions of some representative oscillograph records obtained during landing, showing the responses of the landing-gear strain gages, are presented in figure 5. Although the traces are identified as axial, drag, and side loads, it should be noted that the true loads are determined from the combined responses of all the strain gages, and that no one trace represents pure axial, drag, or side load. Since no significant differences appeared to exist between right and left main-gear loads for symmetrical landings, only right main-gear loads are presented in this paper with one exception, where right main-gear loads were not available.

Figure 5(c) is a portion of a record taken 55 seconds after the landing impact shown in figure 5(b). This record is of interest because it is near the end of the landing run where the speed is about 50 feet per second and may be considered a record taken during taxiing operations.

Time histories of measured landing-gear loads and airplane center-of-gravity normal accelerations corresponding to the landing records shown in figure 5 are shown in figure 6.

Figure 6(a) presents right main-gear loads obtained from the record of figure 5(a). All oscillations of the traces were read from impact until $t = 56$ seconds, but for subsequent time values the high-frequency oscillations were faired out. The forward velocity was 347 feet per second. Sinking-speed data are not available for this flight.

It can be seen from the axial-load variation, as well as from the normal accelerations, that a number of short slight bounces occur after impact, indicating that most of the airplane weight is being carried by wing lift. This is further indicated by the fact that the axial load reaches only 7,800 pounds at a normal acceleration of 1.77g, while the calculated reaction load for this acceleration and zero wing lift is approximately 15,500 pounds per wheel in the two-point attitude. The maximum normal acceleration is 25.4 percent of the design ultimate landing condition of 7g (ref. 3), while the maximum axial load was only 11.8 percent of the design ultimate load of 65,720 pounds (ref. 3). The normal-acceleration peaks can be seen to occur at roughly the same time as the axial-load peaks.

The peak drag load of 3,400 pounds occurred during the period of peak axial load. This peak load is only slightly more than 10 percent of the design ultimate load of 33,640 pounds (ref. 3). It is apparent that the wheel spin-up is essentially completed in the initial 0.2 second during the first impact, since the subsequent drag loads are very low. A high-frequency, fairly constant amplitude oscillation of drag load during the period of essentially zero axial load is noted. Since the strain gages were located on the axle near a wheel bearing, it is possible that wheel unbalance or other asymmetric conditions may have resulted in local axle strains not related to the applied ground loads. Calculation of the wheel speed for this landing resulted in a value of about 42 revolutions per second, which compares favorably with the frequency of the oscillations observed. These oscillations were, accordingly, faired out of the later portions of the time history. The inclination of the strut in the landing attitude results in a component of the vertical ground reaction which is normal to the strut. The forward direction of this component accounts for the negative values that can be seen in drag load during the later portions of the time history.

The side loads are low, indicating good directional alinement of the airplane at contact. The maximum value of side load was about 1,500 pounds, compared with a design ultimate load of 16,600 pounds (ref. 3).

Presented in figure 6(b) are time histories of right main-gear loads and normal acceleration during another landing impact. Minor high-frequency oscillations of load were not read except through the first impact period. For this landing, the sinking speed was about 2.9 feet per second at a forward velocity of about 308 feet per second. The loads and accelerations are similar in nature to the loads presented in figure 6(a). The maximum normal acceleration was 2.12g, with a maximum axial load of 13,800 pounds, or 21.0 percent of design ultimate. Maximum drag load was 4,300 pounds, or 12.8 percent of design ultimate. These were the highest axial and drag loads measured in landing impact. The maximum side load was 2,600 pounds.

Figure 6(c) presents the loads measured 55 seconds after the initial touchdown at a forward velocity of about 50 feet per second. This is near the end of the landing run where a left turn off the runway was made and may be considered typical of a taxiing operation. The axial loads are of interest, since their general level is considerably above the computed static reaction of 8,165 pounds for the three-point attitude. Also, the maximum axial load of 15,500 pounds, or 23.6 percent of design ultimate, is higher than any maximum axial impact load for which data are available. These large loads on the right gear resulted from a left turn off the runway, so that centrifugal force in the turn increased the load on the right wheel; left-wheel loads, of course, were correspondingly reduced. This effect is probably aggravated by the relatively narrow tread of the X-3 landing gear. It therefore appears that for landing conditions similar to those encountered during these tests, turns while taxiing may impose axial loads on the landing gear larger than those encountered during landing impact.

The drag loads in this interval were negligible, but the side loads varied from 1,600 pounds to 3,000 pounds to the left as a result of the turn. Maximum side load was 18.1 percent of the design ultimate. Normal accelerations during this period ranged from 0.66g to 1.23g, and transverse accelerations up to 0.34g to the left were observed.

Shown in figure 6(d) are left main-gear loads obtained in a landing for which the right-gear loads are not available. It can be seen that these loads are not significantly different from the right-gear loads previously presented. The forward velocity was 356 feet per second, with a rate of descent of about 4.3 feet per second. The maximum normal acceleration was 1.57g, with a maximum axial load of 12,300 pounds during the initial impact. A maximum axial load of 15,400 pounds is shown during the second impact, but it can be seen that this load includes a high-frequency fluctuation of from 1,500 to 3,000 pounds, which is not believed to be part of the applied ground load. The frequency of these oscillations compares with the wheel rotational speed, and it is therefore concluded that the oscillation is probably a result of rotational asymmetry of the wheel, as discussed previously. The maximum drag load was 3,800 pounds and the maximum side load 5,300 pounds (including fluctuations similar to those in the axial loads). This side load was 31.9 percent of the design ultimate, and was the highest side load measured during these tests. The transverse acceleration at impact reached 0.2g, indicating that some sideslipping was present at this time.

Nose-gear loads are shown in figure 6(e) for the landing shown in figure 6(d). Impact occurred about 23.7 seconds after the main-gear impact at a forward velocity of about 247 feet per second. The nosewheel behaves in much the same way as the main gear; that is, the initial impact is followed by a series of short, slight bounces. The maximum axial load is 820 pounds, which is 6.9 percent of the design ultimate value of 11,860 pounds. This load is only 72 percent of the static-reaction value of 1,170 pounds. The maximum drag load of 1,000 pounds, or 14.9 percent of the design ultimate of 6,730 pounds, occurred during the spin-up, which took about 0.25 second. The time history shows a considerable fluctuation in drag load during the spin-up which is different in character from the main-gear drag-load fluctuations. This fluctuation is attributed to spring-back vibration, since the strut is considerably smaller and less rigid than the main-gear struts and is therefore more likely to be subject to these vibrations. It can be seen that these spring-back loads die out after the spin-up is completed, with subsequent low values of drag load. Side loads were negligible throughout the time interval shown, averaging less than 2.5 percent of the design ultimate value of 1,990 pounds.

To facilitate comparison of the loads presented in figure 6, table II has been prepared summarizing the peak loads and accelerations for each landing, together with the forward and vertical velocities.

CONCLUDING REMARKS

It has been found that landing speeds for the Douglas X-3 research airplane in normal flight research operations ranged from 106 percent to 145 percent of the stalling speed of 283 feet per second, with rates of descent ranging from about 2 to 5 feet per second. No apparent correlation existed between forward speed and sinking speed for the data obtained.

Landing-loads data showed that normal landings generally consisted of a series of short, mild bounces, with peak normal accelerations at the airplane center of gravity ranging from about 1.6g to 2.1g, and peak axial loads ranging from 11.8 to 21.0 percent of the design ultimate load of 65,720 pounds per wheel in the main gear. For comparison, the main-gear static-reaction load was 8,165 pounds, or 12.5 percent of design ultimate.

Maximum drag loads in the main struts varied from 10.1 to 12.8 percent of the design ultimate drag load of 33,640 pounds. Wheel spin-up appeared to be essentially complete in from 0.2 to 0.3 second following initial touchdown, after which the drag loads were generally low.

Side loads were generally low except for one landing in which some sideslipping of the airplane at impact was indicated, where 31.9 percent of the design ultimate load of 16,600 pounds was obtained.

Data obtained near the end of a landing run, and considered representative of taxiing operations, indicated that for landing conditions similar to those encountered in these tests, maximum axial loads resulting from turns during taxiing may be higher than impact loads. Axial loads up to 23.6 percent of design ultimate and side loads up to 18.1 percent of design ultimate were measured in this time interval as a result of a turn made off the runway. Drag loads were small.

Nosewheel axial loads up to 6.9 percent of ultimate were measured in one landing, with the nosewheel touchdown occurring at a forward velocity of about 247 feet per second. Nosewheel drag loads were strongly influenced by spring-back, with maximum values reaching 14.9 percent of ultimate design loads. Side loads were negligible.

High-Speed Flight Station,
National Advisory Committee for Aeronautics,
Edwards, Calif., November 19, 1957.

REFERENCES

1. Stillwell, Wendell H.: Results of Measurements Made During the Approach and Landing of Seven High-Speed Research Airplanes. NACA RM H54K24, 1955.

2. Rothi, R. D.: The Development of High Speed Tires as Experienced by the X-3 Airplane. Rep. No. SM-18316, Douglas Aircraft Co., Inc., Santa Monica, Calif., Apr. 1954.

3. Bell, N. W., et al.: Design Criteria, Model X-3. Report No. SM-13481, Douglas Aircraft Co., Inc., Santa Monica, Calif., Aug. 1949.

TABLE I.- PERTINENT DIMENSIONS AND CHARACTERISTICS

OF DOUGLAS X-3 RESEARCH AIRPLANE

Airplane:	
Length, overall, ft	66.7
Wing span, ft	22.6
Wing area, sq ft	166.5
Aspect ratio	3.09
Wing sweep at 0.75-chord line, deg	0
Wing loading at landing, lb/sq ft	105
Weight (landing), lb	17,500
Landing gear (tricycle-type):	
Wheelbase, ft	9.67
Tread, ft	6.17
Shock strut travel, in.:	
Nose gear	8
Main gear	9
Tire size:	
Nose gear	20 by 4.4
Main gear	32 by 8.8
Static reaction loads (lb) at normal landing weight:	
Nose gear	1,170
Main gear	8,200

TABLE II.- SUMMARY OF MAXIMUM LANDING-GEAR LOADS

Figure	Gear	Maximum measured loads, lb			Design ultimate, percent			V_f, ft/sec	V_v, ft/sec	$a_{n_{max}}$, g units
		F_A	F_D	F_Y	F_A	F_D	F_Y			
6(a)	Right main	7,800	3,400	1,500	11.8	10.1	9.0	347	---	1.77
6(b)	Right main	13,800	4,300	-2,600	21.0	12.8	15.7	308	2.9	2.12
6(c)	Right main	15,500	1,300	-3,000	23.6	3.9	18.1	51	---	1.23
6(d)	Left main	15,400	3,800	5,300	23.4	11.3	31.9	356	4.3	1.57
6(e)	Nose	820	1,000	-50	6.9	14.9	2.5	247	---	----

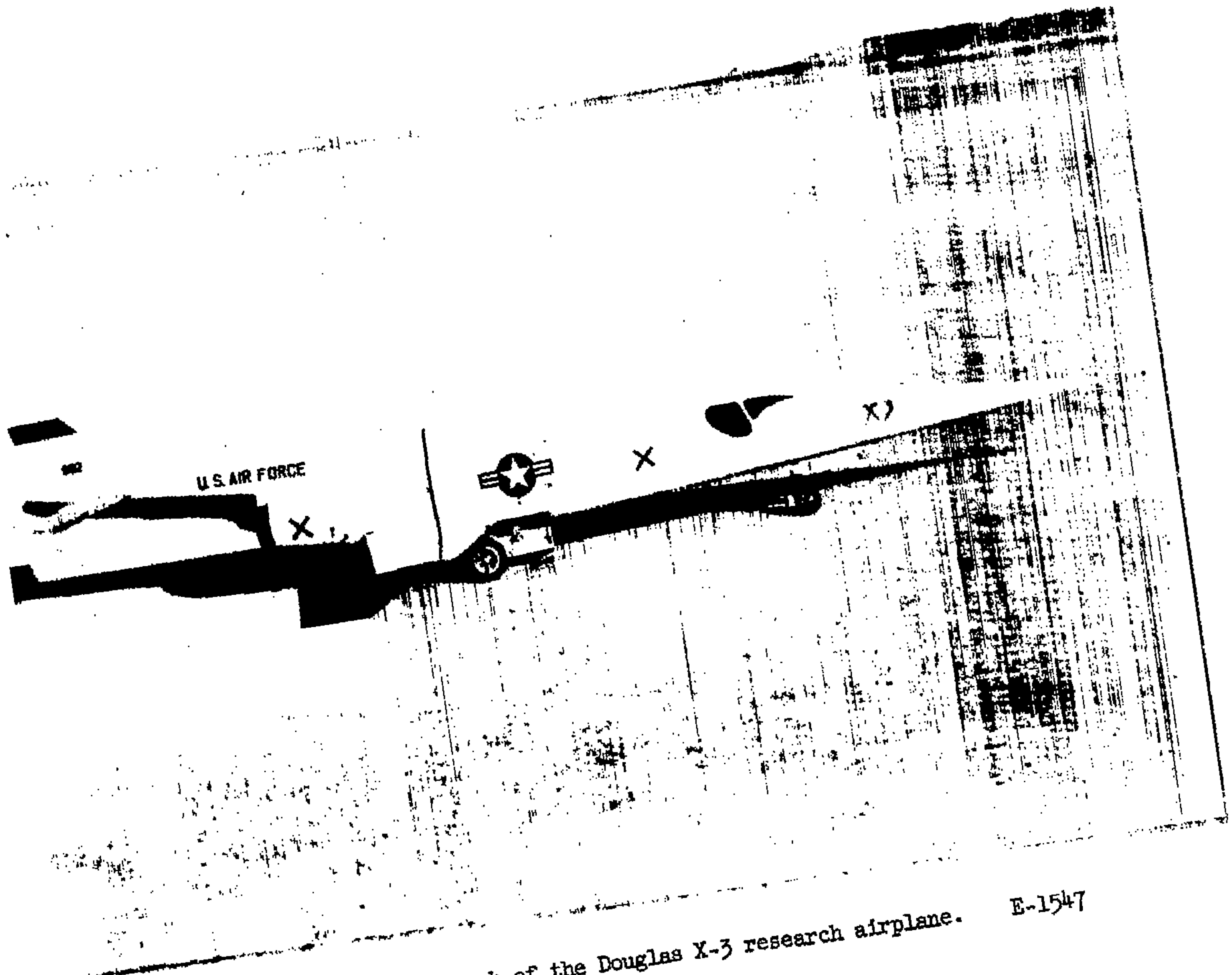

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Figure 1.- Photograph of the Douglas X-3 research airplane.

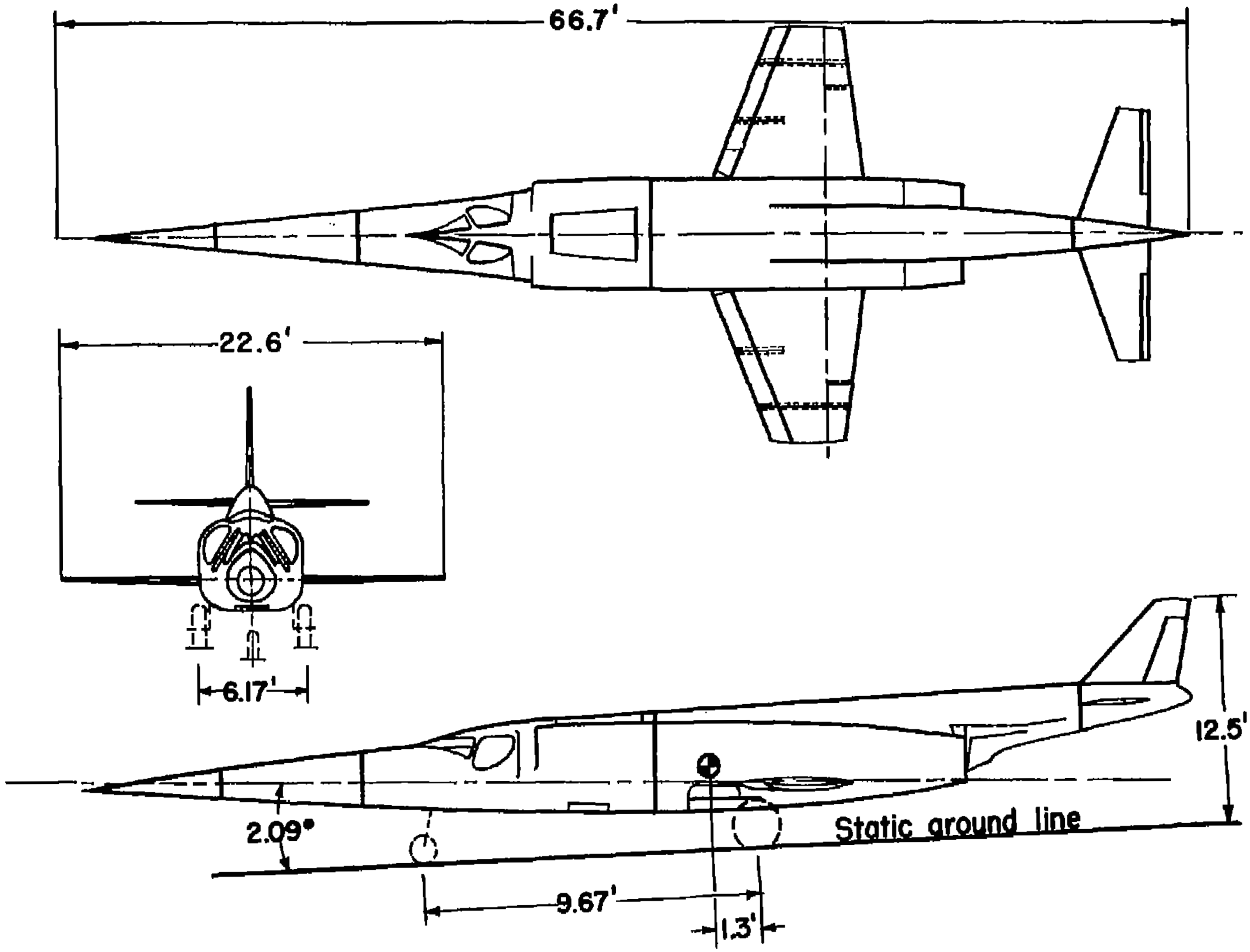
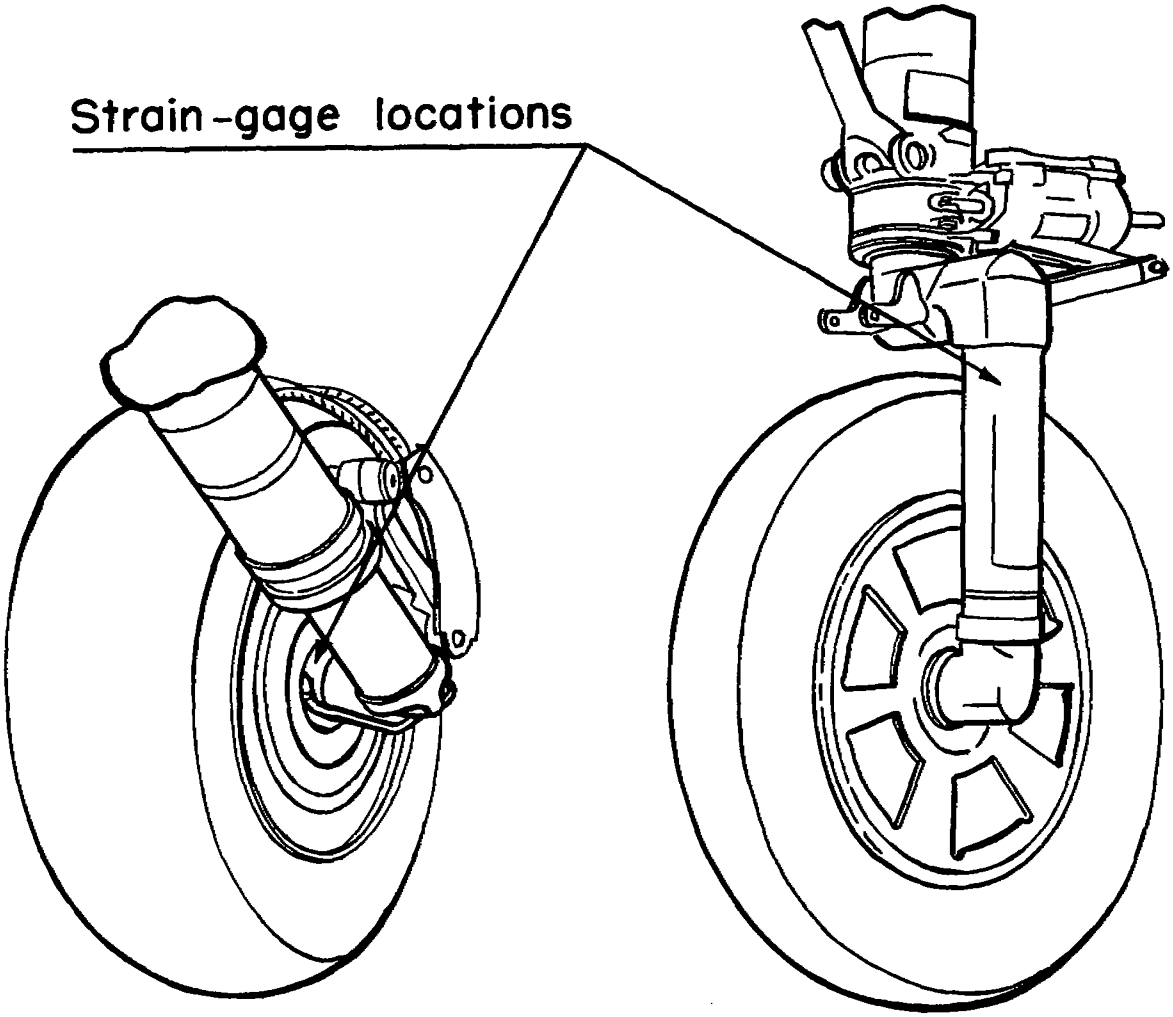


Figure 2.- Three-view drawing of the Douglas X-3 research airplane.



(a) Main gear.

(b) Nose gear.

Figure 3.- Sketch of X-3 airplane landing gear showing location of landing-gear strain gages.

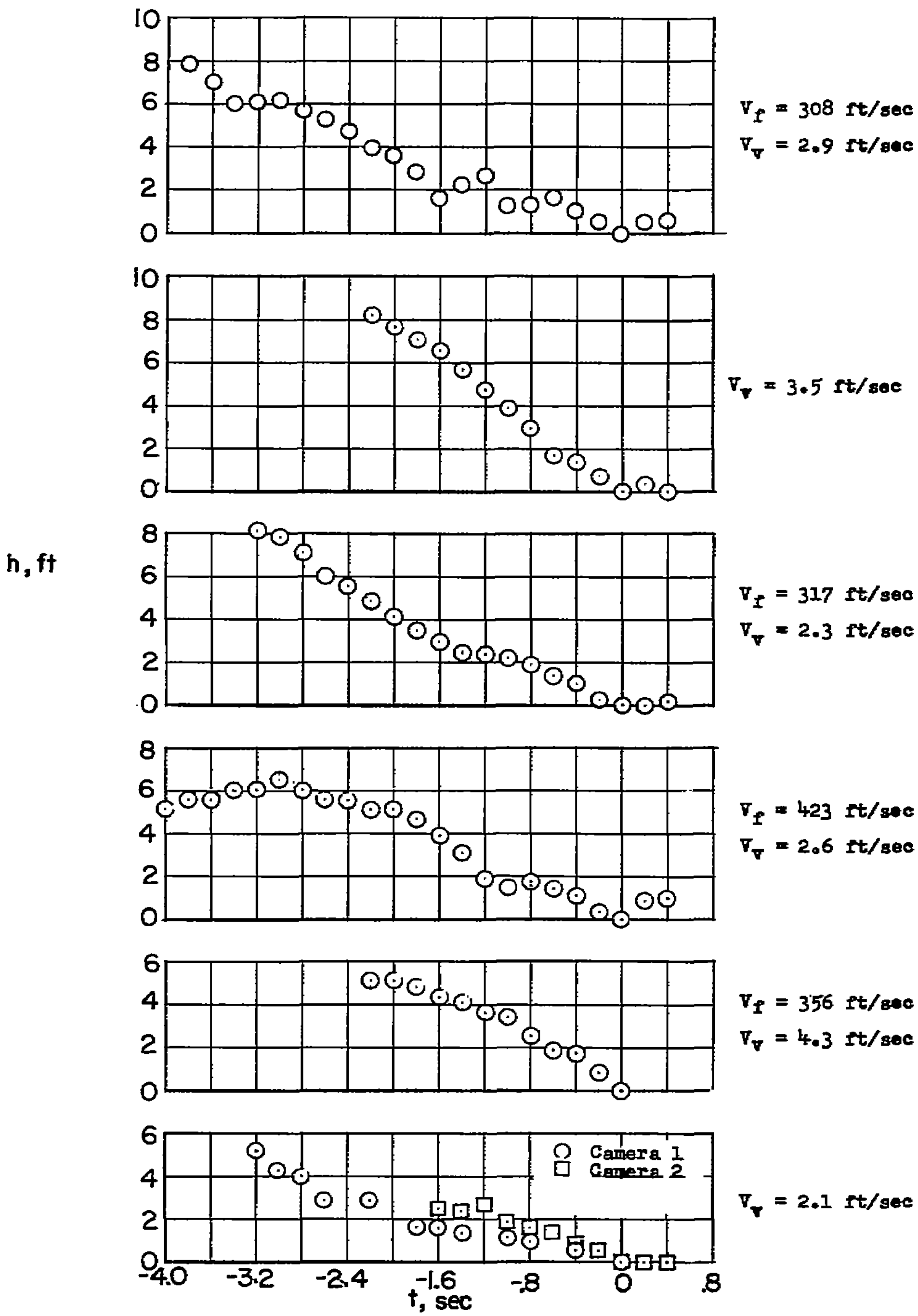
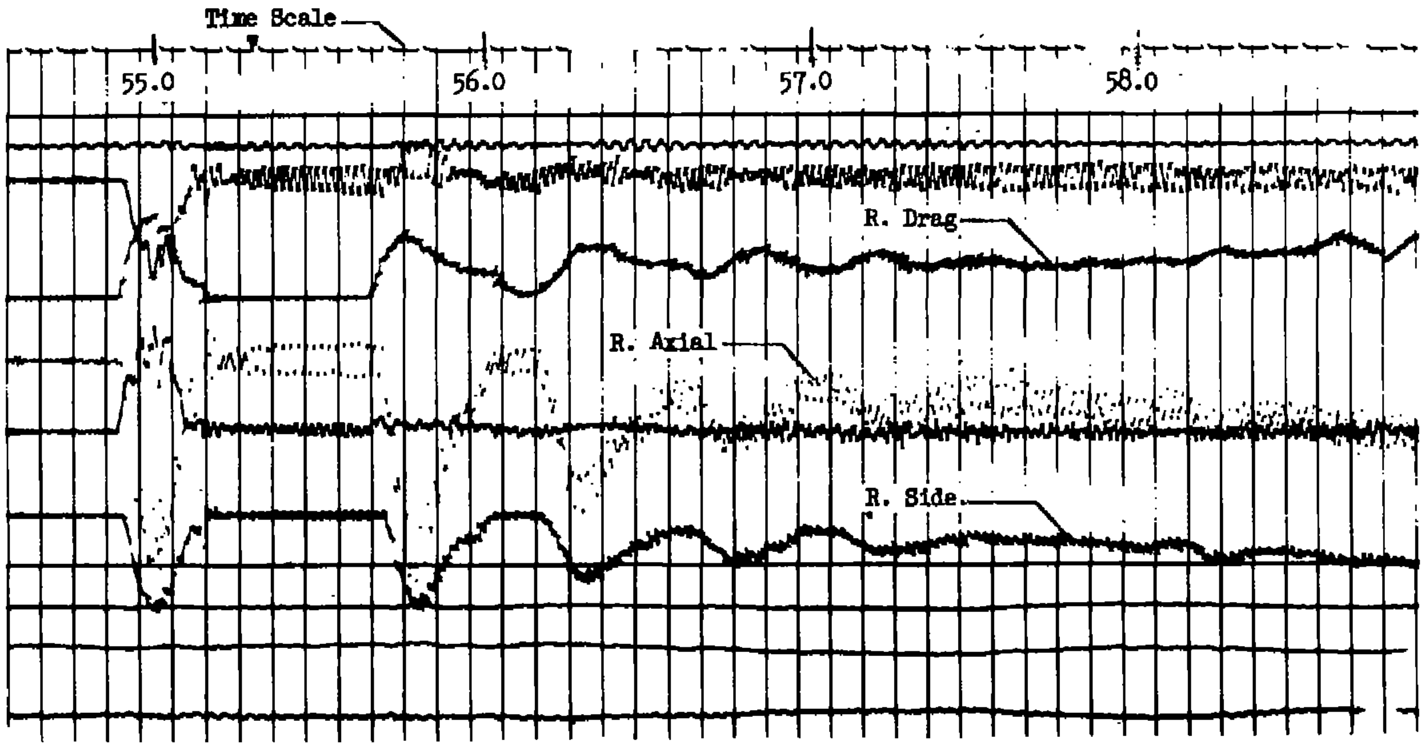
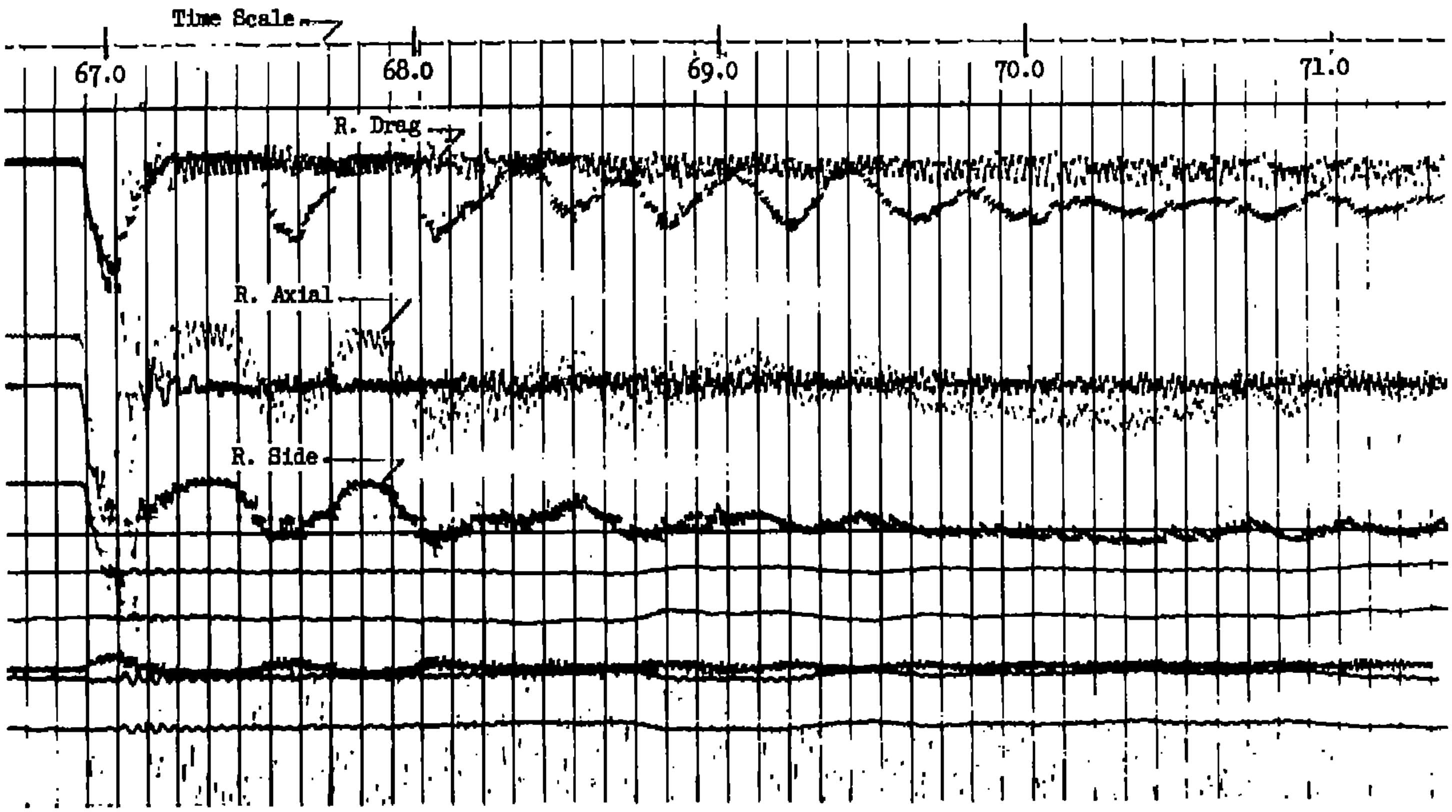


Figure 4.- Variations of altitude with time for six typical landings of the X-3 airplane.



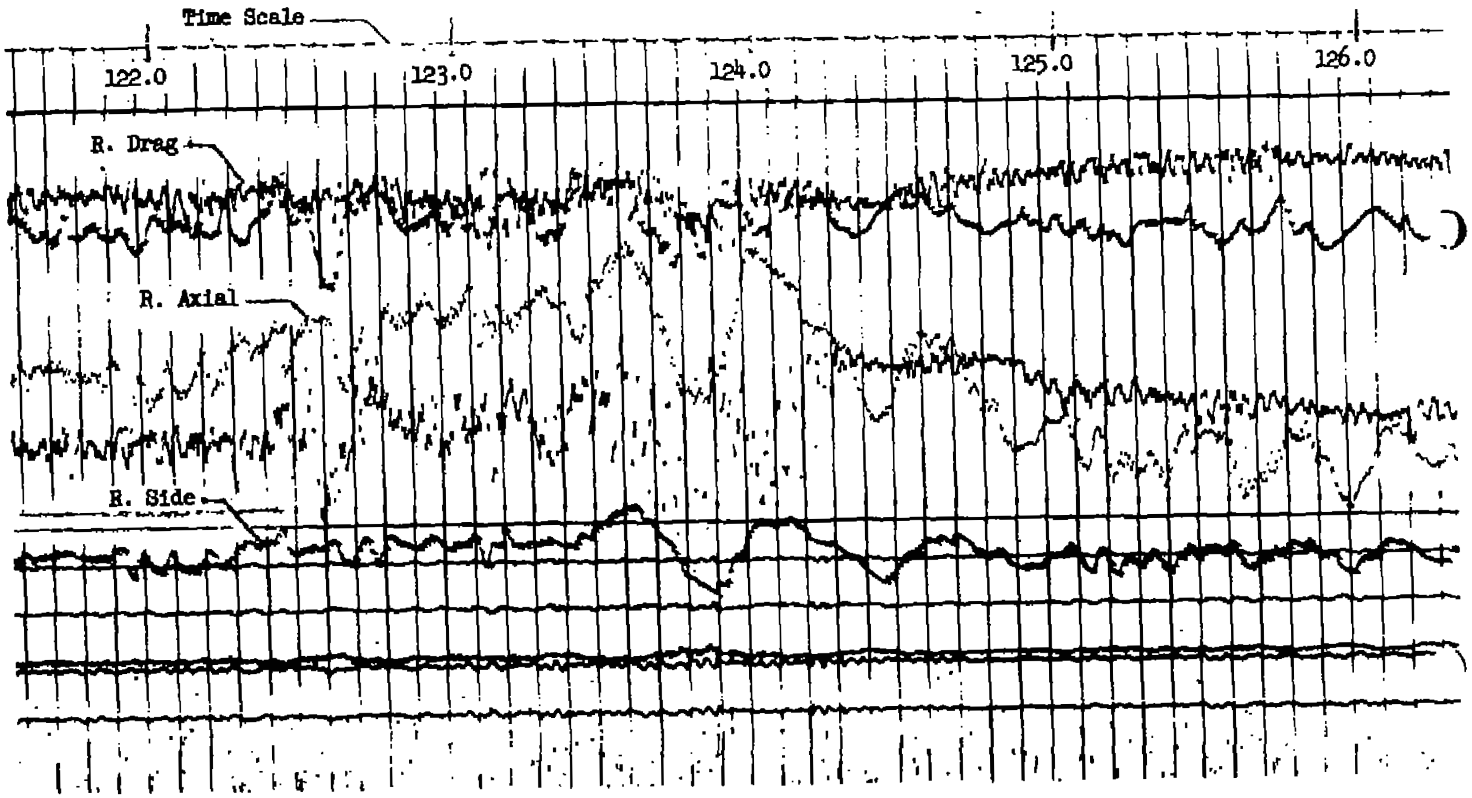
(a) Flight A; impact time 54.94 seconds.

Figure 5.- Reproductions of portions of X-3 airplane oscillograph records showing the response of the landing-gear strain gages.



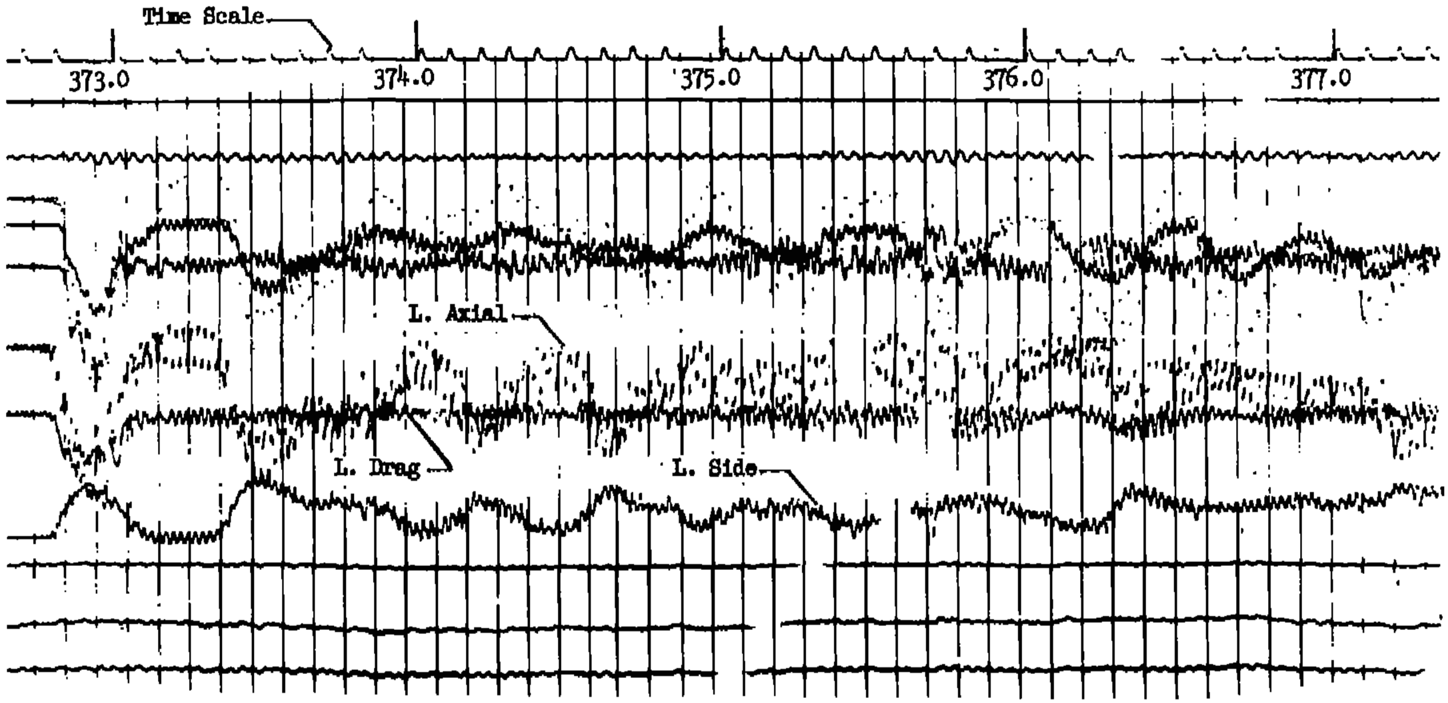
(b) Flight B; impact time 66.90 seconds.

Figure 5.- Continued.



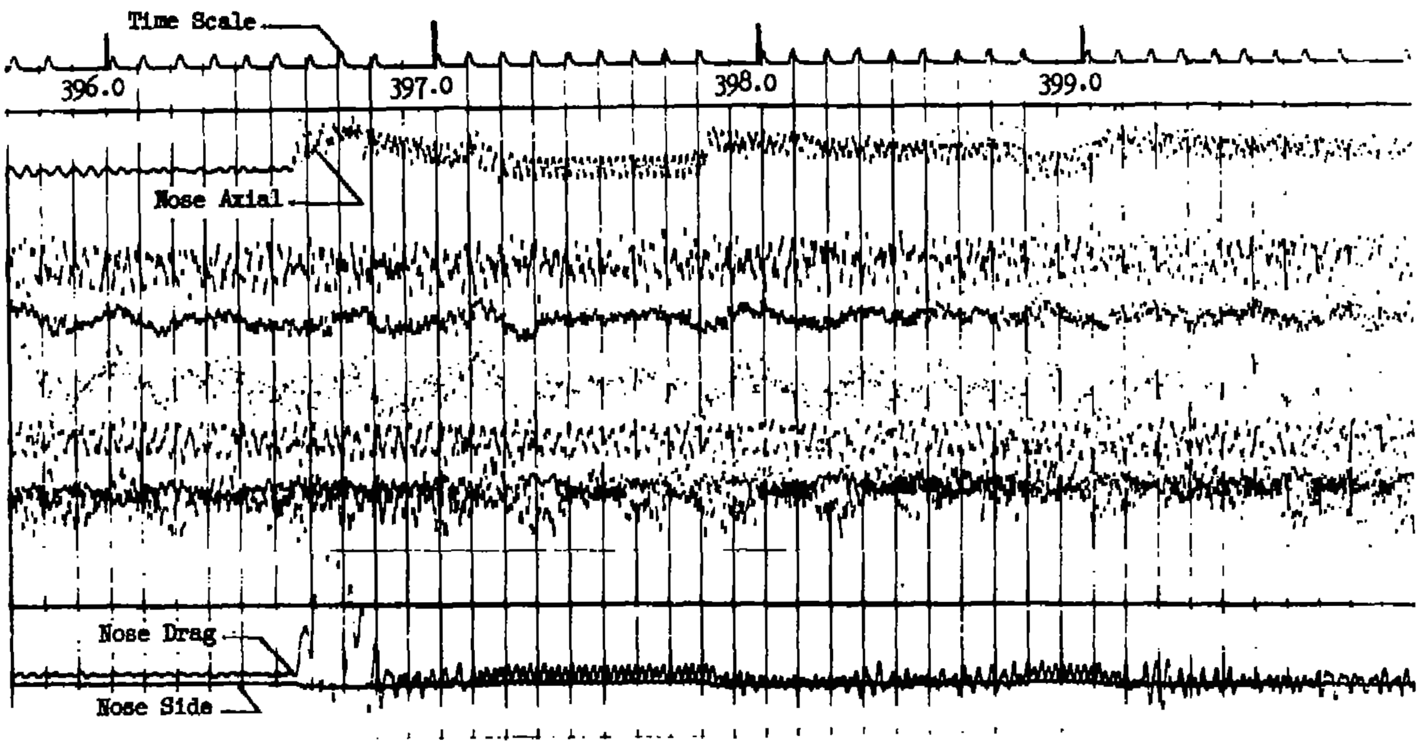
(c) Flight B; 56 seconds after impact.

Figure 5.- Continued.



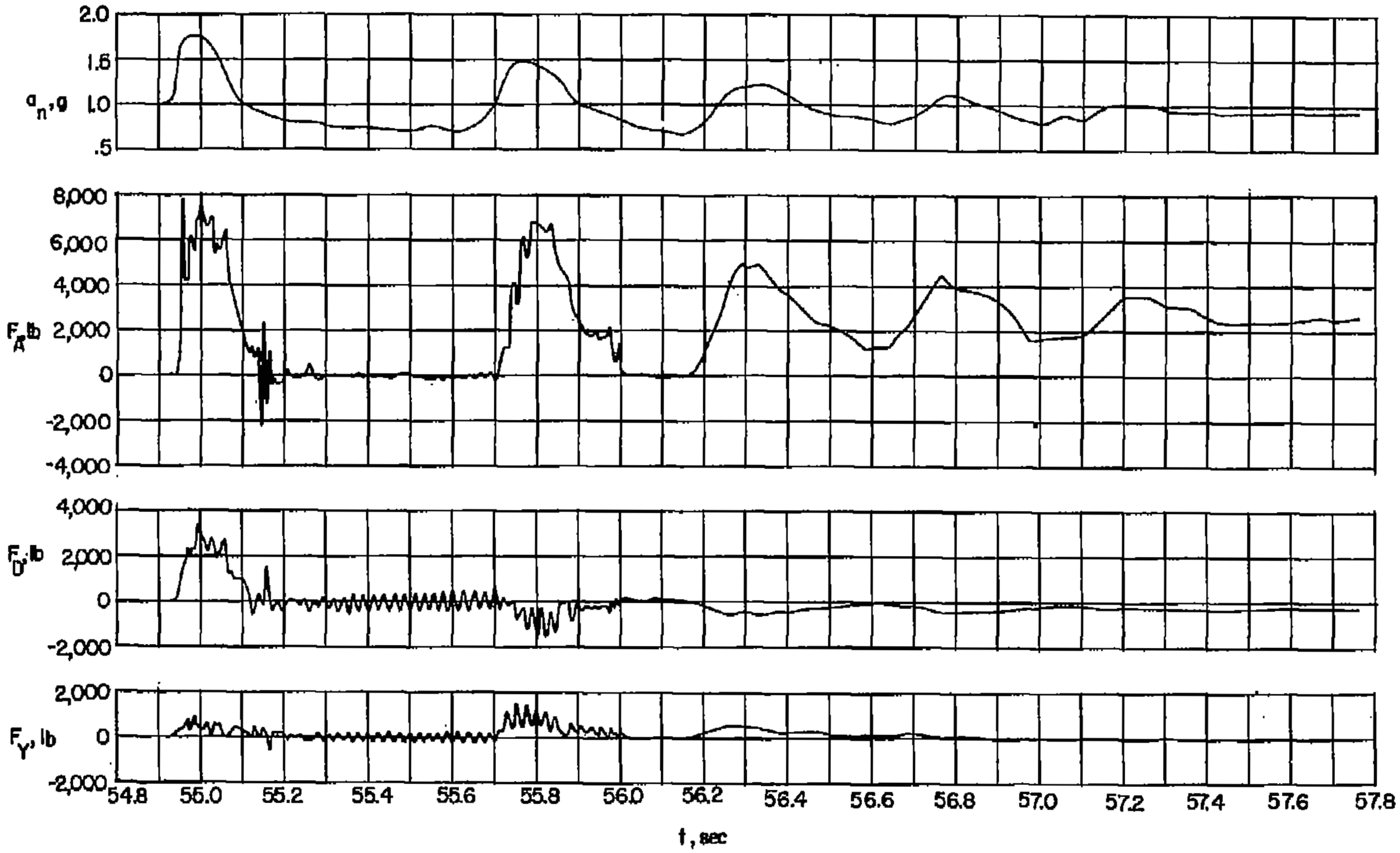
(d) Flight C; impact time 372.80 seconds.

Figure 5.- Continued.



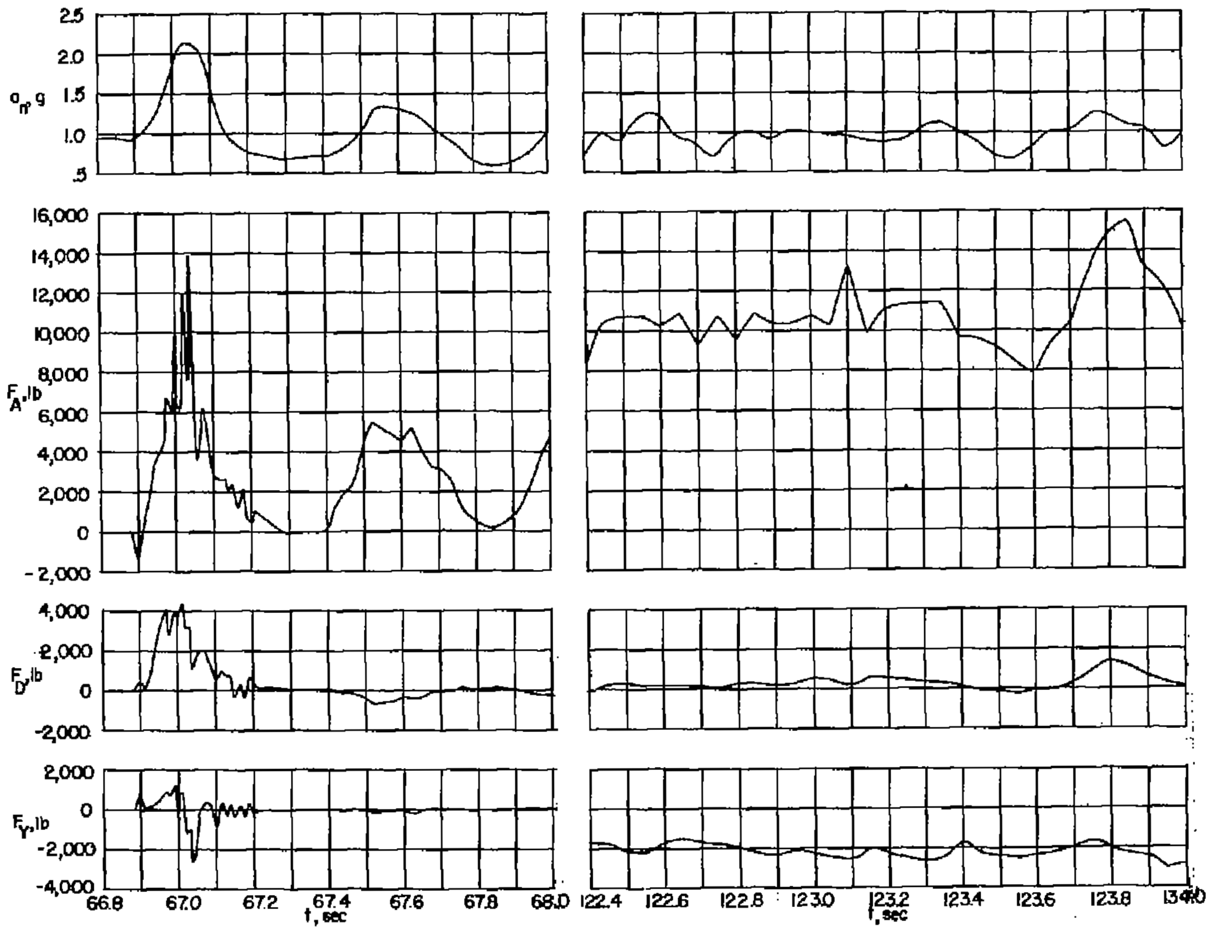
(e) Flight C; nose-gear impact.

Figure 5.- Concluded.



(a) Flight A; right main-gear impact loads; forward velocity 341 ft/sec.

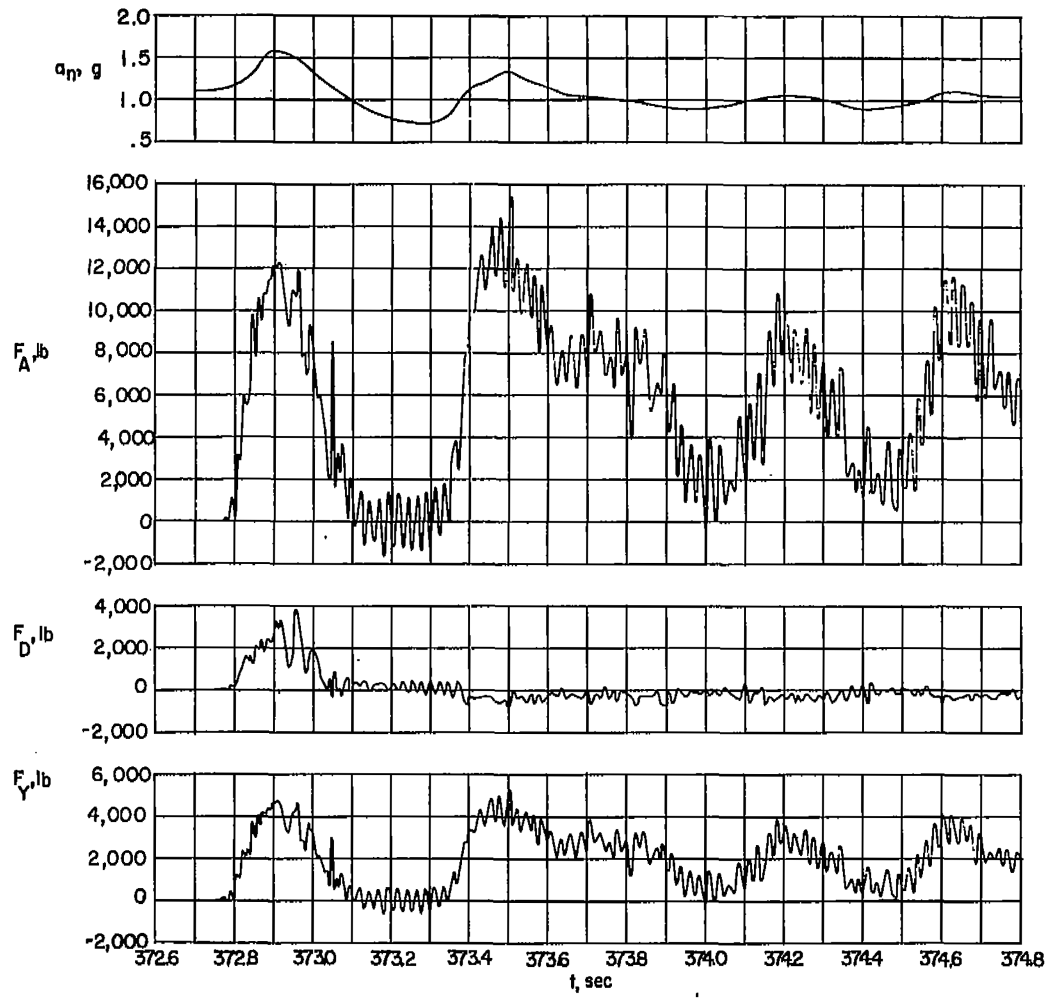
Figure 6.- Time histories of landing-gear loads during routine operations of the X-3 airplane.



(b) Flight B; right main-gear impact loads; forward velocity 308 ft/sec; sinking speed 2.5 to 3.5 ft/sec.

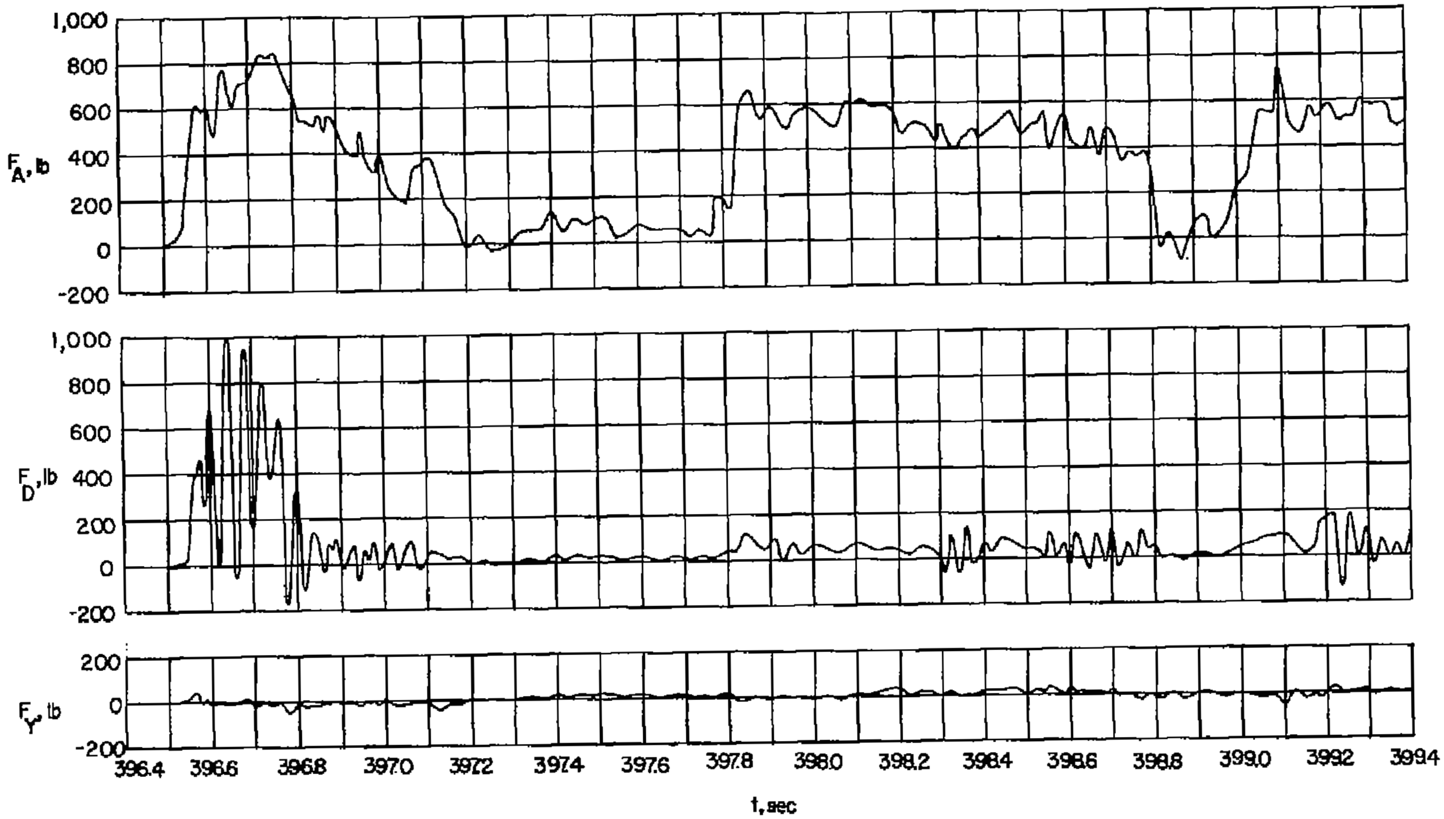
(c) Flight B; right main-gear loads during landing runout; forward velocity ≈ 50 ft/sec.

Figure 6.- Continued.



(d) Flight C; left main-gear impact loads; forward velocity 356 ft/sec; sinking speed 4.3 ft/sec.

Figure 6.- Continued.



(e) Flight C; nose-gear impact loads; forward velocity about 247 ft/sec.

Figure 6.- Concluded.

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