MR Aug. 1944

AUG 8 1947

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
August 1944 as
Memorandum Report

ACCELERATIONS MEASURED AT CENTER OF GRAVITY AND ALONG SPAN OF THE WING OF A B-24D AIRPLANE IN LANDING IMPACTS

By John R. Westfall

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

ACCELERATIONS MEASURED AT CENTER OF GRAVITY AND ALONG SPAN OF THE WING OF A B-24D AIRPLANE IN LANDING IMPACTS

By John R. Westfall

SUMMARY

During the course of a series of tests on a Consolidated B-24D airplane, made with the primary purpose of determining loads imposed upon the horizontal tail, measurements were taken of accelerations at various points on the wing during landing impacts.

Landings were made with the wheels initially stationary but free to rotate, with the brakes set before contact, and with the main wheels rotating prior to contact. The landings were generally moderate, the average vertical velocity at contact being about 2.3 feet per second, and the highest 6.9 feet per second. The maximum value of increment of wing-tip acceleration was 13.5g, occurring with a maximum increment of acceleration at the center of gravity of 1.4g. The average ratio of maximum increment of wing-tip acceleration to maximum increment of center-of-gravity acceleration was about 7.

In general, there appeared to be little difference in the magnitude of the peak accelerations recorded for normal, braked, and prerotation landings of comparable severity. However, the vibrations of the wing were prolonged in the braked landings, whereas in the normal and prerotation landings they damped out rather rapidly.

INTRODUCTION

At the request of the Army Air Forces, Materiel Command, the NACA conducted a series of tests

on a B-24D airplane that included measurements of the horizontal-tail loads in flight and landing and supplementary measurements of wing vibration and landing-gear behavior.

The results of the tail-load investigations in landing impacts have been presented in reference 1. The data presented in this paper consist primarily of time histories of accelerations at the center of gravity and along the span of the wing of the B-24D, and also of the normal component of the landing-gear loads. This information was requested by the Army Air Forces, Materiel Command, Wright Field, in January 1944.

APPARATUS AND INSTRUMENTATION

The airplane on which the tests were conducted was a four-engine bomber, the Consolidated B-24D. Its general specifications are given in table I, and two views of its external appearance are shown in figures 1 and 2.

For determining the horizontal-tail loads, the airplane was instrumented with electrical strain gages and accelerometers. The strain gages were attached to the front and rear spars of the horizontal stabilizer to determine the tail bending moments, and to the main landing-gear struts and nose-wheel strut to determine the vertical and drag components of the ground reactions. Standard NACA three-component accelerometers were installed near the center of gravity of the airplane, at the center of the fuselage, and the center of the stabilizer. Before the landing tests began, it was decided to install two more accelerometers, one near the tip of each wing. After about half of the landings had been made, two more accelerometers were installed in the left wing, one near the attachment of the main landing-gear strut to the wing and the other in the wheel well near the outboard engine nacelle. Figures 3 and 4 show the attachment of the strain gages to the landing-gear struts, and figures 5 through 8 show installation of the accelerometers at the center of gravity, the center of the stabilizer, the outboard nacelle, and the wing tips. Figure 9 is a sketch of the airplane showing the accelerometer locations in the airplane.

A photographic record of the behavior of the main landing gear during impact was obtained by two 35-millimeter cameras having speeds of about 60 frames per second, mounted beneath the fuselage of the airplane. Stationary targets, attached to the lower end of a tripod-supported boom whose upper end was secured to the wing structure, were installed in the fields of view of the cameras to serve as reference points in determining the movement of the gear. Camera and target installations are shown in figures 10 and 11. All of the instruments in the airplane were synchronized by means of an NACA timer.

Attitude angle of the airplane and vertical velocity at contact were determined by means of two phototheodolites. A description of the phototheodolites and the method of evaluating their data is given in reference 2.

The airspeed and ground speed at contact were determined from the readings of the pilot's airspeed indicator, which had been calibrated against true airspeed, and the surface wind velocity and direction. As a check, the ground speed was computed from the wheel pictures and gave good agreement.

Two hydraulic pressure gages were installed in the airplane's brake lines to indicate brake pressure for certain landings which were made with varying amounts of pressure applied to the brakes before landing.

PRECISION OF DATA

The measurements presented in this paper are believed to lie within the limits of error shown below. The amount of deviation is based on the spread between repeat readings of the same point, the differences in values obtained from different instruments, the known mechanical limitations of the instruments, and the conditions under which the loads were applied to the instruments.

Gross weight of airplane at contact, lb	±100
Ground speed at contact, mph	±3
Vertical velocity, ft/sec	±1.0
Attitude angle at contact, deg	±0.7
Main wheel loads, from strain gages, percent	±5.0
Nose wheel loads, from strain gages, percent	±15.0
Normal component of acceleration, from accelerometer records, g	
Center of gravity	±0.2
Center of tail	±0.3
Left tail tip	±0.3
Inboard nacelle	±0.2
Outboard nacelle	±0.3
Wing tip	±1.0

TEST PROCEDURE

A total of 58 landings were made. These included (a) normal landings (that is, the main wheels were stationary prior to contact but free to rotate); (b) braked landings, the brakes being set before contact, with varying amounts of pressure, but being released again as soon as the initial impact was over; and (c) landings in which the main wheels were given rotational speed prior to contact.

All of the landings were made on the concrete runways of Langley Field, Va. The runways had been coated, about a year and a half earlier, with a camouflage material consisting of sawdust spread on an asphalt binder. At the time these tests were begun, perhaps one-third of the surface of the runways used was still covered with the camouflage coating in patches of varying size, shape, and thickness. The airplane was flown by NACA test pilots who had a great deal of previous experience with other aircraft although no previous experience with the B-24.

Landings were made over a wide range of landing speeds and a somewhat narrower range of landing attitudes. No completely stalled landings were made because of the possibility of the tail contacting first, with resultant structural damage. The angle of the longitudinal axis of the airplane at the time of contact ranged from -1.4° to 6.1°, corresponding to a wing angle-of-attack range of from 1.6° to 9.1°. Ground speed at contact varied

from 80 to 128 miles per hour, and vertical velocities from 0.9 to 6.9 feet per second at contact were recorded.

Loading the brakes before contact was done by means of a device which permitted an adjustable pressure to be put on the hydraulic brake lines. A release lever, operated by the co-pilot, made possible instantaneous release of the brakes at any desired time. The brakes were usually cut off immediately after the initial impact. The maximum brake pressure used during the tests was 25 pounds per square inch. Observations of the brake pressures during taxying after landing showed that about 20 pounds per square inch was the maximum used in decelerating the airplane in normal landings in which the brakes were not set prior to contact.

An attempt was made to bring about prerotation of the main landing wheels by means of special fittings with anemometer-cup-type wind vanes; however, they did not prove satisfactory. Prerotation of the wheels was accomplished by touching the wheels to the runway to bring them up to rotational speed, lifting the airplane off the runway by speeding up the engines, and again making contact with the runway while the wheels were revolving at high speed.

PRESENTATION AND DISCUSSION OF DATA

Table II lists the natural frequency of vibration of the various structural components of the airplane. Table III classifies the landings as to type and severity of impact, and lists conditions at contact and maximum accelerations and loads.

Most of the landings were of normal or moderate severity, the average vertical velocity at contact being about 2.3 feet per second, and the highest 6.9 feet per second. Ground speeds at contact averaged about 97 miles per hour.

Figures 12 through 29 are time histories of wing and center-of-gravity accelerations and landing-gear normal loads for representative normal, braked, and prerotation landings. The time after contact specified on the charts is the time after the first wheel contacted the ground,

whether that was left or right main landing wheel or the nose wheel. Peak values of increment of wing-tip acceleration as high as 13.5 were recorded (fig. 17), though the average was about 7g. The highest value of increment of acceleration at the center of gravity was about 1.6g and the average was 0.6g. For comparison purposes, landings in which the maximum increment of acceleration at the center of gravity was less than 0.6g are hereinafter referred to as soft landings, and those in which the value was higher are called hard landings. It is recognized that the hardest landings recorded in these tests were not extremely severe. For normal, braked, and prerotation landings of comparable severity, there seemed, in general, to be little difference in the magnitude of the accelerometer record peaks. However, in the case of braked landings, the vibrations usually continued over a longer period of time than in the case of the normal and prerotation landings. This seemed to be generally true regardless of the relative severity of the impact. Figure 30 compares a normal, braked, and prerotation landing of about the same severity of impact (moderate, in all cases) and figure 31 compares the magnitude and duration of the vibrations for a normal and braked landing that were among the hardest made during these tests.

After one landing, accelerometer records were taken during the run while the airplane was decelerating. The pilot applied his brakes hard several times, the purpose being to determine tail accelerations. The wing accelerations were small and the vibrations did not persist as in the case of a braked landing. A time history of the wing accelerations in this taxi run is shown in figure 32.

Figures 33 through 53 depict time histories of wing and center-of-gravity accelerations for miscellaneous normal, braked, and prerotation landings, most of them being comparatively soft.

Figures 54 and 55 present the ratio of maximum increment of wing-tip acceleration to maximum increment of center-of-gravity acceleration, plotted against maximum increment of center-of-gravity acceleration. The increments of acceleration were determined by subtracting an assumed airload of 1g from the maximum values recorded by the accelerometers. There was considerable scatter in the values, probably due chiefly to large percentage

of error in determining the smaller values of acceleration, especially at the center of gravity. (See section on Precision of Data.) However, there seemed to be a trend toward higher ratios for the softer landings (smaller values of center-of-gravity acceleration) and smaller ratios for harder landings. The average value for all landings was about 7.

SUMMARY OF RESULTS

1. The maximum increment of wing-tip acceleration recorded was 13.5g, in a landing in which the center-of-gravity maximum acceleration increment was 1.4g.

2. Normal, braked, and prerotation-type landings of comparable severity seemed to have maximum accelerations of roughly equal magnitude.

3. The wing vibrations were usually more prolonged in braked landings, even though the brakes were released immediately after impact.

4. The average ratio of maximum increment of wing-tip acceleration to maximum increment of center-of-gravity acceleration was about 7.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., August 8, 1944

REFERENCES

1. Westfall, John R.: Measurements of Landing-Gear Forces and Horizontal-Tail Loads in Landing Tests of a Large Bomber-Type Airplane. NACA TN No. 1140, 1946.

2. Wetmore, J. W.: NACA Apparatus and Methods for Take-Off and Landing Measurements. NACA CB, Jan. 1943.

TABLE I

SPECIFICATIONS OF THE CONSOLIDATED

B-24D AIRPLANE

Gross weight at landing, lb	48,900 to 50,100
Wing span, ft	110
Wing area, sq ft	1,048
Horizontal tail area, total, sq ft	192.0
Stabilizer area, sq ft	140.5
Weight of tail assembly, lb	869.6
Normal rated horsepower	4,400
Center-of-gravity location, as flown, percent M.A.C.	27.9 to 28.2
Height of center of gravity above ground, static position of airplane, ft	8.2
Approximate moment of inertia in pitch, as flown, slug-ft^2	150,000
Moment of inertia of main wheel, slug-ft^2	33.5
Wheel tread, ft	25.62
Wheelbase, ft	16.00

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TABLE II

NATURAL VIBRATION FREQUENCIES OF THE B-24E AIRPLANE

[The B-24E is practically identical structurally to the B-24D]

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Part	Type of vibration	Frequency cpm	Vibrator location	Remarks
Wing (approx. 400 gal gas in each wing)	Symmetrical bending	215	Outboard end of aileron.	Nodal line just outboard of inboard engine. Large fuselage vertical motion.
	Symmetrical inner-panel torsion combined with symmetrical bending	315	Outboard end of aileron.	Nodal line runs diagonally from just outboard of outboard engine at leading edge to wing root at trailing edge. Outboard engine pitching considerably.
	Inner-panel torsion	520	Between cylinders No. 7 and 9 on engine No. 2.	Small response outboard engines; larger response inboard engines. Amplitude too small to check phase. Rear of fuselage moving vertically.
		515	Floor of fuselage just forward of tail turret.	
	Higher order bending	590	Outboard end of aileron.	Phase symmetrical by pickups.
		990	Outboard end of aileron.	Phase unsymmetrical by pickups.
		1360	Outboard end of aileron.	Phase symmetrical by pickups.
Fuselage	Side-bending	340	Inspection door on bottom of fuselage, 2 feet forward of tail light. Lateral impulses.	Very small amplitude.
		520	Thrustwise impulses at bottom rudder hinge.	Large amplitude mode. Node at waist gun cutout.
	Vertical-bending	980	Floor of fuselage just forward of tail turret.	Amplitude too small to determine node line.
Stabilizer	Symmetrical bending combined with wing symmetrical bending. Pitching of airplane excited also.	400	Vertical impulses at second rudder hinge from bottom.	Stabilizer nodes $4\frac{1}{2}$ feet from center line of airplane. Wing tip and stabilizer tip in phase.
	Torsion	640	Thrustwise impulses at bottom rudder hinge.	Phase symmetrical by pickups.
Main landing gear	Fore-and-aft bending	410		Nodal line near rear spar.

(From AAF Memorandum Report on Flutter Inspection of the Ford B-24E Airplane. Wright Field, Dayton, Ohio, October 1-5, 1942.)

TABLE III

LANDINGS CLASSIFIED ACCORDING TO TYPE AND SEVERITY OF IMPACT

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Landing number	Increment of maximum acceleration, g							V_v, fps	Ground speed, mph	Attitude angle degrees	Maximum main gear vertical loads, lb.			*Maximum nose wheel vertical loads, lb.
	at c.g.	at inboard nacelle	at outboard nacelle	at left wing tip	at right wing tip	at center of tail	at left tail tip				Left	Right	Total	
							NORMAL							
7	1.55	----	----	7.65	11.60	3.55	7.20	6.5	102	-0.9	40,500	31,200	70,100	15,400
16	1.40	----	----	6.80	13.50	3.90	6.00	4.2	118	3.9	28,700	33,600	61,800	------
39	1.35	2.10	1.70	6.70	4.65	3.10	6.20	6.9	128	-1.4	40,000	22,800	57,000	3,500
36_1	1.00	.60	1.12	2.90	3.15	1.55	5.60	2.6	102	---	22,350	21,300	43,600	------
10	.80	----	----	4.50	3.10	1.10	3.10	4.0	107	.9	28,000	15,000	31,700	------
13	.70	----	----	4.60	6.80	1.60	2.30	2.9	103	5.2	27,900	24,700	50,200	------
27_1	----	----	----	----	----	----	----	2.6	82	---	19,000	25,100	40,000	------
35_1	.65	.80	1.48	4.15	5.30	2.20	2.70	3.1	100	0.5	11,830	16,550	26,700	------
9	----	----	----	3.85	3.10	1.10	1.40	2.2	102	1.7	15,200	27,300	33,400	------
5	.60	----	----	2.97	4.00	1.70	6.10	2.5	106	1.2	23,300	16,400	29,400	3,200
17	.60	----	----	4.05	6.50	1.45	5.80	2.4	84	---	20,400	14,500	33,600	------
3	----	----	----	----	4.42	1.00	2.90	1.8	97	5.3	1,800	------	34,100	------
29_1	.60	1.20	1.72	4.92	2.30	1.10	2.70	2.9	100	---	32,200	7,300	32,200	------
40	.60	.60	.70	2.30	5.30	1.20	2.70	1.1	102	0.2	13,050	16,400	29,000	------
30_1	.60	.79	1.08	5.00	4.90	1.15	3.30	1.9	98	3.6	28,650	25,700	24,900	------
20	.55	----	----	2.63	3.65	1.25	2.00	2.3	100	3.6	4,900	9,850	25,100	------
25_1	----	1.50	1.00	2.80	2.70	1.05	1.70	1.5	90	---	7,600	19,250	27,500	------
$33a_1$	.60	1.15	1.65	4.35	1.85	1.20	1.90	1.4	98	1.1	15,560	6,400	17,800	------
26_1	.55	.40	.60	2.00	6.50	.80	2.30	1.4	87	---	10,800	17,980	23,400	------
33_1	.35	.40	.60	2.00	----	.85	1.25	1.4	87	---	7,900	10,900	18,800	------
2a	.65	----	----	3.40	4.65	1.45	2.90	1.9	116	1.0	20,900	13,800	30,500	------
2	----	----	----	----	3.25	1.15	2.50	1.7	113	-0.1	32,800	34,200	34,200	------
24_1	----	----	4.20	7.45	----	1.70	3.70	1.6	82	---	18,600	8,140	26,600	------
1	----	----	----	----	3.75	1.40	2.90	1.3	96	5.1	20,400	------	31,600	------
37	.30	.60	.90	3.15	1.90	.90	1.30	1.4	87	3.0	14,400	15,900	26,000	------
38	.35	.70	.90	2.60	1.40	.90	1.40	1.3	89	4.4	15,950	10,675	16,000	------
6	.30	----	----	1.50	3.08	.55	----	.7	91	6.1	13,560	9,700	21,900	------
14	.30	----	----	1.50	3.20	.30	1.00	---	98	4.5	------	------	------	------
21	---	----	----	3.00	2.90	.60	1.25	.9	94	3.9	13,600	6,050	9,500	------
$34a_1$	.20	.40	.60	1.55	2.95	.40	.80	1.6	98	0.8	8,560	7,900	11,200	------
34_1	.30	.25	.65	1.90	----	.75	1.15	---	--	---	10,500	12,500	------	------
							BRAKE							
41	1.10	.35	.90	7.85	10.70	2.60	4.00	5.8	91	1.0	34,000	40,700	69,300	3,600
31	1.20	----	1.85	5.70	----	2.25	3.90	4.9	96	0.8	26,800	35,900	61,700	------
11	.80	----	----	3.78	5.75	.35	4.80	3.6	87	0.4	25,650	20,700	48,800	------
8	.90	----	----	5.42	5.37	1.20	3.00	4.1	98	3.7	29,400	21,400	44,900	------
22	.65	----	----	4.60	6.30	1.70	2.80	4.2	96	1.9	20,700	23,000	43,200	------
18	.75	----	----	7.10	6.50	1.35	2.70	2.8	90	---	28,700	26,400	52,400	------
12	.50	----	----	5.23	2.85	1.30	2.90	3.0	89	2.4	19,350	38,650	39,800	------
16	.35	----	----	2.10	4.57	.50	2.10	2.2	105	3.2	24,500	25,750	38,700	------
32	.30	----	1.13	4.00	----	.75	1.90	1.8	91	4.5	11,400	11,400	25,100	------
4	----	----	----	----	2.07	1.10	1.60	1.8	88	5.7	1,800	------	33,000	------
28	.30	.45	.82	2.88	2.40	.80	1.90	1.0	81	---	1,600	10,880	21,000	------
19	---	----	----	2.30	3.75	.20	1.60	1.2	84	5.1	11,750	8,525	21,900	------
23	.35	----	----	2.62	2.21	.70	1.30	.9	94	2.7	11,300	10,300	23,700	------
							PREROTATION							
27_2	.80	1.20	1.25	2.60	2 60	.95	2.55	2.3	80	---	20,300	17,430	37,700	1,400
35_2	.80	.85	1.00	2.40	3.35	1.20	2.40	2.9	94	2.5	9,200	17,400	24,700	------
34_2	.35	.50	1.13	4.15	----	.70	1.50	3.1	---	---	11,200	10,200	34,600	------
24_2	.80	1.30	1.66	4.80	3.15	1.35	3.12	1.8	80	---	19,850	17,700	34,900	------
29_2	.65	.86	1.00	2.17	6.31	1.25	3.10	3.0	97	4.8	13,800	17,000	30,800	------
36_2	.55	----	----	----	----	.50	.20	2.1	100	3.8	17,100	13,000	28,600	------
33_2	.40	.50	1.25	3.55	----	.75	1.25	2.2	---	---	9,100	26,100	29,200	------
30_2	.40	.50	.95	2.20	----	.60	1.50	1.2	96	3.7	19,500	16,100	22,000	------
26_2	.30	.45	1.50	1.80	1.80	.35	1.00	1.0	82	---	10,300	9,325	18,700	------
$33a_2$	.40	.45	.65	2.70	2.00	.60	.80	1.0	94	2.4	9,030	7,900	10,100	------
26_2	.25	.70	1.12	2.75	2.65	.35	1.70	.9	83	---	12,550	16,150	15,200	------
$34a_2$	.35	.45	.55	1.35	1.30	.45	.40	1.3	90	4.9	9,060	9,950	13,000	------

* Nose wheel loads listed only when nose wheel contacted during major portion of impact.

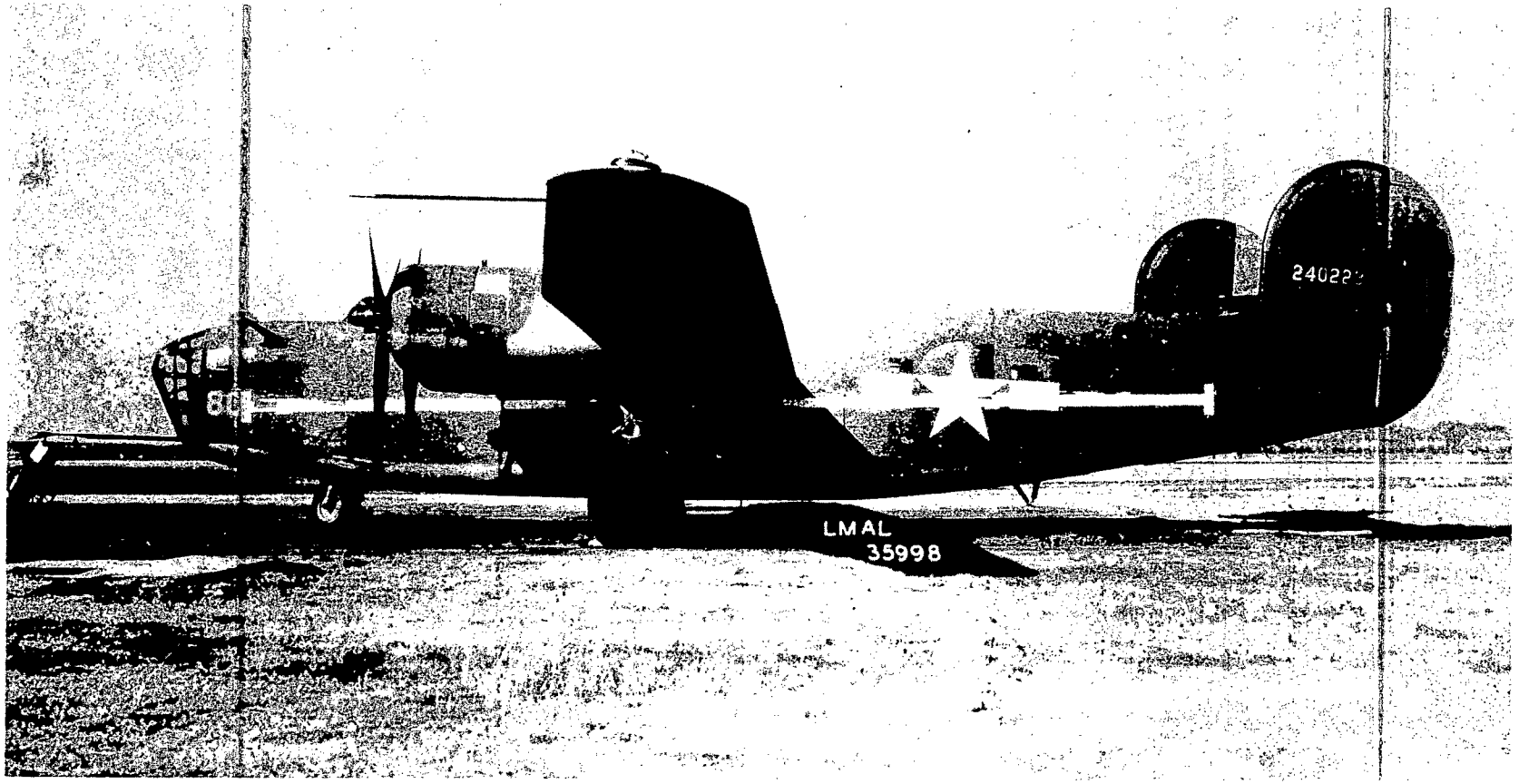

Figure 1.- Side view of the B-24D airplane.

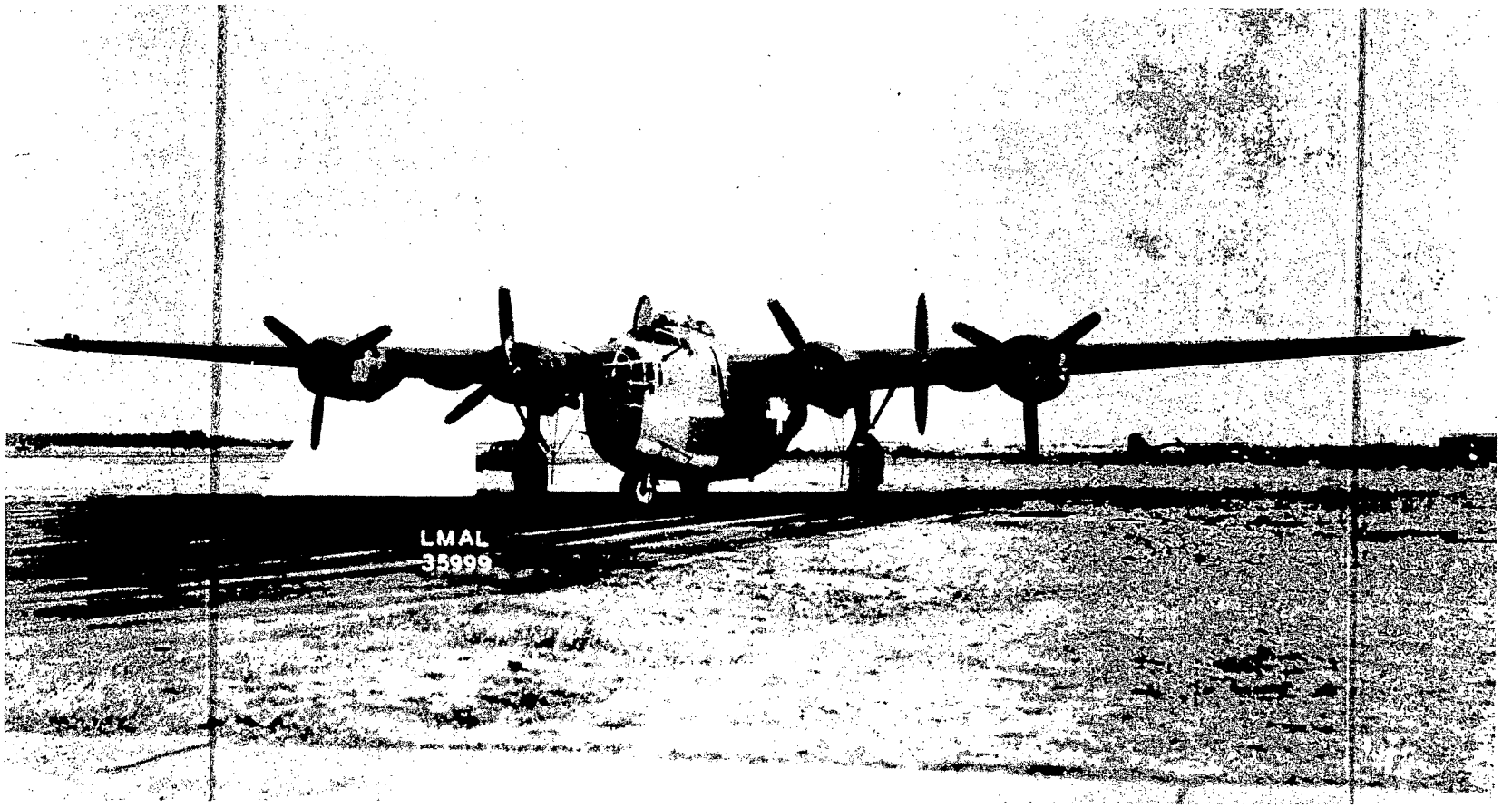

Figure 2.- Three-quarters front view of the B-24D airplane.

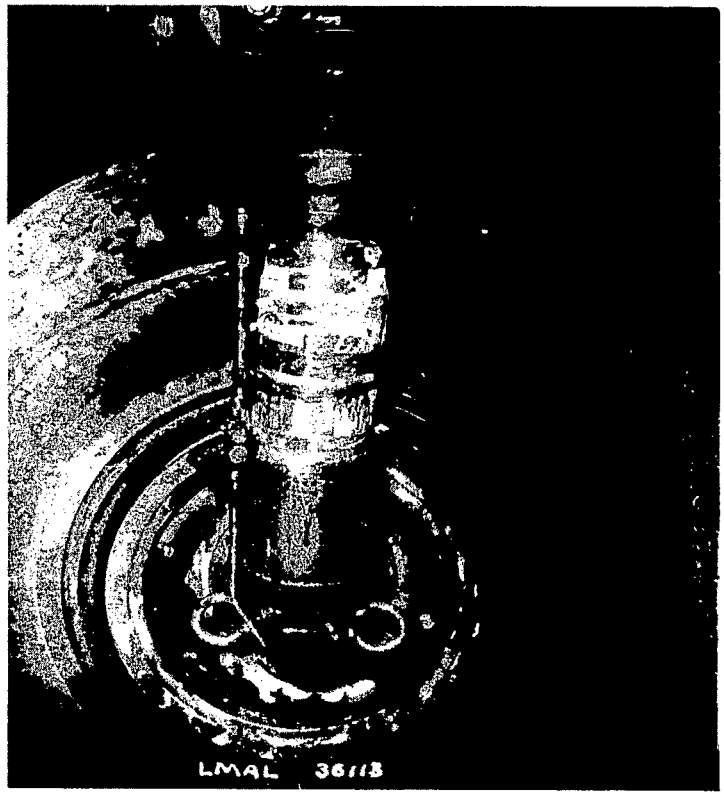

Figure 3.- Strain gage installation on left main landing-gear strut of B-24D airplane. Protective covering of tape and wax removed.

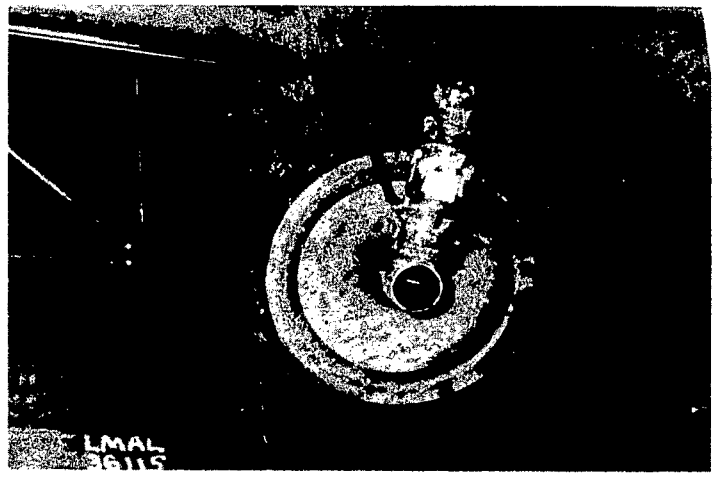

Figure 4.- Strain gage installation on nose wheel strut of B-24D airplane. Protective covering of tape and wax removed.

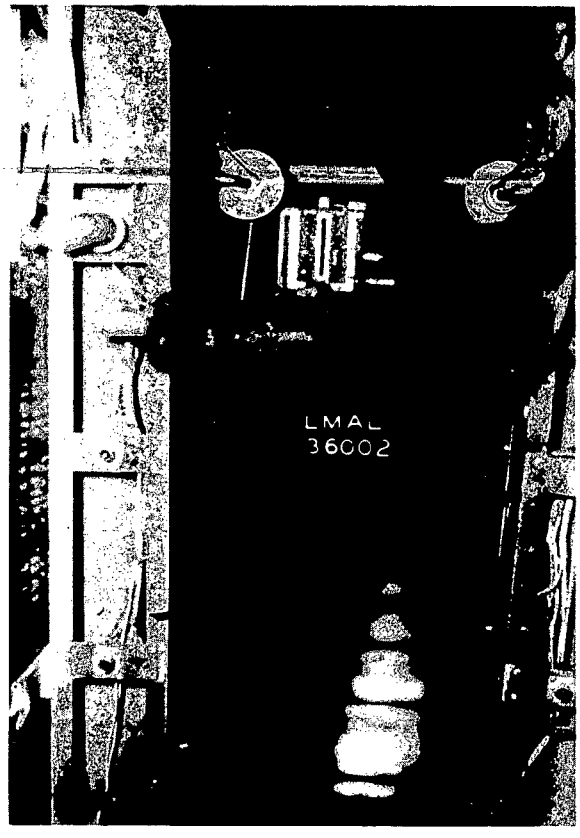

Figure 5.- Installation of NACA three-component accelerometer near center of gravity of B-24D airplane.

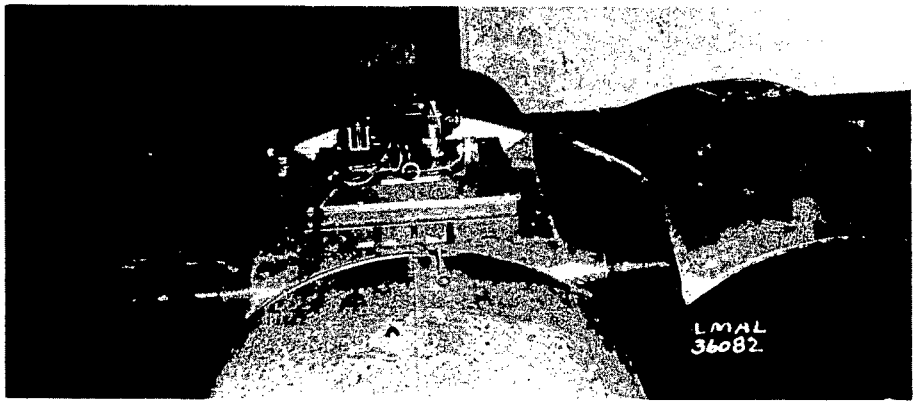

Figure 6.- NACA three-component accelerometer located at the center of the stabilizer of the B-24D airplane. Fairing removed.

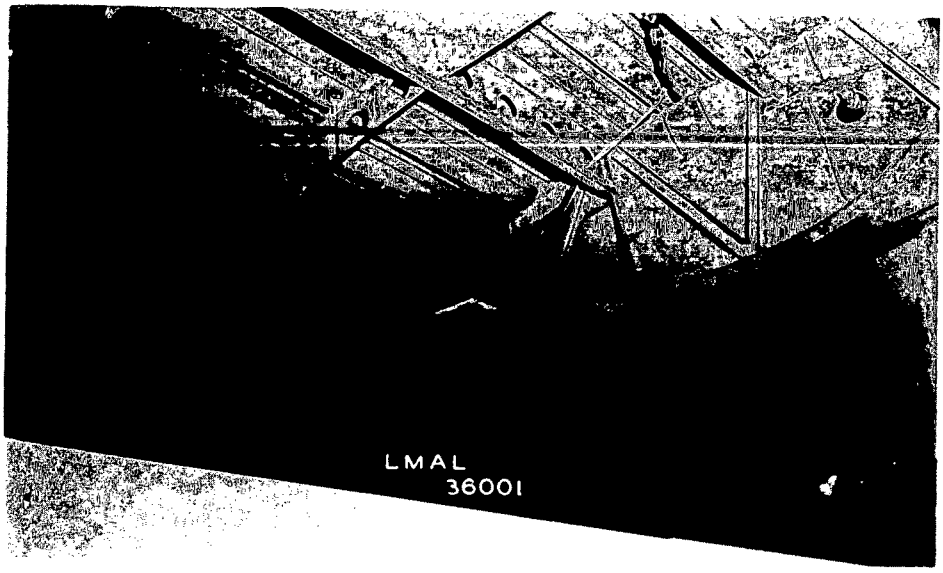

Figure 7.- NACA accelerometer No. 291, located in left wheel well near outboard nacelle.

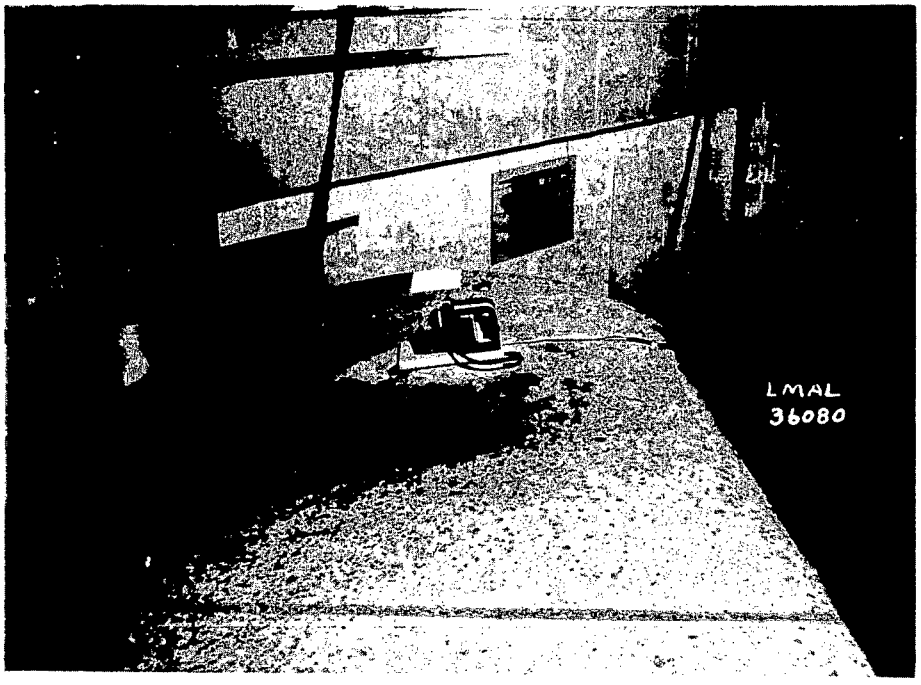

Figure 8.- NACA accelerometer No. 286, located near left wing tip. Fairing removed.

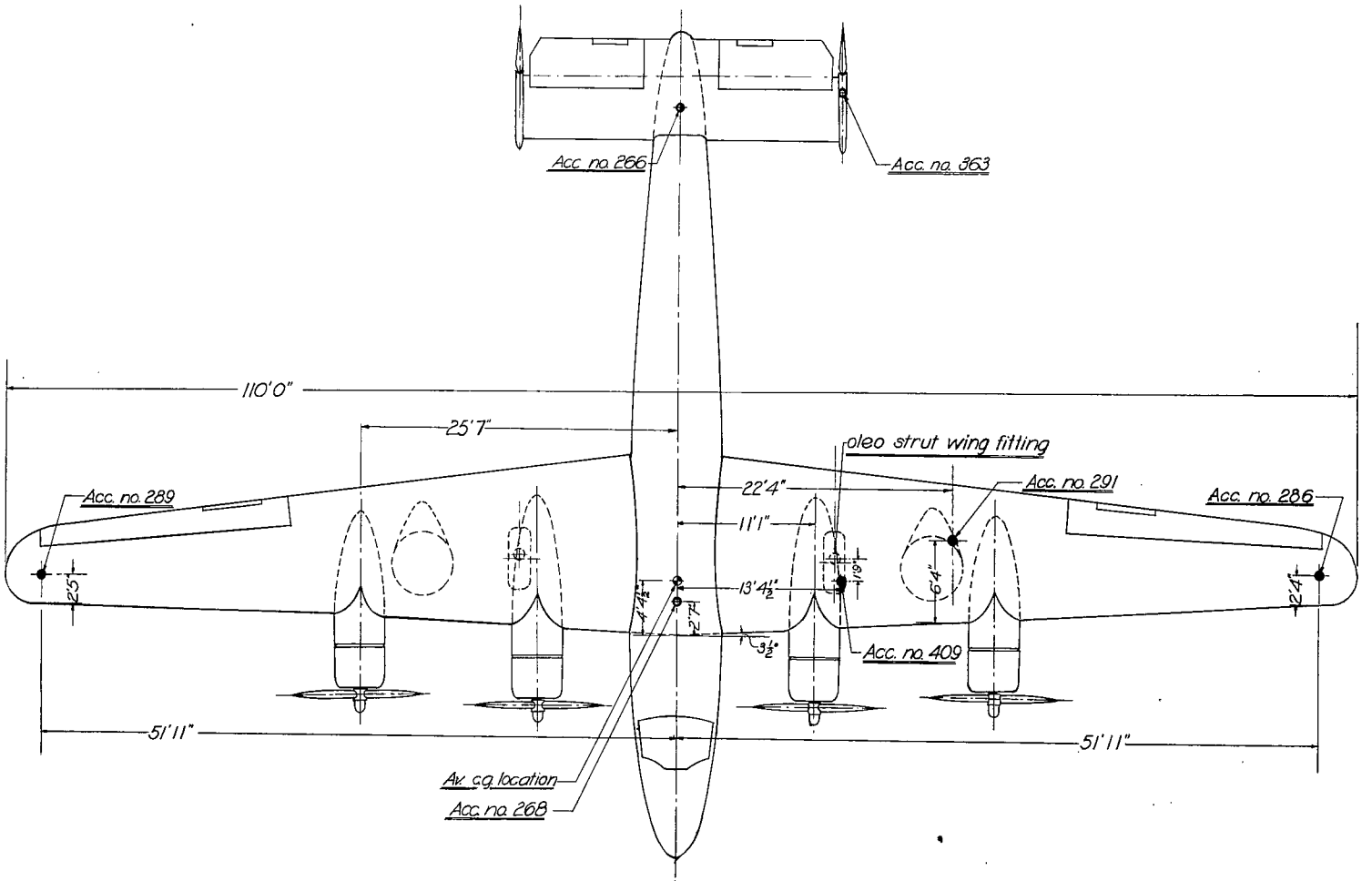

Figure 9.-Installation of accelerometers in the B-24D airplane

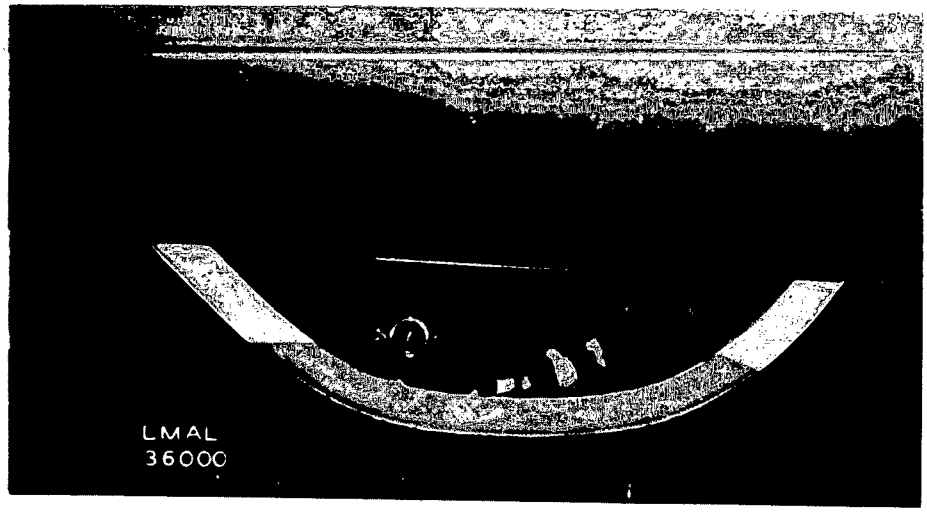

Figure 10.- Cameras used to photograph main landing wheels of B-24D airplane, installed beneath the fuselage.

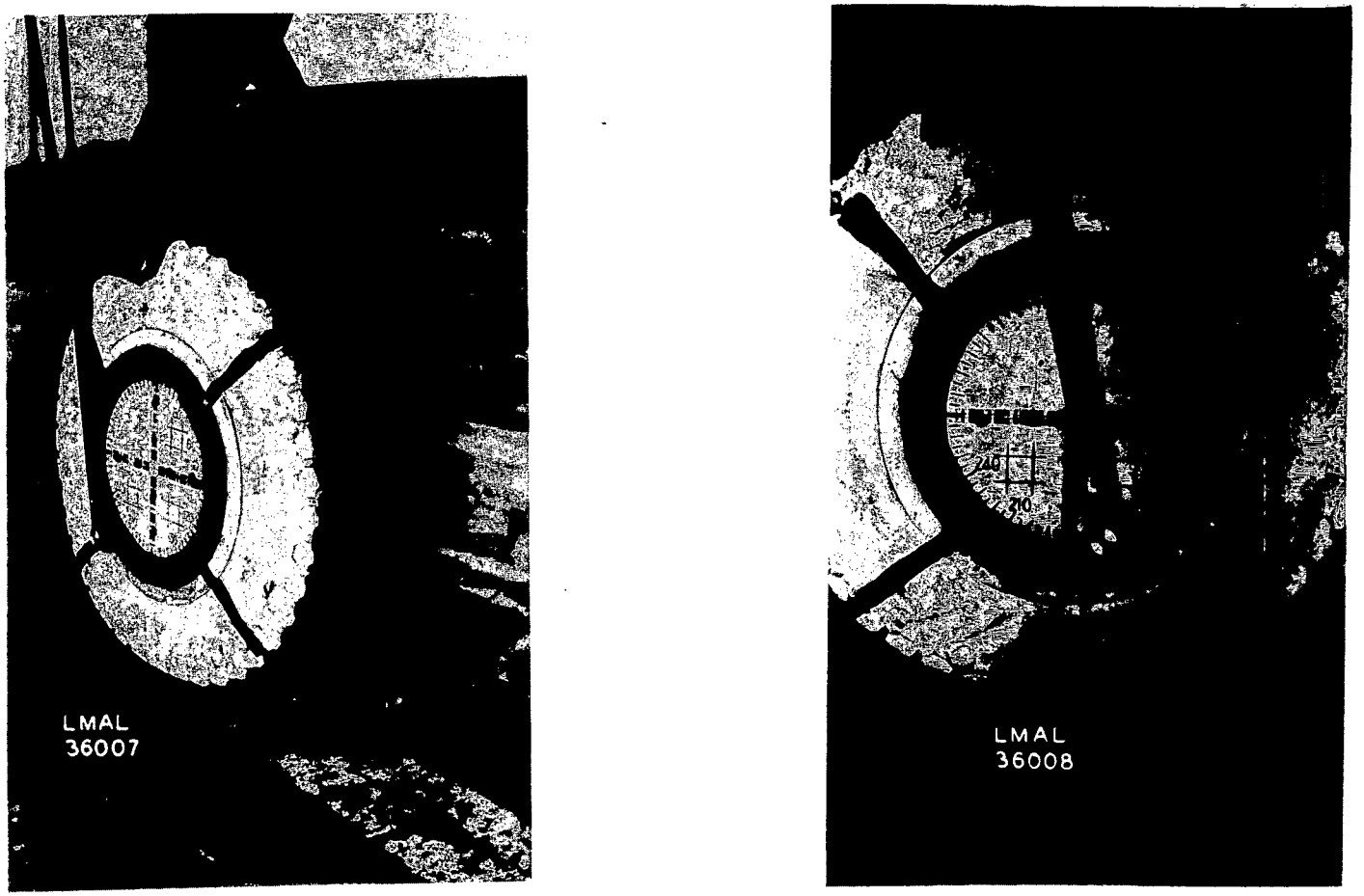

Figure 11.- Two views of the left main landing wheel of the B-24D airplane, showing wheel markings and reference target. Inboard face of wheel shown.

Figure 12. - Time history of wing and center of gravity accelerations and landing gear normal loads in a normal landing. Vertical velocity 2.5 fps, landing 5, B-24D airplane.

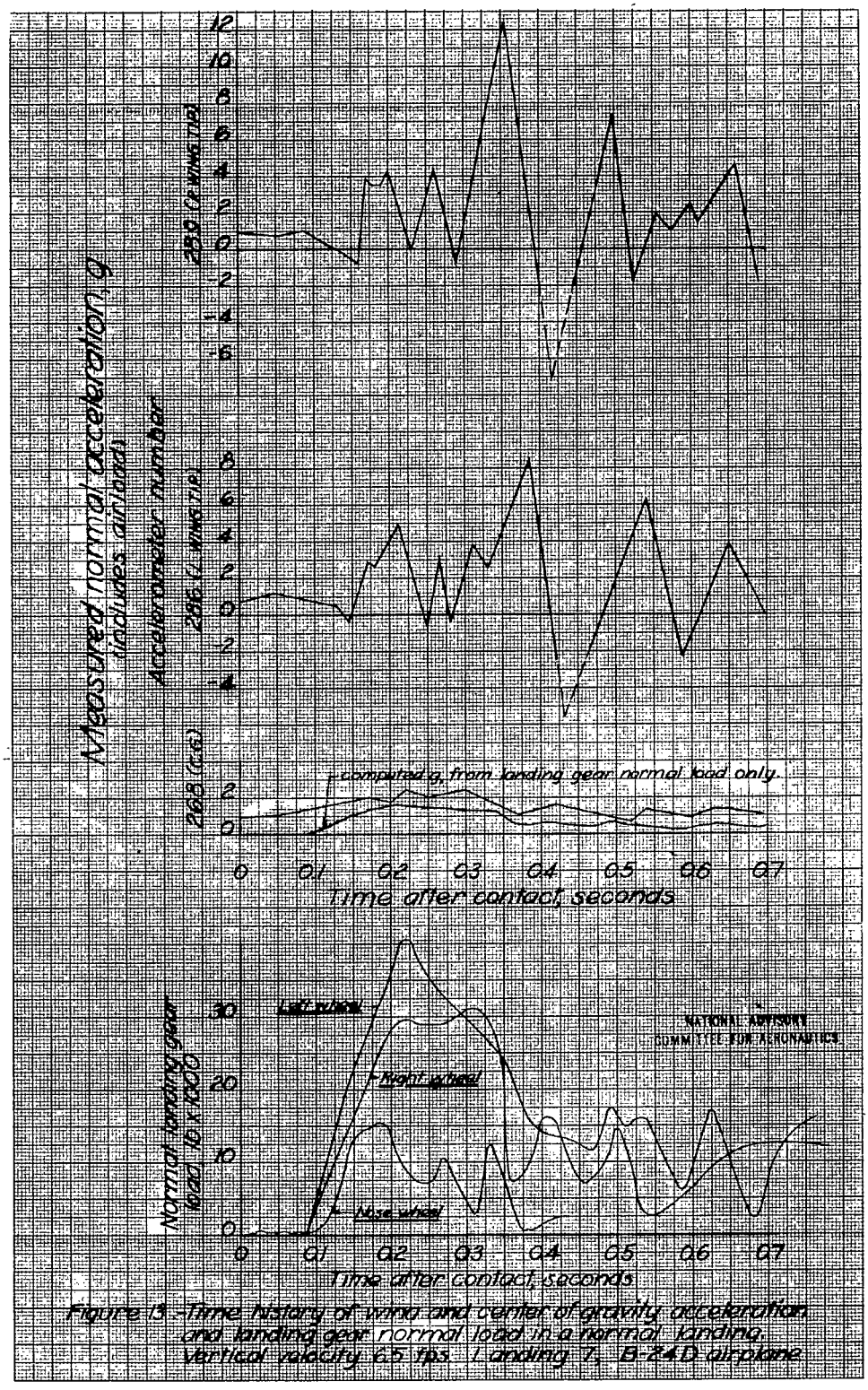

Figure 13.- Time history of wing and center of gravity accelerations and landing gear normal load in a normal landing. Vertical velocity 6.5 fps. Landing 7, B-24D airplane.

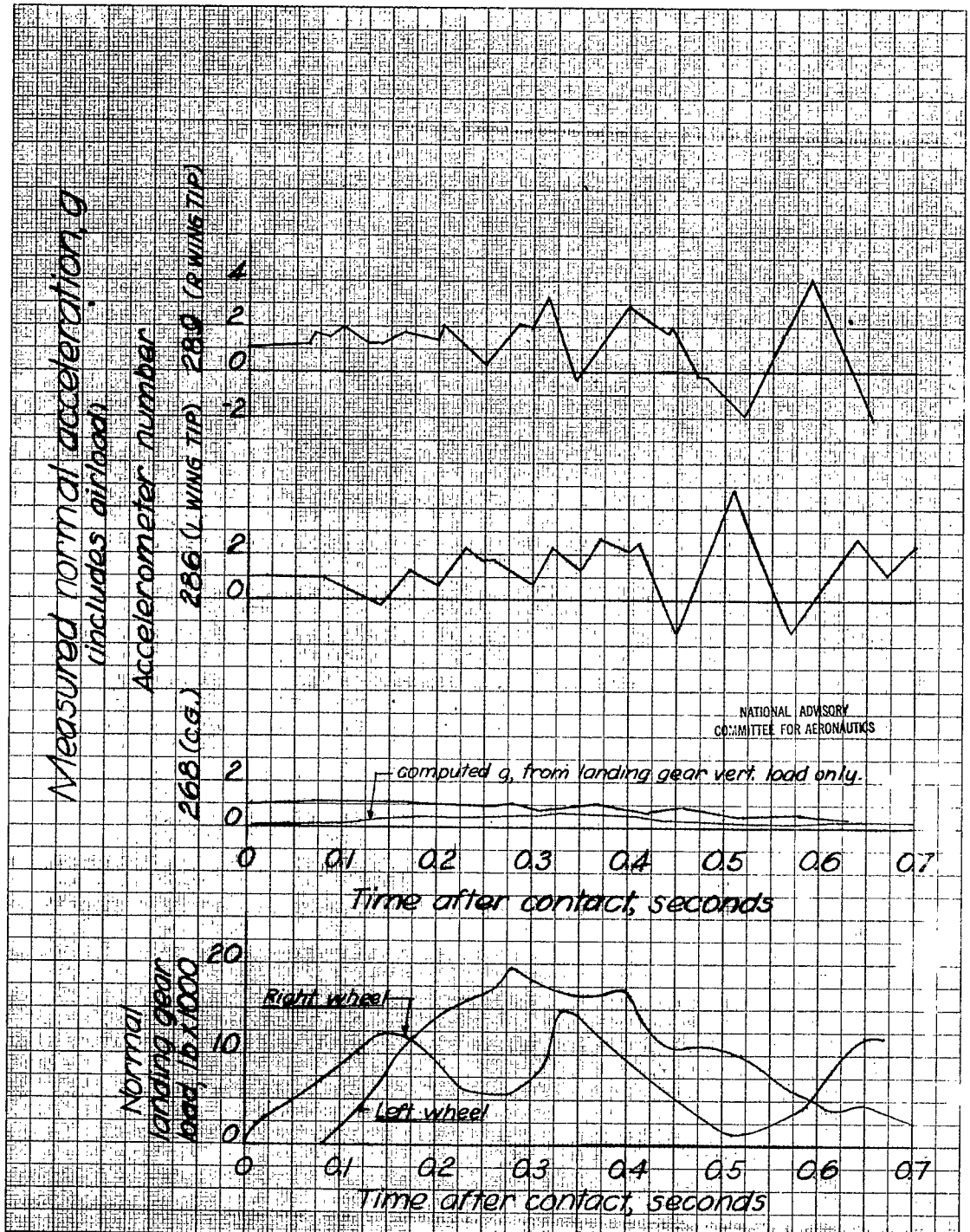

Figure 14.- Time history of wing and center of gravity acceleration and landing gear normal load in a normal landing. Vertical velocity 2.2 fps. Landing 9, B-24D airplane

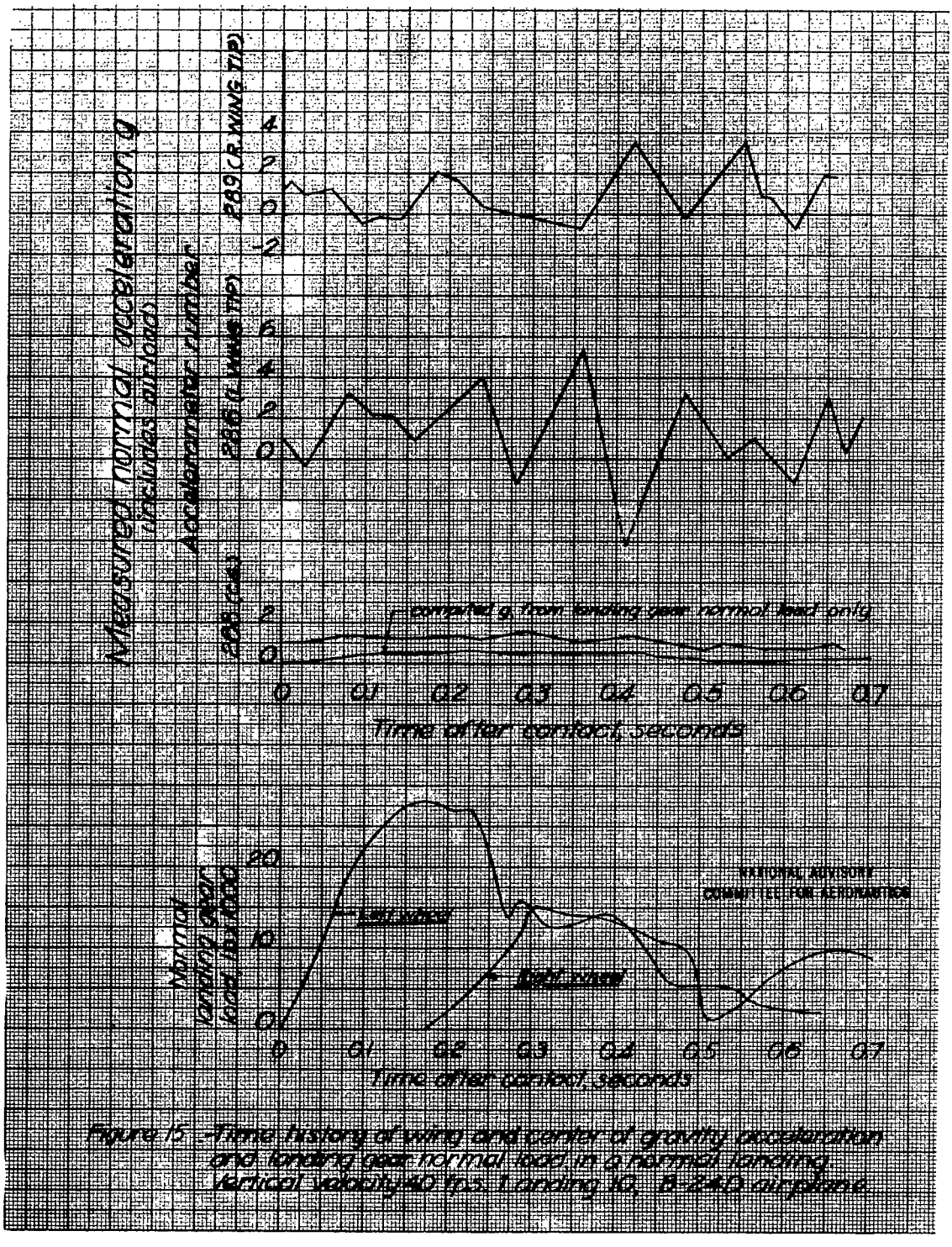

Figure 15.-Time history of wing and center of gravity acceleration and landing gear normal load in a normal landing. Vertical velocity 4.0 f.p.s. Landing 10, A-240 airplane.

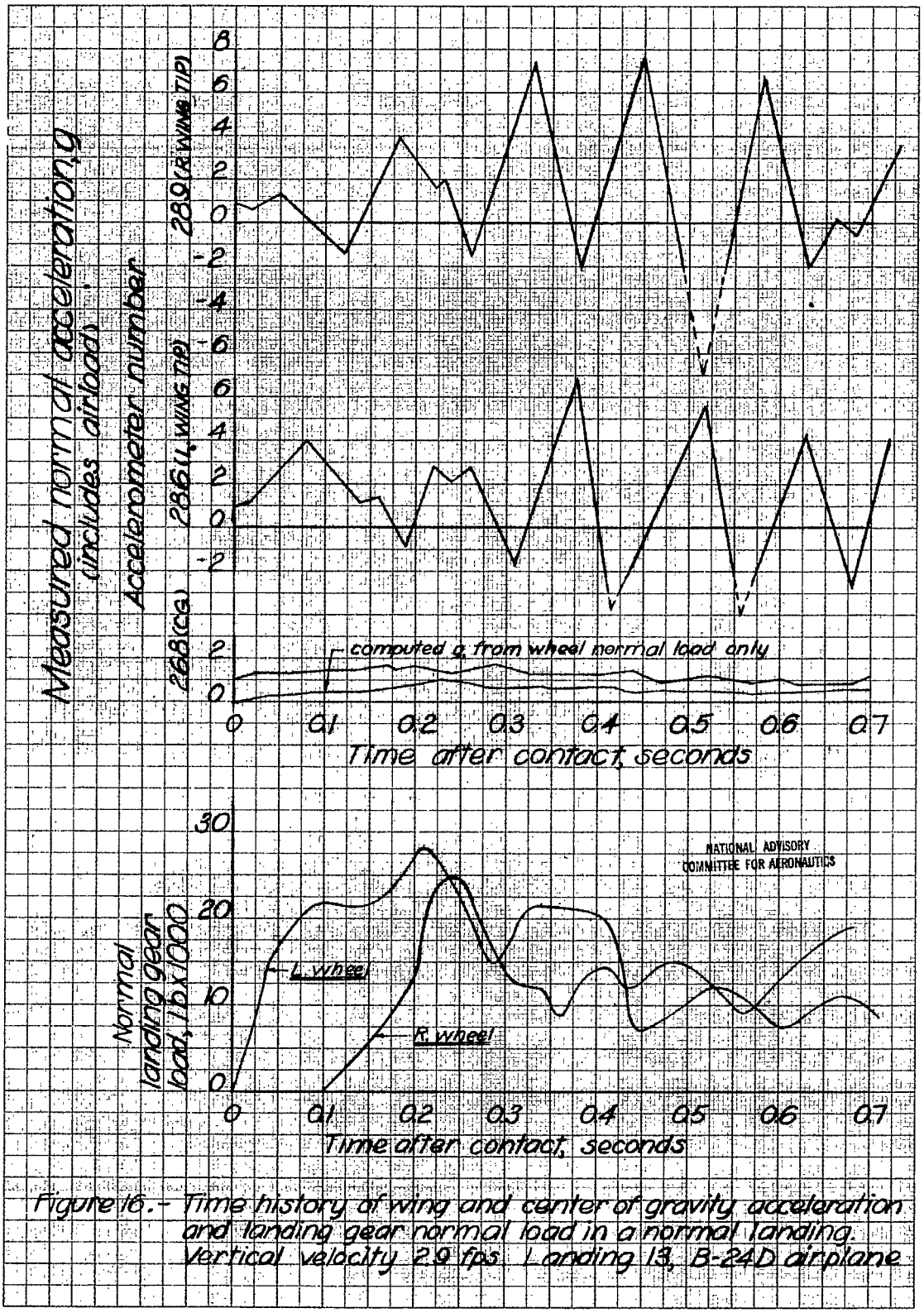

Figure 16.- Time history of wing and center of gravity acceleration and landing gear normal load in a normal landing. Vertical velocity 2.9 fps. Landing 13, B-24D airplane

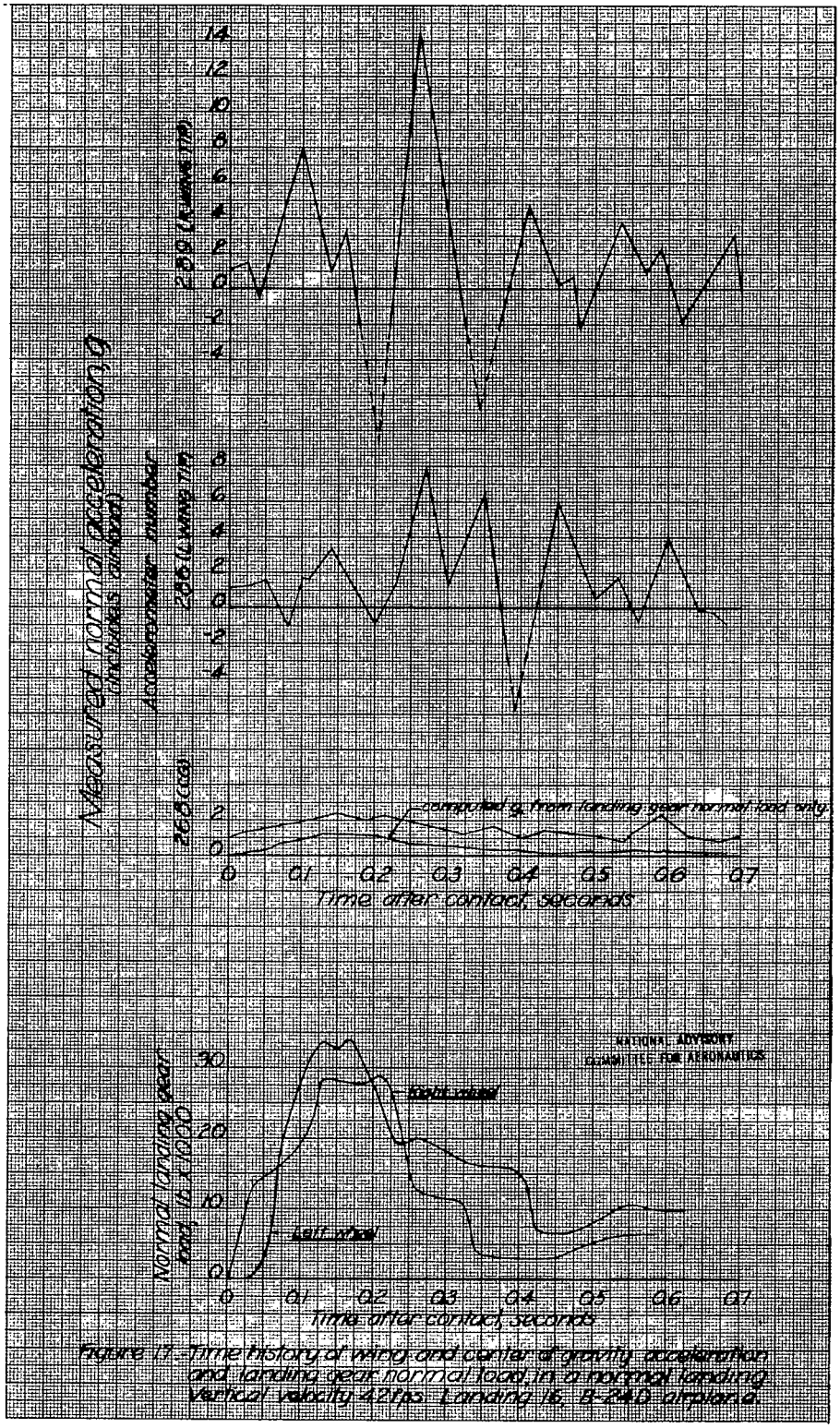

Figure 17.-Time history of wing and center of gravity acceleration and landing gear normal load in a normal landing. Vertical velocity 4.2 fps. Landing 16, B-240 airplane.

Figure 18.- Time history of wing and center of gravity acceleration and landing gear normal load in a normal landing. Vertical velocity 2.2 fps. Landing wt, B-240 airplane.

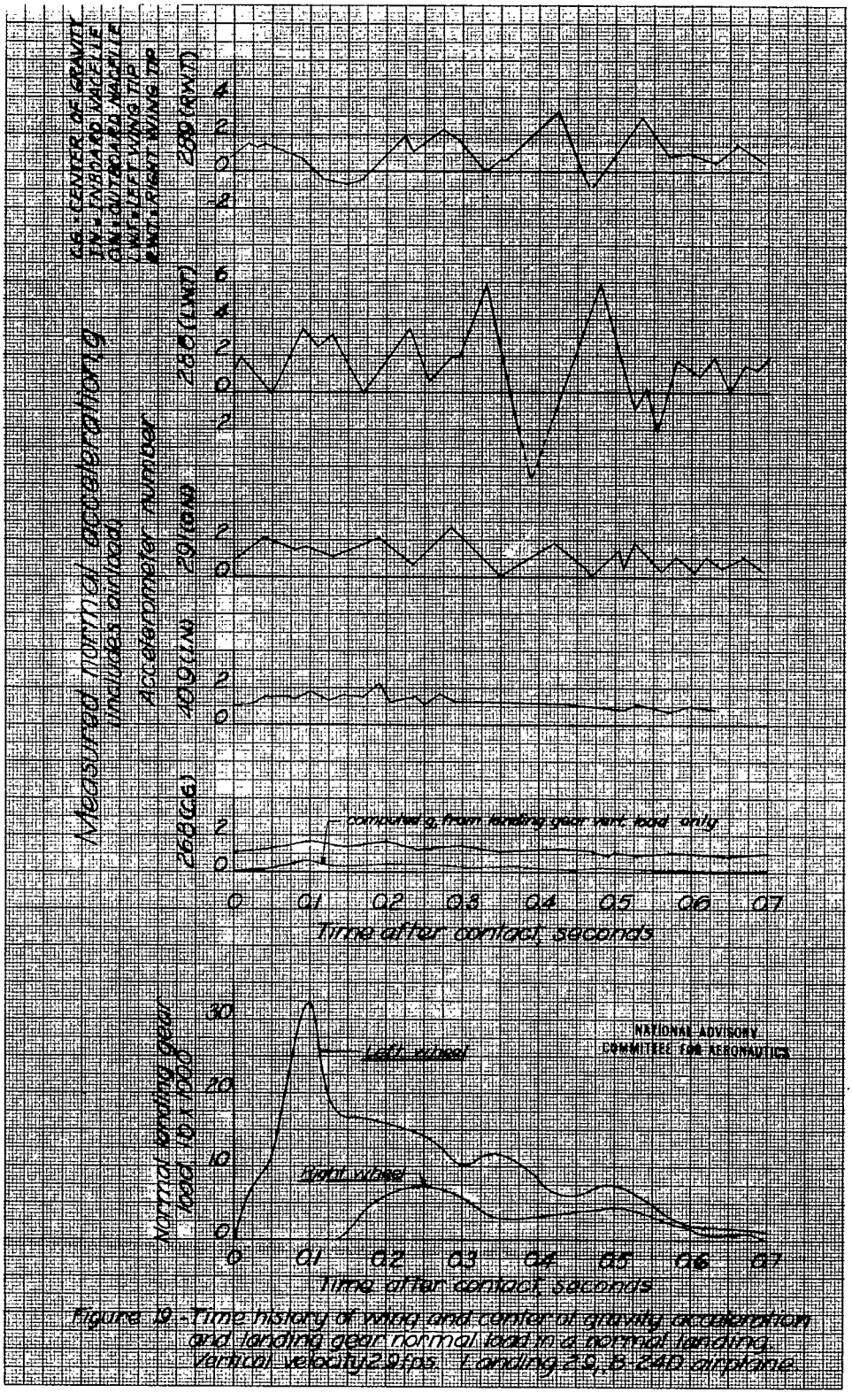

Figure 19.- Time history of wing and center of gravity acceleration and landing gear normal load in a normal landing. Vertical velocity 2.9 fps. Landing 2.9, 8-240 airplane.

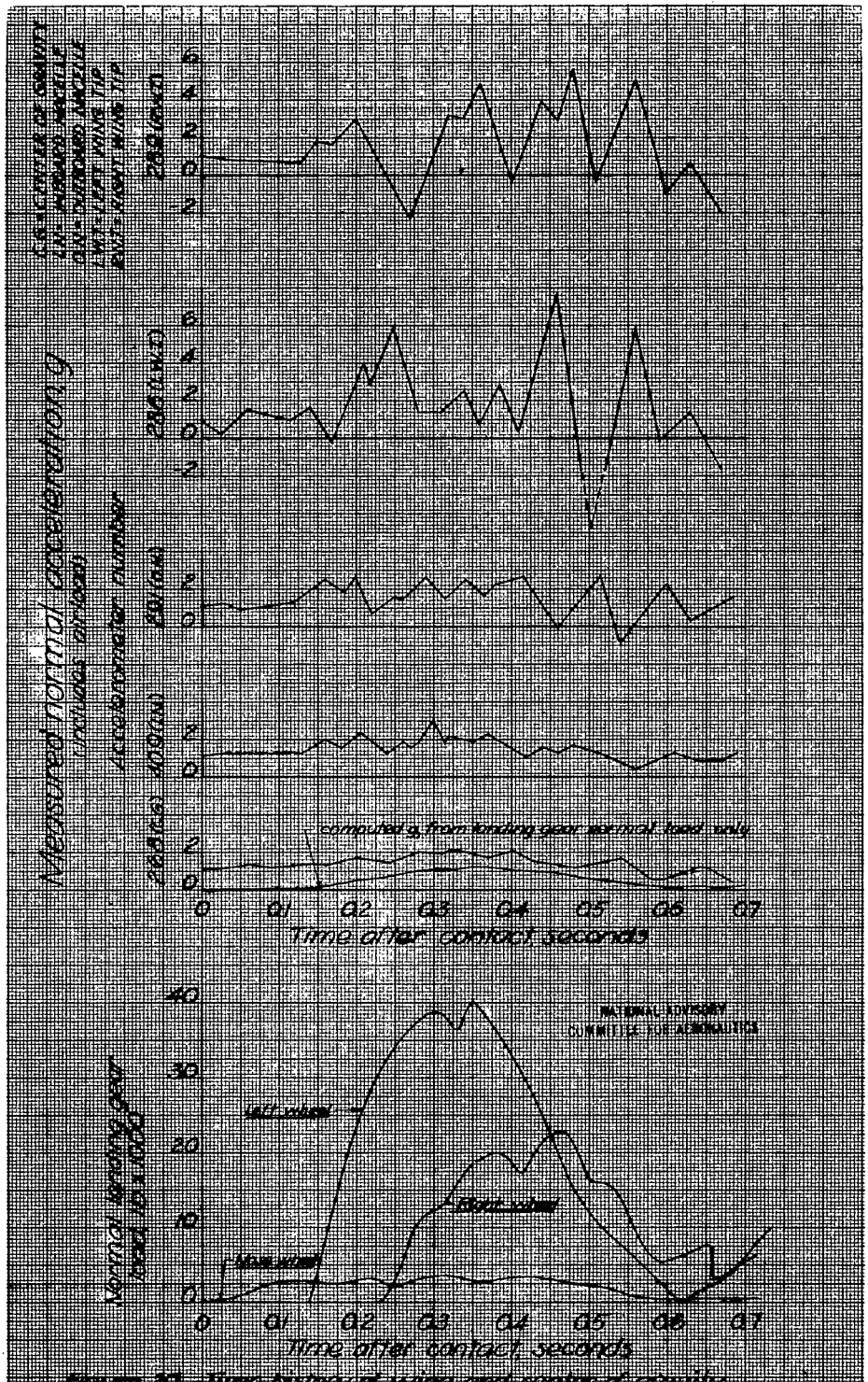

Figure 20.- Time history of wing and center of gravity acceleration and landing gear normal load, in a normal landing. Vertical velocity 6.9 fps. Landing 39, B-24B airplane.

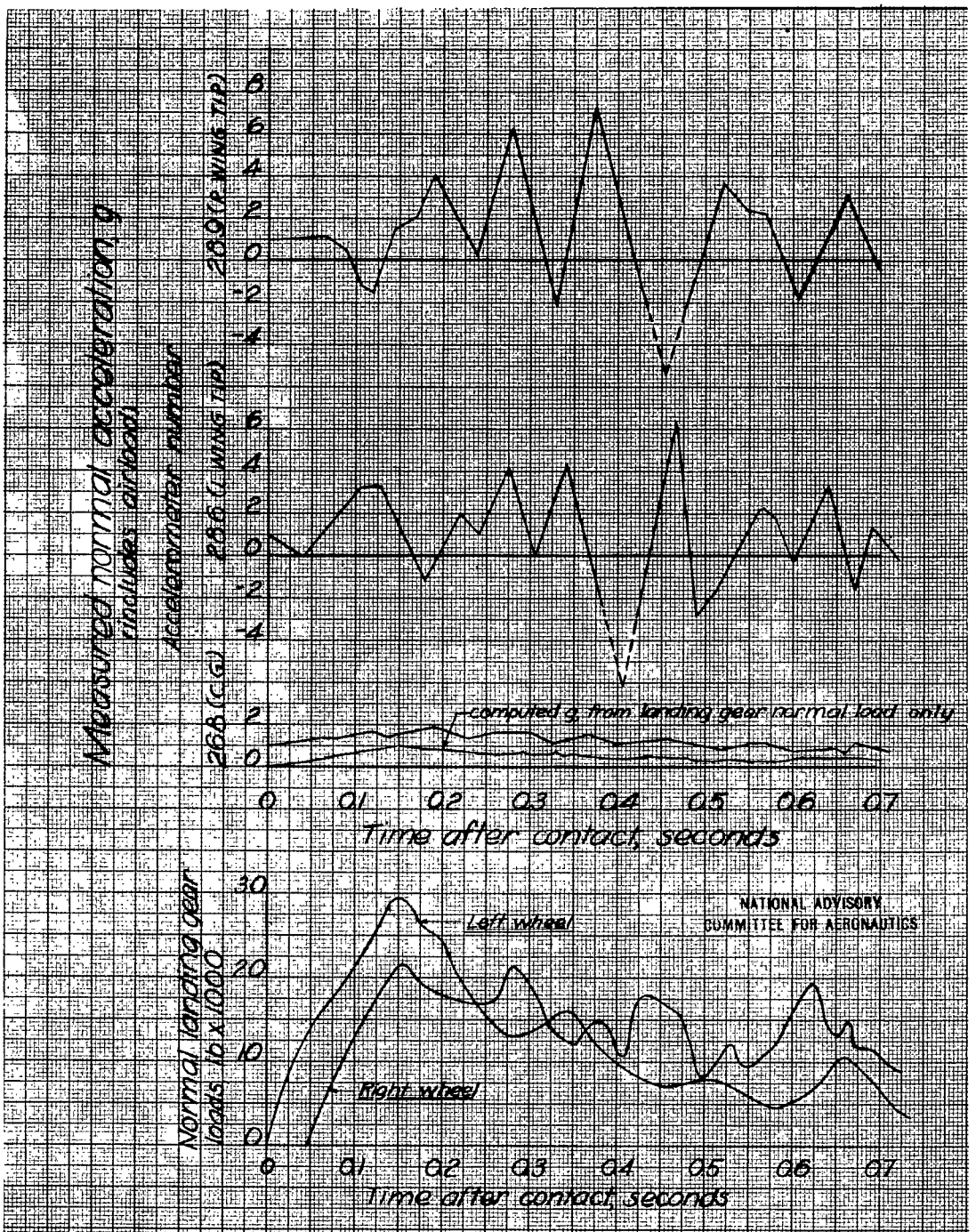

Figure 21.- Time history of wing and center of gravity acceleration and landing gear normal load in a braked landing. Brake pressure 7 lb/sq inch. Vertical velocity 4.1 fps. Landing 6, P-240 airplane.

Figure 22.-Time history of wing and center of gravity acceleration and landing gear normal load in a braked landing. Brake pressure 12 lb/sq inch. Vertical velocity 25 fps. Landing 15, B-24D airplane.

Figure 23 - Time history of wing and center of gravity acceleration and landing gear normal load in a braked landing. Brake pressure 20 lb/sq inch. Vertical velocity 4.0 fps. Landing 22, B-24D airplane.

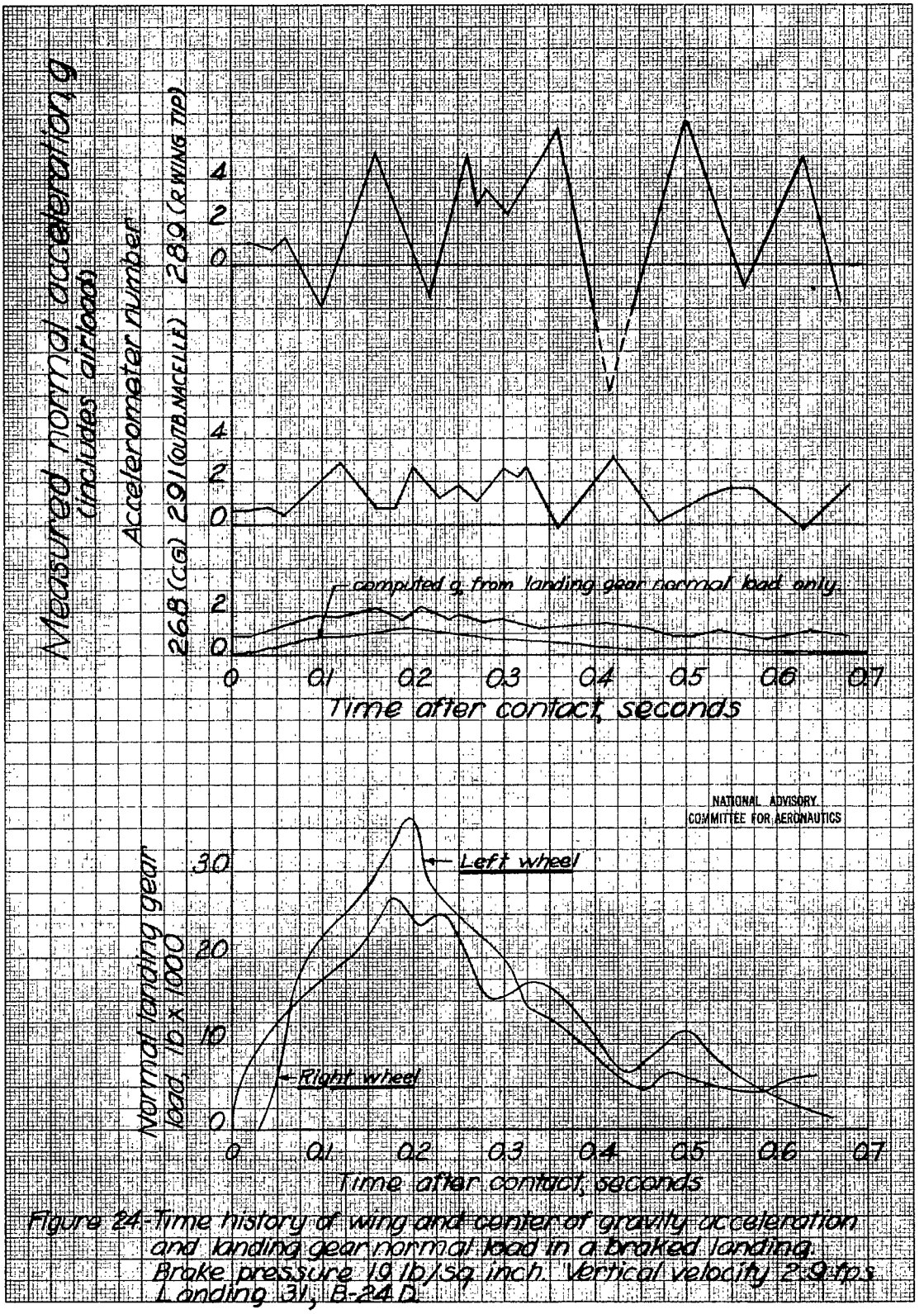

Figure 24.-Time history of wing and center of gravity acceleration and landing gear normal load in a braked landing. Brake pressure 1910 lb/sq inch. Vertical velocity 2.9 fps. Landing 31, B-24D.

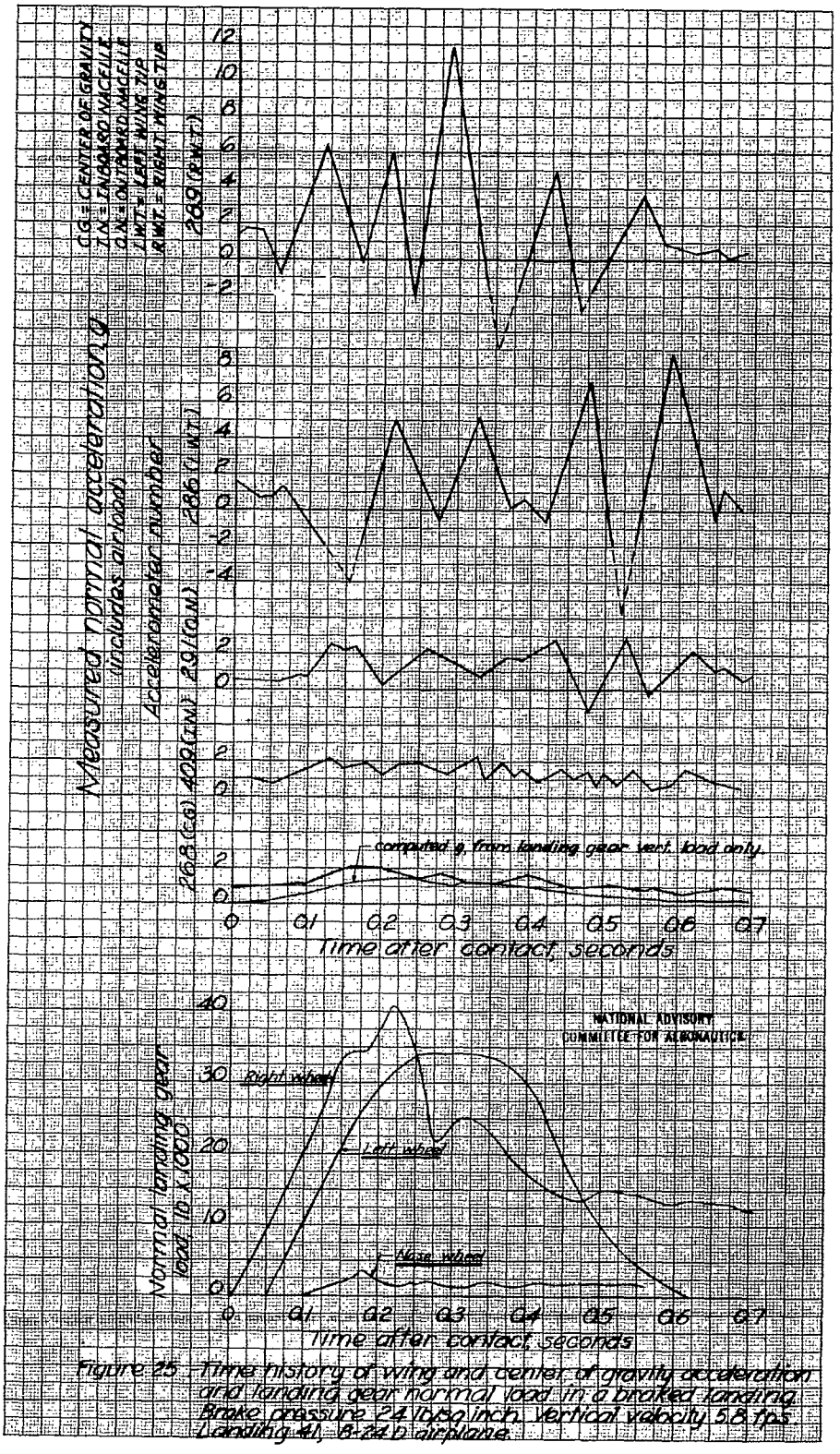

Figure 25.- Time history of wing and center of gravity acceleration and landing gear normal load in a braked landing. Brake pressure 24 lb/sq inch, vertical velocity 5.8 fps, landing 41, 8-24 D airplane.

Figure 22. Time history of wing and center of gravity acceleration and landing gear normal load in a prerotation landing. Vertical velocity, 2.3 fps. Landing CL, 1.24. B-24D airplane.

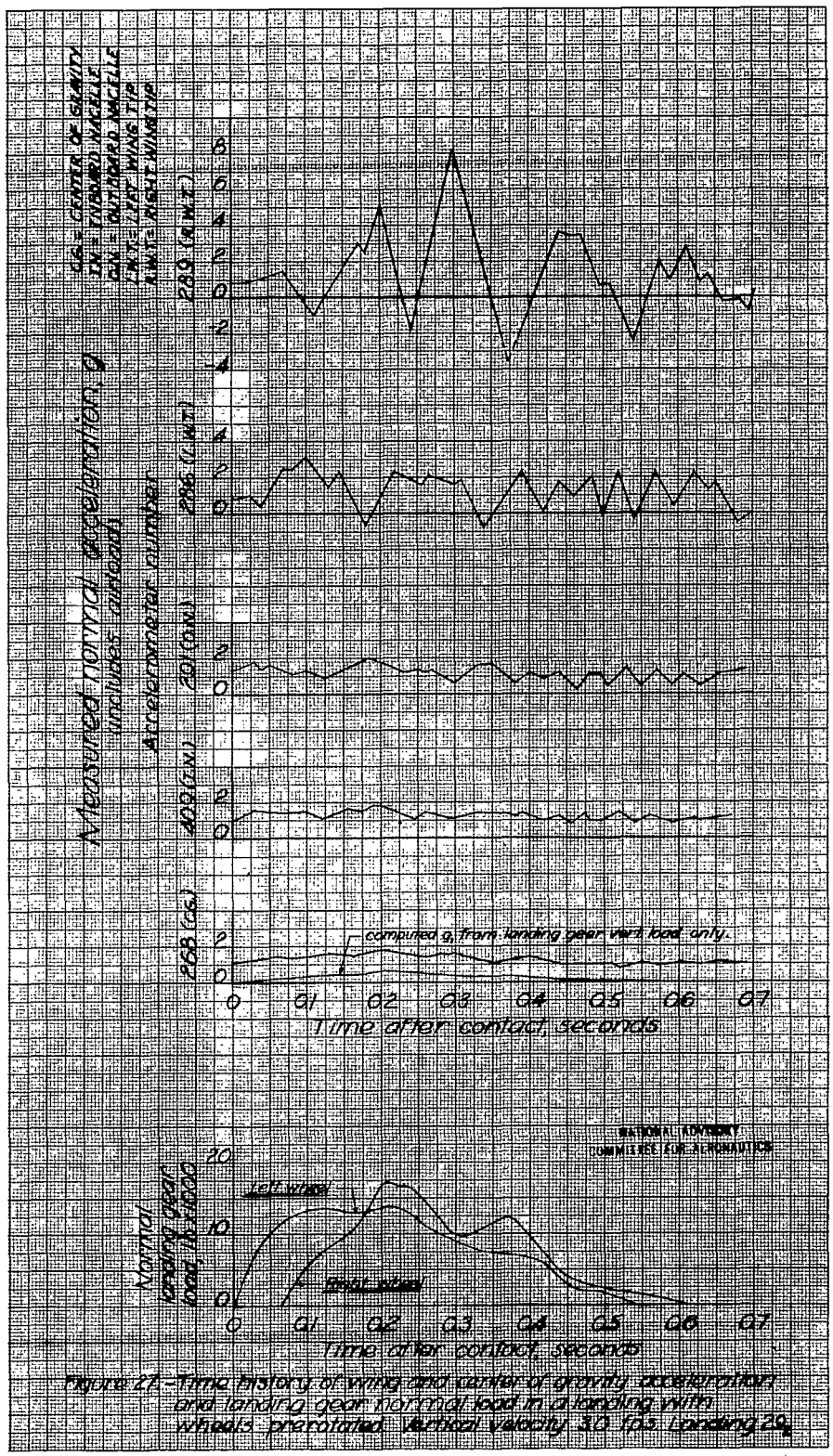

Figure 22.–Time history of wing and center of gravity accelerations and landing gear normal load in a landing with wheels prerotated. Vertical velocity 3.0 fps. Landing 29.

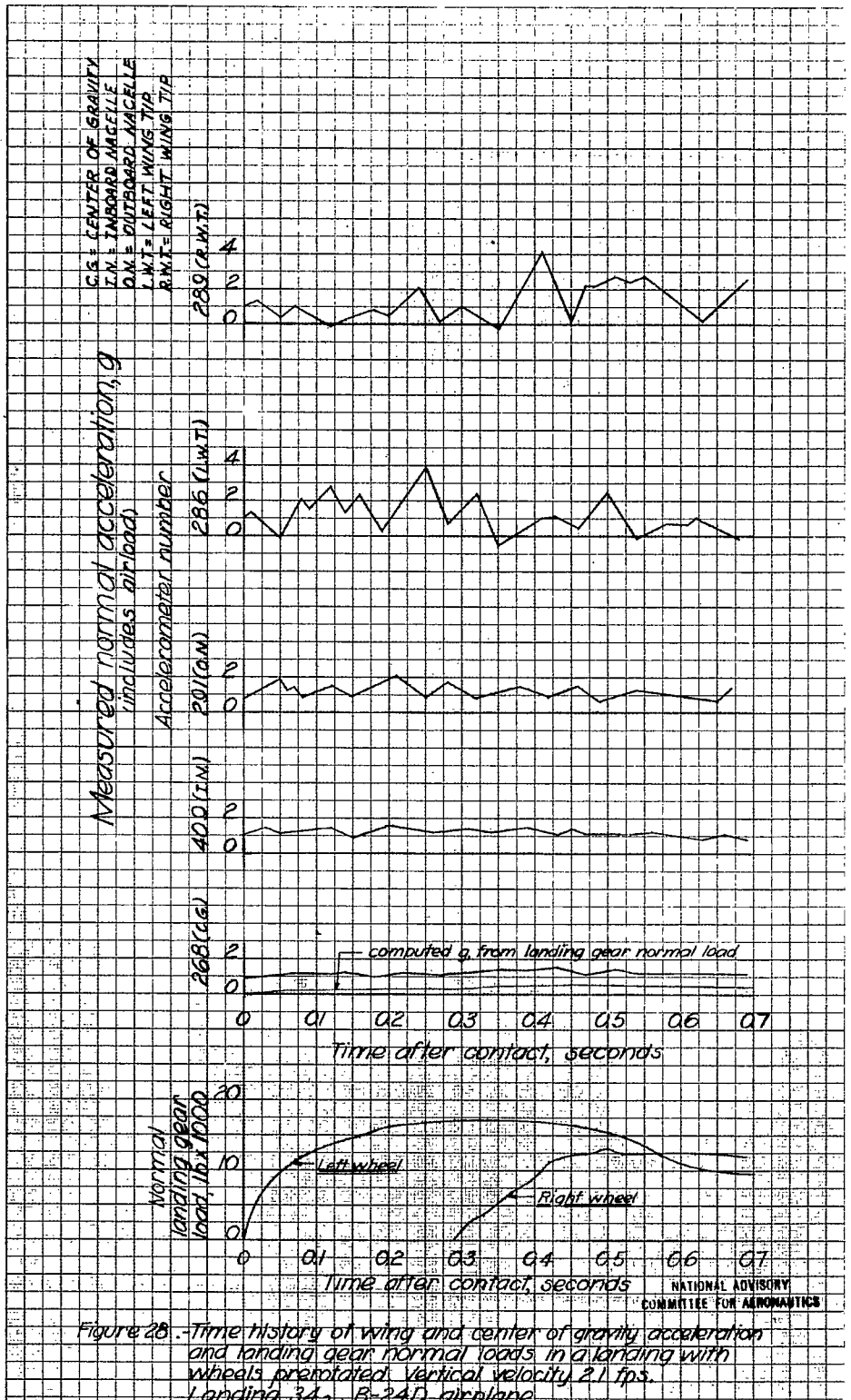

Figure 28.-Time history of wing and center of gravity acceleration and landing gear normal loads in a landing with wheels prerotated. Vertical velocity 2.1 fps. Landing 34_2, B-24D airplane.

Figure 29.- Time history of wing and center of gravity acceleration and landing gear normal load in a landing with wheels prerotated. Vertical velocity 2.9 fps. Landing 35_2-B-24D

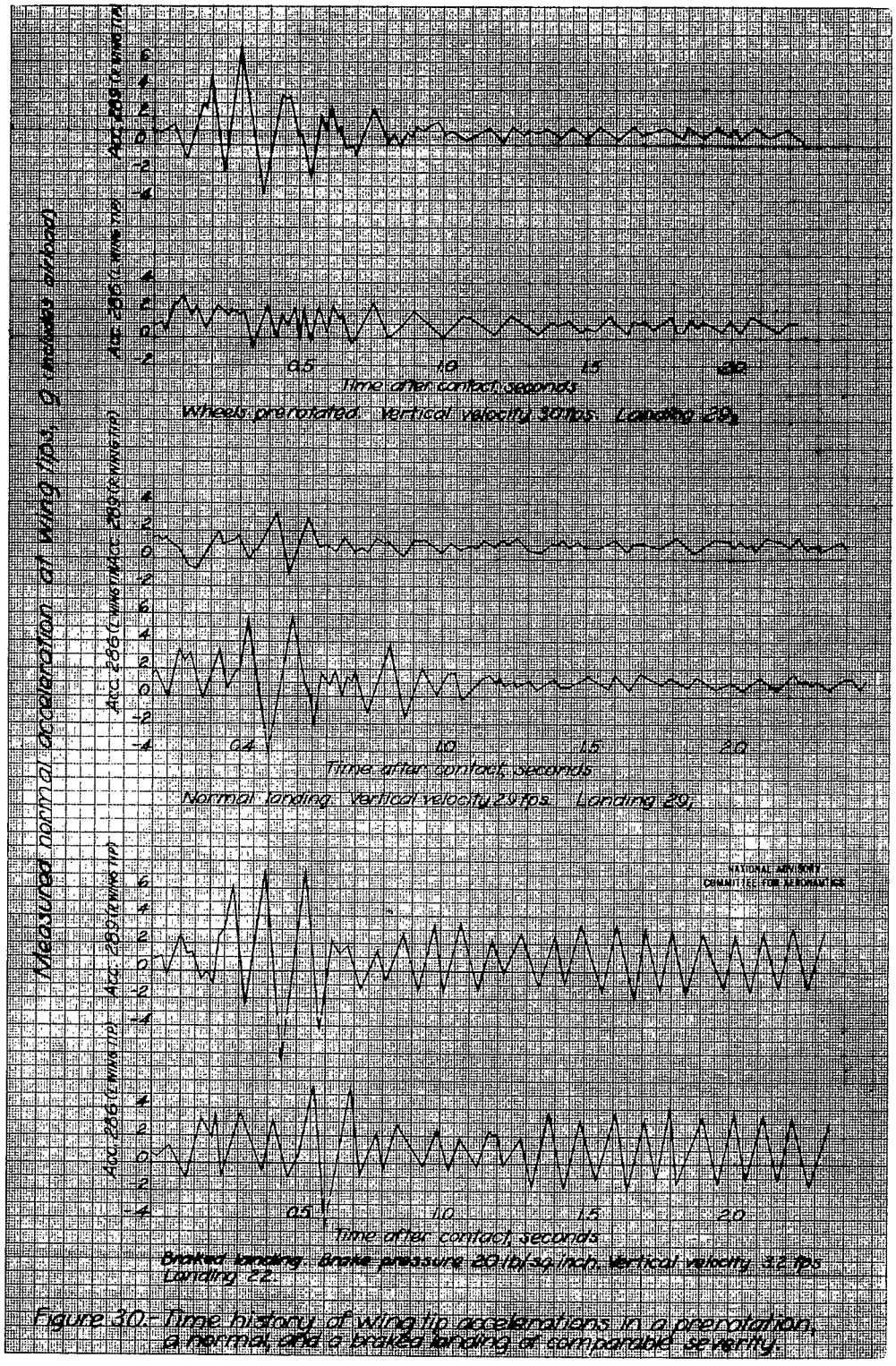

Figure 30.- Time history of wing tip accelerations in a prerotation, a normal, and a braked landing of comparable severity.

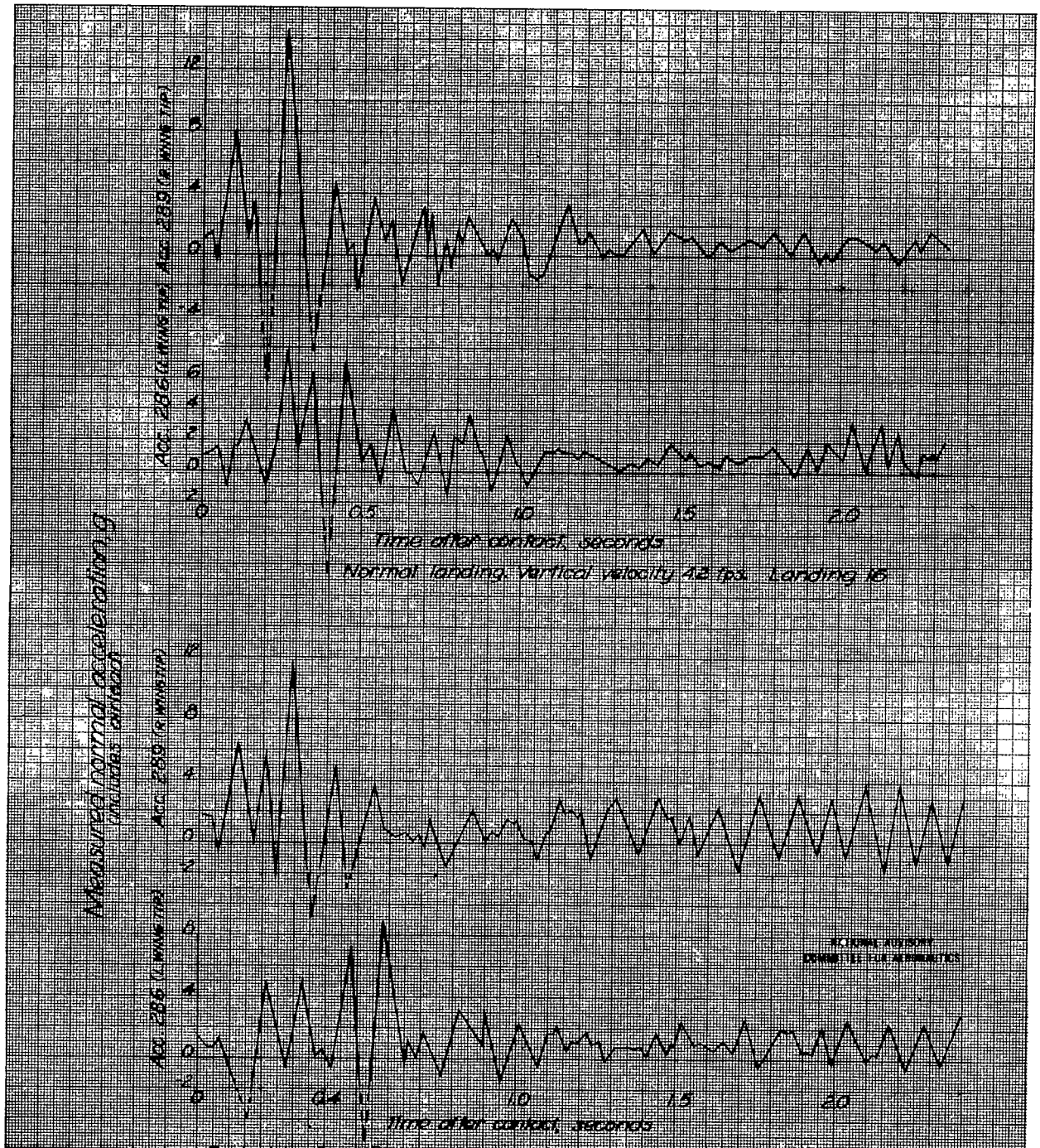

Figure 31.- Time history of wing tip acceleration in a normal and a braked landing in which large accelerations were recorded.

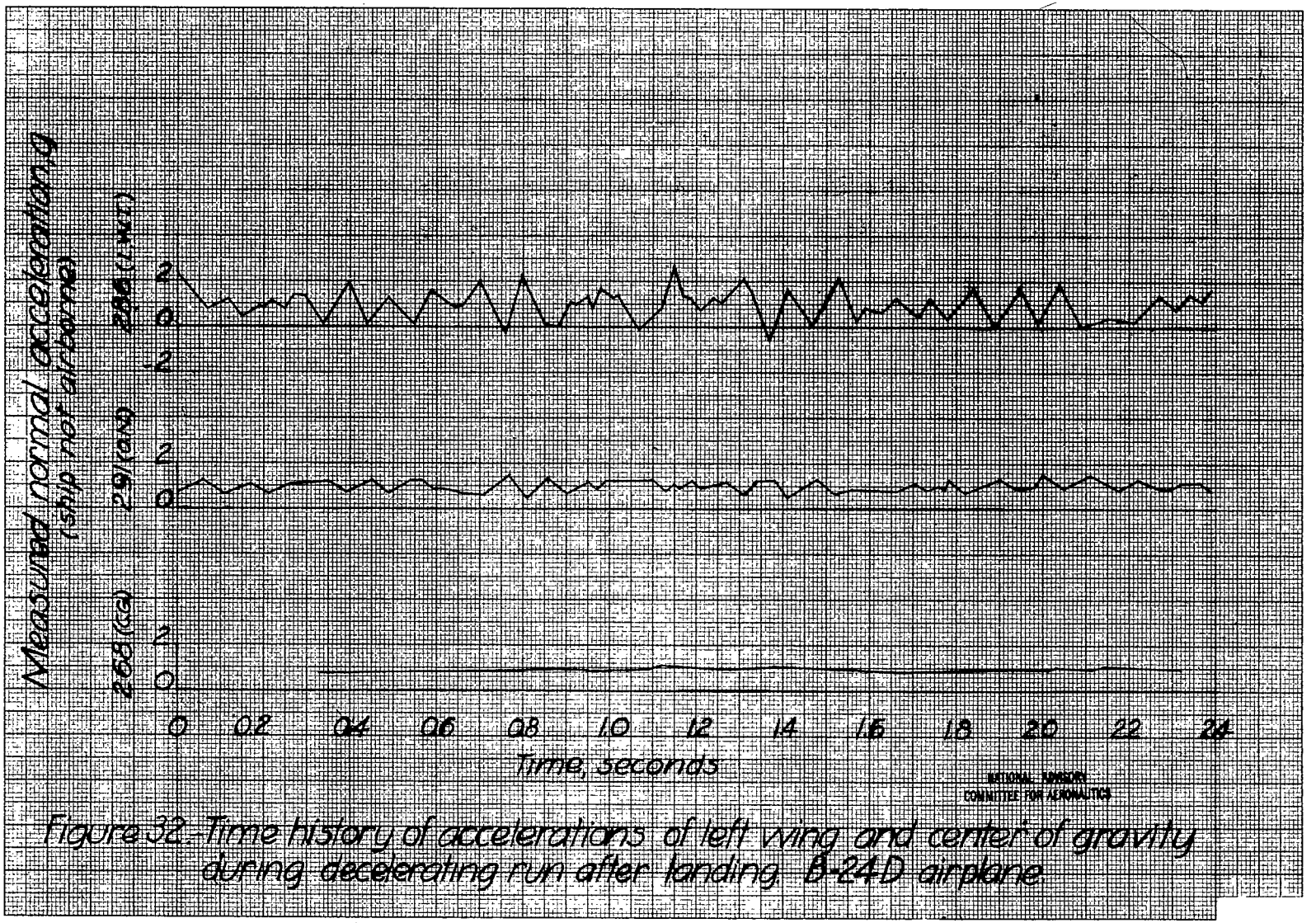

Figure 32.- Time history of accelerations of left wing and center of gravity during decelerating run after landing, B-24D airplane.

Figure 33 Time history of wing tip and center of gravity accelerations in two normal landings, B-24D airplane.

Figure 34-Time history of wing and center of gravity accelerations in a normal landing. Vert velocity 1.4 fps. Landing 26.

Figure 35.-Time history of accelerations of left wing and center of gravity in a normal landing. Vertical velocity 14 fps. Landing 33.

Figure 36. Time history of wing and center of gravity accelerations in a normal landing. Vertical velocity 1.4 fps. Landing 33_a.

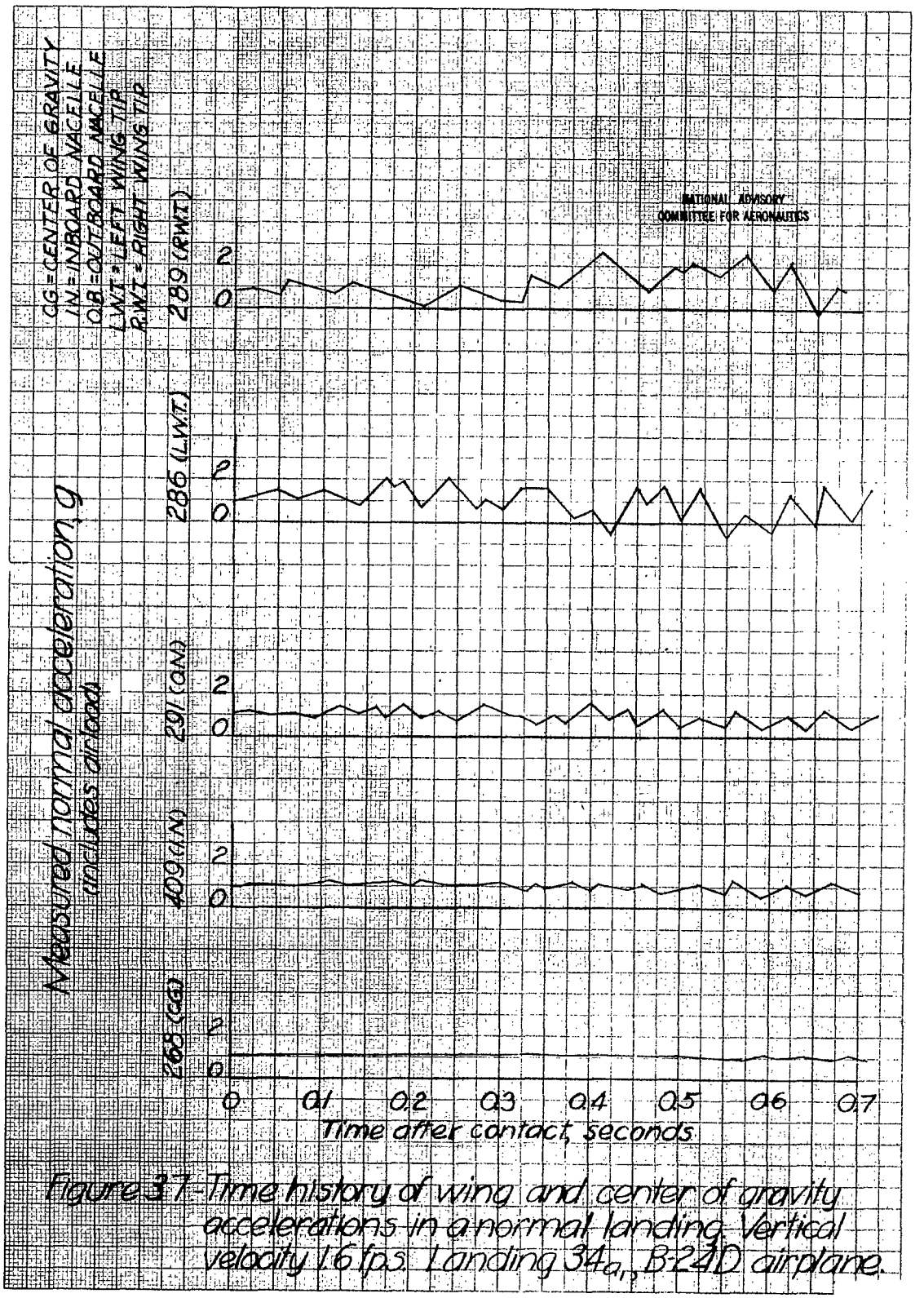

Figure 37.-Time history of wing and center of gravity accelerations in a normal landing. Vertical velocity 16 f.p.s. Landing $34_{a,p}$ B-24D airplane.

Figure 38.-Time history of accelerations of left wing and center of gravity in a normal landing. Landing 34, B-24D airplane

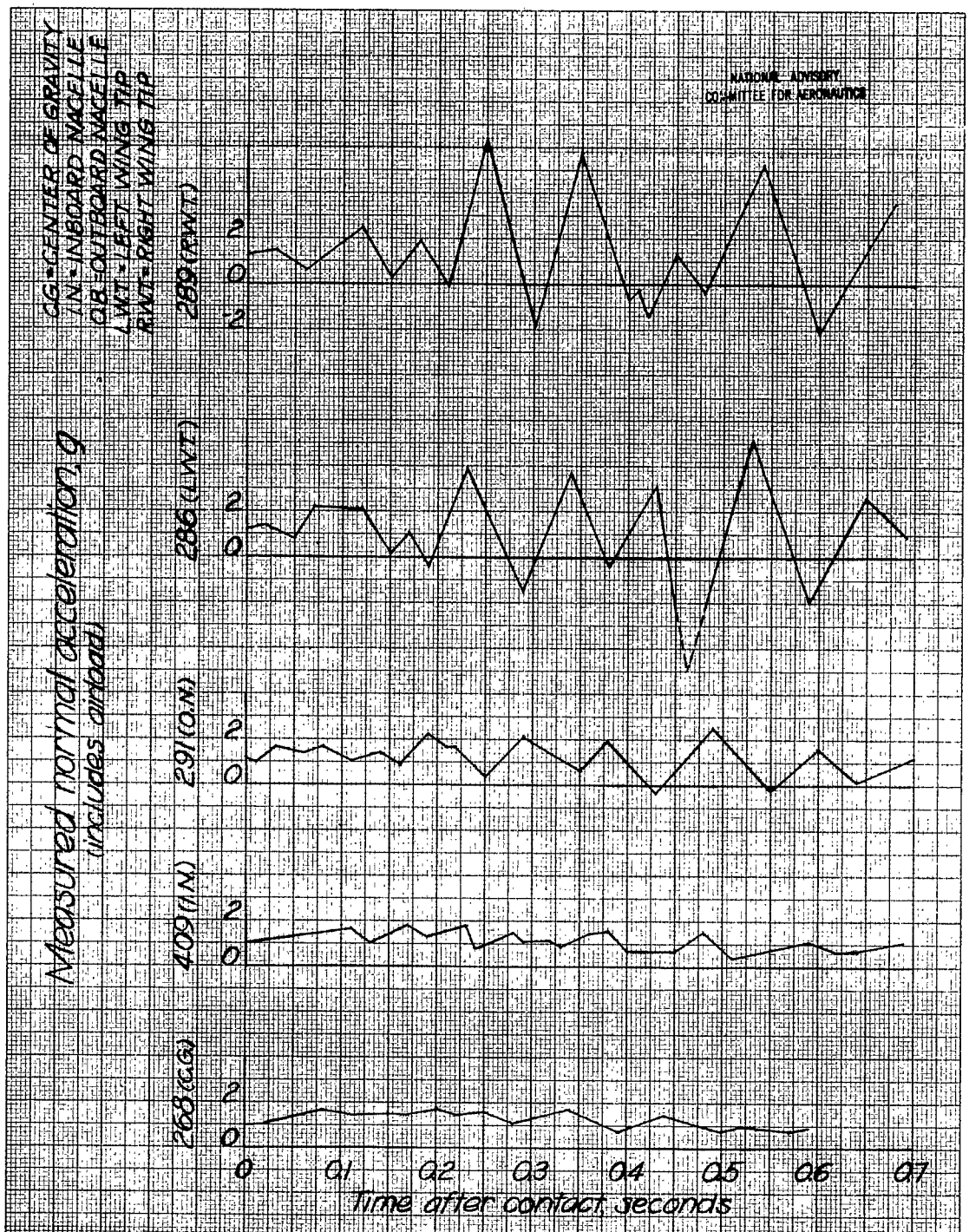

Figure 39- Time history of wing and center of gravity acceleration in a normal landing, vertical velocity 3.1 fps. Landing 35,, B-24D

Figure 40.-Time history of wing and center of gravity accelerations in a normal landing. Vertical velocity 1.4 fps. Landing 37.

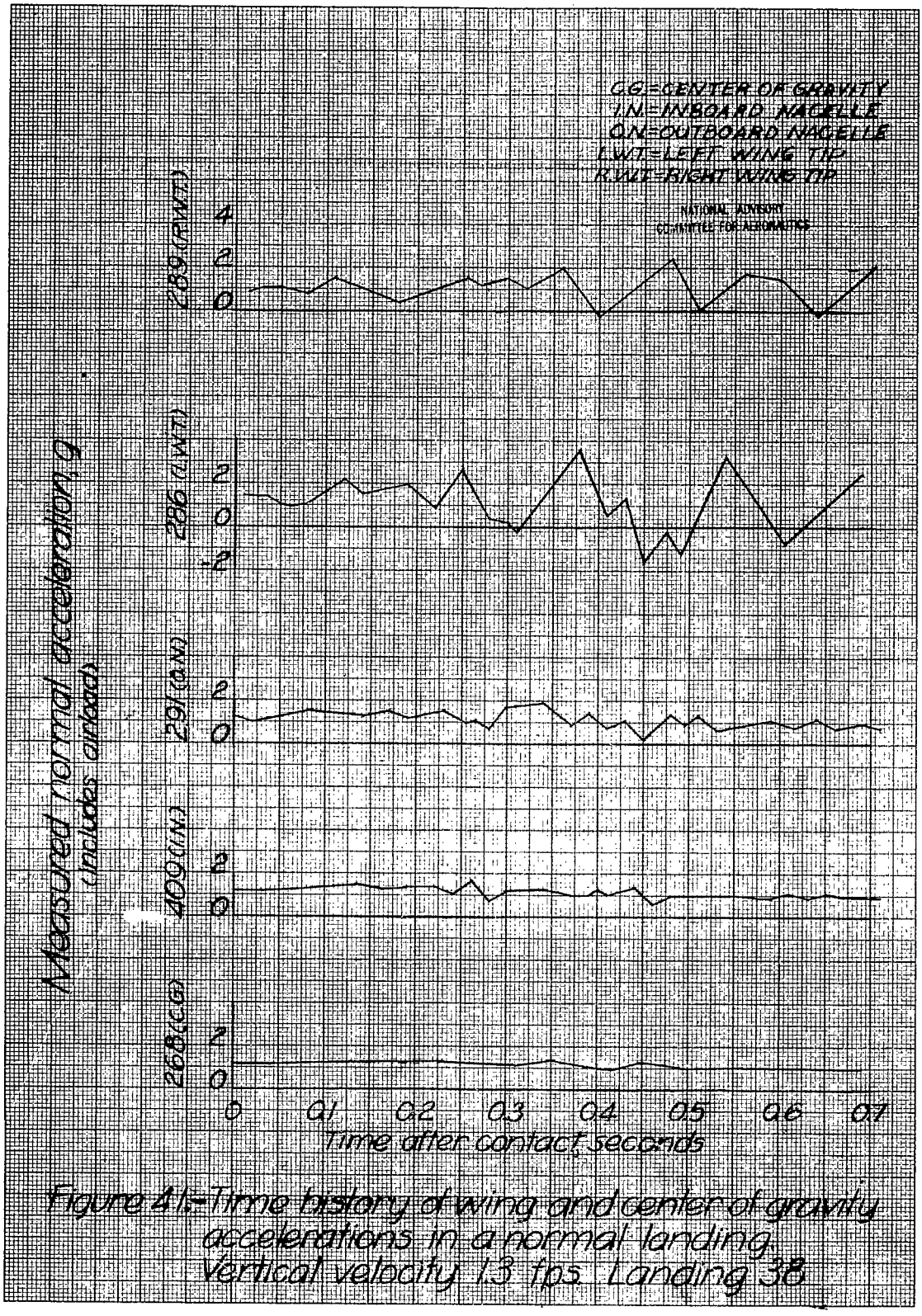

Figure 41.- Time history of wing and center of gravity accelerations in a normal landing. Vertical velocity 1.3 fps. Landing 38

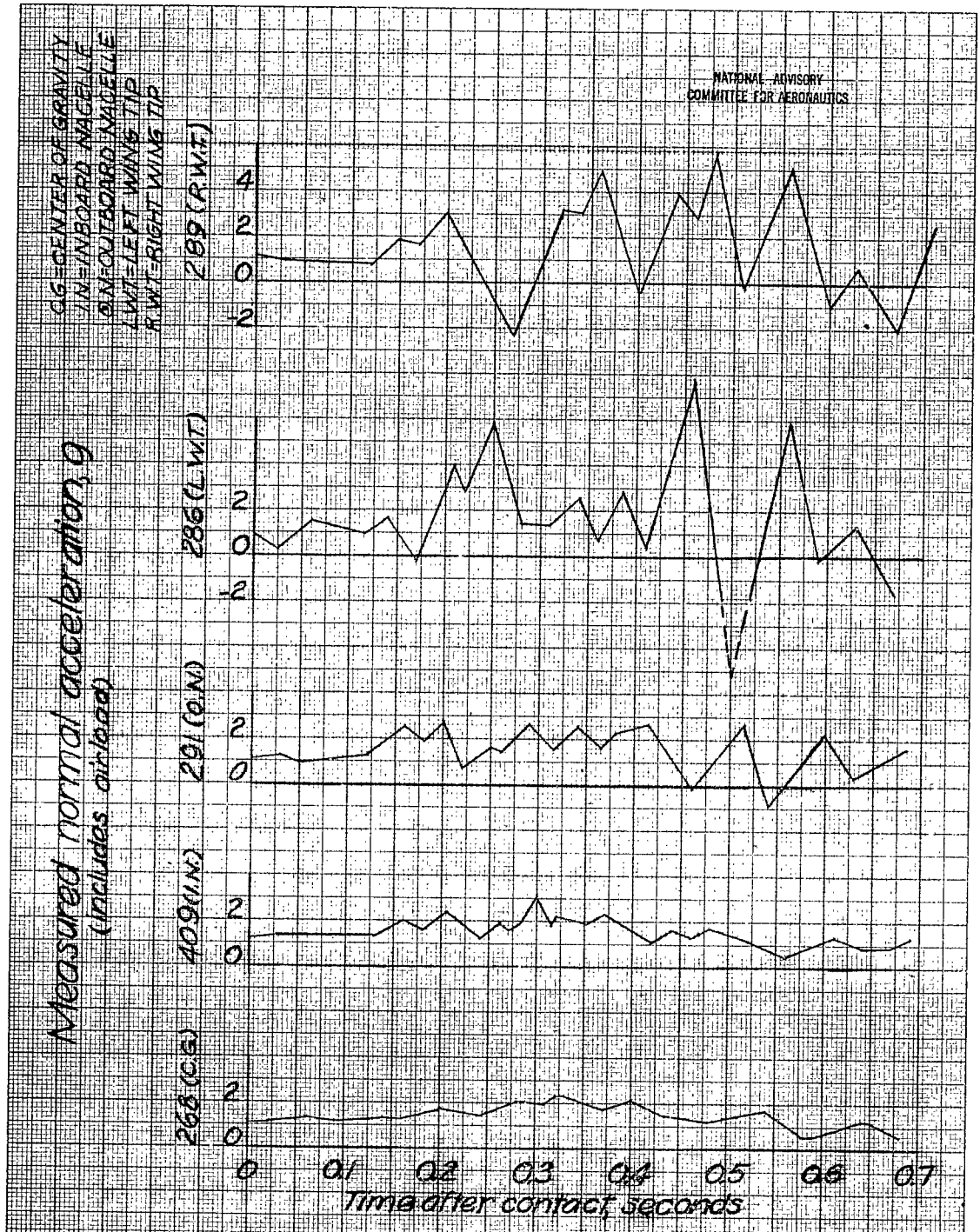

Figure 42.-Time history of wing and center of gravity accelerations in a normal landing. Vertical velocity 1.1 f.p.s. Landing 40, B-24D airplane

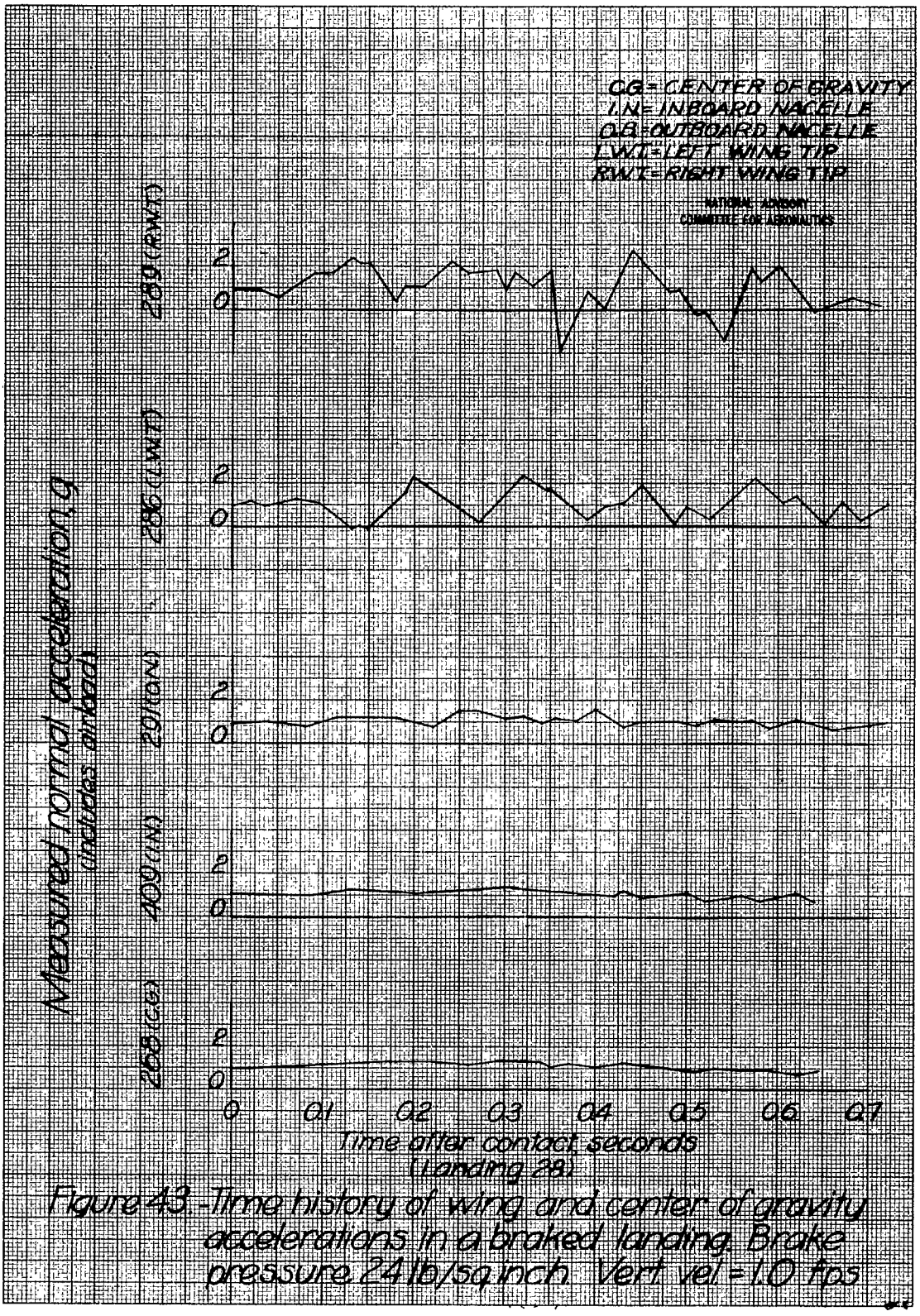

Figure 43.-Time history of wing and center of gravity accelerations in a braked landing. Brake pressure 24 lb/sq inch. Vert vel = 1.0 fps

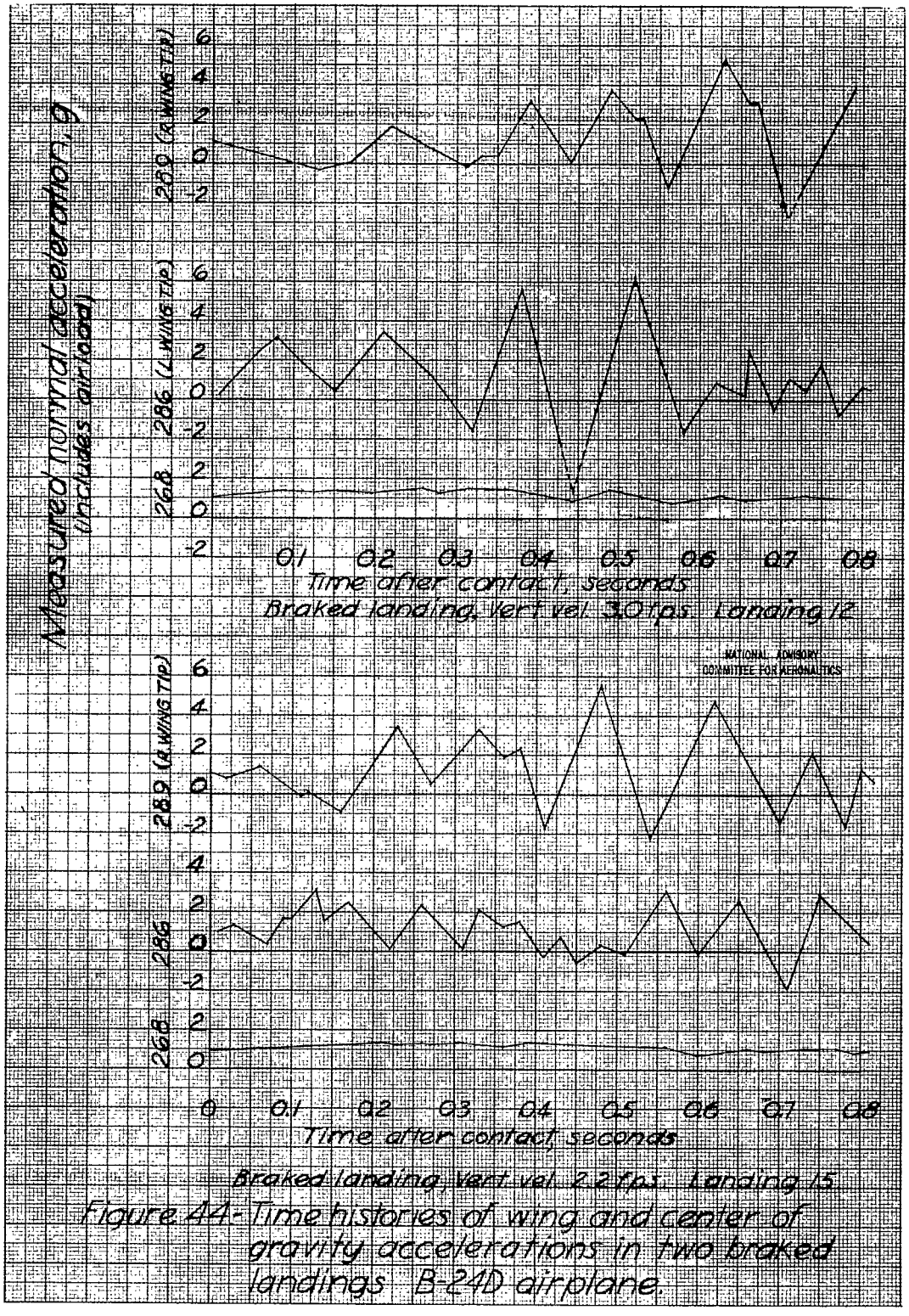

Figure 44- Time histories of wing and center of gravity accelerations in two braked landings B-24D airplane.

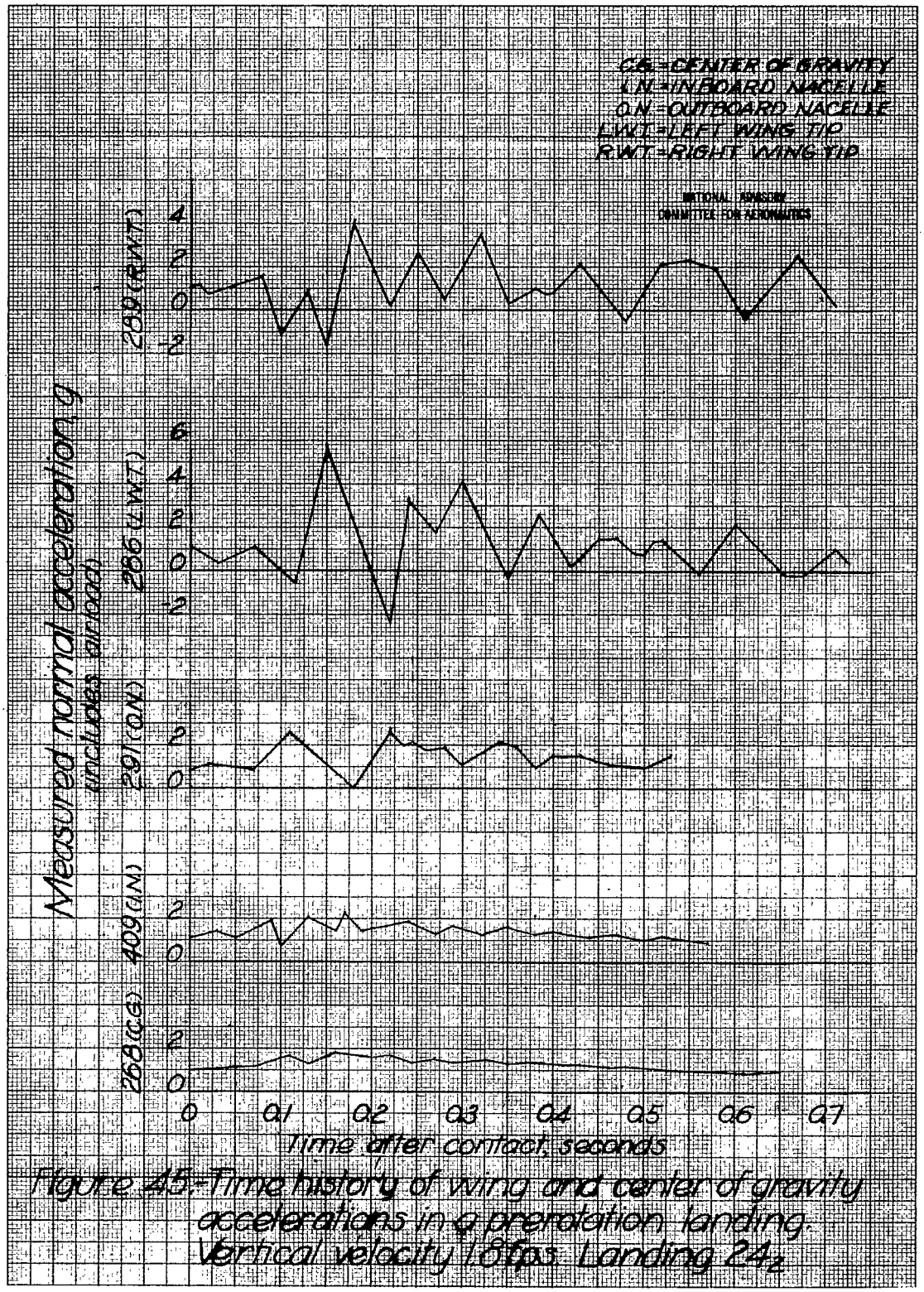

Figure 45.-Time history of wing and center of gravity accelerations in a prerotation landing. Vertical velocity 16 fps. Landing 24.

Figure 46.-Time history of wing and center of gravity accelerations in a prerotation landing. Vert. velocity 10 fps. Landing 25_2

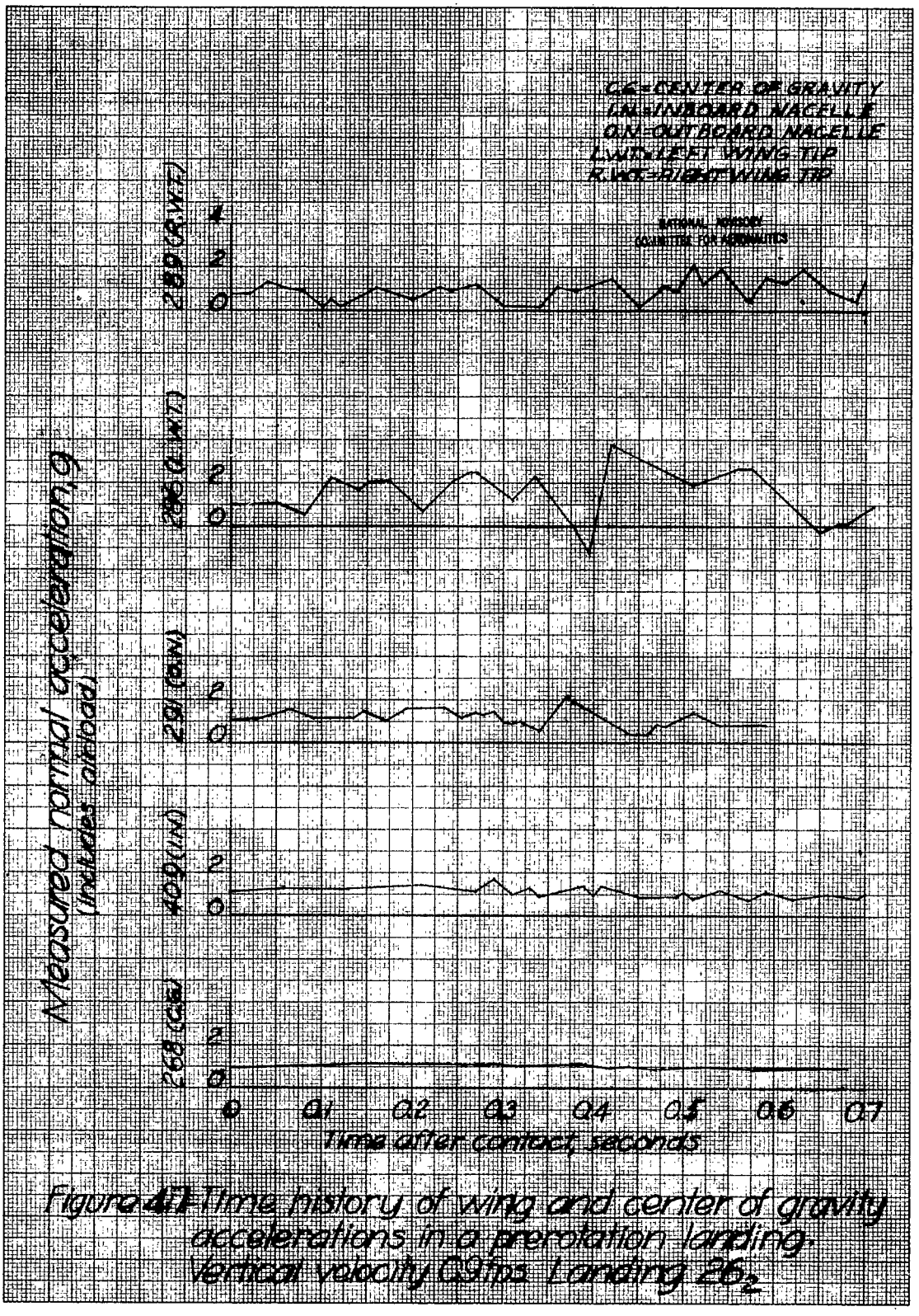

Figure 42.- Time history of wing and center of gravity accelerations in a prerotation landing. Vertical velocity 8 fps. Landing 26.

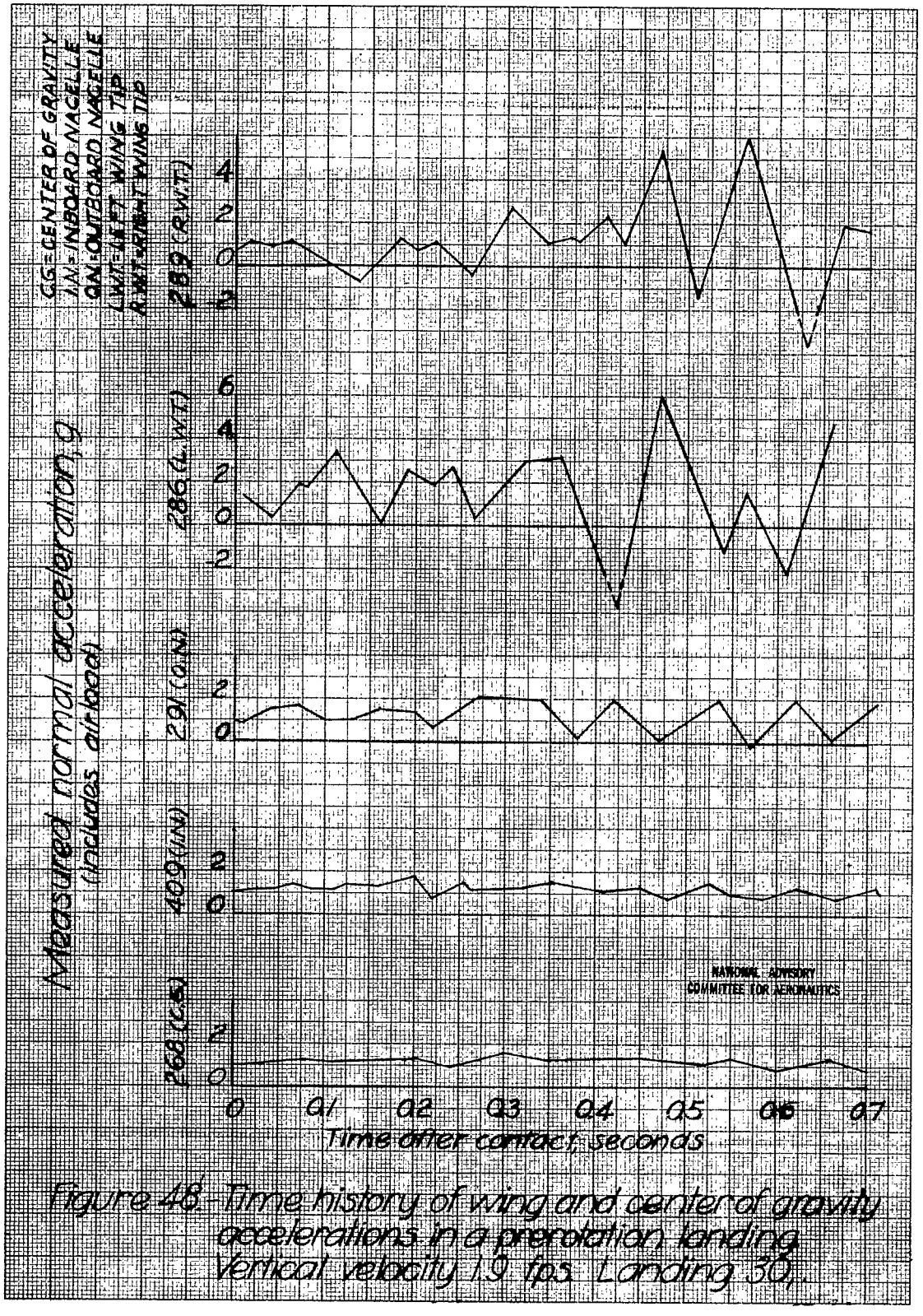

Figure 48.- Time history of wing and center of gravity accelerations in a prerotation landing. Vertical velocity 1.9 fps. Landing 30.

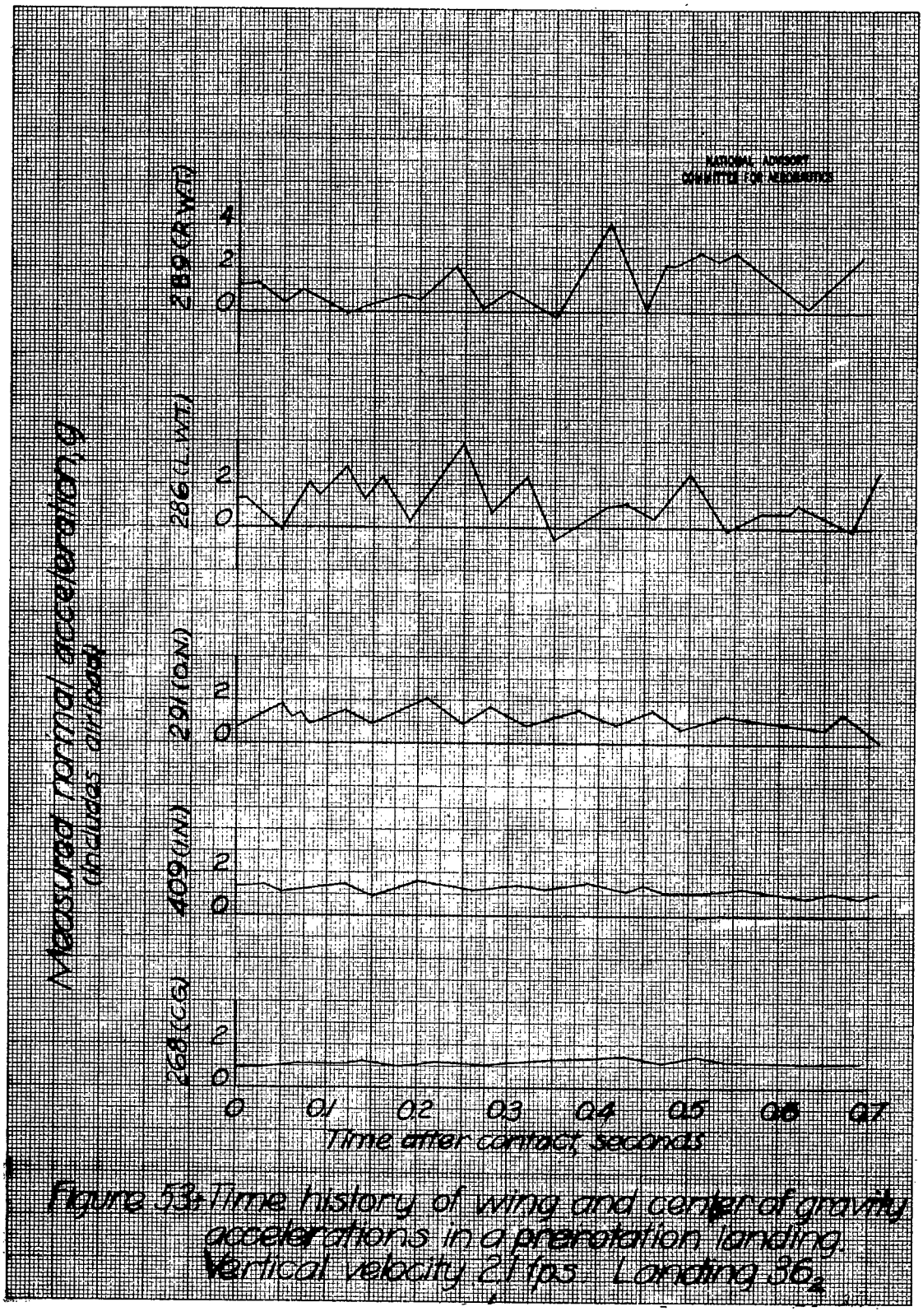

Figure 53.- Time history of wing and center of gravity accelerations in a prerotation landing. Vertical velocity 2.1 fps. Landing 36.

Figure 54.- Variation of ratio of wing tip to center of gravity acceleration increment with center of gravity acceleration increment. Left wing.

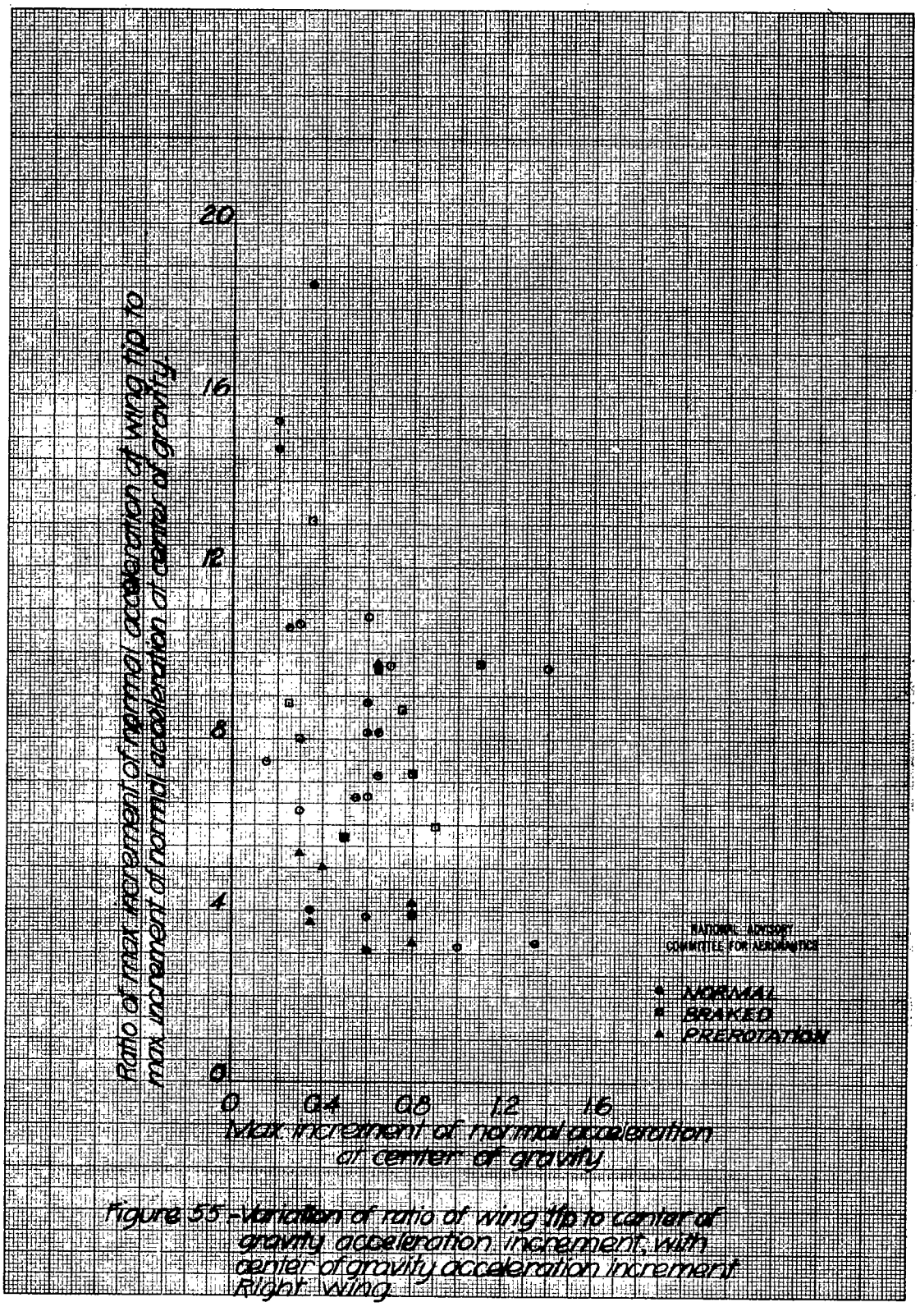

Figure 55.-Variation of ratio of wing tip to center of gravity acceleration increment with center of gravity acceleration increment. Right wing.

TITLE: Accelerations Measured at Center of Gravity and Along Span of the Wing of a B-24D Airplane in Landing Impacts

AUTHOR(S) : Westfall, J. R.

ORIG. AGENCY : Langley Aeronautical Laboratory, Langley Air Force Base, Va.

PUBLISHED BY : National Advisory Committee for Aeronautics, Washington, D.C.

ATI- 9613

DIVISION (None)

ORIG. AGENCY NO. (None)

PUBLISHING NO. (None)

DATE	U. S. CLASS	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Aug '44	Unclass.	U.S.	English	66	photos, tables, diagrs, graphs

ABSTRACT:

387543

Landing tests were conducted and B-24D airplane with wheels stationary, braked, and in prerotation. Average vertical velocity during instant of contact varied between 2.3 and 6.9 feet per second. Maximum wing-tip-acceleration increment was 13.5 g, coincident with CG-acceleration of 1.4 g. Test results indicate but slight difference in maximum acceleration magnitudes for normal, braked, and prerotation landings of comparable severity. Prolonged wing vibrations were established during braked landing.

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(23) * Aircraft Landings
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ATI No: 16343

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OA No:

CANCELLED - DUPE OF 9613

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AUTHOR(S): Westfall, John R.

OA: National Advisory Committee for Aeronautics

Foreign Title:

Previously cataloged under No:

Translation No:

Subject Division: Aerodynamics

Section: 6

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