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ATI-73926

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UNANNOUNCED

MEMORANDUM REPORT

ATI-73926

U. S. AIR FORCE
AIR MATERIEL COMMAND
WRIGHT FIELD, DAYTON, OHIO

Date	Serial No.	Copy No.
27 February 1948	MCREXA6-45257-4-1	

Subject

Tests for Determining the Coefficient of Friction of 44" Smooth Contour Tires on Concrete Runways.

HqAMC Form No 80-34B (20 Dec 46) WF-L-9 JUN 47 1M

Hq AMC Form No. 80-34C
(24 Jun 47)
WF-O-2 DEC 47 3M

82 04 13 087

HEADQUARTERS
AIR MATERIEL COMMAND
WRIGHT PATTERSON AIR FORCE BASE
DAYTON, OHIO
MEMORANDUM REPORT ON

No. of Pages 31

RGA/WTC/is

Date 27 February 1948

SUBJECT: Tests for Determining the Coefficient of Friction of 44" Smooth Contour Tires on Concrete Runways.

OFFICE: Aircraft Laboratory.... Contract or Order No....................

SERIAL NO. MCREXA6-45257-4-1... Expenditure Order No. 452-260............

A. PURPOSE:

1. To determine the friction characteristics of rubber on concrete at various rubbing speeds and under heavy loading.

B. FACTUAL DATA:

2. The test vehicle used in conducting the tests was an A-20G type airplane with the outer wing panels removed (Photographs No's. 232991 and 232986, Appendix 6). The weight per wheel of the unloaded vehicle was 6765 pounds while the weight per wheel of the vehicle with a 6000 lb. load was 9305 pounds.

3. The ground speed was measured by a 12" tail wheel assembly attached to the right main landing gear of the taxi vehicle (Photographs No's 232981 and 23298 Appendix 6). For details pertaining to the construction and operation see Appendix 2.

4. Racks, for the purpose of containing the additional weight were built into the bomb-bay of the vehicle. A maximum load of 9000 pounds was planned for use in the racks (Photograph No. 232988 Appendix 6).

5. The shock strut pressure was also increased in order to minimize pitching of the vehicle.

ive channels of SR-4 strain gages were installed to instrument the , for details see Appendix 2. These channels recorded drag load, ver load, side load, fore and aft bending and vertical shear loads (Photogr io's. 232983 and 232984, Appendix 6).

. The potentiometer circuits and resistances of the SR-4 systems w cated in a bridge box fastened inside the rear compartment of the v (Photograph No. 23298, Appendix 6).

8. The galvanometer (G fig. 2, Appendix 3) was located in the osc aph (Photograph No. 232980, Appendix 6).

9. The oscillograph and the bridge were both operated from a 12 v attery and were connected in parallel (Photograph No. 232980, Appendix

10. The apparatus was calibrated for drag loads, side loads, and vertical loads. Calibration procedure is described in Appendix 2.

11. Motion Pictures were taken of the actual skids and test procedure, and may be reviewed by contacting the Air Material Command, Attn: MCREXA6.

12. This report contains six Appendixes as listed below:

a. Appendix 1, Description of Test Procedure and Discussion of Results.

b. Appendix 2, Detailed Discussion of Instrumentation and Calibration.

c. Appendix 3, Strain Gage Locations and Bridge Circuit Diagrams.

d. Appendix 4, Calibration Curves.

e. Appendix 5, Coefficient of Friction, Vertical, and Drag Load Curves.

f. Appendix 6, Tire Friction Test Photographs.

C. CONCLUSIONS:

13. That the subject method of measurement is a practical means of obtaining values for determining the coefficient of friction of aircraft tires at high speeds and high loadings.

14. That on dry concrete runways, the skidding coefficient of friction varies from a maximum of 0.63 to a minimum of 0.32 and decreases with increase in aircraft speeds and loads. "Figures 1 and 2 Appendix 5." Additional test work will be required before definite conclusions as to the specific variations may be drawn.

15. The coefficient of friction values for the point of pending s were very erratic and were not plotted. The value of the coefficient of friction at this point was generally higher then that for the actual skid values. This is to be expected, however, the erratic nature of the readings will be checked during future skid tests with an A-26 type taxi vehicle.

16. A marked discontinuity in the coefficient of friction vs. speed curve was noted in the range of 90-115 MPH. A similar variation was noted during inertia drag load studies on the 110" S.C. tire and described in Memorandum Report No. TSEAL-2 4263-46-4 Addendum 1. Data obtained from the subject test confirms the hypothesis that a definite change of the surface tread rubber occurs within this speed range.

D. RECOMMENDATIONS:

17. An A-26 type taxi test vehicle will be obtained to verify and supplement the above results and to extend the range of tests to higher speeds and loads. The A-20 type vehicle used in the subject test would not exceed 100 MPH with a 6000 pound load.

18. Additional tests will be run at higher loadings and speeds with the A-26 type taxi vehicle on different types of surfaces.

19. During the above tests particular emphasis will be placed on the obtaining of data from which the values of the coefficient of friction during the initial transition from free roll through full skid may be studied.

R. G. Allen

Distribution:

(See attached sheet)

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Appendix I

Description of Test Procedure and Discussion of Results.

1. Upon completion of the initial calibration of the test apparatus in the vehicle, taxi tests were conducted at speeds from 30 to 115 MPH in 10 MPH increments. The skids were of approximately 3 seconds duration. After the completion of this series of tests a load of 6000 pounds was added to the bomb-bay and the vehicle was again calibrated to determine any possible changes caused by the increased vertical load. No change in the original calibration data was noted. Additional tests were then accomplished with the added weight at speeds from 30 to 100 MPH in 10 MPH increments.

2. The oscillograph charts were analyzed and converted into pounds drag per wheel and vertical weight per wheel. The drag load was taken directly from the drag load curve without any corrections since the drag load gage was effected only by fore and aft loads. The vertical loads were taken from the rosette curve since it was affected mainly by vertical shear loads (Figure 11, Appendix 4) and needed only slight correction for drag load effects (Figure 9, Appendix 4). Side loads affected the rosette gage to such a small extent that it was not deemed necessary to make correction for them (Figure 4, Appendix 4).

3. The vertical, side, and fore and aft gages picked up considerable interference from each other and could not be adequately corrected, so they were not used for computation of test results.

4. As stated previously the rosette gage was affected mainly by vertical load and drag load. The drag was first determined at a particular point of the curve and from the calibration curve (Figure 9, Appendix 4) the effect, of the particular drag under consideration, on the rosette gage was determined. This correction was applied to the rosette curve, after which it was possible to take the vertical load direct from the rosette calibration curve (Figure 11, Appendix 4). This procedure permitted the determination of drag and vertical load for three separate points per skid. Using the drag and vertical loads plus the static vertical load, it was possible to determine the coefficient of friction between the tire and runway during each skid. The coefficient of friction versus skid has been plotted for the unloaded vehicle on Figure 1, Appendix 5, and for the loaded vehicle on Figure 2, Appendix 5.

5. Drag and vertical load curves were plotted for both the unloaded and loaded vehicle (Figures No's. 3 and 4, Appendix 5). The similarity of the contours of the drag and vertical curves on both figures indicates that the drag load varies directly and proportionally with the vertical load, thereby confirming the assumption of a constant coefficient of rubbing friction for any given load and speed.

Discussion:

The results, to date, indicate that the coefficient of friction decreases with increased load and increased speed. This phenomenon can only be explained by the fact that the rubber becomes much hotter and tends to rub off the tire at a more rapid rate due to a lowering of the adhesive characteristics between the rubber particles. This would tend to occur at both high speeds and high loads.

The hump that occurs in the curve of the unloaded vehicle (Figure 1, Appendix 9) can not be fully explained at this time. However, it is believed that a change occurs in the physical properties of the rubber at the contact surface because of the sudden local temperature change, and that this hump may indicate a break-down of the surface rubber from a pealing to a completely melted condition.

Appendix 2

Detailed Discussion of Instrumentation and Calibration.

1. The ground speed was measured by the use of a 12" tail wheel assembly attached to the right main landing gear as an extra wheel. A spring was used to hold the wheel in firm contact with the ground. A six inch pulley was attached to the wheel and a twelve inch pulley was attached to the tachometer generator. The two pulleys were connected by a belt. The generator rotated at one-half the angular velocity of the speedometer; however, since the tachometer indicated twice the generator speed, the tachometer readings were true indications of the speedometer wheel speeds. Wires were run from the tachometer generator to tachometers in the pilot's cockpit and in the rear instrument compartment (Photographs No. 232985 and 23299, Appendix 6). The tachometer generator and tachometers were calibrated in miles per hour on the 192" dynamometer at Wright Patterson Air Force Base.

2. Racks were built into the bomb-bay for the purpose of containing the additional weight to be added to the vehicle. To reduce the hazard of the weight shifting during the skids the platforms were sectioned off by using 4" steel angles bolted to the platform. The platform was made of wood and supported by steel stringers.

3. Five channels of SR-4 strain gages were installed to instrument the test. They were drag load, vertical load, side load, fore and aft bending, and vertical shear load.

4. The drag load SR-4 gages were located on the drag strut (Figure 1, Gage 1, Appendix 3). There were two gages on the strut for measurement of the drag, consequently two dummy gages were installed to complete the legs of the bridge circuit and to provide temperature compensation. R-1 and R-3 Figure 2, Appendix 3) are the SR-4 gages on the drag strut while R-2 and R-4 are the dummy SR-4 gages. The gages on the strut were affected solely by compression or tension and, therefore, gave a true indication of drag loads.

5. The vertical load gage was located on the underside of the axle (Figure 1, Gage 2, Appendix 3). The other SR-4 gages (Figure 2, R2, 3, & 4 Appendix 3) were dummy gages. This gage R-1 was subjected to bending load only. It was effected by both vertical and side loads.

6. The side load gages were located on the side brace strut Figure 1, Gage 3, Appendix 3 and Photograph No. 232984, Appendix 6). The wiring diagram was exactly the same as the diagram referenced in paragraph No. 4. Like the drag load gages they were subjected purely to compression and tension. These gages were affected by side loads only.

7. The fore and aft SR-4 gages were located on the fore and aft sides of the axle between the torque flange and the axle elbow (Figure 1, Gages 4, Appendix 3). On Figure 2 (Appendix 3) R-1 and R-2 are the live SR-4 gages, while R-3 and R-4 are the dummy gages. These gages were subjected mainly to drag loads; however, under a side load some response was noted.

8. The rosette gages (Figure 1, Gages 5, Appendix 3) was mainly for the purpose of measuring the vertical shear loads in the axle. R-1 through R-4 (Figure 2, Appendix 3) were live gages. The gages were subjected primarily to shear; however, some bending loads were recorded. Thus these gages record both drag and vertical loads with the vertical load having the predominate effect.

9. The potentiometer circuits and resistances of the SR-4 gages were contained in a bridge box fastened inside the rear compartment of the taxi vehicle (Photograph No. 232989, Appendix 6). This bridge box also contained the two static resistances R-5 and R-7 and the variable resistance or rheostat R-6 (Figure 2, Appendix 3).

10. The galvanometer (Figure 2, G, Appendix 3) was located in the Oscillograph Photograph No. 232980, Appendix 6). The oscillograph first used was a Heiland 6 channel instrument. This instrument was damaged early in the test and was replaced by a fourteen channel Consolidated Oscillograph. The instrument was bolted to the floor of the vehicle, using shock mounts in order to reduce the effect of jars and vibrations.

11. The Oscillograph and the bridge were both operated from a 12 Volt battery and were hooked in parallel (Photograph No. 232980, Appendix 6).

12. The instruments were calibrated for drag load, side load, and vertical loads. These calibrations were first accomplished with the Heiland Oscillograph and later repeated with the Consolidated Oscillograph.

13. The drag load calibration was obtained by immobilizing the taxi vehicle with the parking brake and chocking the wheels. A steel cable was attached to the nose gear strut. The other end of the cable was attached to a tensiometer which in turn was attached by a steel cable to a roustabout type tractor The bridge circuit was roughly balanced and then the oscillograph was switched into the circuit for final balancing. A short oscillograph record was then made to identify the position of the galvanometer with a zero drag load. A forward load was then applied to the nose gear by means of the apparatus described above. An oscillograph record was made at each 1000 pound load increment up to the maximum load, which was 5700 pounds total load on both main wheels. The same recording procedure was followed while

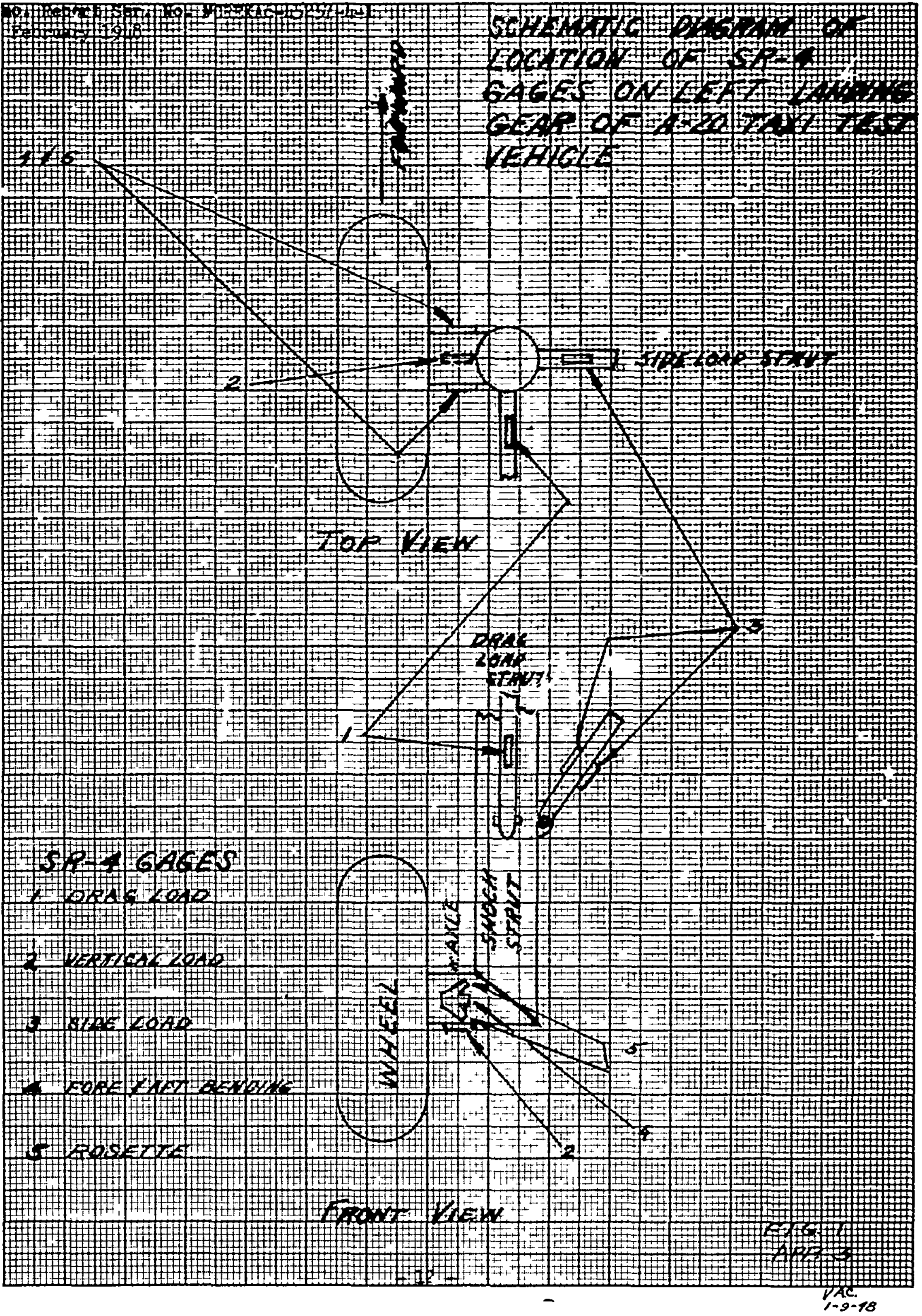
releasing the load. The drag load was applied and released in the manner described in order to get a mean deflection versus load calibration curve. It was anticipated that both the drag gages (Figure 1, Gage 1, Appendix 3) and the fore and aft bending gages (Figure 1, Gage 4, Appendix 3) would respond to forward drag. This was verified on the oscillograph however, it was found that the rosette gages also registered response to drag. The deflections registered by the above gages were then plotted versus applied drag load (Figure 7 thru 10, Appendix 4).

14. The side load calibration was obtained by placing the right main landing gear on a steel plate approximately two feet square. The plate was supported by cylindrical steel bars resting on a smooth concrete surface. The reason for this arrangement was to allow the right landing gear to move freely when lateral force was applied thereby imposing a side load on the left main landing gear which contained the strain gage instrumentation. The lateral force was applied through a steel cable attached to the right landing gear strut and passing over the left landing gear wheel through a tensiometer to a roustabout tractor. This arrangement simulated left side load. An oscillograph record was made with a zero side load and at every 1000 pound increment to a maximum of 4000 pounds. Oscillograph records were also made at similar increments while decreasing the load. The right side calibration was performed in the manner described heretofore except that the load was applied in the opposite direction. The oscillograph revealed that side loads caused response from the side load gages (Figure 1, Gage 3, Appendix 3), vertical load gage, and a small erratic deflection of the rosette gages (Figure 1, Gage 5, Appendix 3) which was considered negligible. Side load versus deflection curves were drawn from the oscillograph records to show the effect of side loads on the various strain gages (Figure 3 thru 6, Appendix 4).

15. The vertical calibration was obtained in the following manner. The left main landing gear of the taxi test vehicle was placed on a platform type scale. A wing type hydraulic jack was placed under the left wing of the vehicle so that the weight on the scale could be varied. An oscillograph record was made with the full weight of the left landing gear resting on the scale. The weight was then removed from the left landing gear by lowering the scale platform, and oscillograph records were taken at 1000 pound increments. This procedure was also followed while adding weight to the landing gear up to the initial weight. Variations in the vertical load caused response in the vertical bending gages and the rosette gages. When the load versus deflection curves were drawn the curves were extended to a point greater than normal static load in order to qualify the calibration in the event that shock loads greater than the normal static loads were encountered (Figure 11, thru 13, Appendix 4).

Appendix 3

Strain Gage Locations and Bridge Circuit Diagrams.

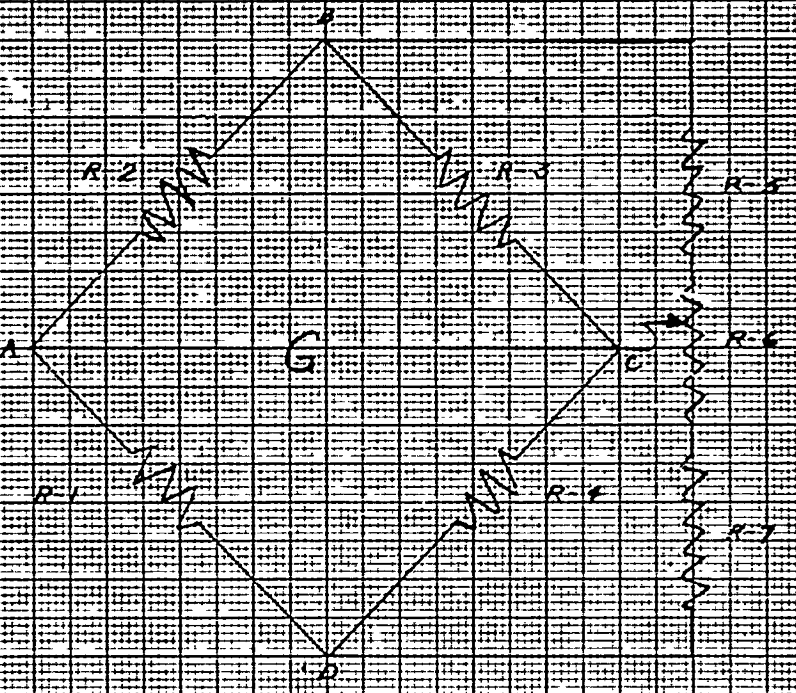


SCHEMATIC DIAGRAM OF LOCATION OF SR-4 GAGES ON LEFT LANDING GEAR OF A-20 TAXI TEST VEHICLE

SR-4 GAGES
1 DRAG LOAD
2 VERTICAL LOAD
3 SIDE LOAD
4 FORE & AFT BENDING
5 ROSETTE

FIG. 1
APP. 3

VAC.
1-9-48



BRIDGE CIRCUIT DIAGRAM

FIG. 2
APP. 3

V.A.C.
1-9-48

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Appendix 4

Calibration Curves.

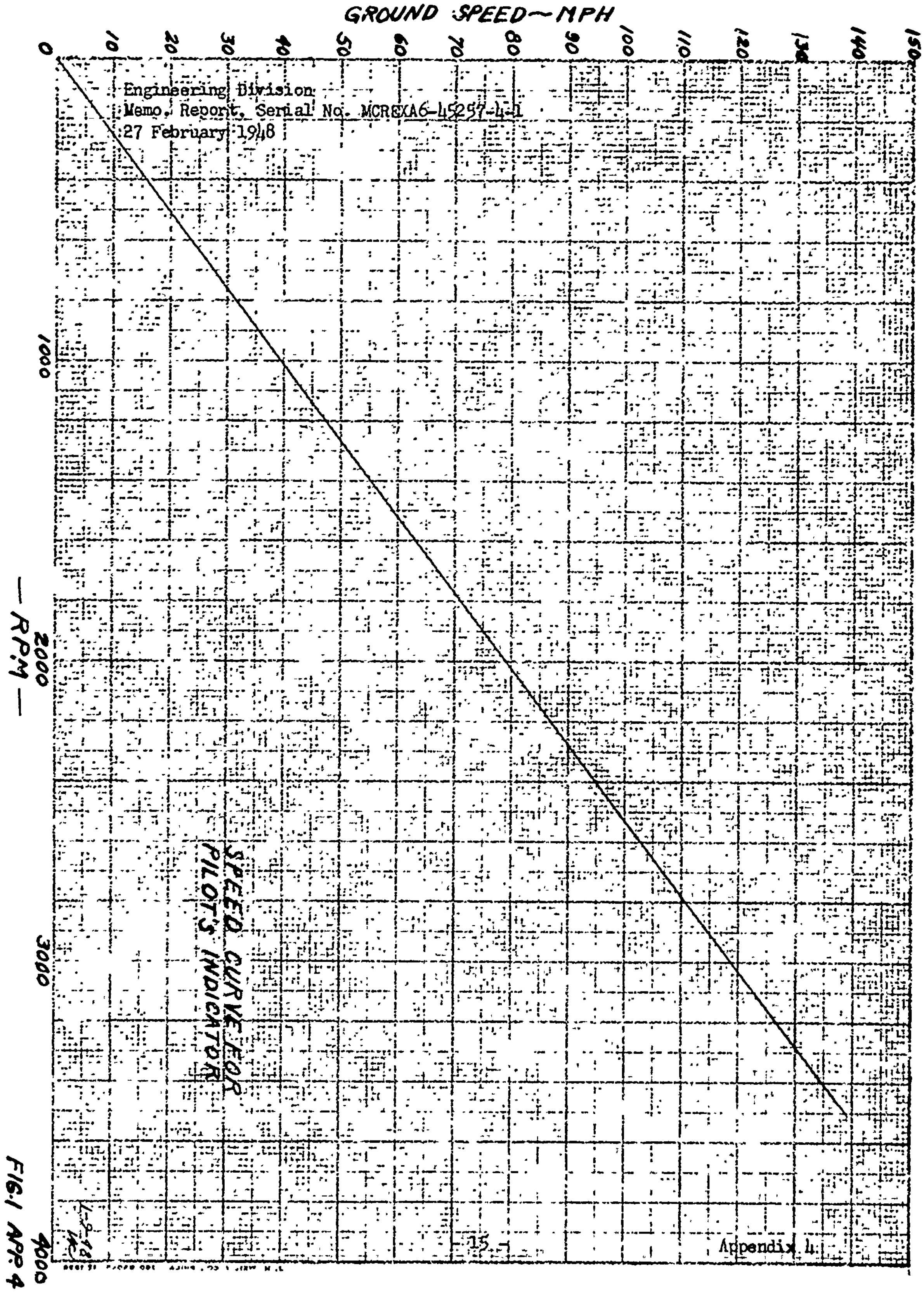
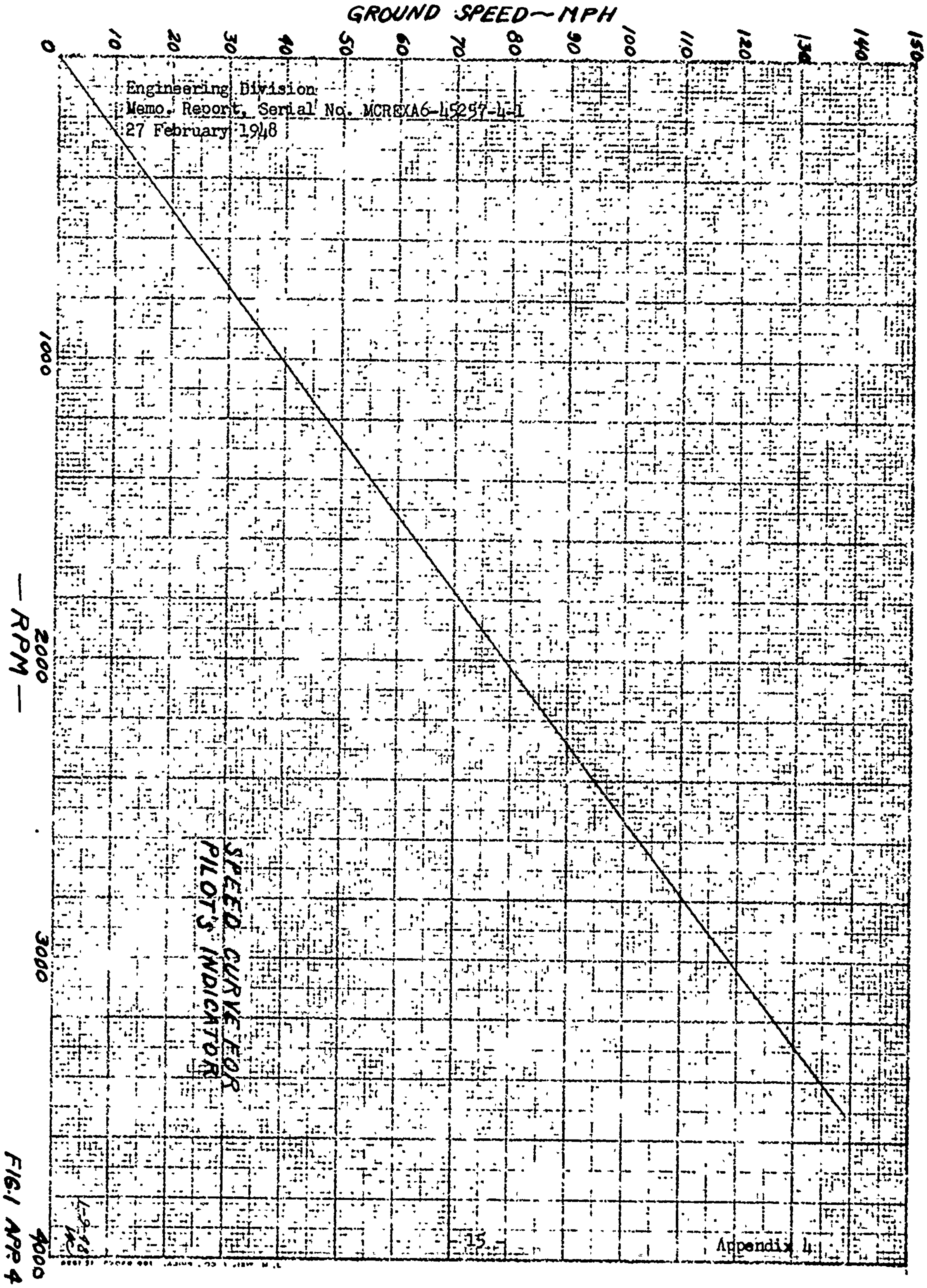
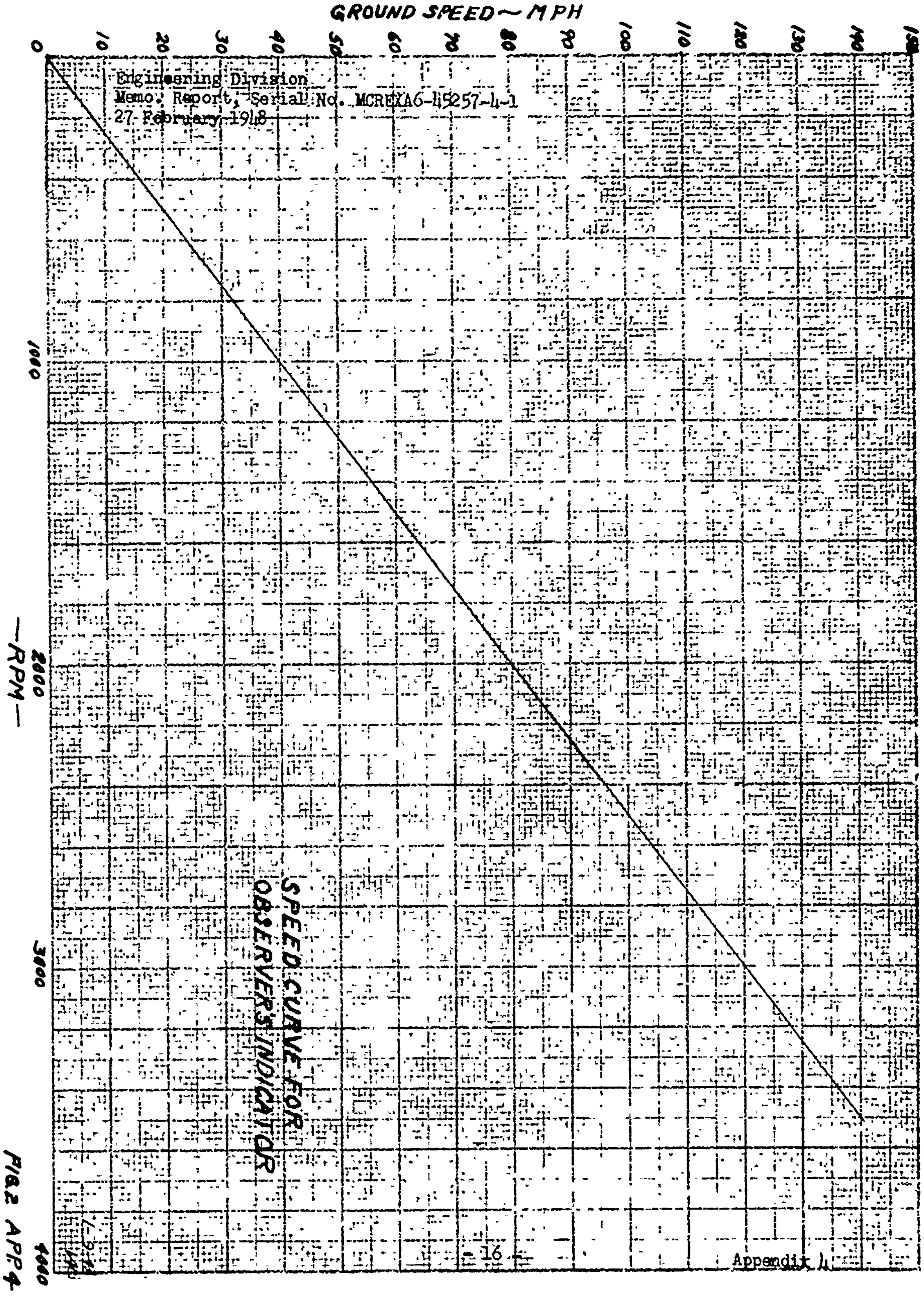

GROUND SPEED ~ MPH
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
— RPM —
1000
2000
3000
4000
SPEED CURVE FOR
PILOT'S INDICATOR
6-9-48
14

FIG. 1 APP. 4



SPEED CURVE FOR PILOT'S INDICATOR

FIG. 1 APP. 4



SPEED CURVE FOR OBSERVER'S INDICATOR

FIG.2 APP.4

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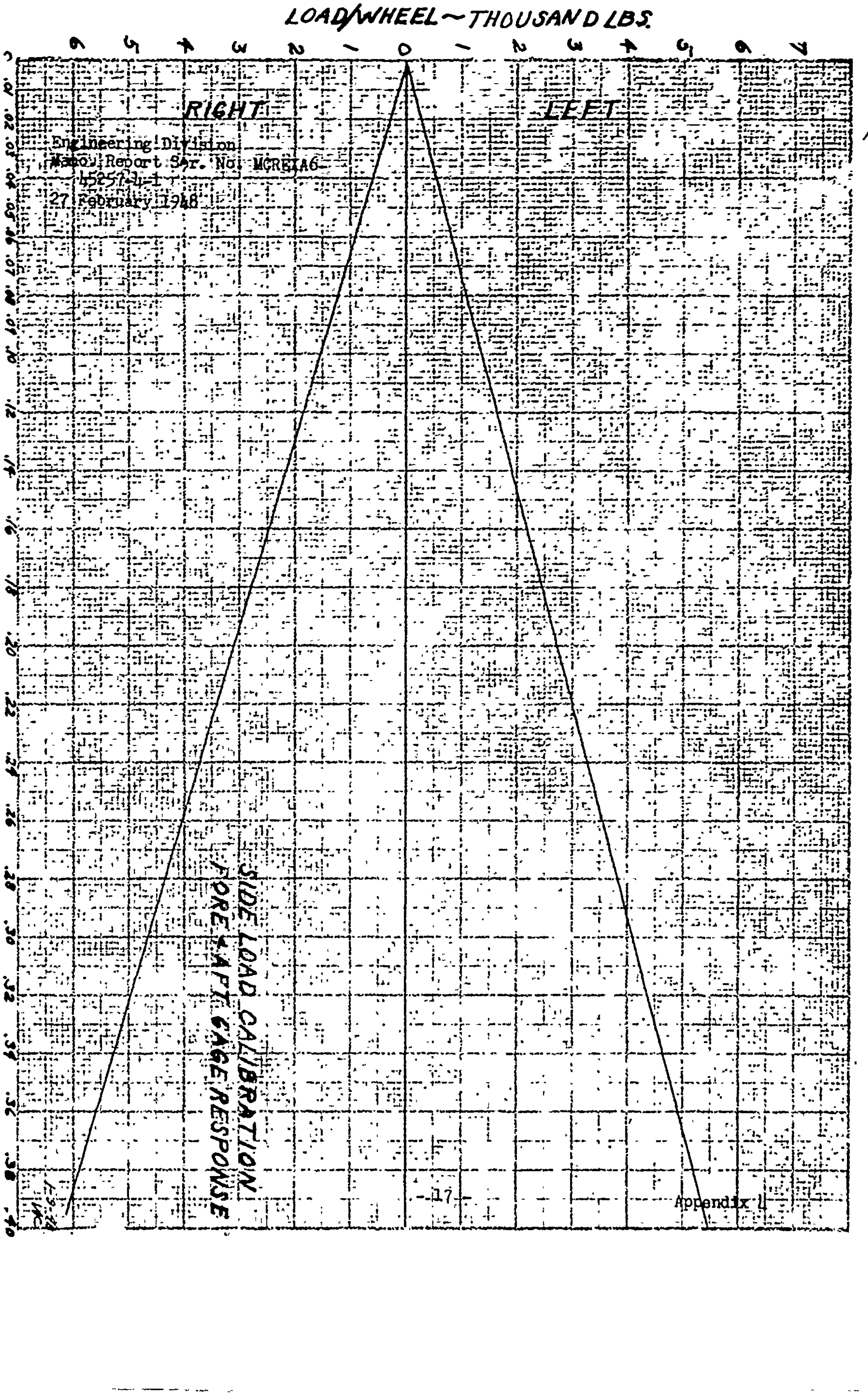

FIG. 3 APP. 4

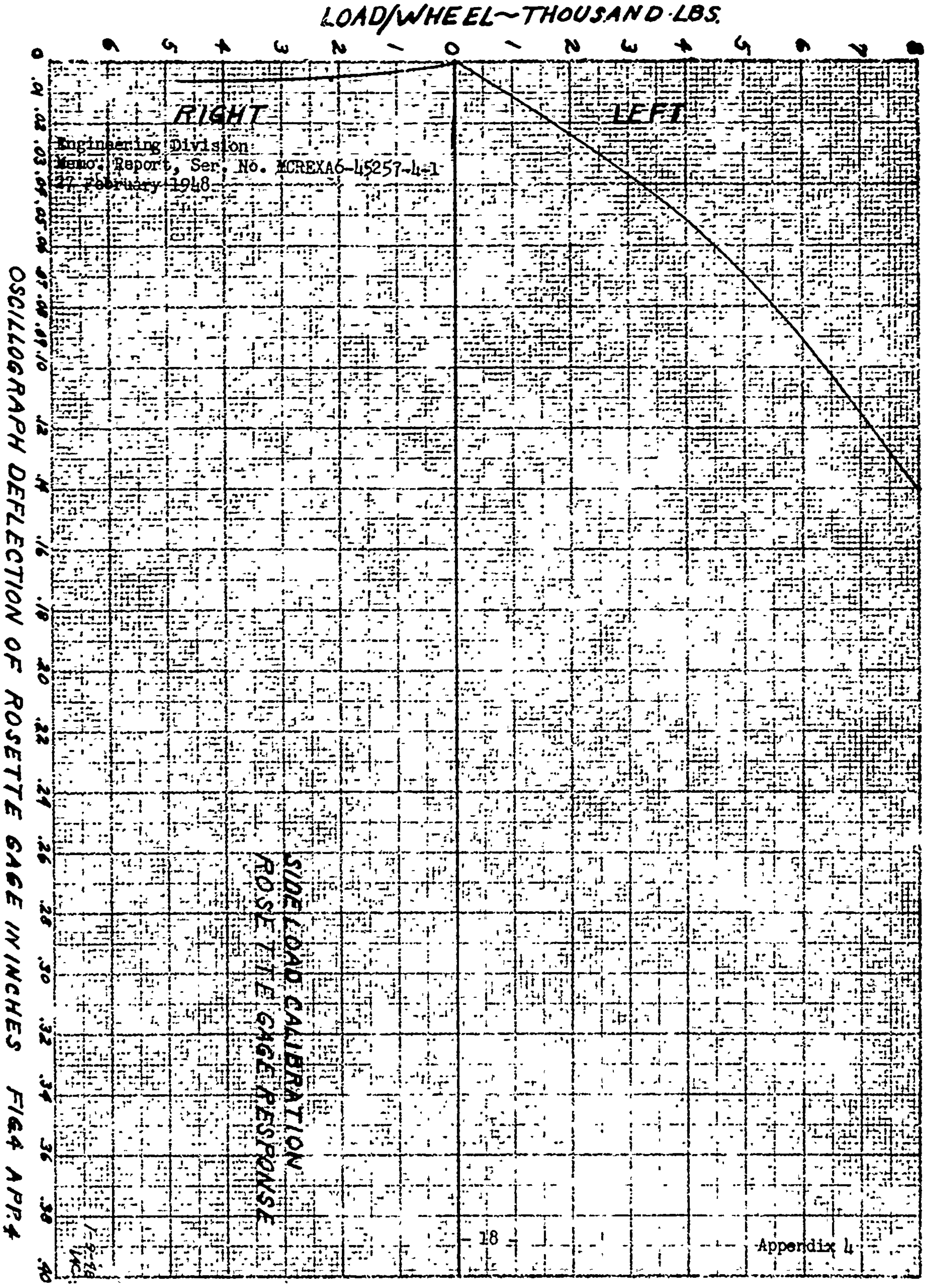
LOAD/WHEEL~THOUSAND LBS.
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
RIGHT
LEFT
SIDE LOAD CALIBRATION
ROSETTE GAGE RESPONSE
OSCILLOGRAPH DEFLECTION OF ROSETTE GAGE IN INCHES
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
7-9-48
WC

FIG.4 APP.4

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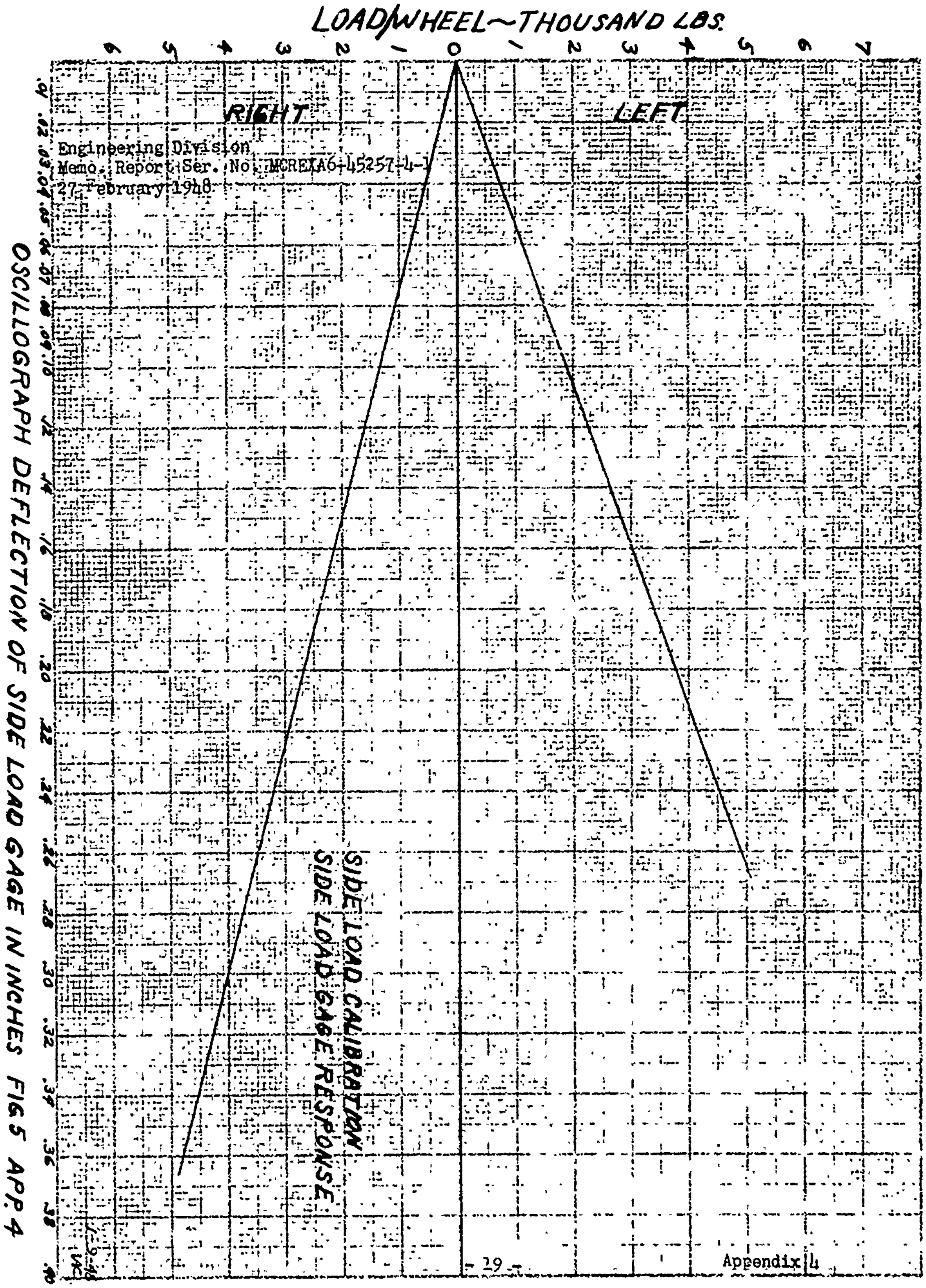

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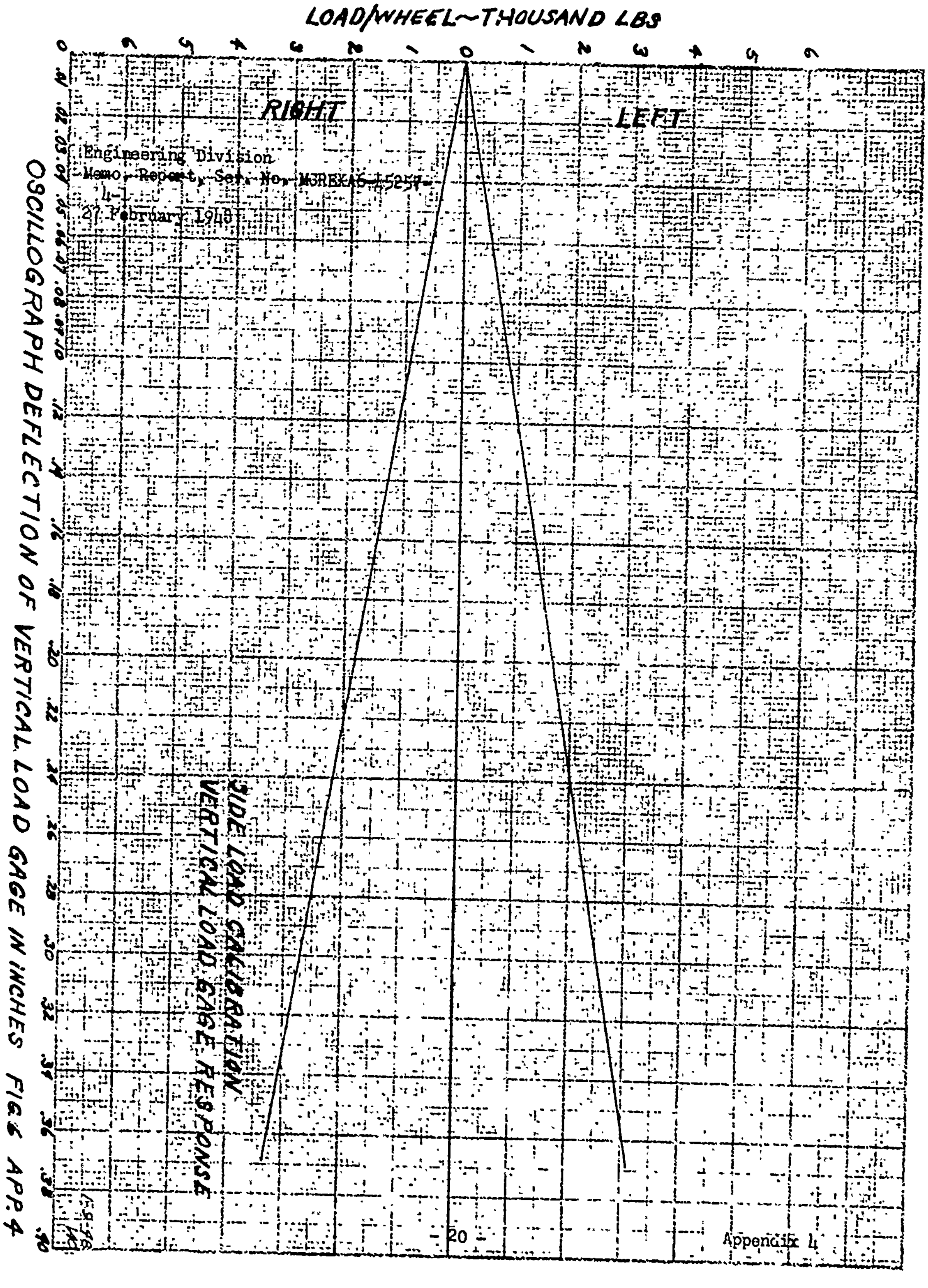

FIG 6 APP. 4

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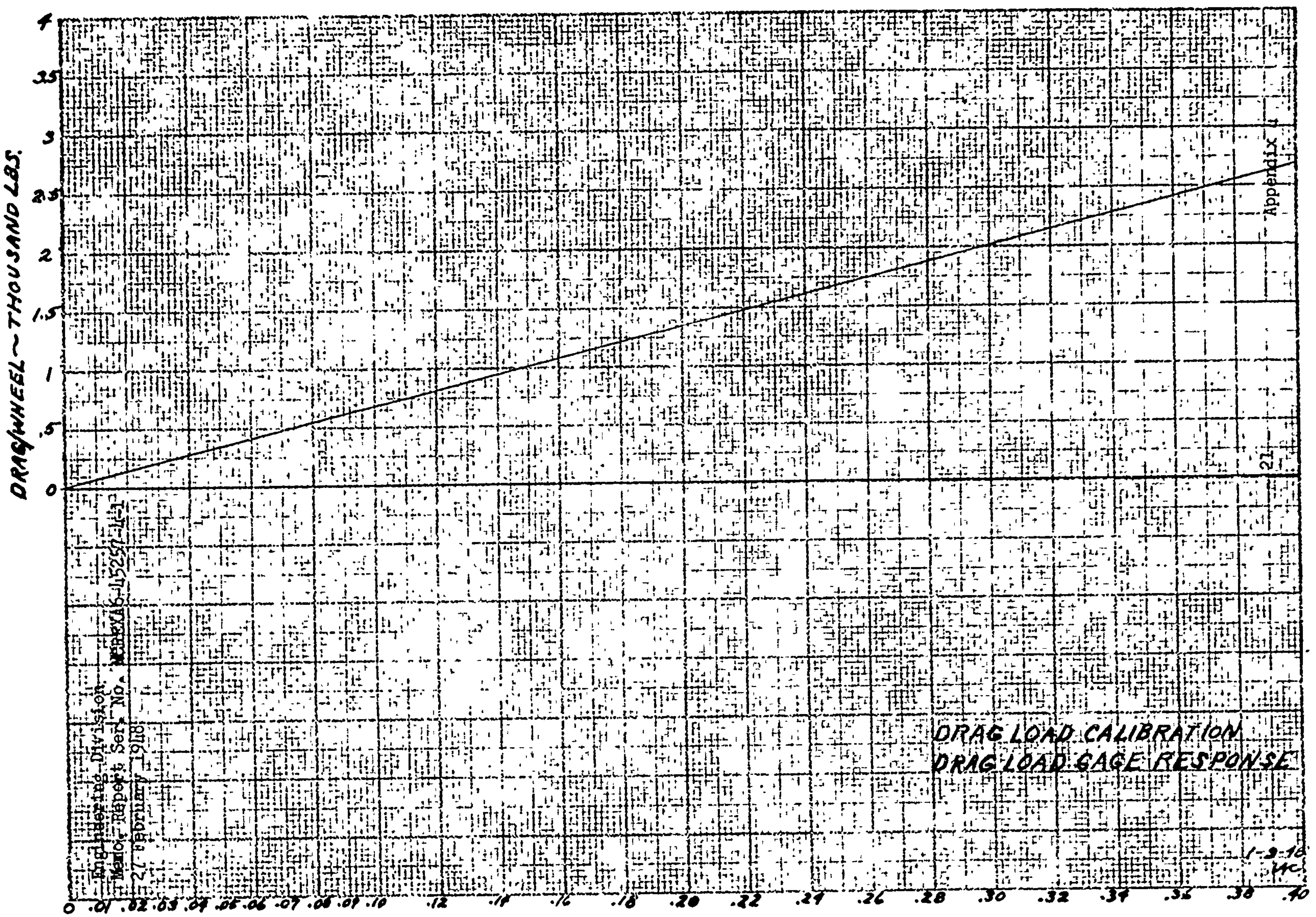

FIG 7 APP. 4

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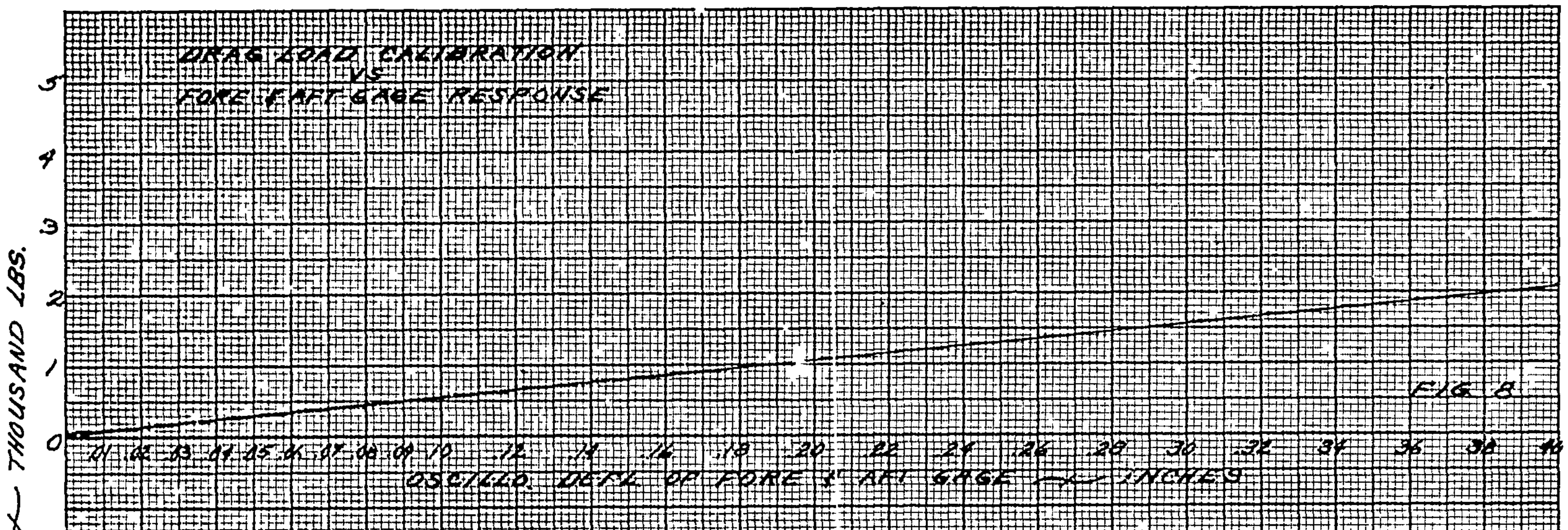


FIG. 8

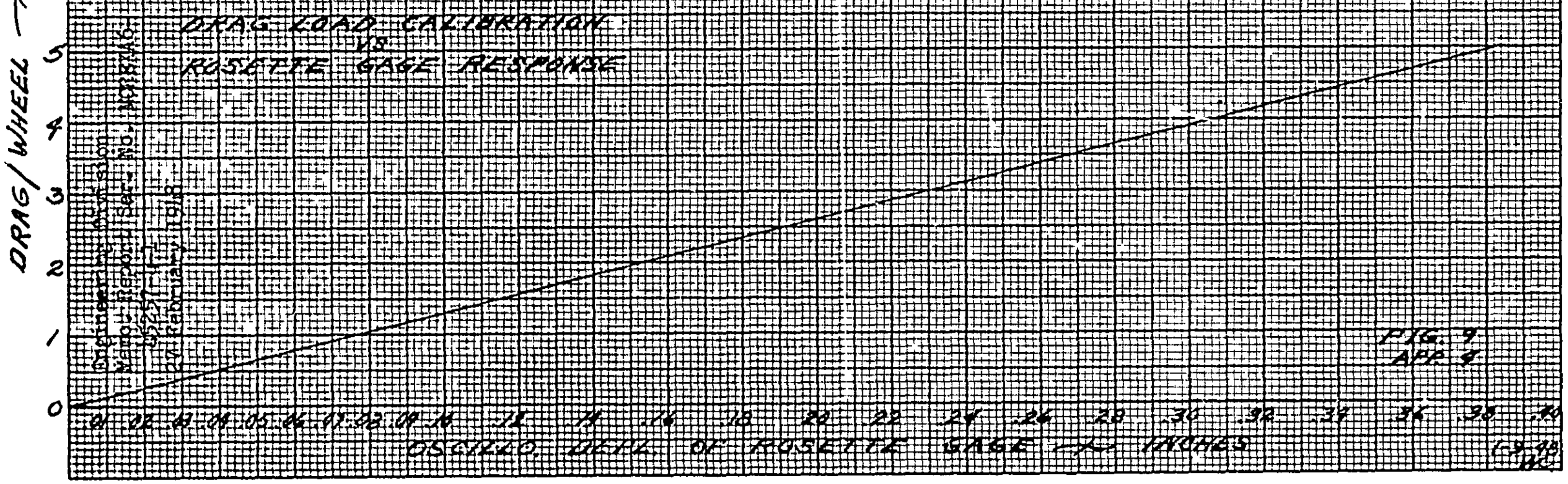
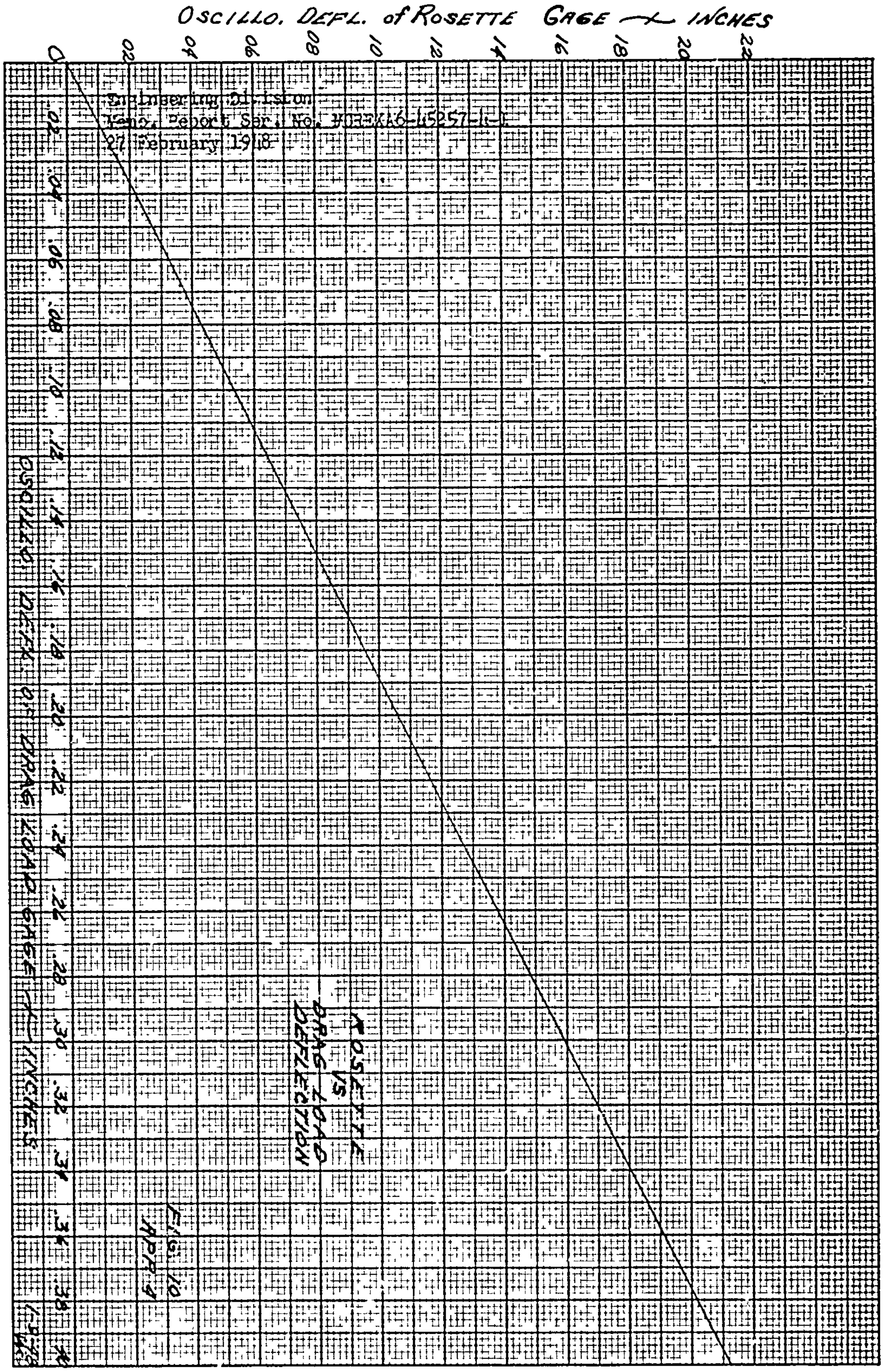


FIG. 9
APP. 4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ROSETTE VS DRAG LOAD DEFLECTION

FIG. 10
APP. 4

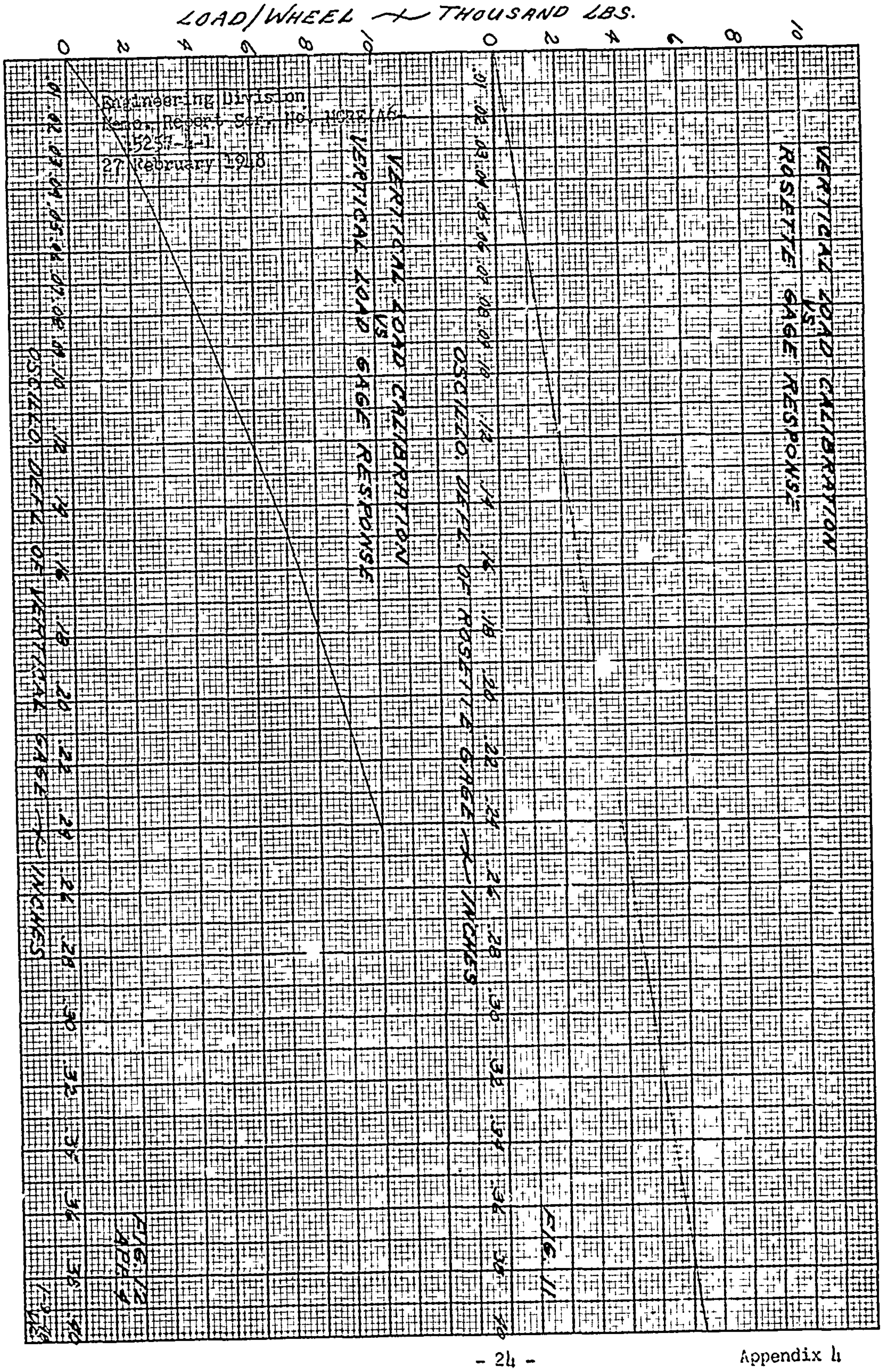
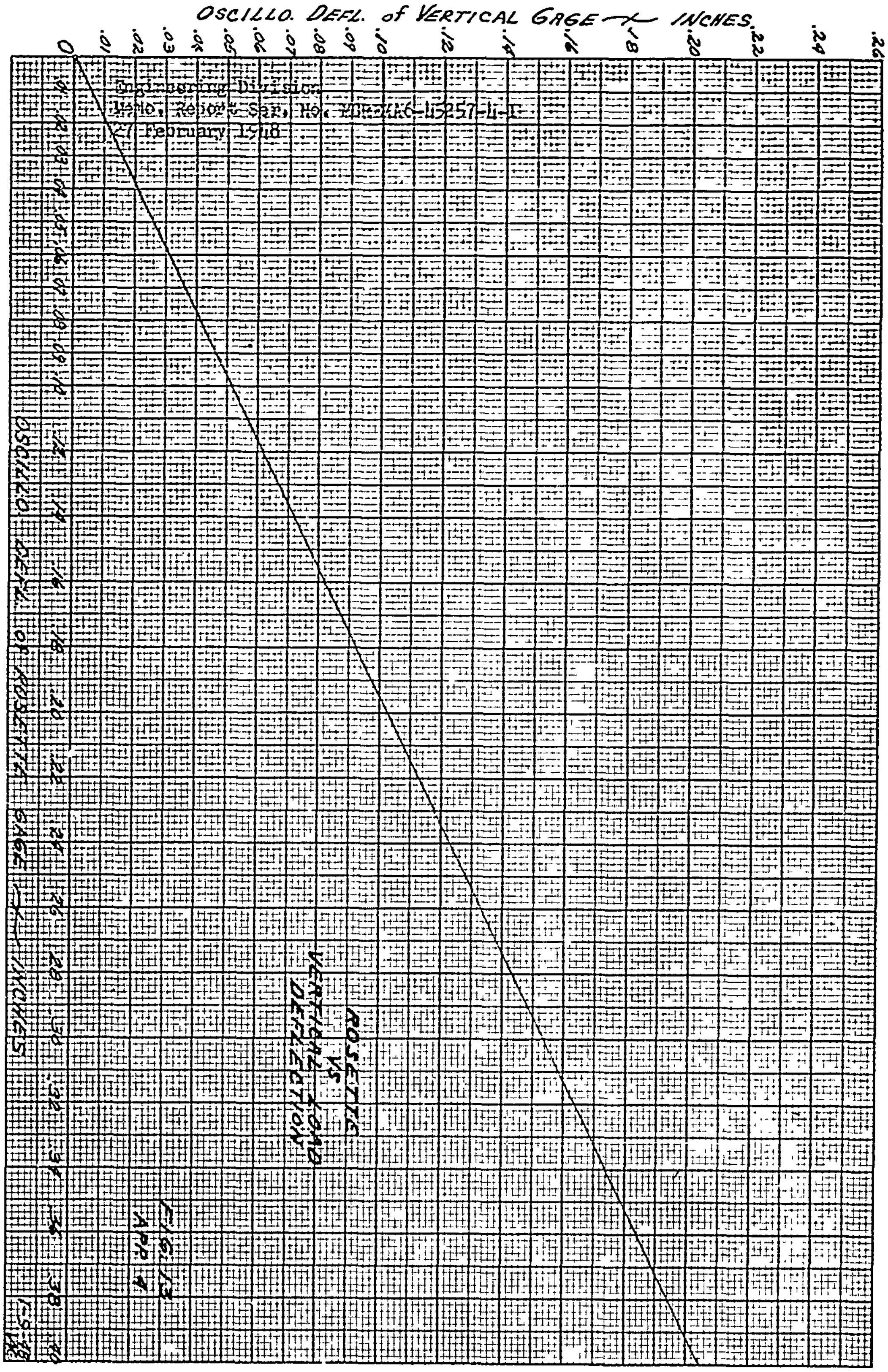


FIG. 12
APP. 4

FIG. 11



ROSETTE VS VERTICAL LOAD DEFLECTION

FIG. 13
APP. 4

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Appendix 5

Coefficient of Friction, Vertical, and Drag Load Curves.

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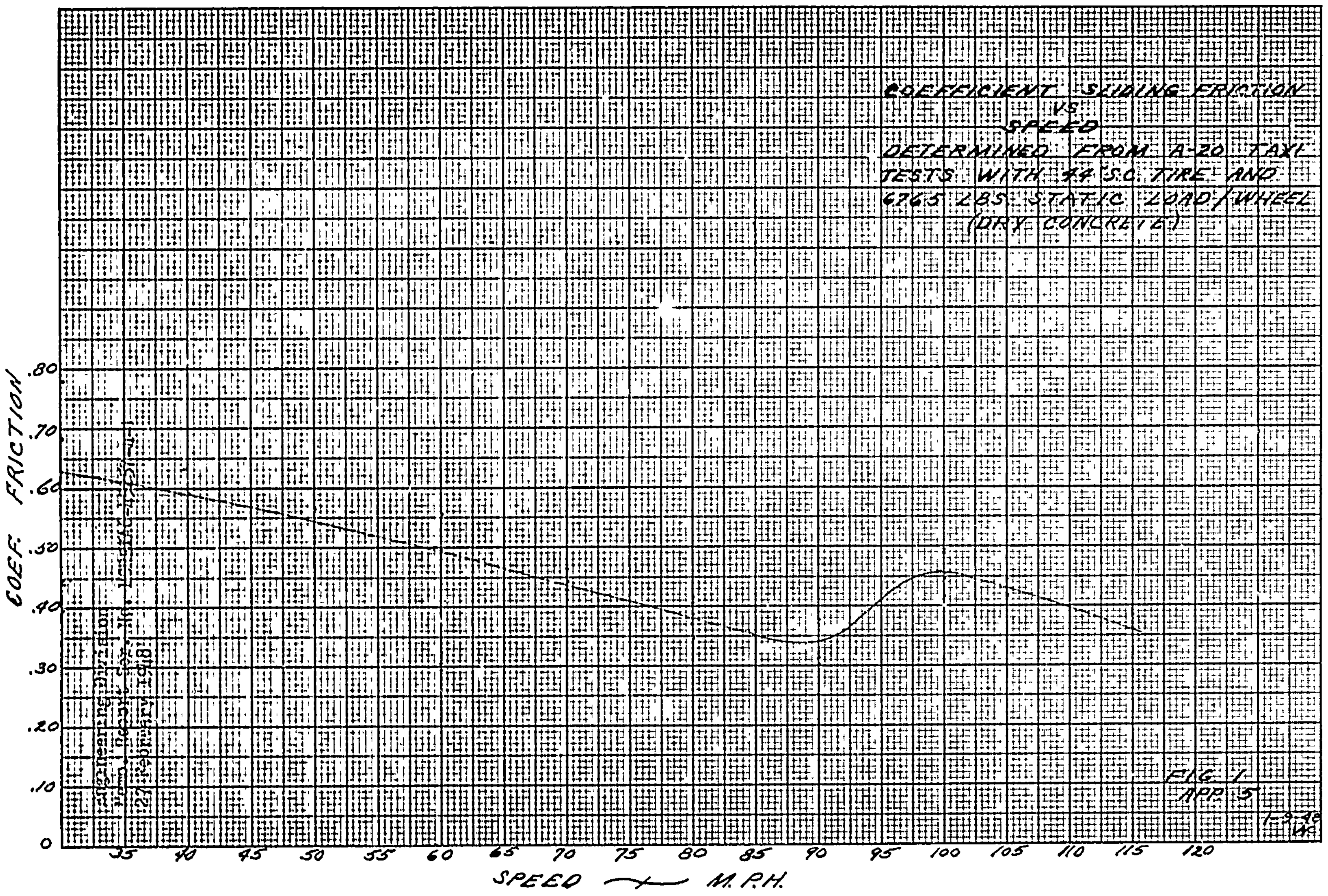
27 February 1948



COEFFICIENT SLIDING FRICTION
VS
SPEED
DETERMINED FROM A-20 TAXI
TESTS WITH 44" S.C. TIRE AND
6765 LBS STATIC LOAD/WHEEL
(DRY CONCRETE)

FIG 1
APP 5

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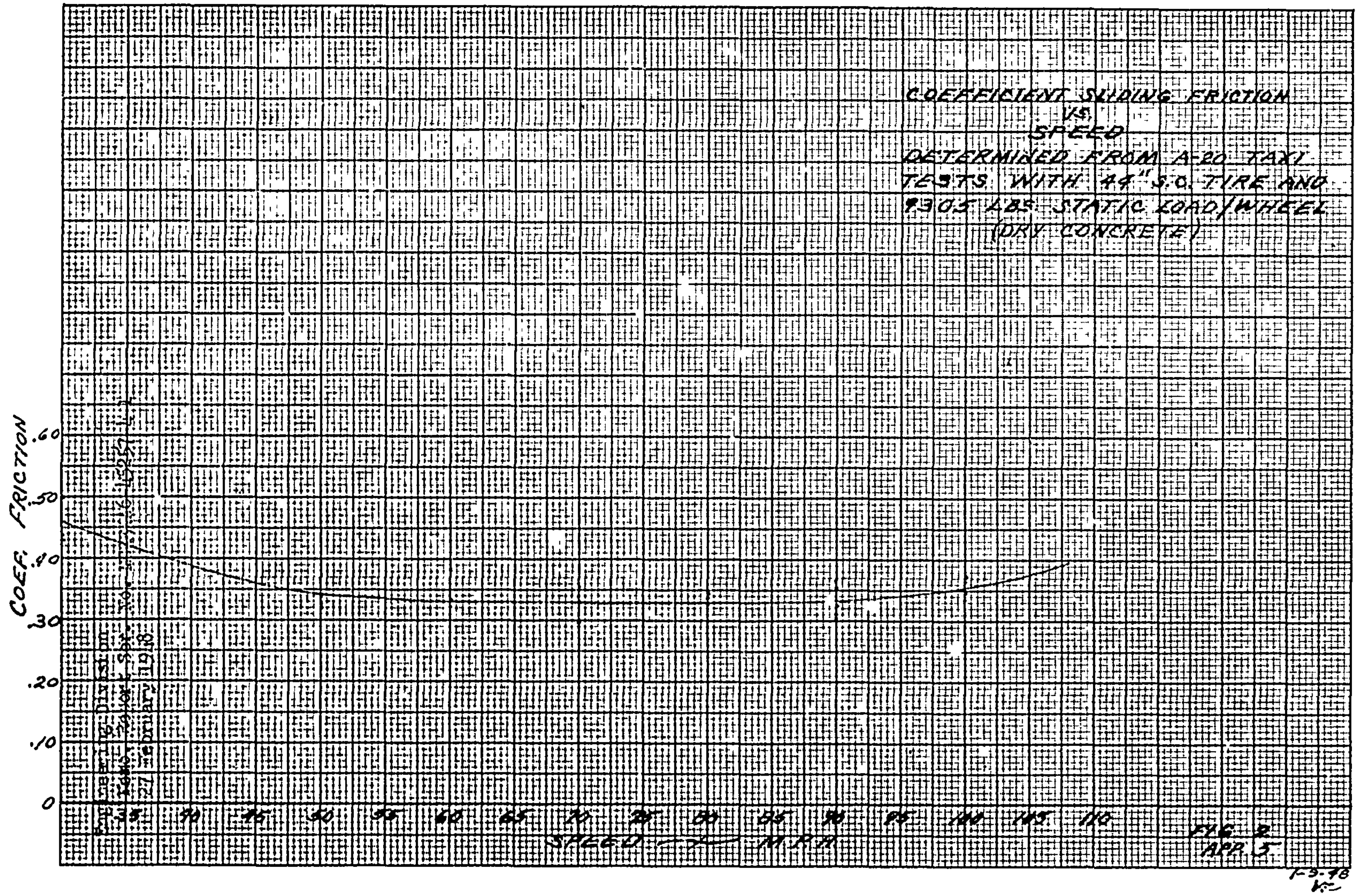

COEFFICIENT SLIDING FRICTION
VS
SPEED
DETERMINED FROM A-20 TAXI
TESTS WITH 44" S.C. TIRE AND
9305 LBS STATIC LOAD/WHEEL
(DRY CONCRETE)

FIG. 2
APP. 5

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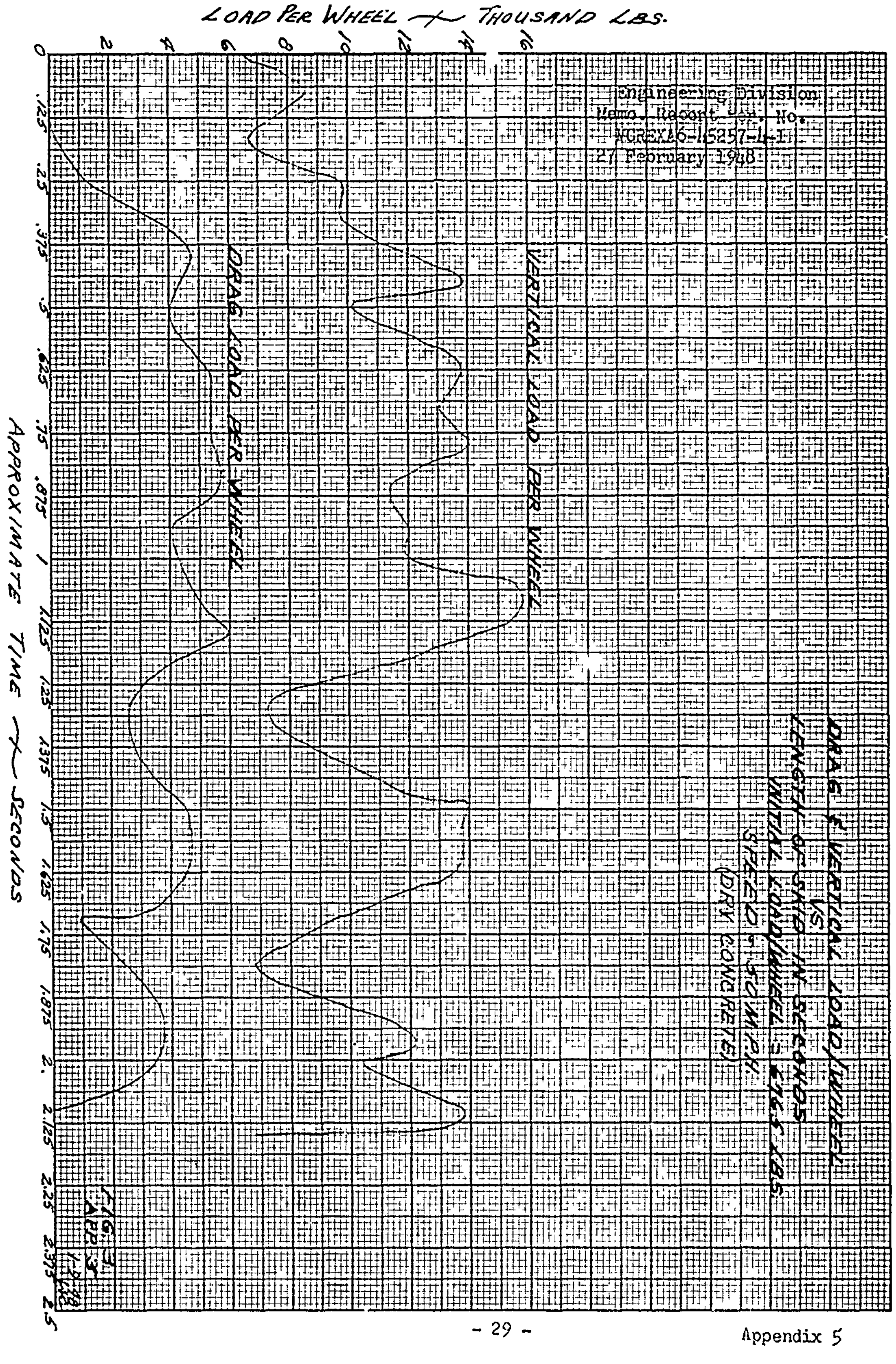
27 February 1948



DRAG & VERTICAL LOAD/WHEEL
VS
LENGTH OF SKID IN SECONDS
INITIAL LOAD/WHEEL = 2765 LBS
SPEED = 30 M.P.H.
(DRY CONCRETE)

FIG. 3
APP. 5

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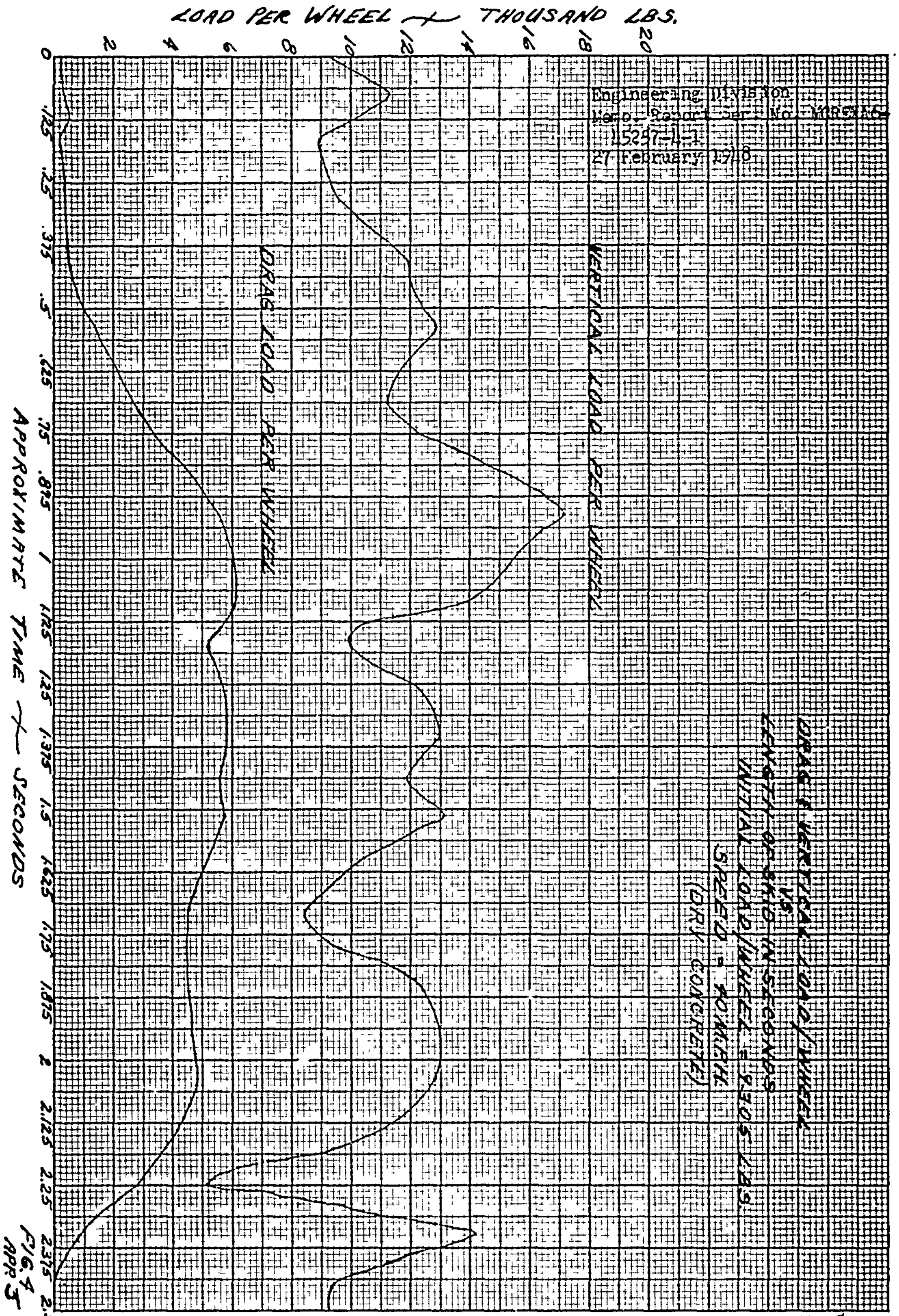
15297-1-1
27 February 1948



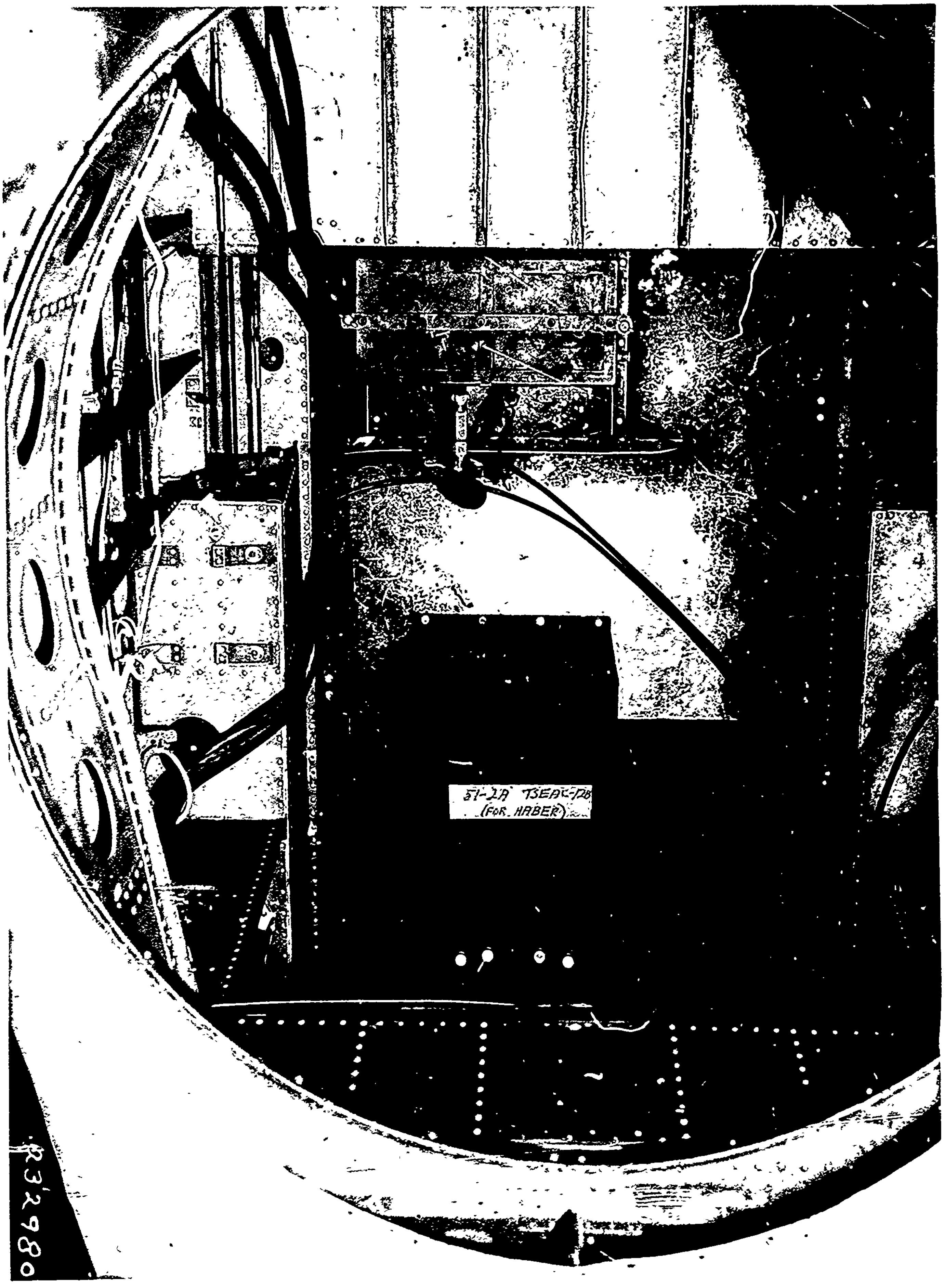
DRAG & VERTICAL LOAD/WHEEL
VS
LENGTH OF SKID IN SECONDS
INITIAL LOAD/WHEEL = 9305 LBS.
SPEED = 40 M.P.H.
(DRY CONCRETE)

FIG. 4
APP. 5
1-9-48
W.K.

Appendix 6

Tire Friction Test Photographs

Photo No.	Title
232980	Location of Oscillograph and Battery
232981	Speedometer Wheel & Pulley
232982	Speedometer Wheel and Generator
232983	Stain Gage Installation - Side View
232984	Strain Gage Installation - Rear View
232985	Rear Compartment Speedometer
232986	Front View of Taxi Vehicle
232987	High Pressure Nose Wheel
232988	Bomb Bay Weight Racks
232989	Location of Bridge
232990	Pilots Cockpit Speedometer
232991	Side View of Taxi Vehicle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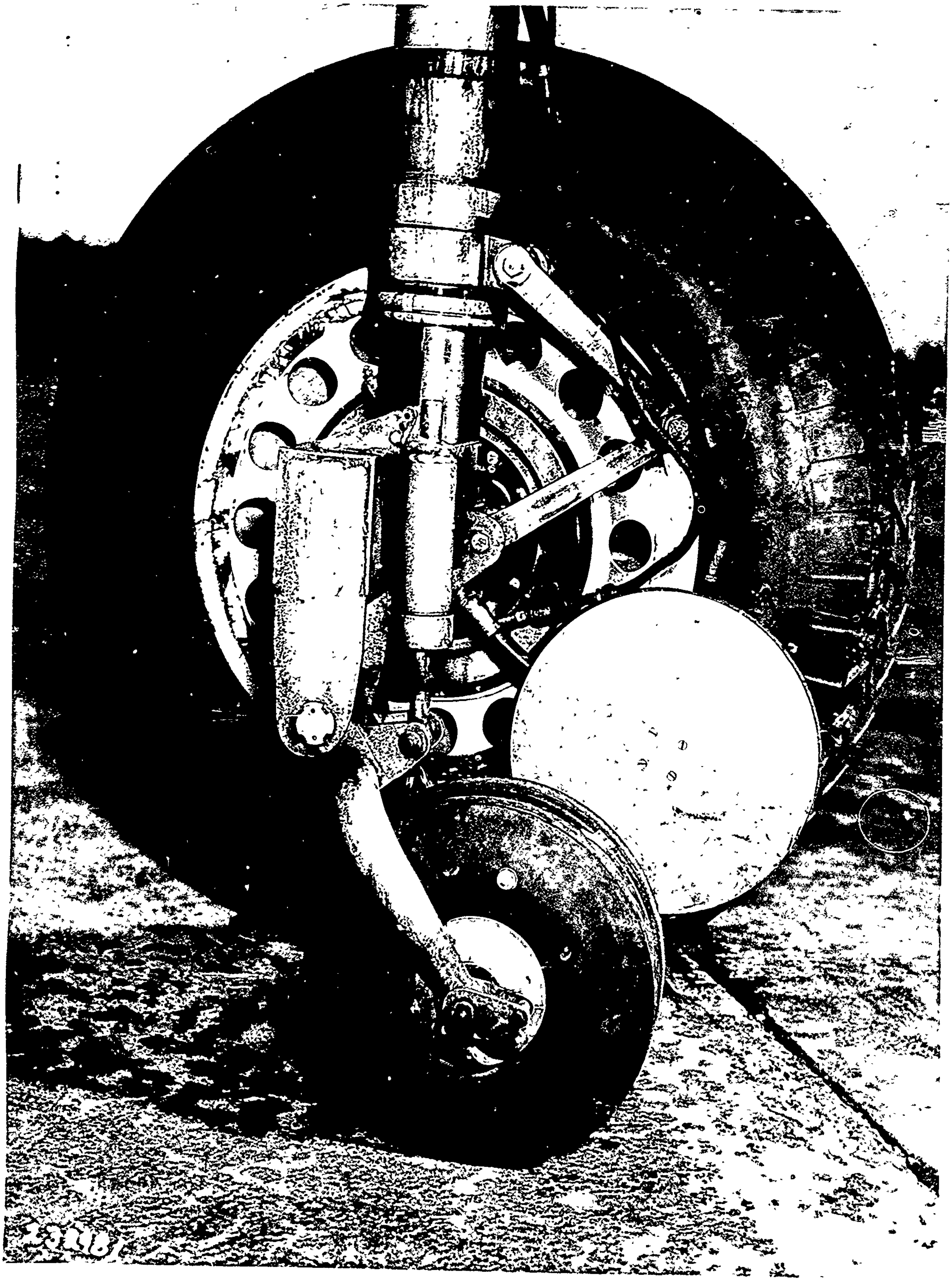
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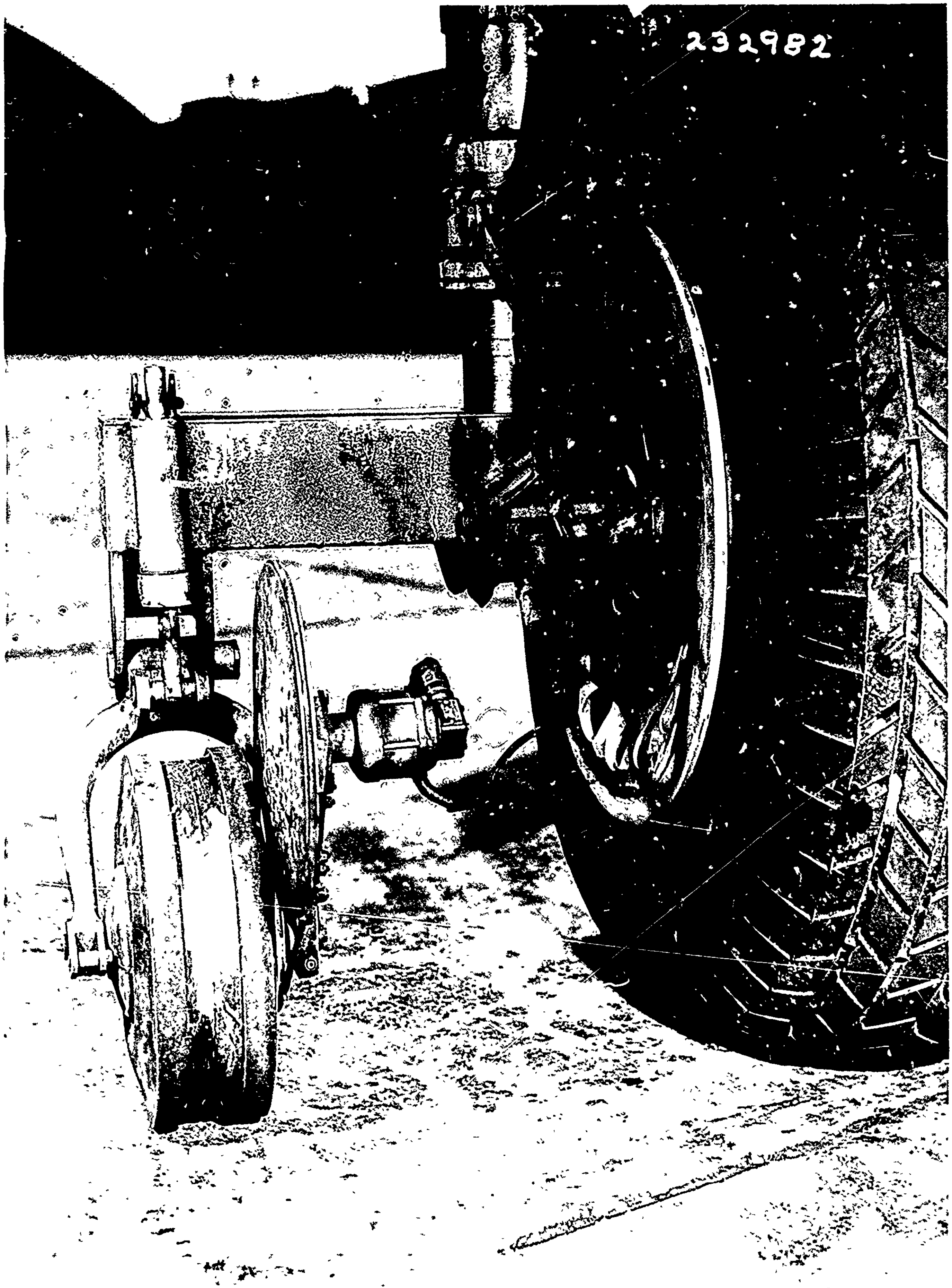
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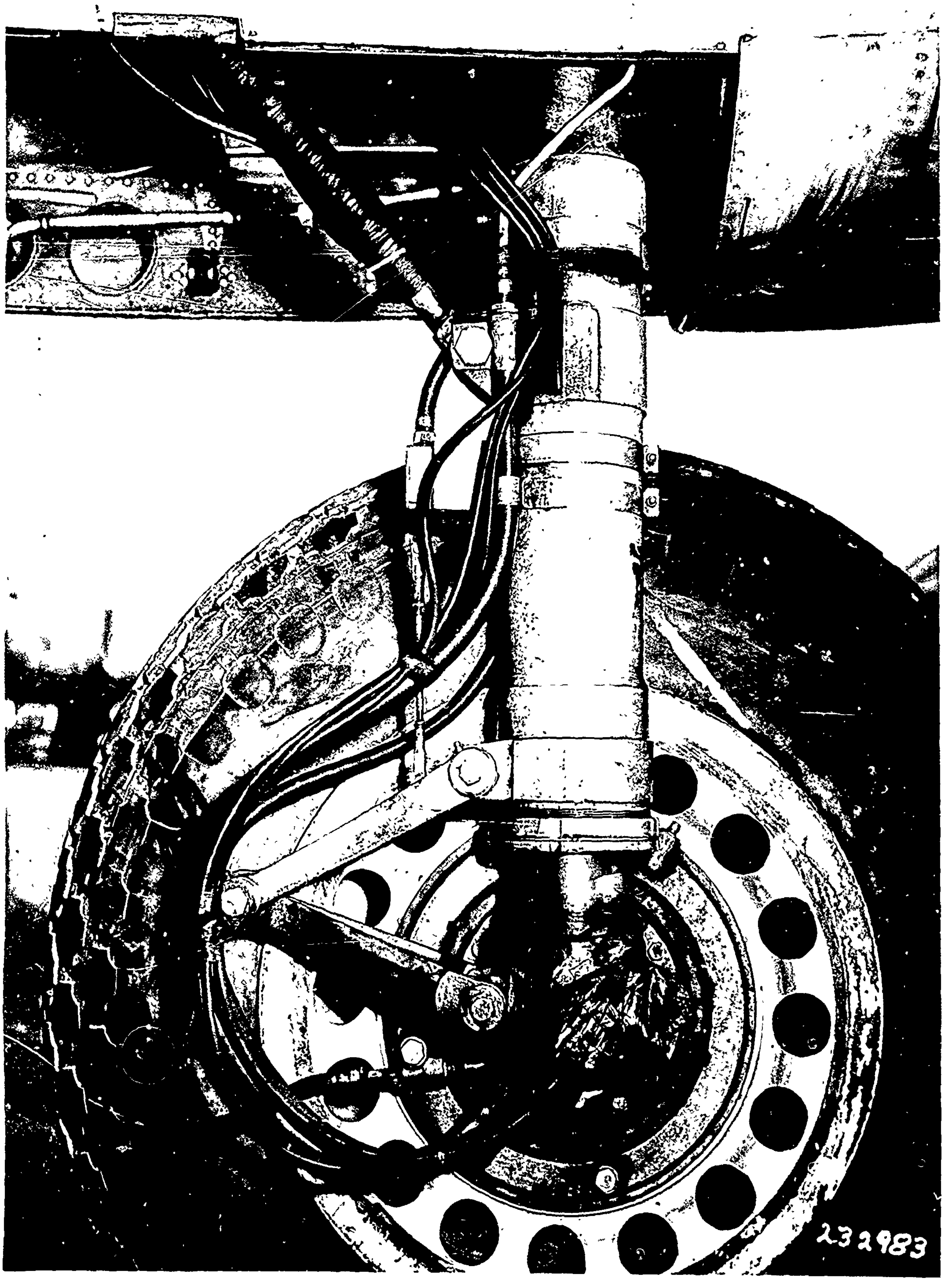

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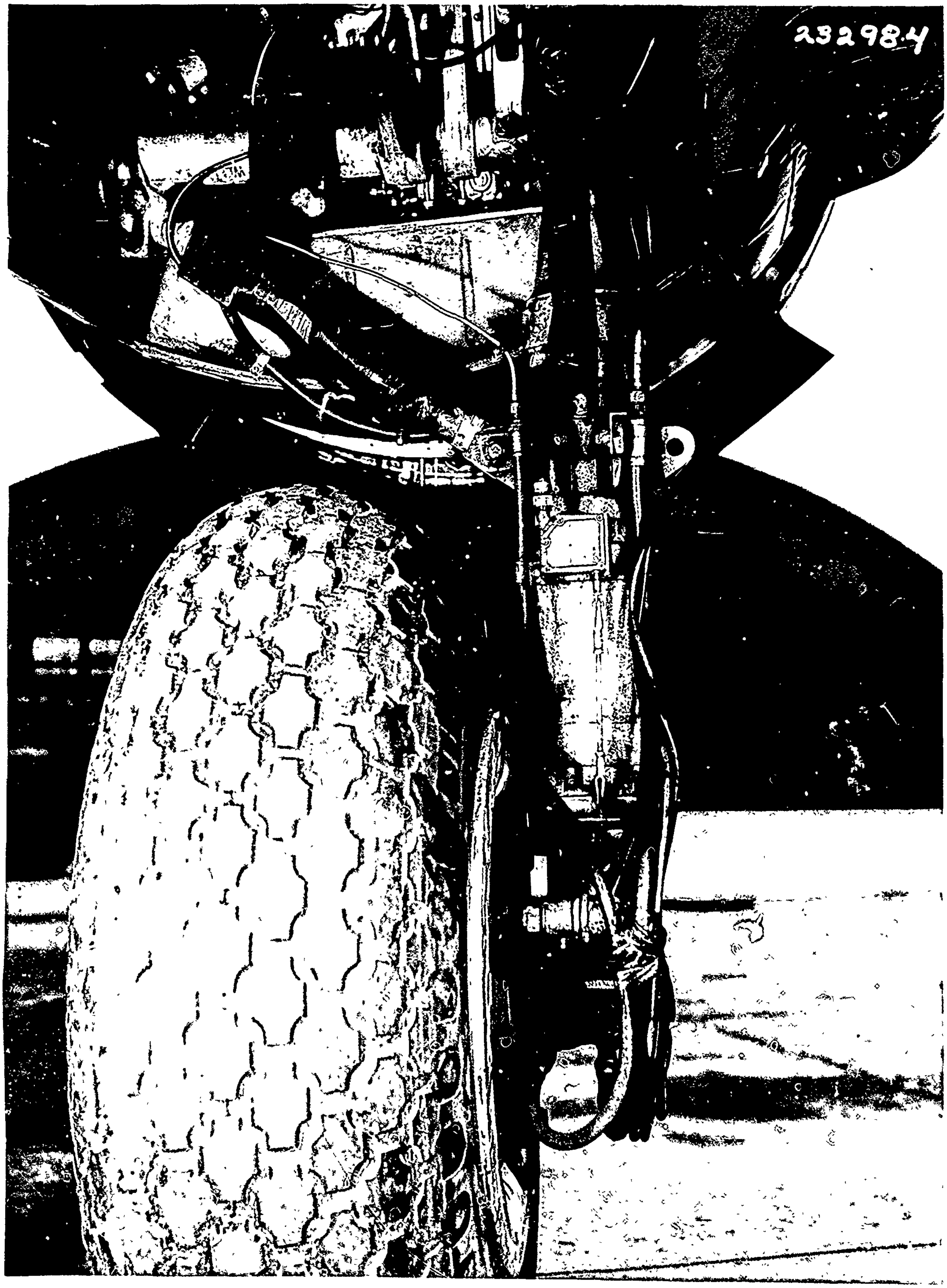
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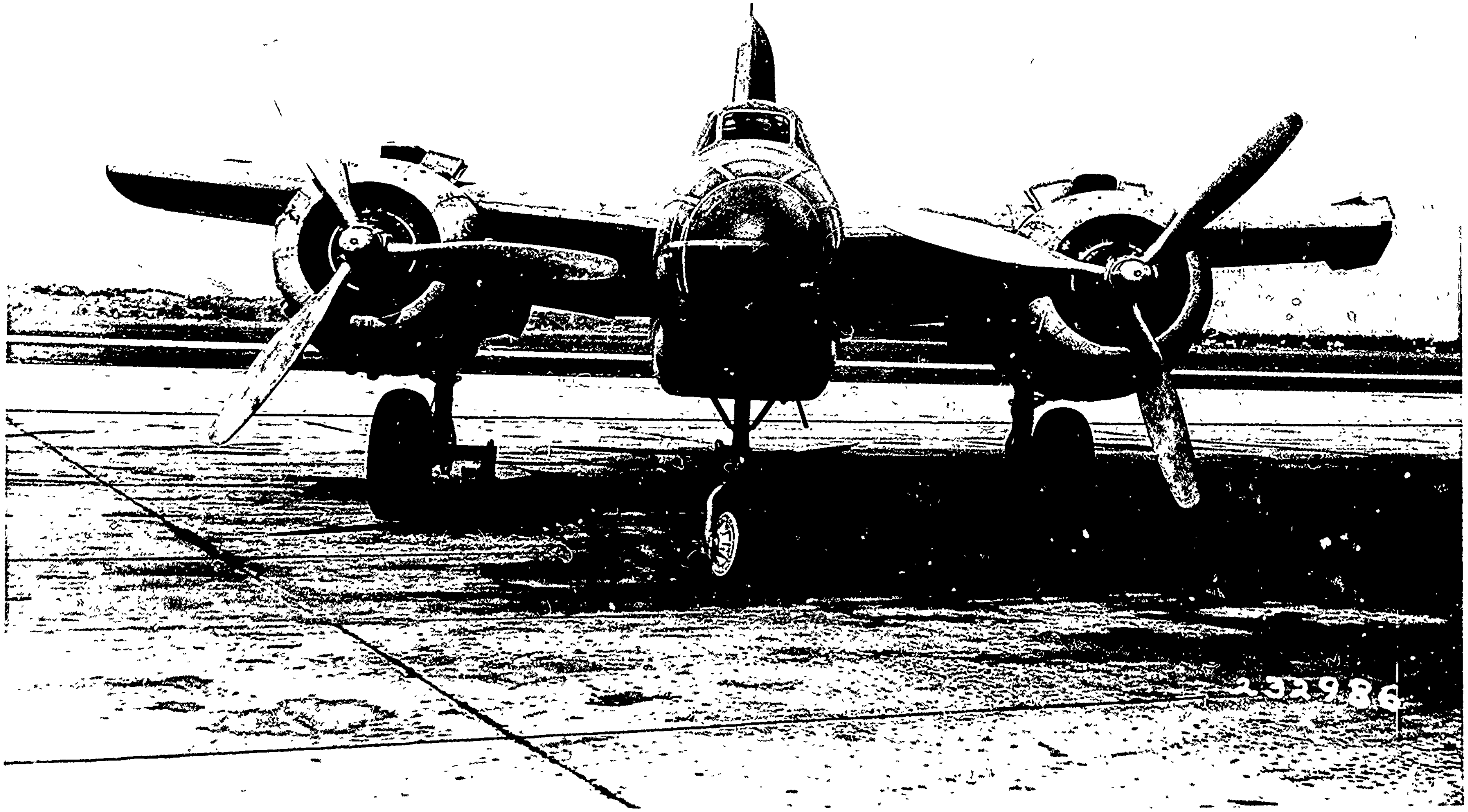
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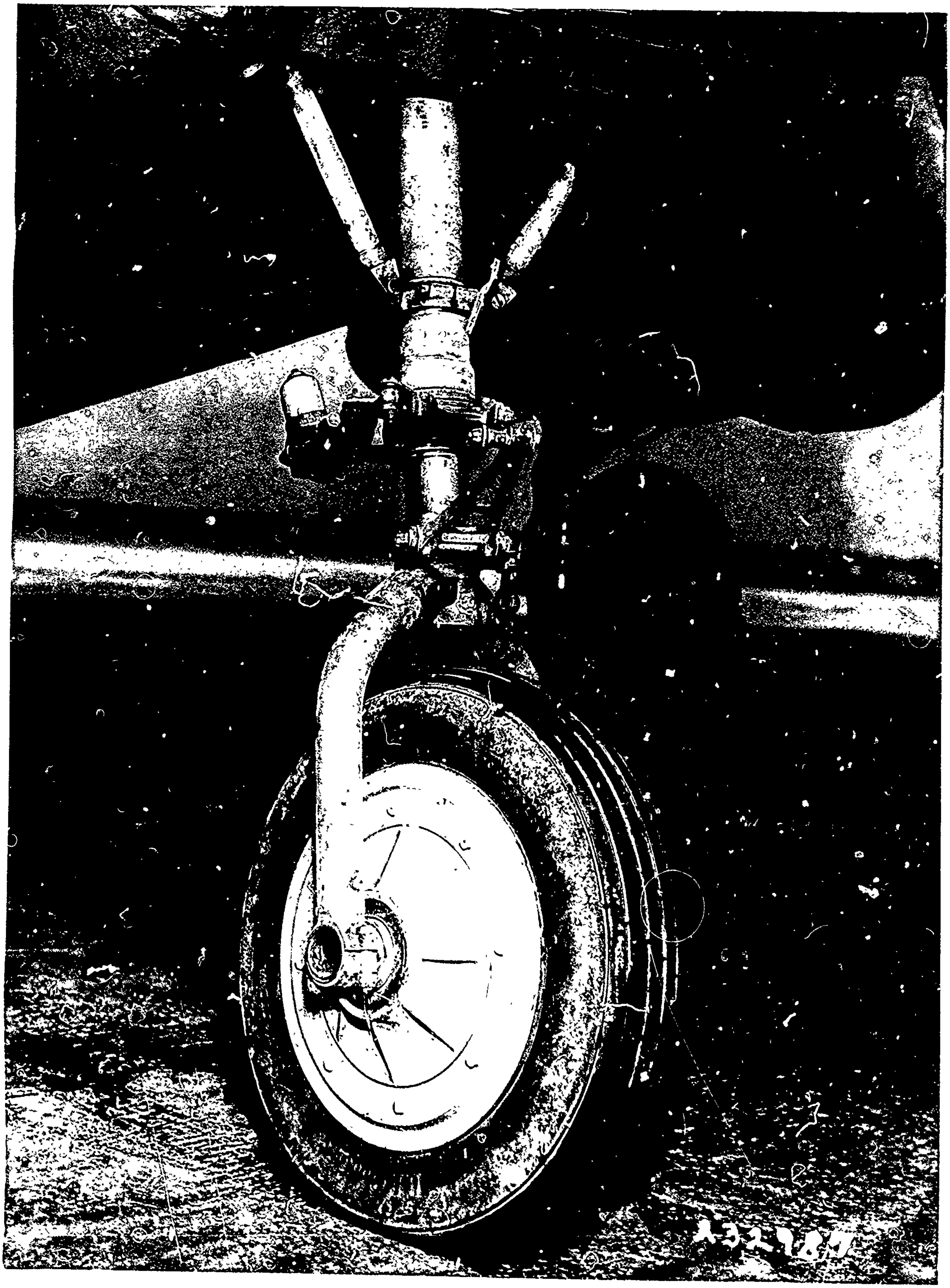
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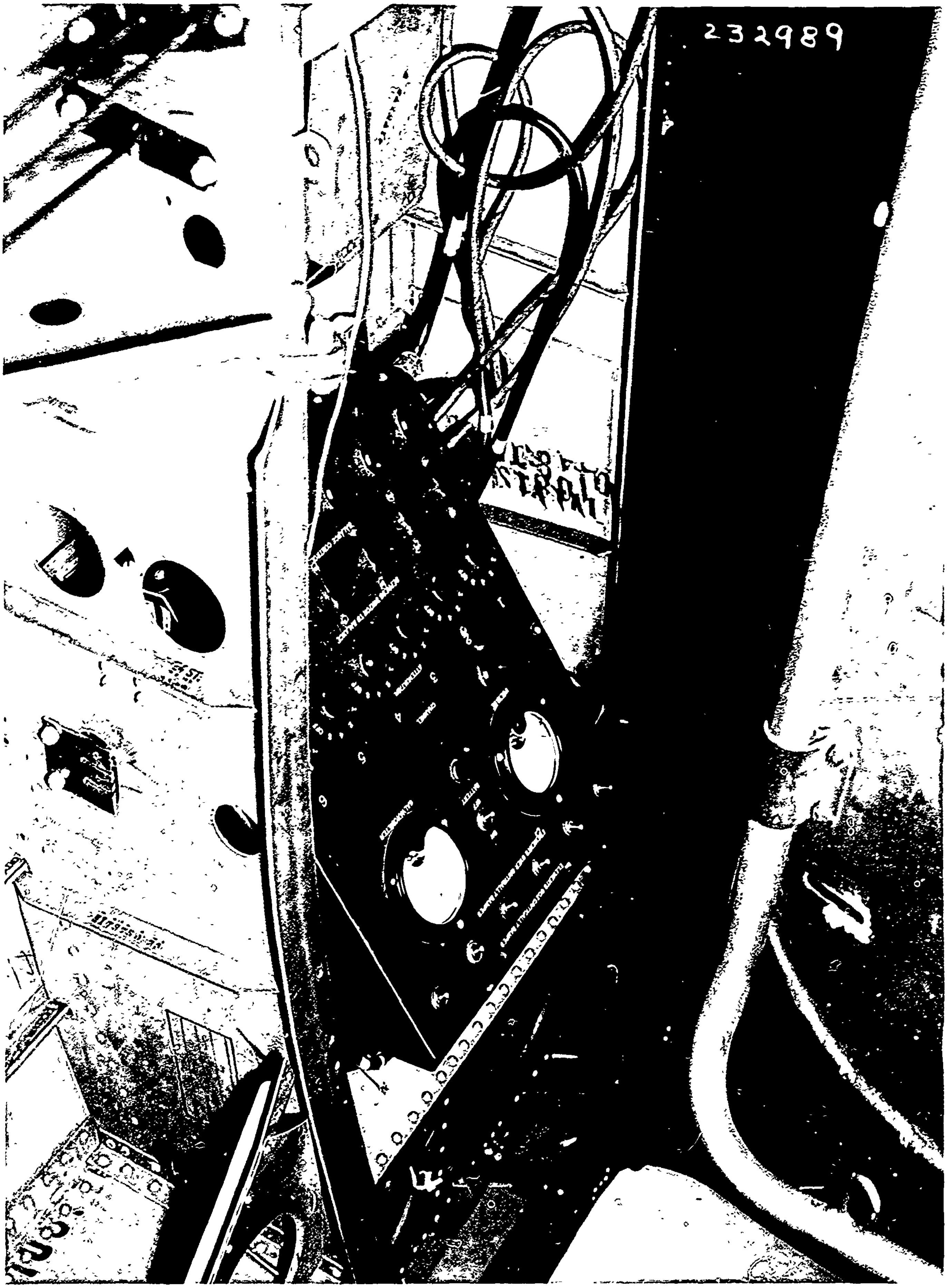

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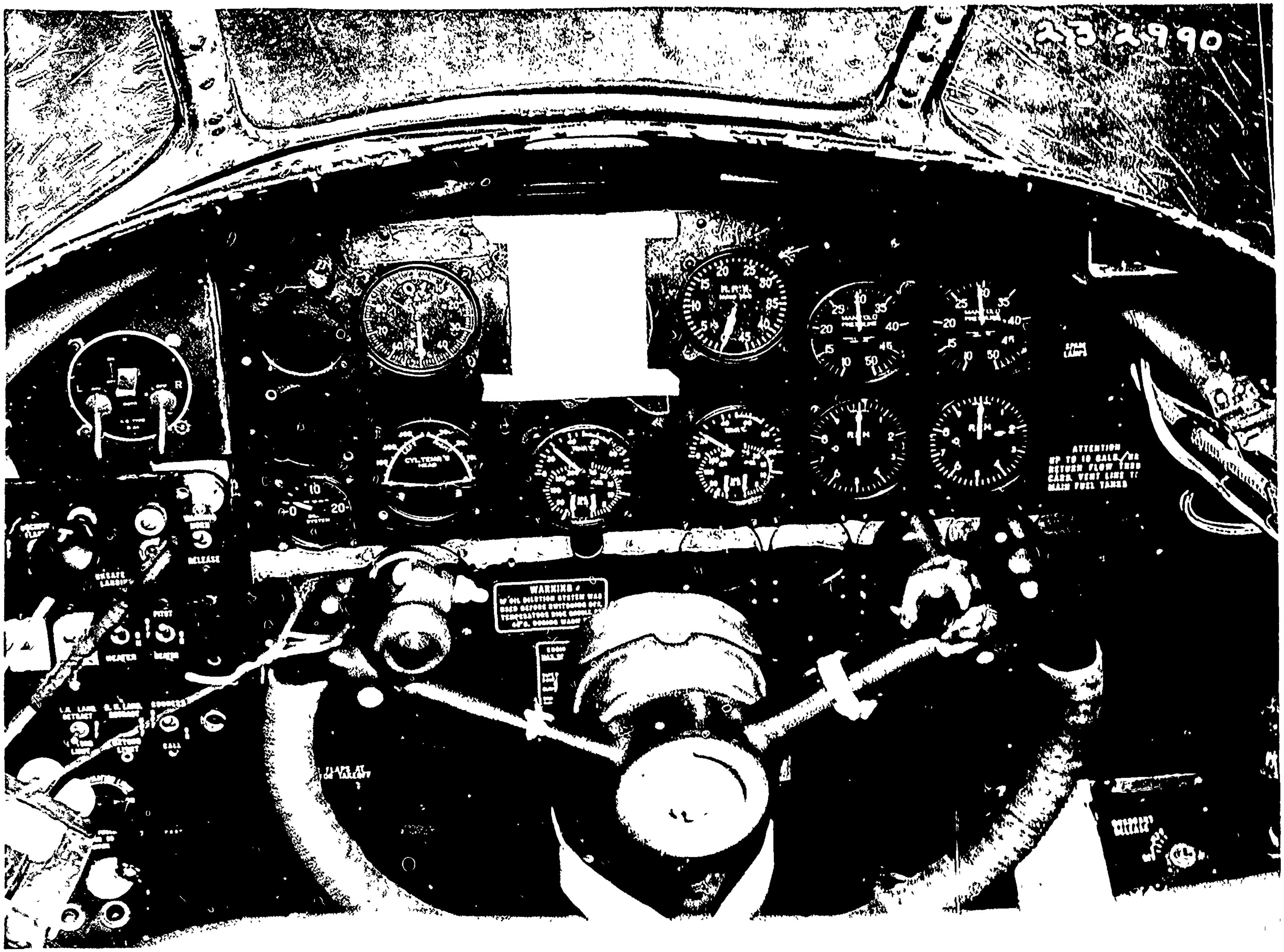
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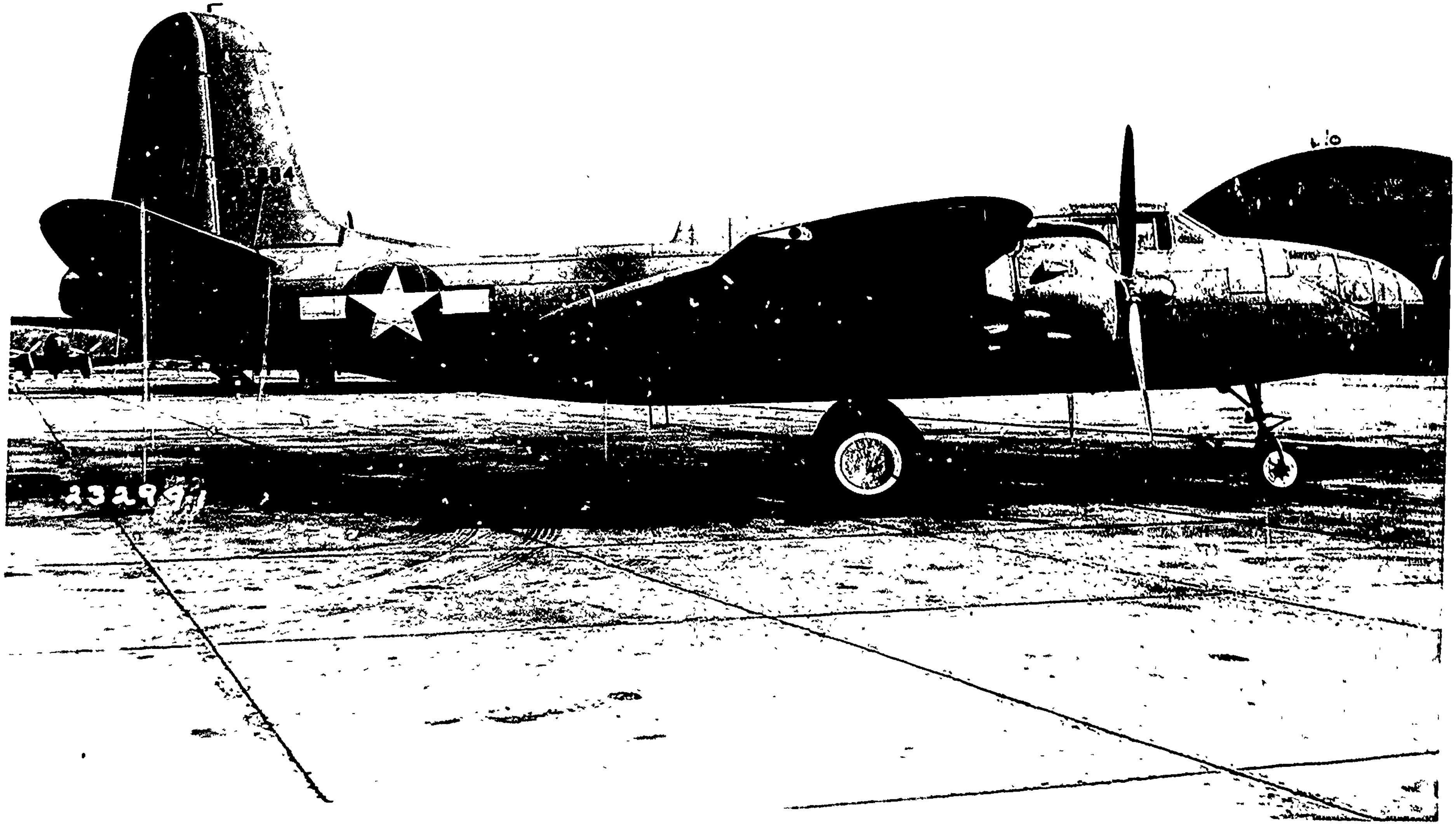
ATTENTION
UP TO 10 GALS/HR
RETURN FLOW THRU
CARB. VENT LINE TO
MAIN FUEL TANKS
WARNING
RELEASE
PITOT
HEATER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ATI-73 926

Air Materiel Command, Engineering Div.,
Dayton, O. (MCREXA6-45257-4-1)
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II. Creech, W.T.

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CFSTI, auth: USAME. ltr, 31 Jan 67