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AFFDL-TDR-66-43
PART I

AIRCRAFT GROUND-FLOTATION INVESTIGATION

PART I — BASIC REPORT

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FOREWORD

The investigation reported herein was conducted from May 1964 to January 1966 by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, for the Landing Gear Group, Air Force Flight Dynamics Laboratory, Air Force Systems Command, United States Air Force, under USAF MIPR AS-4-177, dated 8 May 1964, to develop landing gear design criteria for the CX-HLS aircraft (later designated the C-5A aircraft). This manuscript was released by the authors in July 1967, for publication as an RTD Technical Report.

The investigation reported herein was conducted under the general supervision of Messrs. W. J. Turnbull, A. A. Maxwell, and R. G. Ahlvin and under the direct supervision of Mr. D. N. Brown. Other personnel actively engaged in the study were Messrs. C. D. Burns, D. M. Ladd, H. H. Ulery, Jr., W. J. Hill, Jr., W. N. Brabston, J. E. Watkins, G. M. Hammitt II, A. H. Rutledge, A. J. Smith, and M. J. Mathews. Several tests were conducted by the Army Mobility Research Branch, Mobility and Environmental Division, WES, under the general supervision of Messrs. W. G. Shockley, S. J. Knight, and D. R. Freitag and under the direction of Mr. J. L. Smith. This report was written by Messrs. D. M. Ladd and H. H. Ulery, Jr. Appendix II was written by Mr. W. N. Brabston. The Flight Dynamics Laboratory engineers who monitored this program were Messrs. Peter Smits, Robert J. Parker, and Paul Wagner working under the supervision of Aivars V. Petersons, Technical Manager.

Directors of the WES during the coduct of the study and the preparation of this report were Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

FOR THE DIRECTOR

AIVARS V. PETERSONS
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ABSTRACT

The Flexible Pavement Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., has conducted a series of tests to establish aircraft ground-flotation criteria with special emphasis on developing criteria for the C-5A aircraft. This report presents an analysis of data collected as a result of traffic tests on unsurfaced soils and soils surfaced with M8 and T11 landing mat. Also presented are introductory and background information on the WES ground-flotation research program, a description of the test equipment, materials, procedures, and techniques used, and examples of use of the criteria.

This abstract is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Flight Dynamics Laboratory (FDFM), Wright-Patterson AFB, Ohio 45433.

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SUMMARY

This report summarizes results of an extensive study to develop a method for designing an efficient landing gear configuration for aircraft required to operate on TO-type airfields. This method was developed from a series of ground-flotation tests conducted on mat-surfaced subgrades and unsurfaced subgrades. Also presented is a discussion of the testing procedures and techniques and of the data analysis of all tests conducted in conjunction with the ground-flotation investigation, including tracking, drag, and speed tests.

To develop criteria for the efficient design of aircraft landing gear, a series of traffic tests was conducted with numerous wheel configurations, loads, and tire pressures. The configurations varied from a single wheel up to 12 wheels; the loadings varied from 1000 to 273,000 lb; the tire pressures ranged from 10 to 250 psi, and wheel spacings varied from 2.0 radii up to 6.8 radii. These tests provided sufficient data to develop ground-flotation criteria for a wide range of conditions. The data were analyzed to develop basic single-wheel criteria. Then a method of extending the single-wheel criteria to multiple-wheel data was determined. Drawbar pull measurements were made at the beginning of each test, at intervals during testing, and at failure in order to obtain drag information.

Several scale model tests were conducted to obtain speed versus drag data. These tests were run using various speeds, loads, tire pressures, and tire sizes. The principles of scale modeling were used in planning these tests so that dimensional analysis principles could be used in analyzing the results.

Specifically, in this study:

a. Single-wheel or equivalent single-wheel loads were related to tire pressure in terms of an index of available airfield surfacing strength (I_A) for T11 and M8 landing mats.

b. Unsurfaced-soil strength requirements were related to single-wheel or equivalent single-wheel loads, tire pressures, and coverages.

c. A procedure for resolving multiple-wheel loads operating on landing mats or unsurfaced soils to an equivalent single-wheel load was developed by relating spacing to percent increase in single-wheel load for each adjacent wheel.

d. Results of the simulated C-5A test (12 wheels) on landing mat compared favorably with the T11 criteria but indicated that the M8 criteria were conservative for the C-5A type loading.

e. Results of the simulated C-5A tests (12 wheels) on unsurfaced soils were more favorable than the criteria developed for determining ground-flotation requirements indicate. However, the criteria are considered applicable to the C-5A because of the unknown effects of turning and braking on unsurfaced soils.

f. Drawbar pull measurements were related to soil subgrade strengths for T11 and M8 landing mats and for unsurfaced soil.

g. The general trend of the effect of tire size, tire ply rating, and tire pressure on ground-flotation capabilities of aircraft operating on unsurfaced soil was determined.

h. A general relation between velocity and drag was established for slow speeds and small loads.

i. A general relation between tire contact pressure and tire inflation pressure was established for the types of tires used.

SECTION I: INTRODUCTION

Background

Aircraft designers must design aircraft landing gears that will allow aircraft to fly a given number of sorties from a designated airfield. The current concept of aircraft operation in a theater-of-operations (TO) is that heavy-cargo aircraft must be capable of flying in and out of areas very close to combat troops. This concept requires that some type of airfield from which the aircraft can operate be constructed in these areas. In the TO, the airfields that are constructed will either be surfaced with airfield landing mat or remain unsurfaced. Either of these types of airfields usually has a low strength and a short life, making it capable of accommodating most heavy-cargo aircraft for only a few takeoffs and landings. Therefore, newly developed aircraft must be designed so that they can perform a sufficient number of takeoffs and landings to accomplish the desired mission on low-strength airfields. This requires the aircraft landing gear to have a sufficient number of tires of such a size, inflation pressure, and spacing that they will not overload the airfield.

The C-5A is a heavy-cargo aircraft with a maximum gross weight of 700,000 to 800,000 lb and a combat weight for support areas of 500,000 to 600,000 lb. The mission of this aircraft requires that it operate in combat areas from support-area airfields which characteristically have a strength equivalent to that of M8 landing mat on a 4-CBR subgrade. To operate on this type of airfield requires that adequate flotation be designed into the landing gear. Criteria for determining ground-flotation requirements for aircraft landing gear are contained in U. S. Army Engineer Waterways Experiment Station (WES) Miscellaneous Paper No. 4-459, "Ground-Flotation Requirements for Aircraft Landing Gear,"[1]* and U. S. Air Force Systems Command, Headquarters, "Handbook of Instructions For Aircraft Design," AFSC Manual 80-1.[2] However, the criteria presented therein are somewhat limited because they are based on only a small amount of data, and most of the criteria have received only limited validation. It was determined that for a program as large as the C-5A program, the criteria should be further validated and improved. The Air Force, therefore, requested that WES conduct a series of tests to develop adequate ground-flotation criteria for the C-5A, which could also be applied to other aircraft. In addition, the WES was requested to make a study of the rolling resistance forces that might be experienced by the C-5A and to try to develop a relation between speed and rolling resistance.

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* Raised numbers refer to similarly numbered items in the list of References following the text of this report.

Purpose and Scope

The purpose of this report is to summarize results of an extensive study to study a method for designing an efficient landing gear configuration for aircraft required to operate on TO-type airfields. This method was developed from a series of ground-flotation tests conducted on mat-surfaced and unsurfaced soils. Also presented in this report is a discussion of the testing procedures and techniques and of the data analysis of all tests conducted in conjunction with the ground-flotation investigation, including the traffic, rolling resistance, and speed tests.

To develop criteria for the efficient design of aircraft landing gear, a full series of traffic tests was conducted with numerous wheel configurations, loads, and tire pressures. The wheel configurations varied from a single wheel up to 12 wheels; the loadings varied from 1000 to 275,000 lb; the tire pressures ranged from 10 to 250 psi, and wheel spacing varied from 2.0 radii up to 6.8 radii. The multiple-wheel tests were run to determine the effect of tire spacing on equivalent single-wheel loads. These tests provided sufficient data to develop ground-flotation criteria for a wide range of conditions. The data were analyzed to develop basic single-wheel criteria. Then a method of extending the single-wheel criteria to multiple-wheel data was determined.

Drawbar pull measurements were made at the beginning of each test, at intervals during testing, and at failure. These measurements were made to obtain rolling resistance information.

Several tests were conducted in the WES Army Mobility Research Branch (AMRB) test facility to obtain speed versus rolling resistance data. Twenty-three tests were run using various speeds, loads, tire pressures, and tire sizes. The principles of scale modeling were used in planning these tests so that dimensional analysis principles could be used in analyzing the results.

Reporting of Data

All data collected under this investigation are reported as separate parts of this series of reports. The following list relates each report part to the information contained therein.

Report Part	Title
I	Basic Report
II	Data Report on Test Section 1
III	Data Report on Test Section 2
IV	Data Report on Test Section 3
V	Data Report on Test Section 4
VI	Data Report on Test Section 5
VII	Data Report on Test Section 6

(Continued)

Report Part	Title
VIII	Data Report on Test Section 7
IX	Data Report on Test Section 8
X	Data Report on Test Section 9
XI	Data Report on Test Section 10
XII	Data Report on Test Section 12*
XIII	Data Report on Test Section 13
XIV	Data Report on Test Section 14
XV	Data Report on Test Section 14A
XVI	Data Report on Test Section 15
XVII	Data Report on Test Section 16
XVIII	Data Report on Test Section 17
XIX	Data Report on Light-Load Tests

* Test section 11 is reported separately as the Model Wide-Tire Report.[9]

Definitions

Some of the terms used in this report are defined as follows:

a. Flotation. The floating or supporting of an aircraft on the ground by a landing gear system.

b. California Bearing Ratio (CBR). The CBR is a measure of soil strength and is used to evaluate the ability of soils to resist shear deformation. The CBR test is conducted by forcing a 2-in.-diam piston into the soil. The load required to force the piston into the soil [illegible] in. is expressed as a percentage of the standard value for crushed stone. This percentage is the CBR. (See MIL-STD-621A[8] for standard testing procedures.)

c. Cone index (CI). An index of soil strength obtained with the cone penetrometer. It is the unit load required to maintain movement of the cone-shaped probe normal to the surface of the soil. It has the dimensions pounds per square inch, and is usually given as an average value for a specified layer of soil several inches thick.

d. Coverage. Sufficient passes of load tires in adjacent tire paths to cover a given width of surface area one time. A coverage is equivalent to the load repetition factor used in previous ground-flotation studies.

e. Equivalent single-wheel load (ESWL). A load on a single tire which produces effects on the supporting medium that are equivalent to the effects produced by a load on a multiple-wheel assembly.

f. Equivalent radius. The radius of a circle having the same area as the gross contact area of a single tire.

g. Theater-of-operations (TO) airfields. Limited-life facilities which are classified and defined as follows.

h. Rear-area airfields. TO airfields that normally must support the operations of heavy-cargo aircraft, medium-cargo aircraft, and fighter-bomber aircraft for a period of 4 to 6 months. The controlling rear-area airfield is characterized as a field having the equivalent of a T11 landing mat surface lying directly on a 4-CBR subgrade.

i. Support-area airfields. TO airfields that normally must support the operations of medium-cargo aircraft (and conceivably certain fighter-bomber aircraft designed for close tactical support) for a period of 2 to 4 weeks. The controlling support-area airfield is characterized as a field having the equivalent of an M8 landing mat surface lying directly on a 4-CBR subgrade.

j. Forward-area airfields. TO airfields that must support the operations of liaison, observation, and light-transport-type aircraft, including heavy-cargo helicopters, for a period ranging from a few days to 3 weeks. The controlling forward-area airfield is characterized as a field having a 4-CBR subgrade with no structural surfacing. It should be noted that an aircraft having sufficient flotation to operate on a 4-CBR subgrade for a substantial number of operations will have the capability of operating a fewer number of times on subgrades having strengths below 4 CBR.

k. Drag. For the purpose of this report drag and rolling resistance have the same meaning.

SECTION II: TEST EQUIPMENT AND MATERIALS

Test Section

A layout of a typical test section is shown in Figure 1. The test sections generally were constructed with two traffic lanes, and each traffic lane consisted of three items. The natural soil in most test sections was excavated to a depth of 6 ft, and the excavation was backfilled with the soils described below. For the initial tests, two test sections were excavated to a depth of only 2 ft. This was consistent with past practice and is considered adequate for the loads and wheel spacings used. However, because of the magnitude of the loads and the very wide wheel spacings involved in many of the later tests, it was decided that test sections should be excavated at least to a depth of 6 ft. After backfilling was completed in each test section and the desired soil strengths were obtained, one test item was surfaced with T11 landing mat, one item was surfaced with M8 landing mat, and one item remained unsurfaced. The items of a test section were constructed so that when completed they would have comparable strengths. That is, the subgrade CBR strengths were prepared so that each item would have about the same capability for carrying traffic. The T11 mat on a 2-CBR subgrade was considered approximately equal in strength to M8 mat on a 4-CBR subgrade or an unsurfaced item with a soil strength of 10 CBR. Once the test sections were constructed, they were ready for trafficking.

Soils

Classification data and gradation curves for the subgrade soils used in the test sections are shown in Figure 2. The two soils used were generally the same with only some small differences in characteristics. Soil No. 1, used in test sections 1-4, was a fat, buckshot clay (CH) with a liquid limit of 58, a plastic limit of 27, and a plasticity index of 31. Soil No. 2, used in all other test sections, was a fat, buckshot clay (CH) with a liquid limit of 61, a plastic limit of 24, and a plasticity index of 37. These soils were used primarily because their strengths can be easily controlled and maintained.

Landing Mat

As indicated in the definitions of TO-type airfields, the strengths of the rear-area and support area airfields are defined in terms of T11 and M8 landing mats, respectively. Therefore, the T11 and M8 mats should be used in the ground-flotation study.

The M8 is a heavy, deep-ribbed, steel mat. Figure 3 shows M8 mat, and a complete description of the mat is given in WES Technical Memorandum No. 3-324, "Airplane Landing Mat Investigation, Engineering Tests on Steel, Pierced Type, M8 and Aluminum, Pierced Type, M9."[3]

The modified T11 mat is a lightweight, extruded-aluminum panel with a solid surface. T11 mat is shown in Figure 4, and a complete description is given in WES Technical Report No. 3-634, "Engineering Tests of Experimental T11 Aluminum Airplane Landing Mat."[4]

Load Carts

The load cart with which the majority of the test traffic was applied is shown in Figure 5. The cart is drawn by a commercial-type tractor and consists of an interior load compartment with loaded tracking wheels and an outer support frame. Weights were placed in the load compartment to provide the desired test load, and the configuration and tire size of the tracking wheels were varied according to test requirements. The load compartment is connected to the frame by a single draw pin in the front, providing free vertical movement independent of the frame. The frame prevents lateral movement of the load compartment but does not produce any significant load on the test section. The wheels of the tractor traffic the test section, but the weight and tire pressure are small and this traffic is considered negligible.

The load cart shown in Figure 6 is similar to the one discussed above, except that it balances itself and has no need for an outer frame. This cart was used for the twin-twin assembly tests.

The load cart used to apply the prototype load traffic (12-wheel tests) is shown in Figure 7. This load cart is driven by electric motors located in each wheel and consists of a power unit and frame and three interior load compartments with the tracking wheels. Weights were placed in the load compartments to provide the desired test load, and the configuration and tire size of the tracking wheels were varied according to test requirements. The load boxes are interconnected, and the forward box is connected to the frame by two draw pins. The boxes are free to move in a vertical direction independent of the frame. This load cart was operated in such a manner that the wheels of the frame and the power unit did not traffic the test section.

The load cart used for several single-wheel tests is shown in Figure 8. This cart consists of the front end of a 2-1/2-ton truck and a special frame which contains the tracking wheel. A wheel is cantilevered to the side of the frame to provide support. The load for the tracking wheel is applied directly to the frame. The truck and cantilevered wheel are balanced with weights so that when the load is applied to the tracking wheel, the vehicle will not overturn. The front wheels of the truck traffic the test section, but the weight and tire pressure are small and this traffic is considered negligible.

Several special tests using model wide tires[9] were conducted. The load cart for these tests is shown in Figure 9. This cart consists of the front end of a 2-1/2-ton, 6x6 truck and a frame constructed to cantilever the tracking wheels off to the side of the truck. A platform which was loaded to apply weight to the wheels was constructed above the tracking wheels. The platform and wheels were connected to the special frame in such a manner that they provided free vertical movement. The configuration of the tires and tire sizes on the tracking assembly were varied according to test requirements.

Tires, Wheels, and Axles

The sizes and characteristics of tires used in the ground-flotation studies were determined by a combination of test requirements and availability. Considerations of timing and availability required substitution of some tires of sizes different than those stated in the test plan. The tires used in most tests were not new; therefore, there were individual variations even among tires of the same size. The tire sizes used for traffic tests are shown in Tables I, II, and III.

The tire wheels used in the tests were actual aircraft wheels obtained from the Air Force. However, the axles had to be made so that they not only would fit the wheels but also could be attached to the load carts. Axles were made for each wheel size.

AMRB Facility

A description of that portion of the AMRB test facility and related equipment used in this investigation is given in part XIX of this report. A more complete description of the facility and related equipment and test procedures and techniques is presented in WES TR 3-666.[5]

SECTION III: TESTS

Traffic Tests

A series of traffic tests that would provide the data needed for development of ground-flotation criteria was planned. These tests are presented in Table VII of Appendix I which describes the test plan for development of design criteria for the CX-HLS aircraft. However, the tests which were actually performed varied somewhat from those which were planned because of special test developments or because some tests indicated that other planned tests were unnecessary. A summary of the results of tests actually conducted is shown in Tables I, II, and III.

The traffic tests were conducted to simulate actual aircraft traffic on an airfield. A load cart was prepared by attaching the desired number of tires of a given size and spacing to an axle and connecting the axle to a load cart. The tires were inflated to the inflation pressure specified by the test plan, and the cart was loaded to the desired test load. The load cart was then driven back and forth across the test lane. Traffic on test lanes 1 through 11A was evenly distributed, i.e. all points in the traffic lane received the same amount of traffic. However, experience has indicated that in actual operation of aircraft the center portions of a runway or taxiway receive more traffic than the outer edges, and the distribution of the traffic is a normal statistical distribution. Therefore, test lanes 12 through 37 were trafficked using the normal distribution in order to better simulate an actual traffic situation. Guidelines placed on the test section for the load cart to follow while applying traffic were spaced to allow control of the distribution of traffic across the traffic lane.

Drawbar Pull Tests (DBP)

DBP measurements (Table IV) were taken in conjunction with the traffic tests and were obtained before traffic, at any significant point during traffic, and at failure. These tests were conducted by connecting a load cell between the power unit of the load vehicle and the load box. A typical load cell hookup is shown in Figure 10. The DBP force was measured as the power unit transmitted force to the load box through the load cell. The load cell was equipped with strain gages that fed an electrical signal into an amplifier, which translated the strain into pounds force and transmitted this information into a continuous strip recorder from which the DBP could be read directly.

DBP measurements obtained from related studies are shown in Table V. These data were obtained from tests conducted by the Douglas and Boeing aircraft companies. Two types of data were provided by the Douglas company. One set of data was obtained during traffic tests on unsurfaced soil and M8 landing mat by connecting a load cell between a tractor and a load cart. The other set of Douglas data and the Boeing data were obtained during actual flight tests at Harper's Dry Lake in California by towing the aircraft with a tractor and measuring the DBP by use of a load cell.

Speed Tests

To accomplish the necessary speed testing, soil subgrades were constructed to a uniform strength, with approximately the same strength being used for all tests. The speed tests were then conducted on these subgrades using single-wheel loads and several velocities, as shown in Table VI. A single wheel with a given tire pressure was loaded to the designated weight and then towed down the subgrade at a designated velocity. Each test consisted of individual passes down the soil subgrade with all necessary data being recorded on each pass.

SECTION IV: FAILURE CRITERIA

The failure criteria presented below were used to judge failure of items during traffic testing. See Appendix II for definitions of terms.

a. Unsurfaced items. Failure of unsurfaced items was based primarily on permanent deformation or rutting. However, elastic deflection was also taken into consideration. When rutting exceeded a 3-in. depth, an item was judged failed. Failure was also considered to have occurred when the elastic deflection exceeded 1.5 in.

b. Landing mat. Failure of the mat-surfaced items was judged on the basis of (1) development of roughness, and (2) excessive mat breakage. When deviations of the mat surface from a 10-ft straightedge equaled or exceeded 3 in. in any direction within the traffic lane, the test item was considered failed due to roughness. When mat breakage developed in 10 percent or more of mat panels within the traffic lane, the test item was considered failed.

SECTION V: DATA COLLECTION

Soil Data

Water content, density, and CBR determinations were made prior to traffic, at intervals during traffic when a change in strength was indicated, and at the point of failure in all test items. However, when failure occurred after a few passes, only the before-traffic data were obtained. This was done because the time-to-failure lapse was not sufficient to permit a change in soil characteristics. Soil tests were made at the surface of the soil and at depths of 6, 12, and 18 in. Three tests were made at each depth. The rated strength of the test items was normally based on combined effects of the CBR values for the surface and for 6- and 12-in. depths for all data obtained before, during, and at end of traffic. However, in certain instances, extreme or irregular values were ignored when the analyst decided that they were not properly representative. Test procedures and techniques for these soil tests are presented in Military Standard MIL-STD-621A.[8]

Coverages

A coverage is a measure of the amount of traffic applied to a test item. Coverages were recorded at failure of a test item and at any time that significant measurements or observations were accomplished. The procedures for applying traffic and counting coverages for any test lane are presented in the data report for that lane.

Tire Contact Area

The tire contact area is an average contact area determined by obtaining a tire print and measuring its gross area by use of a planimeter. The tire print was obtained by rolling the loaded tire onto a piece of heavy paper lying on a hard surface and spraying paint around that part of the tire in contact with the paper. The paint was then allowed to dry and the tire was rolled away, leaving a tire print outline on the paper.

Tire Inflation Pressure

The tire inflation pressure is the gage pressure to which a tire is inflated prior to a given test. Tire inflation pressure was checked prior to and periodically throughout each test, and maintained constant at the specified value throughout each test.

Tire Contact Pressure

The tire contact pressure was determined by dividing the load on a tire by the measured tire contact area.

Drawbar Pull

The specific types of data obtained from this test were (a) maximum force required for a load cart to overcome static inertia and commence forward movement (initial DBP), (b) average force required to maintain a constant speed once the load vehicle was in motion (rolling DBP), and (c) maximum force measured during a constant speed run (peak DBP). Typical oscillograph recordings of DBP are shown in figures 11 and 12. The initial DBP value was the maximum force obtained during a series of start-stop operations on the test item and was read directly from the highest point on a graph as indicated in figure 11. The rolling DBP was obtained by drawing a line through the graph (Figure 12), which approximated the average value of the readings obtained from a constant speed run across the test section. Peak DBP was taken to be the value of the highest point on the graph (Figure 12). Peak DBP was obtained during a constant speed run.

Surface Deviations on Test Sections

The surface measurements obtained during these tests were deformations and deflections.

Deformations

The various types of deformation measurements obtained during these tests were permanent deformation, differential deformation, rutting, and dishing. The permanent deformation measurements were used to plot cross sections and profiles for the various items. The differential deformation is a measure of the roughness of an item and was used in determining failure. Rutting is a differential deformation measurement but is applicable to only one rut. Dishing is the term applied to the measure of the differential deformation occurring across the width of one landing mat panel. A more complete discussion and illustrations of deformations obtained and procedures for making the measurements are presented in Appendix II.

Deflections

The deflection measurements obtained during these tests were total and elastic deflections. Elastic deflection measurements were obtained to assist in judging failure of an item. Total deflection measurements were obtained in order to relate elastic deflection and permanent deformation since permanent deformation is the difference between total and elastic deflection. A more complete discussion of deflections obtained and procedures for making the measurements is presented in Appendix II.

Mat Breaks

The mat breaks that occur as a result of trafficking a landing mat item are of several different types. These breaks have been classified for the two types of mats used in this study and are discussed below.

T11 mat

The mat breaks that occur on the T11 mat are illustrated in Figure 13 and classified as follows:

Type A: Crack occurring at the end of panel on male side of center-line splice joint.

Type B: Shearing of end connector rivets installed by factory. This type break is called a ringout.

Type C: Shearing of rivets along center-line splice joint.

Type D: Shearing of drive rivets installed in field during laying operation.

Type E: Any other type of break in mat surface not discussed above.

M8 mat

The mat breaks that occur on the M8 mat are illustrated in Figures 14 and 15 and are classified as follows:

Type A: Break occurring on the underlapping side of mat panel between locking lug hole and side connector slot opposite the end joint of adjacent panel.

Type B: Break occurring through the curl on the overlapping side of mat panel at the end joint.

Type C: Break occurring between curl on the overlapping side of mat panel and tubulated hole.

Type D: Break from side connector hole to tubulated hole.

Type E: Any other type of mat break not discussed above.

SECTION VI: DATA ANALYSIS

Approach

The analysis of data collected during this study was directed toward the development of ground-flotation requirements for aircraft landing gears. The criteria needed for designing an aircraft landing gear consist of a method of determining the number of tires, tire spacings, and tire contact area or tire pressure required to support a given load on an airfield for a stated number of coverages. For unsurfaced soils, these variables have been related through the development of a nomograph for single-wheel loads, and a load adjustment curve for multiple-wheel assemblies. The load-adjustment curve is used to resolve multiple-wheel assemblies into an equivalent single-wheel load. This equivalent single-wheel load can then be used with the nomograph to determine strength requirements for unsurfaced soils, and inversely to determine the relative flotation capability of a proposed landing gear design on unimproved surfaces. For landing mat, these variables have been related for single wheels by use of an "equivalent thickness concept" and a "CBR formula." In order that these criteria for multiple-wheel assemblies could be used, a means was developed for relating multiple-wheel-assembly loads to equivalent single-wheel loads. This equivalent single-wheel load could then be used with the single-wheel criteria to design a multiple-wheel gear for desired flotation, or inversely to determine requirements of a mat-surfaced airfield to support the intended loading.

Equivalent Thickness Concept

The procedure used to analyze the landing mat data was to relate the load-carrying capabilities of the mat to the load-carrying capabilities of a flexible airfield pavement. This was done by assuming that for a given landing mat failure point the mat is equivalent in strength to that thickness of flexible pavement required (as indicated by the CBR formula) by the conditions causing failure of the mat. This follows the basic procedures set forth in analyzing data in TR No. 3-539,[7] for single-wheel loads. In order to use this criterion for multiple-wheel loads, a means was developed for relating multiple-wheel loads to equivalent single-wheel loads.

CBR Formula

To determine the thickness of flexible pavement structure required for any loading condition, the following formula is used:

$$t = (0.23 \log C + 0.15) \sqrt{\frac{P}{8.1CBR} - \frac{A}{\pi}}$$

where

t = thickness of flexible pavement structure, in.
C = number of coverages
P = single-wheel or equivalent single-wheel load, lb
CBR = soil strength measurement
A = tire contact area, sq in.

By using the CBR formula, a thickness of pavement structure can be calculated which will provide the same load-support capability for each test loading and subgrade condition as did the landing mat tested. For the purposes of this study, this thickness is termed "equivalent thickness" and is defined as an index of the strength of an airfield surfaced with landing mat. In keeping with this definition, the symbol "I" is substituted for "t" in the CBR formula as shown below.

$$I = (0.23 \log C + 0.15) \sqrt{\frac{P}{8.1CBR} - \frac{A}{\pi}}$$

This index of the airfield surfacing strength is referred to in two different ways in this report. The first use of the index, I_A , is to evaluate and express the available strength of an existing mat-surfaced airfield. The second use of the index, I_R , is to evaluate landing gear designs for mat-surfaced airfields of specific design.

The CBR formula relates all the variables used in the testing program, as well as the variables needed in designing an adequate landing gear.

Normalizing of Data

Although comparable test items were prepared the same in an attempt to develop identical conditions, it was inevitable that some variation would result.

To analyze the test results, therefore, it was necessary in some cases to normalize the data. That is, the results of each test, expressed as coverages at failure, were adjusted to show the coverages which would have produced failure in the test had the CBR been exactly that desired. In one instance an adjustment of coverages was made to compensate for a change in load. This normalizing of the data was accomplished by entering the CBR formula with the actual test conditions and determining an "equivalent thickness." Then, using this "equivalent thickness" and a CBR (or load) adjusted to the desired value, the number of coverages which could be expected to produce failure at this CBR (or load) was computed by again using the equation. For example, consider a load which failed on a 3.5-CBR subgrade at 76 coverages with a tire contact pressure of 100 psi, and is to be normalized to a 4.0-CBR subgrade. The equation would be as follows:

$$(0.23 \log 76 + 0.15) \sqrt{\frac{P}{8.1(3.5)} - \frac{P}{100\pi}} = t = (0.23 \log C_x + 0.15) \sqrt{\frac{P}{8.1(4)} - \frac{P}{100\pi}}$$

The load P will cancel out of the formula, and solving for the normalized coverage level (C_x) the result is 119 coverages. Therefore, a load which makes 76 coverages on a 3.5-CBR subgrade with a 100-psi tire contact pressure can be expected to make 119 coverages on a 4-CBR subgrade.

Single-Wheel Traffic Tests on Modified T11 Aluminum Landing Mat

For the purpose of analysis, the basic data obtained during testing on T11 landing mat are summarized in Table I. In addition, data used in this analysis but obtained during related investigations are also shown in Table I. Each test is assigned a test number for easy reference.

The index of available airfield-surfacing strength (I_A) was calculated for all single-wheel tests, and values are shown in Table I under the column heading "I_A for Single Wheels." To develop ground-flotation criteria for single wheels, a relation was needed that would relate tire contact area or average tire contact pressure, CBR, coverages, and load. Therefore, I_A , which relates these factors, was plotted against the wheel load. Using this type of plot, the aircraft designer can design a single-wheel landing gear when the load that the gear must carry is known.

The initial data plot involved the 200-psi tire pressure data and is shown in Figure 16. A curve was drawn through the data, with the general shape of the curve being based somewhat upon prior experience. Test point T25 was a nonfailure, indicating that the point would be plotted higher if failure had occurred, so the curve was drawn above the point to better approximate failure. The curve breaks downward as the loads get very large, indicating a very rapid failure more related to the mat characteristics than to the mat-subgrade structure at these loads.

After the 200-psi curve was established, the data for the 100-psi curve were plotted (Figure 17). Only two single-wheel,100-psi points were obtained. The general shape and slope of the previously established 200-psi curve was used to draw the 100-psi curve. The curve was drawn through test point T3 with very little consideration given to test T12 because the traffic in test T12 was mixed. Six hundred coverages of a 35-kip, 50-psi, single-wheel load had been applied to this test item prior to the application of 60-kip traffic.

Only one single-wheel test was conducted using 50-psi tire pressure, and it was a nonfailure point. However, this point (T11) was plotted (Figure 17). To properly establish the 50-psi curve, an estimate was made of the test point location if failure had occurred. To do this, the previous pattern of spacing of the I_A curves shown in MP 4-459[1] was used. A ratio of the 50- and 100-psi values of I_A provides an estimate of the location of the 50-psi point in this investigation. The 50-psi curve was then drawn through the estimated point using the general shape and slope of the 200-psi curve.

By cross-plotting the three curves developed in this investigation, a family of I_A curves was drawn for the T11 mat. These curves are shown in Figure 18 and are designated for rear-area airfields since the rear-area airfield is defined in terms of the T11 mat.

Multiple-Wheel Traffic Tests on Modified T11 Aluminum Landing Mat

Multiple-wheel tests were conducted to obtain data that would permit the development of procedures for designing multiple-wheel aircraft landing gears. The tests conducted and data collected permit a direct comparison of trafficking with single- and multiple-wheel assemblies, and permit a study of the effects of wheel spacing on the performance of a multiple-wheel assembly. If this data can be used to relate multiple-wheel data to single-wheel data, i.e. resolve multiple-wheel loads to equivalent single-wheel loads, then the previously developed I_A curves can be used for multiple-wheel gear design. The approach, therefore, was to develop procedures for resolving multiple-wheel loads into equivalent single-wheel loads (ESWL). An equivalent single-wheel load can be expressed either as a percentage of the assembly load, or as a percentage of the load on one tire of the assembly. This study expresses the ESWL as a percentage of the load per tire, and the ESWL will always be greater than the load per tire.

A summary of the multiple-wheel test data on T11 landing mat is shown in Table I. The data were normalized to a 2-CBR subgrade, and the resulting coverage values are shown in the column entitled "Normalized Coverages."

The initial plot for the multiple-wheel analysis was of the twin- and single-tandem assembly data. This approach would provide a direct indication of the effect of spacing on the ESWL when comparing the twin-wheel data to single-wheel data. Figure 19 shows a plot of normalized coverages versus wheel spacing (in radii) for test points T4 to T8. These were twin- and single-tandem tests conducted using 35,000 lb per tire and 100-psi tire pressure. As the wheels were moved farther apart, the ESWL became less, and each wheel began to perform as an individual single wheel. Therefore, the curve becomes horizontal at 250 coverages, which is the number of coverages (normalized to a 2-CBR subgrade) sustained in the single-wheel test (test point T3). The largest ESWL that could occur for twin wheels would be twice the load per tire. This would occur if the load on two wheels were considered to be all one wheel, and the condition producing this situation (which cannot occur) would be that in which one wheel is on top of the other or where the center to center (c-c) spacing is zero. However, to draw the complete coverages versus spacing curve, it is necessary to calculate the coverages for the zero spacing point using the CBR formula and to draw the curve to this point as shown in Figure 19. This curve relates coverages and spacing. The objective of this study is to relate spacing and load in order to be able to obtain an equivalent single-wheel load for multiple wheels. Therefore, a companion plot was produced, by use of the CBR formula, which related coverages and load for single wheels. This is shown in the right-hand portion of Figure 19.

To obtain an ESWL, it is necessary to determine that load on a single tire (with characteristics equivalent to one tire of the assembly) which will produce the same effect on a pavement as the total assembly. The ESWL will be equal to the load on one tire of the assembly plus the additional load contributed by each nearby tire. This additional load over and above the actual load per tire can be determined from Figure 19 and plotted as the percentage by which the load on one tire of the assembly must be increased to arrive at the ESWL representing the entire assembly. This percentage is shown in figure 20, and is called the load-adjustment curve. It is used in determining an ESWL when the spacing between the wheels, in radii, is known. The load on one wheel of an assembly is adjusted to the ESWL merely by increasing the one-wheel load by the percentage effect from all surrounding wheels.

Only the single-wheel data were used for the developments in Figure 17 to avoid unknowns which might exist in ESWL determinations. With a means of determining ESWL now established, however, it becomes possible to further verify the Figure 17 curves by using the multiple-wheel test results. Accordingly, an equivalent single-wheel load was determined for each multiple-wheel test, and I_A was calculated. These values of I_A are shown in Table I, and are plotted in Figure 21.

Many of these test points fall directly on or very near the corresponding I_A curve, indicating that the load-adjustment curve works for these points. However, several of the points do not compare favorably, and these are discussed in the following paragraphs.

There is some indication that the load-adjustment curve may vary with load. This is indicated by points T1 and T2 for the 200-psi data and T13 for the 100-psi data. These particular tests were run at a load other than the 35-kip load used to develop the load-adjustment curve, and each one falls off the I_A curve.

Test points T9 and T10 fall off the 100-psi curve and T15 falls off the 50-psi curve; however, they are considered sufficiently close to provide an adequate check of the load-adjustment curve.

Test points T18 and T19 are representative of the three-wheel tests and plot considerably above the 100-psi curve. These tests produced much better results than expected. The reason for the results of these tests being as good as they were is not known. Although they were conducted with a softer tire (24 ply) than some of the other tests, this difference in ply rating is not considered sufficient to cause the differences that occurred.

Test point T20 falls off the 50-psi curve. However, failure in test T20 was due to elastic deflection of the mat, whereas failure in the other tests was due to roughness. Had sufficient traffic been applied to produce greater differential deformations, the data point would have fallen on or near the 50-psi curve.

This analysis of the T11 multiple-wheel data indicates that the criteria as developed and as shown in Figures 18 and 20 can be used for the design of aircraft landing gears required to operate on modified T11 landing mat, but that some variation of the load-adjustment curve with load may not be reflected by the criteria.

Traffic Tests on M8 Steel Landing Mat

For the purpose of analysis, the basic M8 landing mat traffic data obtained during this investigation are summarized in Table II. Each test is assigned a test number for easy reference.

The existing ground-flotation criteria for M8 mat contained in MP 4-459[1] for single wheels are based on a wide range of early tests. These criteria are, however, known to be somewhat conservative because of the procedures used in determining the rated CBR for each test. Also, the load-adjustment curve in MP 4-459 was based on only limited indications from previous tests that the effect of one wheel upon another was zero at approximately four-radii spacing. The tests on M8 mat were, therefore, to be conducted for updating the I_A curves, and for developing an adequate load-adjustment curve.

Very few single-wheel tests were run on M8 mat in this investigation, and these were not sufficient for revising the I_A curves, although they indicate that a revision is necessary.

The approach to the M8 data analysis was to assume that the load-adjustment curve developed for the T11 landing mat was also applicable to M8 mat. This load-adjustment curve and the CBR formula were then used to develop the I_A curves. The equivalent single-wheel load was determined for all multiple-wheel tests and is shown in Table II. This equivalent single-wheel load was substituted into the CBR formula for the corresponding test conditions and I_A was calculated (Table II). These I_A values along with the single-wheel I_A values were plotted versus the single-wheel or equivalent single-wheel load and are shown in Figure 22. The test points plotted are 50- and 100-psi data and define a pattern of performance. Curves following the general shape and slope of the previously developed T11 curves were then drawn through these points (Figure 22).

The I_A curves, as drawn, pass through or near most of the test points, indicating that the load-adjustment curve developed for T11 landing mat can be used for these M8 data points. However, some of the data points fall considerably off the curves. These points are discussed in the following paragraphs.

Test point M1 is a single-wheel test point which does not fall on the I_A curve. There seems to be no reason why the item in this test failed under fewer coverages than expected. Since most of the data points obtained at the same load per wheel defined an I_A curve, not much consideration was given to point M1 in drawing the curve.

Tests M10 and M11 were run at wheel loads greater than 35 kips and indicate that the load-adjustment curve may vary with load. This also was indicated in the T11 tests.

Tests M16 and M17 are the three-wheel gear tests and resulted in test points that fall considerably off the 100-psi I_A curve. These tests produced better results than all other comparable tests, and a study of the data shows no specific reason why these tests do not conform to the pattern established by the other 35-kip wheel load tests.

Test point M20 represents the 12-wheel test run to simulate the C-5A landing gear. This point plots higher than the 100-psi I_A curve and is also a nonfailure point. Test points which plot above the I_A curve indicate that the use of the criteria as developed would be conservative.

Test point M9 falls below the 50-psi I_A curve; however, it is a nonfailure point. Had this test been continued to failure, this point would be plotted higher. Test M12 was a rerun of test M9 and plots exactly on the I_A curve.

Using the pattern of spacing developed in MP 4-459,[1] the 50- and 100-psi curves were extrapolated to develop a 200-psi curve. These curves were then cross plotted and a family of I_A curves was developed and is shown in Figure 23. These curves are entitled support-area airfield curves since the support-area airfield is defined in terms of the M8 mat.

This analysis of M8 data indicates that the criteria as developed and as shown in Figures 20 and 23 can be used to design a landing gear for an aircraft required to operate on an M8 landing-mat-surfaced airfield.

Single-Wheel Traffic Tests on Unsurfaced Soil

The results of the single-wheel traffic tests on unsurfaced soil are summarized in Table III. Eight single-wheel loads ranging from 1 to 60 kips were used during the ground-flotation test program. Approximately 40 percent of the single-wheel tests were conducted with a 25-kip wheel load. A nomograph (Figure 24) which incorporates the variables of tire pressure, load, CBR, and coverages has been used for a number of years to determine unsurfaced-soil strength requirements. Therefore, to analyze the single-wheel tests the failure data were plotted on the nomograph form. The ground contact pressures were calculated for all tests and were used exclusively in making the plots. By cross plotting, smoothing operations, and taking previous work into account (Figure 24 and References 6 and 7), a complete set of load curves was derived and is shown in the left-hand portion of Figure 25. This nomograph is presented as a revision to the unsurfaced requirements as given in the nomograph shown in Figure 24. The relations between test data and the finalized load curves are presented in Figure 26. All single-wheel load failure data are shown. This figure shows that generally the load curves have been drawn to produce a conservative relation in terms of coverages. Figures 27 and 28 are plots of all 25- and 35-kip single-wheel load data. For comparison purposes, curves obtained from the nomograph (Figure 25) are superimposed on these figures.

Multiple-Wheel Traffic Tests on Unsurfaced Soil

In addition to the results of single-wheel traffic tests, Table III presents a summary of all multiple-wheel tests conducted during this study. The majority of the multiple-wheel tests were performed using a 100-psi tire inflation pressure and a 35-kip wheel load. In order to relate these test data to the unsurfaced nomograph, which was developed with the single-wheel test data, the relation between the load per tire and the tire spacing of the multiple-wheel assemblies is needed in order to resolve the multiple-wheel loads into equivalent single-wheel loads. Figure 29 shows a load-adjustment curve for multiple-wheel assemblies that has been in use for several years. This curve is contained in reference 1 and shows that an adjustment is required when the adjacent tires of a multiple-wheel assembly are spaced less than four equivalent radii center to center. This curve, which was used to determine equivalent single-wheel loads for aircraft operating on both landing-mat-surfaced and unsurfaced areas, is based on a very limited number of multiple-wheel tests on landing mat (Reference 7). The ground-flotation tests on unsurfaced soil present the first opportunity to actually develop an equivalent single-wheel load relation for multiple-wheel assemblies operating on unsurfaced areas.

Since the bulk of the ground-flotation multiple-wheel test data involved the use of 35-kip wheel loads and 100-psi tire inflation pressures, these data were used in the analysis and development of a load-adjustment curve for the determination of equivalent single-wheel loads. After the test data had been normalized to 10 CBR, a plot of normalized coverages versus tire spacing was made and is shown in the left-hand portion of figure 30. The 100-psi criteria as obtained from the unsurfaced nomograph (Figure 25) were used as an aid in drawing the curve. The upper part of the curve was drawn to extend to 85 coverages, which represents a single-wheel load of 33 kips (P) that was obtained from the nomograph. The lower part of the curve was drawn to 4.9 coverages as obtained from the nomograph and represents 2P or 66 kips. The load curve, right-hand plot, was then drawn with intermediate load values for 100-psi tire pressures being obtained by use of the nomograph. These two curves show that a relation between spacing and load can be developed, as shown in Figure 31, where load is expressed as a percentage increase in load per tire. The value P as read from Figure 30 would be zero percent increase, and the value 2P would be 100 percent increase. This curve, called the load-adjustment curve, can be used to determine the equivalent single-wheel load by estimating the effect of one wheel upon another when the spacing between the wheels, in radii, is known.

As shown in Figure 30 some of the multiple-wheel data fit the curve as drawn fairly well; however, some of the data do not fit the curve. A general discussion of all multiple-wheel data is contained in the following paragraphs.

Five two-wheel-assembly tests (U39 through U43) with the wheels abreast and one two-wheel test (U44) with the wheels aligned in tandem were conducted during this investigation. Figure 30 shows the data from these tests and in all cases represents normalized 35-kip, 100-psi, 10-CBR results. As shown in this figure, the twin spacing varied from 2.4 to 5.56 radii. The spacing on the one single-tandem test was 5.56 radii.

When these data are compared with an average single-wheel test data point (Figure 30), there is a strong indication that there is no effect of the second wheel of the twin assembly when the two wheels are spaced at least 4.2 radii apart. The average single-wheel data point shown is an average of tests U30 and U31.

A direct comparison can be made between test U43, which involved a twin-wheel assembly with twin spacing of 5.56 radii, and test U44, which involved a single-tandem assembly that had a tandem spacing of 5.56 radii. From Figure 30, it should be noted that for the same assembly load, tire pressure and spacing, and CBR, the single-tandem configuration produced twice as many coverages as the twin-wheel configuration. This would indicate that for the two-wheel assembly it is more beneficial to arrange the wheels in tandem than abreast from the soil load standpoint. Although not as pronounced, this same trend is evident in the test results obtained from comparable twin-tandem (U48) and twin-twin assembly (U47) tests (see Figure 30).

Tests U45 and U46 were performed using three wheels abreast with each wheel loaded to 35 kips and tires inflated to 100 psi. From Figure 30, which presents data normalized to 10 CBR, it should be noted that by increasing the center-to-center tire spacing of the three wheels from 2.6 to 3.2 radii, coverages at failure increased from 22 to 50. The increase in coverages is as would be expected. Also shown in Figure 30 are tests U30 and U31, which are single-wheel tests that have been averaged and normalized to give the indicated average single-wheel test point that is plotted at zero spacing and 55 coverages. When this point is compared with the three-wheel tests, it can be seen that the single wheel is not as severe as the three wheels spaced at 2.6 radii, but the single- and three-wheel test results are approximately the same when the three wheels are spaced 3.2 radii apart. This is an indication that the effect of adjacent wheels on the load on one wheel of the assembly is negligible when the adjacent wheels are spaced approximately 3.2 radii apart. The analysis of the 100-psi, 12-wheel tests (3.3-radii spacing) discussed subsequently can also lead to this same conclusion. However, it is believed that this trend is not sufficiently developed to warrant changing the approach used to develop the load-adjustment curve discussed previously and shown in Figure 31.

A further comparison can be made between the three-wheel assembly tests and tests U39 and U40, which involved twin-wheel assemblies. Figure 30 shows that when the wheel spacing is about 2.6 radii, the twin- and three-wheel test results are approximately the same. However, when the wheel spacing was about 3.2 radii, the three-wheel test, which produced approximately the same number of coverages as the single-wheel tests, produced significantly more coverages than the twin-wheel test. There is no apparent reason for this last finding.

Two tests with four-wheel assemblies were performed during this study. Test U48 was a twin-tandem test (two sets of twin wheels aligned in tandem), and test U47 was a twin-twin-assembly test that involved two sets of twin wheels aligned abreast. Figure 30 shows that a single wheel with the same tire pressure and load as one wheel of the four-wheel assemblies produced a greater number of coverages than either the twin-tandem or twin-twin assemblies. It also shows that although the twin-tandem configuration produced slightly more coverages than the twin-twin gear, for all practical purposes the action of the two different types of configurations is about the same. Thus, from these four-wheel tests, there is no indication of a distinct advantage of one type of gear over the other.

Several tests were performed with a 12-wheel assembly (4 abreast, 3 in line) to simulate the C-5A aircraft landing gear. These tests are not shown in Figure 30 for comparative purposes due to differences in load per tire. Therefore, several additional plots were made to provide an analysis of the 12-wheel tests and are discussed below.

Twelve-Wheel Traffic Tests on Unsurfaced Soil

Table III summarizes all 12-wheel traffic test data. A 21-kip wheel load was used in all tests except test U63 which had a 22,750-lb wheel load. All tests were conducted using a 20.00-20/22 ply tire inflated to either a 100- or 55-psi tire pressure. To analyze these tests, a plot of rated CBR versus coverages at failure is shown in Figure 32. This figure indicates that except for test U56 which is suspect, the 12-wheel tests produced consistent straight-line results. Test U56 is suspect because while this test was being conducted, a variation in tire pressure from 50 to 90 psi was discovered. This finding placed the test in doubt and resulted in the decision to rerun the entire test, and subsequently test lane 34 was tested.

Single-wheel tests U12, U13, and U14 were performed to obtain test data that could be compared with that from 12-wheel tests U60, U61, and U62. Figure 33, presenting this comparison, is a plot of rated CBR versus coverages at failure for the 21-kip, 100-psi, single-wheel load tests and the 100-psi, 12-wheel test which had each wheel loaded to 21 kips. This figure shows that there is very little difference between the single-wheel and the 12-wheel test results for rated CBR values of approximately 4 and 6 (tests U12, U13, U60, and U61). It would appear from Figure 33 that the 12-wheel gear would allow more coverages than the single wheel for a given CBR. However, for all practical purposes, the coverages are identical. This indicates that for this particular 12-wheel gear arrangement (3.3x 3.8x3.3 radii spacing) the equivalent single-wheel load for the gear would be equal to the load on one wheel and that there is no effect of the adjacent wheels on the load on one wheel of the assembly. The load-adjustment curve, therefore, would not give adequate results for the 12-wheel tests used in this program because it shows some influence of adjacent wheels and would result in an equivalent single-wheel load greater than the load on one wheel. Use of the nomograph and the load-adjustment curve for all 12-wheel tests conducted on unsurfaced soils produces conservative results when comparing predicted coverages with actual coverages. This conservatism varies among tests, but in general the nomograph predicts about one-third as many coverages as the actual 12-wheel test data indicate.

Although the criteria as developed do not directly reflect behavior for 12-wheel gear assemblies, they are considered applicable because of the unknown effects of turning and braking on unsurfaced soils.

Drawbar Pull Data

The results of the drawbar pull (DBP) tests were used to gain an indication of the landing gear rolling resistance as a function of landing surface. The DBP data obtained in this study are presented in Table IV as drawbar pull measurements. Data used in this analysis but obtained from other sources are presented in Table V. Use of the term "rolling resistance" in this report refers to drawbar pull.

To relate DBP and landing surface, the DBP data were expressed as a percentage of gross load and plotted versus average CBR at time of test divided by tire contact pressure for landing-mat-surfaced and unsurfaced soils. These were the primary variables affecting test results. The data for unsurfaced soils are shown in Figure 34 for initial DBP, Figure 35 for average rolling DBP, and Figure 36 for peak DBP. After plotting the data, a limiting curve was drawn on each figure. The data were grouped because most of the data were obtained over a small range of CBR's. The use of the curves as drawn would result in safe or conservative drawbar pull determinations. The wide scatter of the data within the CBR range indicates that perhaps more factors influence the rolling resistance than were measured. These curves may be used to estimate a limiting rolling resistance value that can be expected to occur on a landing surface with a given subgrade CBR value.

The DBP data obtained on landing mat are shown in Figure 37 for initial DBP, Figure 38 for average rolling DBP, and Figure 39 for peak DBP. These data were all clustered within a small CBR range, and no attempt was made to draw a limiting curve.

Velocity Versus Rolling Resistance

The objective of the speed tests was to obtain a relation between velocity and rolling resistance and to use the principles of scale modeling in planning the tests so that the results could be extended to prototype conditions. The tests which were conducted in the AERB facility were planned and scaled, and a summary of the test results is shown in Table VI.

Since the objective of this test program was to develop a relation between rolling resistance and velocity, these variables were plotted and are shown in Figure 40. The rolling resistance is shown as a ratio of the rolling resistance in pounds to the weight on the wheel in pounds. A curve was then drawn through the points plotted. As the velocity increased, the data became scattered, probably because of wheel bounce that occurred as the wheel moved down the soil subgrade and the resulting effect of inertial forces acting on the load cell. Although a curve can be drawn through the points as plotted, the use of this curve is limited to the range of velocities for which tests were run. By plotting the results of the scaled tests as dimensionless quantities, it was anticipated that a curve would be developed that could be used to ~~determine the rolling resistance~~ for a wide range of tire sizes, weights, and velocities. However, several plots were made using the scaled terms and velocity, and these produced only a wide scatter of data, as shown in a typical plot in Figure 41. The results did not produce successful scaling. However, recent tests conducted in a related study using powered wheels and more experience with this type of study have produced good results using the principles of scaling. The indications, therefore, are that these tests should be rerun in the light of recent findings.

Comparison of Tire Inflation Pressure and Ground Contact Pressure

Table III includes a summary of tire inflation pressures used during these tests and the corresponding computed ground contact pressures. Figure 42 is a plot of these data and also includes data from tests previously conducted and reported in Reference 7. It can be seen that up to 100 psi the ground contact pressure is approximately 10 percent greater than the tire inflation pressure. At some point between 100 and 200 psi the reverse becomes true, and from 200 to 300 psi the tire inflation pressure is up to 15 percent greater than the ground contact pressure. The point where inflation and ground contact pressures are equal is difficult to define; however, it would appear to be at approximately 130 psi. Any effect of tire size and ply rating on ground contact pressure could not be determined.

Tire Ply Tests

A few single-wheel load tests on unsurfaced soils were conducted specifically to determine the relation between tire characteristics as reflected by ply rating and coverages. These tests are summarized as follows.

Test No.	Single-Wheel Load kips	Inflation Pressure psi	Ground Contact Pressure psi	Rated CBR	No. of Coverages at Failure	Tire Ply	Tire Size
U30	35	100	110	9.5	60	24	56x16
U32	35	100	112	6.7	4	38	56x16
U33	35	100	112	9.2	16	38	56x16
U29	35	100	110	6.7	10	24	56x16
U31	35	100	110	11.0	50	24	56x16

These tests were performed with a 35-kip single-wheel load on a 56x16 tire inflated to 100 psi. Tire ply ratings of 24 and 38 were used. These tests can be divided into two groups and analyzed as follows. Tests U32 and U29 offer a direct comparison of the effect of changing from 38 to 24 ply as all test variables except the ply rating were the same for both tests. These two tests indicate that by decreasing the ply from 38 to 24 the coverages increase from 4 to 10 or by a factor of 2.5. Except for rated CBR values and coverages at failure, tests U30 and U31 are duplicate 24-ply tests. By averaging these two tests a CBR of 10.25 and 55 coverages are obtained. By normalizing the rated CBR (9.2) of test U33, which was a 38-ply test, to 10.25 CBR, a coverage level of 23 is obtained. This can then be directly compared with the 55 coverages, and a ratio of 2.4 is obtained. Thus, from these two groups of tests performed to determine the relation between coverages and ply rating, it can be concluded that by decreasing the ply rating from 38 to 24, coverages increase by a factor of 2.5.

Therefore, the tests conducted to study the relations between tire ply and coverages indicate that this relation changes with the load on the tire.

Tire Size Tests

Traffic test data used to investigate the effects of tire size on flotation are shown in the following tabulation.

Test No.	Single-Wheel Load kips	Infla-tion Pres-sure psi	Ground Con-tact Pres-sure psi	Tire Size and Ply Rating	Tire Diam-eter in.	Rated CBR	Cover-ages at Fail-ure	Cover-ages at Failure Normal-ized to 8.5 CBR and 25,000 lb
U30	35	100	110	56x16/24	56	9.5	60	107
U21	25	100	103	56x16/22	56	9.1	70	54
U20	25	100	110	25.00-28/30	70	7.8	200	290
U24	25	100	100	17.00-16/12	45	7.8	100	142
U11	19	100	116	34x9.9/14	34	8.5	32	17
U33	35	100	112	56x16/38	56	9.2	16	27
U14	21	100	84	20.00-20/22	56	7.5	40	39

Tires of five different sizes were used, inflated to 100 psi, and loaded as shown. The data have been normalized to 25,000 lb and 8.5 CBR. The data indicate that coverages increase with an increase in tire diameter, and thus, for a given tire diameter, coverages increase with a reduction in ply rating. Test U14 does not compare favorably with tests U30, U21, and U33. The reason for this is not apparent from the data.

Tire Pressure Tests

Results of tests performed on unsurfaced soils to investigate the effects of different tire pressures are summarized in the following tabulation.

Test No.	Single-Wheel Load kips	Infla-tion Pres-sure psi	Ground Contact Pres-sure psi	Rated CBR	Cover-ages	Cover-ages at Failure Normal-ized to 5 CBR	Remarks
U15	25	25	34	3.9	200	--	Nonfailure
U17	25	60	63	4.6	30	40	
U16	25	40	49	4.7	150	207	
U18	25	80	82	5.0	20	20	
U19	25	100	100	3.9	3	4-1/2	

Traffic of a 25-kip single-wheel load on a 25.00-28, 30-ply tire was applied to test lanes having approximately the same rated CBR. Five different inflation pressures ranging from 25 to 100 psi were used in these tests. Figure 43 is a plot of coverages versus ground contact pressure and shows test data that have been normalized to 5 CBR. As would be expected, the test data show that by decreasing the tire pressure, a substantial increase in coverages can be obtained. Also shown in Figure 43 is the coverages versus tire pressure relation for a 25-kip single-wheel load (test data normalized to 5 CBR) as obtained from the unsurfaced nomograph (Figure 25). For these particular tests the nomograph agrees with test data for the lower tire pressures and is slightly conservative for the upper tire pressure range (80-100 psi).

SECTION VII: USE OF CRITERIA

Evaluation Procedures

The criteria presented herein may be used to determine ground-flotation requirements for single- and multiple-wheel landing gear assemblies. The use of the criteria is an evaluation rather than a design procedure. That is, a gear is proposed for a given set of conditions and then checked to determine if it will be satisfactory for those conditions. For operation on landing mat, an I_R value is calculated using the CBR formula and compared with an I_A value read from Figure 18 or 23. If the I_R is equal to or less than the I_A, the proposed gear is capable of performing the specified mission. For operation on unsurfaced soil, the unsurfaced nomograph is entered with the characteristics of the proposed gear, and its capabilities in terms of coverages or CBR are read from the nomograph. The capabilities are then compared with the stated requirements to determine if the proposed gear is capable of performing the stated mission. Examples of the use of the criteria are as follows.

Typical Examples

Example 1

Required. Design a landing gear for an aircraft with a gross weight of 83,500 lb and a main gear load of 37,500 lb that will operate for 1000 coverages on a 4-CBR subgrade surfaced with T11 landing mat.

Proposed. A single-wheel landing gear with a tire inflation pressure of 125 psi.

Solution. To determine if the proposed landing gear will satisfy the stated requirements, it is first necessary to calculate I_R.

$$I_R = (0.23 \log C + 0.15)\sqrt{\frac{P}{8.1\ \mathrm{CBR}} - \frac{P}{p\pi}}$$

$$I_R = (0.23 \log 1000 + 0.15)\sqrt{\frac{37{,}500}{8.1\ (4)} - \frac{37{,}500}{125\pi}}$$

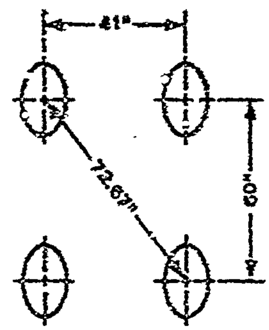
$$I_R = 27.4$$

I_R is then compared with I_A which is read from figure 18 and is equal to 27.6. This comparison shows that I_R is slightly less than I_A; therefore, the aircraft landing gear proposed is sufficient to perform the stated mission.

Example 2

Required. Design a landing gear for an aircraft with a gross weight of 341,000 lb and a main gear load of 153,500 lb that will operate for 200 coverages on a 4-CBR subgrade surfaced with T11 landing mat.

Proposed. A twin-tandem landing gear assembly with tire spacings of 41 by 60 in., a tire contact area of 260 sq in., and a tire pressure of 150 psi.



Solution. To determine if the proposed landing gear will satisfy the stated requirements, it is necessary to determine the equivalent single-wheel load. This is done by first calculating the equivalent radius as follows:

$$r = \sqrt{\frac{\text{Contact Area}}{\pi}} = \sqrt{\frac{260}{\pi}} = 9.10 \text{ in.}$$

Then calculate tire spacings in terms of the equivalent radius:

$$\text{Twin Spacing} = \frac{41 \text{ in.}}{9.10 \text{ in.}} = 4.50 \text{ radii}$$

$$\text{Tandem Spacing} = \frac{60 \text{ in.}}{9.10 \text{ in.}} = 6.59 \text{ radii}$$

$$\text{Diagonal Spacing} = \frac{72.67 \text{ in.}}{9.10 \text{ in.}} = 7.99 \text{ radii}$$

From Figure 20, the increase in the load per tire due to the adjacent tires is determined. The tires are symmetrical around the center of the assembly, so that any of the tires may be chosen as the critical tire. For this example, wheel 1 was chosen. The influence of the other tires is as follows:

Wheel 2 at 4.50 radii spacing = 15.7 percent

Wheel 3 at 6.59 radii spacing = 0.0 percent

Wheel 4 at 7.99 radii spacing = 0.0 percent

Total 15.7 percent

Therefore, the ESWL is $1.157 \times 38{,}375 = 44{,}400$ lb; I_R is then calculated as follows:

$$I_R = (0.23 \log C + 0.15) \sqrt{\frac{P}{8.1\ \mathrm{CBR}} - \frac{A}{\pi}}$$

$$I_R = (0.23 \log 200 + 0.15) \sqrt{\frac{44{,}400}{8.1\ (4)} - \frac{260}{\pi}}$$

$$I_R = 24.4$$

I_R must then be compared with I_A which is read from Figure 18 and is equal to 24.5. This comparison shows that I_R is slightly less than I_A; therefore, the aircraft landing gear proposed is sufficient to perform the stated mission.

Example 3

Required. Design a landing gear for an aircraft with a gross weight of 55,500 lb and a main gear load of 25,000 lb that will operate for 175 coverages on an unsurfaced 6-CBR subgrade.

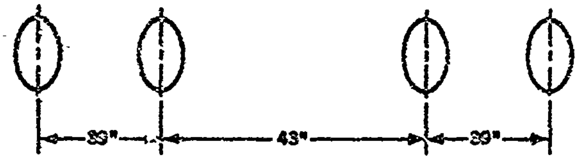
Proposed. A single-wheel landing gear assembly with a tire pressure of 60 psi.

Solution. To determine if the proposed gear will satisfy the stated requirements, it is necessary to enter the nomograph (Figure 25) with the given wheel load, tire pressure, and coverage level and read the CBR required to perform the desired operation. The CBR value read for this example is 6; therefore, the proposed gear is capable of performing the desired mission.

Example 4

Required. Design a landing gear for an aircraft with a gross weight of 250,000 lb and a main gear load of 112,000 lb that will operate for 100 coverages on an unsurfaced 10-CBR subgrade.

Proposed. A twin-twin landing gear assembly with tire spacings of 39-43-39 in., tire contact area of 295 sq in., and a tire pressure of 95 psi.



Solution. To determine if the proposed landing gear will satisfy the stated requirements, it is necessary to determine the equivalent single-wheel load. This is accomplished by first calculating the equivalent radius as follows:

$$r = \sqrt{\frac{\text{Contact Area}}{\pi}} = \sqrt{\frac{295}{\pi}} = 9.69 \text{ in.}$$

Then calculate the distance from wheel 2 to the other wheels. If the critical wheel for an assembly is not known, all wheels must be checked.

$$\text{Wheel 2 to wheel 1} = \frac{39 \text{ in.}}{9.69} = 4.02 \text{ radii}$$

$$\text{Wheel 2 to wheel 3} = \frac{43}{9.69} = 4.44 \text{ radii}$$

$$\text{Wheel 2 to wheel 4} = \frac{82}{9.69} = 8.46 \text{ radii}$$

From Figure 31 the increase in the load per tire due to the adjacent tires is determined. This increase is as follows:

Wheel 1 at 4.02 radii spacing =	17.0 percent
Wheel 3 at 4.44 radii spacing =	7.5 percent
Wheel 4 at 8.46 radii spacing =	0.0 percent
Total	24.5 percent

Therefore, the ESWL is 1.245 x 28,000 lb = 34,860 lb. Using this ESWL, enter the nomograph (Figure 25) with the tire pressure and coverage level desired and read the CBR required to perform the desired operation. This CBR value for this example is 10; therefore, the proposed gear is capable of performing the desired mission.

SECTION VIII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results of the study described herein, the following conclusions are drawn:

a. Single-wheel or equivalent single-wheel loads can be related to tire pressure in terms of an index of available airfield surfacing strengths (I_A) for T11 and M8 landing mats. As indicated in Figures 18 and 23, I_A increases with load until failure becomes more related to the characteristics of the mat than to the subgrade structure. At this point, I_A decreases as the load is increased. IA also increases as the tire pressure decreases.

b. Multiple-wheel loads operating on landing mats can be resolved into equivalent single-wheel loads by relating spacing and percent increase in single-wheel load for each adjacent wheel. Figure 20 presents this relation, and shows that the percent increase changes very rapidly between 3 and 5 radii, and becomes zero at 5.5 radii. The equivalent single-wheel load can be applied to the basic I_A curves for determining ground-flotation requirements for multiple-wheel loads. There is an indication, however, that the load-adjustment curve may vary somewhat with load.

c. Unsurfaced-soil strength requirements can be related to single-wheel or equivalent single-wheel loads, tire pressures, and coverages. The nomograph presented in Figure 25 illustrates this relation and shows that the allowable traffic increases as the load or tire pressure decreases or as the CBR increases.

d. Multiple-wheel loads operating on unsurfaced soils can be resolved into equivalent single-wheel loads by relating spacing and percent increase in single-wheel load for each adjacent wheel. Figure 31 presents this relation and shows that an equivalent single-wheel load will decrease with an increase in spacing with a very rapid change occurring between 2- and 4-radii spacing. The influence of spacing on the ESWL is zero at 5.5-radii spacing. The ESWL can be applied to the nomograph (Figure 25) to determine ground-flotation requirements for multiple-wheel gears.

e. Results of the simulated C-5A test (12 wheels) on landing mat compared favorably with the T11 criteria but indicated that the M8 criteria were conservative for the C-5A type loading.

f. Results of the simulated C-5A test (12 wheels) on unsurfaced soil were more satisfactory than the criteria developed for determining ground-flotation requirements indicate. However, the unsurfaced criteria for C-5A type gear configurations are considered applicable because of the unknown effects of braking and turning on unsurfaced soils.

g. Drawbar pull measurements can be related to soil subgrade strengths for M8 and T11 landing mats and for unsurfaced soils. Figures 34-39 present this relation and show that the drawbar pull decreases as the CBR increases.

h. The general trend of the effect of tire size, tire ply rating, and tire pressure on ground-flotation capabilities of aircraft operating on unsurfaced soil was determined. The data indicate that the allowable traffic on an unsurfaced soil increases as the tire diameter gets larger and decreases as the ply rating increases. Also, the allowable traffic increases as the tire pressure gets smaller.

i. A relation was established between velocity and drawbar pull. This relation is presented in Figure 40 and shows that as the velocity increases, the drawbar pull decreases.

j. Average hard surface tire contact pressure can be generally related to tire inflation pressure for the types of tires used. Figure 42 shows that for inflation pressures below about 130 psi the contact pressure is greater than the inflation pressures, and that for inflation pressures above 130 psi, the contact pressure is less than the inflation pressure.

Recommendations

Based upon the results of this study, the following recommendations are presented:

a. Additional tests should be conducted to establish the effect of load on the load-adjustment curve since these tests indicated that the load-adjustment curve may vary with load.

b. Since these tests developed only a trend, further tests should be conducted to establish fully the effects of tire pressure, tire ply rating, and tire size on ground flotation.

c. Although the modeling tests to study speed versus drag were unsuccessful, further attempts should be made to use modeling to study this relation since recent model testing with powered wheels has been successful.

d. Additional tests and studies should be made to determine specifically the reason for the 3- and 12-wheel tests producing consistently better results than anticipated.

e. There was an indication from these tests that wheels in tandem performed better on unsurfaced soils than wheels abreast at the same spacing; therefore, additional testing should be conducted to establish this relation.

f. An outgrowth of this study has been to indicate that for flexible pavements the procedures used for obtaining the equivalent single-wheel load for many wheel assemblies may yield unduly conservative results. Therefore, a study of these procedures should be conducted since C-5A aircraft will be required to operate from pavements.

g. A study should be made of the procedures for counting coverages since the method used may contribute to some of the differences occurring in the test results reported herein.

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TABLE I

SUMMARY OF TRAFFIC TEST RESULTS, T11 LANDING MAT

Test No.	Section	Lane	Assembly Load lb	Wheel Configuration	Load per Tire lb	Tire Inflation Pressure psi	Average Measured Tire Contact Area sq in.	Equivalent Radius in.	C-C Tire Spacing in.	C-C Tire Spacing radii	Tire Size	Tire Ply Rating	Rated CBR	Coverages at Failure	I_A for Single Wheels	Normalized Coverages for CBR = 2	Load Adjustment Factor	Equivalent Single-Wheel Load lb	I_A for Multiple Wheels
								Data from Ground-Flotation Investigation											
T1	1	1	104,000	Twin	52,000	200	307	9.90	37	3.73	56x16	36	7.4	300	--	8	1.57	81,600	23.6
T2		2	104,000	Twin	52,000	200	303	9.84	24	2.43	56x16	36	8.7	40	--	2.5	1.97	102,400	19.8
T3	2	3	35,000	Single	35,000	100	318	--	--	--	56x16	24	2.5	600	31.9	250	--	--	--
T4		4	70,000	Twin	35,000	110	329	10.25	25	2.43	56x16	32	2.3	20	--	14	1.97	61,950	27.0
T5	3	5	70,000	Twin	35,000	100	329	10.25	35	3.41	56x16	32	2.0	88	--	28	1.76	61,700	27.7
T6		6	70,000	Twin	35,000	100	365	10.80	45	4.16	56x16	24	2.0	130	--	130	1.28	44,800	33.0
T7	4	7	70,000	Single-Tandem	35,000	100	365	10.80	60	5.56	56x16	24	2.1	300	--	240	1.02	35,700	38.1
T8		8	70,000	Twin	35,000	100	365	10.80	60	5.56	56x16	24	2.4	460	--	230	1.02	35,700	31.7
T9	5	9	140,000	Twin-Twin	35,000	100	317	10.00	37-60-37	3.7-6.0-3.7	56x16	24	2.4	199	--	107	1.60	56,000	36.0
T10		10	140,000	Twin-Tandem	35,000	100	327	10.00	37x60	3.7x6.0	56x16	24	2.6	74	--	35	1.60	56,000	29.5
T11	6	11	35,000	Single	35,000	50	640	--	--	--	25.00-28	30	1.5	600+*	41.0+	2500+	--	--	--
T12		11A	60,000	Single	60,000	100	606	--	--	--	25.00-28	30	2.3	130	35.2	85	--	--	--
T13		12	120,000	Twin	60,000	100	599	13.85	56	4.04	25.00-28	30	2.9	90	--	30	1.37	82,800	34.6
T14	9	21	35,000	Single	35,000	50	640	--	--	--	25.00-28	30	1.5	600+*	41.0+	2500+	--	--	--
T15		22	70,000	Twin	35,000	50	669	14.60	42	2.87	25.00-28	30	1.8	400	--	600	1.92	66,850	49.6
T16	10	23A	50,000	Single	50,000	250	228	--	--	--	56x16	32	3.0	32	22.7	14	--	--	--
T17		23B	75,000	Single	75,000	250	324	--	--	--	56x16	32	3.5	4	14.6	2	--	--	--
T18	12	26	105,000	3 wheels	35,000	100	333	10.30	33-33	3.2-3.2	56x16	24	2.2	150	--	95	2.68	93,800	46.0
T19		27	105,000	3 wheels	35,000	100	337	10.38	27-27	2.6-2.6	56x16	24	2.4	60	--	43	2.91	101,850	41.5
T20	13	28	70,000	Twin	35,000	50	649	14.40	58.5	4.06	25.00-28	30	2.1	700	--	560	1.35	47,300	41.0
T21		29	70,000	Twin	35,000	50	686	14.80	29.5	2.0	25.00-28	30	1.8	140	--	210	1.99	69,690	43.7
T22	16	35	273,000	12 wheels	22,750	100	[illegible]	9.45	34-44-34	3.6-4.7-3.6	20.00-20	22	2.2	210	--	155	1.76	40,040	32.0
								Data from Related Studies**											
T23	--	--	50,000	Single	50,000	200	270	--	--	--	56x16	32	5.9	130	19.6	7.5	--	--	--
T24	--	--	41,500	Single	41,500	200	220	--	--	--	56x16	32	3.9	40	18.3	9	--	--	--
T25	--	--	24,000	Single	24,000	200	120†	--	--	--	56x16	32	5.1	300+*	18.0+	25+	--	--	--
T26	--	--	52,000	Single	52,000	200	313	--	--	--	56x16	32	6.6	286	21.3	10	--	--	--
T27	--	--	35,000	Single	35,000	200	191	--	--	--	56x16	32	4.4	130	18.3	12	--	--	--
T28	--	--	65,000	Single	65,000	200	325†	--	--	--	56x16	32	6.7	26	15.7	3	--	--	--

* No failure developed.
** TR 3-634 (Appendix B).
† Calculated.

TABLE XI

SUMMARY OF TRAFFIC TEST RESULTS, M8 LANDING MAT

Test No.	Section	Lane	Assembly Load lb	Wheel Configuration	Load per Tire lb	Tire Inflation Pressure psi	Average Measured Tire Contact Area sq in.	Equivalent Radius in.	C-C Tire Spacing in.	C-C Tire Spacing radii	Tire Size	Tire Ply Rating	Rated CBR	Coverages at Failure	I_A for Single Wheels	Normalized Coverages for CBR = 4	Load-Adjustment Factor	Equivalent Single-Wheel Load lb	I_A for Multiple Wheels
M1	2	3	35,000	Single	35,000	100	318	--	--	--	56x16	24	5.1	120	17.2	--	--	--	--
M2		4	70,000	Twin	35,000	110	329	10.25	25	2.43	56x16	32	3.6	30	--	33	1.970	68,950	39.75
M3	3	5	70,000	Twin	35,000	100	329	10.25	35	3.41	56x16	32	3.8	28	--	42	1.765	61,775	21.80
M4		6	70,000	Twin	35,000	100	365	10.80	45	4.16	56x16	24	3.6	76	--	119	1.275	44,625	28.50
M5	4	7	70,000	Single-Tandem	35,000	100	365	10.80	60	5.56	56x16	24	4.9	200	--	145	1.016	35,560	19.00
M6		8	70,000	Twin	35,000	100	365	10.80	60	5.56	56x16	24	4.0	143	--	142	1.016	35,560	20.30
M7	5	9	140,000	Twin-Twin	35,000	100	317	10.00	37-68-37	3.7-6.8-3.7	56x16	24	4.1	102	--	90	1.598	55,930	24.40
M8		10	140,000	Twin-Tandem	35,000	100	317	10.00	37x60	3.7x6.0	56x16	24	4.0	48	--	48	1.598	55,930	21.00
M9	6	11	35,000	Single	35,000	50	640	--	--	--	25.00-28	30	4.1	600+*	23.1**	--	--	--	--
M10		11A	60,000	Single	60,000	100	606	--	--	--	25.00-28	30	4.3	130	25.0	--	--	--	--
M11		12	120,000	Twin	60,000	100	599	13.85	56	4.04	25.00-28	30	4.2	44	--	38	1.370	82,200	25.00
M12	9	21	35,000	Single	35,000	50	640	--	--	--	25.00-28	30	1.9	300	32.8	--	--	--	--
M13		22	70,000	Twin	35,000	50	669	14.60	42	2.87	25.00-28	30	1.9	100	--	2800	1.912	66,920	39.80
M14	10	23A	50,000	Single	50,000	250	228	--	--	--	56x16	32	3.8	2	8.7	--	--	--	--
M15		23B	75,000	Single	75,000	250	324	--	--	--	56x16	32	3.9	2 passes	10.5	--	--	--	--
M16	12	26	105,000	3 wheels	35,000	100	333	10.30	33-33	3.2-3.2	56x16	24	3.7	150	--	200	2.680	93,800	36.00
M17		27	105,000	3 wheels	35,000	100	337	10.28	27-27	2.6-2.6	56x16	24	3.7	68	--	90	2.910	102,000	32.90
M18	13	28	70,000	Twin	35,000	50	649	14.40	58.5	4.06	25.00-28	30	2.8	700	--	4000	1.350	47,250	35.00
M19		29	70,000	Twin	35,000	50	686	14.80	29.5	2.0	25.00-28	30	2.0	200	--	780	1.990	69,650	36.50
M20	16	35	273,000	12 wheels	22,750	100	280	9.45	34-44-34	3.6-4.7-3.6	20.00-20	22	3.7	1300+*	--	2850	1.780	40,495	24.60

* No failure developed.

TABLE III

SUMMARY OF TRAFFIC TEST RESULTS, UNSURFACED SOIL

Test No.	Section	Lane	Item	Assembly Load lb	Wheel Configuration	Load per Tire lb	Tire Pressure: Inflation Pressure psi	Tire Pressure: Contact Pressure psi	Average Contact Area: Computed sq in.	Average Contact Area: Measured sq in.	Equivalent Radius in.	C-C Tire Spacing: in.	C-C Tire Spacing: Radii	Tire Size	Tire Ply Rating	Rated CBR	Coverages to Failure	[illegible] Load Coverages for CBR = 10
									Single-Wheel Tests									
U1	AMRB*	8	--	1,000	Single	1,000	10	15	100	65	--	--	--	9.00x14	8	1.1	170	--
U2	AMRB	1	--	1,000	Single	1,000	10	15	100	65	--	--	--	9.00x14	8	1.4	200	--
U3	AMRB	2	--	1,000	Single	1,000	20	25	50	40	--	--	--	9.00x14	8	1.0	24	--
U4	AMRB	3	--	1,000	Single	1,000	30	35	33	29	--	--	--	9.00x14	8	1.1	18	--
U5	AMRB	4	--	1,000	Single	1,000	40	45	25	22	--	--	--	9.00x14	8	1.2	50	--
U6	AMRB	5	--	2,000	Single	2,000	40	46	50	34	--	--	--	9.00x14	8	2.3	38	--
U7	AMRB	6	--	2,000	Single	2,000	60	63	33	32	--	--	--	9.00x14	8	2.6	50	--
U8	AMRB	7	--	2,000	Single	2,000	80	81	25	25	--	--	--	9.00x14	8	2.5	44	--
U9	11**	25	1	2,500	Single	2,500	25	31	100	81	--	--	--	34x9.9	14	1.3	30	--
U10			2	2,500	Single	2,500	25	31	100	81	--	--	--	34x9.9	14	2.1	60	--
U11	7	16	--	19,000	Single	19,000	100	116	190	164	--	--	--	34x9.9	14	8.4	32	--
U12	14	31	1	21,000	Single	21,000	100	84	210	249	--	--	--	20.00-20	22	4.2	3	--
U13			2	21,000	Single	21,000	100	84	210	249	--	--	--	20.00-20	22	6.3	26	--
U14			3	21,000	Single	21,000	100	84	210	249	--	--	--	20.00-20	22	7.5	40	--
U15	8	17	1	25,000	Single	25,000	25	34	1000	746	--	--	--	25.00-28	30	3.9	200†	--
U16	8	19	1	25,000	Single	25,000	40	49	625	510	--	--	--	25.00-28	30	4.7	150	--
U17	8	18	1	25,000	Single	25,000	60	63	417	399	--	--	--	25.00-28	30	4.6	30	--
U18	8	20	1	25,000	Single	25,000	80	82	313	307	--	--	--	25.00-28	30	5.0	20	--
U19	8	17A	1	25,000	Single	25,000	100	100	250	251	--	--	--	25.00-28	30	5.9	3	--
U20	7	14	--	25,000	Single	25,000	100	110	250	227	--	--	--	25.00-28	30	7.8	200	--
U21	7	13	--	25,000	Single	25,000	100	103	250	242	--	--	--	56x16	32	9.2	70	--
U22	14A	32A	2	25,000	Single	25,000	250	177	100	141	--	--	--	56x16	32	10.0	10	--
U23	14A	32A	3	25,000	Single	25,000	250	177	100	141	--	--	--	56x16	32	14.0	60	--
U24	7	15	--	25,000	Single	25,000	100	100	250	251	--	--	--	17.00-16	12	7.8	100	--
U25	14A	32	2	25,000	Single	25,000	250	228	100	110	--	--	--	30x11.5	24	10.0	1 pass	--
U26	14A	32	3	25,000	Single	25,000	250	228	100	110	--	--	--	30x11.5	24	14.0	1	--
U27	6	11	2	35,000	Single	35,000	50	55	700	640	--	--	--	25.00-28	30	12.0	600†	--
U28	9	21	3	35,000	Single	35,000	50	55	700	640	--	--	--	25.00-28	30	4.7	300	--
U29	17	37	1	35,000	Single	35,000	100	109	350	319	--	--	--	56x16	24	6.7	10	--
U30	2	3	3	35,000	Single	35,000	100	110	350	318	--	--	--	56x13	24	9.5	60	--
U31	17	37	2	35,000	Single	35,000	100	109	350	319	--	--	--	56x16	24	11.0	50	--
U32	17	36	1	35,000	Single	35,000	100	112	350	312	--	--	--	56x16	38	6.7	4	--
U33	17	36	2	35,000	Single	35,000	100	112	350	312	--	--	--	56x16	38	9.2	16	--
U34	6	11A	3A	60,000	Single	60,000	100	99	600	606	--	--	--	25.00-28	30	12.0	112	--
U35	6	11A	3B	60,000	Single	60,000	100	99	600	606	--	--	--	25.00-28	30	16.0	130	--

(Continued)

* Army Mobility Research Branch.
** Data from Model Wide-Tire Report[2].
† No failure developed.

TABLE III (Concluded)

Test No.	Section	Lane	Item	Assembly Load lb	Wheel Configuration	Load per Tire lb	Tire Pressure: Inflation Pressure psi	Tire Pressure: Ground Contact Pressure psi	Average Contact Area: Computed sq in.	Average Contact Area: Measured sq in.	Equivalent Radius in.	C-C Tire Spacing: in.	C-C Tire Spacing: Radii	Tire Size	Tire Ply Rating	Rated CBR	Coverage at Failure	Normalized Coverages for CBR = 10
									Multiple-Wheel Tests									
U36	13	29	3	70,000	Twin	35,000	50	51	700	686	14.80	29.5	2.00	25.00-28	30	4.5	200	--
U37	9	22	3	70,000	Twin	35,000	50	52	700	669	14.60	42	2.87	25.00-28	30	4.8	100	--
U38	13	28	3	70,000	Twin	35,000	50	54	700	649	14.40	58.5	4.06	25.00-28	30	4.7	200	--
U39	2	4	3	70,000	Twin	35,000	110	106	318	329	10.25	25	2.43	56x16	32	10.0	20	20
U40	3	5	3	70,000	Twin	35,000	100	106	350	329	10.25	35	3.41	56x16	32	9.2	12	16
U41	3	6	3A	70,000	Twin	35,000	100	96	350	365	10.80	45	4.16	56x16	24	9.0	36	53
U42	3	6	3B	70,000	Twin	35,000	100	96	350	365	10.80	45	4.16	56x16	24	10.0	50	50
U43	4	8	3	70,000	Twin	35,000	100	96	350	365	10.80	60	5.55	56x16	24	9.8	62	68
U44	4	7	3	70,000	Single-Tandem	35,000	100	96	350	365	10.80	60	5.56	56x16	24	9.3	120	135
U45	12	27	3	105,000	3 wheels	35,000	100	104	350	337	10.38	27-27	2.6-2.6	56x16	24	10.0	30	22
U46	12	26	3	105,000	3 wheels	35,000	100	105	350	333	10.30	33-33	3.2-3.2	56x16	24	11.0	72	50
U47	5	9	3	140,000	Twin-Twin	35,000	100	110	350	317	10.00	37-68-37	3.7-6.8-3.7	56x16	24	9.8	20	22
U48	5	10	3	140,000	Twin-Tandem	35,000	100	110	350	317	10.00	37x60	3.7x6.0	56x16	24	9.8	24	26
U49	1	2	1	104,000	Twin	52,000	200	169	260	308	9.90	24	2.43	56x16	36	10.0	2 passes	--
U50	1	2	2	104,000	Twin	52,000	200	169	260	308	9.90	24	2.43	56x16	36	18.0	130	--
U51	1	1	1	104,000	Twin	52,000	200	172	260	303	9.84	37	3.73	56x16	36	10.0	2 passes	--
U52	1	1	2	104,000	Twin	52,000	200	172	260	303	9.84	37	3.73	56x16	36	27.0	300†	--
U53	6	12	3	120,000	Twin	60,000	100	100	600	599	13.85	56	4.04	25.00-28	30	9.0	44	66
U54	15	33	1	252,000	12 wheels	21,000	55	53	382	399	11.28	34x44x34	3.0x3.9x3.0	20.00-20	22	2.3	1.3	--
U55			2	252,000	12 wheels	21,000	55	53	382	399	11.28	34x44x34	3.0x3.9x3.0	20.00-20	22	4.4	25	--
U56			3	252,000	12 wheels	21,000	55	53	382	[illegible]	11.28	34x44x34	3.0x3.9x3.0	20.00-20	22	8.1	59	--
U57	15	34	1	252,000	12 wheels	21,000	55	53	382	399	11.28	34x44x34	3.0x3.9x3.0	20.00-20	22	2.5	1.3	--
U58			2	252,000	12 wheels	21,000	55	53	382	399	11.28	34x44x34	3.0x3.9x3.0	20.00-20	22	4.7	49	--
U59			3	252,000	12 wheels	21,000	55	53	382	399	11.28	34x44x34	3.0x3.9x3.0	20.00-20	22	7.0	400	--
U60	14	30	1	252,000	12 wheels	21,000	100	81	210	259	9.09	30x34x30	3.3x3.8x3.3	20.00-20	22	3.8	2.4	--
U61			2	252,000	12 wheels	21,000	100	81	210	259	9.09	30x34x30	3.3x3.8x3.3	20.00-20	22	6.1	28	--
U62			3	252,000	12 wheels	21,000	100	81	210	259	9.09	30x34x30	3.3x3.8x3.3	20.00-20	22	10.0	730	--
U63	16	35	3	273,000	12 wheels	22,750	100	88	228	280	9.45	34x44x34	3.6x4.7x3.6	20.00-20	22	9.0	455	--

† No failure developed.

TABLE IV

DRAWBAR PULL DATA FROM AIRCRAFT GROUND-FLOTATION INVESTIGATION 1

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CBR at Given Coverage Level	CBR/ Contact Pressure	Drawbar Pull, kips Initial	Drawbar Pull, kips Peak	Drawbar Pull, kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
1	1	Twin, 37	56x16/36	200	104	615.8	168.9	1 Unsurfaced	0	10.0	0.059	13.00	19.00	10.54	12.5	18.3	10.1
								2 Unsurfaced	0	15.0	0.088	10.25	11.50	4.86	9.9	11.1	5.7
									135	31.0*	0.183	10.00	9.25	3.43	9.6	8.9	3.3
									300	30.0	0.178	11.50	13.50	3.65	11.1	13.0	3.5
								3 Modified T11 aluminum mat	0	7.0	0.041	9.50	15.00	4.60	9.1	14.4	4.4
									135	7.0*	0.041	10.75	15.50	5.76	10.3	14.5	5.5
									300	8.3	0.049	10.75	15.20	5.74	10.3	14.6	5.5
	2	Twin, 24	56x16/36	200	104	605.7	171.7	1 Unsurfaced	0	10.3	0.060	19.00	12.00	7.60	18.3	11.5	7.3
								2 Unsurfaced	0	14.7	0.086	11.20	9.20	4.70	10.8	8.8	4.5
									120	22.0	0.128	13.50	7.20	4.50	13.0	6.9	4.3
								3 Modified T11 aluminum mat	0	9.0	0.052	11.50	7.70	4.70	11.1	7.4	4.5
									40	8.3	0.048	14.00	10.60	6.30	13.5	10.5	5.1
2	3	Single	56x16/24	100	35	317.9	110.1	1 Modified T11 aluminum mat	20	2.5*	0.023	1.75	2.90	1.05	5.0	8.3	3.0
									50	2.5*	0.023	2.68	2.80	1.20	7.6	8.0	3.4
									60	2.5*	0.023	2.65	2.30	1.30	7.6	6.6	3.7
									120	2.4*	0.022	4.20	3.10	1.60	12.0	8.9	4.6
									200	2.4	0.021	5.70	3.70	1.70	16.3	10.6	4.9
									600	2.9	0.026	5.90	7.60	2.30	16.9	21.7	6.6
								2 M8 steel mat	0	4.3	0.079	1.60	2.80	1.10	4.6	8.0	3.1
									20	4.5*	0.042	2.83	2.80	1.05	8.1	8.0	3.6
									60	5.0*	0.045	3.33	2.90	1.35	9.5	8.3	3.9
									120	5.8	0.053	4.70	3.90	1.60	13.4	11.1	4.6
									200	--	--	5.70	4.60	2.20	16.3	13.1	6.3
								3 Unsurfaced	0	10.3	0.094	2.60	2.60	1.20	7.4	7.4	3.4
									20	9.7*	0.088	2.48	3.60	1.60	7.1	10.3	4.6
									60	8.7	0.079	3.60	5.70	1.90	10.3	16.5	5.4
									122	--	--	3.80	4.00	2.30	10.6	11.4	7.1
	4	Twin, 25	56x16/32	110	70	699.1	106.2	1 Modified T11 aluminum mat	0	2.4	0.023	11.44	7.20	4.02	16.3	10.3	5.7
									20	2.4	0.023	12.57	10.60	6.97	17.9	15.1	10.0
								2 M8 steel mat	0	4.6	0.043	7.64	7.05	3.85	10.9	10.0	5.5
									20	3.8	0.036	8.97	7.20	5.43	12.8	10.3	7.8
								3 Unsurfaced	0	10.5	0.099	6.70	5.90	4.00	9.6	8.4	5.7
									20	10.0	0.094	9.70	8.80	6.47	13.9	12.6	9.2
3	5	Twin, 35	56x16/32	100	70	699.1	106.2	1 Modified T11 aluminum mat	0	1.9	0.018	11.00	7.40	5.10	15.7	10.6	7.3
									12	2.0*	0.019	10.60	11.40	7.00	15.1	16.3	10.0
								(Continued)	30	2.2	0.021	13.00	9.10	6.50	18.6	13.0	9.3

* Indicates data are extrapolated.

(1 of 8 sheets)

TABLE IV (Continued)

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CBR at Given Coverage Level	CBR/ Contact Pressure	Drawbar Pull, Kips Initial	Drawbar Pull, Kips Peak	Drawbar Pull, Kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
3 (Cont'd)	5	Twin, 35	56x16/32	100	70	659.1	106.2	2 M8 steel mat	0	4.0	0.038	9.60	6.50	4.20	13.7	9.3	6.0
									12	3.9*	0.037	9.10	10.50	5.30	13.0	15.0	7.6
									30	3.7	0.035	11.20	8.20	5.30	16.0	11.7	7.6
								3 Unsurfaced	0	9.1	0.086	11.10	7.40	4.60	15.9	10.6	6.6
									12	9.3	0.088	10.70	14.80	8.50	15.3	21.1	12.1
	6	Twin, 45	56x16/24	100	70	731.4	95.7	1 Modified T11 aluminum mat	0	1.8	0.019	8.57	6.30	4.10	12.2	9.0	5.8
									20	1.8*	0.019	10.16	8.00	6.37	14.5	11.4	9.1
									50	1.9*	0.020	--	7.30	5.90	--	10.4	8.1
								2 M8 steel mat	0	3.9	0.041	8.17	6.70	3.50	11.7	9.6	5.0
									20	3.7*	0.039	9.95	7.90	4.97	14.2	11.3	7.1
									50	3.5*	0.037	--	9.60	5.30	--	13.7	7.6
								3 Unsurfaced	0	9.9	0.097	7.13	4.70	3.90	10.2	6.7	5.6
									20	9.7*	0.101	10.13	6.50	4.50	14.5	9.3	6.4
									50	10.0*	0.104	10.98	11.50	8.40	15.7	16.4	12.0
4	7	Single-Tandem 60	56x16/24	100	70	731.4	95.7	1 Modified T11 aluminum mat	0	2.1	0.022	5.90	4.20	2.50	8.4	6.0	3.6
									40	2.1*	0.022	6.60	5.30	2.80	9.4	7.6	4.0
									200	2.1*	0.022	9.00	5.20	3.40	12.9	7.4	4.9
									300	2.1	0.022	8.10	5.60	3.20	11.6	8.0	4.6
								2 M8 steel mat	0	4.7	0.049	6.10	4.40	2.10	8.7	6.3	3.0
									40	4.8*	0.050	6.50	4.90	2.60	9.3	6.4	3.7
									200	5.1	0.053	8.20	5.50	2.70	11.7	7.9	3.9
								3 Unsurfaced	0	10.0	0.104	6.40	4.00	2.30	9.1	9.7	3.3
									40	9.6*	0.100	6.70	5.00	3.70	9.6	7.2	5.3
									128	8.7	0.091	8.20	6.60	4.80	11.7	9.4	6.9
	8	Twin, 60	56x16/24	100	70	731.4	95.7	1 Modified T11 aluminum mat	0	2.4	0.025	9.50	7.10	3.00	13.6	10.1	4.3
									20	2.4*	0.025	10.20	5.90	3.30	14.6	8.4	4.7
									62	2.4*	0.025	13.70	8.20	4.20	19.6	11.7	6.0
									142	2.4*	0.025	9.80	8.20	4.00	14.0	11.7	5.7
									460	2.4	0.025	10.70	9.00	3.90	15.7	12.9	5.6
								2 M8 steel mat	0	3.8	0.040	9.40	6.50	2.60	13.4	9.3	3.7
									20	3.9*	0.041	8.90	8.30	2.50	12.7	11.9	3.6
									62	4.0*	0.042	9.80	6.60	3.00	14.0	9.4	4.3
									142	4.2	0.044	10.00	7.90	3.40	14.3	11.3	4.9
								3 Unsurfaced	0	11.0	0.115	9.70	10.10	3.70	13.9	14.4	5.3
									20	10.3*	0.108	10.20	8.90	3.90	14.6	12.7	5.6
									62	8.7	0.091	9.60	10.50	6.20	13.7	15.0	8.9
5	9	Twin-Twin 37-68-37	56x16/24	100	140	1270	110.2	1 Modified T11 aluminum mat	0	2.3	0.021	17.20	12.60	10.20	12.3	9.0	7.3
									20	2.3*	0.021	--	16.40	13.50	--	11.7	9.6
									199	2.4	0.022	22.30	24.20	16.20	15.9	17.3	11.6
								2 M8 steel mat	0	3.7	0.034	15.30	13.50	8.40	10.9	9.6	6.0
									20	3.9*	0.035	--	13.20	8.00	--	9.4	5.7
									102	4.5	0.041	17.30	14.00	9.90	12.4	10.0	7.1
								3 Unsurfaced (Continued)	0	9.7	0.088	15.30	19.10	10.30	12.4	13.6	7.3
									20	10.0	0.091	25.70	24.40	11.60	18.3	17.4	13.6

* Indicates data are extrapolated.

(2 of 3 sheets)

TABLE IV (Continued)

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CBR at Given Coverage Level	CBR/ Contact Pressure	Drawbar Pull, kips Initial	Drawbar Pull, kips Peak	Drawbar Pull, kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
5 (Cont'd)	10	Twin-Tandem 37x60	56x16/24	100	140	1270	110.2	1 Modified T11 aluminum mat	0	2.4	0.022	15.80	11.70	9.90	11.3	8.4	7.1
									24	2.5*	0.023	--	13.20	10.80	--	9.4	7.7
									48	2.7*	0.024	16.70	14.10	12.00	11.9	10.1	8.6
									74	2.8	0.025	13.40	13.50	9.50	9.6	9.6	6.8
								2 M8 steel mat	0	4.3	0.039	15.00	9.50	6.90	10.7	6.8	4.9
									24	4.0*	0.036	--	10.00	8.00	--	7.1	5.7
									48	3.7	0.034	14.90	10.30	8.80	10.6	7.4	6.3
								3 Unsurfaced	0	10.3	0.093	15.80	9.40	7.40	11.3	6.7	5.3
									24	9.3	0.084	11.80	11.70	9.10	8.4	8.4	6.5
6	11	Single	25.00x28/30	50	35	640	78.1	1 Modified T11 aluminum mat	0	1.5	0.019	6.90	2.80	1.00	19.7	8.0	2.9
									20	1.5*	0.019	4.90	2.20	1.00	14.0	6.3	2.9
									300	1.5*	0.019	6.50	2.60	1.00	18.6	7.4	2.9
									500	1.5*	0.019	3.80	2.90	1.20	10.9	8.3	3.4
								2 M8 steel mat	0	4.1	0.072	6.00	2.20	1.00	17.1	6.3	.9
									20	4.1*	0.072	4.50	1.70	1.00	12.9	4.9	2.9
									300	4.1*	0.072	6.40	1.90	1.00	18.3	5.4	2.9
									600	4.1*	0.072	3.20	2.10	1.20	9.1	6.0	3.4
								3 Unsurfaced	0	10.3	0.132	6.60	2.00	1.00	18.9	5.7	2.9
									20	10.4*	0.133	4.40	2.10	0.90	12.6	6.0	2.6
									300	12.3*	0.157	7.40	2.20	0.90	21.1	6.3	2.6
									600	14.3	0.183	3.10	2.20	1.10	8.9	6.3	2.9
	11A	Single	25.00x28/30	100	60	606	99.0	1 Modified T11 aluminum mat	0	2.3*	0.023	6.90	4.30	3.00	11.5	7.2	5.0
									20	2.4*	0.024	7.80	4.60	3.00	13.0	7.7	5.0
									130	3.2	0.032	3.90	4.40	2.40	6.5	7.3	4.0
								2 M8 steel mat	0	4.3*	0.043	5.60	4.00	2.40	9.3	6.7	4.0
									20	4.3*	0.043	7.70	4.10	3.00	12.8	6.8	5.0
									130	4.5	0.045	6.30	5.00	3.10	10.5	8.3	5.2
								3 Unsurfaced				DATA QUESTIONABLE					
	12	Twin, 56	25.00x28/30	100	120	1198	100.2	1 Modified T11 aluminum mat	0	2.4	0.024	12.20	8.40	6.10	10.2	7.0	5.1
									20	2.6*	0.026	13.20	10.10	7.50	11.0	8.4	6.2
									44	2.9*	0.029	13.50	11.30	7.50	11.2	9.4	6.2
									90	3.4	0.034	12.50	9.40	7.30	10.4	7.8	6.1
								2 M8 steel mat	0	4.3	0.043	11.40	6.00	4.90	9.5	5.0	4.1
									20	4.2*	0.042	12.20	8.70	6.00	10.2	7.2	5.0
									44	4.1	0.041	12.30	10.30	6.80	10.2	8.6	5.7
								3 Unsurfaced	0	9.3	0.093	10.60	7.40	5.20	8.8	6.2	4.3
									20	8.8*	0.088	12.80	7.40	6.00	10.7	6.2	5.0
									44	8.3	0.083	10.50	11.00	7.60	8.7	9.2	6.3
7	13	Single	56x16/32	100	25	241.8	103.4	Unsurfaced	0	8.0	0.077	3.90	2.90	0.80	15.6	11.6	3.2
									20	8.7*	0.084	3.00	2.50	1.30	12.0	10.0	5.2
									70	10.3	0.100	5.30	3.20	1.60	21.2	12.8	6.4
	14	Single	25.00x28/30	100	25	227.4	109.9	Unsurfaced	0	8.0	0.073	2.80	1.30	0.70	11.2	5.2	2.8
									20	8.0*	0.073	4.00	1.50	0.80	16.0	6.0	3.2
									200	7.7	0.070	3.60	1.40	0.50	14.4	5.6	2.0

(Continued)

* Indicates data are extrapolated.

(3 of 8 sheets)

TABLE IV (Continued)

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CBR at Given Coverage Level	CBR/ Contact Pressure	Drawbar Pull, kips Initial	Drawbar Pull, kips Peak	Drawbar Pull, kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
7 (Cont'd)	15	Single	17.00x16/12	100	25	250.7	99.7	Unsurfaced	0	8.0	0.080	3.20	2.30	1.50	12.8	9.2	6.0
									20	7.9*	0.079	4.50	3.00	1.80	18.0	12.0	7.2
									100	7.7	0.077	5.00	4.40	3.00	20.0	17.6	12.0
	16	Single	34.00x9.9/14	100	19	163.6	116.1	Unsurfaced	0	8.0	0.069	3.30	2.40	1.40	13.2	9.6	5.6
									20	8.6*	0.074	5.10	5.30	2.30	20.4	21.2	9.2
									32	9.0	0.077	5.80	5.80	2.50	23.2	23.2	10.0
8	17	Single	25.00x28/30	25	25	745.5	33.5	Unsurfaced	0	3.9	0.116	4.60	3.20	0.70	18.4	12.8	2.8
									20	3.9*	0.116	3.50	0.80	0.30	14.0	3.2	1.2
									200	4.0	0.119	3.50	1.70	0.90	14.0	6.8	3.6
	17A	Single	25.00x28/30	100	25	250.6	99.8	Unsurfaced	0	3.9	0.039	5.20	3.60	1.60	20.8	14.4	6.4
	18	Single	25.00x28/30	60	25	399.3	62.6	Unsurfaced	0	3.9	0.062	4.20	2.40	1.20	16.8	9.6	4.8
									20	4.9*	0.078	4.10	2.40	1.60	16.4	9.6	6.4
									30	5.3	0.085	6.30	3.10	1.30	25.2	12.4	5.2
	19	Single	25.00x28/30	40	25	510.0	49.0	Unsurfaced	0	4.7	0.096	3.80	3.10	0.70	15.2	12.4	2.8
									20	4.7*	0.096	4.40	3.20	0.70	17.6	12.8	2.8
									150	4.6	0.094	3.40	3.10	0.70	13.6	12.4	2.8
	20	Single	25.00x28/30	80	25	306.7	81.5	Unsurfaced	0	4.7	0.058	4.60	3.70	1.50	18.4	14.8	6.0
									20	5.3	0.065	4.50	3.10	1.30	18.0	12.4	5.2
9	21	Single	25.00x28/30	50	35	640.0	54.7	1 Modified T11 aluminum mat	0	1.1	0.020	3.30	2.80	0.70	10.0	8.0	2.0
									20	1.1*	0.020	3.10	1.60	0.70	8.9	4.6	2.0
									300	1.5*	0.027	4.00	3.20	1.60	11.4	9.1	4.6
									600	1.9	0.035	4.30	2.90	1.60	12.3	8.3	4.6
								2 M8 steel mat	0	2.0	0.037	3.10	2.50	0.50	8.9	7.1	1.4
									20	2.0*	0.037	3.50	1.50	0.60	10.0	4.3	1.7
									300	1.8	0.033	3.90	3.50	1.70	11.1	10.0	4.9
								3 Unsurfaced	0	4.7	0.086	4.60	2.00	0.90	13.1	5.7	2.6
									20	4.7*	0.086	3.90	2.50	1.10	11.1	7.1	3.1
									300	4.7	0.086	4.40	3.50	2.10	12.6	10.0	6.0
	22	Twin, 42	25.00x28/30	50	70	1338.0	52.3	1 Modified T11 aluminum mat	0	1.4	0.027	8.00	5.60	3.90	11.4	8.0	5.6
									20	1.4*	0.027	8.40	7.80	5.50	12.0	11.1	7.9
									100	1.5*	0.029	8.00	6.60	5.10	11.4	9.4	7.3
									400	1.8	0.034	7.90	7.80	5.60	11.3	11.1	8.0
								2 M8 steel mat	0	1.6	0.031	2.20	6.70	3.80	3.1	9.6	5.4
									20	1.7*	0.033	7.90	6.40	4.60	11.3	9.1	6.6
									100	2.1	0.040	8.30	7.20	4.80	11.9	10.3	6.9
								3 Unsurfaced	0	5.2	0.099	7.10	4.60	2.80	10.1	6.6	4.0
									20	5.0*	0.096	7.20	6.80	3.50	10.3	5.7	5.0
									100	4.4	0.084	9.70	7.80	5.10	13.9	11.1	7.3
10	23A	Single	56x16/32	250	50	228.2	219.1	1 Modified T11 aluminum mat	2	3.0	0.014	8.70	4.10	2.40	17.4	8.2	4.8
									32	2.9	0.013	8.70	5.30	2.90	17.4	10.6	5.8
								2 M8 steel mat	2	4.1	0.019	7.70	5.80	4.70	15.4	11.6	9.4

(Continued)

* Indicates data are extrapolated.

(4 of 8 sheets)

TABLE XV (Continued)

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CBR at Given Coverage Level	CBR/ Contact Pressure	Drawbar Pull, kips Initial	Drawbar Pull, kips Peak	Drawbar Pull, kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
10 (Cont'd)	23	Single	56x16/32	250	75	324.0	231.5	1 Modified T11 aluminum mat	4	4.0	0.017	12.10	8.90	6.10	16.1	11.9	8.1
								2 M8 steel mat	2 passes	4.2		NO DRAWBAR DATA					
11	24	4 wheels	5.50x4 (Square Shoulder)	25	2.5	78.0	33.3	1 Unsurfaced	0	1.2	0.036	--	--	0.65	--	--	26.0
									20	1.0	0.030	--	--	0.65	--	--	26.0
	24	4 tires 5.0	5.50x4 (Square Shoulder)	25	2.5	78.0	33.3	2 Unsurfaced	0	2.0	0.060	--	--	0.45	--	--	18.0
									20	2.2*	0.066	--	--	0.52	--	--	21.0
	24A	4 tires 4.8	5.00x4 (Round Shoulder)	25	2.5	83.0	30.1	1 Unsurfaced	0	1.2	0.040	--	--	0.58	--	--	23.0
									20	1.0*	0.033	--	--	0.60	--	--	24.0
									26	0.9	0.030	--	--	0.60	--	--	24.0
								2 Unsurfaced	0	2.0	0.066	--	--	0.39	--	--	14.0
									20	2.1*	0.070	--	--	0.39	--	--	12.0
									72	2.3	0.076	--	--	0.40	--	--	16.0
	24B	4 tires 8.0	5.00x4 (Round Shoulder)	25	2.5	93.1	26.9	1 Unsurfaced	0	1.2	0.045	--	--	0.55	--	--	22.0
									10	1.5	0.056	--	--	0.65	--	--	26.0
								2 Unsurfaced	0	2.0	0.074	--	--	0.20	--	--	8.0
									10	2.0*	0.074	--	--	0.20	--	--	8.0
									20	2.0*	0.074	--	--	0.15	--	--	6.0
									54	2.0*	0.074	--	--	0.20	--	--	8.0
									72	2.0*	0.074	--	--	0.30	--	--	12.0
									90	2.0	0.074	--	--	0.30	--	--	12.0
	24C	4 tires 8.0	5.00x4 (Square Shoulder)	25	2.5	69.9	35.8	1 Unsurfaced	0	1.2	0.034	--	--	0.35	--	--	14.0
									20	1.4*	0.039	--	--	0.43	--	--	18.0
									50	1.7	0.047	--	--	0.50	--	--	20.0
								2 Unsurfaced	0	2.0	0.056	--	--	0.20	--	--	8.0
									20	1.9*	0.053	--	--	0.28	--	--	11.0
									50	1.7	0.047	--	--	0.25		--	10.0
									100	2.3	0.094	--	--	0.33	--	--	13.0
	24D	4 tires 8.0	5.00x4 (Round Shoulder)	25	2.5	93.1	26.9	1 Unsurfaced	0	1.2	0.045	--	--	0.30	--	--	12.0
									10	1.4	0.052	--	--	0.40	--	--	16.0
								2 Unsurfaced	0	2.0	0.074	--	--	0.20	--	--	8.0
									10	2.1*	0.078	--	--	0.30	--	--	12.0
									20	2.2	0.082	--	--	0.33	--	--	13.0
	24E	4 tires 5.0	5.00x4 (Square Shoulder)	25	2.5	75.0	33.3	1 Unsurfaced	0	1.2	0.036	--	--	0.32	--	--	12.0
									26	1.7	0.051	--	--	0.48	--	--	19.0
								2 Unsurfaced	0	2.0	0.060	--	--	0.15	--	--	6.0
									26	2.3*	0.069	--	--	0.20	--	--	8.0
									60	2.6	0.078	--	--	0.38	--	--	15.0
	25	Single	34.00x9.9	25	2.5	80.6	31.0	1 Unsurfaced	0	1.2	0.039	--	--	0.50	--	--	20.0
									20	1.5	0.048	--	--	0.44	--	--	17.0
								2 Unsurfaced	0	2.0	0.065	--	--	0.30	--	--	12.0
									20	2.0*	0.065	--	--	0.20	--	--	8.0
									80	2.1	0.068	--	--	0.29	--	--	12.0

(Continued)

* Indicates data are extrapolated.

(5 of 5 sheets)

TABLE IV (Continued)

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CBR at Given Coverage Level	CBR/ Contact Pressure	Drawbar Pull, kips Initial	Drawbar Pull, kips Peak	Drawbar Pull, kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
12	26	3 wheels 33-33	56x16/25	100	105	997.5	105.3	1 Modified T11 aluminum mat	0	2.2	0.021	8.10	10.00	4.40	7.7	9.5	4.2
									72	2.2*	0.021	12.50	12.80	6.50	12.9	12.2	6.2
									150	2.3	0.022	13.60	11.20	7.20	12.9	10.7	6.9
								2 M8 steel mat	0	3.3	0.031	7.30	9.00	3.10	6.9	8.6	3.0
									72	3.7	0.035	9.70	9.40	5.90	9.2	8.9	5.6
									150	4.1	0.039	12.80	12.80	7.50	12.2	12.2	7.1
								3 Unsurfaced	0	9.7	0.092	8.90	7.40	3.30	8.5	7.0	3.1
									72	12.0	0.114	9.40	7.00	4.70	8.9	6.7	4.5
	27	3 wheels 27-27	56x16/24	100	105	1012.7	103.7	1 Modified T11 aluminum mat	0	2.4	0.023	13.60	10.80	8.60	12.9	10.3	8.2
									68	2.4	0.023	--	15.80	9.60	--	15.0	9.1
								2 M8 steel mat	0	3.7	0.036	9.50	9.60	6.00	9.0	9.1	5.7
									68	3.6	0.035	14.90	10.40	7.20	14.2	9.9	6.9
								3 Unsurfaced	0	10.0	0.096	9.60	7.00	2.70	9.1	6.7	2.6
									30	11.0	0.106	14.00	9.60	6.80	13.3	9.1	6.5
13	28	Twin, 58-1/2	25.00x28/30	50	70	1298.0	53.0	1 Modified T11 aluminum mat	0	1.5	0.023	6.50	3.70	2.60	9.3	5.3	3.7
									40	1.6*	0.030	6.70	4.10	2.90	9.6	5.9	4.1
									200	1.8*	0.033	7.30	5.10	3.70	10.4	7.3	5.3
									550	2.3	0.043	7.40	5.30	3.70	10.6	7.6	5.3
									700	2.7	0.050	8.10	6.40	4.30	11.6	9.1	6.1
								2 M8 steel mat	0	2.1	0.039	6.60	4.50	2.50	9.4	6.4	3.6
									40	2.2*	0.041	6.50	4.60	2.90	9.3	6.6	4.1
									200	2.4*	0.045	6.80	5.30	3.20	9.7	7.6	4.6
									550	2.8	0.052	7.60	7.00	3.40	10.9	10.0	4.9
									700	3.4	0.063	8.50	7.00	3.30	12.1	10.0	5.6
								3 Unsurfaced	0	4.9	0.091	7.20	4.60	3.20	10.3	6.6	4.6
									40	4.8*	0.089	7.70	5.00	3.50	11.0	7.1	5.0
									200	4.6	0.085	9.50	6.00	4.20	13.6	8.6	6.0
	29	Twin, 29-1/2	25.00x28 30 ply	50	70	1372.0	51.0	1 Modified T11 aluminum mat	0	1.3	0.025	7.60	4.80	3.00	10.9	6.9	4.3
									42	1.6*	0.031	8.80	6.50	4.60	12.6	9.3	6.5
									140	2.4	0.047	8.50	6.60	4.80	12.1	9.4	6.9
								2 M8 steel mat	0	2.4	0.047	7.20	4.80	2.90	10.3	6.9	4.1
									42	2.6*	0.051	7.90	4.90	3.70	11.3	7.0	5.3
									140	3.1	0.061	7.90	6.80	4.30	11.3	9.7	6.1
									200	2.7	0.053	8.10	8.00	4.80	11.6	11.4	6.9
								3 Unsurfaced	0	4.6	0.090	7.60	3.90	2.80	10.9	5.6	4.0
									42	4.6*	0.090	8.80	5.30	4.00	12.5	7.6	5.7
									140	4.7	0.092	9.10	5.80	4.30	13.0	8.3	6.1
									200	4.2	0.082	9.50	6.50	4.60	13.6	9.3	6.6
14	30	12 wheels 30-34-30	20.00-20/22	100	252 21 per wheel	259.4 per wheel	81.0	1 Unsurfaced	2 passes	3.7	0.046	--	29.40	28.30	--	11.7	11.2
								2 Unsurfaced	2 passes	6.3	0.078	--	16.40	14.40	--	6.5	5.7
									23 passes	6.0	0.074	--	16.00	13.40	--	6.3	5.3

(Continued)

* Indicates data are extrapolated.

(6 of 8 sheets)

TABLE IV (Continued)

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total *Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CBR at Given Coverage Level	CBR/Contact Pressure	Drawbar Pull, kips Initial	Drawbar Pull, kips Peak	Drawbar Pull, kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
14 (Cont'd)	30	12 wheels 30-34-30	20.00-20/22	100	252 21 per wheel	259.4 per wheel	81.0	3 Unsurfaced	2	10.2	0.126	--	11.40	7.60	--	4.5	3.0
									23	10.2	0.126	--	15.00	9.60	--	6.3	3.8
									300	10.1	0.125	--	10.00	7.60	--	4.0	3.0
									600 passes	10.0	0.123	--	11.20	7.30	--	4.4	2.9
	31	Single	20.00-20/22	100	21	248.6	84.4	1 Unsurfaced	0	4.6	0.055	--	--	2.40	--	--	11.4
									3	3.8	0.045	--	--	2.40	--	--	11.4
								2 Unsurfaced	0	6.2	0.073	--	--	1.30	--	--	6.2
									3	6.1*	0.072	--	--	1.40	--	--	6.7
									26	5.3	0.063	--	--	2.30	--	--	11.0
								3 Unsurfaced	0	8.3	0.098	--	--	0.90	--	--	4.3
									3	8.2*	0.097	--	--	0.90	--	--	4.3
									26	7.3*	0.087	--	--	1.30	--	--	6.2
									40	6.7	0.079	--	--	1.20	--	--	5.2
15	33	12 wheels 34-44-34	20.00-20/22	55	252 21 per wheel	337.5 per wheel	62.4	1 Unsurfaced	1 pass	2.5	0.040	--	48.80	38.10	--	19.4	15.1
								2 Unsurfaced	1 pass	4.1	0.066	--	11.00	8.40	--	4.4	3.3
									20 passes	4.6	0.074	--	19.10	12.30	--	7.6	4.9
								3 Unsurfaced	1 pass	8.5	0.136	--	8.70	6.60	--	3.5	2.6
									20 passes	8.2	0.131	--	8.00	6.00	--	3.2	2.4
									47 passes	7.8	0.125	--	9.30	8.00	--	3.7	3.2
	34	12 wheels 34-44-34	20.00-20/22	55	252 21 per wheel	399.2 per wheel	52.7	1 Unsurfaced	1 pass	2.5	0.045	--	38.00	28.30	--	15.2	11.2
								2 Unsurfaced	1 pass	4.6	0.084	--	9.40	8.20	--	3.7	3.2
									37 passes	4.9	0.089	--	15.80	14.80	--	6.3	5.9
								3 Unsurfaced	1 pass	7.8	0.142	--	7.40	6.20	--	2.9	2.5
									37 passes	7.6*	0.138	--	8.60	6.00	--	3.4	2.4
									300 passes	6.2	0.113	--	11.90	9.00	--	4.7	3.6
16	35	12 wheels	20.00-20/22	100	273 22.75 per wheel	279.5 per wheel	87.6	1 Modified T11 aluminum mat	0	2.2	0.025	29.00	26.70	14.50	10.6	6.1	5.3
									130	2.2*	0.025	29.90	23.40	20.30	10.9	8.6	7.4
									210	2.2	0.025	30.40	24.70	21.50	11.1	8.7	7.7
								2 M8 steel mat	0	4.4	0.050	15.00	11.10	7.00	5.5	4.1	2.6
									130	4.7*	0.054	19.00	14.70	8.20	7.0	5.4	3.0
									210	4.8*	0.055	19.00	14.20	9.50	7.0	5.2	3.5
									455	5.3*	0.060	16.90	14.30	10.70	6.2	5.2	3.9
									1200	7.1	0.081	18.80	14.50	9.90	6.9	5.4	3.6
								3 Unsurfaced	0	9.7	0.111	14.20	10.00	6.60	5.2	3.7	2.4
									1[illegible]0	9.1	0.104	16.40	13.50	9.50	6.0	4.9	3.5
									210	8.8	0.100	16.50	13.50	9.50	6.0	4.9	3.5
									455	7.7	0.088	17.50	17.70	11.00	6.4	6.5	4.0
17	36	Single	56x16 38	100	35	[illegible]	114.[illegible]	1 Unsurfaced	0	6.7	0.060	--	3.70	2.40	--	10.6	6.9
									[illegible]	6.7	0.060	--	5.00	2.80	--	14.3	8.0
								2 Unsurfaced	0	[illegible].7	0.084	--	2.30	1.50	--	6.6	4.[illegible]
									[illegible]	[illegible].5*	0.085	--	2.40	2.00	--	[illegible]	5.7
									1[illegible]	[illegible].7	0.078	--	[illegible].00	2.10	--	[illegible]	[illegible]
								(Continued)									

* Indicates data are extrapolated.

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TABLE IV (Continued)

Test Section	Lane	Wheel Assembly and Spacing in. (c-c)	Tire Size/Ply	Inflation Pressure psi	Assembly Load kips	Total Contact Area sq in.	Average Contact Pressure psi	Item Number and Type Surface	Coverage Level	CIN at Given Coverage Level	CIN/Contact Pressure	Drawbar Pull, kips Initial	Drawbar Pull, kips Peak	Drawbar Pull, kips Rolling	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Peak	Drawbar Pull as Percent of Gross Load Rolling
17 (Cont'd)	37	Single	56x16/24	100	35	319.4	109.7	1	0	6.7	0.061	--	2.00	1.50	--	5.7	4.3
								Unsurfaced	10	6.7	0.061	--	4.30	3.50	--	12.3	10.0
								2	0	9.7	0.088	--	1.50	1.20	--	4.3	3.4
								Unsurfaced	10	9.9*	0.090	--	1.70	1.50	--	4.9	4.3
									50	11.0	0.100	--	2.60	2.00	--	7.4	5.7
AMHB Tests	1	Single	9.00x14/8	10	1.0	65.2	15.4	Unsurfaced	1	1.4	0.090	--	0.08	0.05	--	8.0	4.5
									2	1.4	0.090	--	0.10	0.05	--	10.0	5.1
									6	1.4	0.090	--	0.11	0.06	--	10.5	6.0
									24	1.4	0.090	--	0.11	0.07	--	11.0	7.0
									48	1.4	0.090	--	0.13	0.08	--	12.5	7.9
									100	1.4	0.090	--	0.14	0.08	--	13.5	8.3
									200	1.4	0.090	--	0.25	0.08	--	24.5	8.2
	2	Single	9.00x14/8	20	1.0	40.1	24.9	Unsurfaced	1	1.0	0.040	--	0.14	0.11	--	13.5	11.0
									2	1.0	0.040	--	0.16	0.12	--	16.0	11.5
									6	1.0	0.040	--	0.19	0.14	--	18.5	14.0
									24	1.0	0.040	--	0.26	0.18	--	26.0	18.0
	3	Single	9.00x14/8	30	1.0	28.6	35.0	Unsurfaced	1	1.1	0.031	--	0.17	0.13	--	17.0	13.0
									2	1.1	0.031	--	0.17	0.13	--	17.0	12.8
									6	1.1	0.031	--	0.23	0.17	--	22.5	16.8
									24	1.1	0.031	--	0.26	0.19	--	25.5	19.2
	4	Single	9.00x14/8	40	1.0	22.3	44.8	Unsurfaced	1	1.2	0.027	--	0.19	0.15	--	19.0	14.5
									2	1.2	0.027	--	0.19	0.14	--	19.0	14.2
									6	1.2	0.027	--	0.21	0.17	--	21.0	16.8
									24	1.2	0.027	--	0.29	0.19	--	28.5	19.0
									48			--	0.28	0.20	--	27.5	19.5
	5	Single	9.00x14/8	40	2.0	43.5	46.0	Unsurfaced	1	2.3	0.050	--	0.24	0.18	--	11.7	9.0
									2	2.3	0.050	--	0.24	0.18	--	12.0	9.1
									6	2.3	0.050	--	0.30	0.23	--	14.7	11.5
									24	2.3	0.050	--	0.34	0.24	--	16.7	12.0
									38	2.3	0.050	--	0.37	0.24	--	18.2	10.0
	6	Single	9.00x14/8	60	2.0	31.7	63.1	Unsurfaced	1	2.6	0.041	--	0.24	0.18	--	11.7	9.0
									2	2.6	0.041	--	0.27	0.19	--	13.2	9.5
									6	2.6	0.041	--	0.31	0.25	--	15.2	12.4
									24	2.6	0.041	--	0.39	0.29	--	19.2	14.5
									48	2.6	0.041	--	0.40	0.32	--	20.0	15.7
									50	2.6	0.041	--	0.30	0.30	--	14.7	15.0
	7	Single	9.00x14/8	80	2.0	24.7	81.1	Unsurfaced	1	2.5	0.031	--	0.30	0.23	--	15.0	11.5
									6	2.5	0.031	--	0.38	0.27	--	19.0	13.5
									24	2.5	0.031	--	0.46	0.31	--	22.7	15.3
									44	2.5	0.031	--	0.43	0.32	--	21.5	15.1
	8	Single	9.00x14/8	10	1.0	65.2	15.4	Unsurfaced	1	1.1	0.071	--	0.09	0.05	--	8.3	4.5
									2	1.1	0.071	--	0.09	0.05	--	8.5	4.8
									6	1.1	0.071	--	0.08	0.06	--	8.0	5.5
									24	1.1	0.071	--	0.11	0.09	--	11.0	8.5
									48	1.1	0.071	--	0.16	0.09	--	16.0	8.8
									100	1.1	0.071	--	0.18	0.10	--	17.5	10.0

* Indicates data are extrapolated.

(8 of 8 sheets)

TABLE V

DRAWBAR PULL DATA FROM RELATED SOURCES

Wheel Assembly	Tire Spacing in.	Tire Size	Tire Inflation Pressure psi	Gross Load kips	Type of Surface	Number of Passes	CBR	CBR/Inflation Pressure	Drawbar Pull, lb Initial	Drawbar Pull, lb Rolling	Drawbar Pull, lb Peak	Drawbar Pull as Percent of Gross Load Initial	Drawbar Pull as Percent of Gross Load Rolling	Drawbar Pull as Percent of Gross Load Peak	Source
8 wheels*	24-30-24x120	40x14	55	120	Unsurfaced	341	15.0	0.27	--	4,000	10,200	--	3.3	8.5	Douglas Aircraft Group C-5 Division, "Study of the Effects of Aircraft Landing Gear Parameters on Support Area Airfield Flotation Capability," Report 50088, 1 May 1965
8 wheels	24-30-24x120	40x14	80	120	Unsurfaced	370	15.0	0.22	--	3,500	6,500	--	2.9	5.4	
8 wheels	24-30-24x120	40x14	110	120	Unsurfaced	400	15.0	0.14	--	--	--	--	--	--	
8 wheels	24-30-24x120	40x14	160	120	Unsurfaced	86	15.0	0.093	--	3,500	7,900	--	2.9	6.6	
8 wheels	18-30-24x120	40x14	110	120	Unsurfaced	264	15.0	0.14	--	4,000	7,500	--	3.3	6.25	
8 wheels	24-30-24x120	40x14	80	200	Unsurfaced	26	8.0	0.10	--	12,000	17,500	--	6.0	8.75	
8 wheels	30-30-30x120	40x14	80	200	Unsurfaced	49	8.0	0.10	--	10,500	16,500	--	5.3	8.25	
8 wheels	24-30-24x120	40x14	55	160	Unsurfaced	119	8.0	0.145	--	7,000	12,000	--	[illegible]	7.5	
8 wheels	30-30-30x120	40x14	55	160	Unsurfaced	58	8.0	0.145	--	6,000	12,800	--	3.8	8.0	
8 wheels	18-30-18x120	40x14	55	160	Unsurfaced	102	8.0	0.145	--	10,200	16,000	--	6.4	10.0	
8 wheels	24-30-24x120	40x14	110	120	M8 mat	50	4.0	0.036	--	17,000	23,600	--	14.2	19.7	
8 wheels	30-30-30x120	40x14	110	120	M8 mat	120	4.0	0.036	--	14,500	21,500	--	[illegible]	17.9	
8 wheels	30-30-30x120	40x14	110	200	M8 mat	49	4.0	0.036	--	28,000	34,700	--	14.0	17.4	
8 wheels	30-30-30x120	40x14	80	200	M8 mat	52	4.0	0.050	--	27,200	31,300	--	13.6	15.7	
8 wheels	18-30-18x120	40x14	60	160	M8 mat	62	4.0	0.067	--	23,000	28,000	--	14.4	17.5	
8 wheels	30-30-30x120	40x14	60	160	M8 mat	120	4.0	0.067	--	20,500	30,000	--	12.8	18.8	
Twin-twin (mounted on DC-7)	26-32-26	40x14	110	90,000	Unsurfaced	1	4.0	0.036	15,000	14,000	17,200	16.7	15.6	19.1	Flight tests conducted by Douglas Aircraft Co. at Harpers Dry Lake, Calif.
	26-32-26	40x14	80	90,000	Unsurfaced	1	4.0	0.05	15,600	11,000	16,000	17.3	12.2	17.8	
	26-32-26	40x14	55	90,000	Unsurfaced	1	4.0	0.073	18,000	9,400	11,600	20.0	10.4	12.9	
Dual-twin tandem, (mounted on Boeing 707)	21-34-21x56	46x16	25	160,000	Unsurfaced	1	8.0	0.32	12,000	5,500	11,000	7.5	3.5	6.9	Flight test conducted by the Boeing Co. at Harpers Dry Lake, Calif.
	21-34-21x56	46x16	[illegible]	160,000	Unsurfaced	1	3.0	0.12	11,500	11,000	22,000	7.2	6.9	13.7	

* Assembly consisted of 8 wheels (2 rows of 4 wheels). Tandem spacing 120 in.

TABLE VI

SUMMARY OF SPEED TEST RESULTS

Test	Cone Index (CI)	Tire Diameter (d) in.	Tire Width (b) in.	Tire Size	Velocity fps (V)	Wheel Load (W) lb	Drawbar Pull lb	Drawbar Pull/ Wheel Load	$\frac{CIdbV}{W}$*
1	44	26.83	7.86	9.00-14	6.01	985	109.30	0.111	57
2	49	8.38	2.46	2.50-4	0.49	108	11.00	0.102	5
3	63	8.38	2.46	2.50-4	0.51	107	10.70	0.100	6
4	51	8.38	2.46	2.50-4	7.72	109	12.43	0.114	74
5	58	8.38	2.46	2.50-4	8.06	111	11.99	0.108	87
6	62	8.38	2.46	2.50-4	23.04	110	11.44	0.104	268
7	52	8.38	2.46	2.50-4	1.88	109	13.84	0.127	18
8	60	8.38	2.46	2.50-4	1.80	108	12.96	0.120	21
9	51	8.38	2.46	2.50-4	5.84	105	12.18	0.116	58
10	63	8.38	2.46	2.50-4	5.96	103	11.33	0.110	75
11	48	26.83	7.86	9.00-14	0.51	1012	119.42	0.118	5
12	49	26.83	7.86	9.00-14	19.61	1003	101.30	0.101	202
13	49	26.83	7.86	9.00-14	25.25	980	123.48	0.126	266
14	45	14.12	4.20	4.00-7	11.88	273	26.48	0.097	116
15	44	14.12	4.20	4.00-7	23.29	291	25.02	0.086	209
16	48	14.12	4.20	4.00-7	0.52	276	32.84	0.119	5
17	45	8.38	2.46	2.50-4	22.39	108	15.44	0.143	192
18	45	14.12	4.20	4.00-7	22.30	262	23.84	0.091	227
19	44	14.12	4.20	4.00-7	16.70	265	27.29	0.103	186
20	48	14.12	4.20	4.00-7	22.07	278	28.63	0.103	226
21	49	28.38	8.30	9.00-14	24.38	978	81.17	0.083	288
22	50	28.38	8.30	9.00-14	24.53	968	82.28	0.085	298
23	47	28.38	8.30	9.00-14	15.50	972	76.79	0.079	176

* See column headings for definitions of symbols.

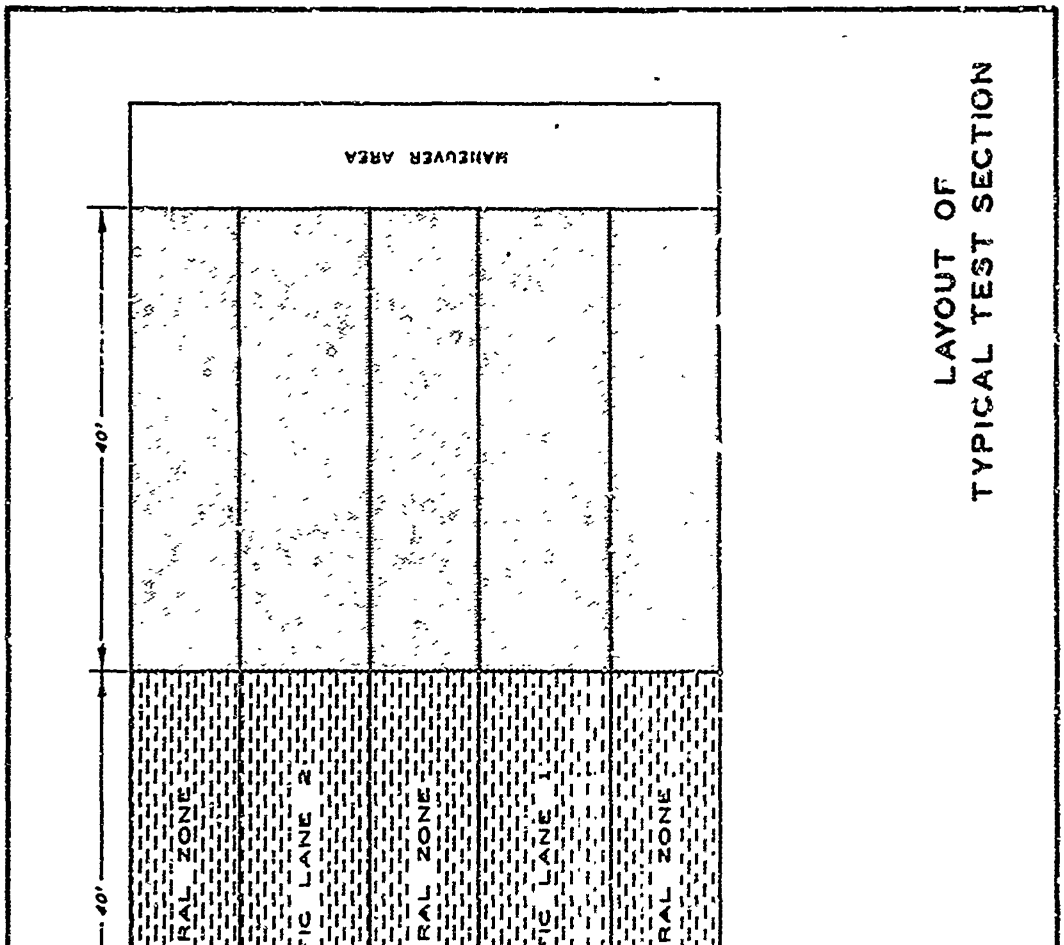
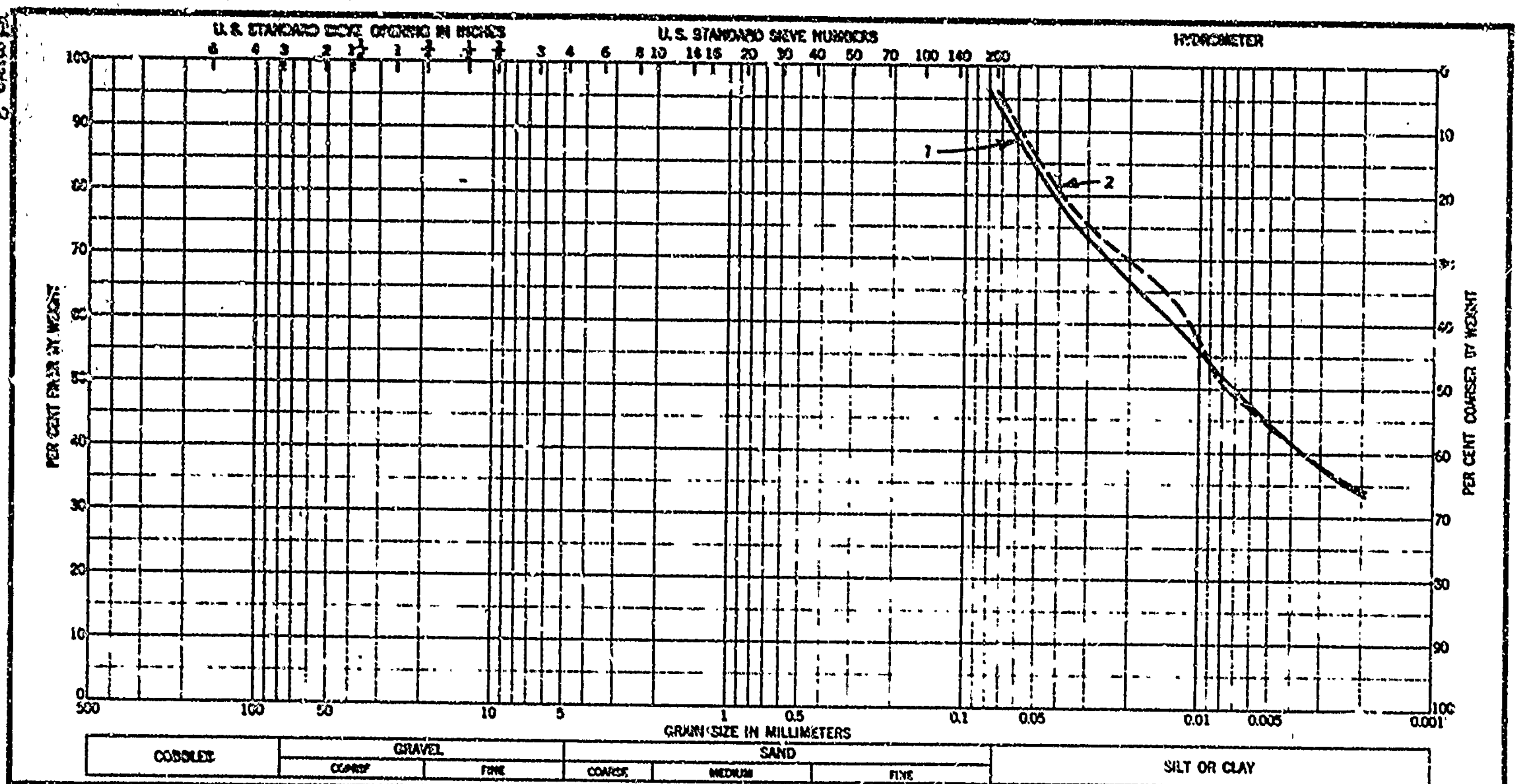

LAYOUT OF
TYPICAL TEST SECTION
MANEUVER AREA
40'
40'
30'
NEUTRAL ZONE
TRAFFIC LANE 2
NEUTRAL ZONE
TRAFFIC LANE 1
NEUTRAL ZONE
10'
12'
10'
12'
10'
MANEUVER AREA
ITEM 1 UNSURFACED
ITEM 2 SURFACED WITH M8 LANDING MAT
ITEM 3 SURFACED WITH T11 LANDING MAT

Figure 1



1. TEST SECTIONS 1-4, CLAY (CH), LL = 58, PL = 27, PI = 31
2. ALL OTHER TEST SECTIONS, CLAY (CH), LL = 61, PL = 24, PI = 37

SOIL GRADATION AND CLASSIFICATION DATA

Figure 2

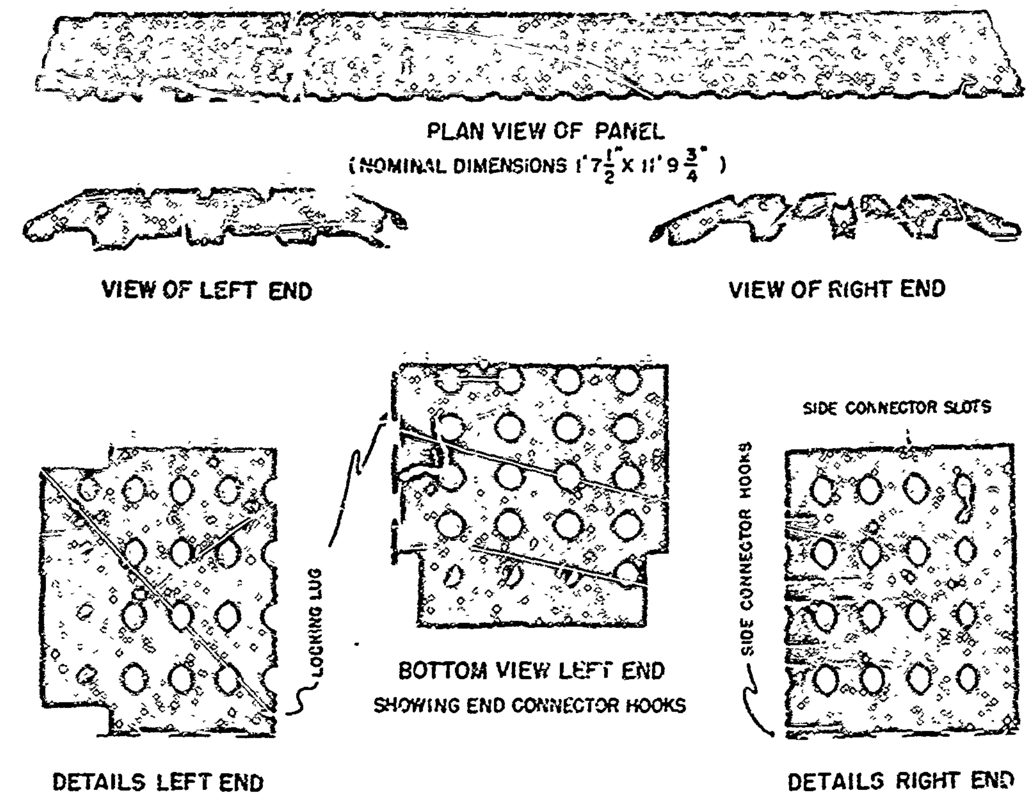


Figure 3. M8 landing mat

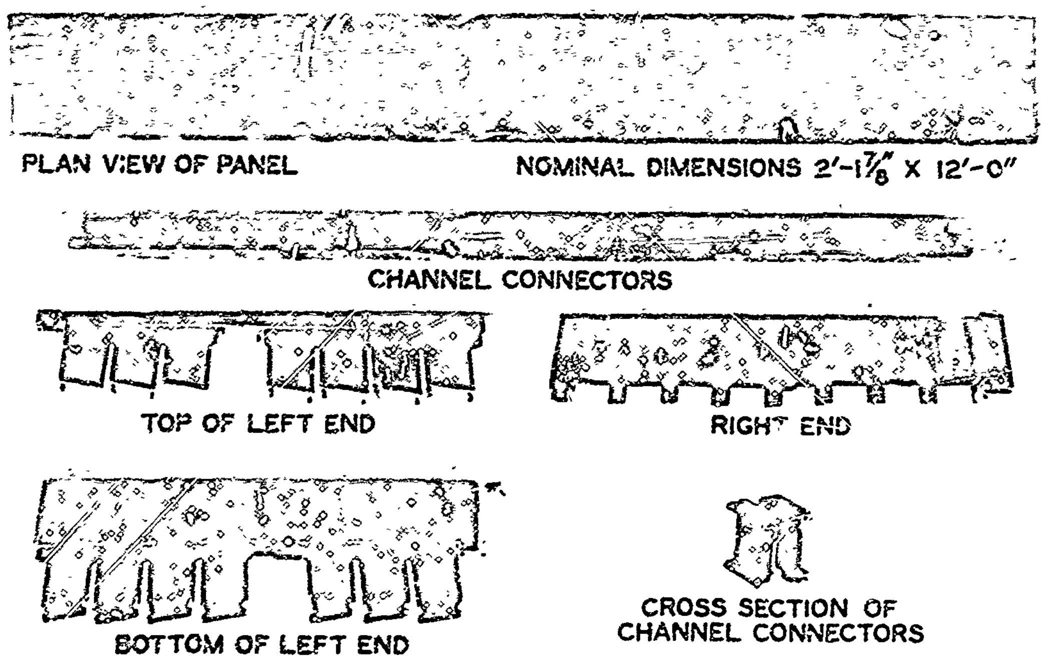


Figure 4. Modified T11 landing mat

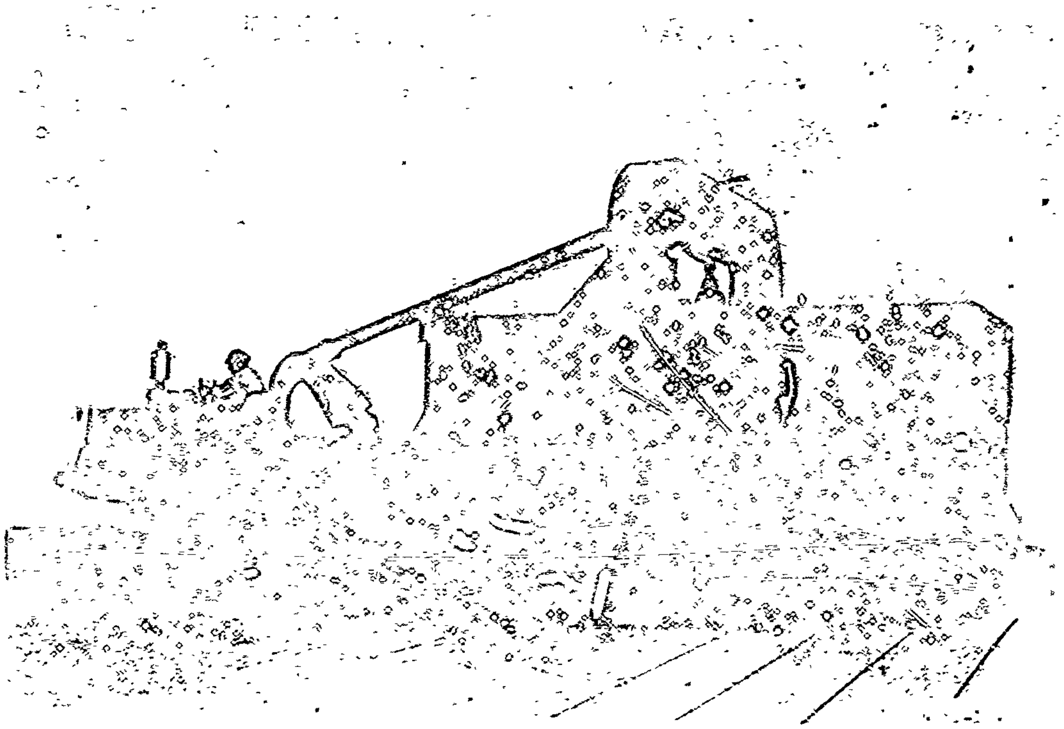


Figure 5. Load vehicle used for majority of tests

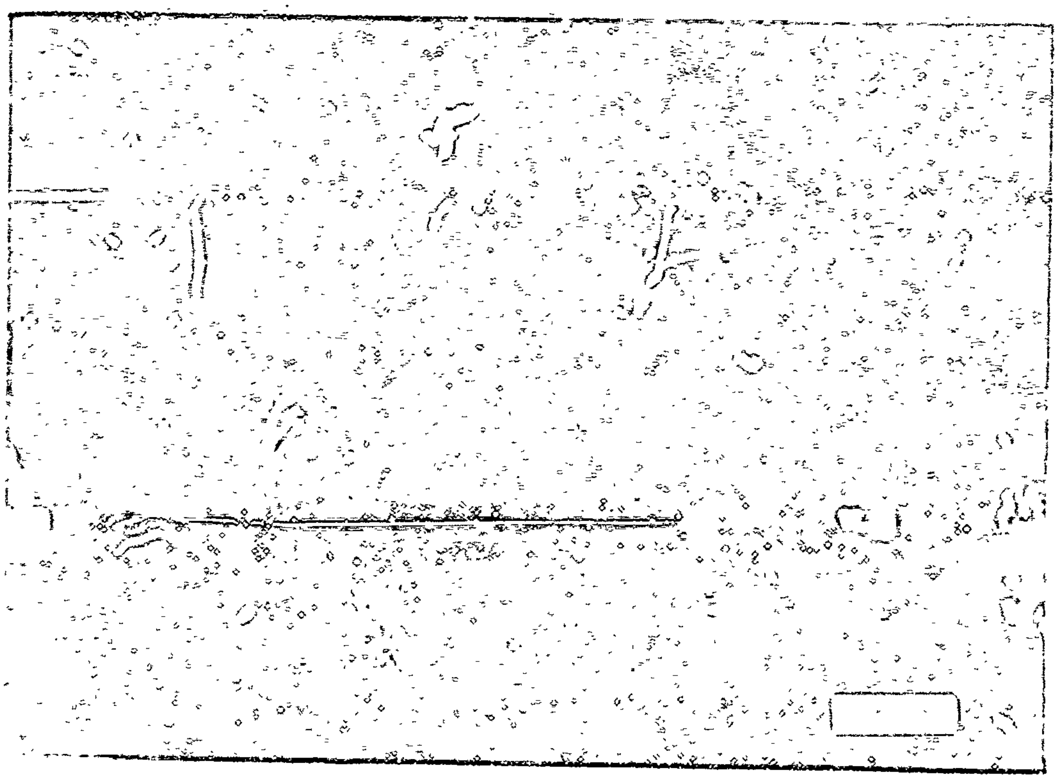


Figure 6. Load cart used for twin-twin assembly tests

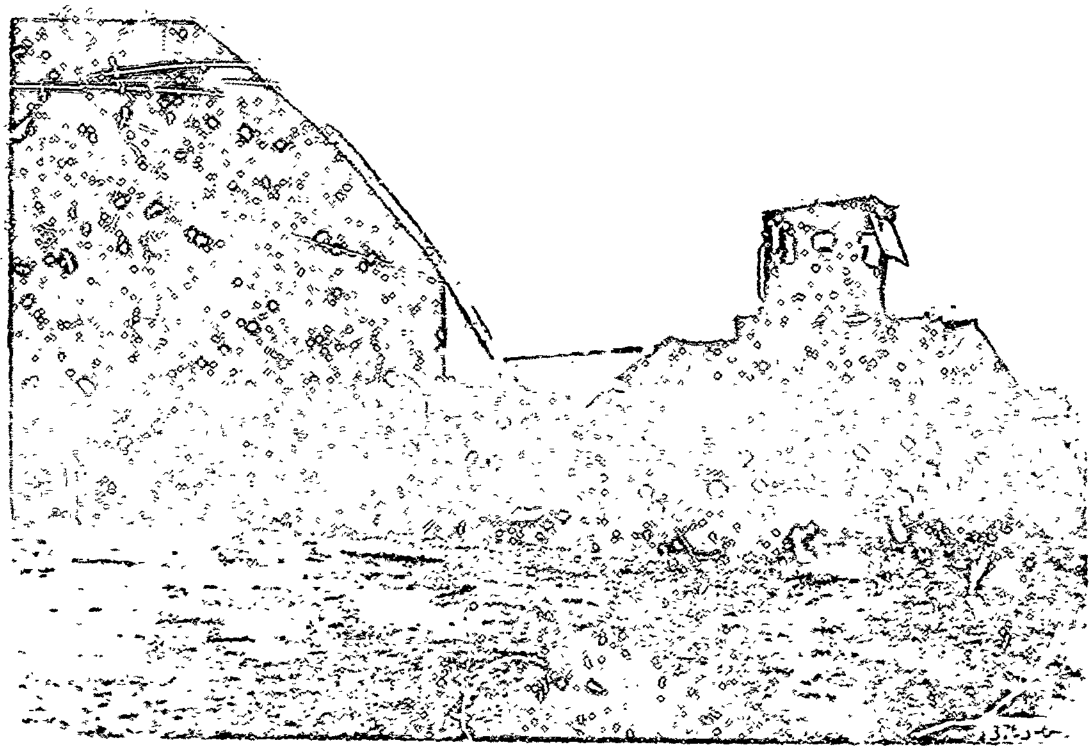


Figure 7. Load vehicle used for 12-wheel tests

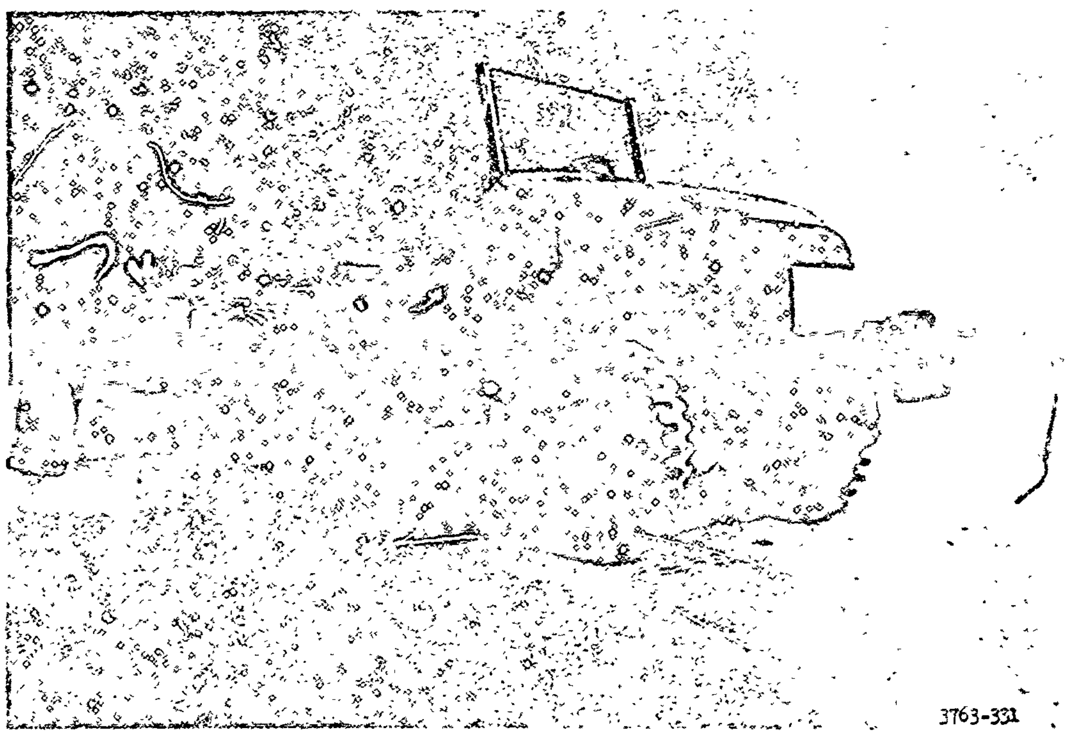


Figure 8. Load vehicle used for single-wheel tests

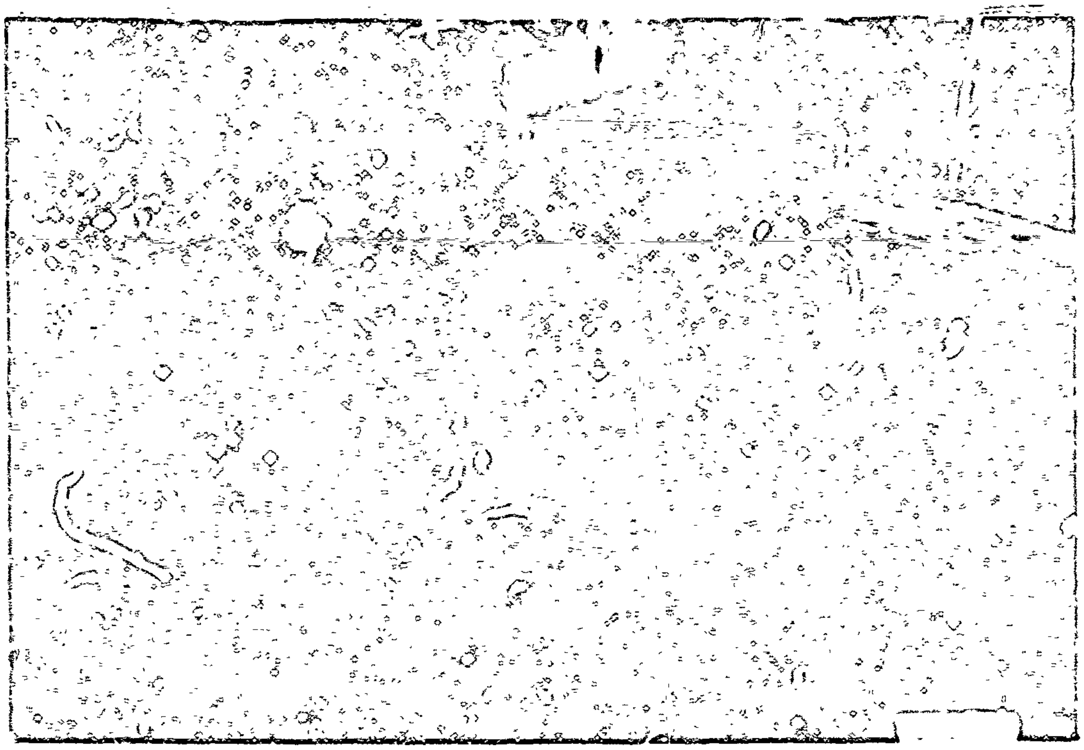


Figure 9 Load vehicle used for model wide-tire tests

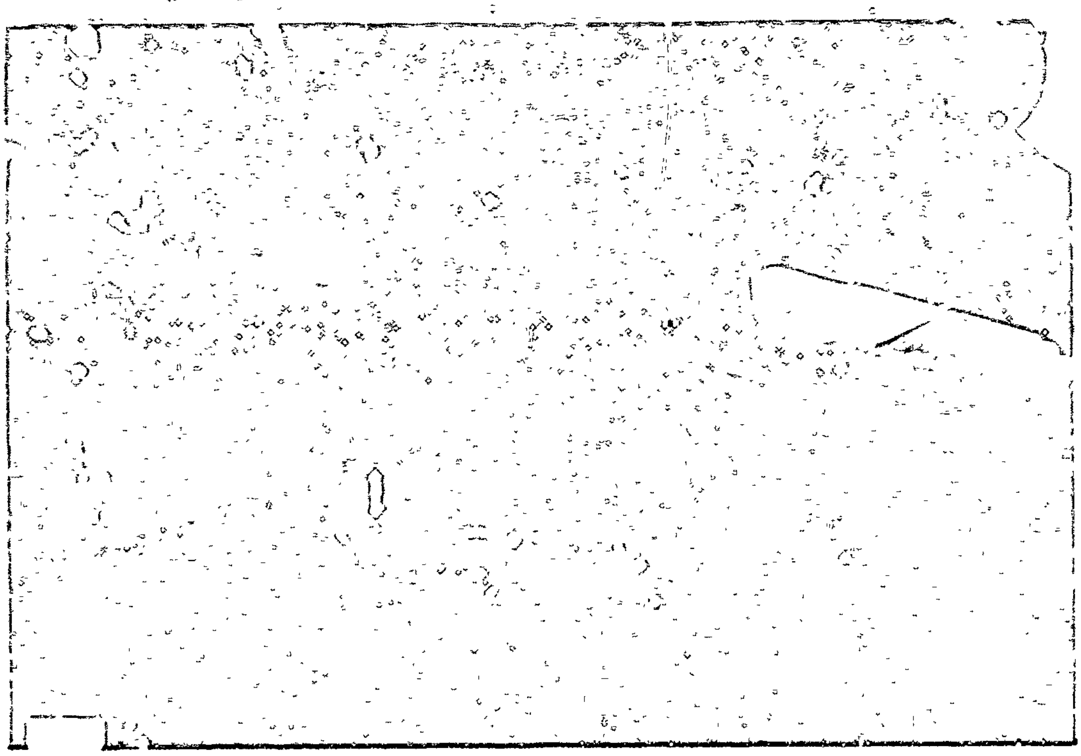


Figure 10. Load cell used in drawbar pull tests

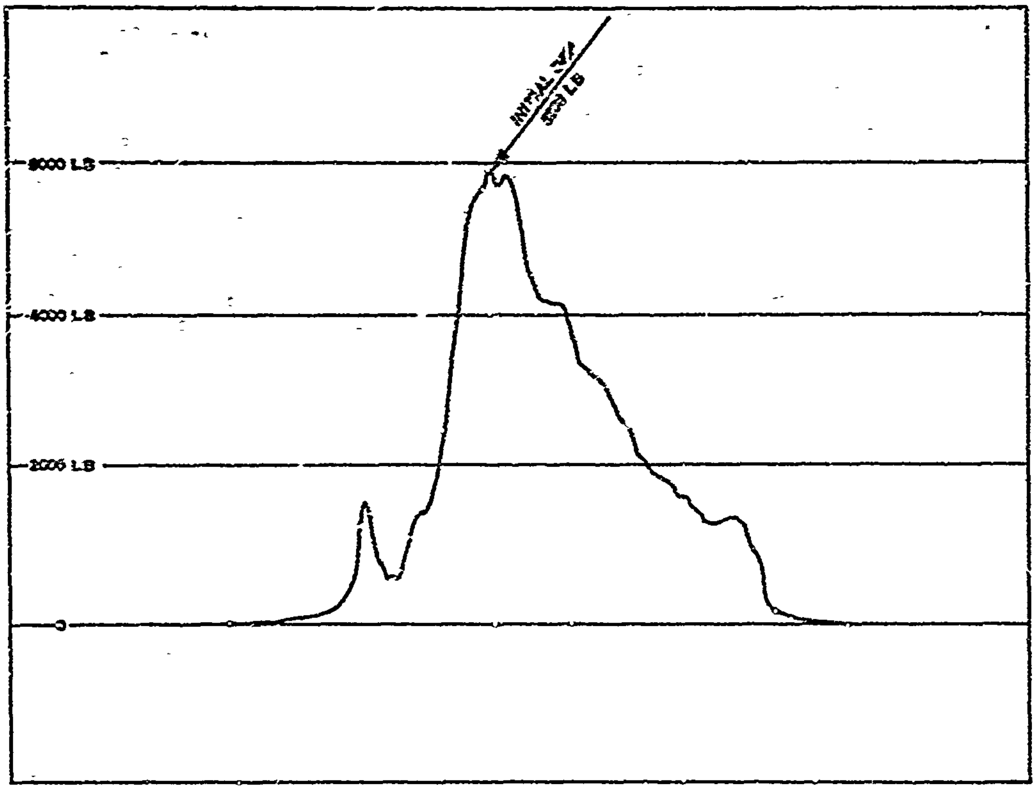


Figure 11. Typical oscillograph recording of initial drawbar pull

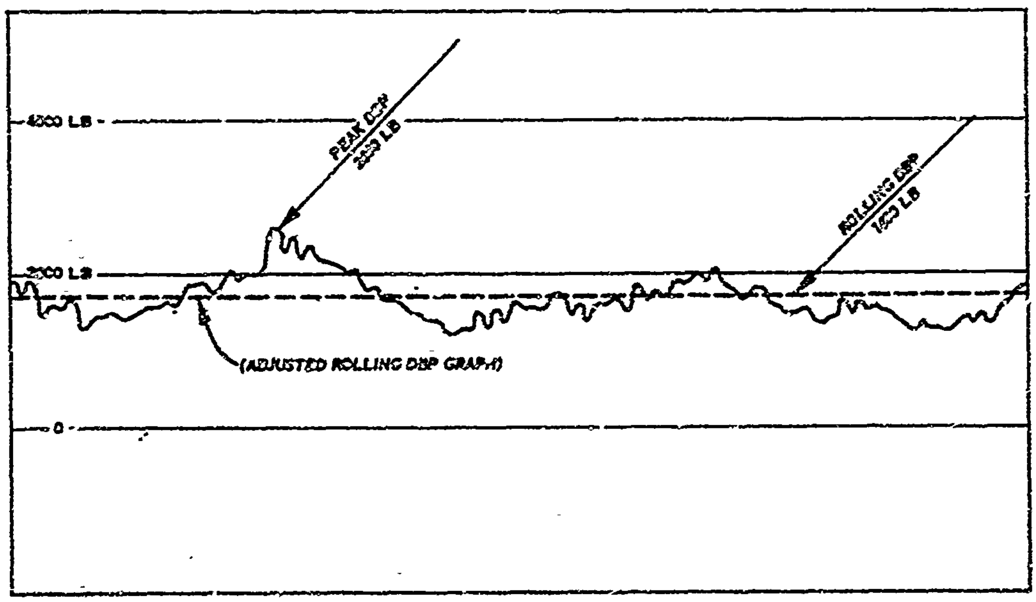
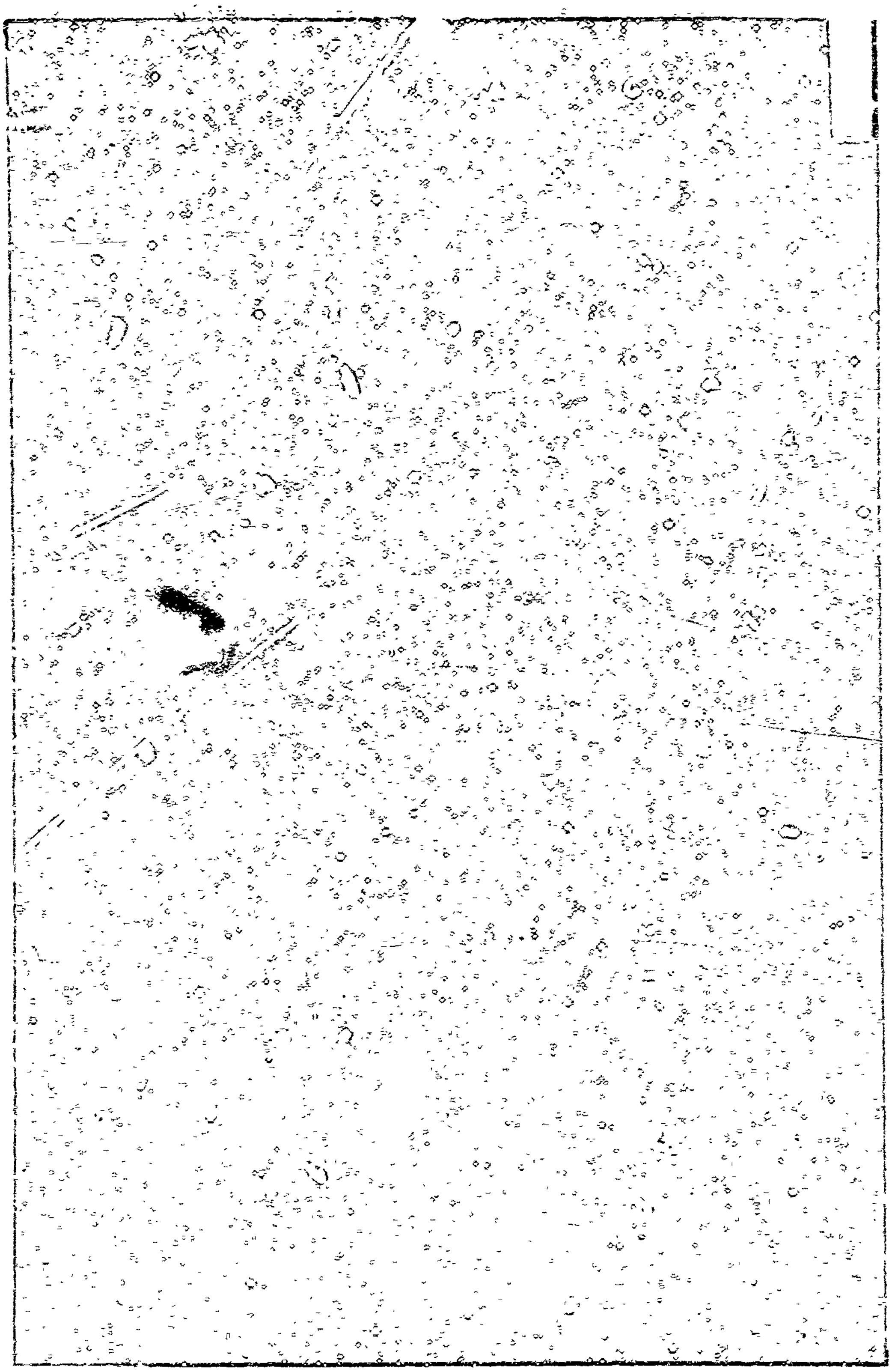
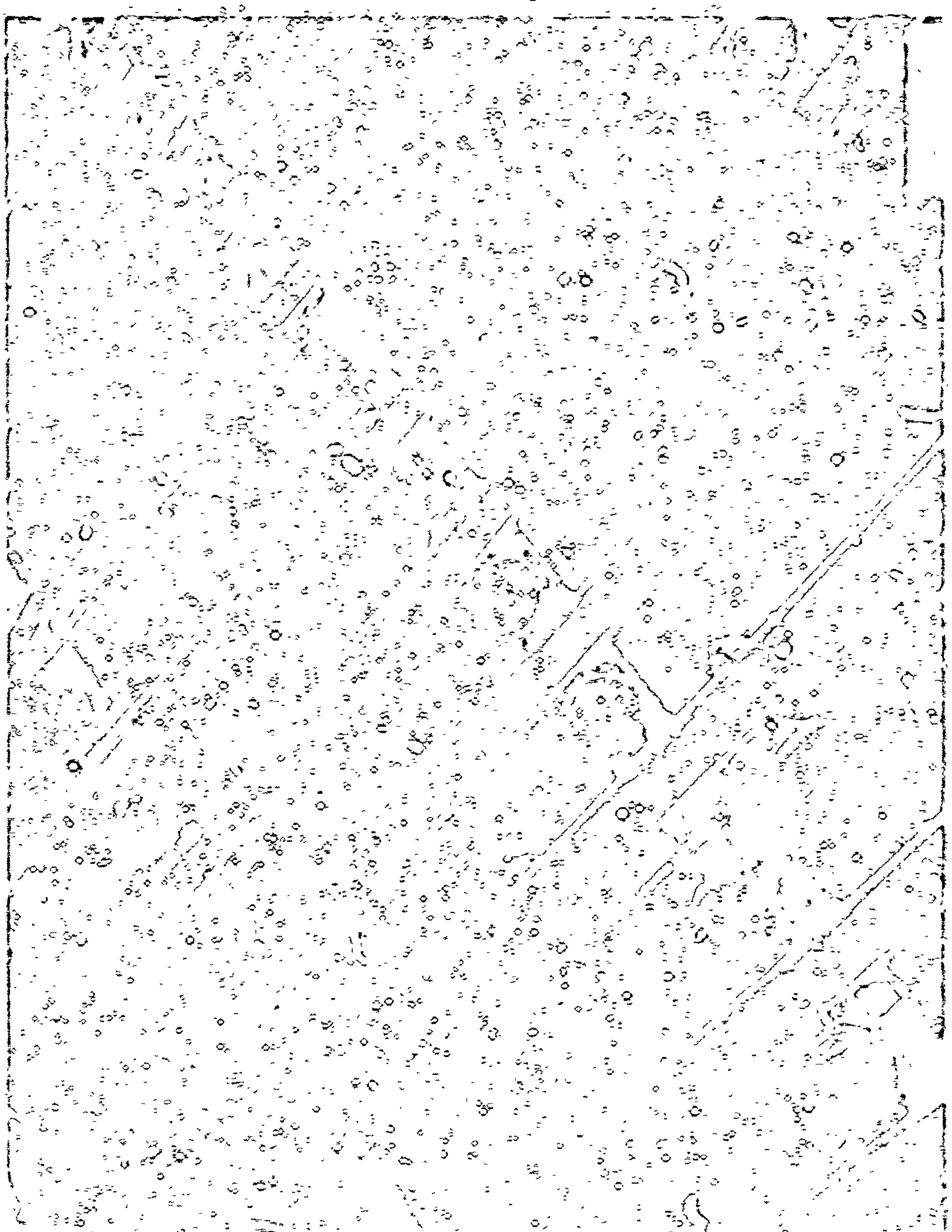
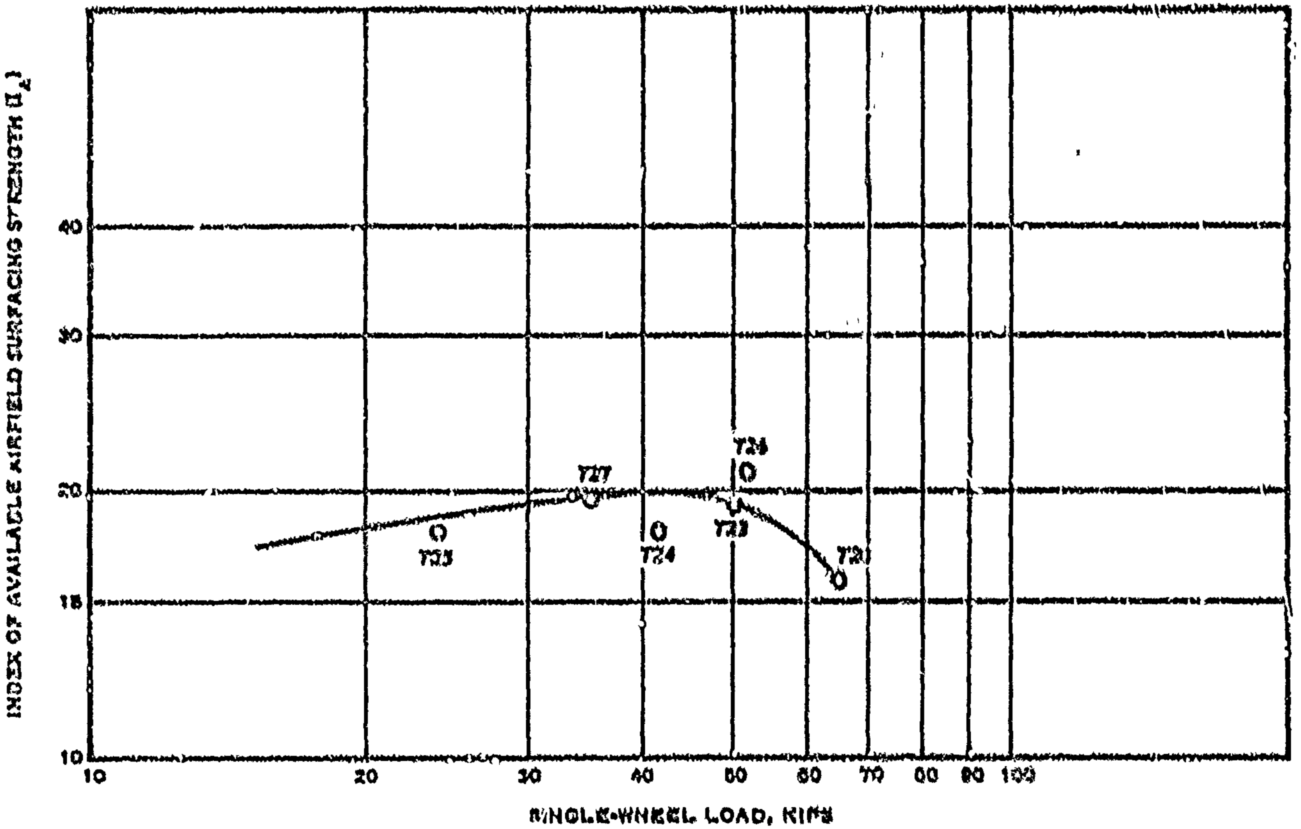


Figure 12. Typical oscillograph recording of peak and rolling drawbar pull



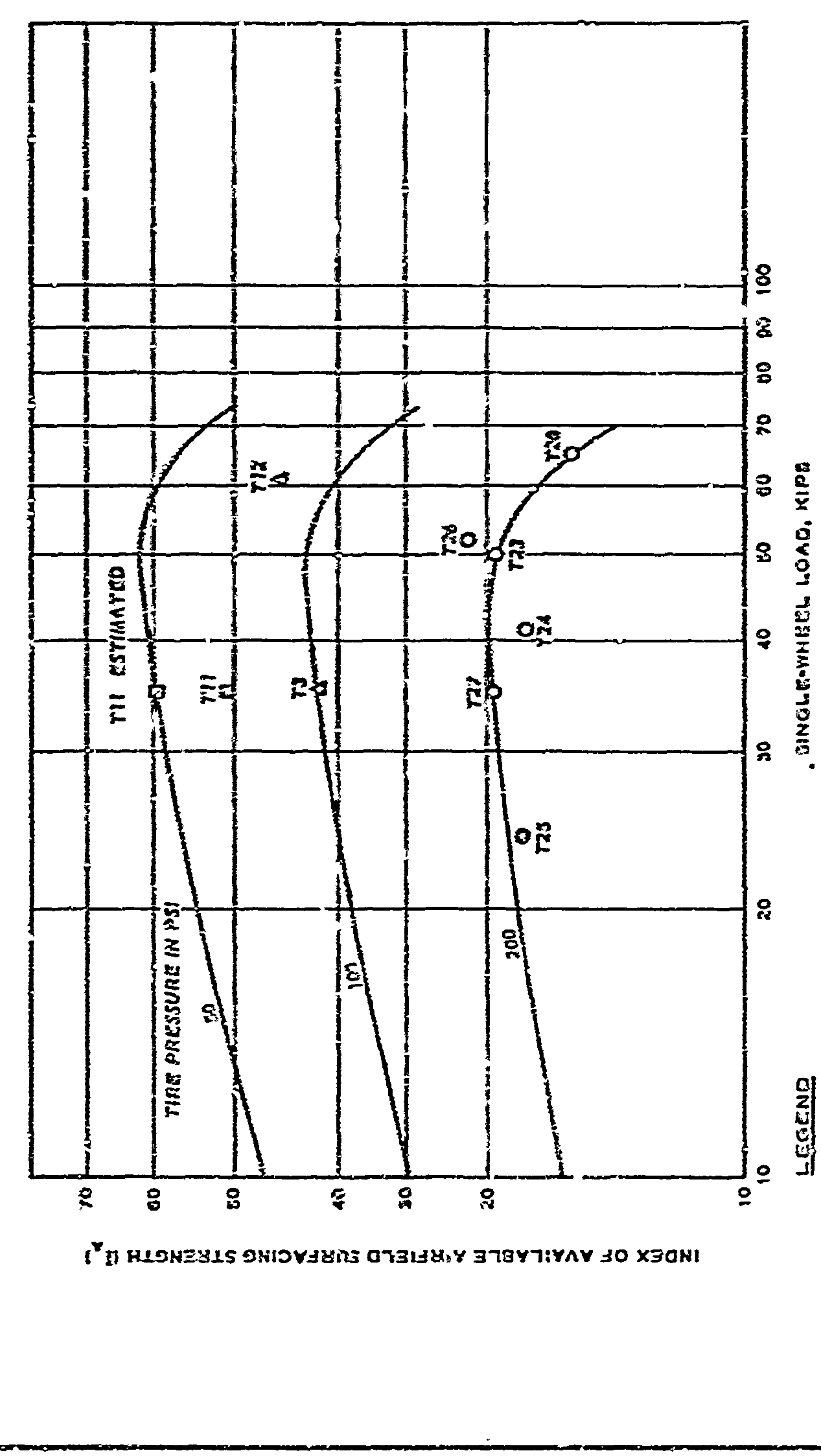




NOTE: OPEN SYMBOLS REPRESENT FAILURES.
CLOSED SYMBOLS REPRESENT NONFAILURES.
NUMBER NEAR POINT IS TEST NUMBER.

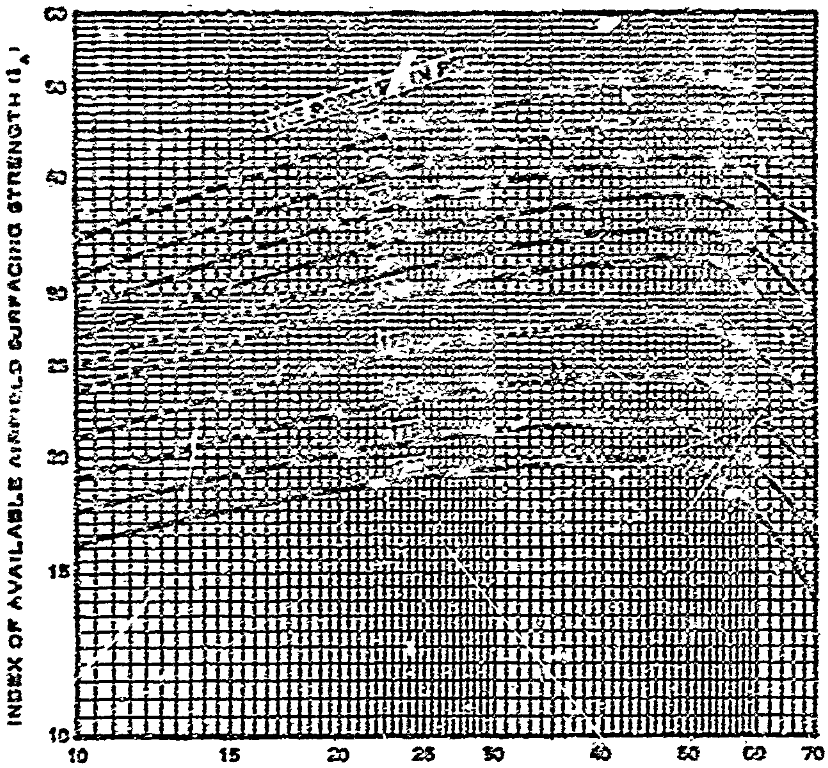
SINGLE-WHEEL TRAFFIC TEST DATA
T11 LANDING MAT
200-PSI TIRE PRESSURE

Figure 16



SINGLE-WHEEL TRAFFIC TEST DATA
T11 LANDING MAT
50-, 100-, AND 200-PSI TIRE PRESSURES

Figure 17



NOTE: DEVELOPED FROM
T11 LANDING MAT DATA.

INDEX OF AVAILABLE AIRFIELD
SURFACING STRENGTH (I_A)

REAR-AREA AIRFIELD

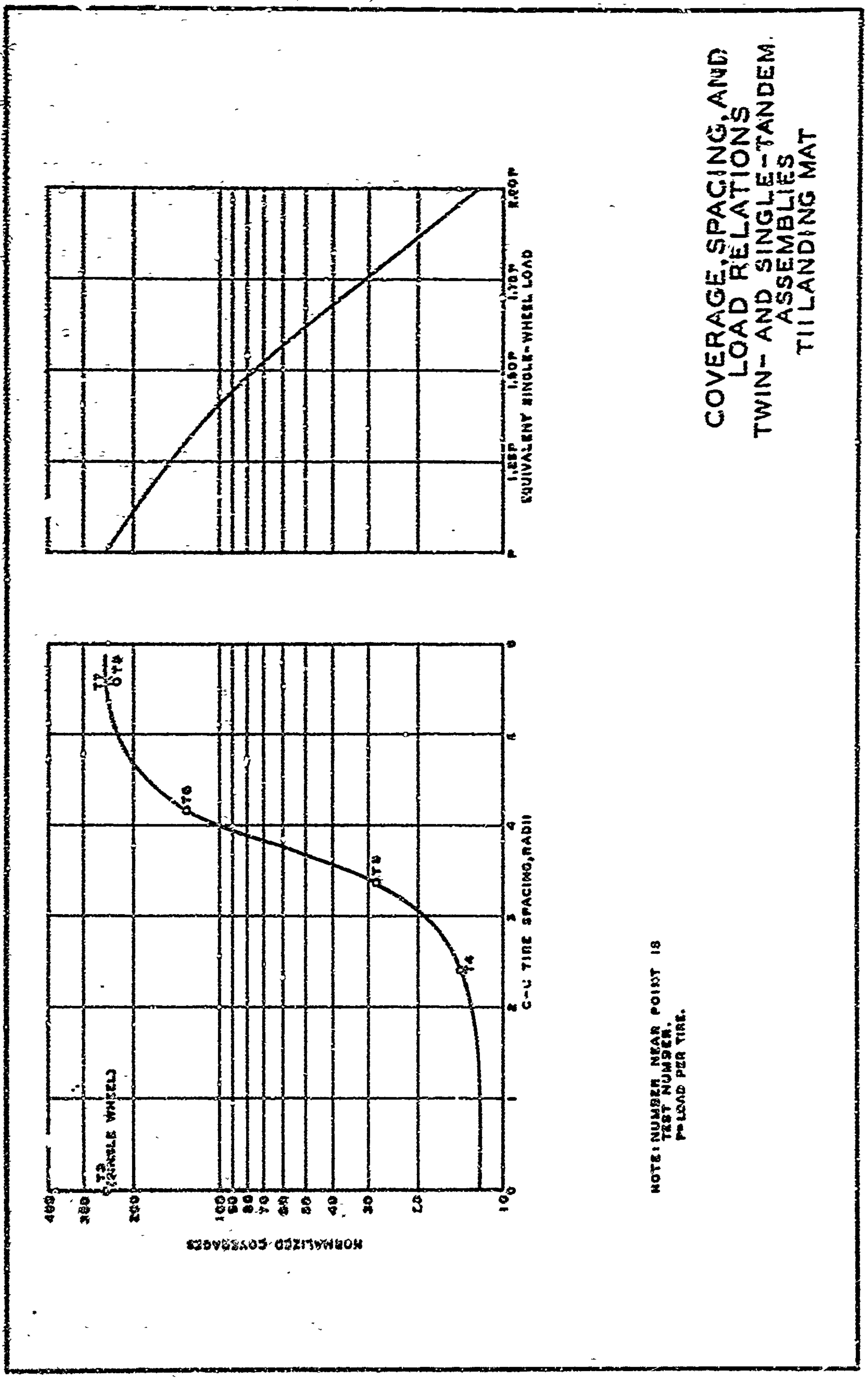
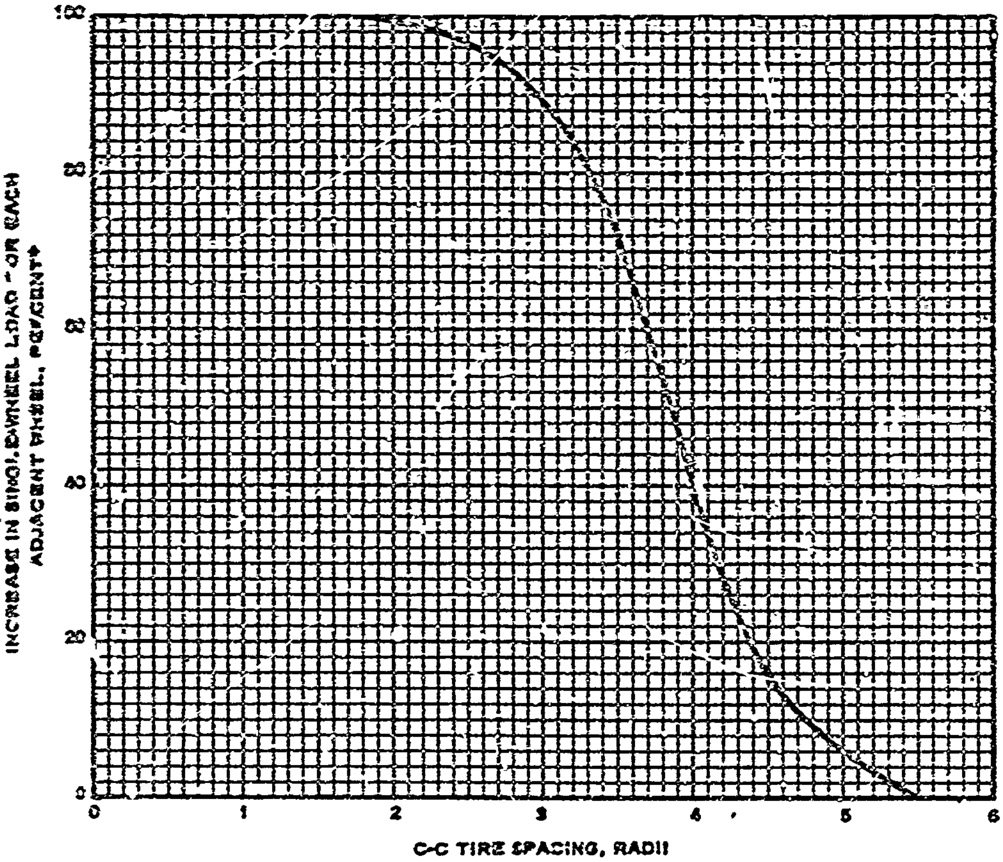

COVERAGE, SPACING, AND
LOAD RELATIONS
TWIN- AND SINGLE-TANDEM
ASSEMBLIES
T11 LANDING MAT
NORMALIZED COVERAGES
C-C TIRE SPACING, RADII
EQUIVALENT SINGLE-WHEEL LOAD
T3 (SINGLE WHEEL)
NOTE: NUMBER NEAR POINT IS
TEST NUMBER.
P=LOAD PER TIRE.

Figure 19

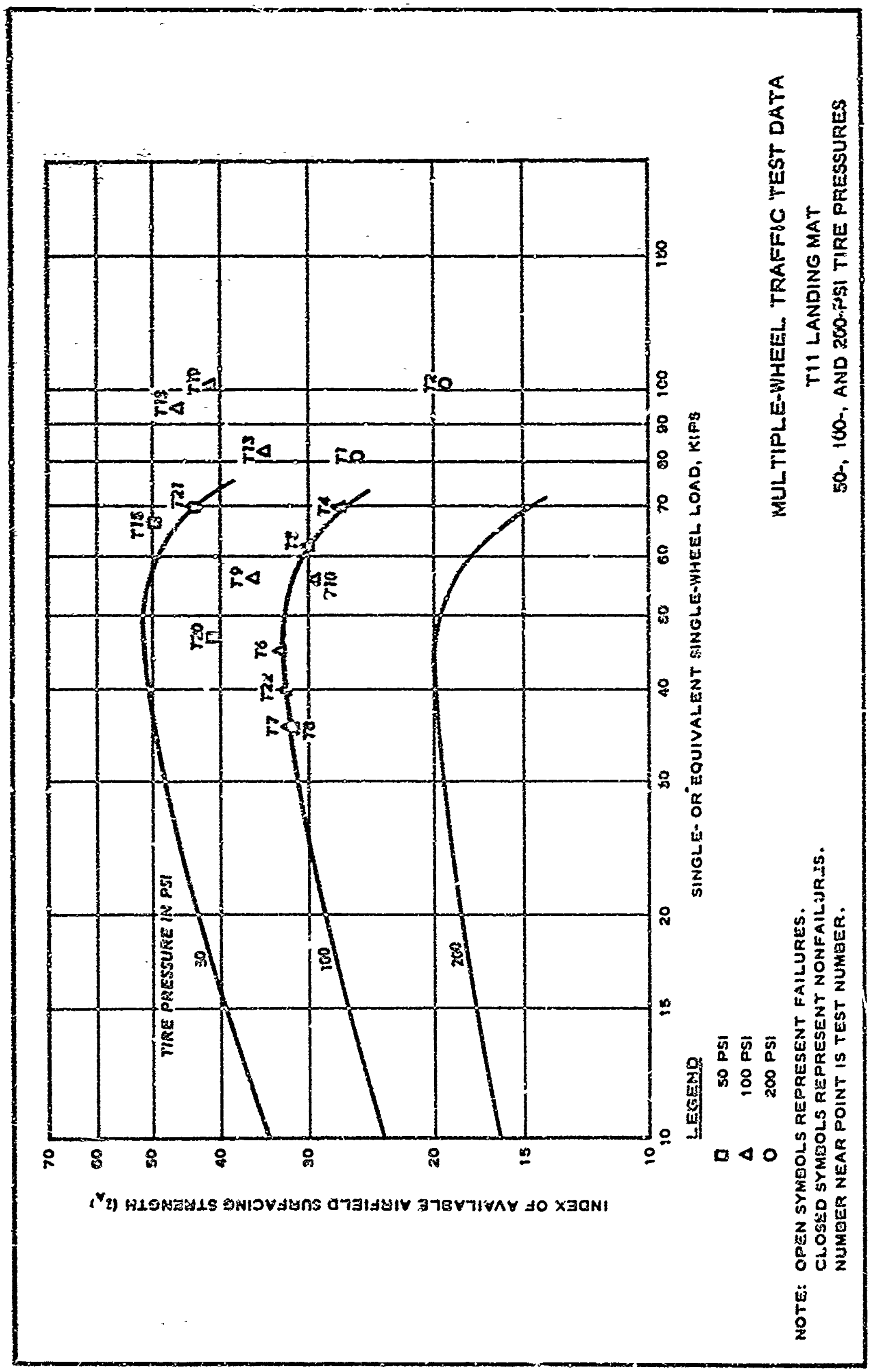


* INCREASE IN LOAD ON A SINGLE WHEEL OF A MULTIPLE-WHEEL GEAR TO ACCOUNT FOR EFFECTS OF ADJACENT WHEELS OF THE MULTIPLE-WHEEL GEAR IN ARRIVING AT AN EQUIVALENT SINGLE WHEEL LOAD.

EQUIVALENT SINGLE-WHEEL LOAD-ADJUSTMENT CURVE FOR LANDING MAT

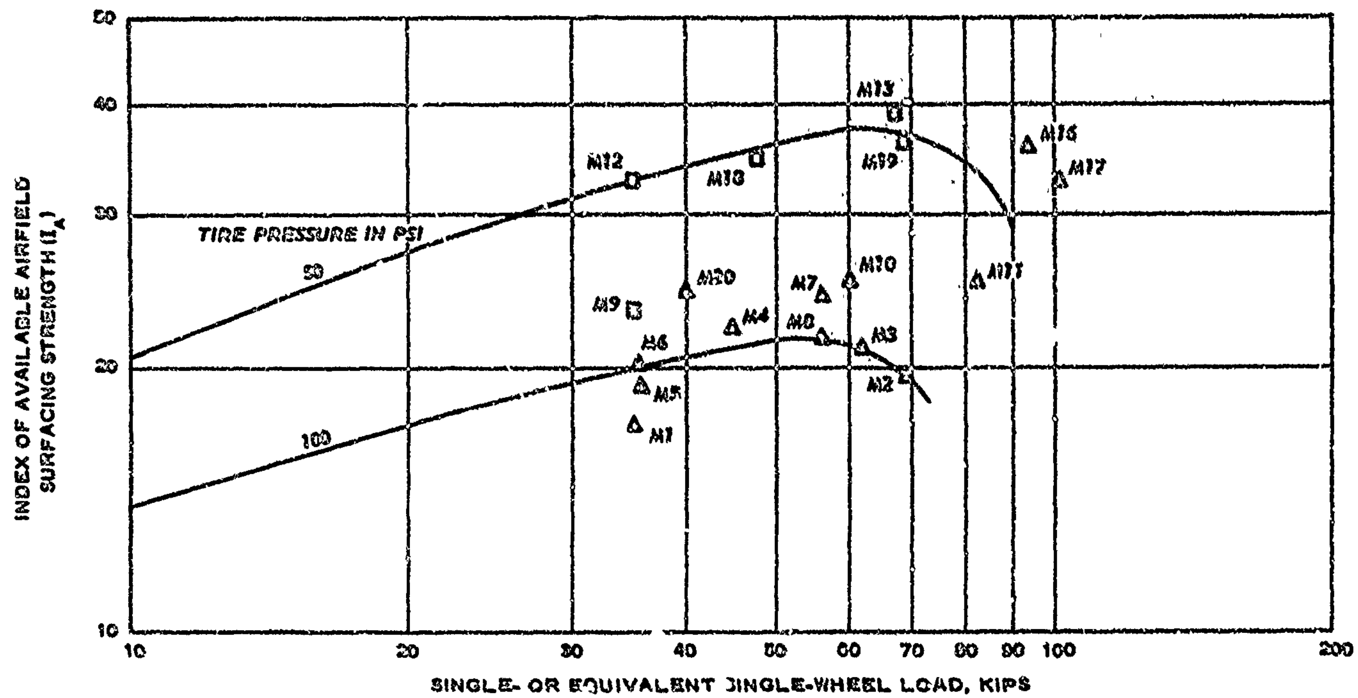
042333 E

Figure 20



MULTIPLE-WHEEL TRAFFIC TEST DATA
T11 LANDING MAT
50-, 100-, AND 200-PSI TIRE PRESSURES
INDEX OF AVAILABLE AIRFIELD SURFACING STRENGTH (I_A)
SINGLE- OR EQUIVALENT SINGLE-WHEEL LOAD, KIPS
TIRE PRESSURE IN PSI
50
100
200
LEGEND
□ 50 PSI
Δ 100 PSI
O 200 PSI
NOTE: OPEN SYMBOLS REPRESENT FAILURES.
CLOSED SYMBOLS REPRESENT NONFAILURES.
NUMBER NEAR POINT IS TEST NUMBER.

Figure 21



LEGEND

□ 50 PSI

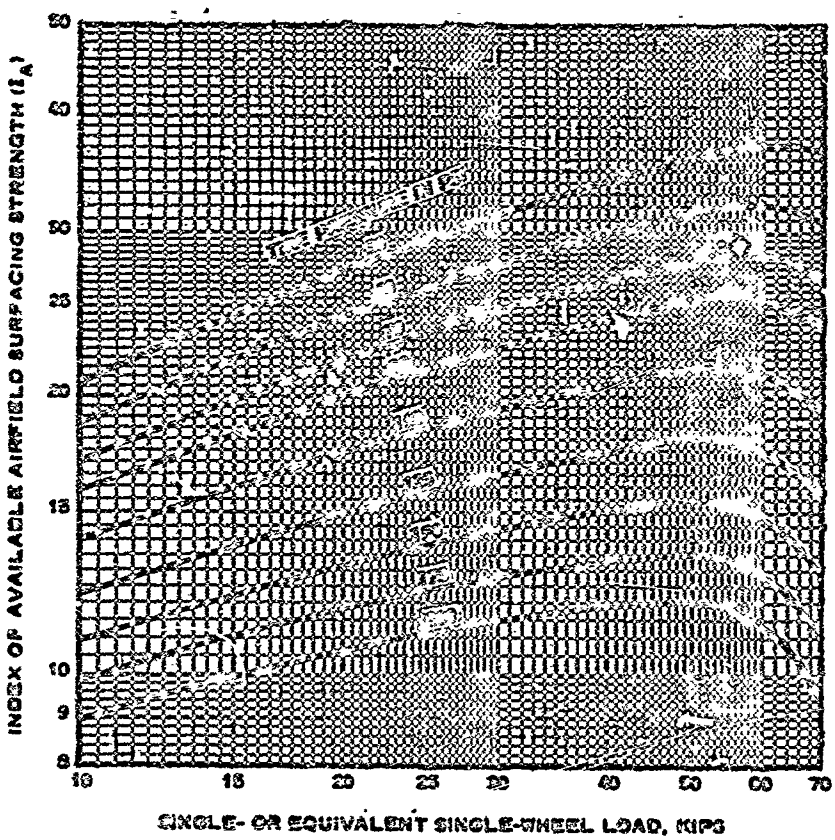
Δ 100 PSI

NOTE: OPEN SYMBOLS REPRESENT FAILURES.
CLOSED SYMBOLS REPRESENT NONFAILURES.
NUMBER NEAR POINT IS TEST NUMBER.

TRAFFIC TEST RESULTS

M8 LANDING MAT
50- AND 100-PSI TIRE PRESSURES

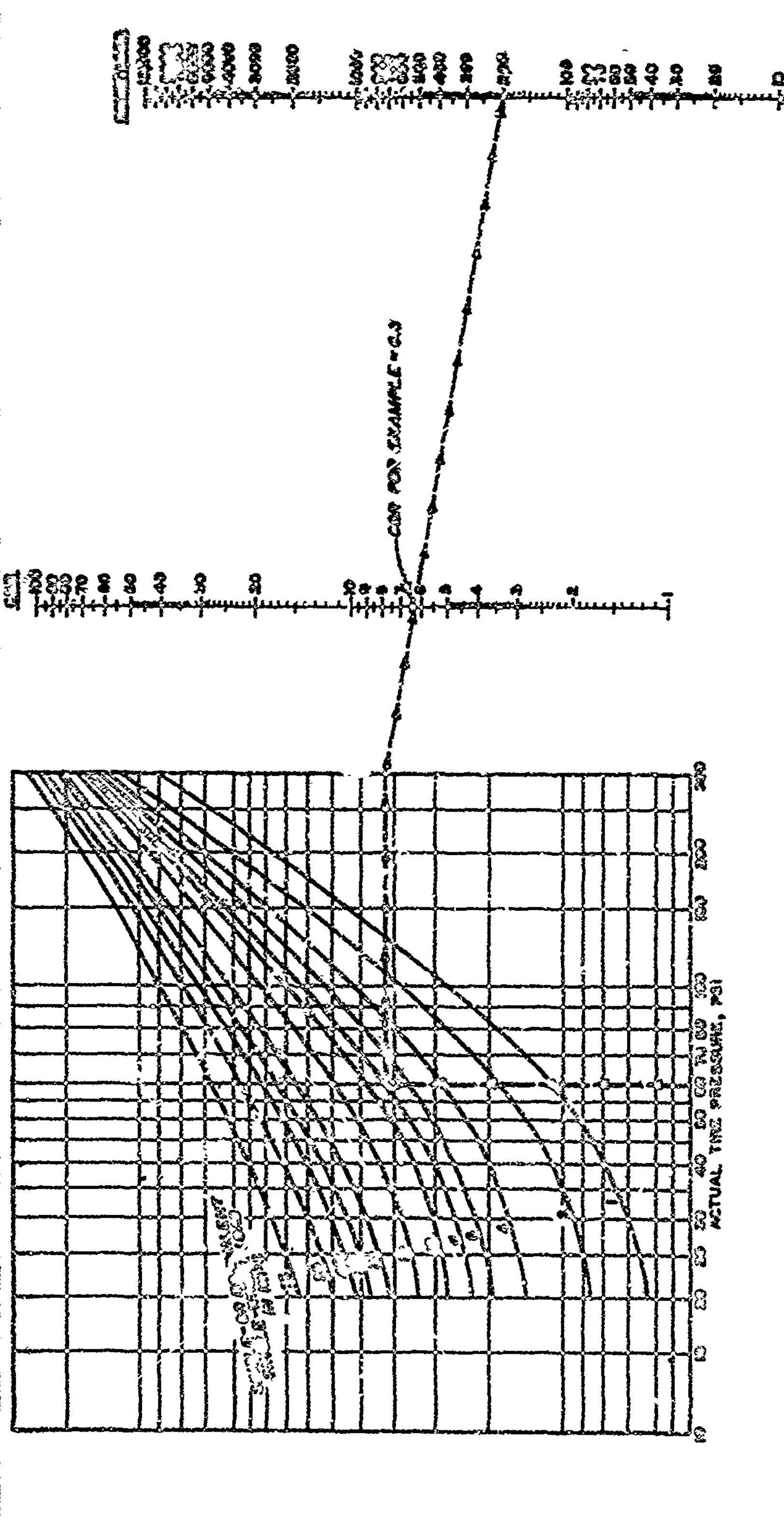
Figure 22



NOTE: DEVELOPED FROM
LANDING MAT DATA.

INDEX OF AVAILABLE AIRFIELD SURFACING STRENGTH (I_A)

SUPPORT-AREA AIRFIELD



EXAMPLE: GIVEN [illegible] TIRE PRESSURE AND [illegible] SINGLE-WHEEL LOAD,
CBR REQUIRED FOR 200 COVERAGES = 6.3

NOTE: THIS NOMOGRAPH WAS USED PRIOR TO THE GROUND-FLOTATION INVESTIGATION

CBR REQUIRED FOR OPERATION OF AIRCRAFT ON UNSURFACED SOILS

Figure 24

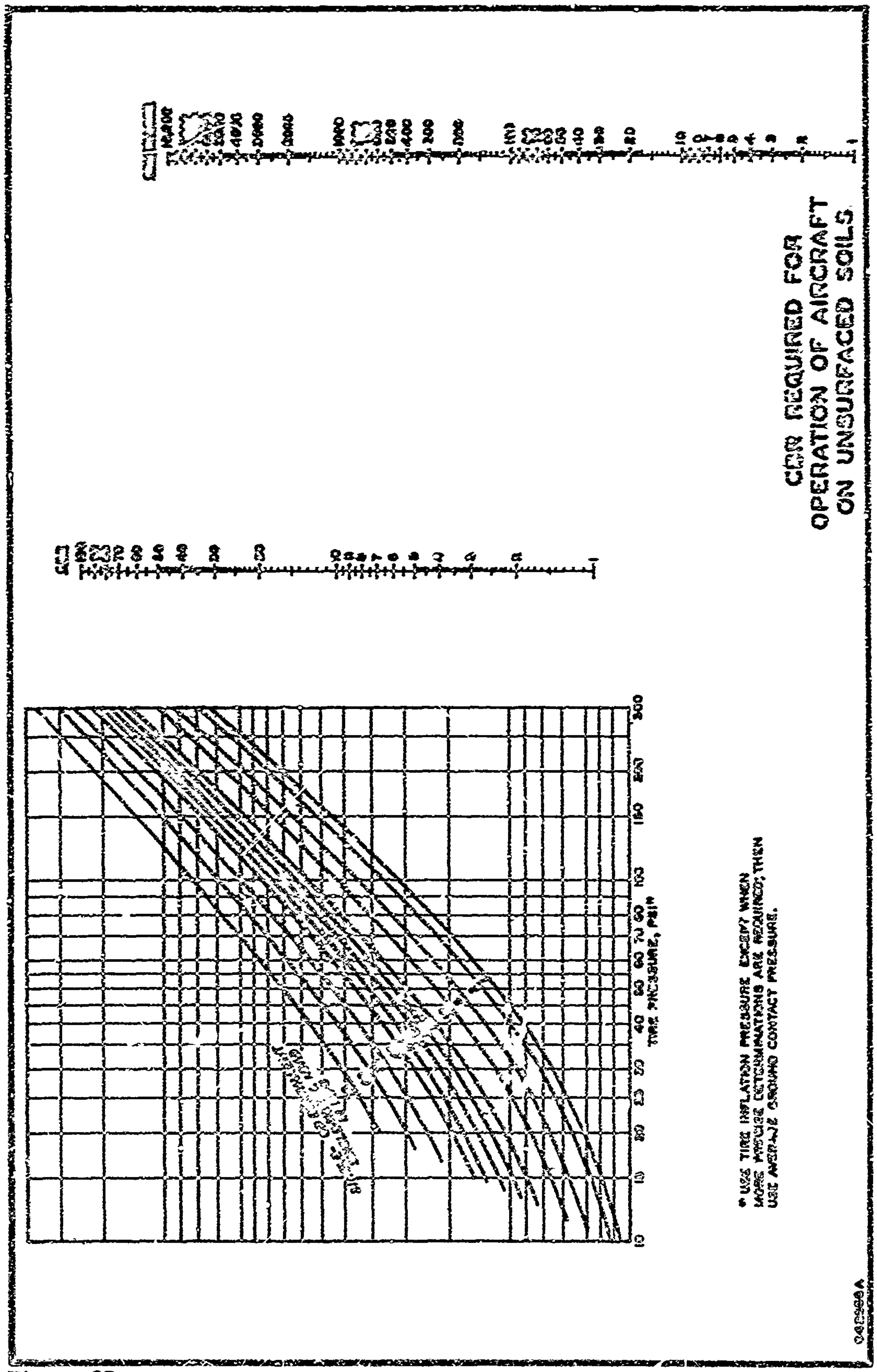
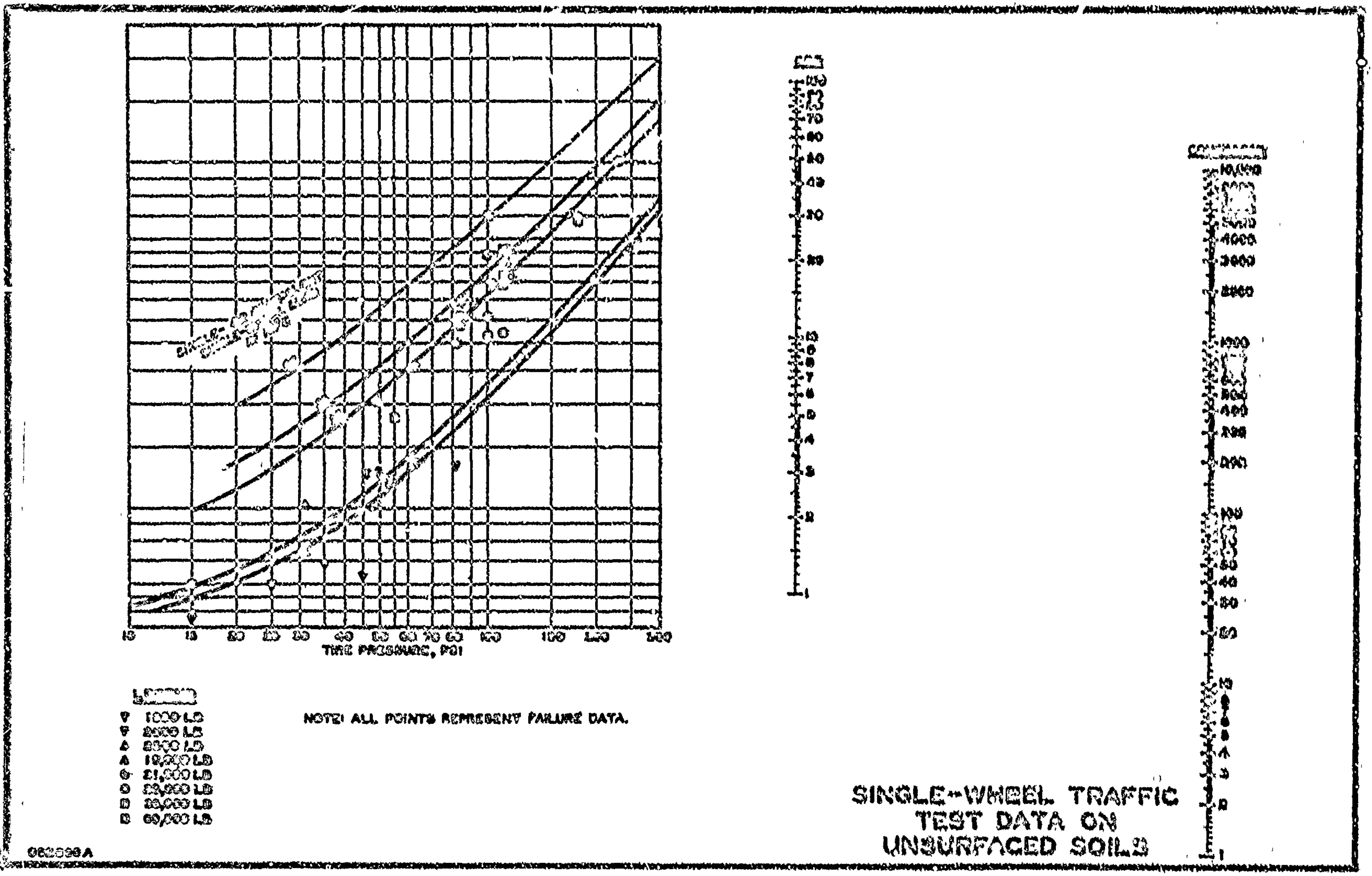

CBR REQUIRED FOR
OPERATION OF AIRCRAFT
ON UNSURFACED SOILS
TIRE PRESSURE, PSI*
* USE TIRE INFLATION PRESSURE EXCEPT WHEN MORE PRECISE DETERMINATIONS ARE REQUIRED; THEN USE AVERAGE GROUND CONTACT PRESSURE.

Figure 25



SINGLE-WHEEL TRAFFIC
TEST DATA ON
UNSURFACED SOILS

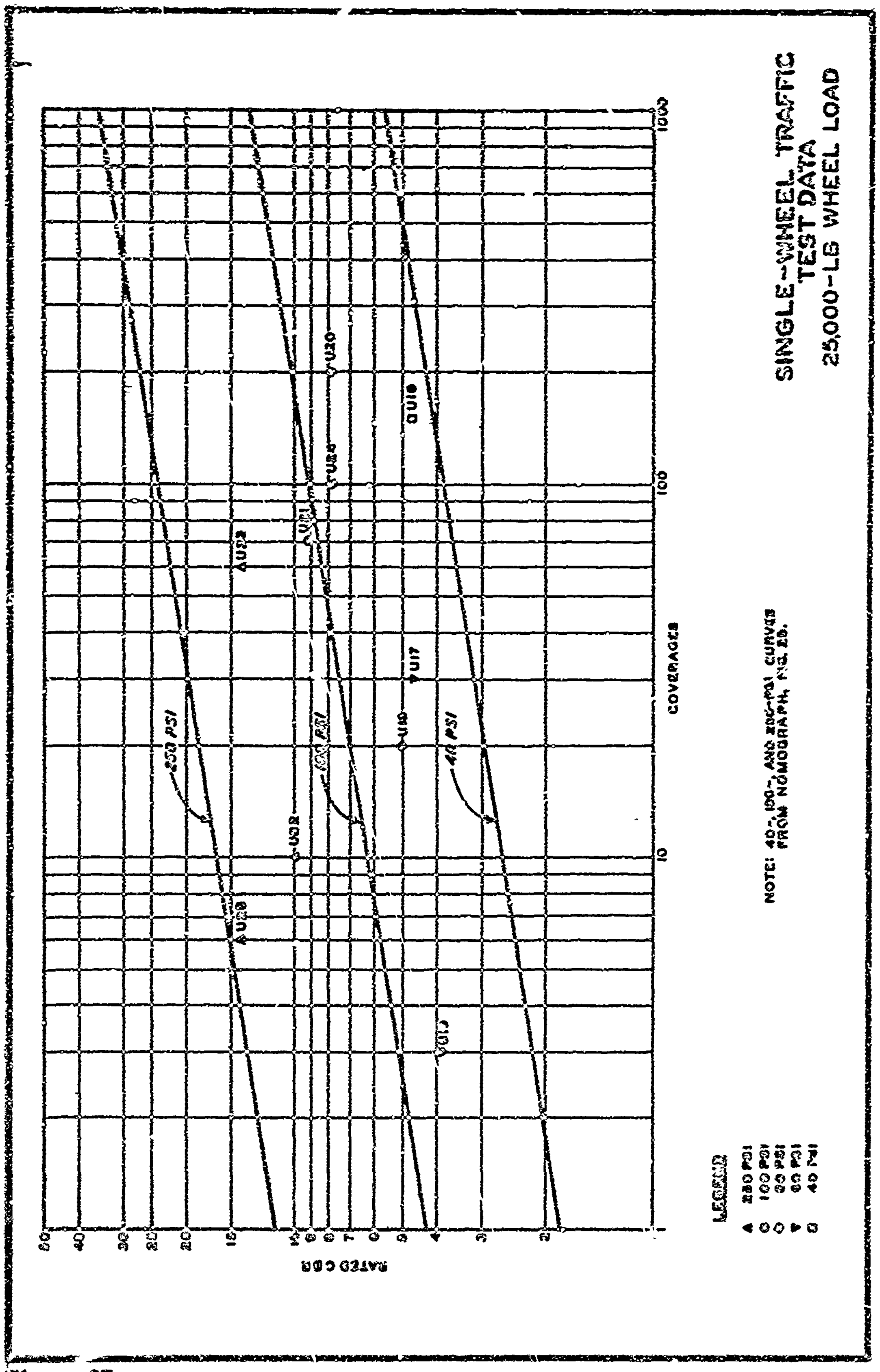
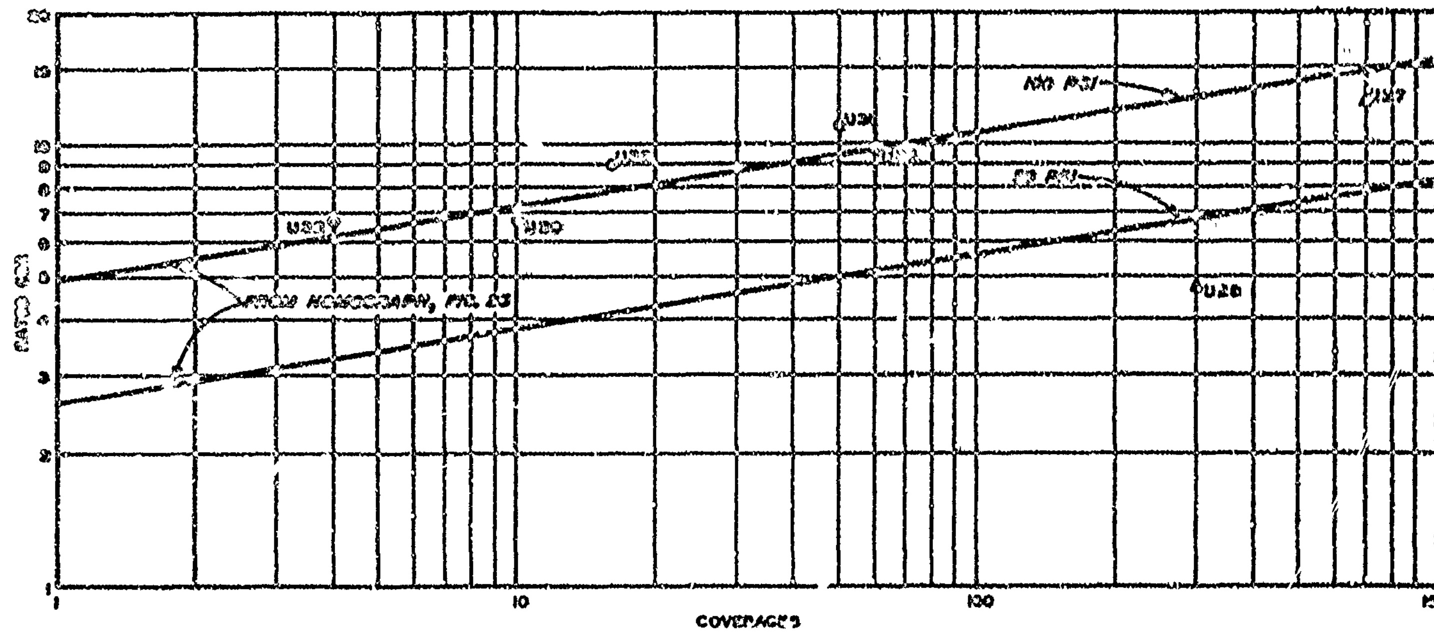

SINGLE-WHEEL TRAFFIC
TEST DATA
25,000-LB WHEEL LOAD
RATED CBR
COVERAGES
250 PSI
100 PSI
40 PSI
NOTE: 40-, 100-, AND 250-PSI CURVES
LEGEND

Figure 27



LEGEND

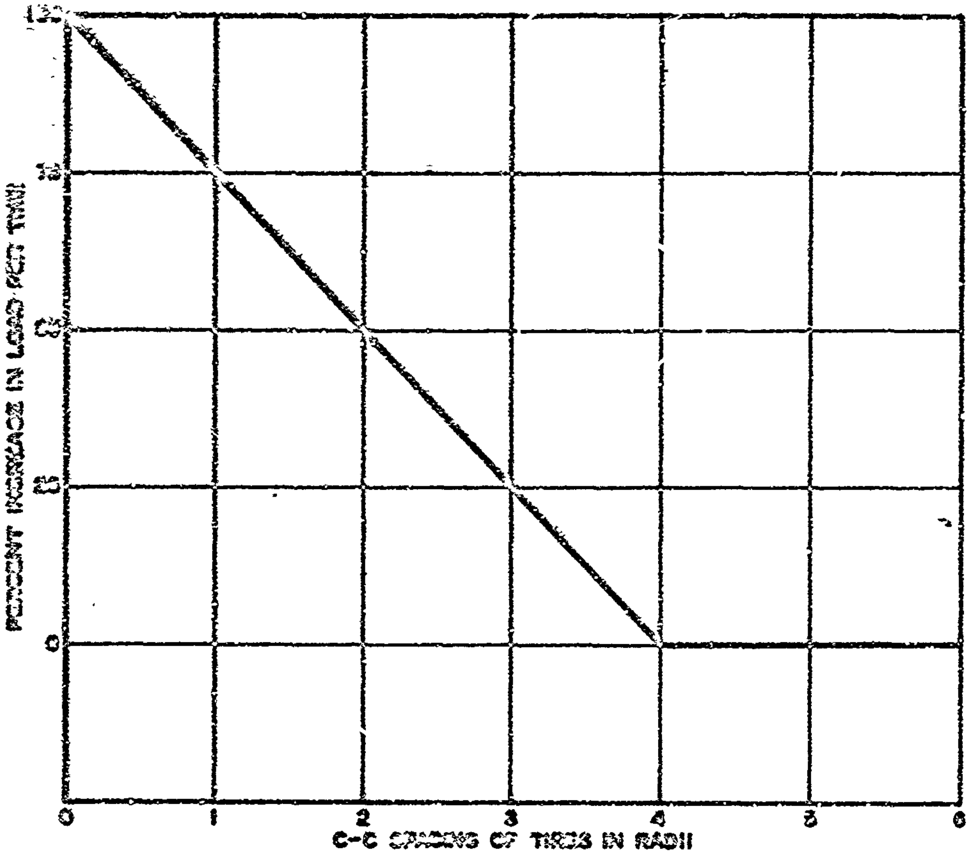
O 100 PSI

▲ 80 PSI

NOTE: CLOSED SYMBOL REPRESENTS NONFAILURE.

SINGLE-WHEEL TRAFFIC
TEST DATA
35,000-LB WHEEL LOAD

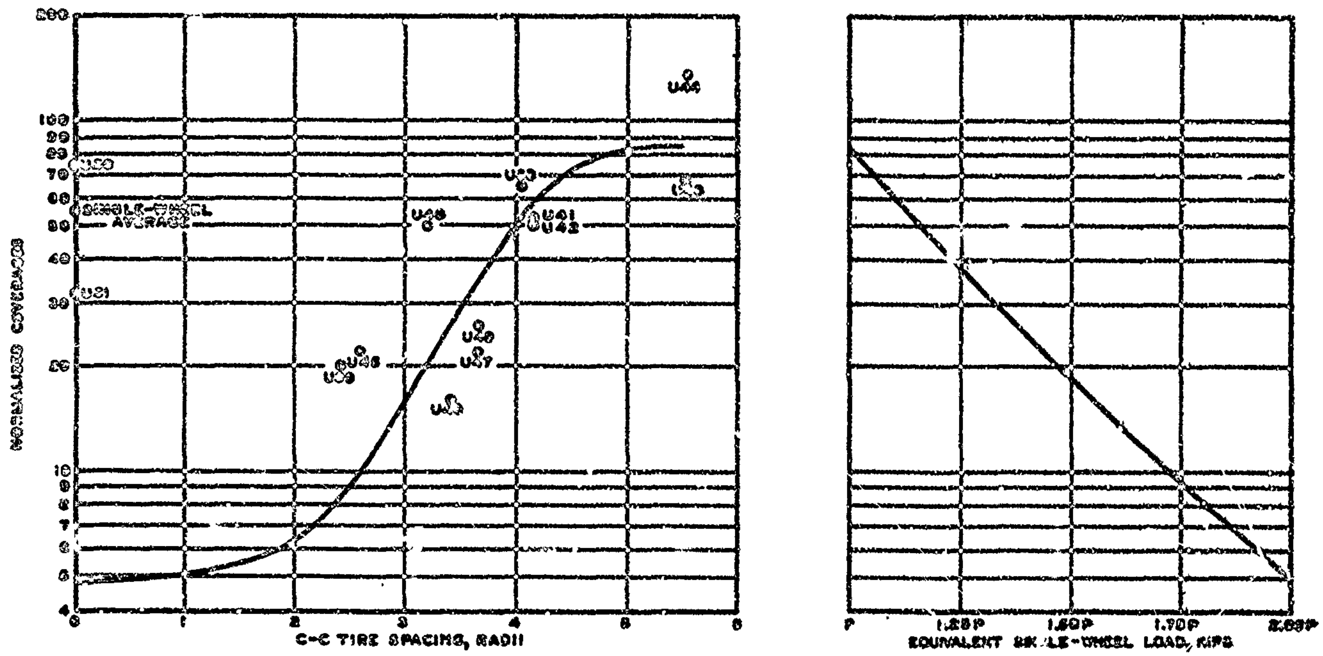
Figure 28



NOTE: THIS LOAD-ADJUSTMENT CURVE WAS IN USE PRIOR TO GROUND-FLOTATION INVESTIGATION.

LOAD-ADJUSTMENT CURVE
THEATRE OF OPERATIONS AIRFIELDS

Figure 29

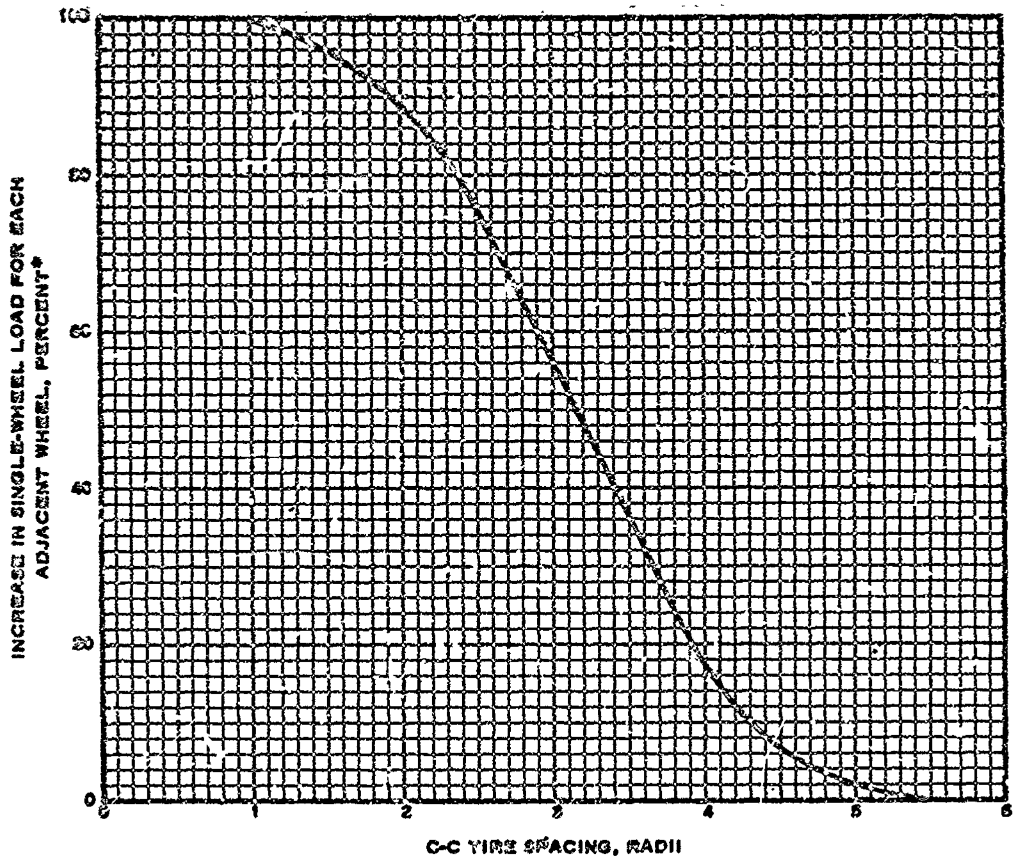


NOTE: CLOSED SYMBOLS REPRESENT TWIN-WHEEL TESTS.
NUMBER NEAR POINT IS TEST NUMBER.

COVERAGE, SPACING, AND LOAD RELATIONS

MULTIPLE-WHEEL ASSEMBLIES ON UNSURFACED SOILS

Figure 30

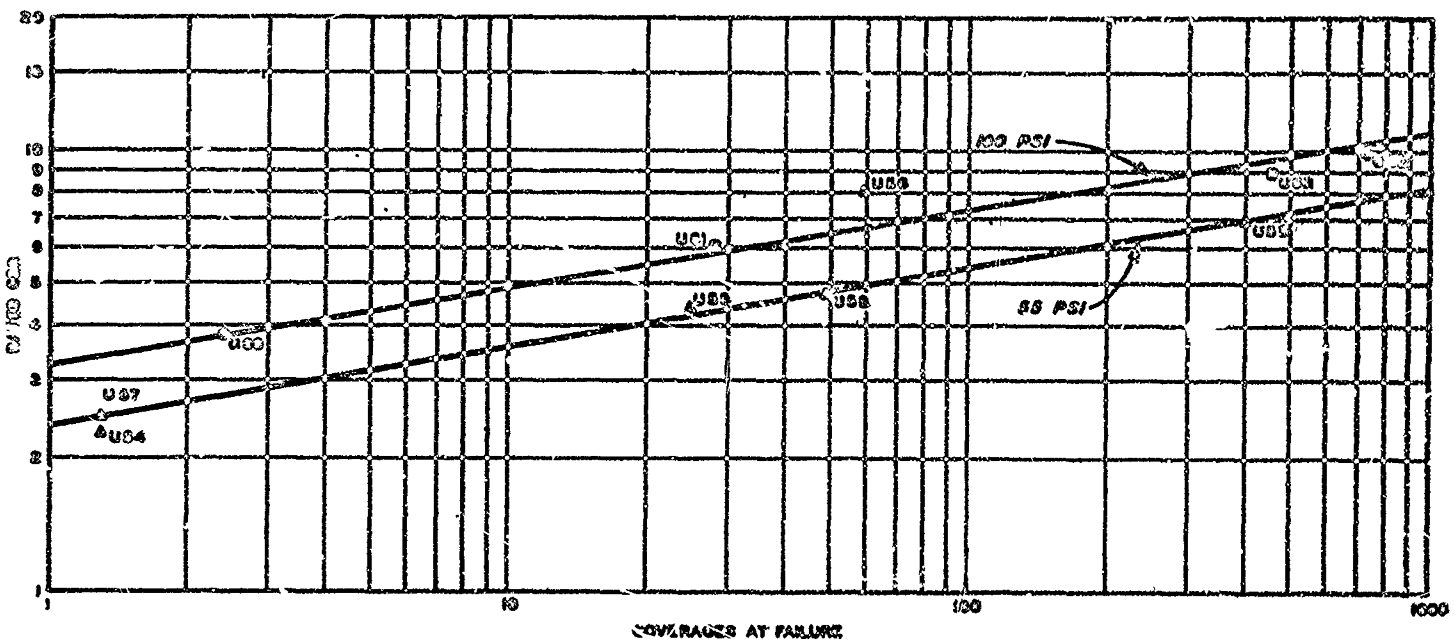


* INCREASE IN LOAD ON A SINGLE WHEEL OF A MULTIPLE-WHEEL GEAR TO ACCOUNT FOR EFFECTS OF ADJACENT WHEELS OF THE MULTIPLE-WHEEL GEAR IN ARRIVING AT AN EQUIVALENT SINGLE-WHEEL LOAD.

EQUIVALENT SINGLE-WHEEL LOAD-ADJUSTMENT CURVE FOR UNSURFACED SOILS

063050 B

Figure 31



LEGEND

- ○ 100 PSI, 21,000 LB PER WHEEL
- △ 88 PSI, 21,000 LB PER WHEEL
- □ 100 PSI, 22,750 LB PER WHEEL

NOTE: NUMBER NEAR POINT IS TEST NUMBER.

TRAFFIC TEST DATA
TWELVE-WHEEL ASSEMBLY

Figure 32

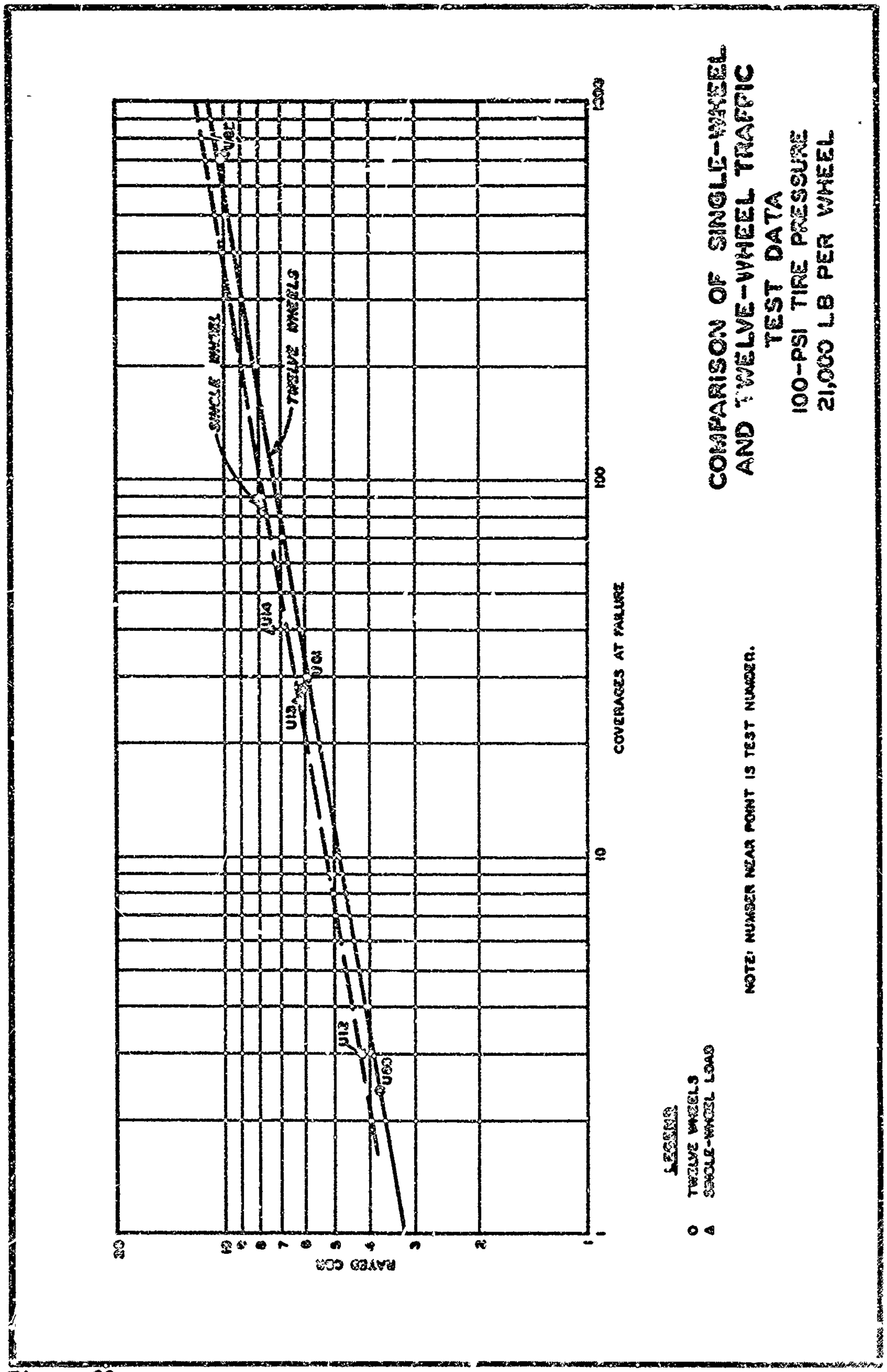
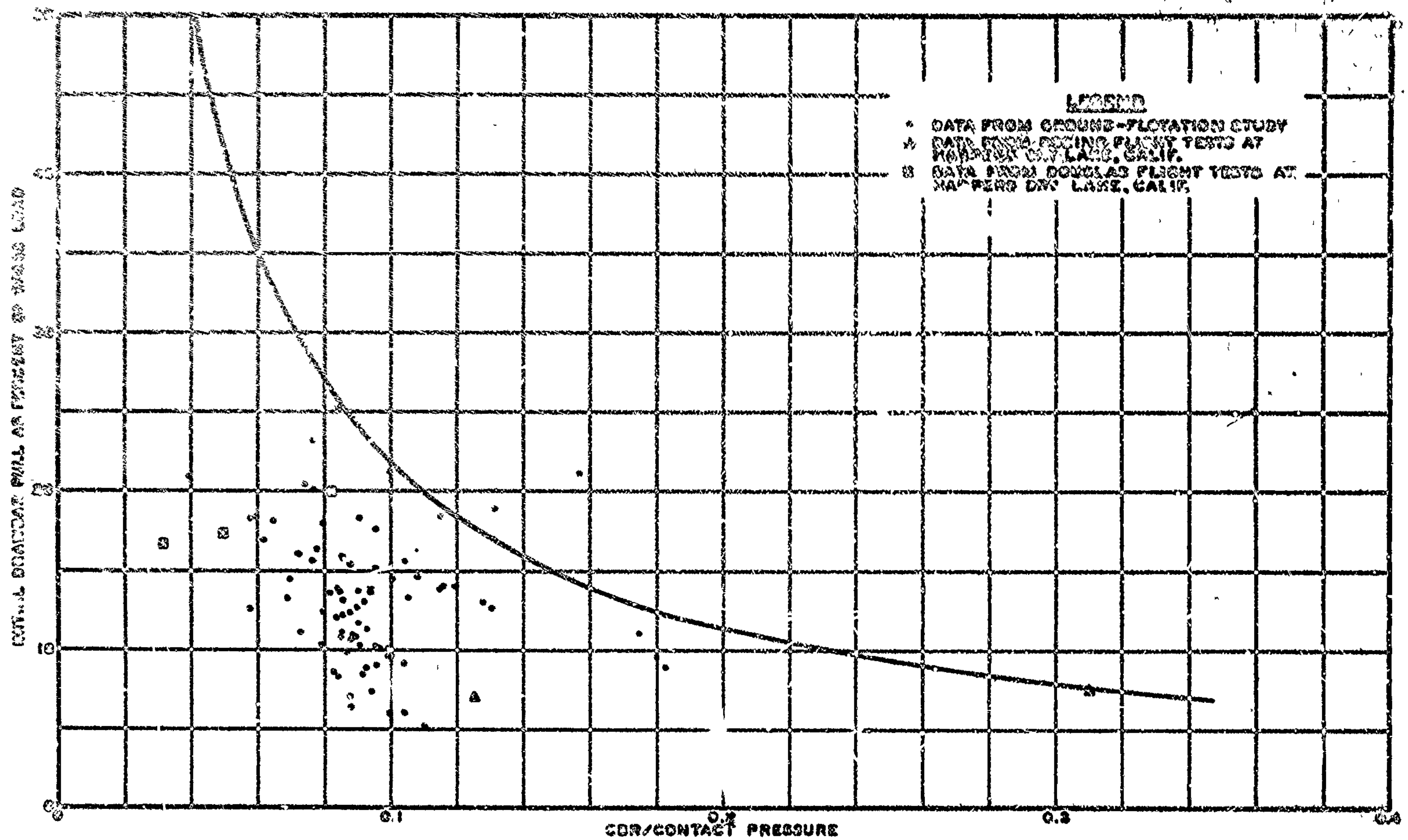
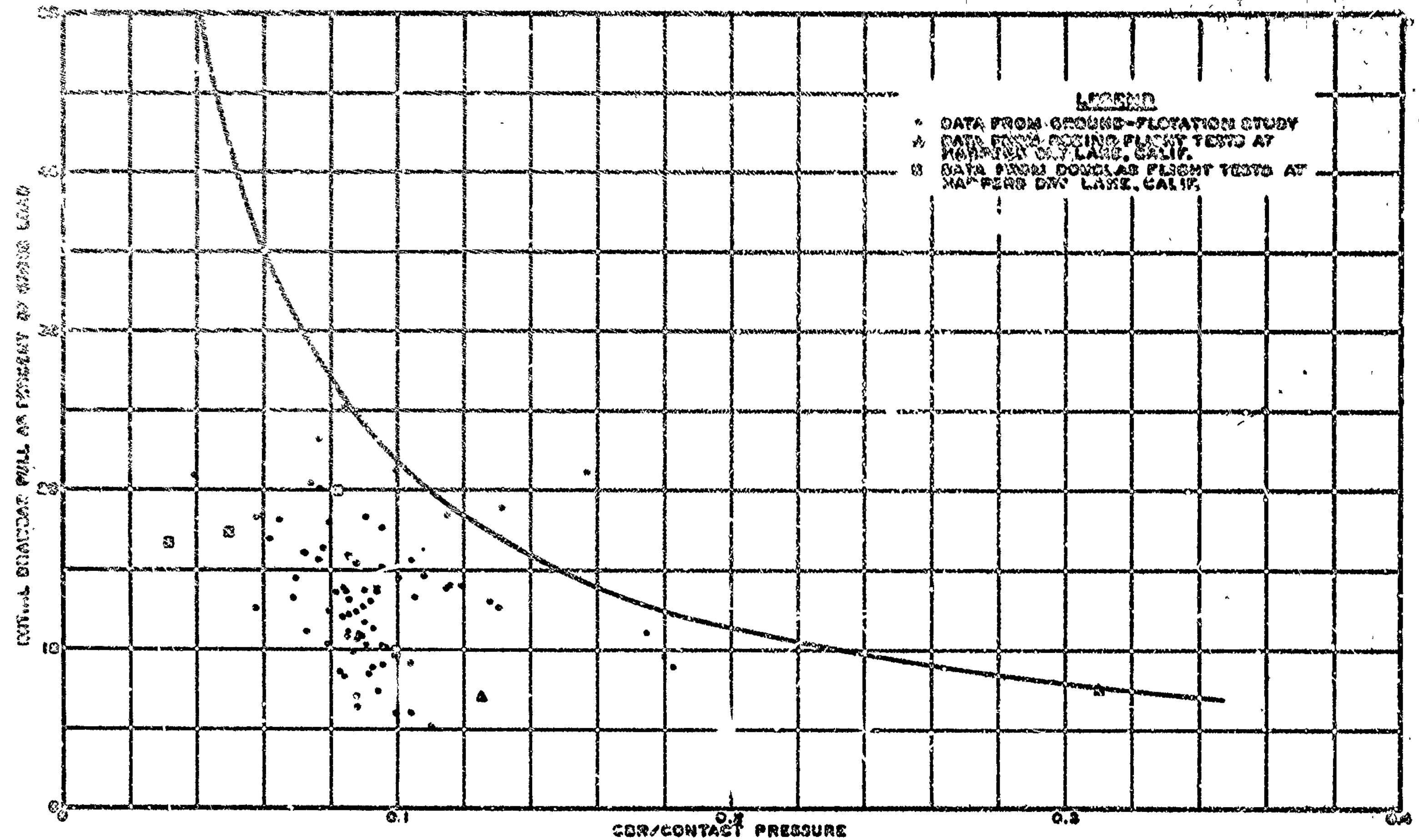

COMPARISON OF SINGLE-WHEEL
AND TWELVE-WHEEL TRAFFIC
TEST DATA
100-PSI TIRE PRESSURE
21,000 LB PER WHEEL
RATED CBR
COVERAGES AT FAILURE
SINGLE WHEEL
TWELVE WHEELS
U12
U60
U13
U61
U14
U62
NOTE: NUMBER NEAR POINT IS TEST NUMBER.
LEGEND
TWELVE WHEELS
SINGLE-WHEEL LOAD

Figure 33



INITIAL DRAWBAR PULL
UNSURFACED SOIL

Figure 34



INITIAL DRAWBAR PULL
UNSURFACED SOIL

Figure 34

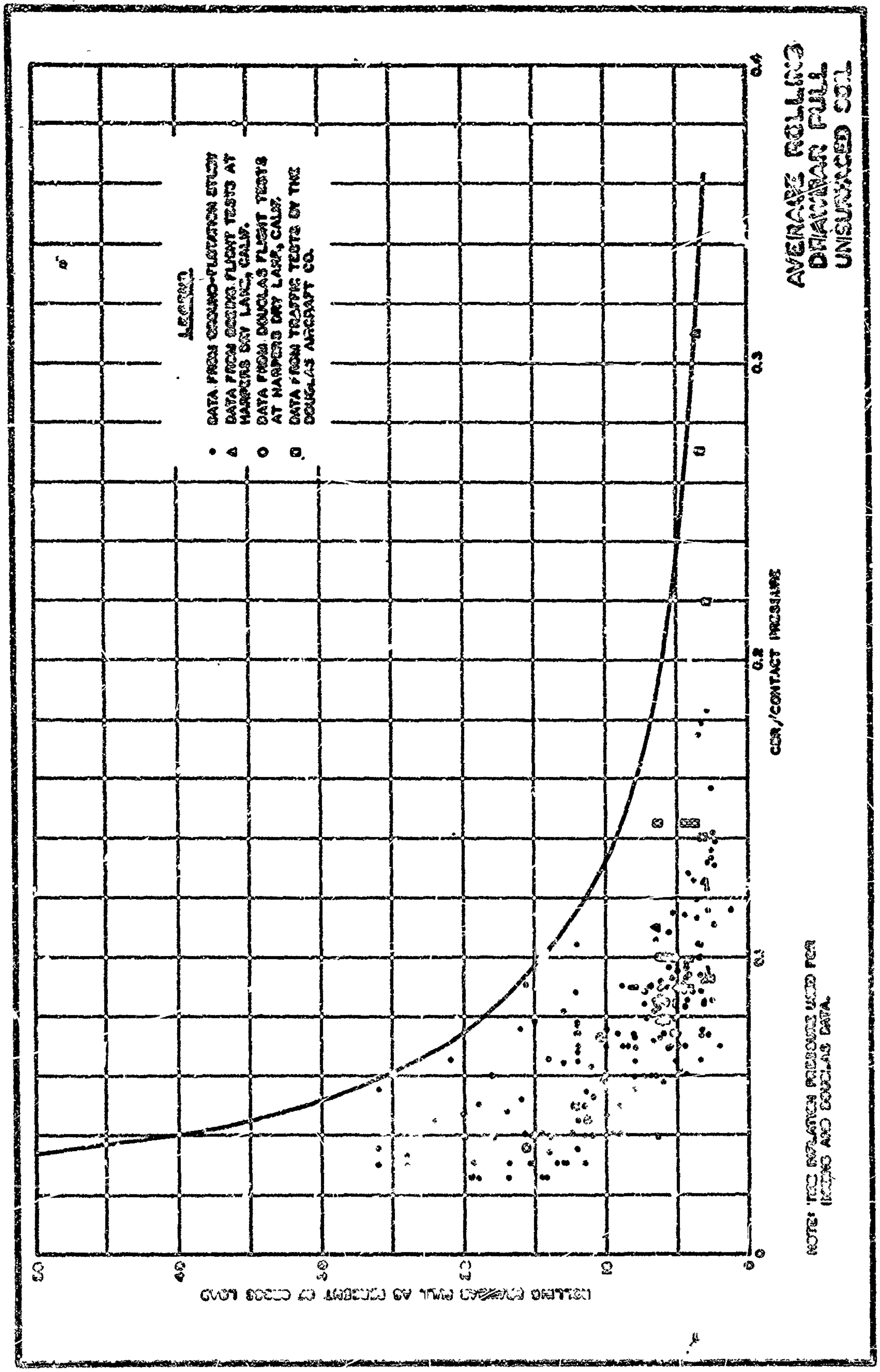

AVERAGE ROLLING
DRAWBAR PULL
UNSURFACED SOIL
LEGEND
DATA FROM GROUND-FLOTATION STUDY
DATA FROM GROUND FLIGHT TESTS AT HARPERS DRY LAKE, CALIF.
DATA FROM DOUGLAS FLIGHT TESTS AT HARPERS DRY LAKE, CALIF.
DATA FROM TRAFFIC TESTS BY THE DOUGLAS AIRCRAFT CO.
CBR/CONTACT PRESSURE
0
0.1
0.2
0.3
0.4
ROLLING DRAWBAR PULL AS PERCENT OF GROSS LOAD
0
10
20
30
40
50

Figure 35

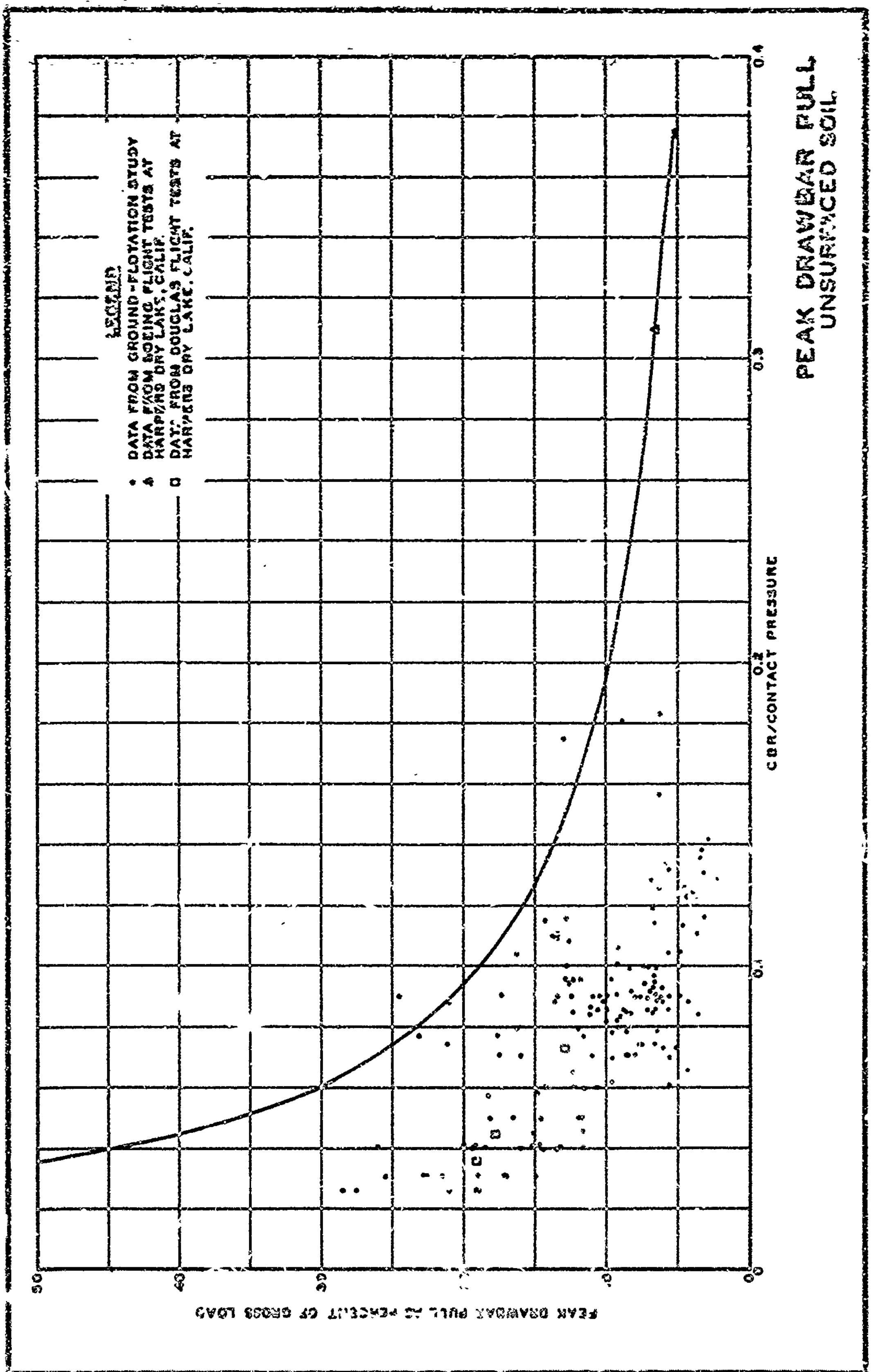
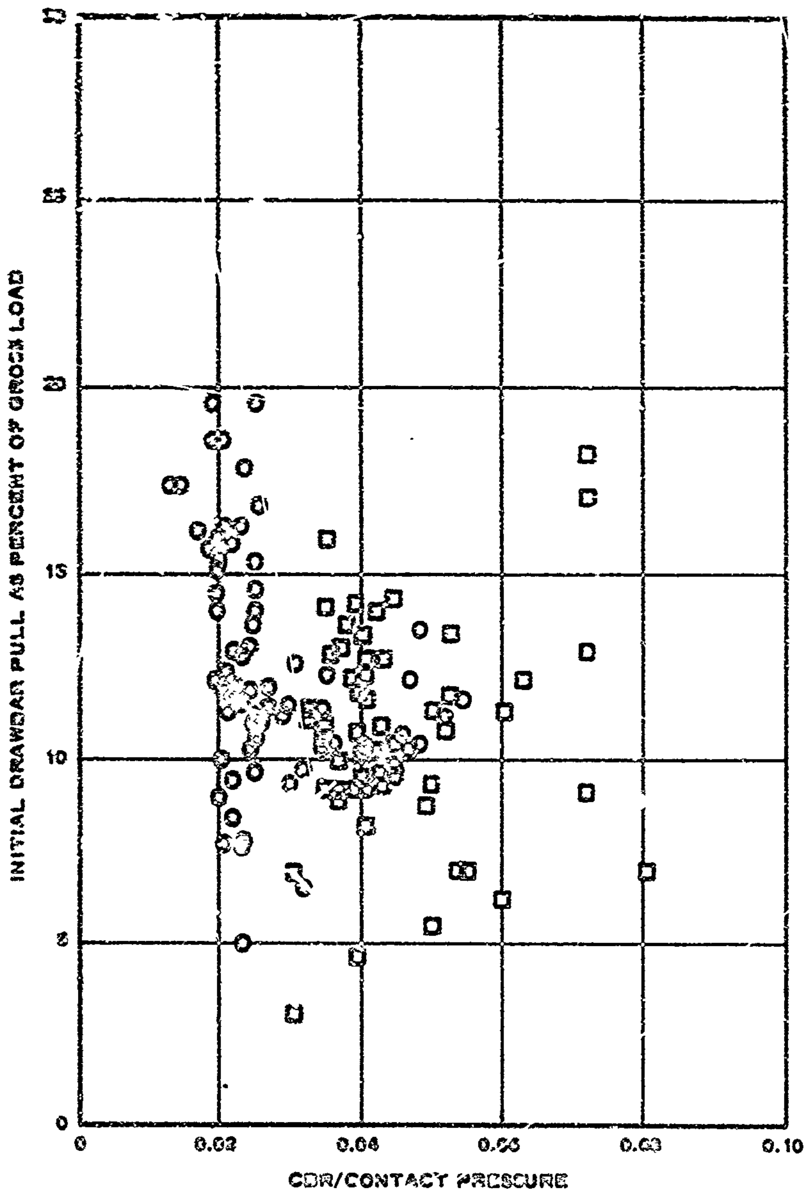

PEAK DRAWBAR PULL
UNSURFACED SOIL
LEGEND
DATA FROM GROUND-FLOTATION STUDY
DATA FROM BOEING FLIGHT TESTS AT HARPERS DRY LAKE, CALIF.
DATA FROM DOUGLAS FLIGHT TESTS AT HARPERS DRY LAKE, CALIF.
CBR/CONTACT PRESSURE
0
0.1
0.2
0.3
0.4
PEAK DRAWBAR PULL AS PERCENT OF GROSS LOAD
0
10
20
30
40
50

Figure 36



LEGEND

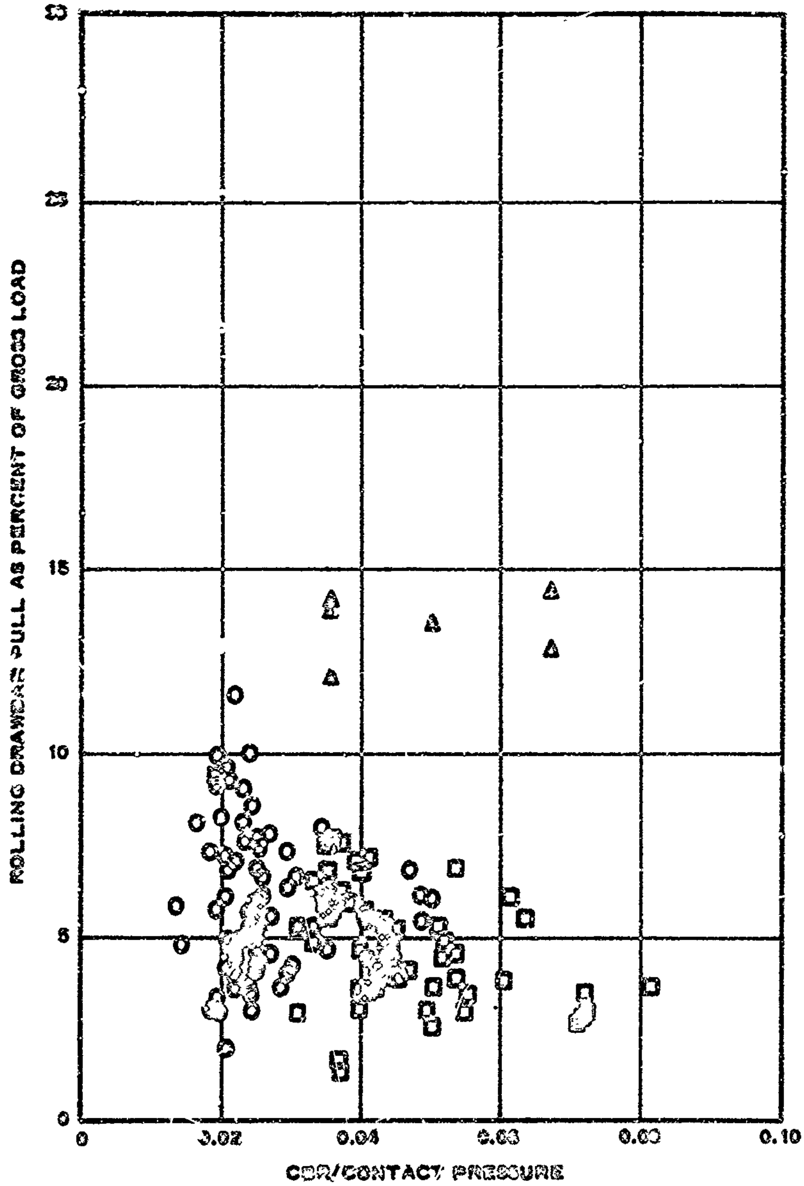
O MODIFIED T11 MAT

□ M8 MAT

INITIAL DRAWBAR PULL

LANDING MAT

Figure 37



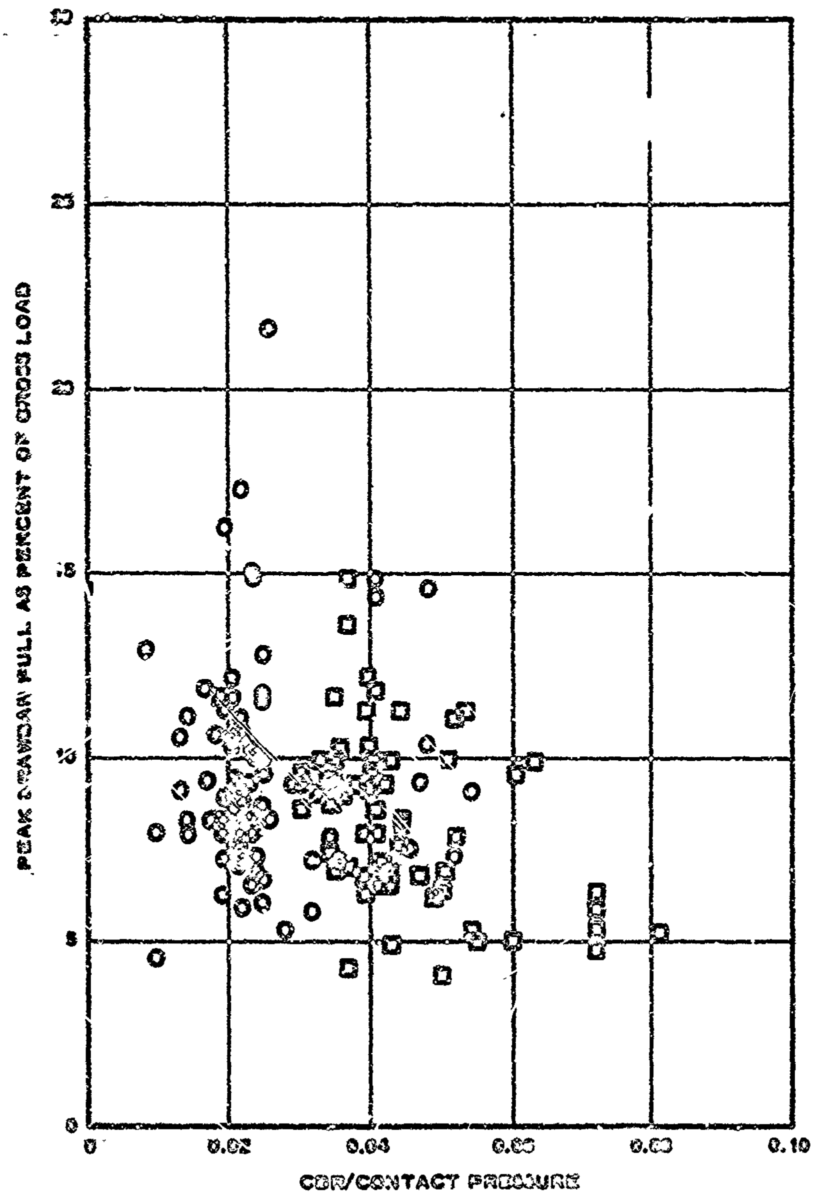
LEGEND

- O MODIFIED T11 MAT
- □ NO MAT
- △ DATA FROM TRAFFIC TESTS ON NO MAT BY DOUGLAS AIRCRAFT CO.

AVERAGE ROLLING DRAWBAR PULL

LANDING MAT

Figure 33



LEGEND

O MODIFIED T11 MAT
◻ [illegible] MAT

PEAK DRAWBAR PULL

LANDING MAT

Figure 39

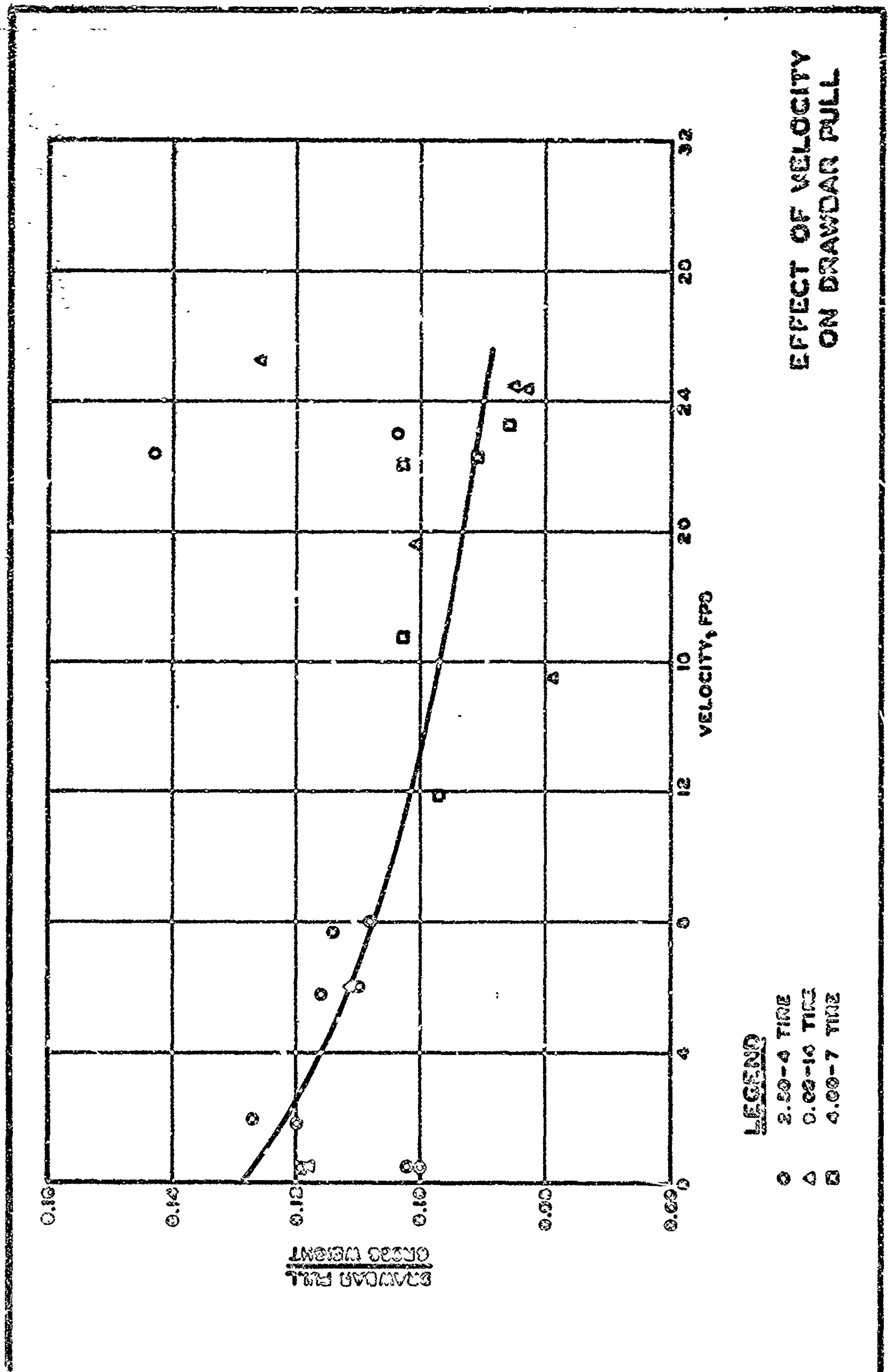

EFFECT OF VELOCITY
ON DRAWBAR PULL
VELOCITY, FPS
DRAWBAR PULL
GROSS WEIGHT
LEGEND

Figure 40

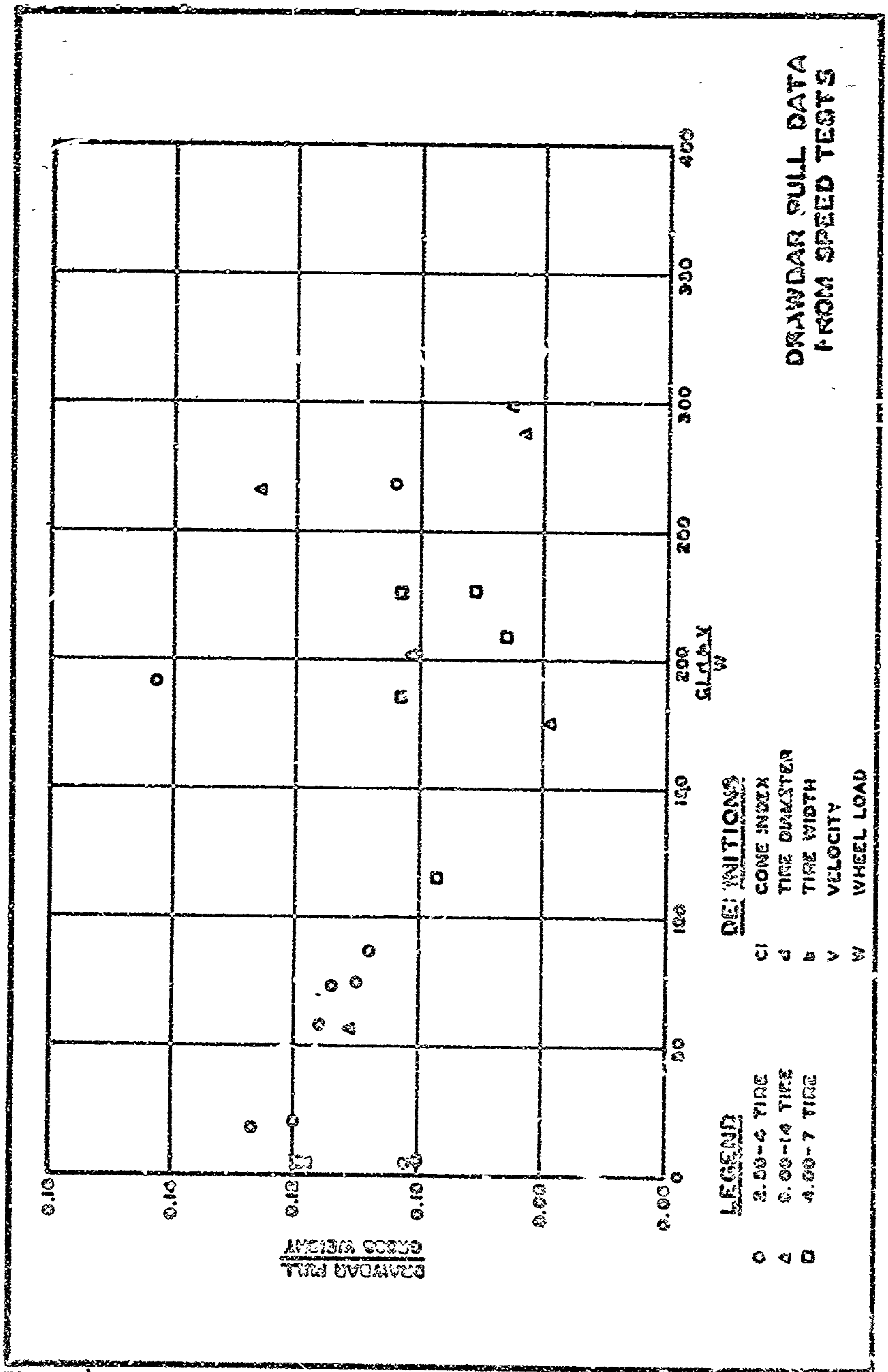
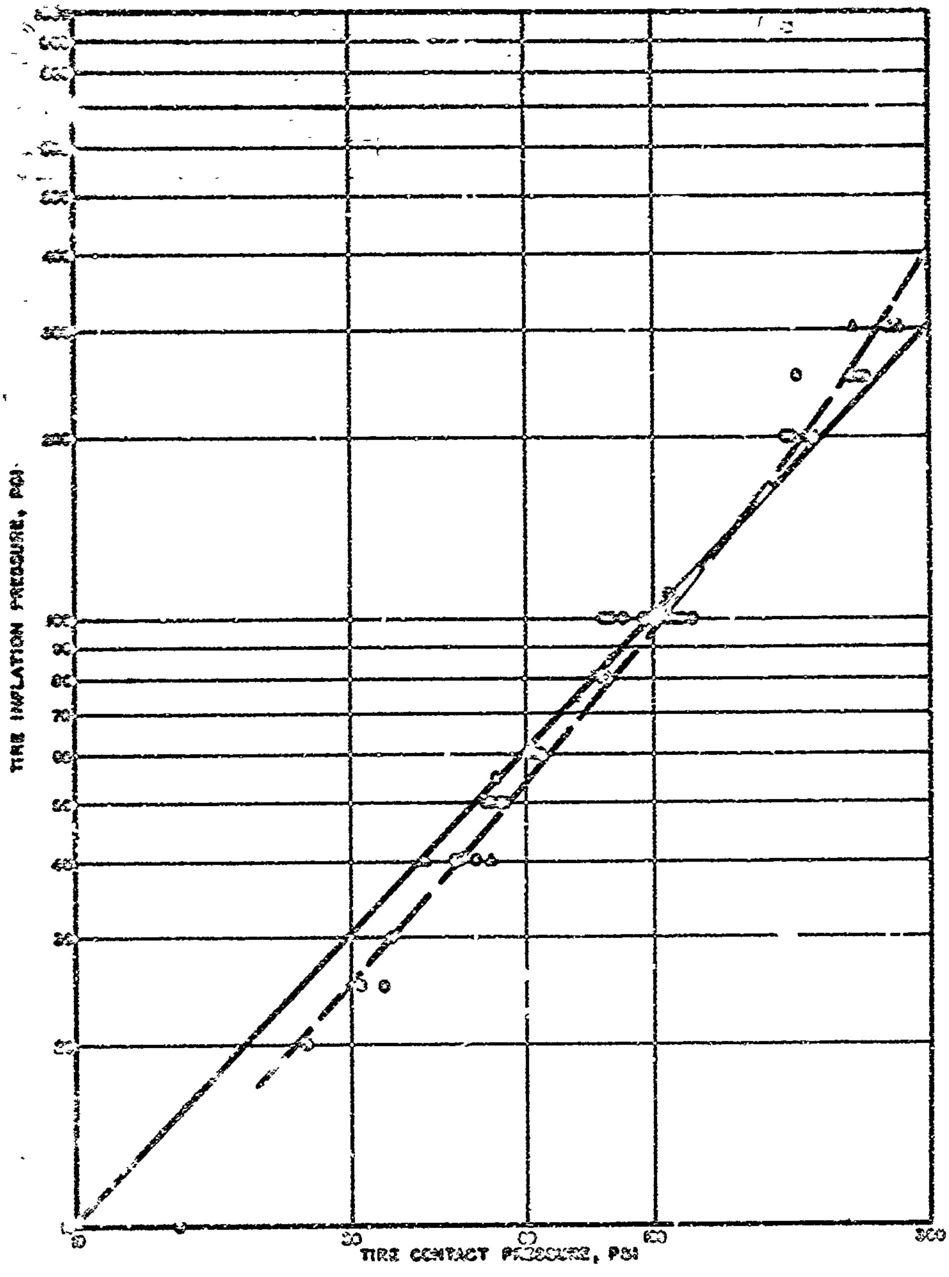

DRAWBAR PULL DATA
FROM SPEED TESTS
DRAWBAR PULL / GROSS WEIGHT
0
50
100
150
200
250
300
350
400
CI d b V / W
LEGEND
2.50-4 TIRE
6.00-14 TIRE
4.00-7 TIRE
DEFINITIONS
CI CONE INDEX
d TIRE DIAMETER
b TIRE WIDTH
V VELOCITY
W WHEEL LOAD

Figure 41



LEGEND

○ DATA FROM GROUND-FLOTATION STUDY

△ DATA FROM TR 3-630

COMPARISON OF TIRE INFLATION PRESSURE AND TIRE CONTACT PRESSURE

Figure 42

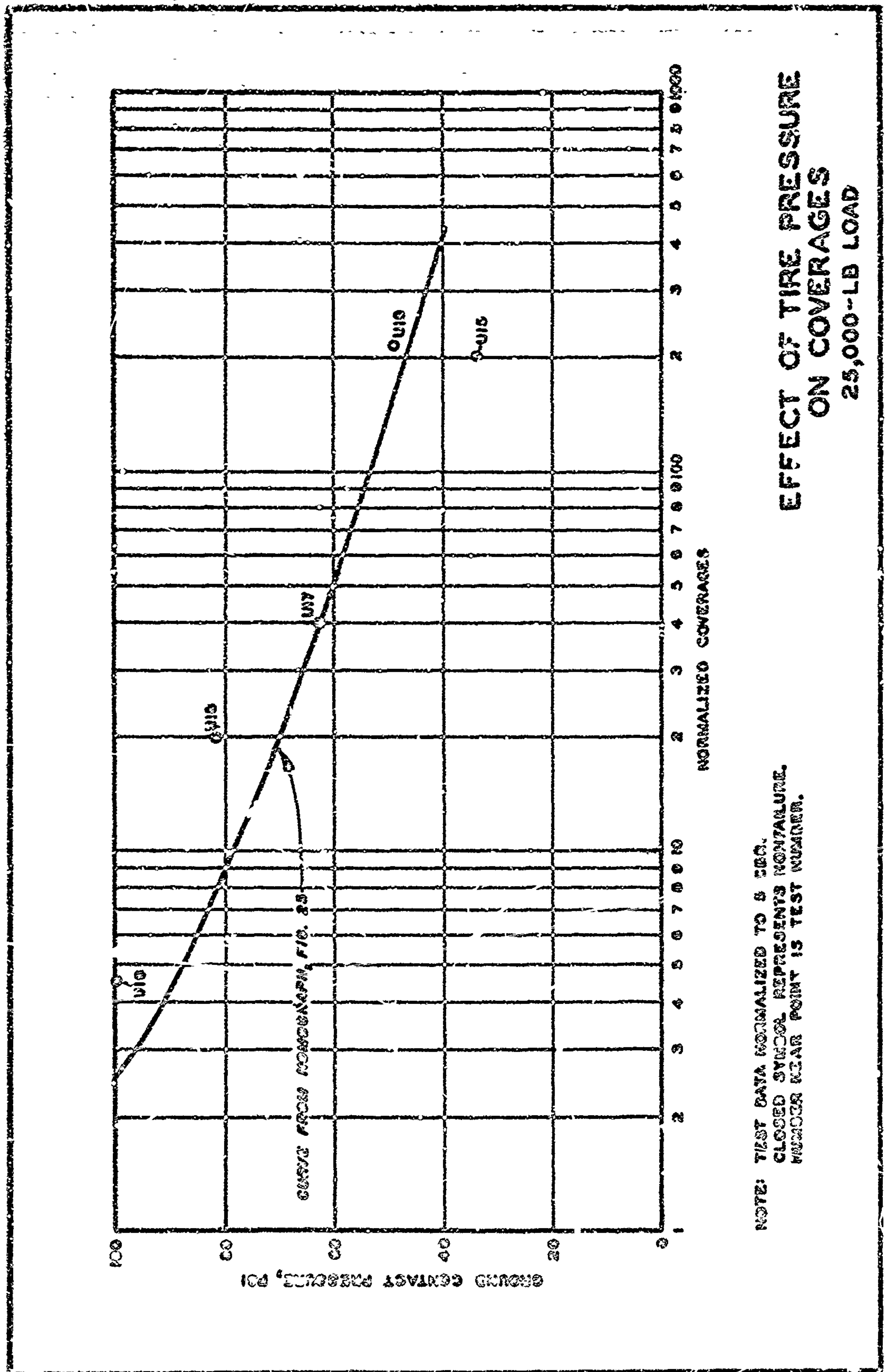

EFFECT OF TIRE PRESSURE
ON COVERAGES
25,000-LB LOAD
GROUND CONTACT PRESSURE, PSI
NORMALIZED COVERAGES
CURVE FROM NOMOGRAPH, FIG. 25
NOTE: TEST DATA NORMALIZED TO 5 SEC.
CLOSED SYMBOL REPRESENTS NONFAILURE.
NUMBER NEAR POINT IS TEST NUMBER.

Figure 43

APPENDIX E: PLAN OF TEST FOR DEVELOPMENT OF DESIGN CRITERIA FOR THE CX-HLS AIRCRAFT

Purpose

The primary objective of this program is to obtain sufficient data for establishing criteria which will permit design of an efficient landing-gear configuration for a 700,000- to 800,000-lb gross weight subsonic transport aircraft that will be capable of operating on support-area airfields. It is also desired to obtain data for improving existing ground-flotation criteria, particularly in regard to low-pressure tires and light wheel loads. Specific objectives of the field tests outlined herein are to determine the effects of the following variables on surface distortions and rolling resistances on both unsurfaced and mat-surfaced soils:

a. Tire-inflation pressure

b. Wheel load

c. Multiple-wheel assemblies

d. Wheel spacing on multiple assemblies

e. Tire size

f. Speed (to a limited degree)

Scope

A proposed schedule of tests to meet the test objectives is shown in Table VII. This schedule indicates a rather extensive and time-consuming test program which should furnish a considerable amount of basic data for use in revising and improving current ground-flotation criteria. However, due to the importance of the time element in this investigation, completion of this schedule of testing may not be possible. Deviations from this schedule will be made as test data are obtained and by information furnished by the supporting agency (USAF) from related studies. Every effort will be made to obtain the maximum amount of information with minimum effort. Spot-check tests will be used to the fullest extent possible.

Procedure

The proposed tests with 1000- and 2000-lb single-wheel loads will be conducted in the mobility research facility at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. Each test will be conducted in a separate test lane which will be subjected to traffic of a specific wheel load and tire pressure. Each test lane will consist of one item with a uniform soil strength. The traffic test lane will have a width of approximately four tire prints and will be subjected to uniform-coverage traffic.

The tests for wheel loads greater than 2000 lb will be conducted on specially prepared test sections in hangar 4 at WES. These sections will consist of one or more test lanes that will be subjected to traffic of a specific wheel or assembly load and a specific tire pressure. Each test lane will consist of several test items of different subgrade strengths or types of surfacing. The traffic lanes will be approximately 12 ft wide and will be subjected to uniform-coverage traffic. A typical layout of a test section is shown in Figure 44.

Prototype Test Cart

Most of the tests in hangar 4 will be conducted using present load carts. However, the size of the prototype gear is expected to be such that a special load cart must be designed and built in order to test it. This load cart will be designed and built so that it will be versatile and capable of being adapted to almost any type gear that may be proposed for the CX-HLS aircraft. Pressure distribution on a smooth, hard soil surface for tires used in the prototype tests will be obtained using CEC pressure cells mounted on a rigid plate.

Speed Tests

Limited speed tests will be conducted in conjunction with tests shown in Table VII. The WES will attempt to develop relations between drag (rolling resistance) and speed through the use of dimensional analysis and scale-model testing or other recommended procedures. Relations between drag and rate of acceleration will also be studied.

The possiblity of conducting full-scale drag speed tests will also be examined. There are at least two organizations that may have the capability of conducting these full-scale drag speed tests: NASA Landing Loads Track, Langley Research Center, Langley Air Force Base, Va., and All-American Engineering Company, Wilmington 5, Del. These organizations will be contacted after this plan of test has been approved.

Traffic Coverages

The load and tire pressures shown in table A1 for the various subgrade strengths were selected to produce failure within 200 coverages.

In some cases, failure should develop in less than 20 coverages. In all traffic tests, traffic will be applied until failure develops or to a maximum of 200 coverages.

Subgrade Soil

A heavy clay soil (CH) will be used for the test section subgrades. The subgrades will be constructed as required by test conditions to a total thickness of 24 to 72 in. in 6-in.-thick compacted layers at water contents as required to obtain the desired subgrade strengths. All unsurfaced test items will be kept covered with membrane to prevent drying, except for the actual time that traffic is being applied. Sprinkling of the surface to prevent drying and a buildup in strength will also be accomplished as required.

Test Observations

Water content, density, and CBR determinations will be made prior to traffic and at point of failure in all test items. Similar determinations may also be made at intervals during traffic where there is any visual indication of a change in strength. These tests will be made at surface of subgrade and at depths of 6, 12, and 18 in. The rated strength of the test items will normally be based on combined effects of the CBR values for the surface and 6- and 12-in. depths for all data obtained before, during, and at end of traffic.

The rolling resistance or drag forces will be measured for each test item at the beginning and end of traffic and at some interval during traffic.

Level readings to determine surface distortions and elastic deflection of subgrade and/or mat will be taken prior to traffic, at intervals during traffic, and at end of traffic.

Close visual observations of behavior of subgrades and mat during traffic will be made and recorded throughout the traffic period. These observations will be supplemented with photographs as appropriate.

Tentative Failure Criteria

The failure criteria presented below are tentative only and are subject to change. Any changes will be based on a more detailed study than has been possible up to this time of previous failure criteria and data relating thereto.

Failure of unsurfaced test items will be based on elastic deflection under load and permanent deformation or rutting. When the elastic deflection exceeds 1.5 in. or rutting exceeds a 3-in. depth, the test item will be judged as failed. A maximum allowable rolling resistance in percent of wheel load may also be incorporated in the failure criteria.

Failure of the mat-surfaced test items will be judged on the basis of (a) development of roughness and (b) excessive mat breakage. When surface deviations from a 10-ft straightedge equal or exceed 3 in. in any direction within the traffic lane, the test item will be considered failed due to roughness. When mat breakage develops in 10 percent or more of mat panels within the traffic lane to the extent of producing tire hazards or endangering aircraft operations, the test item will be considered failed. This will allow for a 10 percent mat replacement during the period of traffic.

TABLE VII

SCHEDULE OF TESTS

Tire Size	Inflation Pressure (psi)	Contact Area (sq in.)	Single-Wheel Load (lb)	Wheel Configuration	Assembly Load (lb)	Wheel Spacing (radii)	Subgrade Strength (CBR) Unsurfaced	M8	T11
8.50-10	10*	100	1,000	Single	1,000	--	1	--	--
	20*	50	1,000	Single	1,000	--	1	--	--
	30	33.34	1,000	Single	1,000	--	1	--	--
	30	33.34	1,000	Single	1,000	--	1	--	--
	30	33.34	1,000	Single	1,000	--	1	--	--
	40	25.00	1,000	Single	1,000	--	1	--	--
8.50-10	40	50.00	2,000	Single	2,000	--	2	--	--
	60	33.34	2,000	Single	2,000	--	2	--	--
	80	12.50	2,000	Single	2,000	--	2	--	--
25.00-28	10	1,000	10,000	Single	10,000	--	3	--	--
	15	1,000	15,000	Single	15,000	--	4	--	--
	20	1,000	20,000	Single	20,000	--	4	--	--
	25	1,000	25,000	Single	25,000	--	4	--	--
56x16**	200	175.00	35,000	Single	35,000	--	20	8	4†
	200	175.00	35,000	Twin	70,000	3.0	20	8	4†
	200	175.00	35,000	Twin	70,000	4.5	20	8	4†
	200	175.00	35,000	Twin	70,000	6.0	20	8	4
	200	260	52,000	Single	52,000	--	20	4	4
	200	260	52,000	Twin	104,000	3.0	20	4	4
	200	260	52,000	Twin	104,000	4.5	20	4	4
	200	260	52,000	Twin	104,000	6.0	20	4	4
20.00-20	100	350	35,000	Single	35,000	--	10	4	2
	100	350	35,000	Twin	70,000	3.0	10	4	2
56x16	100	350	35,000	Twin	70,000	4.5	10	4	2
	100	350	35,000	Twin	70,000	6.0	10	4	2
	100	350	35,000	Twin-Twin	140,000	4.0	10	4	2
	100	350	35,000	Single-Tandem	70,000	4.0	10	4	2
	100	350	35,000	Twin-Tandem	140,000	4.0	10	4	2
25.00-28	50	700	35,000	Single	35,000	--	8	4	2
	50	700	35,000	Twin	70,000	3.0	8	4	2
	50	700	35,000	Twin	70,000	4.5	8	4	2
	50	700	35,000	Twin	70,000	6.0	8	4	2
25.00-28	100	250	25,000	Single	25,000	--	8	--	--
56x16	100	250	25,000	Single	25,000	--	8	--	--
17.00-16	100	250	25,000	Single	25,000	--	8	--	--
34x9.9	100	250	25,000	Single	25,000	--	8	--	--
20.00-20	100	300	30,000	(12 wheels	360,000	3.0	8	4	2
	75	400	30,000	configuration	360,000	3.0	8	4	2
				will be de-					
25.00-28	60	500	30,000	termined)	360,000	3.0	8	4	2
	40	750	30,000		360,000	3.0	8	4	2

* These tests will be repeated with an extra wide tire if this appears desirable as the test program progresses.

** These tests will be conducted as part of a related study. Only spot-check tests with 200-psi tires will be included in this program.

† These tests have been completed on T11 mat as part of a related study.

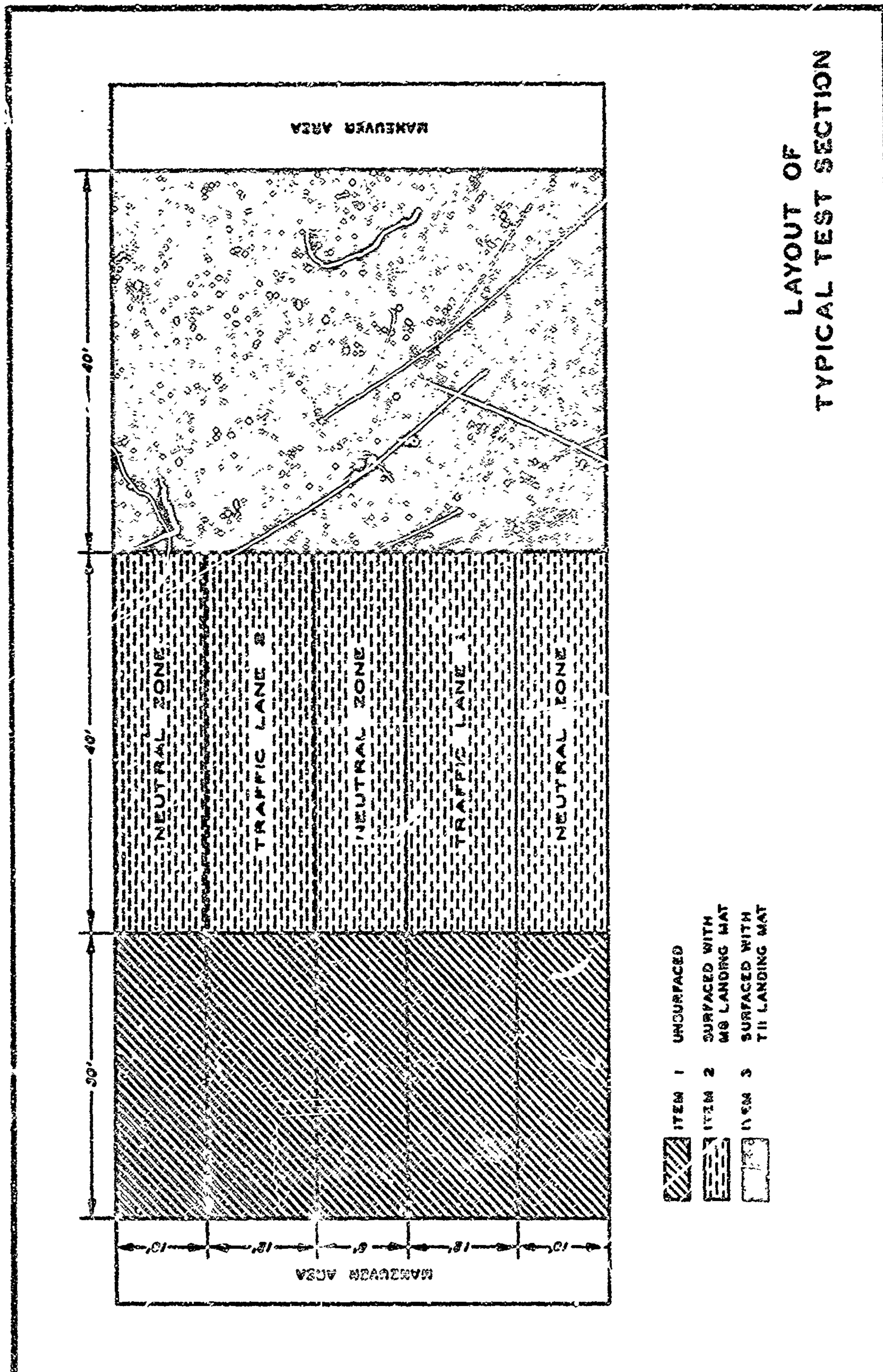

LAYOUT OF
TYPICAL TEST SECTION
MANEUVER AREA
40'
40'
30'
NEUTRAL ZONE
TRAFFIC LANE 2
NEUTRAL ZONE
TRAFFIC LANE 1
NEUTRAL ZONE
ITEM 1 UNSURFACED
ITEM 2 SURFACED WITH M8 LANDING MAT
ITEM 3 SURFACED WITH T11 LANDING MAT
10'
18'
6'
18'
10'
MANEUVER AREA

Figure 44

APPENDIX II: DEFORMATIONS AND DEFLECTIONS

Deformations and deflections reflect the general shape or condition of the surface of a test section and are used in judging failure conditions. Definitions of and procedures for determining the various types of deformations and deflections are given in the following paragraphs.

Deformation

Deformation is the difference between the elevation of a point on the surface of a test section prior to trafficking and the elevation of the same point after a specified number of traffic coverages. Generally, the points of elevation are along a line perpendicular to the direction of traffic (known as cross-section deformations) or parallel to traffic (profile deformation). A typical cross-section deformation is determined as follows (Figure 45): Points A, B, C, D, and E are points on the surface of a test section. Theoretically, the surface is uniformly horizontal prior to the application of test traffic, but due to irregularities in the surface of the test section, small differences in elevation exist. As traffic is applied, the test surface is deformed and the relative positions of the points change in a vertical direction to A', B', C', D', and E'. The differences between the elevations of points A through E and A' through E' are equal to a, b, c, d, and e, respectively. These values are then plotted from a common line, as shown in Figure 45(b), in order to illustrate graphically deformation of surface along the particular line selected.

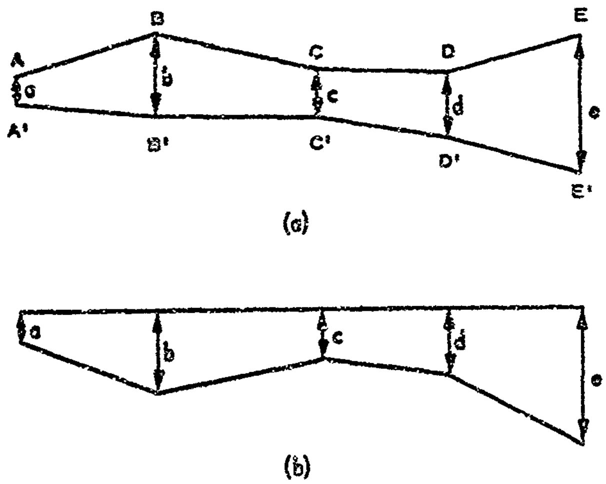


Figure 45. Cross-section deformation measurements

Deflection

a. Total deflection. Total deflection is the difference between the elevation of a point on the surface of a test section as it exists at any coverage level and the elevation of the same point when a static test load is applied. Deflection generally is measured at points directly under the load wheel or assembly and at specified intervals on either side. For example, in Figure 46 deflection is measured at point C under the load wheel, and at points A, B, D, and E on either side of the load wheel. Prior to application of the static load, points A, B, C, D, and E

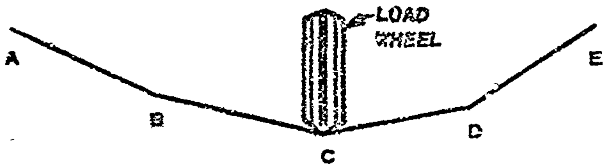


Figure 46. Deflected surface of test section

on the test surface appeared as in Figure 47(a). With the static test load applied at point C (large arrow), the surface deflects vertically, changing the positions of these points to A', B', C', D', and E', respectively. The differences in elevations between points A through E and A' through E' are a, b, c, d, and e, respectively. These values are then plotted from a common line as in Figure 47(b) in order to illustrate the total deflection caused by the static application of the test load.

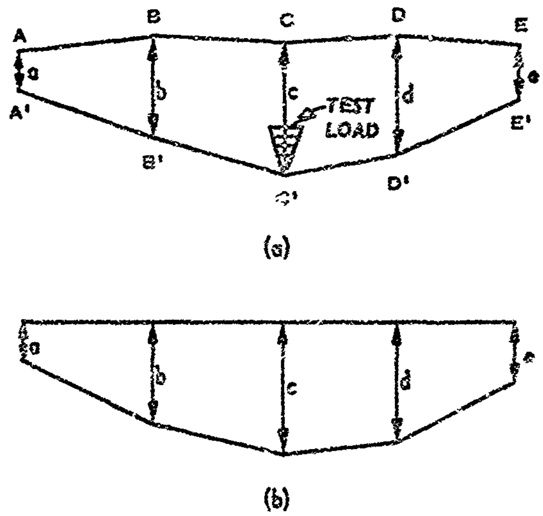


Figure 47. Illustration of total deflection measurements on landing mat

b. Elastic deflection and permanent deformation. In the measurement of total deflection on metal landing mats, it is assumed that for all practical purposes the surface of the test section returns to its original shape and elevation upon removal of the static load; thus, the total deflection also is considered to be an elastic deflection for that particular surface. For an unsurfaced plastic soil, however, this assumption generally is invalid because there is a significant permanent deformation as well as an elastic deflection upon application of the static load. Permanent deformation is caused by rutting or soil consolidation and failure of the soil to rebound fully to its original elevation. Total deflection, therefore, is the sum of the permanent deformation and elastic deflection. This is illustrated in Figure 48. The original elevation of a soil surface, A, is shown in Figure 48(a). The soil is deflected

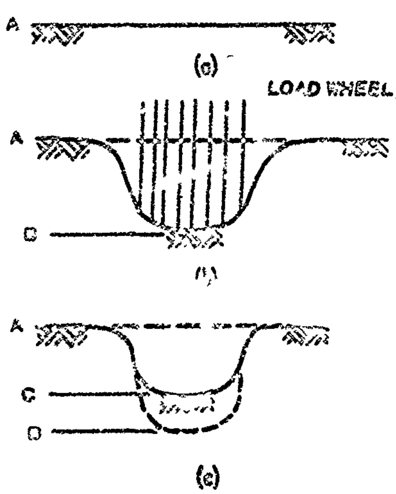


Figure 48. Illustration of total deflection on unsurfaced soil

compressed by a load wheel (Figure 48(b)) until it reaches a maximum deflection at B. The soil surface then rebounds to C after the load wheel is removed (Figure 48(c)). In terms of deflection, the total deflection in this case is equal to A - B. Elastic deflection is equal to C - B, and permanent deformation is equal to A - C. In deflection measurements on unsurfaced soils, total deflections on either side of the load wheel are determined in the same manner as on metal landing mats, and these values are plotted from a common line.

c. Deflection under load wheel. The method of measuring deflection directly under a load wheel obviously must differ from the procedure used to determine deflection on either side of the wheel. On a subgrade covered by a metal landing mat this value generally is determined by extrapolation of the curve established by the deflection of points on either side of the load wheel. In Figure 49 below, the total deflections at points A, B, D, and E are determined as described in the preceding paragraphs, and the total deflection at point C is determined by extrapolation of deflection data concerning AB and DE. On unsurfaced soils, however, both total and elastic deflection measurements are made directly under the load wheel. This method involves a steel pin and cap, the elevation of which must be determined before and after the static load is applied. Specifically, the procedure is as follows (Figure 50):

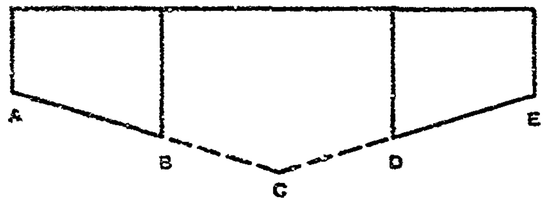


Figure 49. Illustration of deflection measurements under wheel load on landing mat

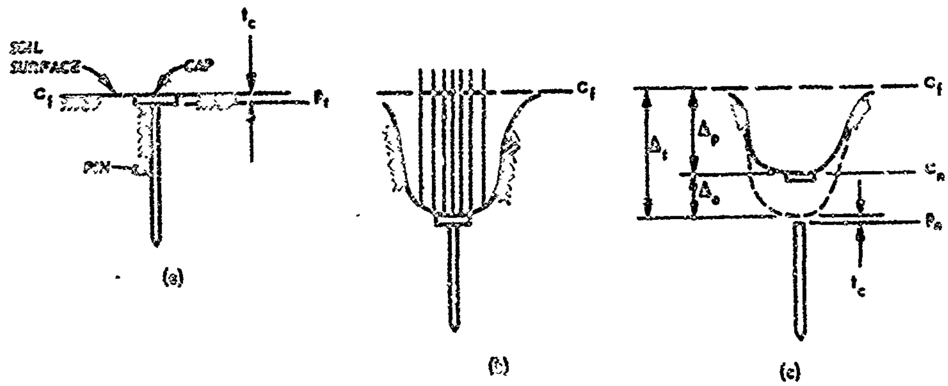


Figure 50. Illustration of deflection measurements under wheel load on unsurfaced soil

In Figure 50(a) the original ground level is designated C_f. A steel pin is forced into the soil with the top of the pin, P_f, slightly below grade level. A steel cap is then placed on the pin and both are forced down until the top of the cap is flush with the soil surface. The elevation of the cap top is also designated C_f. The difference between C_f and p_f is the cap thickness, t_c, or $t_c = C_f - p_f$. In Figure 50(b), the load wheel is applied over the cap and pin, deflecting the soil downward. This is the position of maximum or total deflection. In Figure 50(c), the load wheel has been removed and the soil has rebounded with the cap, leaving the pin embedded at the position of maximum deflection, p_n. Note that p_n is the elevation of the top of the pin, not the soil, which is slightly above the pin top at maximum deflection due to cap thickness. The soil does not rebound to its original position, C_f, but now is slightly lower at C_n (measured at the top of the cap). The difference between the elevation of the cap top at C_f and at C_n is the permanent deformation and is designated Δ_p.

$$\Delta_p = C_f - C_n \tag{1}$$

The total deflection, Δ_t, is the difference between the original elevation of the soil and the elevation of the soil at the maximum deflection (Figure 50(b) and 50(c)). This deflection is calculated by taking the difference between the pin elevation at p_f and p_n. The mathematical expression is derived as follows:

$$\Delta_t = (C_f - p_n) - t_c \tag{2}$$

$$\Delta_t = (C_f - p_n) - (C_f - p_f)$$

$$\Delta_t = p_f - p_n$$

From equations 1 and 2, the elastic deflection, Δ_e, can be obtained as follows:

$$\Delta_e = \Delta_t - \Delta_p \tag{3}$$

$$\Delta_e = (p_f - p_n) - (C_f - C_n)$$

This method of determining soil deflections is normally limited to unsurfaced soils and pierced metal mats; however, it can be used with solid sheet metal mats by cutting an access hole in the mat. When used with metal mats, the top of the cap, C_f, is adjusted to the elevation of the mat, not that of the subgrade.

Dishing

Dishing is a deformation measurement applied only to metal landing mat. It is a measure of the deformation of a single panel and is determined by measuring the maximum departure of the mat panel from a straightedge placed across the width of the panel. A dishing measurement is illustrated in Figure 51.

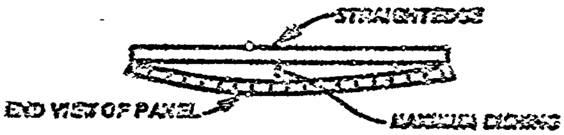


Figure 51. Illustration of dishing

Differential deformation

Differential deformation is a measure of the roughness of a test section. The measurement is made by placing a straightedge 10 ft long on the surface of the test section and measuring the maximum vertical departure of the surface from the straightedge between any two points at which the straightedge rests on the surface (Figure 52). Normally, this measurement is made with the straightedge placed in three different positions: along the direction of traffic, termed longitudinal differential deformation; perpendicular to the direction of traffic, transverse differential deformation; and in a position diagonally across the direction of traffic, diagonal differential deformation.

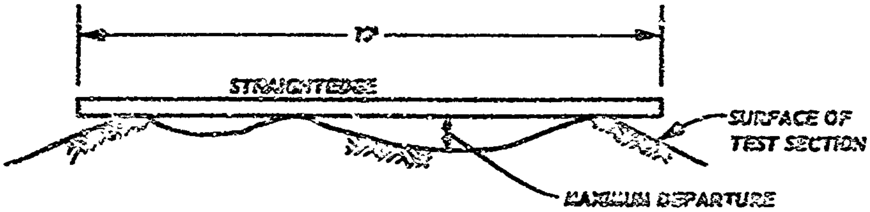


Figure 52. Illustration of differential deformation measurements

Rutting

Another type of deformation measurement in unsurfaced soils is the determination of rut depth. Generally, a rut is the deformation resulting from soil shear displacement caused by an individual tracking tire and has the general cross-sectional configuration shown in Figure 53. In

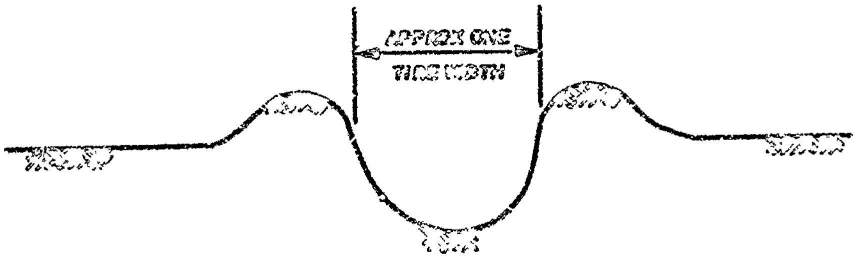


Figure 53. Illustration of rutting

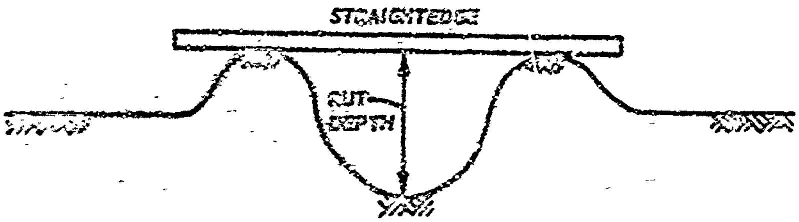


Figure 54. Illustration of rut depth measurements

this case, the rut width is equal approximately to the width of the tracking tire. Measurement of rut depth in this case is performed as follows: a straightedge is placed on the shoulders of the rut as shown in Figure 54, and the maximum vertical distance from the lower edge of the straightedge to the bottom of the rut is measured. Frequently, however, due to such factors as the spacing of the load wheels in multiple-wheel assemblies or the influence of the tracking cart outrigger wheels, a rut as distinguishable as the type shown in Figure 53 is not evident. Instead, although the general shape of a rut is present, the width of the individual deformed area is two to three times the tire width. A configuration of this type of compound rut is shown in Figure 55. Determination of the width of the rut in this case is a matter

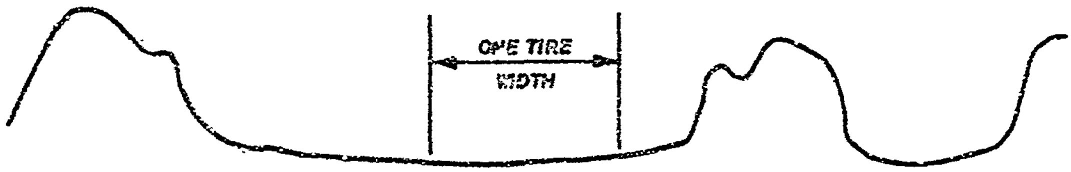


Figure 55. Illustration of compound rut

of judgment. If the rut width is limited to one tire width, as shown in Figure 55, the rut depth will be zero. Obviously this is erroneous because the soil surface is quite rutted. Therefore, in the measurement of the depth of a compound rut, a straightedge is placed so that the ends rest on the closest prominent soil ridges or shoulders, as shown in Figure 56, and

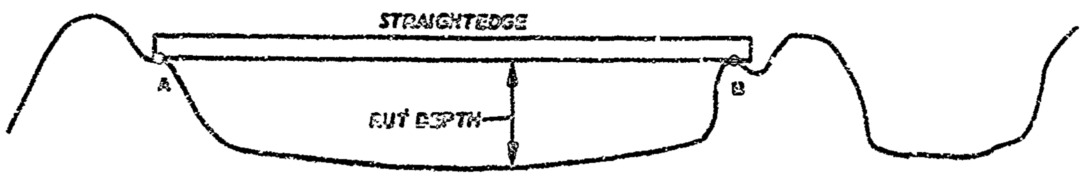


Figure 56. Illustration of rut depth measurement

the rut depth is measured as the maximum distance from the lower edge of the straightedge to the bottom of the deformed area. Obviously, as the distance between closest prominent soil ridges, AB , approaches 10 ft, the measurement is no longer a rut depth determination but becomes a measure of transverse differential deformation. Therefore, the criterion for the maximum allowable distance AB is three times the tire width. If the distance between closest prominent soil ridges exceeds three times the tire width, the measurement is made with a 10-ft straightedge and is called the transverse differential deformation, in which case the rut depth will be zero. Soil deformation in this case is attributed to general consolidation of the soil rather than rutting.

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13. ABSTRACT

The Flexible Pavement Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., has conducted a series of tests to establish aircraft ground-flotation criteria with special emphasis on developing criteria for the C-5A aircraft. This report presents an analysis of data collected as a result of traffic tests on unsurfaced soils and soils surfaced with M8 and T11 landing mat. Also presented are introductory and background information on the Waterways Experiment Station ground-flotation research program, a description of the test equipment, materials, procedures, and techniques used, and examples of use of the criteria.

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