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# HIGHSPEED FREIGHT TRAIN RESISTANCE ITS RELATION TO AVERAGE CAR WEIGHT

BY
JOHN K. TUTHILL

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JOHN K. TUTHILL

Associate Professor of Railway Electrical Engineering

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## ABSTRACT

This bulletin presents values of freight train resistance at train speeds of 40 to 70 mi. per hr. The principal data were obtained in 1937 during a series of locomotive tests on the main lines of the Illinois Central System. Many lowspeed train resistance values were calculated in order to check the results given in Bulletin No. 43 of the Engineering Experiment Station.

The final results of this research are given in the form of a series of curves — Figs. 4 and 5 on pages 28 and 29; in the form of Equations (1)–(12) on pages 27 and 30; and also in Tables 3 and 37 on pages 30 and 77 for anyone desiring to plot large graphs in order to read train resistance values more accurately.

This bulletin contains no description of the railway dynamometer car used in the investigation, since a complete history of University of Illinois dynamometer cars may be found in Circular No. 52, "The Railroad Dynamometer Car of the University of Illinois–Illinois Central Railroad," a publication of the Engineering Experiment Station.

That circular describes in detail most of the important pieces of equipment used in a dynamometer car for obtaining train resistance values or for locomotive testing and tonnage ratings, sets forth the method of calibrating some of the instruments, and explains the manner in which wind direction and velocity measurements are made.

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# HIGHSPEED FREIGHT TRAIN RESISTANCE: ITS RELATION TO AVERAGE CAR WEIGHT

## I. Introduction

1. *Preliminary Statement.*—In 1910 the Engineering Experiment Station published, as Bulletin No. 43, the results of a series of tests on freight train resistance conducted under the direction of the late Professor Edward C. Schmidt, then head of the Department of Railway Engineering of the University of Illinois.* The bulletin demonstrated that train resistance — defined as the resultant of all the forces opposing the movement of a train when operating at constant speed on a straight and level track and in still air — varies not only with the train speed but also with the average weight of the cars making up the train.

Since 1910 a large number of railways have applied these principles in establishing their tonnage ratings. There has resulted the "adjusted" or "equated" method of train loading, whereby the actual weight of the train allotted to a particular type of locomotive varies according to the number of cars in the train. In other words, the rating varies with respect to the average car weight. Though the speed range reported in Bulletin No. 43 was only 5–35 mi. per hr., it was sufficient to permit the computation of maximum locomotive ratings by those railroads desiring to have full-tonnage trains.

Changes in the conditions under which railroads operated have of course changed the nature of the problems they confronted. For example, during the period of light traffic from 1930 to 1939 few roads were greatly interested in hauling trains of maximum tonnage; the load was reduced in order to increase train speed. Many freight trains operated on fast passenger schedules, resulting in high maintenance costs and other problems not encountered in lowspeed movements.

Again, during World War II the Office of Defense Transportation issued, as a conservation measure, orders limiting the speed of freight trains. Many other regulations, particularly that which required maximum car loading, could not but affect greatly the problem of tonnage rating. With the maximum speed of freight trains limited to a low figure, many railroads undoubtedly desired to operate those trains at the highest permissible speed over the greater part of each division.

2. *Purpose and Scope of Bulletin.* — Now that World War II has ended, it may be desirable to run many highspeed freight trains in

* The original issue being exhausted, a reprint (1934; still available) was published of the essential parts of the bulletin.

order to meet competition from truck and air freight lines. It is with this thought in mind that the present bulletin is published.

Maximum tonnage ratings at any speed up to 70 mi. per hr. for all divisions of a railroad may be readily calculated from the results of the investigation herein reported, and especially from the curves of Figs. 4 and 5. The sole requisites are that the profile of the road and the characteristics of each class of locomotive be known.

The data presented in this bulletin were obtained in a series of tests conducted by members of the Railway Engineering Department of the University of Illinois for the Illinois Central Railroad in the summer of 1937, while making performance tests on several steam locomotives. Though most of the data were used for a dual purpose, the results set forth herein have nothing directly to do with the locomotive tests.

The fact that the locomotives were tested at all speeds, especially in the higher ranges, accounts for the many highspeed runs reported.

Though 86 locomotive performance tests were made (during the summer of 1937), only 14 are here reported in full. A considerable amount of data, however, are used from many of the unreported tests, in order to verify the slope of some of the curves at the higher speeds; data of this kind are shown in Fig. 8.

This bulletin may be considered as a sequel to Bulletin No. 43 not only in subject-matter but in presentation. To facilitate comparison between the results of the former investigation and of this, the curves and tables herein, as well as textual material so far as possible, follow the pattern of arrangement used in Bulletin No. 43.

In the first part of this report, as in Bulletin No. 43, the aim has been to present clearly and briefly the conditions under which the tests were made and the results were obtained. The final results are exhibited in Figs. 4 and 5, in Tables 3 and 37, and in Equations (1)–(12). A summary of the conditions under which the tests were conducted, and the conclusions, are on pages 17 and 32. The second part contains six appendixes for those wishing to verify, or to make a detailed study of, the results and conclusions set forth in Part I. The conditions of the track and the exact locations of track sections are stated, as are weather data and train make-up for each test.

The present bulletin does not, however, deal with the history, construction, and operation of the dynamometer car owned jointly by the University of Illinois and the Illinois Central Railroad nor with the nature and the calibration of its essential and auxiliary equipment.

Those matters are treated fully in Circular No. 52 of the Engineering Experiment Station, which can therefore serve as an instructional manual for operators of the car and as a guide for anyone planning to build a new test car or add to existing equipment.

3. *Acknowledgments.* — This investigation is a part of the research work of the University of Illinois Engineering Experiment Station and of the Department of Railway Engineering. The late PROFESSOR EDWARD C. SCHMIDT was head of that department at the time the tests were conducted.

## II. Summary and Conclusions

4. *Summary.* — This report deals with the results obtained from tests of 25 ordinary freight trains in regular traffic, whose chief characteristics were as follows:

| | Minimum | Maximum |
|---|---|---|
| Total weight, tons | 1002 | 5321 |
| Average weight per car, tons | 25.69 | 72.73 |
| Number of cars in train | 26 | 112 |
| Train length, ft. | 1125 | 5084 |

The trains whose average car weights were approximately 25 tons and 72 tons were composed of cars of nearly uniform weight; the others, of cars of various weights.

The weather during the tests was generally fair and from warm to hot. The minimum air temperature during any test was 52 deg. F., the maximum 96 deg. F. The daily average wind velocity prevailing throughout one test was 26.3 mi. per hr.; during all other tests it varied from somewhat less than 25 mi. per hr. down to 2.9.

The track sections upon which the tests were made consisted of 110-lb. and 112-lb. rail, laid mostly on broken stone, slag, or gravel ballast. The track was well constructed and well maintained.

5. *Conclusions.* — The results of the tests are presented in Figs. 4 and 5 on pages 28 and 29; in Table 2 on page 24; and in the equations on pages 27 and 30. The curves, table, and equations are all different expressions of the same facts. It is reasonable to assume that by their application the probable speed resistance of entire freight trains at various high speeds may safely be predicted when they are running upon a straight and level track of good construction during weather of an outside temperature above 52 deg. F. and wind velocity of not more than 26 mi. per hr., provided that the average weight of the cars composing the train is known.

During the tests no effort was undertaken to make up a train in any definite manner; the results are therefore applicable to trains of all varieties of make-up that are met with in regular service and, without appreciable error, to trains composed of cars identical or different in average weights.

All results presented herein were gathered after the train had been in motion for some time and are applicable primarily to such trains. This factor is important if the ruling grade was located near the starting point or close to a regular road stop, since the starting resistance of trains is several times their normal resistance.

Variations in make-up or in external conditions outside the limits to which the tests apply will naturally cause some trains to have a higher resistance than is indicated in Figs. 4 and 5. The individual tests show that, for the same train, resistance varies at different points along the track. On the whole, this variation should be about 8 to 10 per cent. When rating locomotives for high speeds, the occasional excess in the resistance of individual trains will not be serious, since it will lead to only a slight variation in running time. If ratings are made for speeds below 15 mi. per hr., however, the excessive resistance might cause a train to stall on a ruling grade. The tonnage should therefore be reduced to allow for an average excess of 9 per cent in train resistance. An opposing wind should also necessitate a reduction in the train tonnage.

## III. Methods Employed in Conducting the Tests

6. *Test Car No. 30.* — The tests were carried on by means of the dynamometer car designated as Test Car No. 30, which was in operation nearly every day during the summer of 1937, when the tests were being made. When not in use, the car is held at the Burnside Shops of the Illinois Central Railroad in Chicago.

The plan of investigation was to determine, for each of the trains experimented upon, the relation of resistance to speed. The results of each test were to be expressed finally as a resistance–speed curve such as is shown in Fig. 1 and in the similar figures for other tests which are given in Appendix D. Though 86 trains were tested during the period of experimentation, for the present investigation there were selected only a sufficient number whose average car weight varied throughout as great a range as was possible — from 40,000 to 210,000 lb. for individual cars and from 51,380 to 145,460 lb. for the average car weight of all the trains chosen.

7. *Observed Data.* — During each test, continuous graphic records were produced on the test car recorder charts. They gave the following information:

(a) The drawbar pull exerted by the locomotive upon the train.

(b) The train speed.

(c) The time elapsed from the beginning of the test, in 5-sec. and 1-min. intervals.

(d) The pressure existing in the brake cylinder of the test car.

(e) The direction of the wind relative to the direction of motion of the car.

(f) The velocity of the wind relative to the car.

(g) A mile post record giving the location of the test car upon the track.

(h) Steam pressure in the cylinder chest.

On the record chart, lines were drawn upon which the operator recorded the following data from information received over a Laryngaphone telephone set from an observer on the locomotive:

(i) Boiler pressure.

(j) Steam chest pressure.

(k) Back pressure.

(l) Throttle opening.

(m) Reverse lever positions.

For each train tested the following data were known:

(n) Weight of each car.

(o) Number of cars making up the train.

(p) Weather conditions, air temperature, etc.

The curves of drawbar pull and speed provide the important information upon which this investigation is based. Enlarged and accurate profiles of the track sections selected for the tests were available; these, together with the train weights, permitted calculation of the net train resistance values. Since the record chart is geared to the car wheels and runs proportionally to the distance traveled, the time record provides a means of calibrating and checking the speed curve. In fact, if the speed is fairly uniform, speed values may be obtained from the time record. The record of brake cylinder pressure was made in order to identify those sections of the test chart covering the application of brakes to the train, so that such parts of the test could be eliminated when making calculations.

The relative direction and velocity of the wind with respect to the car were obtained by means of a U. S. Weather Bureau Pattern anemometer and wind vane mounted on the roof of the test car. The true values of wind direction and velocity are found by combining vectorially the relative values with the known speed and direction of travel of the car.* In Appendix D there are recorded for each test the actual velocity and direction of the wind with respect to the track for each track section at which train resistance was calculated. The mile post record enables the test car to be located at any point on the road. Whenever the car passed a mile post or an order board at a station, an observer on the car pushed a button, closing an electric circuit which made an offset on a line on the record chart. The recorder operator wrote, on the chart opposite the line offset, the mile post number or the name of the station. This record permits correlating the position of the train at any instant with the track profile.

With few exceptions the tonnage figures were taken from individual scale weights of each car.

All test car instruments were calibrated before the test began and were checked frequently during its progress. It has been found that the calibration of the springs used in the drawbar pull recorder has not varied appreciably during the thirty-nine years the recorder has been in use.

Eighty-six trains were tested during the investigation, a part of which is herein reported; this bulletin includes data on 25 trains, and

* Complete instructions, and a diagram showing the method to be used in determining wind direction and velocity, are given in Circular No. 52 of the Engineering Experiment Station. That publication also contains illustrations of both the exterior and the interior of the test car as it appeared just before the tests of 1937 were made, together with a complete and detailed description of the new car built in 1943. The circular describes the new recorder installed on this car, the auxiliary apparatus, the method of calibration, and the operation of the equipment.

results of tests made on these. Many of the 61 trains not recorded herein were in the same weight range as those reported and gave results in good agreement with those set forth herein.

Some of the 61 were excluded because they were lowspeed trains that seldom reached 40 mi. per hr. (Many results from these slow runs were used, however, to verify the results published in Bulletin No. 43.) Difficulty was experienced in getting train speeds above 55 or 60 mi. per hr. from which train resistance values could be calculated. To eliminate errors so far as possible, calculations were made only when the entire train was on a uniform grade. Having been informed that, though high speeds were desired, trains should at all times be under control and be operated safely, the locomotive engineers often shut off the throttle, when moving on a down grade, before the train was wholly on a uniform grade. Thus many records were useless for the present investigation. Both the "throttle opening" and "steam chest pressure" records on the chart indicate the sections of unusable record.

## IV. Test Conditions and Train Data

8. *Trains Tested.* — The test trains consisted of every type of car used in freight service and represented normal traffic conditions that exist on most American railroads. Care was taken to load the trains with a tonnage which would permit the locomotive to develop the desired average speed over the various divisions of the railroad. Every train was inspected before it left the yards, and a careful watch was maintained to detect hot journals and other failures in car equipment.

All cars of every train were provided with four-wheel trucks and waste-packed journals. No car journals were equipped with roller bearings. It was not deemed necessary to know the size of any car journals or diameter of car wheels, since it was desired to have this investigation apply to the average car or train.

9. *Track.* — The tests selected for this investigation were carried out on the Kentucky Division of the Illinois Central Railroad between Fulton, Kentucky, and Memphis, Tennessee, and between Fulton and Paducah, Kentucky; and on the Illinois Division between Champaign and Chicago, Illinois. Sections of track were selected from an enlarged profile of the road where the grades were uniform, the track was in good repair, and no curvature existed. In every test the entire train was on the uniform grade, it was running at a fairly constant speed, and the locomotive was exerting a reasonably constant drawbar pull. Having the train on a uniform grade will eliminate any contention that the position of the loaded cars in the train will affect the drawbar pull of the locomotive, which in turn would affect train resistance values.

Tables 18 – 22 of Appendix B give the location of each track section upon which tests were conducted, the length of the sections, and the grade in per cent. The "Section Locations" refer to the mile posts along the track. On the Illinois Division the mileage is measured from Chicago; on the Kentucky Division the mile posts refer to the distance from Louisville, Kentucky.

The tracks on which the tests were conducted are ballasted with broken stone, slag, or gravel and all sections were in excellent condition.

The Illinois Division tracks were laid with 110-lb. rail; the Fulton – Paducah sections with 90-lb.; the Fulton – Memphis line with 110-lb. and 112-lb. rail. The cross-ties were mostly of creosoted pine, laid 20 in. center-to-center. Additional details regarding the track are given in Appendix B.

TABLE 1
SUMMARY OF TEST CONDITIONS AND TRAIN DATA

| Test No. Laboratory Serial No. | Test Date | Weather Conditions | | | | Train Data | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Approx. Average Temp., deg. F. | Average Wind Velocity, m.p.h. | Range of Wind Direction with Respect to Track | | Train Length, feet | Weights | | Number of Cars in Train | Conditions of Loading | |
| | | | | from | to | | Gross Weight, tons | Average Gross Wt. per Car tons | | Number of Empty Cars | Number of Loaded Cars |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| S-1101 | 7-12-37 | 82 | 12.5 | +62°R | +32.8°R | 4028.6 | 2158 | 25.69 | 84 | 77 | 7 |
| S-1102 | 6-28-37 | 77 | 13.7 | +63.5°L | +58.0°L | 5084 | 2926 | 25.88 | 112 | 112 | 0 |
| S-1103 | 7-13-37 | 84 | 4.6 | −81.0°R | +76.0°R | 3363.3 | 2015 | 29.64 | 68 | 48 | 20 |
| S-1104 | 6-24-37 | 84 | 14.1 | +86.5°R | +48.0°R | 1927.2 | 1500 | 37.50 | 40 | 8 | 32 |
| S-1105 | 7-23-37 | 81 | 5.9 | +58.0°R | +32.0°R | 1125 | 1002 | 38.53 | 26 | 4 | 22 |
| S-1106 | 7-23-37 | 81 | 4.3 | +78.5°R | −63.0°R | 1160.5 | 1056 | 39.11 | 27 | 4 | 23 |
| S-1107 | 6- 3-37 | 68 | 6.1 | +86.0°R | +27.0°R | 1837.4 | 1505 | 39.60 | 38 | 1 | 37 |
| S-1108 | 7-16-37 | 81 | 10.5 | 90.0°L | +46.0°R | 2254.5 | 1927 | 41.00 | 47 | 3 | 44 |
| S-1109 | 6-28-37 | 77 | 20.5 | +74.0°L | +37.0°L | 1246 | 1136 | 43.69 | 26 | 2 | 24 |
| S-1110 | 7- 5-37 | 81 | 10.2 | +27.0°L | −68.5°L | 1584 | 1468 | 44.48 | 33 | 1 | 32 |
| S-1111 | 7- 2-37 | 78 | 10.8 | +37.0°L | 0.0° | 2640 | 2606 | 47.38 | 55 | 4 | 51 |
| S-1112 | 6-27-37 | 85 | 16.7 | +75.5°L | +38.5°L | 2587.2 | 2647 | 49.01 | 54 | 3 | 51 |
| S-1113 | 7-22-37 | 80 | 9.9 | +72.5°R | −38.0°R | 2112 | 2296 | 51.18 | 50 | 12 | 38 |
| S-1114 | 7-24-37 | 81 | 2.9 | +75.0°R | −88.5°L | 2207.4 | 3346 | 72.73 | 46 | 4 | 42 |
| S-1115 | 9-16-37 | 60 | .... | ........ | ........ | 2608.6 | 2109 | 36.36 | 58 | 28 | 30 |
| S-1116 | 8-29-37 | 76 | 12.7 | 90.0°R | −83.0°R | 2581.0 | 2231 | 40.56 | 55 | 7 | 48 |
| S-1117 | 7-24-37 | 81 | .... | ........ | ........ | 3701.0 | 3889 | 45.22 | 87 | 3 | 84 |
| S-1118 | 6- 4-37 | 78 | 14.3 | +84.0°R | −86.0°R | 3432 | 3370 | 45.54 | 74 | 53 | 21 |
| S-1119 | 6-23-37 | 81 | 19.1 | +50.0°L | +28.5°L | 2930 | 3044 | 46.80 | 65 | 4 | 61 |
| S-1120 | 7-23-37 | 81 | .... | ........ | ........ | 3382 | 3712 | 46.98 | 79 | 4 | 75 |
| S-1121 | 6-25-37 | 86 | .... | ........ | ........ | 2340 | 2548 | 49.00 | 52 | 1 | 51 |
| S-1122 | 5-19-37 | 52 | 26.3 | −60.5°R | −41.0°R | 2428 | 2348 | 49.96 | 47 | 5 | 42 |
| S-1123 | 8-30-37 | 81 | 11.3 | +83.0°R | +61.0°R | 2970 | 3310 | 50.15 | 66 | 1 | 65 |
| S-1124 | 9-11-37 | 74 | 7.0 | +85.0°R | −67.0°R | 4080 | 5321 | 56.01 | 95 | 18 | 77 |
| S-1125 | 9-19-37 | 76 | 5.2 | −70.5°R | +60.0°R | 3320 | 5278 | 66.81 | 79 | 3 | 76 |

10. *Weather Conditions.* — The weather prevailing during this series of tests was normal for those sections of the country. Very few tests were made during a rainstorm, but in those few cases no variation in train resistance could be detected on that account. The temperature of the air varied from 52 deg. F. to 96 deg. F.

In Table 1 are listed the average daily temperatures during which the tests were conducted. At no time during any of the tests was the temperature low enough to prevent the lubricating oil in the car journals from flowing freely. During one test the average wind velocity reached 26.2 mi. per hr. but during all other tests it never exceeded 20.5 mi. per hr., while the average velocity for all tests was 11.6 mi. per hr.

## V. Methods Employed in Calculating Results

11. *General Process.* — The immediate purpose in making the calculations was to obtain for each train tested the necessary values of train resistance in order to plot a curve showing the relation between speed and resistance. The data essential for calculating the values of resistance are: the profile of the track, tonnage, train speed, and drawbar pull of the locomotive. Straight track sections were selected where the grade was uniform and of sufficient length to accommodate the entire train, thus eliminating all curve resistance and the necessity of determining the center of gravity of the train. The portions of the test car record made while running over the chosen track sections were inspected to see that the train was operating normally.

12. *Specific Methods.* — Parts of the test car record representing lengths of 100 ft. to 5280 ft. of track, where speed variations were small and the drawbar pull was fairly constant, were marked off for calculation purposes. The area under the drawbar pull curve was integrated in order to get an average ordinate that corresponded to the average pull of the locomotive. The average speed was taken as the mean of the speeds at the beginning and end of test sections. Using these values of speed and the length of the section enabled the values of acceleration to be calculated. Train resistance values, in pounds per ton, were found by dividing the drawbar pull of the engine by the tonnage of the train and then correcting for the values of acceleration resistance and grade resistance.

A few calculations of resistance were made when the speed and drawbar pull over the section were constant; they are listed as point values. Although the majority of the values of train resistance have been calculated at an average speed over a section of track, since the variations in speed have generally amounted to less than 2.0 mi. per hr. practically no errors would be introduced in the results if all resistances were considered point values.

13. *General Considerations.* — Great care was exercised in calculating acceleration resistance because even in freight train operation the drawbar pull required to accelerate a train may be greater than that required to overcome all other resistances combined. To produce, for example, an acceleration of 0.1 mi. per hr. per sec. requires a force of about 9 lb. per ton, in addition to that required to overcome train, grade, and curve resistance. The calculated results for acceleration resistance include both the force required to produce rotational

acceleration of the wheels and axles, and the force required to produce longitudinal acceleration of the train as a whole.

14. *Derivation of the Resistance Curves.*—There has been calculated, for each test, a series of values of train resistance at speeds mostly above 35 mi. per hr. These values of resistance were plotted against train speed, and gave such a diagram as Fig. 1. The curved line was located by arbitrarily arranging the plotted points into groups, determining the "center of gravity" of each group, and connecting these centers with a smooth line. In all train resistance – speed curves presented herein, the results taken from Bulletin No. 43 (plotted as broken lines) fit in perfectly with the present higher-speed resistance values. Many lowspeed resistance values were calculated; they checked with the results obtained in the earlier investigation, proving that those resistance values are still applicable to trains operating at the lower speeds.

The upper, or higher-speed, sections of the curves, show by the dashed lines or "a dash – two dots – and – a – dash" lines, represent estimated values of train resistance. Some of the points used in drawing the curves were filled in from the calculations after the train resistance formulas shown on pages 27 and 30 had been developed.

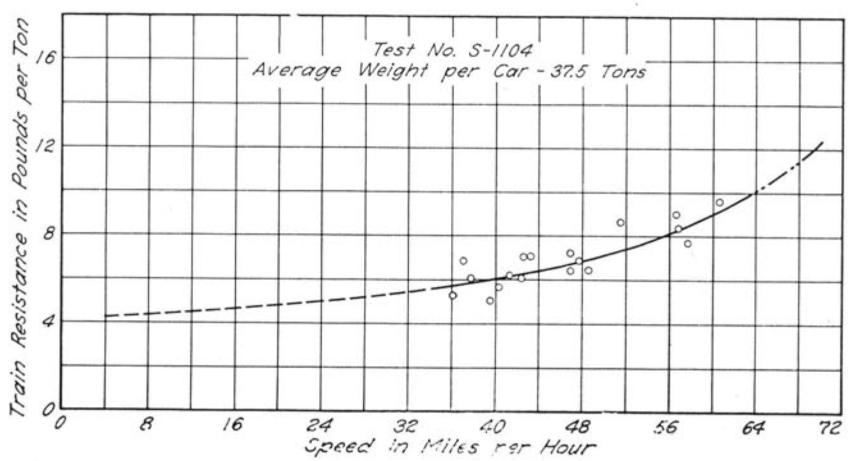



FIG. 1. RELATION OF RESISTANCE TO SPEED, TEST S-1104

## VI. Results of the Tests

15. *Results of the Individual Tests.*—The final result of each test is a curve showing the relation between train resistance and speed for the particular train tested. Figure 1 is such a curve derived from Test No. S-1104. Similar curves for the other tests are exhibited in Appendix D.

As expected, the plotted points show a marked increase in resistance as the speed is increased, but the rate of increase is much greater at the higher speed. In most of the tests the calculated values of train resistance vary through a rather large range from the mean values derived from the curves. This is not due to any errors in calculation but is probably the result of the combined action of those inherent elements of train resistance which vary greatly with the speed of the train. Variations in such components of train resistance as oscillatory, flange, and wind resistance would account for most of the fluctuations. The track structure would also tend to cause varied values of train resistance at high speeds, especially if there should be any deterioration of the roadbed or other defects in the track.

In Fig. 1 the maximum variation from the mean value represented by the curve is about 17 per cent, while the average of all calculated values differs from the mean by less than 8 per cent.

The variation between calculated and mean values of train resistance for each test was determined for speeds between 40 and 45 mi. per hr., 50 and 55 mi. per hr., and 60 and 65 mi. per hr., and the percentage variations were found. These percentages were arranged in two groups, one including all points above the curve and the other the points below the curve. The results are as follows.

Average Deviation (for All Tests) of Calculated Resistance from the Mean Values Derived from the Curves—Expressed in Percentage of the Mean Values

| Speed | Above the Mean | Below the Mean |
|---|---|---|
| 40 to 45 mi. per hr. | 10 per cent | 9 per cent |
| 50 to 55 mi. per hr. | 9 per cent | 13 per cent |
| 60 to 65 mi. per hr. | 8 per cent | 15 per cent |

The variations in the resistance values of most of the tests, though considerable, are in general not excessive for this type of experimental work. As stated before, when these results are used for highspeed tonnage rating purposes, the variation in resistance of any train from the mean values as presented here will result only in increasing the time required to complete a run. In no case would it result in stalling a train and tying up any portion of a railroad.

16. *Results of All the Tests.*—For comparison, the resistance curves of all 25 tests have been brought together on one sheet (Fig. 2). The curves are duplicates of those shown separately in Appendix D. The lower curve gives resistance values varying from 6 to 12.4 lb. per

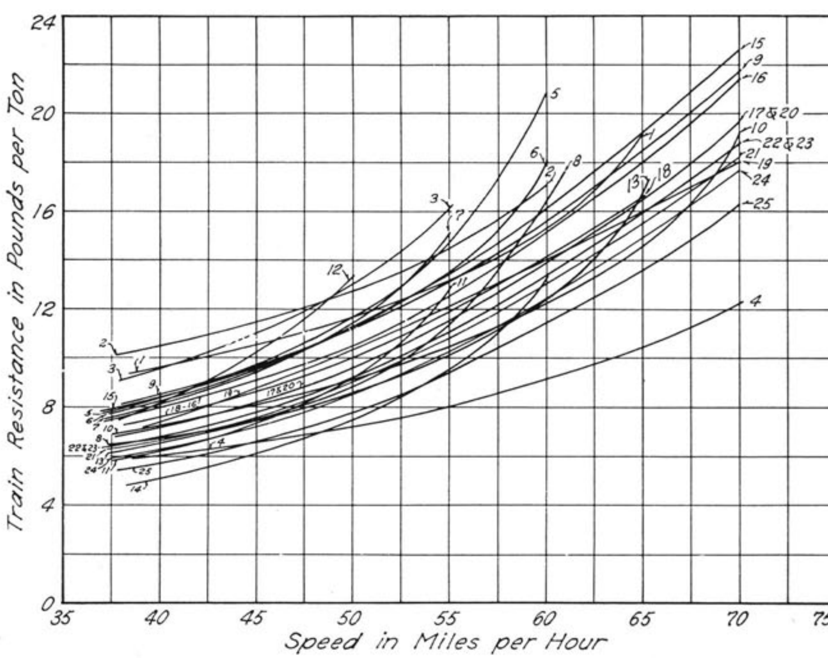



FIG. 2. RELATION OF RESISTANCE TO SPEED FOR EACH OF THE TESTS

ton; the upper curves show resistance values from 8.2 lb. per ton at 40 mi. per hr. to 22.6 lb. per ton at 70 mi. per hr. Train resistance values at the lower speeds differ by about 200 per cent, at higher speeds by 250 per cent.

Since most items affecting train resistance were almost constant during the period when the tests were made, except the average weight of the cars in the train, it is reasonable to assume that train resistance at any given speed varies inversely with average gross car weights.

TABLE 2

VALUES OF RESISTANCE AT VARIOUS SPEEDS, DERIVED FROM THE CURVES FOR THE INDIVIDUAL TESTS

This table provides the coordinates of the points plotted in Fig. 3

| Test No. | Average Weight per Car, tons | Train Resistance, lb. per ton | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 40 m.p.h. | 45 m.p.h. | 50 m.p.h. | 55 m.p.h. | 60 m.p.h. | 65 m.p.h. | 70 m.p.h. |
| S-1101 | 25.69 | 9.6 | 10.5 | 11.7 | 13.2 | 15.3 | 19.2 | .... |
| S-1102 | 25.88 | 10.4 | 11.4 | 12.7 | 14.4 | 17.0 | .... | .... |
| S-1103 | 29.64 | 9.6 | 11.0 | 13.0 | 16.1 | .... | .... | .... |
| S-1115 | 36.36 | 8.5 | 9.6 | 11.3 | (13.4) | (16.1) | (19.2) | (22.6) |
| S-1104 | 37.50 | 6.0 | 6.6 | 7.2 | 8.0 | 9.1 | 10.4 | 12.2 |
| S-1105 | 38.53 | 8.4 | 9.7 | 11.6 | 15.0 | 20.7 | .... | .... |
| S-1106 | 39.11 | 8.3 | 9.6 | 11.2 | 13.5 | 18.0 | .... | .... |
| S-1107 | 39.60 | 8.1 | 9.4 | 11.4 | 15.6 | .... | .... | .... |
| S-1116 | 40.56 | 8.0 | 9.0 | 10.4 | (12.5) | (15.1) | (18.1) | (21.4) |
| S-1108 | 41.00 | 6.7 | 7.5 | 8.9 | 11.4 | 16.4 | .... | .... |
| S-1109 | 43.69 | 8.5 | 9.6 | 11.2 | 13.1 | 15.6 | 18.5 | 21.7 |
| S-1110 | 44.48 | 7.3 | 8.1 | 9.2 | 10.4 | 12.2 | 14.6 | 19.2 |
| S-1117 | 45.22 | 7.1 | 8.2 | 9.6 | 11.5 | (13.9) | (16.6) | (19.7) |
| S-1118 | 45.54 | 7.6 | 8.6 | 10.0 | 11.9 | 14.1 | (16.6) | .... |
| S-1119 | 46.80 | 7.4 | 8.7 | 10.3 | 12.0 | (14.0) | (16.0) | (18.0) |
| S-1120 | 46.98 | 7.3 | 8.3 | 9.6 | (11.5) | (13.9) | (16.6) | (19.6) |
| S-1111 | 47.38 | 6.2 | 7.4 | 9.2 | 12.8 | .... | .... | .... |
| S-1112 | 49.01 | 8.2 | 10.1 | 13.4 | .... | .... | .... | .... |
| S-1121 | 49.11 | 6.6 | 7.6 | 9.0 | 10.8 | (12.9) | (15.5) | (18.2) |
| S-1122 | 49.96 | 6.8 | 7.8 | 9.2 | 11.0 | 13.3 | (16.0) | (18.8) |
| S-1123 | 50.15 | 6.8 | 7.8 | 9.1 | 10.9 | (13.2) | (16.0) | (18.9) |
| S-1113 | 51.18 | 6.5 | 7.4 | 8.6 | 10.2 | 12.4 | 17.0 | .... |
| S-1124 | 56.01 | 6.3 | 7.2 | 8.5 | 10.2 | (12.5) | (15.0) | (17.7) |
| S-1125 | 66.81 | 5.7 | 6.6 | 7.8 | 9.5 | (11.5) | (13.8) | (16.3) |
| S-1114 | 72.73 | 5.1 | 6.1 | 7.5 | 9.5 | 13.3 | .... | .... |

17. *Effect of Car Weight on Resistance.*—The upper curves of Fig. 2 are derived from records of trains made up of lightly loaded cars (25 – 40 tons); the lower curves, in general, from records of heavier cars (40 – 72 tons).

In Table 2 have been assembled data from the individual tests from which Fig. 3 has been plotted. These seven curves show the effect of average car weight on train resistance, the speed for each curve being the same. Resistance values at some of the higher speeds appearing in parentheses in Table 2 indicate that they are taken from those parts of the curve drawn from points obtained from equations but considered practically correct. As would be expected, there is some variation among the points of the curves of Fig. 3, but they indicate clearly a decrease in train resistance as car weight increases. The variations in resistance are no doubt caused by factors inherent in ordinary freight train operation, and when using these data in the solution of tonnage rating problems an allowance should be made in the locomotive tractive effort.

The curves of Fig. 3 are accepted as representing for this series of tests the mean relation between train resistance and average gross

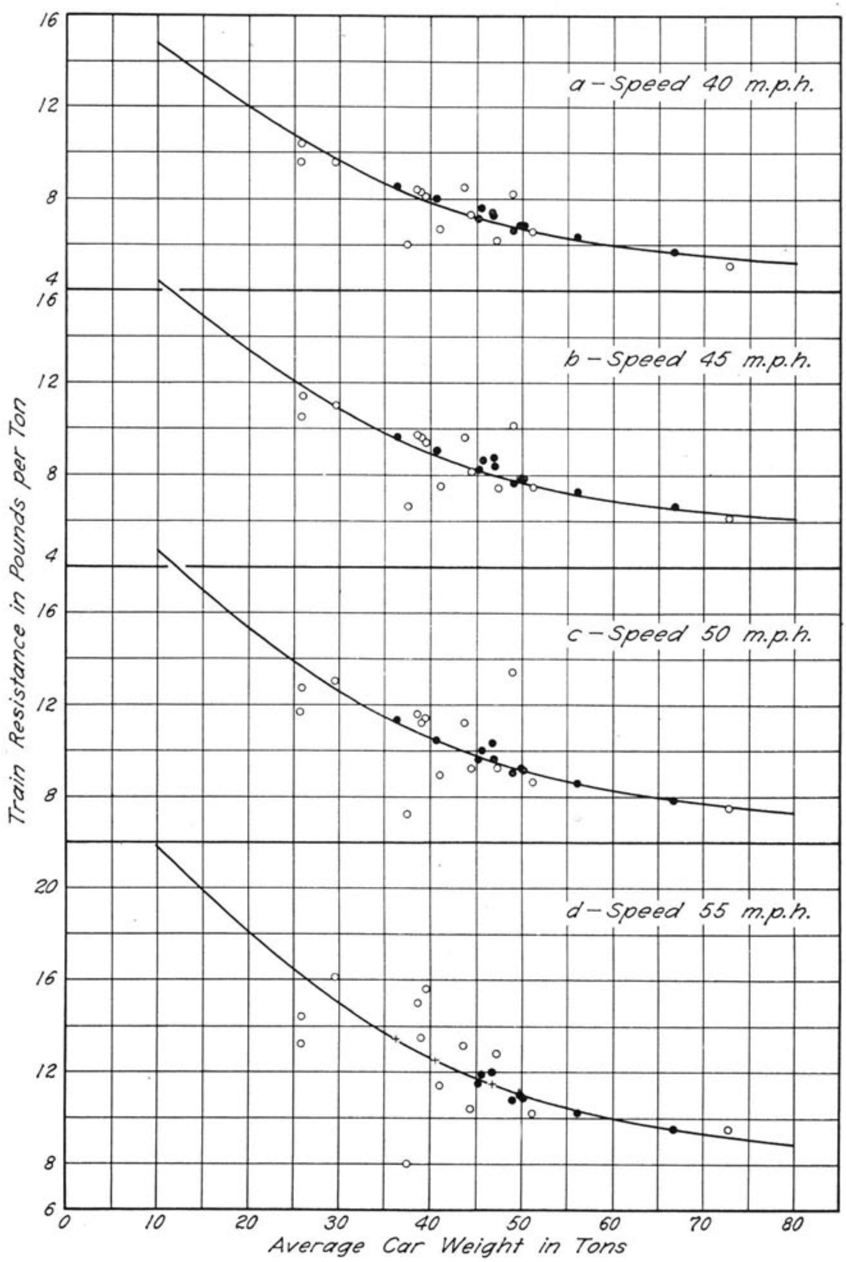



FIG. 3. RELATION OF RESISTANCE TO AVERAGE CAR WEIGHT, AT SPEEDS OF 40–70 MILES PER HOUR (BY 5-MILE INTERVALS)—PART I

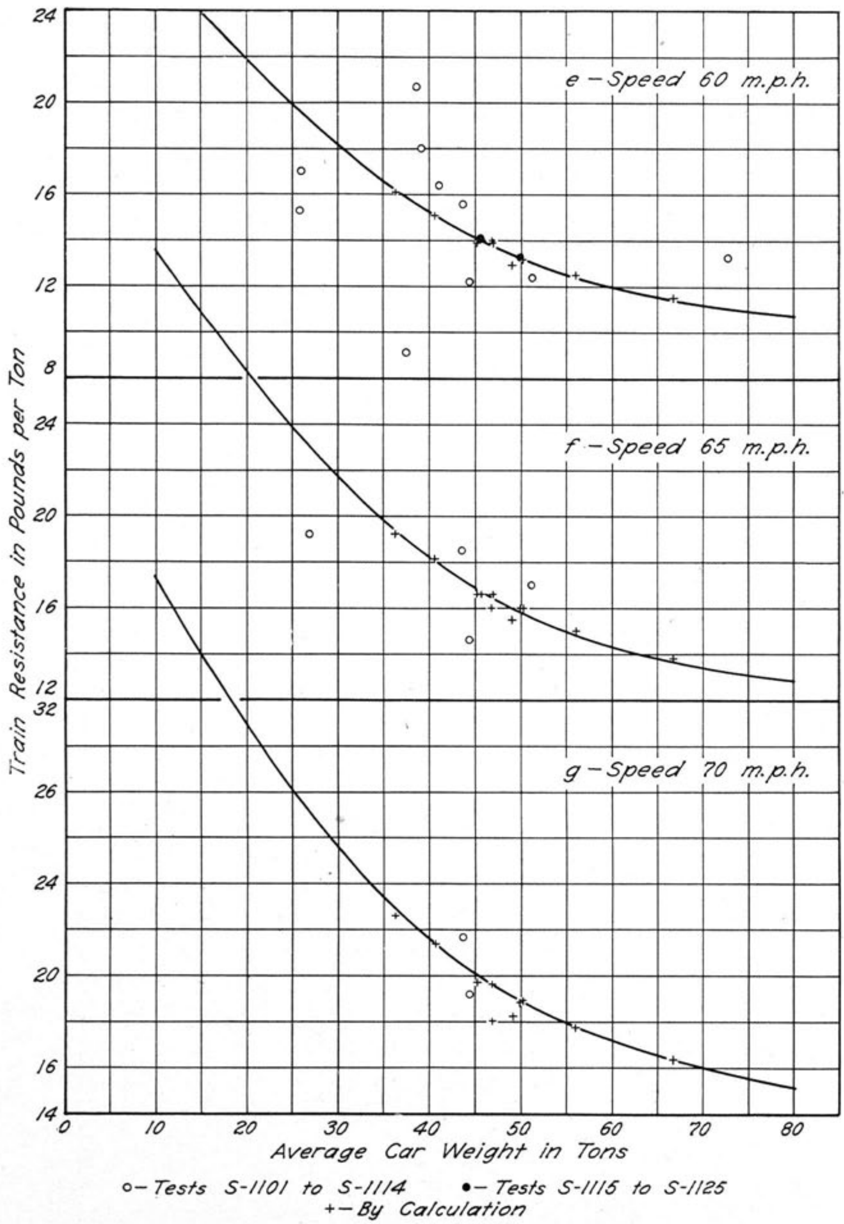



FIG. 3 (CONCLUDED). RELATION OF RESISTANCE TO AVERAGE CAR WEIGHT, AT SPEEDS OF 40–70 MILES PER HOUR (BY 5-MILE INTERVALS)—PART II

car weights of the trains. The seven curves show this relation at speeds of 40, 45, 50, 55, 60, 65, and 70 mi. per hr. For convenience in use, to make comparison easier, and to interpolate for other car weights and speeds, these seven curves have been brought together in one diagram (Fig. 4), which shows the final results of this research.

Each curve shows the average relation that existed during the tests between car weight and train resistance at a definite speed. These curves are applicable to ordinary American freight trains operating at the higher speeds, if conditions of operation are similar to those prevailing during these tests. The curves of Fig. 4 enable one to determine the drawbar pull necessary to operate a freight train at various speeds between 40 and 70 mi. per hr., provided that the average car weights composing the train are known.

18. *Results Expressed as Resistance-Speed Curves.*—Though, as shown in Fig. 4, for any given speed the train resistance varies as the average car weights, it is usually expressed as a relation between resistance and speed. Figure 5 has been prepared directly from Fig. 4 in order to present a group of resistance-speed curves for this research.

19. *Results Expressed in Tabular Form.*—The curves of Fig. 5 were drawn to a large scale, and the values of resistance at various speed have been found and set down in Table 3.

20. *Results Expressed as Equations.*—The relation between resistance and speed may also be expressed in the form of equations. Formulas (1)–(12), pages 27 and 30, empirical equations of parabolas, are chosen to correspond very closely to the curves of Fig. 5. They may be employed to calculate train resistance values for any speed and for various car weights. $R$ is the train resistance in lb. per ton; $V$, the speed expressed in mi. per hr. The maximum difference between any value of resistance obtained by using the formulas and the corresponding values taken directly from the curves of Fig. 5 is less than 6 per cent.

**Train Resistance Formulas**

$$\text{When } W = 20 \text{ tons}, R = 2.0 + 0.04\,V + 0.005\,V^2 \quad (1)$$
$$\text{When } W = 25 \text{ tons}, R = 1.2 + 0.03\,V + 0.0048\,V^2 \quad (2)$$
$$\text{When } W = 30 \text{ tons}, R = 1.2 + 0.0195V + 0.0045\,V^2 \quad (3)$$
$$\text{When } W = 35 \text{ tons}, R = 0.8 + 0.0235V + 0.0041\,V^2 \quad (4)$$
$$\text{When } W = 40 \text{ tons}, R = 1.1 + 0.010\,V + 0.0038\,V^2 \quad (5)$$
$$\text{When } W = 45 \text{ tons}, R = 0.55 + 0.020\,V + 0.00351V^2 \quad (6)$$

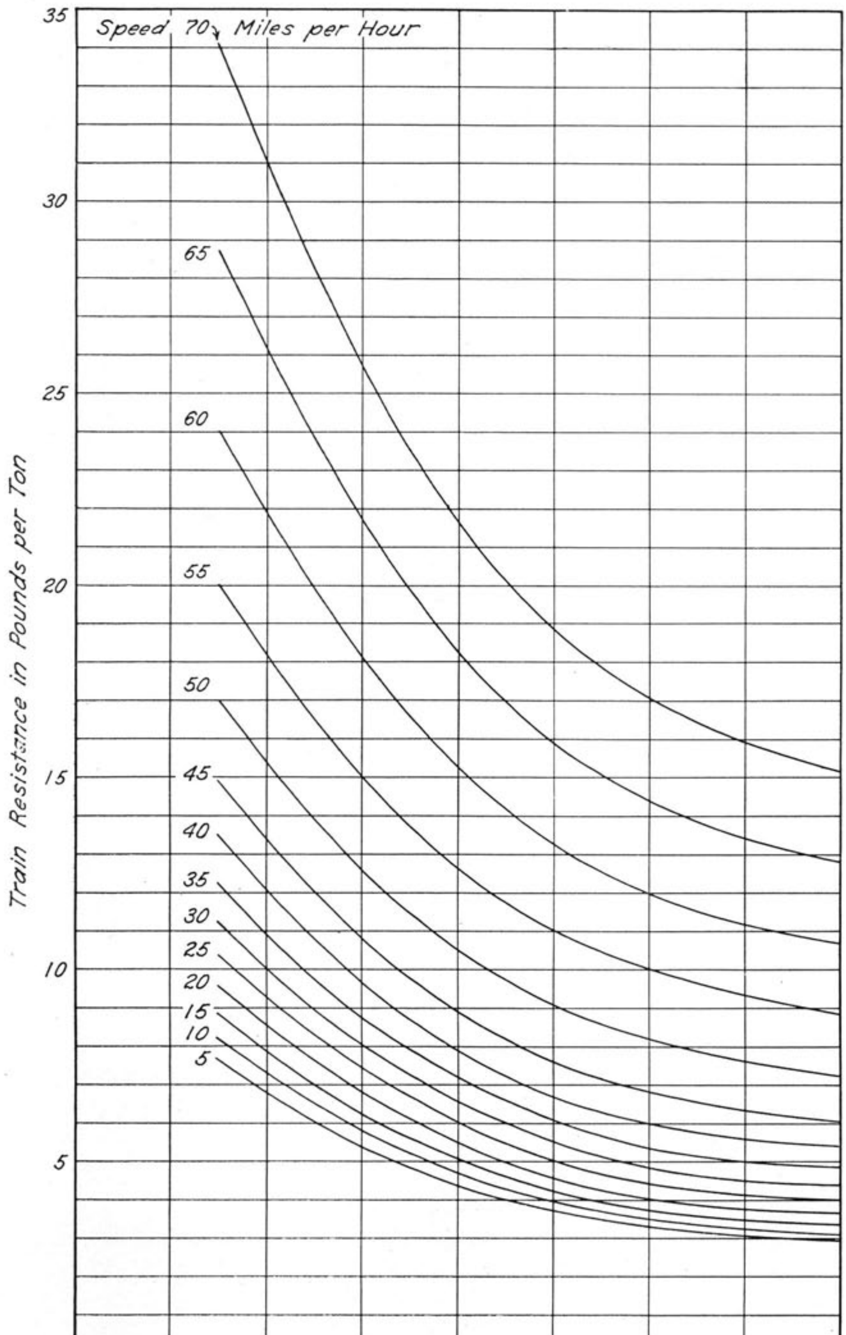



FIG. 4. RELATION OF RESISTANCE TO AVERAGE CAR WEIGHT AT VARIOUS SPEEDS

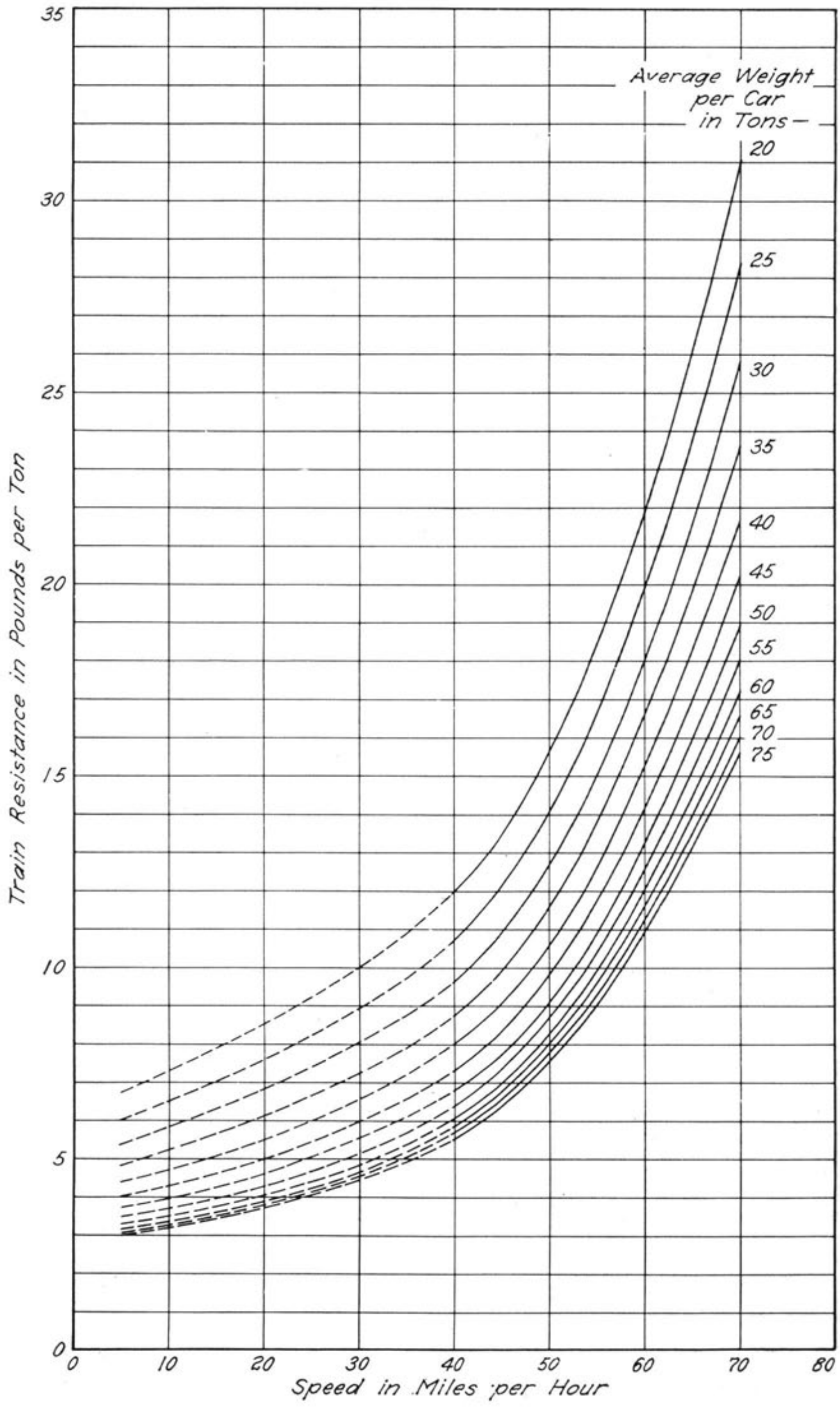



FIG. 5. RELATION OF RESISTANCE TO SPEED FOR VARIOUS WEIGHTS PER CAR

$$\text{When } W = 50 \text{ tons, } R = 0.60 + 0.010\ V + 0.0034\ V^2 \qquad (7)$$
$$\text{When } W = 55 \text{ tons, } R = 0.40 + 0.0125V + 0.00325V^2 \qquad (8)$$
$$\text{When } W = 60 \text{ tons, } R = 0.45 + 0.015\ V + 0.0031\ V^2 \qquad (9)$$
$$\text{When } W = 65 \text{ tons, } R = 0.35 + 0.010\ V + 0.003\ V^2 \qquad (10)$$
$$\text{When } W = 70 \text{ tons, } R = 0.59 + 0.002\ V + 0.00295V^2 \qquad (11)$$
$$\text{When } W = 75 \text{ tons, } R = 0.53 + 0.002\ V + 0.0029\ V^2 \qquad (12)$$

21. *Final Results.*—The final results of this research are presented in Figs. 4 and 5, in Table 3, and in Formulas (1)–(12). By the use of Figs. 4 and 5 alone the train resistance of ordinary freight trains may be quite accurately predicted, provided that the trains are operating in warm weather and under normal conditions such as prevailed during these tests. The results apply to freight trains of any weight or length when running at constant speed on a well-constructed, tangent, and level track, during weather when the temperature is not below 52 deg. F. and the wind velocity not above 20 mi. per hr.

TABLE 3

VALUES OF RESISTANCE AT VARIOUS SPEEDS FOR TRAINS OF DIFFERENT AVERAGE WEIGHTS PER CAR

This table presents the coordinates of the original curves from which Fig. 5 is reproduced

| Speed, Mi. per Hr. | Train Resistance—lb. per ton | | | | | | | | | | | | Speed, Mi. per Hr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Column Headings Indicate the Average Weight per Car | | | | | | | | | | | | |
| | 20 tons | 25 tons | 30 tons | 35 tons | 40 tons | 45 tons | 50 tons | 55 tons | 60 tons | 65 tons | 70 tons | 75 tons | |
| 40 | 12.0 | 10.7 | 9.6 | 8.7. | 8.0 | 7.3 | 6.8 | 6.4 | 6.1 | 5.8 | 5.7 | 5.6 | 40 |
| 41 | 12.2 | 10.9 | 9.8 | 8.9 | 8.2 | 7.5 | 6.9 | 6.5 | 6.2 | 6.0 | 5.9 | 5.7 | 41 |
| 42 | 12.5 | 11.2 | 10.0 | 9.2 | 8.4 | 7.7 | 7.1 | 6.7 | 6.4 | 6.2 | 6.0 | 5.8 | 42 |
| 43 | 12.8 | 11.5 | 10.3 | 9.4 | 8.6 | 7.9 | 7.3 | 6.9 | 6.6 | 6.4 | 6.2 | 6.0 | 43 |
| 44 | 13.1 | 11.8 | 10.6 | 9.6 | 8.8 | 8.1 | 7.5 | 7.1 | 6.8 | 6.6 | 6.4 | 6.2 | 44 |
| 45 | 13.5 | 12.1 | 10.9 | 9.9 | 9.0 | 8.3 | 7.7 | 7.3 | 7.0 | 6.8 | 6.6 | 6.4 | 45 |
| 46 | 13.9 | 12.4 | 11.2 | 10.2 | 9.3 | 8.6 | 7.9 | 7.5 | 7.2 | 7.0 | 6.8 | 6.6 | 46 |
| 47 | 14.3 | 12.8 | 11.5 | 10.5 | 9.6 | 8.9 | 8.2 | 7.8 | 7.4 | 7.2 | 7.0 | 6.8 | 47 |
| 48 | 14.7 | 13.2 | 11.9 | 10.8 | 9.9 | 9.2 | 8.5 | 8.1 | 7.7 | 7.4 | 7.2 | 7.0 | 48 |
| 49 | 15.1 | 13.6 | 12.3 | 11.2 | 10.2 | 9.5 | 8.8 | 8.4 | 8.0 | 7.7 | 7.4 | 7.2 | 49 |
| 50 | 15.6 | 14.0 | 12.7 | 11.6 | 10.5 | 9.8 | 9.1 | 8.7 | 8.3 | 8.0 | 7.7 | 7.5 | 50 |
| 51 | 16.1 | 14.5 | 13.1 | 12.0 | 10.9 | 10.1 | 9.4 | 9.0 | 8.6 | 8.3 | 8.0 | 7.8 | 51 |
| 52 | 16.6 | 15.0 | 13.5 | 12.4 | 11.3 | 10.5 | 9.7 | 9.3 | 8.9 | 8.6 | 8.3 | 8.1 | 52 |
| 53 | 17.2 | 15.5 | 14.0 | 12.8 | 11.7 | 10.9 | 10.1 | 9.6 | 9.2 | 8.9 | 8.6 | 8.4 | 53 |
| 54 | 17.8 | 16.0 | 14.5 | 13.2 | 12.1 | 11.3 | 10.5 | 10.0 | 9.5 | 9.2 | 8.9 | 8.7 | 54 |
| 55 | 18.4 | 16.6 | 15.0 | 13.7 | 12.6 | 11.7 | 10.9 | 10.4 | 9.9 | 9.5 | 9.3 | 9.0 | 55 |
| 56 | 19.0 | 17.2 | 15.5 | 14.2 | 13.1 | 12.1 | 11.3 | 10.8 | 10.3 | 9.9 | 9.6 | 9.3 | 56 |
| 57 | 19.7 | 17.8 | 16.1 | 14.8 | 13.6 | 12.6 | 11.7 | 11.2 | 10.7 | 10.3 | 10.0 | 9.7 | 57 |
| 58 | 20.4 | 18.5 | 16.7 | 15.4 | 14.1 | 13.1 | 12.2 | 11.6 | 11.1 | 10.7 | 10.4 | 10.1 | 58 |
| 59 | 21.1 | 19.2 | 17.3 | 16.0 | 14.6 | 13.6 | 12.7 | 12.0 | 11.5 | 11.1 | 10.8 | 10.5 | 59 |
| 60 | 21.9 | 19.9 | 18.0 | 16.6 | 15.2 | 14.1 | 13.2 | 12.5 | 12.0 | 11.5 | 11.2 | 10.9 | 60 |
| 61 | 22.6 | 20.6 | 18.7 | 17.2 | 15.8 | 14.6 | 13.7 | 13.0 | 12.5 | 12.0 | 11.6 | 11.3 | 61 |
| 62 | 23.4 | 21.3 | 19.4 | 17.8 | 16.4 | 15.2 | 14.2 | 13.5 | 13.0 | 12.5 | 12.0 | 11.7 | 62 |
| 63 | 24.2 | 22.1 | 20.1 | 18.4 | 17.0 | 15.8 | 14.7 | 14.0 | 13.5 | 13.0 | 12.5 | 12.1 | 63 |
| 64 | 25.1 | 22.9 | 20.8 | 19.0 | 17.6 | 16.4 | 15.3 | 14.5 | 14.0 | 13.5 | 13.0 | 12.6 | 64 |
| 65 | 26.0 | 23.7 | 21.5 | 19.7 | 18.2 | 17.0 | 15.9 | 15.1 | 14.5 | 14.0 | 13.5 | 13.1 | 65 |
| 66 | 26.9 | 24.5 | 22.3 | 20.4 | 18.9 | 17.6 | 16.5 | 15.6 | 15.0 | 14.5 | 14.0 | 13.6 | 66 |
| 67 | 27.9 | 25.4 | 23.1 | 21.2 | 19.6 | 18.2 | 17.1 | 16.2 | 15.5 | 15.0 | 14.5 | 14.1 | 67 |
| 68 | 29.0 | 26.3 | 24.0 | 22.6 | 20.3 | 18.8 | 17.7 | 16.8 | 16.0 | 15.5 | 15.0 | 14.6 | 68 |
| 69 | 30.0 | 27.3 | 24.9 | 22.8 | 20.9 | 19.5 | 18.3 | 17.4 | 16.6 | 16.0 | 15.5 | 15.1 | 69 |
| 70 | 31.0 | 28.3 | 25.8 | 23.6 | 21.6 | 20.2 | 18.9 | 18.0 | 17.2 | 16.5 | 16.0 | 15.6 | 70 |

## VII. Discussion of Results

22. *Variations in Resistance of Different Trains.* — At the opening of this investigation it was decided to report the train resistance values obtained from 14 trains whose average car weights extended over as large a range as possible, from approximately 25 to 72 tons. Results of these tests are given in Fig. 7, and are recorded on Fig. 3 by open circles. Tests S-1115 to S-1125 were worked up, and though their speed range was not great and the tonnage was within the range of the 14 trains originally selected, it was decided to add their results to Fig. 3, using circular black spots as symbols. Points indicated on the curves by plus-signs are those located by calculation.

Of the points which do not fall on the seven curves of Fig. 3, about half lie above the final curve and half below. This is to be expected, since each point represents the average resistance to train movement which was acting throughout a particular test. The variation in the points of the curve is a measure of the mean resistance of the various trains.

As the speed of the test trains increased, some of the resistance values tended to vary considerably from the mean as represented by the curves. The following table gives the average deviation.

Average Deviation of All Points in Fig. 3a–g from the Mean as Shown by the Curves There Drawn—Expressed as Percentages of the Curve Ordinates

| | Fig. 3a 40 m.p.h. | Fig. 3b 45 m.p.h. | Fig. 3c 50 m.p.h. | Fig. 3d 55 m.p.h. | Fig. 3e 60 m.p.h. | Fig. 3f 65 m.p.h. | Fig. 3g 70 m.p.h. |
|---|---|---|---|---|---|---|---|
| Points Above the Curve | 5 | 8 | 9 | 9 | 13 | 5 | 5 |
| Points Below the Curve | 9 | 9 | 9 | 8 | 11 | 6 | 5 |

The average deviation for all points above the curves is approximately 8 per cent, and a like percentage exists for those below the curves. The practical result of this 8-per cent variation in train resistance predicted by the use of Figs. 3, 4, and 5 for trains operating on level tangent track, in determining locomotive ratings, is to add 8 per cent to the resistance values obtained from the curves, tables, and equations representing the final results of this investigation. The 8-per cent allowance is intended to cover any unexpected variations in the resistance of different trains under typical operating conditions.

It has nothing to do with a reserve allowance usually made to cover unusual variations in resistance due to cold weather, high winds, or conditions affecting the maximum tractive effort of the locomotive.

23. *Verification of Previous Experiments.* — For many years occasional tests, made by the Railway Engineering Department of the University of Illinois, have demonstrated the reliability of the results published in Bulletin No. 43. It has repeatedly been found that although the weight of rail has been increased, the train resistance values have remained practically constant, because the roadbed has undergone no radical changes in the past 30 years. The results of the present research bear out this contention: in all tests at low speeds the curves of Bulletin No. 43 coincide with present findings. In Fig. 5 the curves from Bulletin No. 43 have been reproduced, in the form of a dashed line, for speeds from 5 to 40 mi. per hr.

In the summer of 1944 a number of check tests were made of resistance values on the Kentucky Division of the Illinois Central Railroad. However, only one train was operated faster than 50 mi. per hr.; hence, no results are included in this research. The results did check with the lower values of train resistance presented here and with those of Bulletin No. 43.

# APPENDIX A

## Tonnage Records of the Trains

Tables 4–17 are records of the make-up and tonnage of the 14 trains reported in detail in this investigation. The car numbers are arranged in the order which the cars occupied in the train, beginning at the head of the train. The weight of the dynamometer car is included for those cases where the measuring drawbar was connected to the drawbar of the locomotive tender. When the measuring drawbar was connected instead to the drawbar of the first car of the train, the recorder did not measure the pull of the test car, and its effect on drawbar pull was considered with that of the locomotive and tender. Though most of the car weights were taken directly from the scale weights attached to the way bills, in accordance with the practice of most railway operators they are listed here to the nearest 1000 lb. For most empty cars the stenciled light weights were used.

### Table 4
### Tonnage Record
Test No. S-1101

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 217 180 | E | 48 000 | C.B.&Q. | 101 748 | E | 40 000 |
| " | 218 561 | E | 48 000 | I.C. | 212 834 | E | 54 000 |
| " | 217 375 | E | 48 000 | " | 713 722 | E | 54 000 |
| " | 217 126 | E | 48 000 | " | 713 165 | E | 54 000 |
| " | 217 393 | E | 48 000 | " | 212 874 | E | 54 000 |
| " | 215 456 | E | 48 000 | " | 713 476 | E | 54 000 |
| " | 217 684 | E | 48 000 | " | 212 950 | E | 54 000 |
| " | 214 870 | E | 48 000 | " | 713 075 | E | 54 000 |
| C.I.L. | 195 884 | E | 48 000 | " | 713 480 | E | 54 000 |
| I.C. | 400 319 | E | 50 000 | " | 208 208 | E | 48 000 |
| " | 402 701 | E | 50 000 | " | 402 662 | E | 50 000 |
| " | 402 297 | E | 50 000 | " | 208 351 | E | 48 000 |
| " | 401 332 | E | 50 000 | " | 200 243 | E | 48 000 |
| " | 215 689 | E | 48 000 | C.I.L. | 30 097 | E | 46 000 |
| " | 214 795 | E | 48 000 | I.C. | 215 560 | E | 48 000 |
| " | 216 350 | E | 48 000 | " | 218 043 | E | 48 000 |
| " | 215 792 | E | 48 000 | " | 218 255 | E | 48 000 |
| " | 401 768 | E | 50 000 | " | 204 890 | E | 48 000 |
| " | 216 328 | E | 48 000 | " | 200 366 | E | 48 000 |
| " | 218 576 | E | 48 000 | " | 214 965 | E | 48 000 |
| " | 402 254 | E | 50 000 | " | 218 267 | E | 48 000 |
| " | 401 647 | E | 50 000 | " | 713 062 | E | 54 000 |
| " | 400 001 | E | 50 000 | " | 713 352 | E | 54 000 |
| " | 214 929 | E | 48 000 | " | 201 165 | E | 48 000 |
| " | 206 286 | E | 48 000 | " | 402 178 | E | 50 000 |
| " | 218 522 | E | 48 000 | " | 401 708 | E | 50 000 |
| " | 400 486 | E | 50 000 | " | 401 561 | E | 50 000 |
| " | 204 647 | E | 48 000 | " | 216 116 | E | 48 000 |
| " | 207 020 | E | 48 000 | " | 218 010 | E | 48 000 |
| " | 201 694 | E | 48 000 | " | 401 062 | E | 50 000 |
| " | 218 319 | E | 48 000 | " | 214 950 | E | 48 000 |
| " | 215 462 | E | 48 000 | A.R.T. | 62 270 | L | 76 000 |
| " | 205 344 | E | 48 000 | " | 62 208 | L | 76 000 |
| " | 218 464 | E | 48 000 | " | 62 169 | L | 76 000 |
| " | 203 994 | E | 48 000 | N.R.C. | 10 278 | L | 82 000 |
| " | 205 708 | E | 48 000 | " | 7 693 | L | 82 000 |
| " | 201 802 | E | 48 000 | " | 7 109 | L | 78 000 |
| " | 201 801 | E | 48 000 | A.R.T. | 62 330 | L | 74 000 |
| " | 201 800 | E | 48 000 | I.C. Cab | 99 399 | E | 50 000 |
| " | 201 799 | E | 48 000 | " | 98 304 | E | 40 000 |
| " | 201 798 | E | 48 000 | | | | |
| " | 201 797 | E | 48 000 | | | | |
| " | 129 274 | E | 52 000 | | | | |
| " | 204 810 | E | 48 000 | | | | |

TABLE 5

TONNAGE RECORD

Test No. S-1102

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 | E | 60 000 | C.W.C. | 8 251 | E | 40 000 |
| | | | | I.C. | 68 818 | E | 40 000 |
| I.C. | 155 022 | E | 46 000 | T.P. | 17 451 | E | 50 000 |
| N.R.C. | 7 052 | E | 60 000 | I.C. | 654 652 | E | 60 000 |
| I.C. | 156 423 | E | 46 000 | M.S. | 6 002 | E | 46 000 |
| " | 654 398 | E | 60 000 | I.C. | 213 172 | E | 50 000 |
| " | 654 271 | E | 60 000 | " | 217 854 | E | 50 000 |
| " | 161 096 | E | 46 000 | " | 216 030 | E | 50 000 |
| " | 161 194 | E | 46 000 | " | 217 596 | E | 50 000 |
| " | 156 168 | E | 46 000 | " | 216 579 | E | 50 000 |
| " | 160 834 | E | 46 000 | " | 218 707 | E | 50 000 |
| " | 161 012 | E | 46 000 | " | 216 430 | E | 50 000 |
| S.P. | 33 979 | E | 46 000 | " | 217 137 | E | 46 000 |
| T.N.O. | 36 558 | E | 46 000 | " | 216 931 | E | 50 000 |
| N.R.C. | 5 668 | E | 60 000 | " | 215 194 | E | 50 000 |
| I.C. | 654 744 | E | 60 000 | " | 216 562 | E | 50 000 |
| N.R.C. | 3 385 | E | 60 000 | " | 247 987 | E | 50 000 |
| I.C. | 70 502 | E | 40 000 | " | 216 325 | E | 50 000 |
| N.R.C. | 6 756 | E | 60 000 | " | 217 909 | E | 50 000 |
| I.C. | 176 445 | E | 46 000 | " | 218 424 | E | 50 000 |
| " | 157 341 | E | 46 000 | " | 216 512 | E | 50 000 |
| " | 652 165 | E | 60 000 | " | 215 247 | E | 50 000 |
| " | 653 601 | E | 60 000 | " | 216 167 | E | 50 000 |
| " | 340 266 | E | 46 000 | " | 217 122 | E | 50 000 |
| S.P. | 27 620 | E | 46 000 | " | 217 406 | E | 50 000 |
| N.R.C. | 5 547 | E | 60 000 | " | 217 053 | E | 50 000 |
| I.C. | 653 768 | E | 60 000 | " | 215 647 | E | 50 000 |
| " | 70 445 | E | 40 000 | " | 217 287 | E | 50 000 |
| " | 652 111 | E | 60 000 | " | 216 615 | E | 50 000 |
| " | 7 481 | E | 60 000 | " | 215 254 | E | 50 000 |
| " | 7 887 | E | 60 000 | " | 215 945 | E | 50 000 |
| " | 6 843 | E | 60 000 | " | 215 970 | E | 50 000 |
| " | 5 566 | E | 60 000 | " | 215 477 | E | 50 000 |
| N.R.C. | 5 673 | E | 60 000 | " | 218 266 | E | 50 000 |
| I.C. | 208 723 | E | 50 000 | " | 216 835 | E | 50 000 |
| " | 652 553 | E | 60 000 | " | 216 503 | E | 50 000 |
| N.R.C. | 10 054 | E | 60 000 | " | 216 255 | E | 50 000 |
| I.C. | 655 756 | E | 60 000 | " | 209 650 | E | 50 000 |
| T.N.O. | 53 019 | E | 44 000 | " | 70 441 | E | 40 000 |
| I.C. | 651 076 | E | 60 000 | " | 200 040 | E | 50 000 |
| S.P. | 15 768 | E | 44 000 | " | 200 073 | E | 50 000 |
| S.A.L. | 46 868 | E | 46 000 | " | 217 119 | E | 50 000 |
| N.R.C. | 5 741 | E | 60 000 | " | 216 197 | E | 50 000 |
| " | 6 906 | E | 60 000 | " | 207 820 | E | 50 000 |
| I.C. | 157 114 | E | 44 000 | " | 218 338 | E | 50 000 |
| " | 652 065 | E | 60 000 | " | 200 494 | E | 50 000 |
| " | 653 998 | E | 60 000 | " | 206 960 | E | 50 000 |
| G.A.R.X. | 1 059 | E | 60 000 | " | 209 048 | E | 50 000 |
| N.R.C. | 10 422 | E | 60 000 | " | 208 343 | E | 50 000 |
| " | 6 669 | E | 60 000 | " | 209 822 | E | 50 000 |
| " | 5 729 | E | 60 000 | " | 209 052 | E | 50 000 |
| " | 5 532 | E | 60 000 | " | 208 489 | E | 50 000 |
| I.C. | 161 498 | E | 46 000 | " | 209 337 | E | 50 000 |
| N.R.C. | 5 468 | E | 60 000 | " | 208 208 | E | 50 000 |
| I.C. | 160 533 | E | 46 000 | " | 208 452 | E | 50 000 |
| " | 654 662 | E | 60 000 | I.C. | Cab | E | 50 000 |
| " | 165 583 | E | 46 000 | | | | |

TABLE 6

TONNAGE RECORD

Test No. S-1103

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 | E | 60 000 | R.I. | 155 967 | L | 78 000 |
| " | 30 315 | E | 40 000 | D.T.I. | 18 053 | L | 80 000 |
| " | 269 622 | E | 32 000 | N.Y.C. | 346 419 | L | 110 000 |
| " | 651 037 | E | 60 000 | B/4 | 58 681 | L | 88 000 |
| " | 70 118 | E | 38 000 | P.R.R. | 569 037 | L | 56 000 |
| " | 200 028 | E | 50 000 | M.S.C. | 6 012 | E | 40 000 |
| " | 68 692 | E | 36 000 | I.C. | 654 988 | E | 60 000 |
| " | 70 218 | E | 38 000 | " | 217 758 | E | 46 000 |
| " | 654 775 | E | 60 000 | " | 215 417 | E | 46 000 |
| " | 652 031 | E | 60 000 | " | 652 110 | E | 60 000 |
| " | 217 307 | E | 46 000 | " | 654 946 | E | 60 000 |
| " | 70 454 | E | 38 000 | " | 652 579 | E | 60 000 |
| " | 70 407 | E | 38 000 | " | 30 708 | E | 40 000 |
| " | 269 622 | E | 36 000 | " | 653 878 | E | 60 000 |
| " | 653 835 | E | 60 000 | " | 652 537 | E | 60 000 |
| " | 30 765 | E | 40 000 | " | 655 772 | E | 60 000 |
| " | 30 303 | E | 40 000 | " | 651 065 | E | 60 000 |
| " | 30 762 | E | 40 000 | " | 31 186 | E | 40 000 |
| " | 30 376 | E | 40 000 | A.C.L. | 75 258 | E | 40 000 |
| " | 654 678 | E | 60 000 | " | 117 | E | 40 000 |
| " | 216 599 | L | 50 000 | S.P. | 62 597 | E | 46 000 |
| S.P. | 84 730 | E | 42 000 | " | 62 413 | E | 46 000 |
| U.T.L.X. | 56 900 | L | 128 000 | M.P. | 70 626 | E | 46 000 |
| P.A. | 60 508 | L | 62 000 | I.C. | 165 530 | E | 50 000 |
| G.A.T.X. | 29 235 | L | 100 000 | S.O.U. | 161 935 | L | 60 000 |
| M.K.P. | 12 116 | L | 88 000 | U.T.L. | 38 340 | E | 50 000 |
| P.A. | 532 998 | L | 90 000 | L.N. | 49 665 | L | 60 000 |
| " | 60 997 | L | 64 000 | P.F.E. | 113 178 | E | 56 000 |
| " | 564 321 | L | 76 000 | U.T.L. | 19 814 | E | 40 000 |
| S.H.P.X. | 54 | E | 40 000 | P.F.E. | 51 715 | E | 56 000 |
| A.C.L. | 49 210 | L | 52 000 | " | 71 418 | E | 54 000 |
| P.L.E. | 31 925 | L | 84 000 | P.A. | 15 315 | L | 136 000 |
| C.I.&L. | 32 608 | L | 88 000 | I.C. | 98 300 | E | 40 000 |
| M.C. | 14 849 | L | 90 000 | I.C. Cab | 98 258 | E | 40 000 |

TABLE 7

TONNAGE RECORD

Test No. S-1104

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 | E | 60 000 | C.B.&Q. | 73 377 | L | 110 000 |
| J.D.P. | 730 | L | 90 000 | I.C. | 653 486 | L | 60 000 |
| C.M.St.P.&P. | 13 039 | L | 72 000 | " | 165 105 | L | 66 000 |
| N.X. | 1 608 | L | 90 000 | " | 165 460 | L | 66 000 |
| S.W.T.X. | 7 005 | L | 102 000 | " | 164 865 | L | 66 000 |
| " | 5 612 | L | 106 000 | T.N.O. | 52 777 | L | 86 000 |
| I.C. | 165 530 | L | 66 000 | " | 36 436 | L | 102 000 |
| " | 164 984 | L | 62 000 | I.C. | 165 160 | L | 66 000 |
| M.O.P. | 46 278 | L | 60 000 | C.B.&Q. | 195 766 | L | 92 000 |
| N.Y.C. | 238 144 | L | 60 000 | B.&O. | 267 211 | L | 70 000 |
| U.P. | 124 238 | E | 46 000 | I.C. | 164 878 | L | 66 000 |
| S.O.U. | 149 582 | E | 48 000 | " | 164 873 | L | 66 000 |
| S.P. | 32 174 | L | 60 000 | " | 165 382 | L | 66 000 |
| M-O | 24 442 | L | 60 000 | " | 165 291 | L | 66 000 |
| CO-LE | 56 169 | L | 86 000 | " | 156 895 | L | 88 000 |
| G.R.L.X. | 17 814 | L | 88 000 | " | 164 705 | L | 66 000 |
| G.A.T.X. | 23 726 | E | 40 000 | C.B.&Q. | 109 643 | L | 130 000 |
| " | 13 935 | E | 40 000 | P.A. | 33 930 | L | 167 000 |
| " | 28 368 | E | 40 000 | I.C. | 653 017 | E | 60 000 |
| B.&O. | 177 852 | L | 116 000 | " | 99 164 | E | 50 000 |

TABLE 8

TONNAGE RECORD

Test No. S-1105

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 | L | 60 000 | B.&O. | 172 032 | L | 112 000 |
| | | | | S.O.W. | 165 192 | L | 110 000 |
| I.C. | 360 057 | L | 74 000 | C.&O. | 9 190 | E | 40 000 |
| " | 154 703 | L | 68 000 | N.A.P.X. | 3 164 | E | 40 000 |
| G.A.R. | 60 387 | L | 80 000 | " | 12 516 | L | 76 000 |
| P.M. | 80 175 | L | 72 000 | L.&.N. | 9 659 | L | 76 000 |
| C.N.U. | 21 398 | L | 54 000 | C.N.W. | 1 145 032 | L | 150 000 |
| S.A.W. | 167 676 | L | 60 000 | Erie | 7 307 | L | 70 000 |
| M.C. | 85 412 | L | 60 000 | C.R.Z. | 4 542 | L | 86 000 |
| I.C. | 15 482 | L | 96 000 | M.P. | 47 280 | L | 84 000 |
| L.U.X. | 449 | E | 40 000 | I.C. | 163 137 | L | 108 000 |
| I.C. | 165 272 | L | 64 000 | C.N.W. | 111 336 | L | 80 000 |
| C.G. | 55 691 | L | 110 000 | I.C. | 99 055 | E | 50 000 |
| Erie | 60 269 | L | 84 000 | | | | |

Table 9
Tonnage Record
Test No. S-1106

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 | E | 60 000 | Erie | 60 269 | E | 84 000 |
| | | | | B.&O. | 172 032 | E | 112 000 |
| " | 360 057 | E | 74 000 | S.O.W. | 165. 192 | E | 110 000 |
| " | 154 703 | E | 68 000 | C.&O. | 9 190 | E | 40 000 |
| G.A.R. | 60 387 | E | 80 000 | N.A.P.X. | 3 164 | E | 40 000 |
| P.M. | 80 175 | E | 72 000 | " | 12 516 | E | 76 000 |
| C.N.U. | 21 398 | E | 54 000 | L.&N. | 9 659 | E | 76 000 |
| S.A.W. | 167 676 | E | 60 000 | C.N.W. | 1 145 032 | E | 150 000 |
| M.C. | 85 412 | E | 60 000 | Erie | 7 307 | E | 70 000 |
| I.C. | 15 482 | E | 96 000 | C.R.Z. | 4 542 | E | 86 000 |
| L.U.X. | 449 | E | 40 000 | M.P. | 47 280 | E | 84 000 |
| I.C. | 165 272 | E | 64 000 | I.C. | 163 137 | E | 108 000 |
| P.K.Y. | 91 026 | E | 108 000 | C.N.W. | 111 336 | E | 80 000 |
| C.G. | 55 691 | E | 110 000 | I.C. | 99 055 | E | 50 000 |

Table 10
Tonnage Record
Test No. S-1107

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| N.R.C. | 6 778 | L | 76 000 | I.C. | 653 200 | L | 82 000 |
| " | 6 693 | L | 76 000 | N.R.C. | 10 112 | L | 82 000 |
| " | 4 731 | L | 78 000 | " | 10 400 | L | 82 000 |
| " | 15 530 | L | 82 000 | " | 5 560 | L | 76 000 |
| " | 15 655 | L | 82 000 | I.C. | 653 519 | L | 82 000 |
| " | 5 664 | L | 78 000 | N.R.C. | 10 332 | L | 82 000 |
| " | 5 671 | L | 80 000 | I.C. | 652 536 | L | 84 000 |
| I.C. | 654 801 | L | 82 000 | " | 650 008 | L | 80 000 |
| N.R.C. | 5 512 | L | 78 000 | " | 654 222 | L | 82 000 |
| " | 5 577 | L | 78 000 | " | 654 357 | L | 82 000 |
| " | 5 579 | L | 80 000 | " | 653 202 | L | 86 000 |
| " | 6 347 | L | 74 000 | N.R.C. | 15 060 | L | 82 000 |
| " | 10 266 | L | 82 000 | I.C. | 651 081 | L | 80 000 |
| " | 5 425 | L | 76 000 | N.R.C. | 15 551 | L | 82 000 |
| " | 5 898 | L | 76 000 | " | 6 045 | L | 76 000 |
| " | 4 118 | L | 76 000 | " | 10 058 | L | 84 000 |
| " | 6 663 | L | 76 000 | " | 7 826 | L | 78 000 |
| " | 15 690 | L | 82 000 | " | 15 574 | L | 82 000 |
| " | 10 330 | L | 82 000 | I.C. | 99 196 | E | 50 000 |

TABLE 11

TONNAGE RECORD

Test No. S-1108

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| N.D.T. | 304 | L | 60 000 | I.C. | 654 603 | L | 82 000 |
| N.R.T. | 84 011 | L | 60 000 | " | 653 358 | L | 82 000 |
| M.C. | 86 600 | L | 96 000 | " | 654 624 | L | 80 000 |
| I.C. | 269 775 | E | 40 000 | " | 650 511 | L | 84 000 |
| " | 269 997 | E | 40 000 | " | 653 194 | L | 78 000 |
| C.W.C. | 8 582 | L | 92 000 | " | 652 106 | L | 82 000 |
| S.L.S.F. | 161 854 | L | 94 000 | " | 652 136 | L | 82 000 |
| I.C. | 176 623 | L | 110 000 | " | 655 122 | L | 82 000 |
| C.G.W. | 85 356 | L | 104 000 | " | 653 160 | L | 84 000 |
| G.F. | 7 087 | L | 80 000 | " | 653 114 | L | 82 000 |
| S.O.U. | 157 032 | L | 74 000 | " | 653 428 | L | 82 000 |
| G.A.T.X. | 20 185 | L | 98 000 | " | 653 260 | L | 80 000 |
| " | 26 048 | L | 100 000 | " | 654 925 | L | 80 000 |
| " | 29 721 | L | 102 000 | " | 652 020 | L | 80 000 |
| I.C. | 653 802 | L | 82 000 | " | 654 701 | L | 82 000 |
| " | 654 441 | L | 84 000 | " | 654 884 | L | 82 000 |
| " | 654 486 | L | 84 000 | " | 655 006 | L | 82 000 |
| " | 654 255 | L | 84 000 | " | 653 743 | L | 82 000 |
| " | 652 074 | L | 84 000 | " | 654 741 | L | 82 000 |
| " | 654 990 | L | 82 000 | " | 650 001 | L | 82 000 |
| " | 654 023 | L | 82 000 | " | 652 524 | L | 82 000 |
| N.R.C. | 10 310 | L | 80 000 | " | 654 432 | L | 80 000 |
| I.C. | 652 114 | L | 84 000 | " | Cab | E | 50 000 |
| " | 655 897 | L | 82 000 | | | | |

TABLE 12

TONNAGE RECORD

Test No. S-1109

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 | E | 60 000 | S.O.O.L. | 135 546 | L | 64 000 |
| T.&N.O. | 53 817 | L | 66 000 | M.S.C. | 6 051 | L | 64 000 |
| U.S.L. | 138 491 | L | 66 000 | B.&O. | 270 276 | L | 96 000 |
| S.P. | 23 855 | L | 66 000 | T.N.O. | 51 623 | L | 82 000 |
| B.&O. | 269 023 | L | 62 000 | S.P. | 23 590 | L | 96 000 |
| I.C. | 175 282 | L | 70 000 | " | 20 025 | L | 82 000 |
| C.G. | 58 101 | L | 96 000 | G.A.T.X. | 29 611 | L | 96 000 |
| I.C. | 157 587 | L | 98 000 | L.&A. | 15 010 | L | 92 000 |
| C.O.S.X. | 577 | L | 118 000 | I.C. | 156 907 | L | 90 000 |
| A.J.A.X. | 113 | L | 96 000 | N.W. | 42 162 | L | 90 000 |
| A.S.I.X. | 1 485 | L | 100 000 | C.M.St.P.&P. | 702 760 | L | 134 000 |
| U.T.L.X. | 11 313 | L | 96 000 | C.C.C.&St.L. | 56 391 | L | 108 000 |
| L.U.X. | 283 | L | 100 000 | I.C. | Cab | E | 50 000 |
| C.C.C.&St.L. | 41 558 | L | 94 000 | | | | |

TABLE 13
TONNAGE RECORD
Test No. S-1110

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| P.M.C.K. | | | | G.&N.W. | 54 853 | L | 76 000 |
| &X | 80 809 | L | 86 000 | I.C. | 157 623 | L | 100 000 |
| S.S.W. | 36 198 | L | 90 000 | D.R.G.W. | 62 622 | L | 76 000 |
| P.A. | 51 717 | L | 86 000 | N.&W. | 46 052 | L | 94 000 |
| S.P. | 67 843 | L | 92 000 | A.T.S.F. | 123 488 | L | 76 000 |
| T.&N.O. | 58 331 | L | 84 000 | I.C. | 165 549 | L | 94 000 |
| W.&L.E. | 27 411 | L | 76 000 | " | 360 126 | L | 88 000 |
| O.S.K.X. | 415 | L | 94 000 | B.&O. | 265 157 | L | 76 000 |
| C.M.St.P.&P. | 592 734 | L | 128 000 | A.R.T. | 18 361 | L | 80 000 |
| C.O.S.X. | 802 | L | 106 000 | " | 601 | L | 86 000 |
| G.A.T.X. | 2 890 | L | 136 000 | I.C. | 159 471 | L | 78 000 |
| N.P. | 5 391 | L | 88 000 | " | 164 161 | L | 106 000 |
| I.C. | 156 739 | L | 56 000 | Erie | 93 658 | L | 134 000 |
| B.&A. | 38 592 | L | 82 000 | R.I. | 40 837 | L | 86 000 |
| L.&N. | 8 146 | L | 84 000 | I.C. | 341 484 | L | 86 000 |
| N.Y.C. | 52 058 | L | 78 000 | S.O.U. | 271 954 | L | 88 000 |
| I.C. | 269 088 | L | 96 000 | I.C. Cab | 98 519 | E | 50 000 |

TABLE 14
TONNAGE RECORD
Test No. S-1111

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| S.C.O.X. | 716 | L | 100 000 | G.A. | 18 596 | L | 84 000 |
| N.Y.C. | 101 102 | L | 80 000 | B.&O. | 174 743 | L | 86 000 |
| G.R.L.X. | 1 149 | L | 90 000 | S.L.&S.F. | 162 712 | L | 88 000 |
| L.U.X. | 417 | L | 130 000 | S.P. | 35 938 | L | 88 000 |
| " | 461 | L | 130 000 | I.C. | 16 214 | L | 90 000 |
| T.N.O. | 50 323 | L | 130 000 | P.R.R. | 45 110 | L | 140 000 |
| S.C.O.X. | 244 | L | 138 000 | " | 80 215 | L | 94 000 |
| I.C. | 32 577 | L | 52 000 | U.T.L.X. | 55 693 | L | 104 000 |
| S.P. | 20 002 | L | 100 000 | " | 71 280 | L | 94 000 |
| S.O.U. | 305 728 | L | 80 000 | " | 59 564 | L | 82 000 |
| I.C. | 70 160 | L | 70 000 | I.C. | 165 237 | L | 106 000 |
| " | 176 356 | L | 76 000 | " | 164 590 | L | 114 000 |
| " | 158 307 | L | 68 000 | C.N.S. | 4 038 | L | 102 000 |
| S.S.W. | 36 008 | L | 110 000 | G.M.&N. | 6 537 | L | 92 000 |
| M.P. | 94 128 | L | 80 000 | P.R.R. | 93 208 | L | 84 000 |
| T.&P. | 70 785 | L | 112 000 | Erie | 68 022 | L | 92 000 |
| C.M.St.P.&P. | 707 477 | L | 88 000 | S.P. | 68 096 | L | 150 000 |
| St.L.&F. | 163 418 | L | 92 000 | C.N.U. | 89 192 | L | 116 000 |
| N.C.St.L. | 15 374 | L | 78 000 | I.C. | 9 231 | E | 46 000 |
| G.N. | 43 468 | L | 84 000 | " | 10 616 | E | 46 000 |
| U.T.L.X. | 3 885 | L | 110 000 | " | 18 041 | E | 46 000 |
| N.H. | 66 647 | L | 92 000 | G.A.T.X. | 686 | L | 80 000 |
| N.Y.C.St.L. | 10 020 | L | 82 000 | C.G. | 50 381 | L | 92 000 |
| S.O.U. | 116 008 | L | 98 000 | I.C. | 154 967 | L | 90 000 |
| E.O.R.X. | 1 895 | L | 98 000 | M.&S.C.L. | 18 066 | L | 90 000 |
| " | 1 932 | L | 96 000 | M.O.P. | 82 662 | L | 108 000 |
| " | 1 790 | L | 96 000 | I.C. Cab | 99 051 | E | 50 000 |
| A.T.S.F. | 122 707 | L | 92 000 | | | | |

TABLE 15
TONNAGE RECORD
Test No. S-1112

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| L.U.X. | 433 | L | 128 000 | I.C. | 201 169 | L | 106 000 |
| " | 604 | L | 128 000 | " | 176 811 | L | 66 000 |
| " | 439 | L | 130 000 | C.B.&Q. | 41 858 | E | 46 000 |
| I.C. | 243 483 | L | 106 000 | U.P. | 180 242 | L | 100 000 |
| " | 157 021 | L | 108 000 | C.&O. | 9 827 | L | 82 000 |
| " | 158 197 | L | 96 000 | P.R.R. | 78 290 | L | 106 000 |
| " | 341 567 | L | 92 000 | S.C.O.X. | 223 | L | 126 000 |
| R.T.L.X. | 1 776 | E | 50 000 | I.C. | 340 025 | L | 86 000 |
| I.C. | 157 521 | L | 78 000 | C.M.St.P.&P. | 650 486 | L | 80 000 |
| W.P. | 17 320 | L | 72 000 | A.C.L. | 76 012 | L | 66 000 |
| U.P. | 152 219 | L | 108 000 | M.D.T. | 17 172 | L | 90 000 |
| S.L.&S.F. | 150 665 | L | 90 000 | " | 146 669 | L | 90 000 |
| I.C. | 164 306 | L | 104 000 | " | 21 772 | L | 90 000 |
| P.M. | 91 873 | L | 104 000 | S.H.P.X. | 396 | L | 100 000 |
| L.&N. | 49 116 | L | 80 000 | M.K.T. | 95 188 | L | 70 000 |
| P.X. | 95 494 | L | 114 000 | S.L.S.F. | 150 279 | L | 86 000 |
| U.T.L.X. | 35 884 | L | 118 000 | I.C. | 156 163 | L | 106 000 |
| M.P. | 85 464 | L | 90 000 | S.O.O.L. | 40 380 | L | 60 000 |
| T.N.O. | 51 339 | L | 134 000 | I.C. | 4 805 | L | 100 000 |
| S.A.L. | 17 736 | L | 86 000 | P.R.R. | 77 868 | L | 60 000 |
| O.S.L. | 136 098 | L | 122 000 | S.O.U. | 161 779 | L | 90 000 |
| C.&N.W. | 109 764 | L | 80 000 | G.A.T.X. | 10 546 | L | 140 000 |
| N.R.C. | 7 471 | L | 100 000 | K.C.S. | 17 712 | L | 136 000 |
| I.C. | 206 357 | L | 86 000 | W.A.B. | 82 116 | L | 126 000 |
| " | 155 897 | L | 98 000 | C.L.C.X. | 1 007 | L | 134 000 |
| S.L.S.F. | 129 428 | L | 146 000 | R.I. | 262 317 | L | 96 000 |
| S.A.L. | 18 697 | L | 146 000 | I.C. | 9 | E | 50 000 |

TABLE 16
TONNAGE RECORD
Test No. S-1113

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 636 | E | 64 000 | S.W.T.X. | 5 301 | L | 106 000 |
| N.C. | 26 145 | E | 64 000 | N.A.M.X. | 8 038 | L | 138 000 |
| I.C. | 30 742 | L | 68 000 | N.P.C.X. | 463 | L | 128 000 |
| A.T.T.X. | 100 | L | 120 000 | A.C.C. | 48 485 | L | 96 000 |
| Erie | 86 023 | L | 68 000 | P.E.N. | 124 730 | L | 118 000 |
| S.O.U. | 161 935 | L | 96 000 | I.C. | 30 882 | L | 72 000 |
| N.Y.C. | 99 104 | L | 98 000 | G.N. | 24 115 | L | 90 000 |
| I.C.N. | 16 132 | L | 90 000 | N.Y.C. | 201 129 | L | 106 000 |
| B.A.R. | 61 249 | L | 88 000 | I.C. | 654 675 | L | 86 000 |
| C.O. | 9 956 | L | 96 000 | " | 655 766 | L | 82 000 |
| S.P. | 69 105 | L | 100 000 | N.C. | 26 011 | E | 68 000 |
| A.T.S.F. | 65 766 | L | 96 000 | " | 26 014 | E | 68 000 |
| S.P. | 31 285 | L | 82 000 | " | 26 061 | E | 66 000 |
| N.Y.C. | S-180 823 | L | 90 000 | U.R.T. | 85 196 | E | 70 000 |
| C.N. | 510 443 | L | 156 000 | N.Y.D.X. | 15 078 | E | 70 000 |
| U.P. | 138 215 | L | 162 000 | T.P. | 22 427 | E | 70 000 |
| P.M. | 71 237 | L | 92 000 | " | 22 421 | E | 72 000 |
| " | 91 985 | L | 84 000 | A.T.S.F. | 58 029 | E | 72 000 |
| " | 89 891 | L | 76 000 | I.C. | 4 640 | E | 70 000 |
| R.I. | 155 107 | L | 92 000 | M.I.L. | 13 049 | L | 98 000 |
| C.N.W. | 126 780 | L | 78 000 | R.I. | 262 352 | L | 112 000 |
| N.Y.C. | 152 652 | L | 98 000 | R.P.X. | 3 448 | L | 128 000 |
| T.N.O. | 52 092 | L | 82 000 | U.T.C. | 50 528 | L | 134 000 |
| N.Y.C. | 252 899 | L | 90 000 | I.C. | 155 510 | L | 92 000 |
| S.A.X. | 235 | L | 100 000 | " | 98 491 | E | 50 000 |

TABLE 17

TONNAGE RECORD

Test No. S-1114

| Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. | Car Initial | Car No. | Loaded or Empty | Gross Weight, lb. |
|---|---|---|---|---|---|---|---|
| I.C. | 30 | E | 60 000 | I.C. | 211 944 | L | 170 000 |
| " | 214 758 | L | 150 000 | " | 218 075 | L | 160 000 |
| " | 217 044 | L | 148 000 | " | 215 899 | L | 150 000 |
| " | 200 173 | L | 154 000 | " | 129 539 | L | 146 000 |
| " | 201 642 | L | 158 000 | " | 203 994 | L | 156 000 |
| " | 402 318 | L | 176 000 | " | 154 778 | L | 80 000 |
| " | 205 118 | L | 144 000 | S.F. | 146 628 | E | 46 000 |
| " | 205 422 | L | 142 000 | W.F.E.X. | 49 622 | L | 142 000 |
| " | 218 629 | L | 154 000 | C.O.S.X. | 859 | E | 46 000 |
| " | 400 389 | L | 164 000 | I.C. | 206 189 | L | 154 000 |
| " | 204 075 | L | 158 000 | " | 216 284 | L | 160 000 |
| " | 201 700 | L | 160 000 | " | 401 600 | L | 164 000 |
| " | 205 739 | L | 162 000 | " | 217 651 | L | 160 000 |
| " | 107 654 | L | 134 000 | " | 215 560 | L | 160 000 |
| " | 401 881 | L | 160 000 | " | 216 236 | L | 162 000 |
| " | 204 815 | L | 144 000 | " | 401 591 | L | 158 000 |
| " | 218 189 | L | 166 000 | " | 218 002 | L | 154 000 |
| " | 215 990 | L | 140 000 | " | 713 062 | L | 210 000 |
| " | 400 361 | L | 150 000 | " | 401 960 | L | 154 000 |
| " | 201 795 | L | 144 000 | " | 129 114 | L | 168 000 |
| " | 218 576 | L | 158 000 | " | 213 155 | L | 150 000 |
| " | 215 547 | L | 152 000 | " | 402 917 | L | 166 000 |
| " | 200 045 | L | 148 000 | " | 99 196 | E | 50 000 |

## APPENDIX B

### The Track

For obtaining data for this investigation, three sections of track were selected where the roadbed was in good repair, no curvature existed, and the track sections were long enough to accommodate the entire train on a uniform grade. Having the train on a uniform grade eliminated many factors likely to cause variations in the final resistance results.

Tables 18-22 give the exact location of the sections of track where data were taken for train resistance calculations. Table 18 gives information on the locations selected on the Illinois Division between Champaign and Chicago. No data were used on trains running southbound, because the scale weight of cars making up the trains was not available at the Chicago terminal. The "Section Location" gives the mile post reference from Chicago. Table 19 gives data points on track sections on the Kentucky Division, northbound, from Memphis to Fulton, while Table 20 is a description and location of test sections on the southbound track between the same cities.

*Roadbed, Ballast, and Ties.* — All sections of track selected for purposes of calculations were in excellent condition — well settled, drained, and maintained. The ties were mostly creosoted pine 6 in. by 8 in. by 8 ft., spaced about 20 in. from center to center. On the Illinois Division, the ballast consists almost entirely of broken stone. The tracks of the Kentucky Division are ballasted mostly with slag, some gravel, and a little broken stone.

*Rail.* — The track on the northbound line of the Illinois Division between Champaign and Chicago where the tests were made consisted entirely of 110-lb. rail. This was almost the condition existing on the southbound, or No. 1, track of the Kentucky Division, which consisted of 3.91 mi. of 112-lb. rail, 105.73 mi. of 110-lb., and 7.22 mi. of 90-lb. rail. The northbound No. 2 track from Memphis to Fulton consisted of 57.33 mi. of 112-lb. and 52.07 mi. of 110-lb. rail.

TABLE 18
TRACK LOCATIONS
Champaign to Chicago

| Section No. | Section Location | Section Length, miles | Grade, per cent | Section No. | Section Location | Section Length, miles | Grade, per cent |
|---|---|---|---|---|---|---|---|
| 1 | 122.30–121.65 | 0.65 | .00 | 16 | 60.45– 59.75 | 0.70 | .00 |
| 2 | 121.10–120.52 | 0.58 | +.063 | 17 | 59.41– 58.75 | 0.66 | +.014 |
| 3 | 119.97–119.51 | 0.46 | −.021 | 18 | 54.50– 52.00 | 2.50 | +.380 |
| 4 | 119.51–119.17 | 0.34 | +.005 | 19 | 51.99– 51.43 | 0.56 | .000 |
| 5 | 119.17–118.66 | 0.51 | +.333 | 20 | 51.43– 50.97 | 0.56 | +.170 |
| 6 | 118.13–117.13 | 1.00 | −.007 | 21 | 50.97– 50.50 | 0.47 | −.221 |
| 7 | 116.61–116.22 | 0.39 | +.143 | 22 | 48.24– 47.73 | 0.51 | −.011 |
| 8 | 114.90–114.38 | 0.52 | +.144 | 23 | 47.73– 46.83 | 0.90 | +.410 |
| 9 | 112.19–111.36 | 0.83 | +.545 | 24 | 46.83– 46.51 | 0.32 | −.088 |
| 10 | 110.53–110.06 | 0.47 | −.016 | 25 | 46.51– 45.83 | 0.68 | −.158 |
| 11 | 109.84–109.17 | 0.67 | −.403 | 26 | 45.83– 45.37 | 0.46 | +.079 |
| 12 | 109.09–108.62 | 0.47 | +.142 | 27 | 45.37– 44.62 | 0.75 | +.012 |
| 13 | 102.54–102.18 | 0.36 | −.420 | 28 | 44.39– 43.78 | 0.61 | +.037 |
| 14 | 101.91–101.46 | 0.45 | +.212 | 29 | 43.73– 43.11 | 0.62 | +.242 |
| 15 | 60.99– 60.45 | 0.54 | −.165 | | | | |

TABLE 19
TRACK LOCATIONS
Memphis to Fulton

| Section No. | Section Location | Section Length, miles | Grade, per cent | Section No. | Section Location | Section Length, miles | Grade, per cent |
|---|---|---|---|---|---|---|---|
| 101 | 379.24–378.65 | 0.59 | +.483 | 121 | 292.05–291.33 | 0.72 | .000 |
| 102 | 376.80–375.85 | 0.93 | .000 | 122 | 291.33–290.74 | 0.59 | +.200 |
| 103 | 375.85–375.23 | 0.62 | −.500 | 123 | 290.73–289.59 | 1.15 | +.400 |
| 104 | 363.83–362.78 | 1.06 | .000 | 124 | 289.53–288.91 | 0.62 | .000 |
| 105 | 362.50–360.90 | 1.58 | −.503 | 125 | 287.90–287.32 | 0.42 | .000 |
| 106 | 358.55–357.76 | 0.80 | +.225 | 126 | 285.36–284.71 | 0.66 | −.500 |
| 107 | 354.70–353.15 | 1.55 | −.504 | 127 | 284.70–284.05 | 0.66 | −.350 |
| 108 | 343.32–342.65 | 0.70 | +.429 | 128 | 282.97–282.10 | 0.88 | +.100 |
| 109 | 342.30–341.58 | 0.73 | +.387 | 129 | 282.08–280.48 | 1.59 | .000 |
| 110 | 318.38–316.88 | 1.58 | −.500 | 130 | 277.57–277.23 | 0.33 | +.669 |
| 112 | 316.26–315.67 | 0.60 | .000 | 131 | 276.79–276.17 | 0.63 | −.087 |
| 113 | 315.60–315.00 | 0.60 | +.100 | 132 | 275.30–274.82 | 0.48 | .000 |
| 114 | 310.47–309.60 | 0.87 | .000 | 133 | 274.80–274.32 | 0.48 | +.057 |
| 115 | 308.71–307.88 | 0.83 | .000 | 134 | 274.31–273.94 | 0.37 | +.250 |
| 116 | 307.88–305.80 | 2.08 | +.500 | 135 | 273.69–273.34 | 0.35 | +.210 |
| 117 | 302.95–300.00 | 2.95 | −.495 | 136 | 273.33–272.83 | 0.51 | .000 |
| 118 | 299.90–298.77 | 1.13 | .000 | 137 | 272.67–272.07 | 0.60 | +.363 |
| 119 | 297.83–297.23 | 0.60 | −.500 | 138 | 271.91–271.46 | 0.45 | −.416 |
| 120 | 297.15–295.85 | 1.32 | .000 | 139 | 271.33–270.71 | 0.62 | +.485 |

*Maintenance.* — The entire mileage of track over which the trains were tested in this investigation was in an excellent state of repair and had been so for some time. At no time during the tests was it necessary to reduce speeds on account of work crews; all maintenance work had been completed before the test started, a fact which accounts for the favorable conditions of the roadbed.

TABLE 20
TRACK LOCATIONS

Fulton to Memphis

| Section No. | Section Location | Section Length, miles | Grade, per cent | Section No. | Section Location | Section Length, miles | Grade, per cent |
|---|---|---|---|---|---|---|---|
| 101 | 378.65–379.24 | 0.59 | −.483 | 121 | 291.33–292.05 | 0.72 | .000 |
| 102 | 375.85–376.80 | 0.93 | .000 | 122 | 290.74–291.33 | 0.59 | −.200 |
| 103 | 375.23–375.85 | 0.62 | +.500 | 123 | 289.59–290.73 | 1.15 | −.400 |
| 104 | 362.85–363.83 | 0.96 | .000 | 124 | 288.91–289.53 | 0.62 | .000 |
| 105 | 360.90–362.50 | 1.58 | +.503 | 125 | 287.32–287.90 | 0.58 | .000 |
| 106 | 357.76–358.55 | 0.80 | −.225 | 126 | 284.71–285.36 | 0.66 | +.500 |
| 107 | 353.15–354.70 | 1.55 | +.504 | 127 | 284.05–284.70 | 0.66 | +.350 |
| 108 | 342.65–343.32 | 0.70 | −.429 | 128 | 282.10–282.97 | 0.88 | −.100 |
| 109 | 341.58–342.30 | 0.73 | −.387 | 129 | 280.48–282.08 | 1.59 | .000 |
| 110 | 317.34–318.27 | 0.94 | +.497 | 130 | 277.23–277.57 | 0.33 | −.669 |
| 111 | 316.30–317.20 | 0.90 | +.450 | 131 | 276.17–276.70 | 0.63 | +.087 |
| 112 | 315.67–316.26 | 0.60 | .000 | 132 | 274.82–275.30 | 0.48 | .000 |
| 113 | 315.00–315.60 | 0.60 | −.100 | 133 | 274.32–274.80 | 0.48 | −.057 |
| 114 | 309.60–310.47 | 0.87 | .000 | 134 | 273.94–274.31 | 0.37 | −.250 |
| 115 | 307.88–308.71 | 0.83 | .000 | 135 | 273.34–273.69 | 0.35 | −.210 |
| 116 | 305.88–307.88 | 2.08 | −.500 | 136 | 272.83–273.33 | 0.51 | .000 |
| 117 | 300.00–302.95 | 2.95 | +.495 | 137 | 272.07–272.67 | 0.60 | −.363 |
| 118 | 298.77–299.90 | 1.13 | .000 | 138 | 271.46–271.91 | 0.45 | +.416 |
| 119 | 297.23–297.83 | 0.60 | +.500 | 139 | 270.71–271.33 | 0.62 | −.485 |
| 120 | 295.85–297.15 | 1.32 | .000 | | | | |

TABLE 21
TRACK LOCATIONS

Fulton to Paducah

| Section No. | Section Location | Section Length, miles | Grade, per cent | Section No. | Section Location | Section Length, miles | Grade, per cent |
|---|---|---|---|---|---|---|---|
| 140 | 261.20–260.50 | 0.70 | +1.156 | 142 | 255.42–255.01 | 0.41 | − .931 |
| 141 | 255.99–255.62 | 0.37 | −1.167 | 143 | 253.89–253.09 | 0.80 | + .617 |

TABLE 22
TRACK LOCATIONS

Paducah to Fulton

| Section No. | Section Location | Section Length, miles | Grade, per cent | Section No. | Section Location | Section Length, miles | Grade, per cent |
|---|---|---|---|---|---|---|---|
| 140 | 253.09–253.89 | 0.80 | − .617 | 142 | 255.62–255.99 | 0.37 | +1.167 |
| 141 | 255.01–255.42 | 0.41 | + .931 | 143 | 260.50–261.20 | 0.70 | −1.156 |

# APPENDIX C

## Methods Employed in Calculating Results

This appendix presents a detailed explanation of the simple process used throughout this investigation in calculating the results of the tests. Since the entire train was on a uniform grade and straight track when data were taken, it is necessary only to consider grade and acceleration resistance in order to determine values of net train resistance.

*The Elements of Gross Resistance.* — Under ordinary operating conditions the various elements which make up gross train resistance are:

(a) Net resistance or train resistance, on straight, level track at constant speed and in still air.

(b) Resistance due to wind.

(c) Resistance due to grades.

(d) Resistance due to acceleration.

(e) Resistance due to track curvature.

Items (a) and (b) are usually considered together, since it is almost impossible to separate wind resistance from the elements that compose net train resistance. Curve resistance has been entirely eliminated from consideration, since only tangent track sections have been used. Grade resistance and acceleration resistance are readily determined by calculation; net train resistance is found by subtracting these two items from the gross train resistance, which is represented by the drawbar pull of the locomotive and recorded autographically upon the dynamometer car record chart.

The following general notation is used in determining grade resistance and acceleration resistance.

$P$ = Gross train resistance = drawbar pull, lb., found by integrating the area under the drawbar pull curve and finding the mean ordinate.

$R$ = Train resistance on tangent, level track, at constant speed, lb. per ton.

$R_g$ = Grade resistance, lb. per ton.

$R_a$ = Acceleration resistance, lb. per ton.

$W$ = Train weight, tons.

$V$, $V_1$, $V_2$ = Train speed, mi. per hr.

$G$ = Grade, feet rise per mi., or per cent rise.

$A$ = Acceleration of train, mi. per hr. per sec.

$E_1, E_2$ = Elevation of beginning and end of track section.
$S$ = Length of track section, ft., measured directly from the dynamometer charts.
$N$ = Number of cars in the train.

*Grade Resistance.*—With the entire train on a uniform grade—and that was the requirement for all tests—the determination of grade resistance, in pounds per ton, is a simple problem in mechanics, $G$ being the feet rise per mile:

$$R_g = 0.379 \cdot G$$
$$\sin \alpha = \frac{f}{w}. \quad (13)$$

$$f = W \sin \alpha \qquad \sin \alpha = \frac{1}{5280}$$
$$= \frac{2000}{5280} = 0.379. \quad (14)$$

If the grade, $G$, is given in per cent rise, then the grade resistance in pounds per ton is:

$$R_g = 20G \qquad f = \frac{2000}{100} = 20 \qquad \sin \alpha = \frac{1}{100}. \quad (15)$$

A one per cent grade represents a rise of 1 ft. for each 100 ft. of track.

Figure 6 shows the determination of grade resistance in feet of rise per mile and also as per cent rise.

If the feet rise per mile or the per cent of the grade is not given for the track section under consideration, the grade resistance may be found by substituting the elevations at the beginning $E_1$ and at

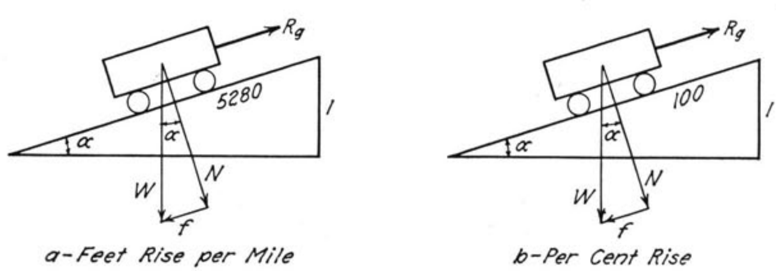



FIG. 6. DETERMINATION OF GRADE RESISTANCE

the end $E_2$ of the section, found from the profile, in the following equations:

$$R_g = 0.379 \cdot (E_2 - E_1) \cdot \frac{5280}{S} = \frac{2000 \cdot (E_2 - E_1)}{S}, \tag{16}$$

or

$$R_g = 20 \cdot (E_2 - E_1) \cdot \frac{100}{S} = 2000 \frac{(E_2 - E_1)}{S}. \tag{17}$$

*Acceleration Resistance.*—That part of the drawbar pull needed to produce acceleration is made up of two parts. The first and most important is the force needed to produce linear acceleration of the entire train; the second is the pull necessary to produce rotative acceleration of the car wheels and axles. The sum of the pull necessary to produce linear and rotative acceleration is the total acceleration resistance, $R_a$, of the train.

Let $R_a$ = total acceleration resistance, lb. per ton.
$P_a$ = drawbar pull needed to produce acceleration, lb.
$P_L$ = drawbar pull needed to produce linear acceleration, lb.
$P_r$ = drawbar pull needed to produce rotative acceleration of all wheels and axles, lb.

Then

$$R_a = \frac{P_a}{W}$$

and

$$P_a = P_L + P_r;$$

therefore

$$R_a = \frac{P_L + P_r}{W}. \tag{18}$$

To find $P_L$:

$$P_L = \text{mass} \cdot \text{acceleration} = \frac{W \cdot 2000}{32.2} a.$$

But

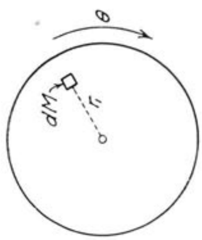
$$a = \text{A} \cdot \frac{5280}{3600} = 1.466A.$$

Hence

$$P_L = \frac{W \cdot 2000 \cdot 1.466A}{32.2} = 91.097WA. \quad (19)$$

To find $P_r$:

Consider a wheel or any of the rotating parts of the car of mass $M$ and radius $r$ rotating about its axis, and $dM$ a particle of mass at a distance $r_1$ from the center of rotation. Let $\theta$ be the angular acceleration of the rotating part; then the tangential acceleration of the mass $dM$ will be $r_1\theta$, and the force required to give it that acceleration will be $dMr_1\theta$. This force acts at a distance $r_1$ from the center of rotation; hence its moment is




$$dMr_1\theta \cdot r_1 = dMr_1^2\theta.$$

The total moment of the rotating mass is

$$\Sigma dMr_1^2\theta = I\theta, \quad (20)$$

where $I$ is the moment of inertia of the wheels and axle about its axis of rotation.

But

$$I = k^2M, \quad (21)$$

where

$k$ is the "radius of gyration";

also

$$r\theta = a \quad (22)$$

or

$$\theta = \frac{a}{r}, \quad (23)$$

where $a$ is the linear acceleration of a point on the periphery of the rotating mass and equals the acceleration of the train.

Therefore:

$$\text{Total moment} = \frac{k^2}{r} Ma \quad (24)$$

and

$$p_r = \frac{\text{moment}}{r} = \left(\frac{k}{r}\right)^2 Ma, \quad (25)$$

$p_r$ being the force in pounds required to produce acceleration of rotation of one pair of wheels and axles.

Changing the quantity $Ma$ in Equation (25) to the more convenient railway system of units,

$$p_r = W_w \cdot 2000 \cdot 1.466A \cdot \left(\frac{k}{r}\right)^2 = 91.097W_wA\left(\frac{k}{r}\right)^2, \qquad (26)$$

where $W_w$ = weight of a pair of 33-in. chilled-iron car wheels and axle which weigh approximately 1950 lb.,

and the value of $\left(\frac{k}{r}\right) = 0.64.$

Substituting in Equation (26),

$$p_r = 91.097 \cdot \frac{1950}{2000} \cdot (0.64)^2 \cdot A = 36.38A.$$

Since there are four pairs of wheels and connecting axles on the ordinary freight car, and there are $N$ cars in a freight train,

$$\begin{aligned} P_r = 4 \cdot N \cdot p_r &= 36.38 \cdot 4 \cdot N \cdot A \\ &= 145.52NA. \end{aligned} \qquad (27)$$

From Equations (18), (19), and (27),

$$R_a = \left(91.097 + 145.52\frac{N}{W}\right) \cdot A. \qquad (28)$$

*The Determination of Acceleration.*—

$v_1, v_2$ = Speed at entrance and exit of track section, ft. per sec.

$V_1, V_2$ = Speed at entrance and exit of track section, mi. per hr., as determined directly from the dynamometer charts.

$t$ = The time elapsed in transit over the section, sec.

Then

$$v_2 = v_1 + at$$

and

$$S = v_1t + \frac{at^2}{2}.$$

Hence, by the elimination of $t$,

since

$$t = \frac{v_2 - v_1}{a}$$

and

$$a = \frac{v_2^2 - v_1^2}{2S}$$

and, since

$$a = 1.466A$$

and

$$v = 1.466V,$$

therefore

$$A = 0.733 \frac{V_2^2 - V_1^2}{S}. \qquad (29)$$

This equation is used to determine average acceleration over the various track sections. $A$ signifies that hypothetical uniform acceleration which, acting during transit over the section, would have caused the absorption of the same energy as was actually expended to produce acceleration when the speed changed from $V_1$ to $V_2$. Equation (29) is correct for all cases, regardless of the shape or variations of the speed curve. However, since acceleration resistance may account for a large percentage of the drawbar pull, the track sections, $S$, were so chosen that $V_1$ and $V_2$ varied but slightly and the speed curve between sections limits was practically a straight line.

*Determination of Net Train Resistance.*—Net resistance on tangent, level track at constant speed is here defined as train resistance, $R$, and is expressed in pounds per ton. It is derived from the equation

$$R = \frac{P}{W} - R_g - R_a, \qquad (30)$$

in which $P$ is determined directly from the drawbar pull record on the test car charts, $W$ from the train data, $R_g$ and $R_a$ as previously explained ($-R_g$ if there is an upgrade and $+R_g$ if the train is moving on a downgrade; $-R_a$ if the speed is increasing and $+R_a$ if the speed is decreasing).

$$R = \frac{P}{W} - 0.379G - \left(91.097 + 145.52\frac{N}{W}\right) \cdot A, \qquad (31)$$

or

$$R = \frac{P}{W} - \frac{2000\,(E_2 - E_1)}{S} - \left(91.097 + 145.52\,\frac{N}{W}\right) \cdot A. \qquad (32)$$

The mean train speed is determined by taking the average of the speeds $V_1$ and $V_2$.

## APPENDIX D

### Results of the Individual Tests

In Appendix D are shown the principal data taken from the dynamometer car charts and the main results of the calculations. The notation following the column headings is the same as that used in Appendix C. The final values of train resistance are given in column 12, and the corresponding values of speed in column 11.

The data from columns 11 and 12 of the tables have been used to plot the curves for each test. The initial portion of the curves, represented by the dashed lines, for speeds from 5 to 40 mi. per hr., is taken from Bulletin No. 43. The dashed lines forming the upper part of the curves are either estimated values, located after the final curves were drawn, or values found by calculations. It is believed that they represent train resistance values which are easily within the 8-per cent limit of variation.

TABLE 23

TEST NO. S-1101

From Memphis to Fulton, July 12, 1939. Total weight behind measuring drawbar = 2158 tons. Train length = 4028.6 ft. 84 cars: 7 loaded; 77 empty. Average weight per car = 25.69 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 105(b) | 361.20–361.49 | 290 | 12 400 | .0634 | 38.1 | 39.8 | −.503 | +62.0°R | 8.7 | 38.95 | 9.67 |
| 105(c) | 360.91–361.20 | 294 | 12 200 | .0419 | 39.8 | 40.9 | −.503 | +62.0°R | 8.7 | 40.35 | 11.66 |
| 107(a) | 353.71–353.91 | 208 | 15 375 | .0669 | 35.1 | 36.5 | −.504 | +32.8°R | 10.6 | 35.80 | 10.73 |
| 107(b) | 353.14–353.43 | 290 | 11 075 | .0726 | 39.0 | 40.9 | −.504 | +32.8°R | 10.6 | 39.95 | 8.18 |
| 118 | 298.76–299.13 | 369 | 14 825 | −.0277 | 53.0 | 52.3 | 0 | +35.0°R | 14.0 | 52.65 | 9.54 |
| 120 | 295.84–296.11 | 265 | 17 250 | −.0349 | 48.0 | 47.3 | 0 | +34.0°R | 12.7 | 47.65 | 11.37 |

TABLE 24
TEST NO. S-1102

From Fulton to Memphis, June 28, 1937. Total weight behind measuring drawbar = 2926. Train length = 5084 ft. 112 cars, all empty. Average weight per car = 25.88 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind | | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Direction | Velocity, m.p.h. | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 116(c) | 307.51–307.72 | 1 114 | 25 125 | .0597 | 50.0 | 50.9 | −.500 | +58.0°L | 12.9 | 50.45 | 12.81 |
| 120 | 296.84–297.14 | 1 589 | 30 125 | −.0077 | 42.2 | 42.0 | 0 | +63.5°L | 14.6 | 42.10 | 11.04 |
| 129 | 281.50–282.92 | 3 089 | 28 125 | −.0080 | 41.5 | 40.5 | 0 | +65.0°L | 10.2 | 40.00 | 10.38 |

TABLE 25

TEST NO. S-1103

From Fulton to Memphis, July 13, 1937. Total weight behind measuring drawbar = 2015 tons. Train length = 3363.36 ft. 68 cars: 20 loaded, 48 empty. Average weight per car = 29.64 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resist-ance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 110 | 318.00–318.26 | 1 410 | 27 425 | −.0418 | 31.6 | 30.3 | +.497 | −81.0°R | 6.0 | 30.85 | 7.68 |
| 116 | 307.82–307.42 | 2 144 | 15 600 | .0754 | 44.8 | 47.2 | −.500 | −33.5 | 6.4 | 46.00 | 10.49 |
| 117(a) | 300.69–301.00 | 1 595 | 22 725 | −.0916 | 44.5 | 42.2 | +.495 | −76.0°R | 5.4 | 43.35 | 10.17 |
| 121 | 292.05–291.96 | 459 | 17 250 | −.0305 | 48.0 | 47.8 | 0 | −49.5°R | 4.7 | 47.60 | 11.49 |
| 127 | 284.70 Point | ..... | 29 125 | 0 | 29.0 | 29.0 | +.350 | 0.0° | 2.3 | 29.00 | 7.45 |
| 129(a) | 281.10–281.44 | 1 827 | 20 400 | 0 | 36.5 | 36.5 | 0 | +76.5°R | 2.9 | 36.50 | 10.12 |

# TABLE 26
## TEST NO. S-1104

From Fulton to Memphis, June 24, 1937. Total weight behind measuring drawbar = 1500 tons. Train length = 1927.2 ft. 40 cars: 32 loaded, 8 empty. Average weight per car = 37.50 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 101 | 379.02–379.20 | 940 | 9 000 | .0706 | 56.2 | 57.0 | −.483 | +64.5°L | 17.2 | 56.60 | 9.10 |
| 104(a) | 363.24–363.45 | 1 141 | 14 725 | .0494 | 38.0 | 39.0 | 0 | +86.5°L | 14.2 | 38.50 | 5.11 |
| 105(a) | 361.30–361.59 | 1 542 | 16 125 | −.0238 | 42.0 | 40.5 | +.503 | +66.0°L | 14.6 | 41.25 | 6.27 |
| 107(b) | 354.69–354.41 | 1 468 | 18 725 | −.0482 | 37.8 | 36.5 | +.504 | +66.5°L | 11.4 | 37.15 | 6.98 |
| 108 | 343.32–343.00 | 1 690 | 9 100 | .0524 | 60.0 | 61.0 | −.429 | +66.0°L | 18.0 | 60.50 | 9.66 |
| 110(a) | 317.72–318.00 | 1 478 | 14 825 | −.0572 | 36.9 | 35.3 | +.497 | +62.0°L | 10.1 | 36.10 | 5.38 |
| 110(b) | 318.00–318.28 | 1 478 | 14 825 | −.0572 | 36.9 | 35.3 | +.497 | +62.5°L | 10.1 | 36.10 | 5.38 |
| 113 | 315.37–315.60 | 1 214 | 13 200 | .0534 | 39.7 | 40.8 | −.100 | +70.0°L | 13.3 | 40.25 | 5.72 |
| 115 | 308.70–308.38 | 1 669 | 8 800 | −.0203 | 58.0 | 57.6 | 0 | +74.0°L | 18.8 | 57.80 | 7.79 |
| 116(a) | 307.85–307.46 | 2 070 | 9 000 | .0804 | 55.8 | 57.8 | −.500 | +77.5°L | 15.8 | 56.80 | 8.36 |
| 116(b) | 306.56–306.25 | 1 663 | 10 350 | .1052 | 46.5 | 49.0 | −.500 | +80.5°L | 16.9 | 47.75 | 6.91 |
| 117(a) | 300.60–300.36 | 1 267 | 12 625 | .0921 | 47.7 | 46.0 | +.495 | +74.0°L | 15.6 | 46.85 | 7.28 |
| 122 | 291.00–291.29 | 1 558 | 9 100 | .0201 | 51.5 | 51.8 | −.200 | +48.0°L | 16.2 | 51.65 | 8.68 |
| 124 | 289.53–289.28 | 1 288 | 10 650 | 0 | 42.9 | 42.9 | 0 | +67.5°L | 11.7 | 42.90 | 7.10 |
| 125 | 287.91–287.69 | 1 130 | 9 650 | 0 | 48.5 | 48.5 | 0 | +66.5°L | 11.7 | 48.50 | 6.43 |
| 129 | 281.67–282.00 | 1 716 | 10 250 | .0040 | 46.9 | 47.0 | 0 | +84.0°L | 15.7 | 46.95 | 6.45 |
| 132 | 275.29–275.14 | 813 | 10 750 | 0 | 43.2 | 43.2 | 0 | +73.0°L | 13.5 | 43.20 | 7.16 |
| 133 | 274.33–273.20 | 686 | 11 200 | .0271 | 42.2 | 42.5 | −.057 | +70.5°L | 12.2 | 42.35 | 6.03 |
| 136 | 273.33–273.20 | 686 | 11 525 | .0161 | 37.5 | 37.9 | 0 | +73.5°L | 12.2 | 37.80 | 6.14 |

TABLE 27

TEST NO. S-1105

From Fulton to Memphis, July 23, 1937. Total weight behind measuring drawbar = 1002 tons. Train length = 1125 ft. 26 cars: 22 loaded, 4 empty. Average weight per car = 38.53 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 121 | 291.77–292.05 | 1 504 | 12 100 | .0097 | 49.9 | 50.1 | 0 | +39.5°R | 5.6 | 50.00 | 11.15 |
| 123 | 290.72–290.50 | 1 193 | 11 425 | .0723 | 53.0 | 54.1 | −.400 | +58.0°R | 4.3 | 53.55 | 12.54 |
| 125 | 287.87–287.59 | 1 525 | 13 200 | .0191 | 49.6 | 50.0 | 0 | +32.0°R | 9.0 | 49.80 | 11.36 |
| 129 | Point | 0 | 12 300 | 0 | 48.1 | 48.1 | 0 | +48.5°R | 4.8 | 48.10 | 12.27 |

TABLE 28

TEST NO. S-1106

From Fulton to Memphis, July 23, 1937. Total weight behind measuring drawbar = 1056 tons. Train length = 1160.54 ft. 27 cars: 23 loaded, 4 empty. Average weight per car = 39.11 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 102 | 276.60–276.39 | 1 119 | 11 300 | .0528 | 36.1 | 37.2 | 0 | +16.0°R | 2.5 | 36.65 | 5.69 |
| 104 | 363.76–363.49 | 1 409 | 10 000 | 0 | 46.0 | 46.0 | 0 | ......... | 2.1 | 46.00 | 9.47 |
| 105 | 361.00–361.62 | 2 006 | 19 100 | .0093 | 42.2 | 42.5 | +.503 | +58.0°R | 5.4 | 42.35 | 7.14 |
| 106 | 358.32–358.00 | 1 705 | 4 800 | 0 | 51.2 | 51.2 | −.225 | −29.0°R | 4.9 | 51.20 | 9.04 |
| 108 | 343.00–342.87 | 665 | 6 625 | .0461 | 52.1 | 52.5 | −.429 | −41.0°R | 4.1 | 52.30 | 10.48 |
| 109 | 342.00–342.22 | 1 161 | 6 100 | .0188 | 49.7 | 50.0 | −.387 | −63.0°R | 3.4 | 49.85 | 11.72 |
| 110 | 318.00–318.22 | 1 161 | 15 375 | −.0193 | 38.6 | 38.2 | +.497 | +78.5°R | 2.3 | 38.40 | 6.45 |
| 111 | 316.81–316.56 | 1 320 | 14 925 | −.0376 | 42.8 | 42.0 | +.450 | −34.0°R | 3.2 | 42.40 | 8.70 |
| 112 | 316.00–316.25 | 1 330 | 14 825 | .0420 | 41.9 | 42.8 | 0 | ......... | 2.4 | 42.35 | 10.05 |
| 113 | 315.59–315.36 | 1 192 | 14 075 | .0765 | 37.8 | 39.4 | −.100 | ......... | 2.6 | 38.60 | 8.07 |
| 114 | 309.82–310.05 | 1 193 | 7 750 | −.0193 | 52.7 | 52.4 | 0 | +53.5°R | 8.1 | 52.55 | 9.17 |
| 115 | 308.52–308.34 | 908 | 7 750 | −.0839 | 52.5 | 51.5 | 0 | +37.0°R | 9.0 | 52.00 | 15.29 |
| 116 | 307.83–307.53 | 1 584 | 8 050 | .0339 | 52.0 | 52.7 | −.500 | +78.0°R | 6.6 | 52.35 | 14.40 |
| 117(s) | 302.89–302.64 | 1 341 | 19 525 | −.0155 | 35.6 | 35.2 | +.495 | −76.0°R | 2.0 | 35.40 | 10.05 |
| 118 | 299.60–299.27 | 1 731 | 14 600 | .0155 | 45.6 | 46.0 | 0 | +31.0°R | 7.1 | 45.80 | 12.35 |

TABLE 29

TEST NO. S-1107

From Champaign to Chicago, June 3, 1937. Total weight behind measuring drawbar = 1505 tons. Train length = 1837.44 ft. 38 cars: 37 loaded, 1 empty. Average weight per car = 39.6 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 122.30–121.65 | 1 647 | 24 250 | .0692 | 40.0 | 41.9 | 0 | +77.0°R | 4.0 | 40.95 | 9.55 |
| 2 | 121.10–120.52 | 1 404 | 23 300 | .0423 | 44.6 | 45.5 | +.063 | +86.0°R | 6.1 | 45.05 | 10.21 |
| 3 | 119.97–119.51 | 686 | 21 850 | .0520 | 48.5 | 49.0 | −.021 | +79.0°R | 7.5 | 48.75 | 10.00 |
| 4 | 119.52–119.17 | 1 840 | 21 900 | 0 | 49.5 | 49.5 | +.005 | +57.0°R | 8.8 | 49.50 | 14.28 |
| 5 | 119.13–118.13 | 5 280 | 21 500 | .0108 | 52.5 | 53.0 | −.007 | +72.0°R | 5.5 | 52.75 | 13.39 |
| 6 | 118.13–117.13 | 3 551 | 21 370 | .0108 | 52.5 | 53.0 | −.007 | +72.0°R | 5.5 | 52.75 | 13.42 |
| 7 | 116.61–116.22 | 334 | 22 350 | 0 | 54.0 | 54.0 | +.143 | +52.0°R | 4.2 | 54.00 | 11.99 |
| 9 | 112.19–111.36 | 2 629 | 23 200 | −.0524 | 47.8 | 49.6 | +.545 | +76.5°R | 3.4 | 48.70 | 9.14 |
| 10 | 110.53–110.06 | 709 | 24 000 | .0383 | 46.1 | 46.5 | −.016 | +50.0°R | 6.7 | 46.30 | 12.63 |
| 11 | 109.84–109.17 | 1 778 | 20 300 | .1077 | 51.0 | 53.5 | −.403 | +79.0°R | 5.1 | 52.25 | 11.34 |
| 12 | 109.09–108.62 | 771 | 20 200 | −.0210 | 55.5 | 55.3 | +.142 | +27.0°R | 8.3 | 55.40 | 12.57 |
| 14 | 101.91–101.46 | 617 | 23 500 | .0982 | 46.0 | 46.3 | +.212 | +57.0°R | 8.4 | 46.15 | 8.20 |

TABLE 30

TEST NO. S-1108

From Memphis to Fulton, July 16, 1937. Total weight behind measuring drawbar = 1927 tons. Train length = 2254.56 ft. 47 cars: 44 loaded, 3 empty. Average weight per car = 41.00 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 101 | 378.65–378.81 | 834 | 29 825 | −.0185 | 35.2 | 34.9 | +.483 | +17.0°R | 13.3 | 35.05 | 7.52 |
| 102 | 376.00–376.30 | 1 605 | 19 300 | .0164 | 46.0 | 46.4 | 0 | + 5.5°R | 19.6 | 46.20 | 8.43 |
| 104 | 362.87–362.07 | 1 030 | 14 125 | 0 | 45.1 | 45.1 | 0 | +12.0°R | 17.0 | 45.10 | 7.33 |
| 107(b) | 353.16–353.46 | 1 095 | 12 200 | .0569 | 51.0 | 52.2 | −.504 | +36.5°R | 12.5 | 51.70 | 10.92 |
| 110(a) | 316.87–317.13 | 1 383 | 7 375 | .0745 | 46.1 | 47.6 | −.500 | +48.0°L | 6.3 | 46.85 | 6.71 |
| 110(b) | 317.54–317.73 | 100 | 8 000 | .0628 | 42.5 | 43.5 | −.500 | +30.0°L | 6.0 | 43.00 | 7.97 |
| 112 | 315.56–315.83 | 1 378 | 6 450 | .0675 | 49.5 | 48.2 | 0 | 90.0°L | 6.3 | 48.85 | 9.76 |
| 114 | 309.60–310.00 | 2 086 | 14 550 | −.0031 | 45.1 | 45.0 | 0 | +11.0°R | 9.3 | 45.05 | 7.82 |
| 115 | 308.03–308.27 | 1 278 | 12 000 | 0 | 42.0 | 42.0 | 0 | +21.5°R | 10.3 | 42.00 | 6.22 |
| 117(a) | 302.21–302.51 | 1 568 | 10 450 | .0821 | 45.3 | 47.2 | −.495 | +15.0°R | 9.0 | 46.25 | 7.58 |
| 117(b) | 301.00–301.32 | 1 705 | 9 500 | .0688 | 52.7 | 54.2 | −.495 | +22.5°R | 11.8 | 53.45 | 8.33 |
| 118 | 298.78–299.00 | 1 125 | 17 200 | .0220 | 42.1 | 42.5 | 0 | +33.0°R | 7.8 | 42.30 | 6.86 |
| 120 | 296.34–296.68 | 1 800 | 14 350 | 0 | 46.2 | 46.2 | 0 | +45.5°R | 9.4 | 46.20 | 7.52 |
| 121 | 291.34–291.45 | 570 | 17 700 | .0276 | 35.7 | 36.0 | 0 | 0.0° | 9.1 | 35.85 | 6.56 |
| 126 | 284.72–284.93 | 1 151 | 10 500 | .0739 | 35.5 | 37.1 | −.350 | +46.0°R | 10.2 | 36.30 | 5.45 |

TABLE 31

TEST NO. S-1109

From Memphis to Fulton, June 28th, 1937. Total weight behind measuring drawbar = 1136 tons. Train length = 1246.08 ft. 26 cars: 2 empty, 24 loaded. Average weight per car = 43.69 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 102 | 376.00–376.57 | 3 015 | 27 750 | .0992 | 54.9 | 58.5 | 0 | +49.0°L | 14.1 | 56.70 | 15.06 |
| 105(a) | 362.00–362.26 | 1 415 | 18 600 | .1054 | 65.3 | 66.1 | −.503 | +51.0°L | 19.0 | 65.70 | 21.29 |
| 105(b) | 361.12–361.42 | 1 584 | 19 350 | .0996 | 71.0 | 72.5 | −.503 | +53.0°L | 25.4 | 71.75 | 17.64 |
| 106 | 357.75–358.01 | 1 341 | 20 950 | −.0197 | 60.5 | 60.2 | +.225 | +52.0°L | 17.5 | 60.35 | 15.81 |
| 110(b) | 317.11–317.29 | 961 | 10 600 | .0930 | 39.9 | 41.4 | −.182 | +61.0°L | 14.8 | 40.65 | 10.55 |
| 114 | 309.60–310.13 | 2 804 | 23 250 | .0836 | 51.8 | 54.8 | 0 | +44.0°L | 17.9 | 53.30 | 12.57 |
| 116(a) | 307.31–307.63 | 1 716 | 22 650 | −.0893 | 58.8 | 57.0 | +.500 | +51.0°L | 19.2 | 57.90 | 18.29 |
| 116(b) | 306.01–306.33 | 1 711 | 22 250 | −.0608 | 55.3 | 54.0 | +.500 | +52.0°L | 20.2 | 54.65 | 15.37 |
| 120 | 295.85–296.09 | 1 272 | 21 750 | .0512 | 55.2 | 56.0 | 0 | +57.0°L | 20.9 | 55.60 | 14.31 |
| 121 | 291.39–291.80 | 2 133 | 22 650 | .0946 | 56.2 | 58.6 | 0 | +54.0°L | 20.9 | 57.40 | 11.00 |
| 122 | 291.33–290.74 | 1 510 | 22 100 | −.0157 | 60.0 | 59.8 | +.200 | +46.0°L | 20.2 | 59.93 | 16.93 |
| 123(a) | 290.48–290.14 | 1 769 | 22 200 | .0391 | 58.6 | 59.4 | +.400 | +50.0°L | 22.0 | 59.00 | 11.63 |
| 123(b) | 289.41–289.65 | 1 309 | 23 750 | .0266 | 59.2 | 59.6 | +.400 | +64.0°L | 19.1 | 59.40 | 14.39 |
| 124 | 288.94–289.28 | 1 800 | 21 500 | .0691 | 60.0 | 61.4 | 0 | +64.0°L | 19.1 | 60.70 | 12.48 |
| 126 | 284.88–285.12 | 1 272 | 9 200 | .0596 | 57.1 | 58.0 | −.500 | +74.0°L | 18.6 | 57.55 | 12.40 |
| 130 | 277.22–277.33 | 628 | 24 250 | −.0673 | 58.0 | 57.5 | +.669 | +38.5°L | 22.7 | 57.75 | 14.32 |
| 131 | 276.52–276.17 | 1 848 | 23 750 | .0464 | 58.0 | 59.0 | −.087 | +50.0°L | 20.4 | 58.50 | 18.27 |
| 132 | 274.82–275.03 | 1 135 | 21 500 | 0 | 62.8 | 62.8 | 0 | +48.0°L | 20.4 | 62.80 | 18.92 |
| 133 | 275.55–275.33 | 1 156 | 21 250 | 0 | 62.5 | 62.5 | +.057 | +53.0°L | 24.8 | 62.50 | 17.56 |
| 134 | 273.94–274.08 | 739 | 21 250 | 0 | 62.2 | 62.2 | +.250 | +53.0°L | 24.8 | 62.20 | 13.70 |
| 135 | 273.45–273.33 | 660 | 21 750 | 0 | 61.1 | 61.1 | +.210 | +38.0°L | 26.0 | 61.10 | 14.94 |
| 136 | 272.84–273.10 | 1 188 | 20 600 | .0077 | 62.5 | 62.6 | 0 | +38.0°L | 26.0 | 62.55 | 17.40 |
| 137 | 272.08–272.41 | 1 785 | 22 700 | −.0663 | 62.8 | 61.5 | +.363 | +38.0°L | 25.9 | 62.15 | 18.72 |
| 141 | 255.61–255.75 | 713 | 13 100 | .2183 | 49.5 | 51.6 | −1.167 | +37.0°L | 13.2 | 50.55 | 14.26 |

## TABLE 32
## TEST NO. S-1110

From Memphis to Fulton, July 5, 1937. Total weight behind measuring drawbar = 1468 tons. Train length = 1584 ft. 33 cars: 32 loaded, 1 empty. Average weight per car = 44.48 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 107(a) | 254.37–253.96 | 2 164 | 18 625 | .0868 | 60.0 | 62.1 | −.504 | +13.5°L | 15.5 | 61.05 | 14.57 |
| 107(b) | 353.73–353.52 | 1 108 | 13 350 | .0421 | 63.5 | 64.0 | −.504 | +13.5°L | 15.5 | 63.75 | 15.19 |
| 108 | 343.00–342.69 | 1 610 | 20 250 | −.0650 | 48.5 | 47.0 | +.429 | +16.0°L | 12.4 | 47.75 | 11.36 |
| 109 | 341.96–341.62 | 1 784 | 19 625 | −.0234 | 47.8 | 47.2 | +.387 | +15.5°L | 12.1 | 47.50 | 7.83 |
| 110 | 318.32–316.88 | 2 370 | 6 125 | .0377 | 60.5 | 61.5 | −.500 | +21.0°L | 10.4 | 61.00 | 10.61 |
| 114 | 310.13–309.64 | 2 587 | 20 050 | .0280 | 54.5 | 55.4 | 0 | +31.0°L | 8.0 | 54.95 | 11.01 |
| 116(b) | 306.37–306.09 | 1 478 | 19 800 | −.0510 | 52.0 | 51.0 | +.500 | +30.0°L | 7.5 | 51.50 | 8.30 |
| 117(a) | 302.64–302.38 | 1 425 | 15 375 | .0612 | 59.0 | 60.0 | −.495 | +13.5°L | 11.8 | 59.50 | 14.60 |
| 117(b) | 301.34–301.04 | 1 562 | 13 750 | .0436 | 66.0 | 66.7 | −.495 | +27.0°L | 8.4 | 66.35 | 15.16 |
| 117(c) | 300.94–300.74 | 1 066 | 12 800 | .0461 | 66.9 | 67.4 | −.495 | +27.0°L | 8.4 | 67.15 | 14.26 |
| 118 | 299.18–298.80 | 2 064 | 16 875 | .0263 | 51.1 | 51.8 | 0 | 0.0° | 6.5 | 51.45 | 9.01 |
| 119 | 297.49–297.23 | 1 330 | 18 625 | .1063 | 52.7 | 54.5 | −.500 | 0.0° | 11.3 | 53.60 | 12.66 |
| 125 | 287.55–287.31 | 1 267 | 15 375 | .0247 | 53.1 | 53.5 | 0 | −68.5°L | 5.2 | 53.30 | 8.14 |

TABLE 33

TEST NO. S-1111

From Memphis to Fulton, July 2, 1937. Total weight behind measuring drawbar = 2606 tons. Train length = 2640 ft. 55 cars: 51 loaded, 4 empty. Average weight per car = 47.38 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 101 | 378.65–378.73 | 433 | 27 050 | −.0368 | 22.0 | 21.5 | +.483 | +37.0°L | 7.7 | 21.75 | 4.18 |
| 103 | 375.23–375.34 | 607 | 17 000 | .1089 | 37.0 | 38.2 | −.500 | +34.0°L | 13.3 | 37.60 | 6.27 |
| 104 | 363.10–363.27 | 924 | 19 750 | .0250 | 31.3 | 31.8 | 0 | +33.0°L | 10.0 | 31.55 | 5.22 |
| 106 | 357.76–358.03 | 1 468 | 16 000 | .0618 | 48.3 | 47.0 | +.225 | +33.5°L | 15.2 | 47.65 | 7.48 |
| 107(b) | 353.14–353.38 | 1 257 | 14 550 | .0818 | 46.0 | 47.5 | −.504 | +26.0°L | 16.6 | 46.74 | 7.96 |
| 108 | 342.55–342.81 | 1 346 | 31 000 | −.0329 | 25.8 | 24.6 | +.429 | 0.0° | 5.1 | 25.20 | 6.41 |
| 109 | 341.58–341.78 | 1 082 | 30 850 | 0 | 25.8 | 25.8 | +.387 | 0.0° | 8.5 | 25.80 | 4.09 |
| 114 | 309.59–309.96 | 1 943 | 18 200 | −.0089 | 39.8 | 39.5 | 0 | +14.0°L | 10.0 | 39.65 | 7.80 |
| 115 | 307.89–308.20 | 1 626 | 22 000 | .0389 | 35.4 | 36.6 | 0 | 0.0° | 9.4 | 36.00 | 4.81 |
| 117(b) | 300.52–300.76 | 1 299 | 13 250 | .0486 | 53.5 | 54.3 | −.495 | 0.0° | 11.6 | 53.90 | 10.44 |
| 119 | 297.22–297.33 | 539 | 18 200 | .1197 | 43.5 | 44.5 | −.500 | + 8.5°L | 11.4 | 44.00 | 5.71 |
| 120 | 296.00–296.28 | 1 526 | 17 900 | 0 | 48.1 | 48.1 | 0 | +14.0°L | 12.6 | 48.10 | 6.84 |
| 121 | 291.33–291.54 | 1 146 | 18 450 | .0117 | 46.0 | 46.2 | 0 | +26.0°L | 11.6 | 46.10 | 5.98 |
| 123(b) | 289.49–289.81 | 1 679 | 21 250 | −.0564 | 41.2 | 39.6 | +.400 | +13.5°L | 10.6 | 40.40 | 5.46 |
| 124 | 288.92–289.00 | 422 | 21 450 | .0142 | 41.0 | 41.1 | 0 | + 9.5°L | 10.0 | 41.05 | 6.89 |
| 128 | 282.19–282.46 | 1 452 | 18 450 | −.0218 | 43.5 | 43.0 | +.100 | 0.0° | 10.0 | 43.25 | 7.15 |
| 129(a) | 281.27–281.52 | 1 315 | 18 800 | −.0097 | 44.0 | 43.8 | 0 | +17.0°L | 12.0 | 43.90 | 8.13 |
| 129(b) | 281.46–281.79 | 1 753 | 18 300 | 0 | 45.2 | 45.2 | 0 | +12.5°L | 11.0 | 45.20 | 7.02 |
| 131 | 276.79–276.17 | 607 | 19 750 | 0 | 45.0 | 45.0 | −.087 | +20.0°L | 9.8 | 45.00 | 9.31 |

TABLE 34

TEST NO. S-1112

From Memphis to Fulton, June 27, 1937. Total weight behind measuring drawbar = 2647 tons. Train length = 2587.2 ft. 54 cars: 51 loaded, 3 empty. Average weight per car = 49.01 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 106 | 357.80–358.00 | 1 056 | 6 525 | −.1319 | 40.8 | 38.4 | +.225 | +75.5°L | 8.0 | 39.60 | 10.37 |
| 108 | 342.65–342.80 | 792 | 33 250 | −.0394 | 30.8 | 30.1 | +.429 | +44.5°L | 17.7 | 30.45 | 7.69 |
| 109 | 341.50–341.80 | 1 061 | 33 000 | 0 | 30.7 | 30.7 | +.378 | +40.0°L | 16.0 | 30.70 | 4.90 |
| 112 | 315.55–315.74 | 982 | 9 250 | .0101 | 22.8 | 22.5 | 0 | +54.5°L | 11.6 | 25.65 | 4.44 |
| 113 | 315.00–315.11 | 618 | 19 125 | 0 | 22.5 | 22.5 | 0 | +43.0°L | 11.3 | 22.50 | 5.22 |
| 114 | 309.64–309.96 | 1 690 | 19 625 | .0032 | 37.0 | 37.1 | 0 | +44.5°L | 17.1 | 37.05 | 7.11 |
| 115 | 307.89–308.20 | 1 639 | 29 825 | .0626 | 34.0 | 36.0 | 0 | +49.5°L | 15.6 | 35.00 | 5.37 |
| 117(a) | 301.56–301.93 | 1 964 | 6 525 | .0308 | 40.8 | 41.8 | −.495 | +49.0°L | 17.0 | 41.30 | 9.46 |
| 118(a) | 299.00–299.27 | 1 452 | 10 900 | .0745 | 50.0 | 48.5 | 0 | +33.5°L | 23.0 | 49.25 | 11.13 |
| 118(b) | 298.78–298.92 | 766 | 12 200 | −.0924 | 48.2 | 47.2 | 0 | +33.5°L | 23.0 | 47.70 | 13.29 |
| 120(a) | 296.63–296.43 | 1 035 | 13 750 | −.0520 | 46.3 | 45.5 | 0 | +38.5°L | 20.3 | 45.90 | 10.08 |
| 128 | 282.12–282.46 | 1 769 | 23 850 | 0 | 42.5 | 42.5 | +.100 | +42.5°L | 18.7 | 42.50 | 7.01 |
| 129(b) | 280.72– | Point | 22 875 | 0 | 45.9 | 45.9 | 0 | +43.5°L | 20.0 | 45.90 | 8.64 |
| 136 | 272.83– | Point | 29 825 | 0 | 33.7 | 33.7 | 0 | +41.0°L | 16.4 | 33.70 | 7.71 |

# Table 35
## Test No. S-1113

From Memphis to Fulton, July 22, 1937. Total weight behind measuring drawbar = 2296 tons. Train length = 2112 ft. 50 cars: 38 loaded, 12 empty. Average weight per car = 51.18 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 101 | 378.64–378.83 | 966 | 31 400 | .0089 | 19.5 | 19.8 | +.483 | +72.5°R | 1.4 | 19.65 | 3.16 |
| 102 | 375.92–376.20 | 1 478 | 19 525 | .0321 | 35.5 | 36.4 | 0 | +41.5°R | 6.6 | 35.95 | 5.48 |
| 103 | 375.23–375.42 | 1 003 | 17 050 | .1184 | 39.5 | 41.5 | −.500 | +29.5°R | 9.4 | 40.50 | 6.27 |
| 104 | 363.09–363.43 | 1 800 | 19 950 | .0252 | 34.1 | 35.0 | 0 | +40.0°R | 5.7 | 34.55 | 6.30 |
| 105(b) | 361.97–362.10 | 702 | 10 900 | .0850 | 40.2 | 41.2 | −.503 | +30.0°R | 9.1 | 40.70 | 6.81 |
| 107 | 353.15–353.48 | 1 721 | 8 700 | .0765 | 43.9 | 45.9 | −.504 | +15.0°R | 12.8 | 44.90 | 6.56 |
| 108 | 342.54–342.71 | 908 | 26 950 | −.0236 | 29.5 | 29.0 | +.429 | +28.0°R | 17.1 | 29.25 | 5.42 |
| 109 | 341.45–341.82 | 1 990 | 26 950 | −.0055 | 18.9 | 18.5 | +.387 | +38.0°R | 6.2 | 18.70 | 4.51 |
| 110 | 317.00–317.32 | 1 705 | 8 800 | .0754 | 40.7 | 42.8 | −.500 | +18.0°R | 11.2 | 41.75 | 6.73 |
| 114 | 309.68–310.00 | 1 663 | 18 175 | .0190 | 43.0 | 43.5 | 0 | +23.0°R | 10.1 | 43.25 | 6.13 |
| 115 | 308.00–308.32 | 1 731 | 21 000 | .0268 | 39.2 | 40.0 | 0 | +19.0°R | 10.4 | 39.60 | 6.62 |
| 116(b) | 307.00–307.29 | 1 536 | 21 575 | −.0877 | 39.5 | 37.1 | +.500 | + 8.0°R | 11.9 | 38.30 | 7.65 |
| 117 | 301.81–302.14 | 1 742 | 9 650 | .0609 | 47.5 | 49.0 | −.495 | +36.0°R | 11.0 | 48.25 | 8.36 |
| 119 | 297.23–297.43 | 1 024 | 15 375 | .1023 | 41.2 | 42.9 | −.500 | +39.5°R | 7.9 | 42.05 | 7.05 |
| 120 | 296.00–296.29 | 1 531 | 16 150 | −.0175 | 46.0 | 45.6 | 0 | +30.0°R | 11.8 | 45.80 | 8.67 |
| 121 | 291.33–291.63 | 1 615 | 16 500 | .0119 | 43.6 | 43.9 | 0 | +13.5°R | 14.4 | 43.75 | 6.06 |
| 122 | 290.74–290.92 | 960 | 16 850 | −.0334 | 44.0 | 43.5 | +.200 | +15.5°R | 13.1 | 43.75 | 6.48 |
| 123 | 289.58–289.84 | 1 378 | 21 100 | −.0451 | 39.1 | 38.0 | +.400 | +21.0°R | 10.7 | 38.55 | 5.44 |
| 128 | 282.09–282.36 | 1 399 | 24 750 | .0355 | 21.8 | 23.3 | +.100 | 0.0° | 6.2 | 22.55 | 5.44 |
| 129(a) | 280.50–280.74 | 1 298 | 22 450 | .0545 | 33.8 | 35.2 | 0 | +28.0°R | 8.0 | 34.50 | 4.65 |
| 129(b) | 281.02–281.25 | 1 203 | 22 700 | .0384 | 31.0 | 32.0 | 0 | +30.0°R | 8.0 | 31.50 | 6.27 |

TABLE 36

TEST NO. S-1114

From Fulton to Memphis, July 24, 1937. Total weight behind measuring drawbar = 3346 tons. Train length = 2207.4 ft. 46 cars: 42 loaded, 4 empty. Average weight per car = 72.73 tons.

| Item No. | Track Section | Section Length | Pull $P$ | Accel. $A$ | Speed $V_1$ | Speed $V_2$ | Grade $G$, per cent | Wind Direction | Wind Velocity, m.p.h. | Ave. Speed | Resistance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 105(b) | 362.21–362.48 | 1 441 | 32 000 | −.0430 | 23.0 | 21.5 | +.503 | −58.5°R | 3.0 | 22.25 | 3.49 |
| 107(a) | 353.86–353.57 | 1 531 | 28 850 | −.0457 | 32.6 | 31.1 | +.504 | −59.0°L | 1.7 | 31.85 | 2.73 |
| 110 | 318.00–318.26 | 1 399 | 29 125 | −.0659 | 28.5 | 26.2 | +.497 | −31.0°R | 4.5 | 27.35 | 4.89 |
| 113 | 315.42–315.59 | 902 | 22 550 | +.0513 | 31.1 | 32.1 | −.100 | −41.5°R | 5.6 | 31.60 | 3.96 |
| 116 | 307.47–307.72 | 1 330 | 2 250 | +.0346 | 44.5 | 45.2 | −.500 | 0.0° | .1 | 44.85 | 7.45 |
| 117(a) | 300.44–300.68 | 1 240 | 24 750 | −.0660 | 38.0 | 36.5 | +.495 | +63.5°L | 3.4 | 37.25 | 3.64 |
| 117(c) | 302.59–302.81 | 1 198 | 33 250 | −.0490 | 26.5 | 25.1 | +.495 | −88.5°L | 1.7 | 25.80 | 4.59 |
| 120 | 296.26–296.57 | 1 626 | 23 875 | +.0477 | 28.5 | 30.3 | 0 | +75.0°R | 2.8 | 29.40 | 2.73 |
| 121 | 292.00–291.79 | 1 108 | 11 700 | 0 | 44.0 | 44.0 | 0 | 0.0° | 4.1 | 44.00 | 3.49 |
| 123 | 290.45–290.73 | 1 494 | 11 250 | .0516 | 39.8 | 41.1 | −.400 | −26.5°R | 8.3 | 40.45 | 6.56 |
| 124 | 289.39–289.53 | 739 | 21 125 | .0134 | 33.8 | 34.0 | 0 | −46.5°R | 3.0 | 33.90 | 5.06 |
| 125 | 287.74–287.90 | 844 | 18 500 | 0 | 37.2 | 37.2 | 0 | 0.0° | 1.2 | 37.20 | 5.53 |
| 126 | 285.13–285.34 | 1 151 | 38 500 | −.0203 | 20.3 | 19.5 | +.500 | +53.0°R | 2.2 | 19.90 | 3.39 |
| 127 | 284.48–284.69 | 1 119 | 34 500 | .0055 | 20.8 | 21.0 | +.350 | −80.0°L | 1.9 | 20.90 | 2.80 |
| 136 | 273.75–273.83 | 422 | 7 650 | .0135 | 39.0 | 39.1 | 0 | 0.0° | 1.0 | 39.05 | 4.01 |

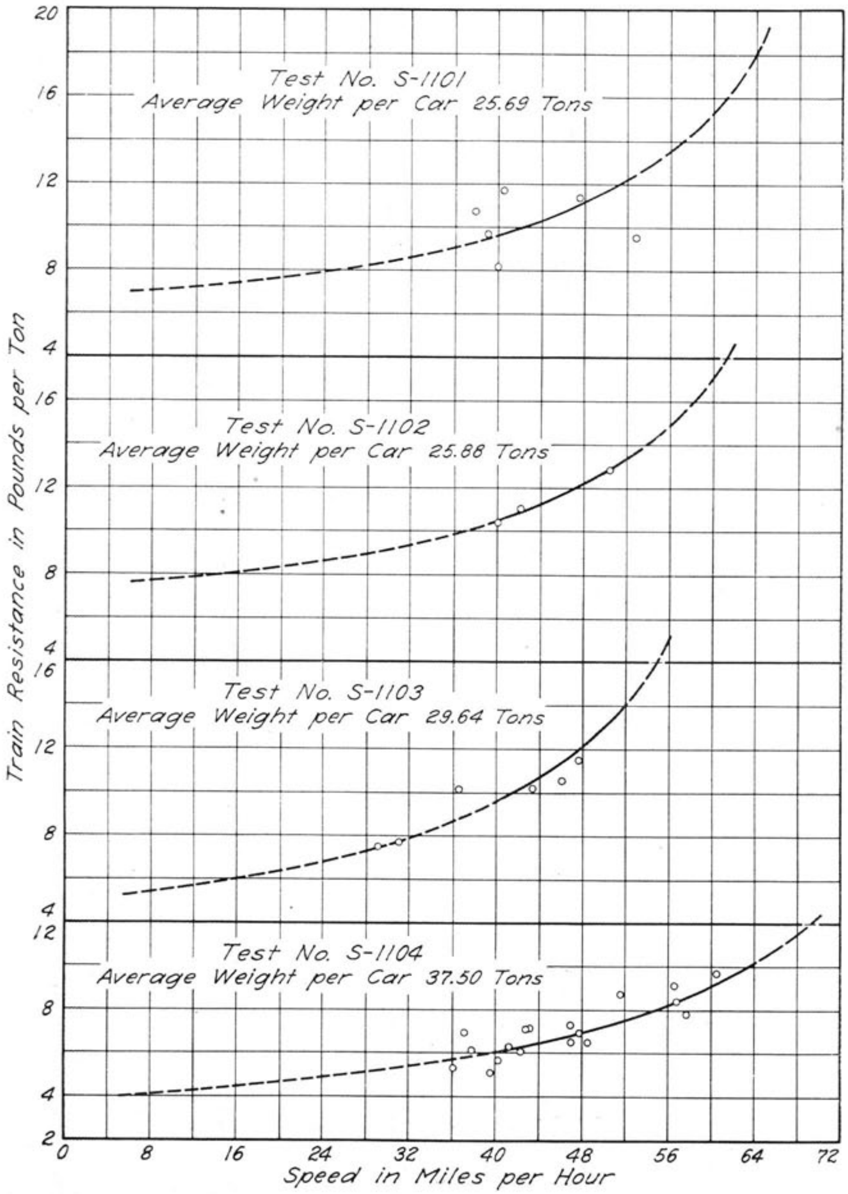



FIG. 7. RELATION OF RESISTANCE TO SPEED: INDIVIDUAL TESTS — PART I

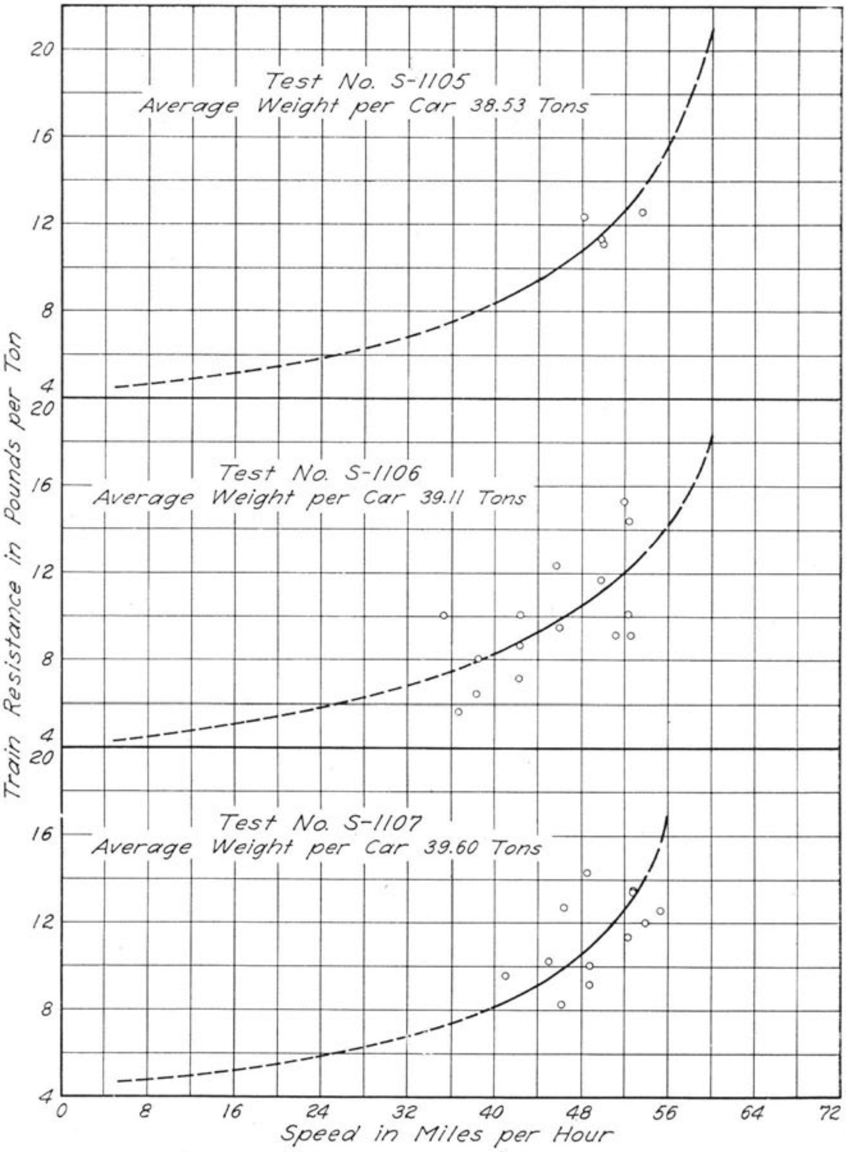



FIG. 7 (CONTINUED). RELATION OF RESISTANCE TO SPEED: INDIVIDUAL TESTS — PART II

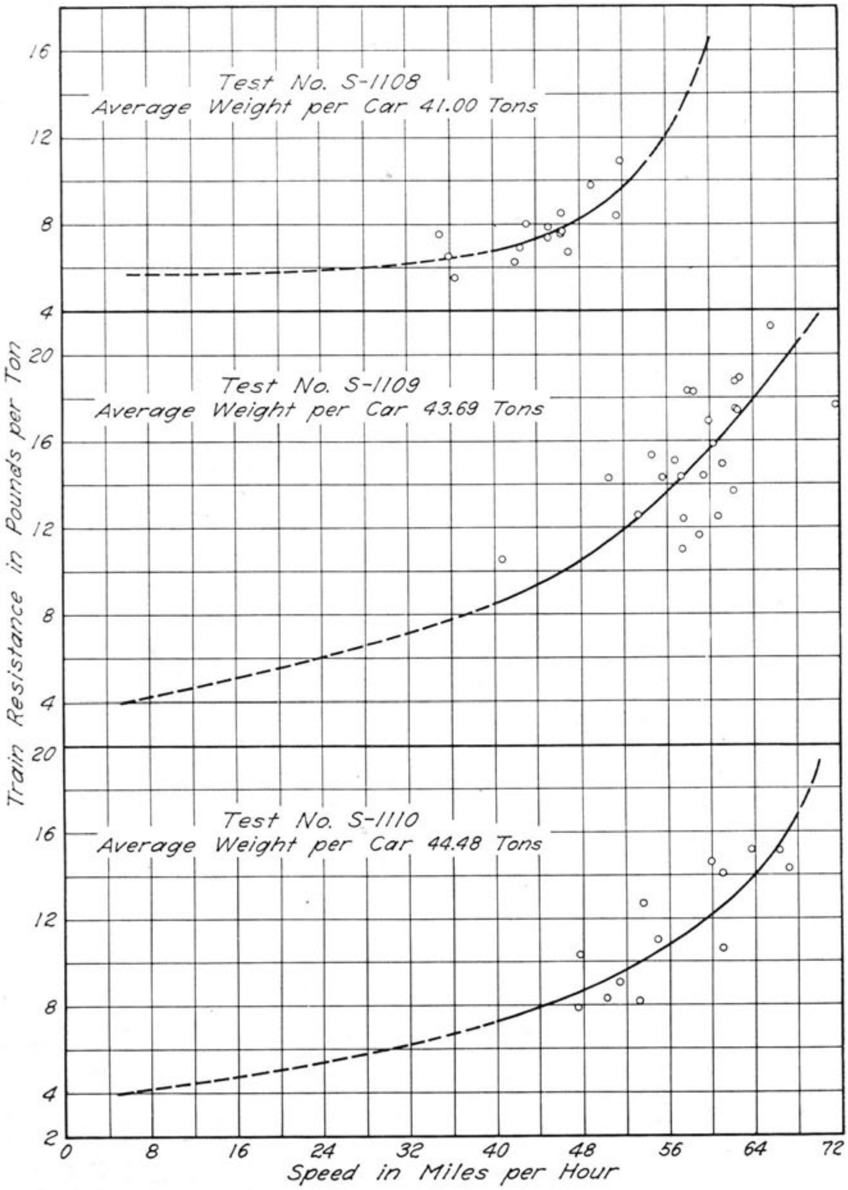



FIG. 7 (CONTINUED). RELATION OF RESISTANCE TO SPEED: INDIVIDUAL TESTS — PART III

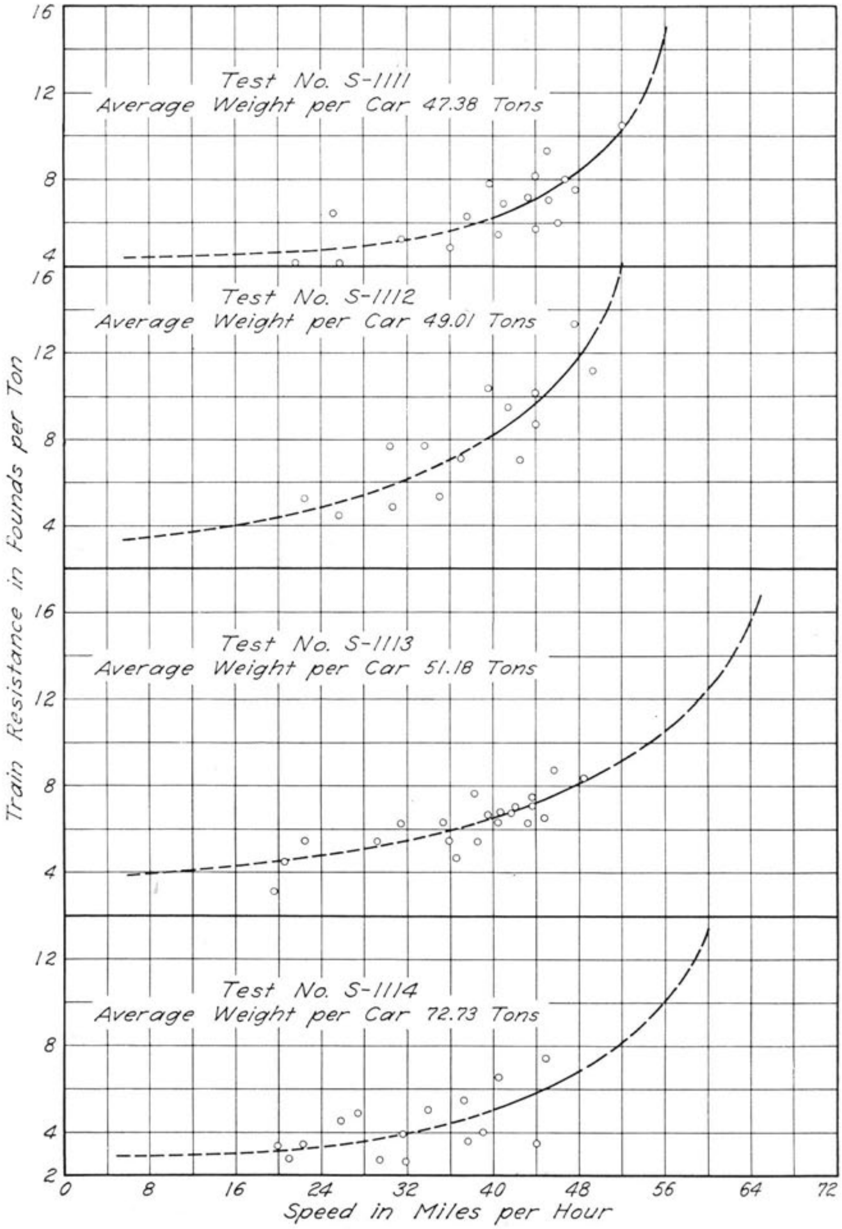



FIG. 7 (CONCLUDED). RELATION OF RESISTANCE TO SPEED: INDIVIDUAL TESTS — PART IV

## APPENDIX E

### Incomplete Curves

Appendix E shows, in the form of Fig. 8, eleven curves plotted from data taken from the test charts but containing too few points to permit calculating the train resistance values necessary for plotting complete curves. The explanation of most of the incomplete data is that the locomotive engineer closed the throttle as the train approached a speed of 50 mi. per hr. Figure 8 was obtained as follows: after the curves of Figs. 4 and 5 were drawn from the data taken from the tests described in Appendix D, the "dash–two dot–dash" portion was added to the solid curve; and the initial or dotted portions of the curves were taken directly from the curves given in Bulletin No. 43 which correspond to the same speeds and car weights.

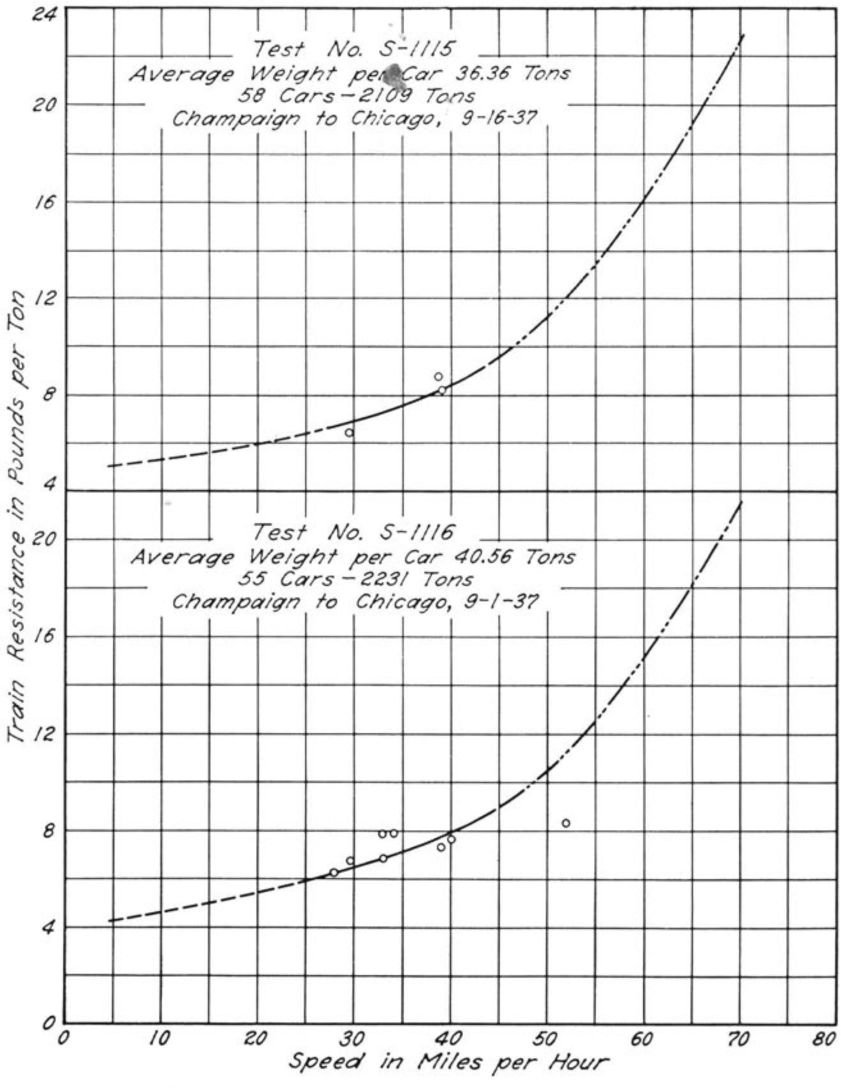



FIG. 8. RELATION OF RESISTANCE TO SPEED: INCOMPLETE TEST-CURVES — PART I

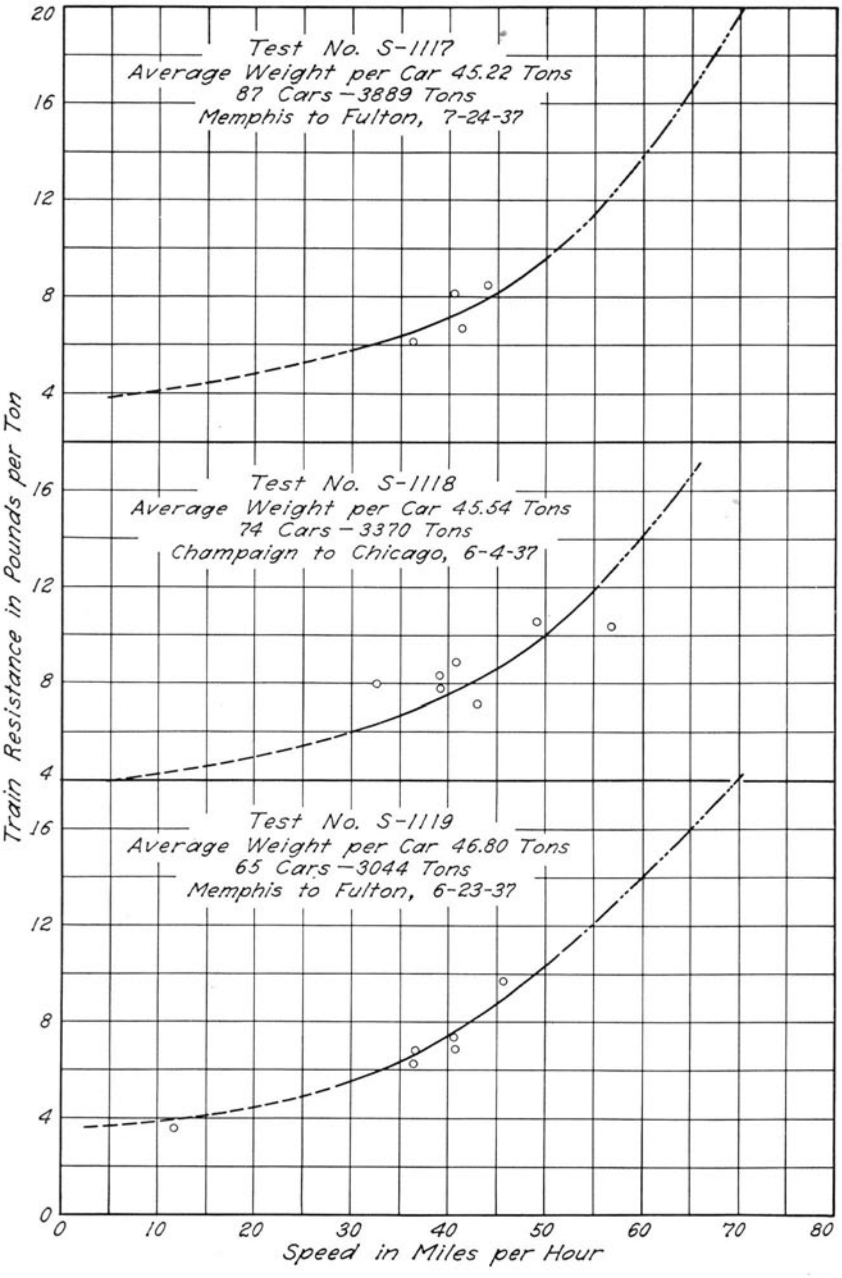



FIG. 8 (CONTINUED). RELATION OF RESISTANCE TO SPEED: INCOMPLETE TEST-CURVES — PART II

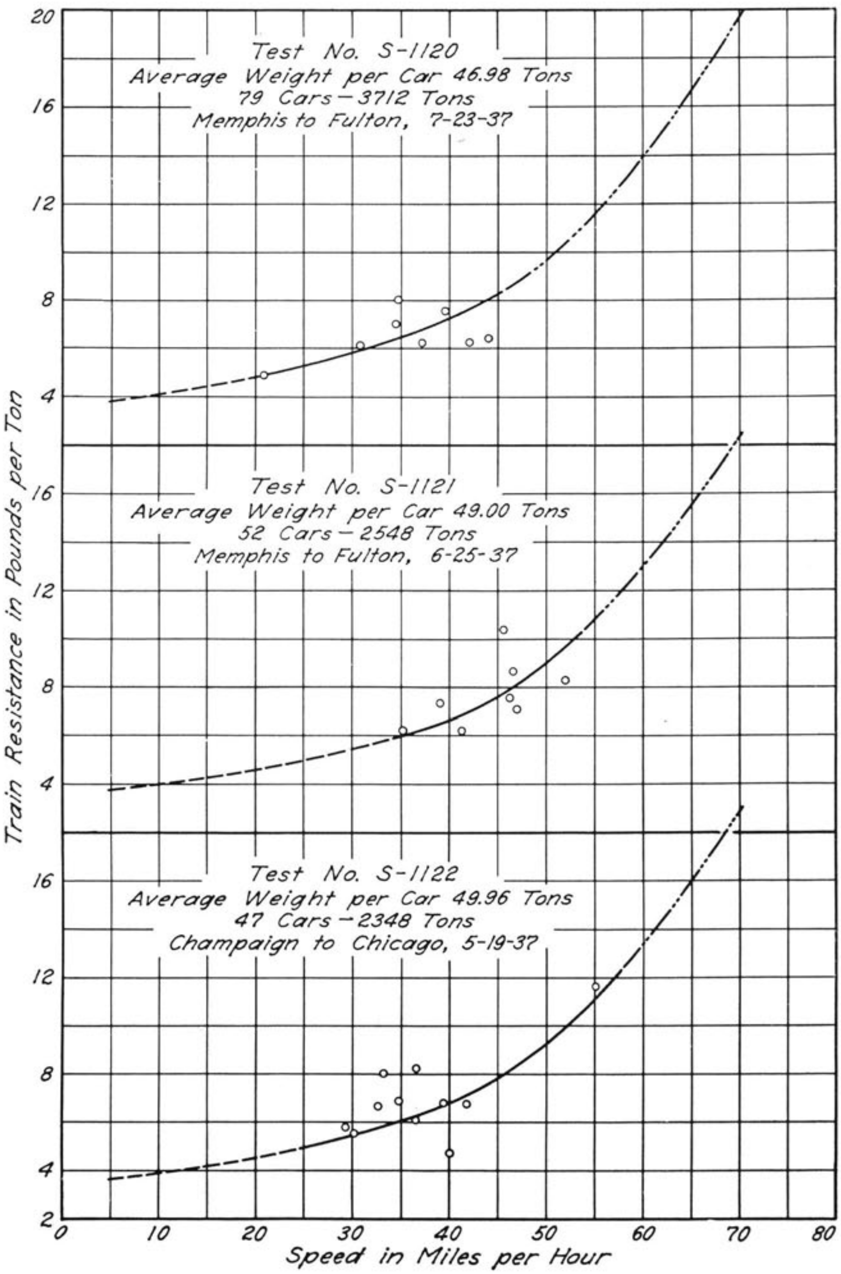



FIG. 8 (CONTINUED). RELATION OF RESISTANCE TO SPEED: INCOMPLETE TEST-CURVES — PART III

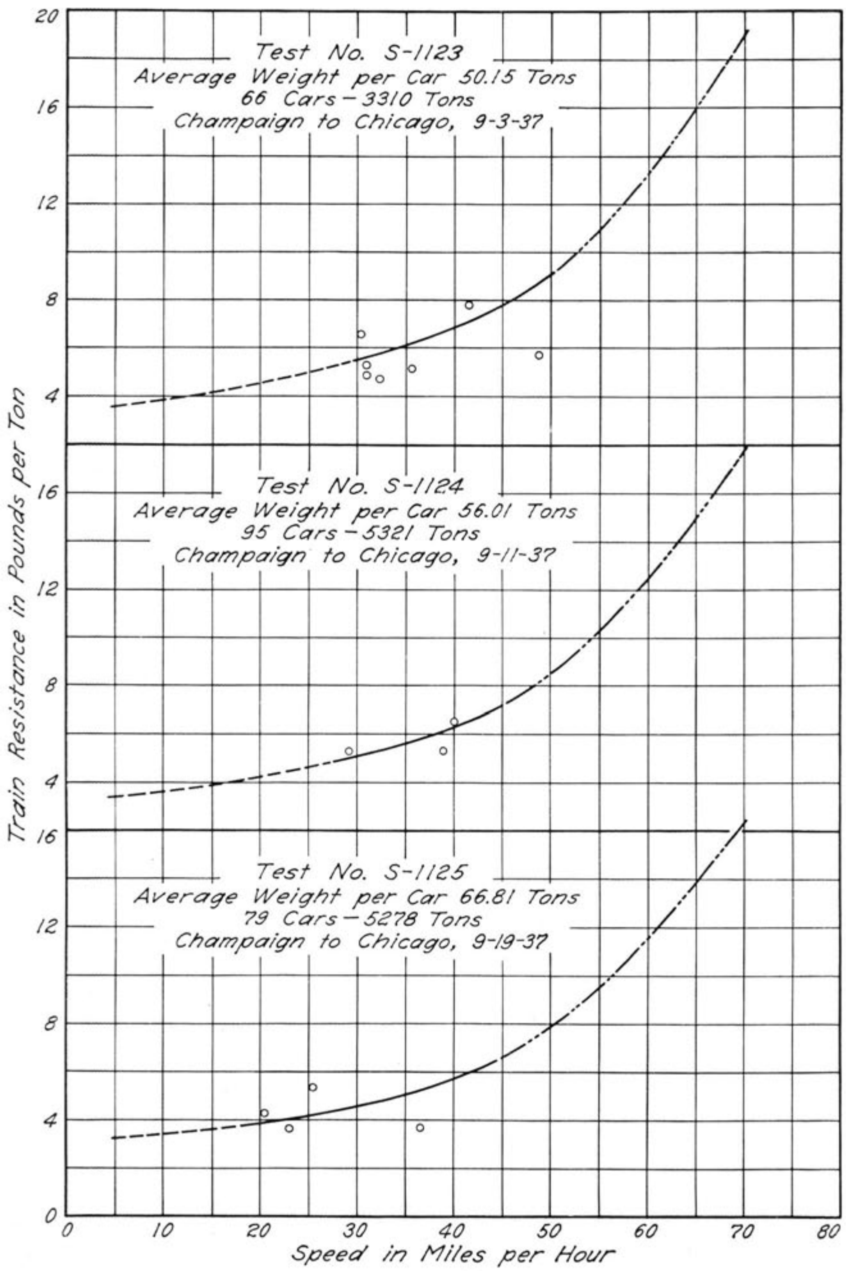



FIG. 8 (CONCLUDED). RELATION OF RESISTANCE TO SPEED: INCOMPLETE TEST-CURVES — PART IV

# APPENDIX F

## Coordinates for the Curves of Figs. 4 and 5

Enlarged drawings were originally made of Figs. 4 and 5; from these the smaller reproductions were prepared for this Bulletin. The coordinates of the points used are listed in Table 37. The curves of Figs. 3 and 4 may be drawn to a large scale by using the values as listed in Table 37. The curves of Fig. 5 may be reproduced from the values already given in Table 3.

Table 37

Values of Resistance for Trains of Various Average Car Weights and for Different Speeds

This table presents the coordinates of the original curves from which Figs. 3 and 4 were reproduced

| Average Weight per Car, tons | | Train Resistance—lb. per ton. Column Headings Indicate the Various Speeds: 40 m.p.h. | 45 m.p.h. | 50 m.p.h. | 55 m.p.h. | 60 m.p.h. | 65 m.p.h. | 70 m.p.h. | Average Weight per Car, tons | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 12.1 | 13.4 | 15.4 | 18.2 | 21.9 | 26.2 | 31.0 | 20 | |
| | 22 | 11.6 | 12.8 | 14.8 | 17.5 | 21.1 | 25.2 | 29.9 | 22 | |
| | 24 | 11.1 | 12.3 | 14.2 | 16.8 | 20.3 | 24.3 | 28.8 | 24 | |
| 25 | | 10.8 | 12.0 | 13.9 | 16.5 | 19.9 | 23.8 | 28.3 | | 25 |
| | 26 | 10.6 | 11.8 | 13.7 | 16.2 | 19.5 | 23.4 | 27.7 | 26 | |
| | 28 | 10.1 | 11.3 | 13.1 | 15.6 | 18.8 | 22.5 | 26.7 | 28 | |
| | 30 | 9.7 | 10.8 | 12.6 | 15.0 | 18.2 | 21.7 | 25.7 | 30 | |
| | 32 | 9.3 | 10.4 | 12.1 | 14.5 | 17.5 | 20.9 | 24.8 | 32 | |
| | 34 | 8.9 | 10.0 | 11.7 | 14.0 | 16.9 | 20.2 | 23.9 | 34 | |
| 35 | | 8.7 | 9.8 | 11.5 | 13.8 | 16.6 | 19.8 | 23.5 | | 35 |
| | 36 | 8.5 | 9.6 | 11.3 | 13.5 | 16.3 | 19.5 | 23.1 | 36 | |
| | 38 | 8.2 | 9.2 | 10.8 | 13.0 | 15.8 | 18.9 | 22.4 | 38 | |
| | 40 | 7.9 | 8.9 | 10.5 | 12.6 | 15.3 | 18.3 | 21.7 | 40 | |
| | 42 | 7.6 | 8.6 | 10.2 | 12.3 | 14.8 | 17.7 | 21.0 | 42 | |
| | 44 | 7.3 | 8.3 | 9.9 | 11.9 | 14.4 | 17.2 | 20.4 | 44 | |
| 45 | | 7.2 | 8.2 | 9.7 | 11.8 | 14.2 | 16.9 | 20.1 | | 45 |
| | 46 | 7.1 | 8.1 | 9.6 | 11.6 | 14.0 | 16.7 | 19.8 | 46 | |
| | 48 | 6.9 | 7.8 | 9.3 | 11.3 | 13.6 | 16.3 | 19.4 | 48 | |
| | 50 | 6.7 | 7.6 | 9.1 | 11.1 | 13.3 | 15.9 | 18.9 | 50 | |
| | 52 | 6.5 | 7.4 | 8.9 | 10.8 | 12.9 | 15.5 | 18.5 | 52 | |
| | 54 | 6.3 | 7.2 | 8.7 | 10.6 | 12.7 | 15.2 | 18.1 | 54 | |
| 55 | | 6.3 | 7.2 | 8.6 | 10.5 | 12.6 | 15.1 | 17.9 | | 55 |
| | 56 | 6.2 | 7.1 | 8.5 | 10.4 | 12.4 | 14.9 | 17.7 | 56 | |
| | 58 | 6.1 | 6.9 | 8.3 | 10.1 | 12.2 | 14.6 | 17.4 | 58 | |
| | 60 | 6.0 | 6.8 | 8.2 | 10.0 | 12.0 | 14.4 | 17.1 | 60 | |
| | 62 | 5.9 | 6.7 | 8.1 | 9.9 | 11.8 | 14.2 | 16.8 | 62 | |
| | 64 | 5.8 | 6.6 | 7.9 | 9.7 | 11.6 | 14.0 | 16.6 | 64 | |
| 65 | | 5.8 | 6.6 | 7.9 | 9.6 | 11.5 | 13.9 | 16.5 | | 65 |
| | 66 | 5.7 | 6.5 | 7.8 | 9.6 | 11.5 | 13.8 | 16.4 | 66 | |
| | 68 | 5.6 | 6.4 | 7.7 | 9.5 | 11.3 | 13.6 | 16.1 | 68 | |
| | 70 | 5.6 | 6.3 | 7.6 | 9.3 | 11.2 | 13.4 | 15.9 | 70 | |
| | 72 | 5.5 | 6.3 | 7.6 | 9.2 | 11.1 | 13.3 | 15.7 | 72 | |
| | 74 | 5.5 | 6.2 | 7.5 | 9.1 | 11.0 | 13.2 | 15.6 | 74 | |
| 75 | | 5.5 | 6.2 | 7.4 | 9.1 | 10.9 | 13.1 | 15.5 | | 75 |

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