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PHYSICAL TESTS OF MOTOR-TRUCK WHEELS

BY

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FIG. 3.—*Side-thrust test*

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I. INTRODUCTION

In designing Class B military trucks, it was found desirable to develop a metal wheel having the good qualities of all the wheels on the market. No comparative values were available, however, and there was no time for service tests. The Bureau of Standards was therefore called on to make laboratory tests.

Cast steel, pressed steel, wrought iron, and wooden wheels were submitted by motor-truck wheel manufacturers and subjected to radial compression and side thrust or skid tests.

In the meantime the representatives of the companies interested, in cooperation with the Quartermaster's Department of the United States Army, designed a cast-steel wheel which they called the "Composite wheel."

Samples of these wheels were cast and were sent to the Bureau of Standards where they were tested in the same way as the other wheels. Certain alterations in design were found to be desirable. These were made and new wheels cast which were in turn tested. They proved to be satisfactory and were accepted by the Quartermaster's Department.

II. WHEEL REQUIREMENTS

The requirements listed below were considered essential in a wheel, and the tests were so conducted that information concerning these requirements might be obtained.

(a) Each wheel should be strong enough to support its proportionate share of the weight of the truck and of the maximum load which the truck is designed to carry.

(b) Each wheel should be strong enough to resist suddenly applied loads and resilient enough to absorb a large part of the shock.

(c) The circumference of the wheel should remain approximately circular.

(d) The wheel should be capable of sustaining stresses due to side thrust. These may be introduced by skidding, by turning, or by running on roadways which are crowned or have a side slope.

There should be no joints or bolts that will be loosened by radial compression, side thrust, vibration, shock, or climatic conditions.

The weight of the wheel should be as low as possible without reducing the strength of the wheel below that of the rest of the truck.

III. LIST OF WHEELS TESTED

The following wheels were submitted for test:

TABLE 1

[Unless otherwise noted the wheels were tested without tires, bearings, or brake bands. The weights listed are the weights of the wheels as tested. The dimensions given in the description are the dimensions of the wheel fitted with a tire]

Wheel No.	Description	Weight in pounds	Wheel No.	Description	Weight in pounds
1	Rear wheel, 36 by 10 inches; wooden wheel; 14 spokes.....	252	13	Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; box rim.....	286
2	Front wheel, 36 by 5 inches; cast-steel disk; box rim.....	169	14	Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design.....	132
3	Rear wheel, 36 by 10 inches; cast-steel disk; box rim.....	268	15	Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design.....	249
a4	Front wheel, 40 by 6 inches; pressed-steel corrugated web; channel iron rim.....	181	16	Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design.....	120
a5	Rear wheel, 40 by 12 inches; pressed-steel corrugated web; channel iron rim.....	354	17	Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design.....	273
a6	Rear wheel, 36 by 6 inches; cast steel; 8 +spokes; brake band cast on wheel.....	215	18	Rear wheel, 40 by 10 inches; cast steel; 7 hollow spokes; composite design.....	325
7	Front wheel, 36 by 5 inches; cast steel; 8 U spokes; box rim.....	134	19	Rear wheel, 40 by 12 inches; cast steel; 7 hollow spokes; composite design.....	325
8	Rear wheel, 36 by 10 inches; cast steel; 8 U spokes; box rim.....	274	20	Front wheel, 36 by 5 inches; malleable iron; 7 hollow spokes; composite design.....	141
9	Front wheel, 36 by 5 inches; cast steel; 7 U spokes; box rim.....	136	21	Rear wheel, 40 by 10 inches; malleable iron; 7 hollow spokes; composite design.....	288
10	Rear wheel, 36 by 10 inches; cast steel; 7 U spokes; box rim.....	321			
11	Front wheel, 36 by 5 inches; cast steel; 5 hollow spokes; box rim.....	144			
12	Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; box rim.....	130			

a Submitted by Ordnance Department, U. S. Army.

IV. PREPARATION OF THE WHEELS FOR TEST

The wheels submitted were all without tires and in most cases were without bearings or brake bands. Where brake bands were attached they formed an integral part of the wheel and were not removed before the wheel was tested. All bearings were removed and brass bushings substituted. The contact area between the brass bushing and the hub was made equal to that between the bearing and the hub.

All wheels were fitted with these brass bushings to make possible the use of a 4-inch axle for the rear wheels and a $3\frac{1}{2}$ -inch axle for the front wheels.

Holes were drilled at four points, 90° apart on the edge of the rim of each wheel, so that dial gages, used for measuring the deformation of the wheel under radial stress, could be fastened to the wheel.

TESTING MACHINE USED.—The Bureau of Standards Emery hydraulic testing machine, having a capacity of 2 300 000 pounds, was used for both the radial-compression and the side-thrust tests.

FIG. 2.—Location of dial gages for radial-compression tests

V. RADIAL-COMPRESSION TEST

For the radial-compression test the wheel was placed on a short axle (*a*) as shown in Fig. 1. This axle was supported on both sides of the wheel by bearing blocks (*b*).

Load was then applied through a block at the rim. This block distributed the load over the full width of the rim and along an arc of 6 inches. The wheel was placed so that the load was applied to a section of the rim between spokes.

The deformation of the wheel under load was measured at points 1, 2, 3, and 4. These points were on the edge of the rim of the wheel and 90° apart, No. 2 being at the point of application of load. Ames dials were adjusted as shown in Fig. 2, and the deformations measured between the axle and the rim of the wheel.

These measurements were made at various loads as the load was increased from 1000 pounds to the maximum load recorded

FIG. 1.—*Radial-compression test*

in Table 2. The data obtained from these tests are shown plotted as load-deformation curves.

In Table 2 are recorded the proportional limit of the wheel, as indicated by the measurements taken at the point of application of load; the maximum applied load; the deformation at maximum load; the permanent set due to stressing the wheel to the maximum load and the slope of the load-deformation curves.

TABLE 2.—Radial Compression

Wheel No.	Proportion- al limit at load in pounds	Maximum applied load in pounds	Deforma- tion at maximum load in pounds	Permanent set at maximum load in pounds	Slope of curve at load, 1000 pounds per inch
1.....	38 000	60 000	0.1062	0.0336	826 000
2.....	31 000	60 000	.0359	.0187	2 450 000
3.....	50 000	100 000	.0881	.0261	1 891 000
4.....	34 000	60 000	.0564	.0072	1 238 000
5.....	85 000	^a 105 000	.1631	.0428	715 000
6.....	31 000	75 000	.0847	.0291	1 875 000
7.....	32 500	50 000	.0490	.0135	1 363 000
8.....	50 000	100 000	.0610	.0103	2 000 000
9.....	35 500	60 000	.1287	.0791	667 000
10.....	77 000	120 000	.1250	.0537	1 316 000
11.....	32 000	60 000	.0695	.0311	1 160 000
12.....	40 000	60 000	.0645	.0220	1 333 000
13.....	20 000	100 000	.0513	.0113	6 060 000
14.....	26 000	60 000	.1135	.0687	1 300 000
15.....	75 000	120 000	.0874	.0318	2 320 000
16.....	44 000	60 000	.0744	.0323	917 000
17.....	71 500	120 000	.1586	.0831	1 250 000
18.....	46 000	120 000	.1230	.0676	1 968 000
19.....	41 000	100 000	.1555	.1100	1 836 000
20.....	43 500	60 000	.0741	.0271	926 000
21.....	64 000	120 000	.1361	.0715	1 818 000

^a Crack developed along rim of wheel where the two channels, of which the rim is formed, were welded.

The elastic resiliencies of the wheels have been computed for points Nos. 1, 2, 3, and 4 and recorded in Table 3. The area under the load-deformation curve from zero load to the proportional limit was here considered. In Table 3 will also be found the elastic resiliencies at load, per pound of metal in wheel.

TABLE 3.—Radial Compression—Elastic Resiliencies

[Area under load-deformation curves from zero to proportional limit]

Wheel No.	No. 2 at load in inch- pounds	No. 1 90° from load in inch- pounds	No. 4 180° from load in inch- pounds	No. 3 270° from load in inch- pounds	At load per pound of metal in wheel in inch- pounds
1.....	875		280	352	3.47
2.....	202				1.20
3.....	660	128	715	447	2.46
4.....	467				2.58
5.....	5050		725		14.3
6.....	257				1.2
7.....	387				2.89
8.....	625				2.28
9.....	1047	119		150	7.70
10.....	2250				7.00
11.....	441				3.06
12.....	600				4.6
13.....	33		390		.1
14.....	260				1.97
15.....	1210		880		4.86
16.....	1056				8.80
17.....	2090	640	319	630	7.65
18.....	538				1.68
19.....	436	195		94	1.34
20.....	1131				8.02
21.....	1128		450	255	3.91

The proportional limit of a wheel is of importance not only because the rate of deformation does not remain constant beyond that point, but also because the wheel becomes permanently deformed if higher stresses are applied. Unless the yield point of the wheel has been reached, this permanent deformation in most cases is small and does not render the wheel unfit for further use. Note that the load-deformation curve above the proportional limit usually deviates but little from the line drawn through the points below the proportional limit. The maximum load applied to the wheels is not the ultimate or breaking load.

In general, only one front and one rear wheel of each type were submitted, and it was necessary to perform both the radial-compression and the side-thrust tests on the same wheel. No attempt was made, therefore, to break the wheel in the compression test. The load was increased, however, until the wheel had been stressed well beyond its proportional limit.

The slope of the load-deformation curve is an index of the stiffness of the wheel, a high value indicating a wheel which deforms but little for all loads below the proportional limit.

Recorded in Table 4 are the resiliencies for various loads. These were computed from the curve of deformation for the point where the load was applied.

TABLE 4.—Radial Compression—Resiliencies at Low Loads

[Area under curve of deformations at load]

Wheel No.	2000 pounds in inch- pounds	4000 pounds in inch- pounds	6000 pounds in inch- pounds	8000 pounds in inch- pounds	10 000 pounds in inch- pounds	12 000 pounds in inch- pounds	14 000 pounds in inch- pounds	16 000 pounds in inch- pounds	18 000 pounds in inch- pounds	20 000 pounds in inch- pounds
1.....	2	10	22	39	61	87	118	155	196	242
2.....	1	3	7	13	20	29	40	52	66	82
3.....	1	4	10	17	26	38	52	68	86	106
4.....	2	7	15	26	40	58	79	103	131	162
5.....	4	12	30	54	80	108	147	208	261	330
6.....	1	4	10	17	27	38	52	68	86	107
7.....	2	6	13	24	37	53	72	94	119	147
8.....	1	4	9	16	25	36	49	64	81	100
9.....	5	18	36	64	95	138	182	240	297	350
10.....	5	17	39	64	95	132	168	208	261	310
11.....	2	7	16	28	43	62	84	110	140	173
12.....	2	6	14	24	38	54	74	96	122	150
13.....	.....	1	3	5	8	12	16	21	27	33
14.....	2	6	14	25	39	55	75	98	125	154
15.....	1	4	8	14	22	31	42	55	70	86
16.....	2	9	20	35	55	79	107	140	177	218
17.....	2	6	14	26	40	58	78	102	130	160
18.....	1	4	9	16	26	37	50	65	82	102
19.....	1	4	10	17	27	39	53	70	88	109
20.....	4	16	33	56	80	108	140	176	221	270
21.....	1	4	10	18	28	40	54	70	89	110

The elastic resiliencies recorded in Table 3 afford another means of comparison. They should not be used, however, without at the same time carefully considering the other qualities of the wheel. Large elastic resiliency is desirable, but it may be large only because of the high proportional limit of the wheel and not because of large elastic deformation. In such cases the resiliency would be small at the loads to which the wheel is ordinarily subjected. The resiliencies at low loads were therefore computed. These resiliencies at low loads may or may not be a proportional part of the total elastic resiliency. In many cases the slope of the load-deformation curve is not a constant at low loads. This is probably due to strains being localized at first and the wheel not acting as a unit. There may also have been some movement necessary to bring the axle and bushings to a firm bearing. This movement would be recorded as deformation in the wheel because the measurements were made between the rim and the axle.

VI. SIDE-THRUST TEST

Each wheel was subjected to a side-thrust or skid test after it had been tested in radial compression.

The wheel was placed on the same axle as in the radial-compression test. As shown in Fig. 3 (frontispiece) one end of the axle was passed through a $1\frac{1}{8}$ -inch plate and then through the web of an $8\frac{1}{2}$ -inch, $90\frac{1}{2}$ -pound Bethlehem H beam to which the plate was fastened. The other end was tied back to the H beam with a $1\frac{1}{4}$ -inch round bar. In this manner an effort was made to hold the axle rigidly, with its axis perpendicular to the side of the H beam, while load was applied to a section of the side of the rim of the wheel.

The wheel, mounted on the H beam, was then placed in the testing machine. The side of the H beam was supported by one head of the machine and the axis of the axle was parallel to the axis of the testing machine and, therefore, parallel to the direction of the applied load. This load was applied to the side of the rim of the wheel at point (a) through a block 6 inches wide. The wheel was so placed that the point of application of load was between spokes and approximately 90° from the point at which the stress had been applied in the radial-compression test. To measure the deformation of the wheel under load, Ames dials were fastened between the H beam and the side of the rim of the wheel at the point where the load was to be applied, and at a point diametrically opposite.

In this test the wheels were loaded to destruction.

Load-deflection curves were plotted, and are shown with the radial-compression curves.

In Table 5 are listed the proportional limits, the ultimate strengths, and the slopes of the curves.

TABLE 5.—Side Thrust

Wheel No.	Proportional limit at load in pounds	Ultimate load in pounds	Slope of curve at load, 1000 pounds per inch	Wheel No.	Proportional limit at load in pounds	Ultimate load in pounds	Slope of curve at load, 1000 pounds per inch
1.....	18 000	43 700	45 200	12.....	16 500	49 200	74 800
2.....	12 000	48 100	54 000	13.....	38 000	101 000	179 000
3.....	36 500	75 500	131 300	14.....	10 500	34 000	63 700
4.....	6 000	19 000	38 500	15.....	37 500	68 000	107 100
5.....	10 000	25 000	45 200	16.....	14 000	30 200	43 000
6.....	15 500	54 000	101 300	17.....	40 000	60 600	104 000
7.....	13 000	31 100	52 500	18.....	35 000	82 300	93 200
8.....	34 500	65 000	131 500	19.....	31 000	59 300	67 100
9.....	7 500	26 700	36 400	20.....	12 500	25 300	45 400
10.....	35 000	81 700	125 000	21.....	28 000	55 400	69 603
11.....	13 000	39 300	58 100				

The elastic resiliencies and the elastic resiliencies per pound of metal in wheel loads are recorded in Table 6.

TABLE 6.—Side Thrust—Resiliencies at Low Loads

[Area under load-deformation curve from zero to proportional limit]

Wheel No.	At load in inch-pounds	180° from load in inch-pounds	At load per pound of metal in wheel in inch-pounds	Wheel No.	At load in inch-pounds	180° from load in inch-pounds	At load per pound of metal in wheel in inch-pounds
1.....	3185	1800	12.65	12.....	1820	1480	14.00
2.....	1333	980	7.90	13.....	4040	5170	14.20
3.....	5060	2640	18.90	14.....	865	330	6.55
4.....	468	575	2.58	15.....	6550	6480	26.30
5.....	1108	618	3.15	16.....	2280	700	19.00
6.....	1185	1470	5.51	17.....	7680	850	20.30
7.....	1610	595	12.00	18.....	6560	4900	20.20
8.....	4520	2880	16.50	19.....	7160	7700	22.00
9.....	772	413	5.67	20.....	1718	310	12.20
10.....	5440	4100	16.90	21.....	7280		25.30
11.....	1460	1680	10.10				

The resiliencies for various loads were computed from the curve of deflection at the point of application of load and are recorded in Table 7.

TABLE 7.—Side Thrust—Resiliencies at Low Loads

[Area under curve of deformation at load]

Wheel No.	2000 pounds in inch- pounds	4000 pounds in inch- pounds	6000 pounds in inch- pounds	8000 pounds in inch- pounds	10 000 pounds in inch- pounds	12 000 pounds in inch- pounds	14 000 pounds in inch- pounds	16 000 pounds in inch- pounds	18 000 pounds in inch- pounds	20 000 pounds in inch- pounds
1.....	45	177	398	708	1105	1590	2170	2830	3580	.....
2.....	37	148	333	593	927	1332	.....	.....	.....	.....
3.....	15	61	137	244	381	549	746	976	1232	1523
4.....	52	208	469	.....	.....	.....	.....	.....	.....	.....
5.....	44	177	398	708	1109	.....	.....	.....	.....	.....
6.....	20	79	177	316	494	710	966	.....	.....	.....
7.....	38	152	343	610	954	1371	.....	.....	.....	.....
8.....	15	61	137	243	380	548	746	973	1232	1521
9.....	55	220	494	879	.....	.....	.....	.....	.....	.....
10.....	20	86	180	320	500	720	980	1280	1530	1900
11.....	35	138	310	551	860	1235	.....	.....	.....	.....
12.....	27	107	241	428	668	963	1310	1710	.....	.....
13.....	11	45	105	179	279	402	547	714	903	1116
14.....	31	126	282	502	785	.....	.....	.....	.....	.....
15.....	19	75	168	299	468	672	914	1195	1512	1866
16.....	47	186	418	744	1160	1675	2280	.....	.....	.....
17.....	19	77	173	308	481	693	943	1232	1558	1924
18.....	21	86	193	343	536	772	1050	1374	1740	2146
19.....	30	119	269	477	745	1073	1460	1906	2413	2975
20.....	44	176	396	705	1100	1584	.....	.....	.....	.....
21.....	70	270	555	900	1300	1740	2240	2760	3380	4000

The character of the failure due to side thrust will be found on the summary sheet for each wheel.

In the majority of tests failure occurred in the spokes, near the hub. This was to be expected because of the large bending moment at that section.

As indicated by the load-deflection curves, large stresses are transmitted through the rim to the portion of the wheel diametrically opposite to that on which the load is applied.

To obtain the actual deformation of the wheel it would be necessary to make a correction due to the bending of the axle. Comparative results only were required and, except in a few tests, no attempt was made to measure the bending of the axle.

In these tests the deflection of the axle was measured at a point which was at the same distance from the support as the deflection points on the edge of the rim. In this way, for a given load the actual deformation of the wheel, either at the point where the load is applied or at the diametrically opposite point, is obtained by subtracting the deflection of the axle from the total deflection of the wheel.

Each load-deflection curve of the axle is shown plotted with the other curves of the test in which the deflection was measured.

As previously stated, the proportional limit is the point at which the rate of deformation changes, and beyond which the wheel becomes permanently deformed. The slope of the load-deformation curve is a measure of the stiffness of the wheel for loads below the proportional limit.

The initial deviation of the load-deformation curve from a straight line is more pronounced here than in the radial-compression tests and again is probably due to localization of strains and to bringing the axle and bushings to a firm bearing.

FIG. 4.—Location of strain gage points, cast-steel, hollow-spoke wheel

VII. DISTRIBUTION OF STRESS IN WHEEL

An attempt was made to determine the distribution of stress in a wheel under radial-compressive loads. Wheel No. 11, the cast-steel wheel having five hollow spokes, was the only one available at the time, so it was used for the test.

Strain-gage lines were located and numbered as shown on Fig. 4. They were symmetrically placed on either side of a line through the center of the loading block and the center of the wheel. The lines were 2 inches in length, their ends being marked by small holes made with a No. 56 twist drill.

FIG. 5.—Stress-strain curves of material for cast-steel wheel with five hollow spokes

FIG. 6.—Load-stress curves, wheel No. II, showing stresses in rim and hub

The wheel was subjected to a radial-compressive test as described in Section V. At each load increment the change in length of each strain-gage line was measured by means of a 2-inch Berry strain gage. The smallest change in length indicated by the gage dial was 0.0002 inch. Changes of 0.00002 inch could be estimated.

The reduction of these linear measurements to stresses necessitated the determination of the modulus of elasticity of the material of which the wheel was constructed. Specimens were therefore cut from the spokes of the wheel and subjected to tensile tests. The results are shown plotted on Fig. 5.

The average mechanical properties determined are listed below:

Ultimate strength.....	pounds per square inch..	61 000
Proportional limit.....	do.....	17 700
Reduction in area.....	per cent..	17.3
Elongation in 2 inches.....	do.....	12.0
Modulus of elasticity.....	pounds per square inch..	28 000 000

This average value of the modulus was used in reducing the strain-gage measurements to stresses.

Load-stress curves were then plotted to show the relation between the load on the wheel and the unit stresses introduced by that load. The curves for the rim and hub are shown on Fig. 6, those for the spokes on Fig. 7.

Curves for gage lines similarly located, with reference to the line through the center of the loading block and the center of the wheel, were plotted in pairs. These curves check fairly closely. Exact duplication was not to be expected as the curves show the relation between applied load and unit stress, and not that between the applied load and the load transmitted through the section, so that, while the loads transmitted through symmetrically located sections are equal, any difference in the thickness or other dimensions of the casting at these points would result in a difference in the unit stresses. For example, spoke sections 22 and 40 will each transmit equal parts of any external load applied through the loading block. If, however, the cross section of the spoke at 22 is less than that of the spoke at 40, then the unit stress at 22 will be greater than the unit stress at 40.

1. STRESSES IN RIM OF WHEEL

It is evident from the load-stress curves for the rim that the circumferential stresses do not exceed the proportional limit of the material (17 700 pounds per square inch) for any load on the wheel up to 60 000 pounds.

FIG. 7.—Load-stress curves, wheel No. 11, showing stresses in spokes

These stresses are compressive in all parts of the rim except in the section between the spokes adjacent to the loading block. These spokes are inclined in the direction of the applied load, and the circumferential components of their reactions to the load are such as to produce tensile stresses in the rim between the spokes. Stresses due to beam action in the section have no appreciable effect on the measurements as the gage lines were approximately on the neutral axis of the beam. The shearing stresses were not measured but are undoubtedly very large.

2. STRESSES IN HUB OF WHEEL

The stresses in the hub do not become excessive except at gage line 47. The tensile stresses at this point pass the proportional limit of the material when the applied load is 50 000 pounds. There is, however, no possibility of a wheel in service being subjected to such a load.

3. STRESSES IN SPOKES OF WHEEL

The stresses in the spokes are all within the proportional limit of the material except at gage lines 24 and 25. These are adjoining gage lines and were probably located in a thin section of the casting. Any reduction from section of the casting as designed, due to blowholes, shifting of cores, etc., should be carefully guarded against as the strains in such a section may become excessive.

Attention is called to the change in direction of many of the load-stress curves at an applied load of about 32 000 pounds. This is the proportional limit of the wheel as determined from the load-deformation curves. (See Fig. 18.) It is probable that at this load the distribution of stress in the wheel began to change. The increase in the rate of deformation of the rim under the loading block would cause a readjustment and perhaps a change in kind of stress in the spokes.

VIII. CONCLUSIONS

These laboratory tests are not intended to supplant service tests. Much information can, however, be obtained in the laboratory which could not be obtained by service tests within a reasonable length of time. Defects in design and material are soon made apparent in laboratory tests and changes can be made before wheels are manufactured in large quantities.

The wheels tested were representative of those used on 3 and 5 ton trucks, and it is quite improbable that any of these wheels would ever be stressed even to its proportional limit.

The wheels tested are all stronger and heavier than is necessary, and a saving in material should be effected.

A reduction in weight is worthy of consideration, not only because of the material saved, but also because it would result in an increase in the life of tires and of roads.

IX. SUMMARY SHEETS AND CURVES

In the following pages are recorded the results of the tests.

Each summary sheet contains all of the information obtained from the tests on a single wheel. On the page facing the summary sheet are the load-deformation curves for that wheel.

TABLE 8.—Wheel No. 1

[Description—Rear wheel, 36 by 10 inches; wood, 14 spokes. Weight—252 pounds]

RADIAL-COMPRESSION TESTS		SIDE-THRUST TEST	
Proportional limit in pounds.....	38 000	Proportional limit in pounds.....	18 000
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	43 700
Deformation at maximum load in inches...	0.1062	Slope of curve in pounds per inch.....	45 200
Permanent set at maximum load in inches.	0.0336	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch.....	826 000	At load.....	3185
Elastic resiliencies in inch-pounds:		180° from load.....	1800
90° from load.....		Elastic resiliency in inch-pounds at load, per	
At load.....	875	pound of metal in wheel.....	12.65
270° from load.....	352	Resiliency in inch-pounds at point of appli-	
180° from load.....	230	cation of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	45
of application of load, per pound of metal		4000 pounds.....	117
in wheel.....	3.47	6000 pounds.....	398
Resiliency in inch-pounds at point of appli-		8000 pounds.....	708
cation of load at—		10 000 pounds.....	1105
2000 pounds.....	2	12 000 pounds.....	1590
4000 pounds.....	10	14 000 pounds.....	2170
6000 pounds.....	22	16 000 pounds.....	2830
8000 pounds.....	39	18 000 pounds.....	3580
10 000 pounds.....	61	Character of failure: Failed by splitting of spokes	
12 000 pounds.....	87	near point of application of load and at 180° from that	
14 000 pounds.....	118	point. Six spokes split near point of application of	
16 000 pounds.....	155	load. Four spokes split at 180° from point of applica-	
18 000 pounds.....	196	tion of load. Felly moved one-half inch along spokes	
20 000 pounds.....	242	at point of application of load.

Fig. 8.—Load-deformation curves, wheel No. 1

TABLE No. 9.—Wheel No. 2

[Description—Front wheel, 36 by 5 inches; cast-steel disk, box rim. Weight—169 pounds. Chemical analysis (per cent)—Carbon, 0.34; sulphur, 0.048; phosphorus, 0.039; manganese, 0.61; silicon, 0.35]

RADIAL-COMPRESSION TEST		SIDE-THURST TEST	
Proportional limit in pounds.....	31 000	Proportional limit in pounds.....	12 000
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	49 100
Deformation at maximum load in inches.....	0.0359	Slope of curve in pounds per inch.....	54 000
Permanent set at maximum load in inches.....	0.0187	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	2 450 000	At load.....	1333
Elastic resiliencies in inch-pounds:		180° from load.....	980
90° from load.....		Elastic resiliency in inch-pounds at load, per	
At load.....	202	pound of metal in wheel.....	7.90
270° from load.....		Resiliency in inch-pounds at point of applica-	
180° from load.....		tion of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	37
of application of load, per pound of metal		4000 pounds.....	148
in wheel.....	1.20	6000 pounds.....	333
Resiliency in inch-pounds at point of applica-		8000 pounds.....	593
tion of load at—		10 000 pounds.....	927
2000 pounds.....	1	12 000 pounds.....	1332
4000 pounds.....	3	Character of failure: Failed by bending of entire	
6000 pounds.....	7	wheel. No signs of rupture in material except small	
8000 pounds.....	13	cracks in felly.	
10 000 pounds.....	20		
12 000 pounds.....	29		
14 000 pounds.....	40		
16 000 pounds.....	52		
18 000 pounds.....	66		
20 000 pounds.....	82

FIG. 9.—Load-deformation curves, wheel No. 2

TABLE 10.—Wheel No. 3

[Description—Rear wheel, 36 by 10 inches; cast-steel disk; box rim. Weight—268 pounds. Chemical analysis (per cent)—Carbon, 0.33; sulphur, 0.051; phosphorus, 0.046; manganese, 0.74; silicon, 0.36]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	50 000	Proportional limit in pounds.....	36 500
Maximum applied load in pounds.....	100 000	Ultimate strength in pounds.....	75 500
Deformation at maximum load in inches..	0.0881	Slope of curve in pounds per inch.....	131 300
Permanent set at maximum load in inches.	0.0261	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch...	1 891 000	At load.....	5060
Elastic resiliencies in inch-pounds:		180° from load.....	2640
90° from load.....	128	Elastic resiliency in inch-pounds at load, per	
At load.....	660	pound of metal in wheel.....	18.90
270° from load.....	447	Resiliency in inch-pounds at point of applica-	
180° from load.....	715	tion of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	15
of application of load, per pound of metal		4000 pounds.....	61
in wheel.....	2.46	6000 pounds.....	137
Resiliency in inch-pounds at point of applica-		8000 pounds.....	244
tion of load at—		10 000 pounds.....	381
2000 pounds.....	1	12 000 pounds.....	549
4000 pounds.....	4	14 000 pounds.....	746
6000 pounds.....	10	16 000 pounds.....	976
8000 pounds.....	17	18 000 pounds.....	1232
10 000 pounds.....	26	20 000 pounds.....	1523
12 000 pounds.....	38	Character of failure: Failed by bending of entire	
14 000 pounds.....	52	wheel. Below point of application of load a crack	
16 000 pounds.....	68	6 inches long ran from circumference of wheel toward	
18 000 pounds.....	86	the hub. Tension hair cracks developed along arc of	
20 000 pounds.....	106	180° at bottom of slope from hub.

FIG. 10.—Load-deformation curves, wheel No. 3

TABLE 11.—Wheel No. 4

[Description—Front wheel, 40 by 6 inches; pressed steel, corrugated web; channel iron rim. Weight—181 pounds. Chemical analysis (per cent.)

	Hub	Web	Rim
Carbon.....	0.19	0.15	0.11
Sulphur.....	0.046	0.063	0.050
Phosphorus.....	0.030	0.044	0.092
Manganese.....	0.59	0.48	0.40
Silicon.....	0.28	0.02	0.02]

RADIAL-COMPRESSION TEST

Proportional limit in pounds.....	34 000
Maximum applied load in pounds.....	60 000
Deformation at maximum load in inches..	0.0564
Permanent set at maximum load in inches.	0.0072
Slope of curve No. 2 in pounds per inch...	1 238 000
Elastic resiliencies in inch-pounds:	
90° from load.....	
At load.....	467
270° from load.....	
180° from load.....	
Elastic resiliencies in inch-pounds at point of application of load, per pound of metal in wheel.....	2.58
Resiliency in inch-pounds at point of application of load at—	
2000 pounds.....	2
4000 pounds.....	7
6000 pounds.....	15
8000 pounds.....	26
10 000 pounds.....	40
12 000 pounds.....	58
14 000 pounds.....	79
16 000 pounds.....	103
18 000 pounds.....	131
20 000 pounds.....	162

SIDE-THRUST TEST

Proportional limit in pounds.....	6000
Ultimate strength in pounds.....	19 000
Slope of curve in pounds per inch.....	385 000
Elastic resiliency in inch-pounds:	
At load.....	468
180° from load.....	575
Elastic resiliency in inch-pounds at load, per pound of metal in wheel.....	2.58
Resiliency in inch-pounds at point of application of load at—	
2000 pounds.....	52
4000 pounds.....	208
6000 pounds.....	469
Character of failure: Failed by web pulling from hub.

FIG. 11.—Load-deformation curves, wheel No. 4

TABLE 12.—Wheel No. 5

[Description—Rear wheel, 40 by 12 inches; pressed steel, corrugated web; channel iron rim. Weight—354 pounds. Chemical analysis (per cent)]

		Hub	Web	Rim
Carbon.....		0.19	0.15	0.11
Sulphur.....		0.046	0.063	0.050
Phosphorus.....		0.030	0.044	0.092
Manganese.....		0.59	0.48	0.40
Silicon.....		0.28	0.02	0.02]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	85 000	Proportional limit in pounds.....	10 000
Maximum applied load in pounds..... ^a	105 000	Ultimate strength in pounds.....	25 000
Deformation at maximum load in inches..	0.1631	Slope of curve in pounds per inch.....	45 200
Permanent set at maximum load in inches.	0.0428	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch.....	715 000	At load.....	1108
Elastic resiliencies in inch-pounds:		180° from load.....	618
90° from load.....		Elastic resiliency in inch-pounds at load, per	
At load.....	5050	pound of metal in wheel.....	3.15
270° from load.....		Resiliency in inch-pounds at point of applica-	
180° from load.....	725	tion of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	44
of application of load, per pound of metal		4000 pounds.....	177
in wheel.....	14.3	6000 pounds.....	398
Resiliency in inch-pounds at point of applica-		8000 pounds.....	708
tion of load at—		10 000 pounds.....	1109
2000 pounds.....	4	Character of failure: Failed by web pulling from	
4000 pounds.....	12	hub. Failure was more pronounced at 90° from the	
6000 pounds.....	30	load than it was at the point where the load was ap-	
8000 pounds.....	54	plied. This was probably due to the crack in the	
10 000 pounds.....	80	rim of the wheel (caused by parting of channel irons)	
12 000 pounds.....	108	which had developed during the radial compression	
14 000 pounds.....	147	test. The brake band pulled away from the web.	
16 000 pounds.....	208		
18 000 pounds.....	261		
20 000 pounds.....	330		

^a Crack developed along rim of wheel where the two channels, of which the rim is formed, were welded.

FIG. 12.—Load-deformation curves, wheel No. 5

TABLE 13.—Wheel No. 6

[Description—Rear wheel, 36 by 6 inches; cast steel; 8+ spokes; brake band cast on wheel. Weight—215 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.083; phosphorus, 0.054; manganese, 0.64; silicon, 0.35]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	31 000	Proportional limit in pounds.....	15 500
Maximum applied load in pounds.....	75 000	Ultimate strength in pounds.....	54 000
Deformation at maximum load in inches..	0.0847	Slope of curve in pounds per inch.....	101 300
Permanent set at maximum load in inches.	0.0291	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	1 875 000	At load.....	1185
Elastic resiliencies in inch-pounds:		180° from load.....	1470
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	257	per pound of metal in wheel.....	5.51
270° from load.....		Resiliency in inch-pounds at point of ap-	
180° from load.....		plication of load at—	
Elastic resiliency in inch-pounds at point		2000 pounds.....	20
of application of load, per pound of metal		4000 pounds.....	79
in wheel.....	1.20	6000 pounds.....	177
Resiliency in inch-pounds at point of ap-		8000 pounds.....	316
plication of load at—		10 000 pounds.....	494
2000 pounds.....	1	12 000 pounds.....	710
4000 pounds.....	4	14 000 pounds.....	966
6000 pounds.....	10	Character of failure: Tension failure at root of	
8000 pounds.....	17	four spokes near point of application of load. Also	
10 000 pounds.....	27	tension failure in rim near same point.	
12 000 pounds.....	38		
14 000 pounds.....	52		
16 000 pounds.....	68		
18 000 pounds.....	86		
20 000 pounds.....	107

TABLE 14.—Wheel No. 7

[Description—Front wheel, 36 by 5 inches; cast steel; 8 U spokes; box rim. Weight—134 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.081; phosphorus, 0.060; manganese, 0.74; silicon, 0.29]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	32 500	Proportional limit in pounds.....	13 000
Maximum applied load in pounds.....	50 000	Ultimate strength in pounds.....	31 100
Deformation at maximum load in inches..	0.0490	Slope of curve at load in pounds per inch..	52 500
Permanent set at maximum load in inches.	0.0135	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch...	1 363 000	At load.....	1610
Elastic resiliencies in inch-pounds:		180° from load.....	595
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	387	per pound of metal in wheel.....	12.00
270° from load.....		Resiliency in inch-pounds at point of ap-	
180° from load.....		plication of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	38
of application of load, per pound of metal		4000 pounds.....	152
in wheel.....	2.89	6000 pounds.....	343
Resiliency in inch-pounds at point of ap-		8000 pounds.....	610
plication of load at—		10 000 pounds.....	954
2000 pounds.....	2	12 000 pounds.....	1371
4000 pounds.....	6	Character of failure: Tension failure in spoke	
6000 pounds.....	13	near point of application of load, and in webbing	
8000 pounds.....	24	between spokes at 180° from load.	
10 000 pounds.....	37		
12 000 pounds.....	53		
14 000 pounds.....	72		
16 000 pounds.....	94		
18 000 pounds.....	119		
20 000 pounds.....	147		

TABLE 15.—Wheel No. 8

[Description—Rear wheel, 36 by 10 inches; cast steel; 8 U spokes; box rim. Weight—274 pounds. Chemical analysis (per cent)—Carbon, 0.14; sulphur, 0.081; phosphorus, 0.080; manganese, 0.78; silicon, —]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	50 000	Proportional limit in pounds.....	34 500
Maximum applied load in pounds.....	100 000	Ultimate strength in pounds.....	65 000
Deformation at maximum load in inches..	0.0610	Slope of curve at load in pounds per inch..	131 500
Permanent set at maximum load in inches.	0.0103	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	2 000 000	At load.....	4520
Elastic resiliencies in inch-pounds:		180° from load.....	2880
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	625	per pound of metal in wheel.....	16.50
270° from load.....		Resiliency in inch-pounds at point of ap-	
180° from load.....		plication of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	15
of application of load, per pound of metal		4000 pounds.....	61
in wheel.....	2.28	6000 pounds.....	137
Resiliency in inch-pounds at point of ap-		8000 pounds.....	243
plication of load at—		10 000 pounds.....	380
2000 pounds.....	1	12 000 pounds.....	548
4000 pounds.....	4	14 000 pounds.....	746
6000 pounds.....	9	16 000 pounds.....	973
8000 pounds.....	16	18 000 pounds.....	1232
10 000 pounds.....	25	20 000 pounds.....	1521
12 000 pounds.....	36	Character of failure: Tension failure at root of	
14 000 pounds.....	49	spokes near point of application load and in web-	
16 000 pounds.....	64	bing and web bracing 180° from load.	
18 000 pounds.....	81		
20 000 pounds.....	100

FIG. 15 — Load-deformation curves, wheel No. 8

TABLE 16.—Wheel No. 9

[Description—Front wheel, 36 by 5 inches; cast steel; 7 U spokes; box rim. Weight—136 pounds. Chemical analysis (per cent)—Carbon, 0.22; sulphur, 0.057; phosphorus, 0.038; manganese, 0.52; silicon, 0.266]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	35 500	Proportional limit in pounds.....	7500
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	26 700
Deformation at maximum load in inches...	0.1287	Slope of curve in pounds per inch.....	36 400
Permanent set at maximum load in inches.	0.0791	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch.....	667 000	At load.....	772
Elastic resiliencies in inch-pounds:		180° from load.....	413
90° from load.....	119	Elastic resiliency in inch-pounds at load per	
At load.....	1047	pound of metal in wheel.....	5.67
270° from load.....	150	Resiliency in inch-pounds at point of appli-	
180° from load.....		cation of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	55
of application of load per pound of metal		4000 pounds.....	220
in wheel.....	7.70	6000 pounds.....	494
Resiliency in inch-pounds at point of appli-		8000 pounds.....	879
cation of load at—		Character of failure: Tension failure in two spokes	
2000 pounds.....	5	at load. One spoke failed near the rim and the	
4000 pounds.....	18	other at the hub.	
6000 pounds.....	36		
8000 pounds.....	64		
10 000 pounds.....	95		
12 000 pounds.....	138		
14 000 pounds.....	182		
16 000 pounds.....	240		
18 000 pounds.....	297		
20 000 pounds.....	350

FIG. 16.—Load-deformation curves, wheel No. 9

TABLE 17.—Wheel No. 10

[Description—Rear wheel, 36 by 10 inches; cast steel; 7 U spokes; box rim. Weight—321 pounds. Chemical analysis (per cent)—Carbon, 0.23; sulphur, 0.061; phosphorus, 0.041; manganese, 0.62; silicon, 0.305]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	77 000	Proportional limit in pounds.....	35 000
Maximum applied load in pounds.....	120 000	Ultimate strength in pounds.....	81 700
Deformation at maximum load in inches.....	0.1250	Slope of curve in pounds per inch.....	125 000
Permanent set at maximum load in inches.....	0.0537	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	1 316 000	At load.....	5440
Elastic resiliencies in inch-pounds:		180° from load.....	4100
90° from load.....		Elastic resiliency in inch-pounds at load	
At load.....	2250	per pound of metal in wheel.....	16.9
270° from load.....		Resiliency in inch-pounds at point of appli-	
180° from load.....		cation of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	20
of application of load per pound of metal		4000 pounds.....	86
in wheel.....	7.00	6000 pounds.....	180
Resiliency in inch-pounds at point of appli-		8000 pounds.....	320
cation of load at—		10 000 pounds.....	500
2000 pounds.....	5	12 000 pounds.....	720
4000 pounds.....	17	14 000 pounds.....	980
6000 pounds.....	39	16 000 pounds.....	1280
8000 pounds.....	64	18 000 pounds.....	1530
10 000 pounds.....	95	20 000 pounds.....	1900
12 000 pounds.....	132	Character of failure: Tension failure at root of two	
14 000 pounds.....	168	spokes adjacent to the load.	
16 000 pounds.....	208		
18 000 pounds.....	261		
20 000 pounds.....	310

FIG. 17.—Load-deformation curves, wheel No. 10

TABLE 18.—Wheel No. 11

Description—Front wheel, 36 by 5 inches; cast steel; 5 hollow spokes; box rim. Weight—144 pounds.
 Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.068; phosphorus, 0.040; manganese, 0.85; silicon, 0.23]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	32 000	Proportional limit in pounds.....	13 000
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	39 300
Deformation at maximum load in inches.....	0.0695	Slope of curve at load in pounds per inch....	58 100
Permanent set at maximum load in inches.....	0.0311	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch..	1 160 000	At load.....	1460
Elastic resiliencies in inch-pounds:		180° from load.....	1680
90° from load.....		Elastic resiliency in inch-pounds at load per	
At load.....	441	pound of metal in wheel.....	10.10
270° from load.....		Resiliency in inch-pounds at point of applica-	
180° from load.....		tion of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	35
of application of load per pound of metal		4000 pounds.....	138
in wheel.....	3.06	6000 pounds.....	310
Resiliency in inch-pounds at point of appli-		8000 pounds.....	551
cation of load at—		10 000 pounds.....	860
2000 pounds.....	2	12 000 pounds.....	1235
4000 pounds.....	7	Character of failure: Tension failure in hub at	
6000 pounds.....	16	180° from point of application of load.	
8000 pounds.....	28		
10 000 pounds.....	43		
12 000 pounds.....	62		
14 000 pounds.....	84		
16 000 pounds.....	110		
18 000 pounds.....	140		
20 000 pounds.....	173

FIG. 18.—Load-deformation curves, wheel No. 11

TABLE 19.—Wheel No. 12

[Description—Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; box rim. Weight—130 pounds.
Chemical analysis—Carbon, 0.307; sulphur, 0.043; phosphorus, 0.032; manganese, 0.75; silicon, 0.61]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	40 000	Proportional limit in pounds.....	16 500
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	49 200
Deformation at maximum load in inches .	0.0645	Slope of curve in pounds per inch.....	74 800
Permanent set at maximum load in inches.	0.0220	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch... 1 333 000		At load.....	1820
Elastic resiliencies in inch-pounds:		180° from load.....	1480
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	600	per pound of metal in wheel.....	14.0
270° from load.....		Resiliency in inch-pounds at point of	
180° from load.....		application of load at—	
Elastic resiliencies in Inch-pounds at		2000 pounds.....	27
point of application of load, per pound of		4000 pounds.....	107
metal in wheel.....	4.60	6000 pounds.....	241
Resiliency in inch-pounds at point of		8000 pounds.....	428
application of load at—		10 000 pounds.....	668
2000 pounds.....	2	12 000 pounds.....	963
4000 pounds.....	6	14 000 pounds.....	1310
6000 pounds.....	14	16 000 pounds.....	1710
8000 pounds.....	24	Character of failure: Failed by buckling on the	
10 000 pounds.....	38	inside of the wheel near the point of application of	
12 000 pounds.....	54	load, in the metal at the base of the spokes near the	
14 000 pounds.....	74	solid metal hub.	
16 000 pounds.....	96		
18 000 pounds.....	122		
20 000 pounds.....	150

FIG. 19.—Load-deformation curves, wheel No. 12

TABLE 20.—Wheel No. 13

[Description—Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; box rim. Weight—286 pounds.
Chemical analysis (per cent)—Carbon, 0.362; sulphur, 0.043; phosphorus, 0.038; manganese, 0.76; silicon, 0.54]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	20 000	Proportional limit in pounds.....	38 000
Maximum applied load in pounds.....	100 000	Ultimate strength in pounds.....	101 000
Deformation at maximum load in inches..	0.0513	Slope of curve in pounds per inch.....	179 000
Permanent set at maximum load in inches.	0.0113	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	6 060 000	At load.....	4040
Elastic resiliencies in inch-pounds:		180° from load.....	5170
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	33	per pound of metal in wheel.....	14.20
270° from load.....		Resiliency in inch-pounds at point of	
180° from load.....	390	application of load at—	
Elastic resiliencies in inch-pounds at		2000 pounds.....	11
point of application of load, per pound of		4000 pounds.....	45
metal in wheel.....	0.10	6000 pounds.....	105
Resiliency in inch-pounds at point of		8000 pounds.....	179
application of load at—		10 000 pounds.....	279
2000 pounds.....	0	12 000 pounds.....	402
4000 pounds.....	1	14 000 pounds.....	547
6000 pounds.....	3	16 000 pounds.....	714
8000 pounds.....	5	18 000 pounds.....	903
10 000 pounds.....	8	20 000 pounds.....	1116
12 000 pounds.....	12	Character of failure: Apparatus broke at 101 000	
14 000 pounds.....	16	pounds, making it necessary to remove the load.	
16 000 pounds.....	21	On reapplying load, the wheel failed at 98 000 pounds	
18 000 pounds.....	27	by tension fracture in the steel where the spokes	
20 000 pounds.....	33	join the hub.

FIG. 20.—Load-deformation curves, wheel No. 13

TABLE 21.—Wheel No. 14

[Description—Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design. Weight—132 pounds. Chemical analysis (per cent)—Carbon, 0.30; sulphur, 0.034; phosphorus, 0.021; manganese, 0.47; silicon, 0.40]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	26 000	Proportional limit in pounds.....	10 500
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	34 000
Deformation at maximum load in inches..	0.1135	Slope of curve in pounds per inch.....	63 700
Permanent set at maximum load in inches.	0.0687	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	1 300 000	At load.....	865
Elastic resiliencies in inch-pounds:		180° from load.....	330
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	260	per pound of metal in wheel.....	6.55
270° from load.....		Resiliency in inch-pounds at point of	
180° from load.....		application of load at—	
Elastic resiliencies in inch-pounds at		2000 pounds.....	31
point of application of load, per pound of		4000 pounds.....	126
metal in wheel.....	1.97	6000 pounds.....	282
Resiliency in inch-pounds at point of		8000 pounds.....	502
application of load at—		10 000 pounds.....	785
2000 pounds.....	2	Character of failure: Failed by the crushing in	
4000 pounds.....	6	of one side of tire seat at point of application of load,	
6000 pounds.....	14	and by distortion of wheel. There were no signs of	
8000 pounds.....	25	rupture in the metal.	
10 000 pounds.....	39		
12 000 pounds.....	55		
14 000 pounds.....	75		
16 000 pounds.....	98		
18 000 pounds.....	125		
20 000 pounds.....	154

FIG. 21.—Load-deformation curves, wheel No. 14

TABLE 22.—Wheel No. 15

[Description—Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design. Weight—249 pounds. Chemical analysis (per cent)—Carbon, 0.40; sulphur, 0.038; phosphorus, 0.021; manganese, 0.69; silicon, 0.46]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	75 000	Proportional limit in pounds.....	37 500
Maximum applied load in pounds.....	120 000	Ultimate strength in pounds.....	68 000
Deformation at maximum load in inches....	0.0874	Slope of curve in pounds per inch.....	107 100
Permanent set at maximum load in inches..	0.0318	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	2 320 000	At load.....	6550
Elastic resiliencies in inch-pounds:		180° from load.....	6480
90° from load.....		Elastic resiliency in inch-pounds at load, per	
At load.....	1210	pound of metal in wheel.....	26.3
270° from load.....		Resiliency in inch-pounds at point of applica-	
180° from load.....	880	tion of load at—	
Elastic resiliencies in inch-pounds at point of		2000 pounds.....	19
application of load, per pound of metal in		4000 pounds.....	75
wheel.....	4.86	6000 pounds.....	168
Resiliency in inch-pounds at point of application		8000 pounds.....	299
of load at—		10 000 pounds.....	468
2000 pounds.....	1	12 000 pounds.....	672
4000 pounds.....	4	14 000 pounds.....	914
6000 pounds.....	8	16 000 pounds.....	1195
8000 pounds.....	14	18 000 pounds.....	1512
10 000 pounds.....	22	20 000 pounds.....	1866
12 000 pounds.....	31	Character of failure: Failed by crushing in of tire	
14 000 pounds.....	42	seat at point of application of load.	
16 000 pounds.....	55		
18 000 pounds.....	70		
20 000 pounds.....	86

FIG. 22.—Load-deformation curves, wheel No. 15

TABLE 23.—Wheel No. 16

[Description—Front wheel, 36 by 5 inches; cast steel; 7 hollow spokes; composite design. Weight—120 pounds. Chemical analysis (per cent)—Carbon, 0.211; sulphur, 0.082; phosphorus, 0.066; manganese, 0.84; silicon, 0.40]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	44 000	Proportional limit in pounds.....	14 000
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	30 200
Deformation at maximum load in inches....	0.0744	Slope of curve in pounds per inch.....	43 000
Permanent set at maximum load in inches....	0.0323	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch.....	917 000	At load.....	2280
Elastic resiliencies in inch-pounds:		180° from load.....	700
90° from load.....	....	Elastic resiliency in inch-pounds at load, per	
At load.....	1056	pound of metal in wheel.....	19.00
270° from load.....	....	Resiliency in inch-pounds at point of applica-	
180° from load.....	....	tion of load at—	
Elastic resiliencies in inch-pounds at point of		2000 pounds.....	47
application of load, per pound of metal in		4000 pounds.....	186
wheel.....	8.80	6000 pounds.....	418
Resiliency in inch-pounds at point of applica-		8000 pounds.....	744
tion of load at—		10 000 pounds.....	1160
2000 pounds.....	2	12 000 pounds.....	1675
4000 pounds.....	9	14 000 pounds.....	2280
6000 pounds.....	20	Character of failure: Failed by spokes tearing from	
8000 pounds.....	35	hub near point of application of load. This wheel	
10 000 pounds.....	55	was a poor casting, and cracks developed due to	
12 000 pounds.....	79	flaws in the material.	
14 000 pounds.....	107		
16 000 pounds.....	140		
18 000 pounds.....	177		
20 000 pounds.....	218

FIG. 23.—Load-deformation curves, wheel No. 16

TABLE 24.—Wheel No. 17

Description—Rear wheel, 36 by 10 inches; cast steel; 7 hollow spokes; composite design. Weight—273 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.084; phosphorus, 0.070; manganese, 0.79; silicon, 0.23]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	71 500	Proportional limit in pounds.....	40 000
Maximum applied load in pounds.....	120 000	Ultimate strength in pounds.....	60 600
Deformation at maximum load in inches....	0.1586	Slope of curve in pounds per inch.....	104 000
Permanent set at maximum load in inches..	0.0831	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	1 250 000	At load.....	7 680
Elastic resiliencies in inch-pounds:		180° from load.....	850
90° from load.....	640	Elastic resiliency in inch-pounds at load, per	
At load.....	2090	pound of metal in wheel.....	28.30
270° from load.....	630	Resiliency in inch-pounds at point of applica-	
180° from load.....	319	tion of load at—	
Elastic resiliencies in inch-pounds at point of		2000 pounds.....	19
application of load, per pound of metal in		4000 pounds.....	77
wheel.....	7.65	6000 pounds.....	173
Resiliency in inch-pounds at point of applica-		8000 pounds.....	308
tion of load at—		10 000 pounds.....	481
2000 pounds.....	2	12 000 pounds.....	693
4000 pounds.....	6	14 000 pounds.....	943
6000 pounds.....	14	16 000 pounds.....	1232
8000 pounds.....	26	18 000 pounds.....	1558
10 000 pounds.....	40	20 000 pounds.....	1924
12 000 pounds.....	58	Character of failure: Failed in hub near root of	
14 000 pounds.....	78	spokes at point of application of load. Poor casting.	
16 000 pounds.....	102		
18 000 pounds.....	130		
20 000 pounds.....	160

FIG. 24.—Load-deformation curves, wheel No. 17

TABLE 25.—Wheel No. 18

[Description—Rear wheel, 40 by 10 inches; cast steel; 7 hollow spokes; composite design. Weight—325 pounds. Chemical analysis (per cent)—Carbon, 0.33; sulphur, 0.038; phosphorus, 0.033; manganese, 0.72; silicon, 0.43]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	46 000	Proportional limit in pounds.....	35 000
Maximum applied load in pounds.....	120 000	Ultimate strength in pounds.....	82 300
Deformation at maximum load in inches..	0.1230	Slope of curve in pounds per inch.....	93 200
Permanent set at maximum load in inches.	0.0676	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	1 968 000	At load.....	6560
Elastic resiliencies in inch-pounds:		180° from load.....	4900
90° from load.....		Elastic resiliency in inch-pounds at load, per	
At load.....	538	pound of metal in wheel.....	20.20
270° from load.....		Resiliency in inch-pounds at point of applica-	
180° from load.....		tion of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	21
of application of load, per pound of metal		4000 pounds.....	86
in wheel.....	1.66	6000 pounds.....	193
Resiliency in inch-pounds at point of appli-		8000 pounds.....	343
cation of load at—		10 000 pounds.....	536
2000 pounds.....	1	12 000 pounds.....	772
4000 pounds.....	4	14 000 pounds.....	1050
6000 pounds.....	9	16 000 pounds.....	1374
8000 pounds.....	16	18 000 pounds.....	1740
10 000 pounds.....	26	20 000 pounds.....	2146
12 000 pounds.....	37	Character of failure: Tension failure in hub near	
14 000 pounds.....	50	point of application of load.	
16 000 pounds.....	65		
18 000 pounds.....	82		
20 000 pounds.....	102

FIG. 25.—Load-deformation curves, wheel No. 18

TABLE 26.—Wheel No. 19

[Description—Rear wheel, 40 by 12 inches; cast steel; 7 hollow spokes; composite design. Weight—325 pounds. Chemical analysis (per cent)—Carbon, 0.19; sulphur, 0.050; phosphorus, 0.048; manganese 0.36; silicon, 0.33]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	40 000	Proportional limit in pounds.....	31 000
Maximum applied load in pounds.....	100 000	Ultimate strength in pounds.....	59 300
Deformation at maximum load in inches... 0.1555		Slope of curve in pounds per inch.....	67 100
Permanent set at maximum load in inches. 0.1100		Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch..... 1 836 000		At load.....	7150
Elastic resiliencies in inch-pounds:		180° from load.....	7700
90° from load.....	195	Elastic resiliency in inch-pounds at load, per	
At load.....	436	pound of metal in wheel.....	22.00
270° from load.....	94	Resiliency in inch-pounds at point of applica-	
180° from load.....	0	tion of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	30
of application of load, per pound of metal		4000 pounds.....	119
in wheel.....	1.34	6000 pounds.....	269
Resiliency in inch-pounds at point of appli-		8000 pounds.....	477
cation of load at—		10 000 pounds.....	745
2000 pounds.....	1	12 000 pounds.....	1073
4000 pounds.....	4	14 000 pounds.....	1460
6000 pounds.....	10	16 000 pounds.....	1906
8000 pounds.....	17	18 000 pounds.....	2413
10 000 pounds.....	27	20 000 pounds.....	2975
12 000 pounds.....	39	Character of failure: Tension failure in hub near	
14 000 pounds.....	53	point of application of load. Flaw in casting at point	
16 000 pounds.....	70	of failure.	
18 000 pounds.....	88		
20 000 pounds.....	109

FIG. 26.—Load-deformation curves, wheel No. 19

TABLE 27.—Wheel No. 20

[Description.—Front wheel, 36 by 5 inches; malleable iron; 7 hollow spokes; composite design. Weight—141 pounds. Chemical analysis (per cent)—Carbon, 2.58; sulphur, 0.056; phosphorus, 0.199; manganese 0.21; silicon, 0.722]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	43 500	Proportional limit in pounds.....	12 500
Maximum applied load in pounds.....	60 000	Ultimate strength in pounds.....	25 300
Deformation at maximum load in inches..	0.0741	Slope of curve in pounds per inch.....	45 400
Permanent set at maximum load in inches.	0.0271	Elastic resiliency in inch-pounds:	
Slope of curve No. 2 in pounds per inch....	926 000	At load.....	1718
Elastic resiliencies in inch-pounds:		180° from load.....	310
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	1131	per pound of metal in wheel.....	12.20
270° from load.....		Resiliency in inch-pounds at point of ap-	
180° from load.....		plication of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	44
of application of load, per pound of metal		4000 pounds.....	176
in wheel.....	8.02	6000 pounds.....	396
Resiliency in inch-pounds at point of ap-		8000 pounds.....	705
plication of load at—		10 000 pounds.....	1100
2000 pounds.....	4	12 000 pounds.....	1584
4000 pounds.....	16	Character of failure: Tension failure in hub at	
6000 pounds.....	33	root of the two spokes under the load.	
8000 pounds.....	56		
10 000 pounds.....	80		
12 000 pounds.....	108		
14 000 pounds.....	140		
16 000 pounds.....	176		
18 000 pounds.....	221		
20 000 pounds.....	270

FIG. 27.—Load-deformation curves, wheel No. 20

TABLE 28.—Wheel No. 21

[Description—Rear wheel, 40 by 10 inches; malleable iron; 7 hollow spokes; composite design. Weight—288 pounds. Chemical analysis (per cent)—Carbon, 2.39; sulphur, 0.078; phosphorus, 0.199; manganese, 0.23; silicon, 0.980]

RADIAL-COMPRESSION TEST		SIDE-THRUST TEST	
Proportional limit in pounds.....	64 000	Proportional limit in pounds.....	28 000
Maximum applied load in pounds.....	120 000	Ultimate strength in pounds.....	55 400
Deformation at maximum load in inches..	0.1361	Slope of curve in pounds per inch.....	69 600
Permanent set at maximum load in inches.	0.0715	Elastic resiliency in inch-pounds:	
Slope of curve No. 2, in pounds per inch...1 818 000		At load.....	7280
Elastic resiliencies in inch-pounds:		180° from load.....	
90° from load.....		Elastic resiliency in inch-pounds at load,	
At load.....	1128	per pound of metal in wheel.....	25.30
270° from load.....	255	Resiliency in inch-pounds at point of ap-	
180° from load.....	450	plication of load at—	
Elastic resiliencies in inch-pounds at point		2000 pounds.....	70
of application of load, per pound of metal		4000 pounds.....	270
in wheel.....	3.91	6000 pounds.....	555
Resiliency in inch-pounds at point of ap-		8000 pounds.....	900
plication of load at—		10 000 pounds.....	1300
2000 pounds.....	1	12 000 pounds.....	1740
4000 pounds.....	4	14 000 pounds.....	2240
6000 pounds.....	10	16 000 pounds.....	2760
8000 pounds.....	18	18 000 pounds.....	3380
10 000 pounds.....	28	20 000 pounds.....	4000
12 000 pounds.....	40	Character of failure: Tension failure in two spokes	
14 000 pounds.....	54	and in rim at point of application of load	
16 000 pounds.....	70		
18 000 pounds.....	89		
20 000 pounds.....	110

FIG. 28.—Load-deformation curves, wheel No. 21

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FIG. 29.—*Wheel No. 1*

FIG. 30.—*Wheels No. 3 and 2*

FIG. 31.—Wheels No. 4 and 5

FIG. 32.—Wheel No. 6

FIG. 33.—Wheels No. 8 and 7

FIG. 34.—Wheels No. 9 and 10

FIG. 35.—*Wheel No. 11*

FIG. 36.—*Wheels No. 13 and 12*

FIG. 37.—Wheels No. 14 and 15

FIG. 38.—Wheels No. 17 and 16

FIG. 39.—*Wheel No. 18*

FIG. 40.—*Wheel No. 19*

FIG. 41.—*Wheel No. 20*

FIG. 42.—*Wheel No. 21*