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EFFECTS OF LOAD, INFLATION PRESSURE AND TIRE DEFLECTION ON TRUCK TIRE NOISE LEVELS

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16. Abstract

SAE Recommended Practice J57a -- Sound Level of Highway Truck Tires -- specifies that the tests be made using tires inflated to the maximum inflation pressure and loaded to the maximum load as specified by the Tire and Rim Association (T&RA). However, if local load limits preclude the use of the maximum rated load, tests may be conducted using lower loads if the inflation pressure is adjusted either to maintain constant tire deflection or according to the T&RA load/inflation pressure tables. Whether these alternate load/inflation pressure conditions result in similar sound levels is an important question. This report presents acoustic data that allows evaluation of the equivalency of these alternate conditions. In addition, laboratory data on the relationships between load, inflation pressure, and tire deflection are presented. On the basis of these data, for tire loads greater than 70 to 75 percent of the maximum rated load, smaller variations of the measured sound level were observed when constant inflation pressure was maintained than when the inflation pressure was adjusted. This is convenient since this essentially represents the typical in-service case where the load varies between trips but the tire inflation pressure is maintained at a constant value.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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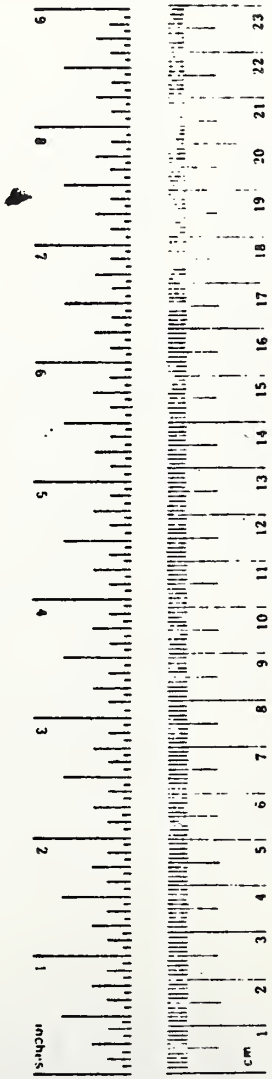
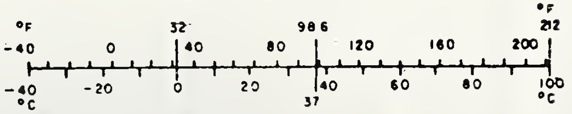
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Abstract

SAE Recommended Practice J57a -- Sound Level of Highway Truck Tires -- specifies that the tests be made using tires inflated to the maximum inflation pressure and loaded to the maximum load as specified by the Tire and Rim Association (T&RA). However, if local load limits preclude the use of the maximum rated load, tests may be conducted using lower loads if the inflation pressure is adjusted either to maintain constant tire deflection or according to the T&RA load/inflation pressure tables. Whether these alternate load/inflation pressure conditions result in similar sound levels is an important question. This report presents acoustic data that allows evaluation of the equivalency of these alternate conditions. In addition, laboratory data on the relationships between load, inflation pressure, and tire deflection are presented. On the basis of these data, for tire loads greater than 70 to 75 percent of the maximum rated load, smaller variations of the measured sound level were observed when constant inflation pressure was maintained than when the inflation pressure was adjusted. This is convenient since this essentially represents the typical in-service case where the load varies between trips but the tire inflation pressure is maintained at a constant value.

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1. INTRODUCTION

Previous studies have shown that truck tire noise is affected by various parameters such as tread design, pavement surface, wear, speed, load, and carcass construction [1-6][1]. At the request of the Office of Noise Abatement,[2] U. S. Department of Transportation (DOT), the National Bureau of Standards (NBS) carried out a study to determine the effects that tire loading, inflation pressure, and deflection have on truck tire noise generation.

The NBS study was conducted to test the hypothesis that load effects on tire noise can be disregarded if the inflation pressure is adjusted according to the load (as specified in the load/inflation pressure tables published by the Tire and Rim Association [7]). The effects of different tire loads were measured in three ways: (1) varying tire inflation pressure with load according to T&RA recommendations; (2) constant tire inflation at 75 psi (0.52 MPa); and (3) constant tire deflection, i.e. constant axle height, maintained by altering inflation pressure with load.

The work was carried out in two parts. First, a table of axle height (tire deflection) versus inflation pressure for various load conditions was developed for a sample of ten tires. This portion of the study was conducted in the laboratory at NBS, and established the conditions for the constant deflection portion of the second phase of the study -- the acoustic measurement test program. For the acoustic measurements two types of bias-ply tires -- a typical rib and a typical cross-bar -- were tested under nominal loads of 100, 90, 80, 75, and 50 percent of maximum rated load per T&RA recommendations. A detailed discussion of the two phases of the study and the results obtained are presented in subsequent sections of this report.

The current[3] Society of Automotive Engineers Recommended Practice SAE J57a [8] -- Sound Level of Highway Truck Tires -- specifies standard operating conditions and test procedures for measuring the noise generated by truck tires. One of the conditions specified by this recommended practice is the vehicle/tire loading to be maintained during the test. SAE J57a specifies that the "...tires shall be inflated to the maximum pressure and loaded to the maximum load specified by the Tire and Rim Association for continuous operation at

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[1] Numbers in brackets refer to the literature references at the end of this report.

[2] Now the Office of Heavy Duty Vehicle Research of the National Highway Traffic Safety Administration.

[3] The complete text of SAE J57a is reproduced in Appendix A.

highway speeds exceeding 80 km/hr (50 mph)." SAE J57a allows an exception to this requirement if the local load limits will not permit full rated load. In this case, "...the test may be conducted at the local load limit with inflation pressure reduced to provide a tire deflection equal to the maximum load and inflation pressure, provided the load is not less than 75% of the maximum rated load." The recommended practice suggests as another alternative that the tire inflation pressure "...be adjusted to correspond to the actual load following the appropriate load/pressure tables in the Tire and Rim Association Yearbook." Thus, SAE J57a permits tests to be conducted using: (1) maximum rated load and inflation pressure as specified by the T&RA, (2) adjustment of inflation pressure to maintain constant tire deflection with reduced loading, i.e., constant axle height, and (3) adjustment of inflation pressure to correspond to the actual load following T&RA recommendations. All three procedures were evaluated in the conduct of this study. In addition, measurements were made for the condition of constant inflation pressure and varying load. This represents the typical in-service case where the load varies between trips but the tire inflation pressure is maintained at a constant value.

Data on the interrelated effects of load, inflation pressure, and tire deflection on tire noise are limited. In past studies in which the effects of load were investigated [1-5, 9-13], the trend has generally been consistent that the sound levels increase with increasing tire load. These studies have shown that, for a constant inflation pressure, increases in load from 30 to 100 percent of the maximum rated load can have a significant effect on the sound level generated by tires with cross-bar tread patterns (4-8 dB increase), while the sound from tires with rib type tread patterns is relatively unaffected (0-3 dB increase).

Inflation pressure also has an effect on tire noise. In the case of cross-bar tires, a decrease in inflation pressure on the order of 30 percent of the maximum recommended pressure (where the load is kept constant) generally causes cross-bar tires to be 1-3 dB louder [9-11]. A similar decrease in the inflation pressure appears to have little effect on the sound level produced by rib tires; in some cases, there is no change in sound level [11] and in other instances, there is a slight increase of about 1 dB [10].

Only one known study reports data on the effect of maintaining a constant tire deflection by reducing the inflation pressure for reduced tire loads. These data, presented in three different references [3,4,10], are shown in Figure 1 for cross-bar and circumferential rib tires of bias-ply design. The range between the maximum and minimum noise levels is 2.1 dB for the rib tire and 7.0 dB for the cross-bar tire. Based on these data it would appear that testing at alternative loads with reduced inflation pressure would only be valid for loads greater than 75 percent of the maximum rated T&RA load. Further data to support this conclusion are presented later in this report.

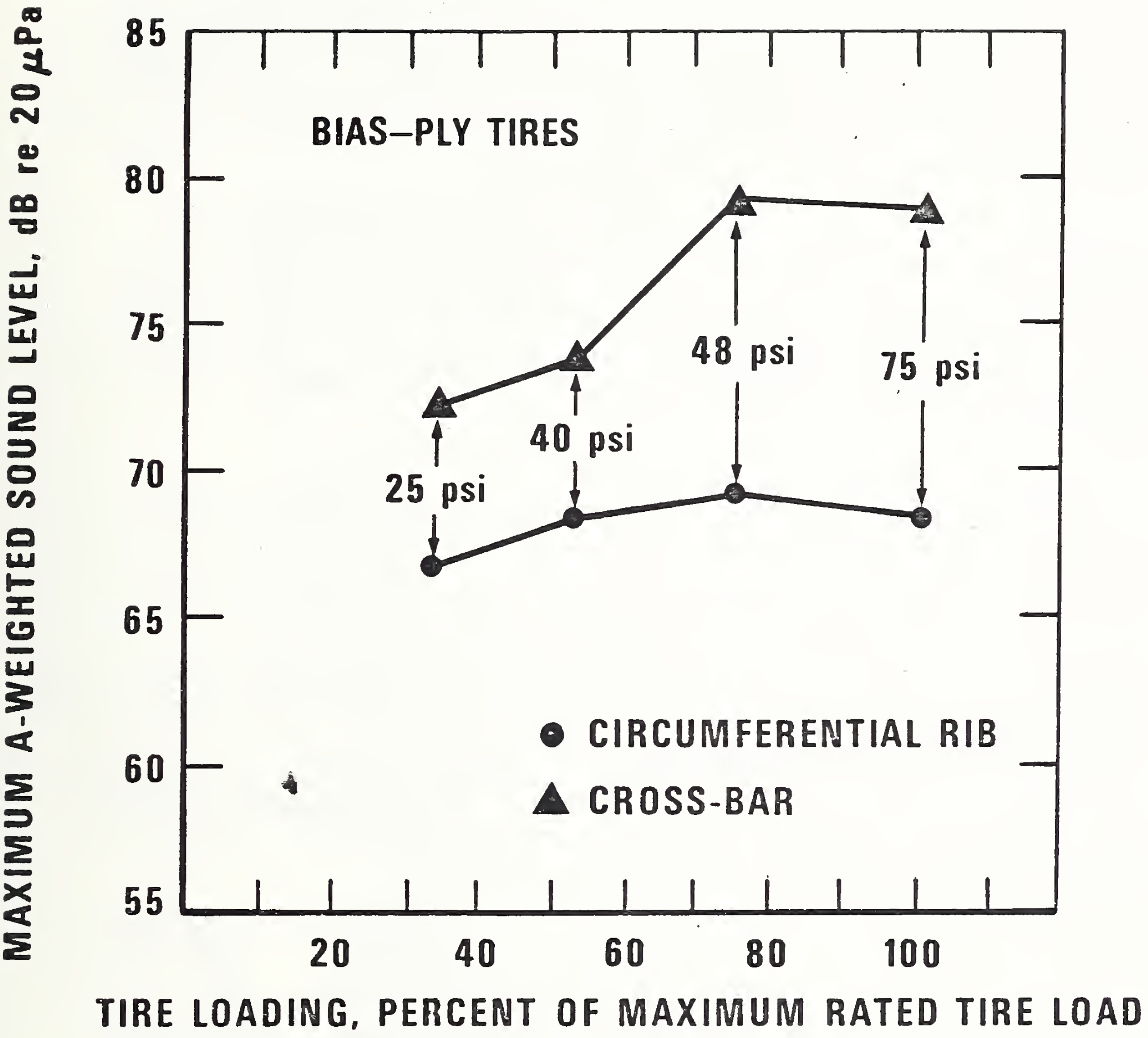

Figure 1. Maximum A-weighted sound level versus tire loading for constant tire deflection. These data are for coastbys at 50 mph (80.5 km/hr) measured using "slow" meter response [10].

2. LOAD/INFLATION PRESSURE/DEFLECTION STUDY

Before the acoustical measurement portion of the program was conducted, it was thought to be desirable to obtain precise information on axle height as a function of load and inflation pressure. This information would then be used as the guideline for adjusting inflation pressure when conducting the acoustical measurements in the field. In addition, these data would also provide indications of the practical limits of altering inflation pressure with load in field test situations as specified in SAE J57a and whether the concept of adjusting inflation pressure to maintain constant tire deflection is practical, especially for radial truck tires.

A sample of ten truck tires[4/] was tested at NBS to determine the relationship between these parameters. These truck tires, chosen to represent a variety of tire types, were all size 10.00-20 or the equivalent tubeless size 11.00-22.5. The carcass construction and basic tread design of these tires are listed in Table 1. Contact patch footprints of these tires for a loading of 4760 lb (2159 kg) and an inflation pressure of 75 psi (0.52 MPa) for the bias-ply tires and 5300 lb (2404 kg) and 95 psi (0.66 MPa) for the radial tires are shown below this table.

For these tests a series of loads were used in examining the inflation pressure and deflection characteristics. These loads, listed in Table 2, correspond to T&RA recommendations for 10.00-20 (or 11.00-22.5) size tires -- with an "F" load rating for the bias-ply tires and a "G" load rating for the radial tires used in dual applications -- for reduced inflation pressures in 5 psi (34.5 KPa) increments from the maximum recommended value at 75 psi (0.52 MPa) for the bias-ply tires and 95 psi (0.66 MPa) for the radial tires. It should be noted that T&RA does not recommend inflation pressures for this size tire below 50 psi (0.34 MPa) for bias-ply tires and 55 psi (0.38 MPa) for radial tires. To get conditions corresponding to 75 and 50 percent of the maximum rated tire loads, tests were also conducted at 3570 lb (1619 kg) and 2380 lb (1080 kg) for the bias-ply tires and 3970 lb (1801 kg) [instead of 3975 lb (1803 kg)] and 2650 lb (1202 kg) for the radial tires. The test procedures for these measurements are discussed below.

2.1. Test Set-Up

These series of tests were performed using a Tinius Olsen[5/] universal testing machine equipped with a deflectometer and an autographic

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[4/] These tires and the tires used in the acoustic measurement program were loaned to the government for use in this study by member fleets of the American Trucking Associations, Inc.

[5/] Commercial test equipment is identified in this report to adequately describe the test procedures that were utilized. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that this equipment was necessarily the best available for the purpose.

Table 1. Construction and basic tread design of tires tested to examine the relationship between load, inflation pressure and tire deflection.

TIRE DESIGNATION	CARCASS CONSTRUCTION	BASIC TREAD DESIGN	TUBE TYPE - T TUBELESS - TL
A	bias-ply	rib	TL
B	bias-ply	cross-bar	TL
C	bias-ply	rib	T
D	bias-ply	recap rib	TL
E	bias-ply	cross-bar	TL
F	bias-ply	recap cross-bar	TL
G	bias-ply	recap rib	TL
H	bias-ply	rib	T
I	radial	rib	TL
J	radial	rib	TL

Contact patch footprints for a loading of 4760 lb (2159 kg) and an inflation pressure of 75 psi (0.52 MPa) for the bias-ply tires and 5300 lb (2404 kg) and 95 psi (0.66 MPa) for the radial tires.

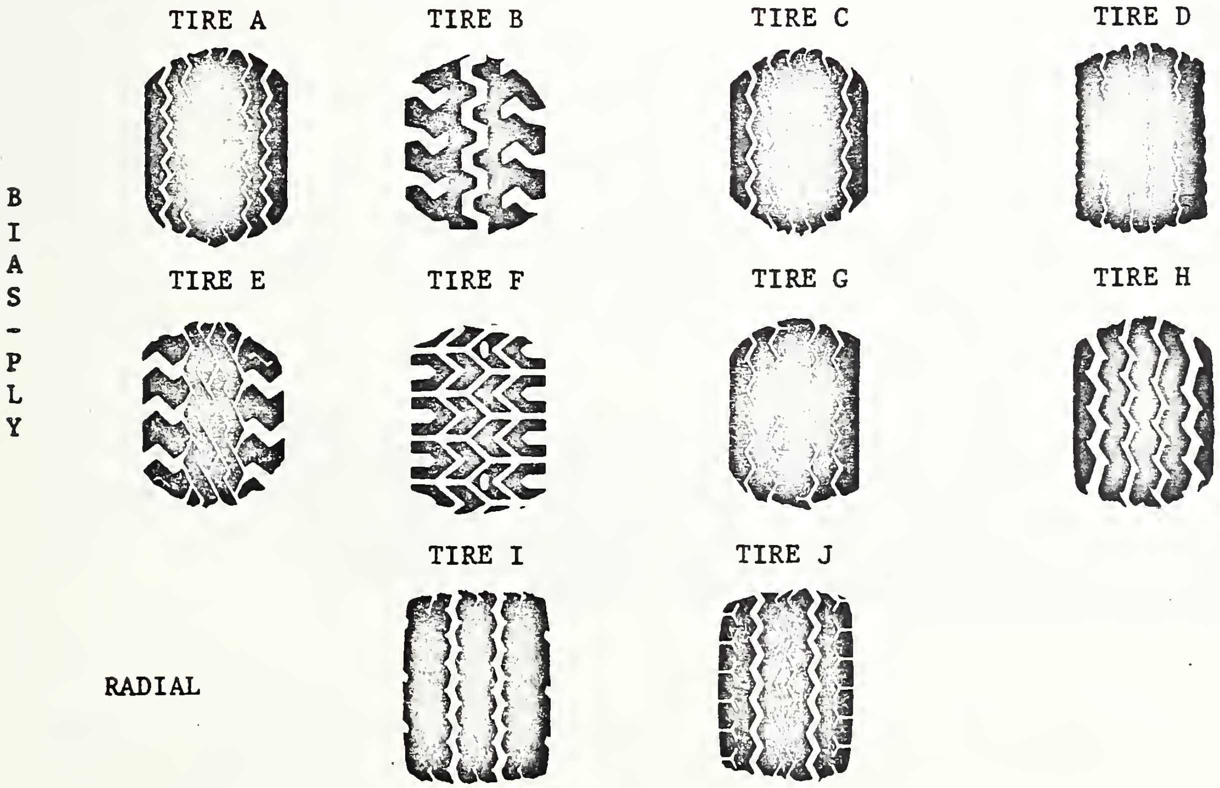


Table 2. T&RA recommended load and inflation pressure conditions for 10.00-20 (or 11.00-22.5) size tires used in dual applications. The bias-ply tires are load range "F" and the radial tires load range "G".

Load, lb*	Inflation Pressure, psi**	
	Bias-Ply Load Range "F"	Radial Load Range "G"
5300	X	95
5120	X	90
4950	X	85
4760	75	80
4580	70	75
4380	65	70
4180	60	65
3970	55	60
3760	50	55
3570	50	X
2650	X	55
2380	50	X

X - No test conducted at this load

* To convert the load in pounds to kilograms divide by 2.2046 lb/kg.

** To convert psi to Pascals multiply by 6894.8 Pa/psi.

load-deflection recorder. The testing machine was calibrated according to American Society for Testing and Materials (ASTM) Standard E4-72, Standard Methods of Verification of Testing Machines [14]. Figure 2 shows the testing machine with a tire mounted on an axle and suspended above the floor. In this configuration only the upper portion of the tire is deflected.

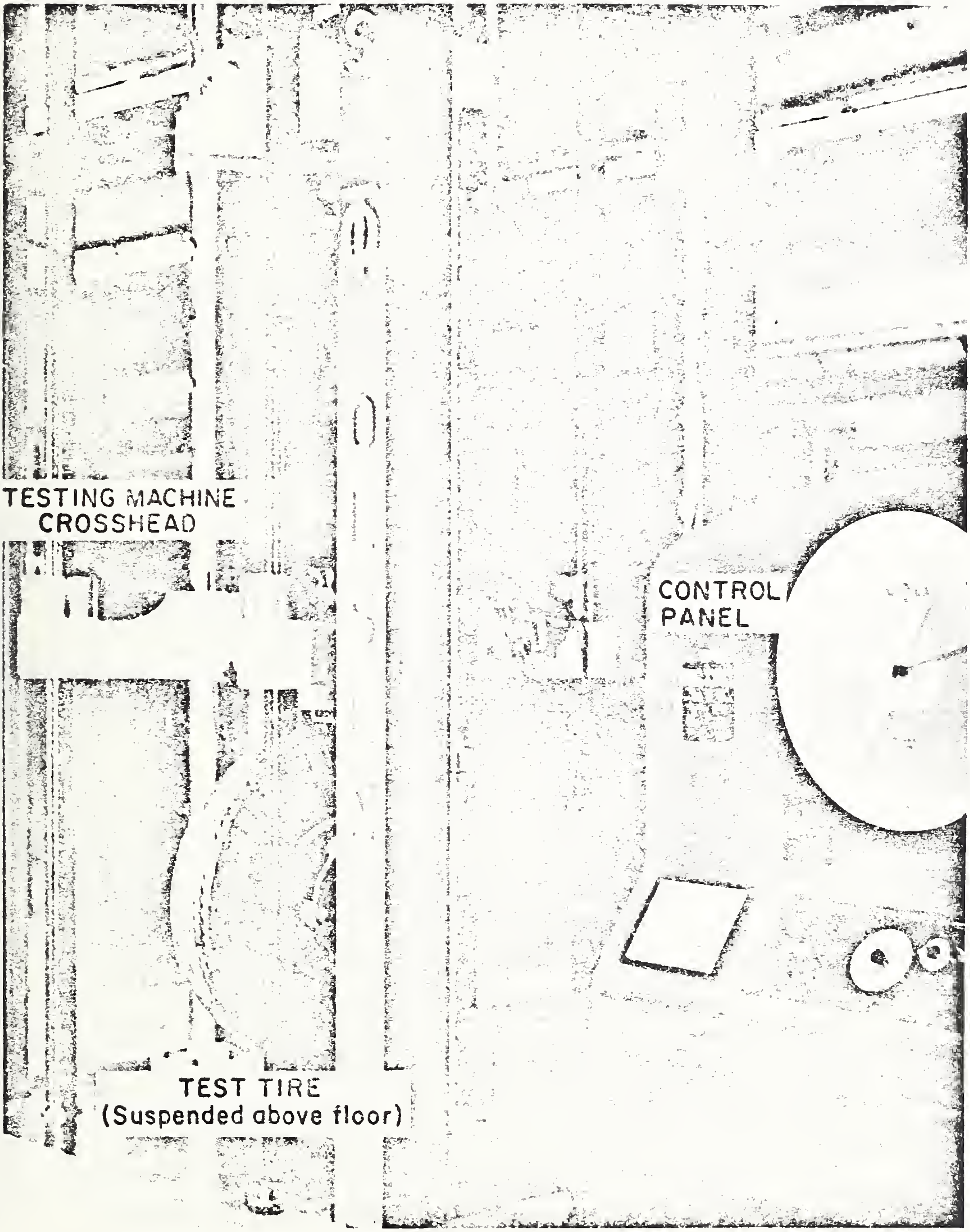


Figure 2. Tinius Olsen universal testing machine with tire mounted for testing.

The tire load was applied to the top of the tire by lowering the loading plate attached to the crosshead of the testing machine. This load was measured using a lever arm-LVDT system and read from the large dial indicator on the control panel. This reading is accurate to within ± 1 percent of the actual load. The crosshead travel of the testing machine was measured with an accuracy of ± 0.054 in. (± 1.372 mm) using the deflectometer attachment mounted as shown in Figure 3. For these tests the crosshead was lowered to apply a small load--less than 10 lb (4.54 kg)--to the tire to ensure contact with the loading plate. This position was assumed to represent zero deflection. The tire was then loaded by further lowering of the crosshead at a speed of 1.5 in./min (0.635 mm/s). When the appropriate load was attained, the crosshead motion was stopped and the tire deflection read from the deflectometer. Figure 4 shows a load applied to a tire and the resultant tire deflection.

For these tests the tire inflation pressure was measured using a spring loaded sliding scale pressure gauge. This particular gauge was chosen so that the same pressure gauge could be used both in the lab and in the field during the acoustic test program. This gauge was checked against calibration standards at NBS and was accurate within ± 1 psi (± 6.9 KPa) for the range of pressures from 20 to 100 psi (0.14 to 0.69 MPa) at 70°F (21°C).

2.2 Test Procedures/Results

a. Varying Load and Inflation Pressure - T&RA

In this test, the tire was inflated to the T&RA recommended pressure and mounted on the testing machine. A compressive load was gradually applied until reaching the maximum rated load for the test inflation pressure at which point the deflection was measured. The load was then removed, the inflation pressure adjusted and the load re-applied. The process was repeated for each combination of load and inflation pressure. The results are shown in Table 3.

b. Constant Inflation

The test tire was inflated to 75 psi (0.52 MPa) for the bias-ply tires and 95 psi (0.66 MPa) for the radial tires and maintained at these pressures throughout the test. A sequence of compressive loads were applied to the tire, and the resulting deflection was recorded for each loading condition. The results are shown in Table 4.

c. Constant Deflection

The maximum rated T&RA loads and inflation pressures were chosen as the reference conditions for maintaining constant deflection. These conditions are 4760 lb (2159 kg) and 75 psi (0.52 MPa) for the bias-ply tires and 5300 lb (2404 kg) and 95 psi (0.66 MPa) for the radial tires. In this test the tire

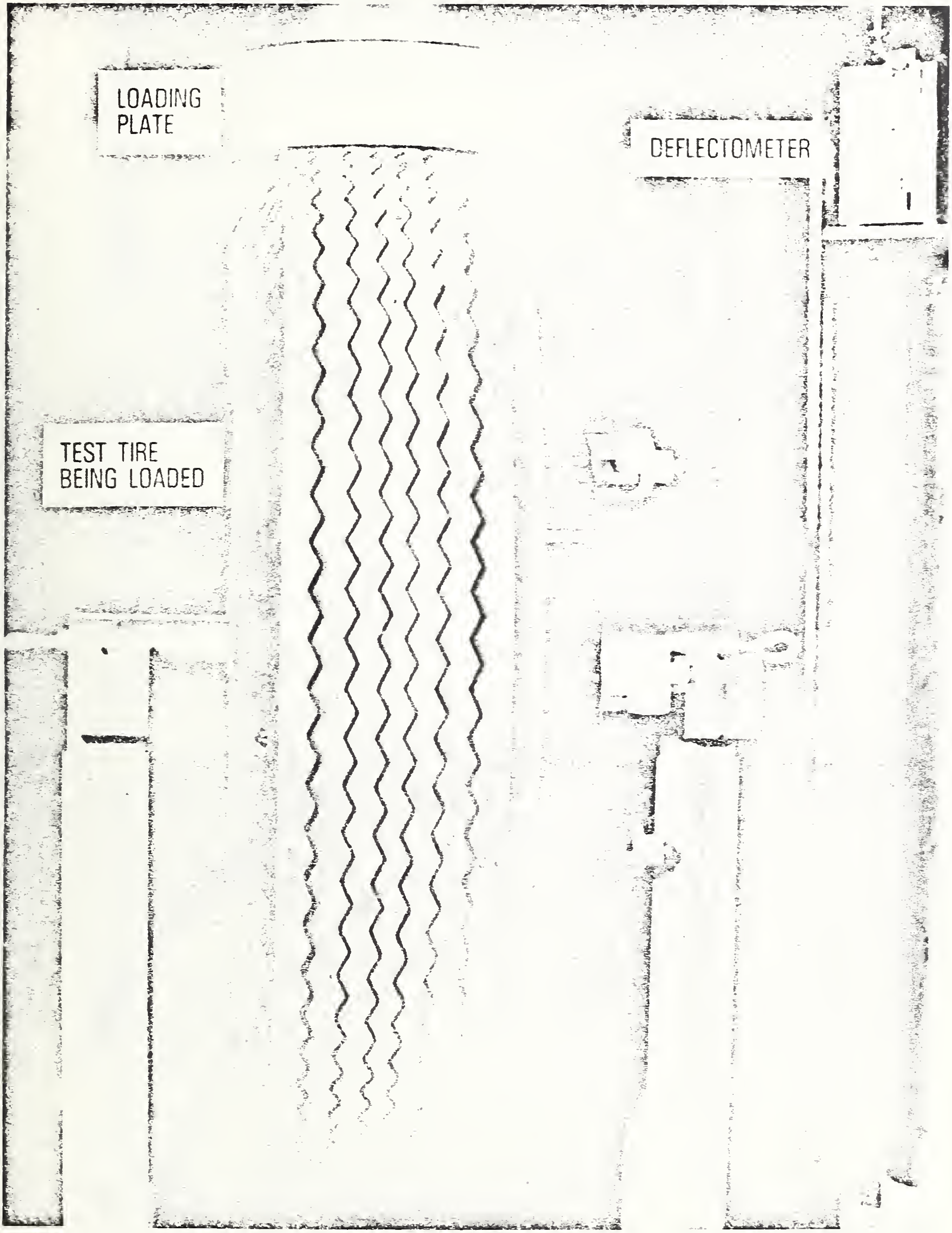


Figure 3. Tire with load being applied showing the deflectometer attachment.

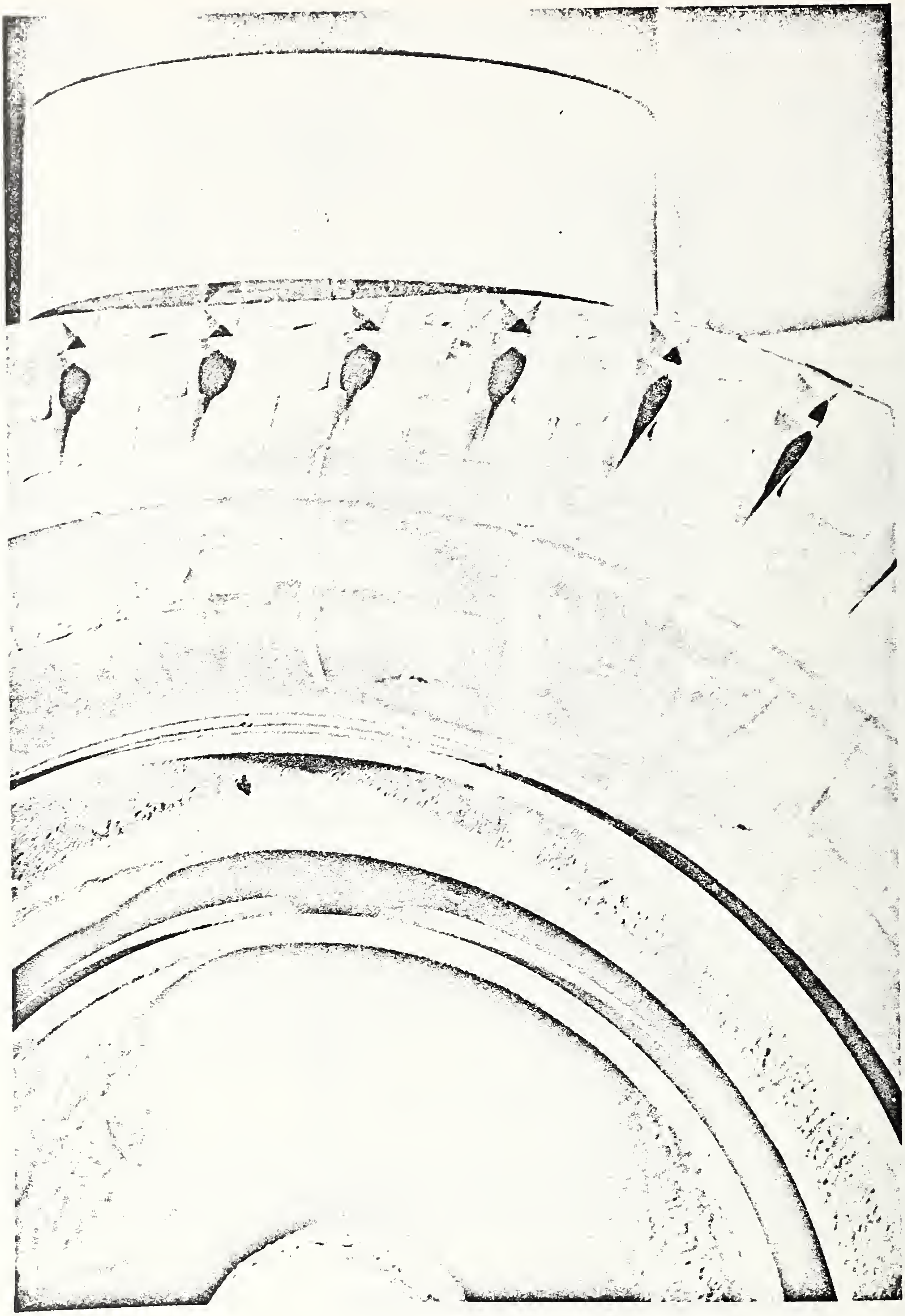


Figure 4. Universal testing machine applying a load to a tire and the resulting tire deflection.

Table 3. Measured deflection of a sample of ten truck tires for a combination of load and inflation pressures based on T&RA recommendations. The means and standard deviations are for the upper test conditions.

Load, lb (kg)	Inflation Pressure, psi (MPa)	TIRE DESIGNATION									
		A	B	C	D	E	F	G	H	I+	J+
		Tire Deflection, inches*									
5300 (2404)	90 (0.62)	X	X	X	X	X	X	X	X	1.43	1.46
5120 (2322)	85 (0.59)	X	X	X	X	X	X	X	X	1.43	1.49
4950 (2245)	80 (0.55)	X	X	X	X	X	X	X	X	1.46	1.52
4760 (2159)	75 (0.52)	1.19	1.09	1.18	1.14	1.15	1.18	1.17	1.22	1.47	1.52
4580 (2077)	70 (0.48)	1.20	1.08	1.13	1.13	1.12	1.14	1.12	1.19	1.47	1.52
4380 (1987)	65 (0.45)	1.14	1.05	1.13	1.13	1.11	1.10	1.14	1.20	1.48	1.55
4180 (1896)	60 (0.41)	1.18	1.06	1.12	1.17	1.12	1.05	1.08	1.19	1.50	1.53
3970 (1801)	55 (0.38)	1.14	1.07	1.12	1.12	1.13	1.02	1.17	1.16	1.51	1.55
3760 (1706)	50 (0.34)	1.15	1.06	1.12	1.13	1.13	0.99	1.14	1.18	1.51	1.54
Mean		1.17	1.07	1.13	1.14	1.13	1.08	1.14	1.19	1.47	1.50
Standard Deviation		0.03	0.01	0.02	0.02	0.01	0.07	0.03	0.02	0.03	0.03
3570 (1619)	50 (0.34)	1.17	1.00	1.07	1.05	0.98	0.94	1.08	1.15	X	X
2650 (1202)	50 (0.34)	X	X	X	X	X	X	X	X	1.18	1.10
2380 (1080)	50 (0.34)	0.89	0.67	0.77	0.80	0.79	0.60	0.77	0.85	X	X

X - No test conducted at this load.

*To minimize the number of values shown in this table, the results are given only in inches. To convert to centimeters multiply by 2.54 cm/in.

+Tests were conducted using the inflation pressures recommended for radial tires which are 5 psi (34.5 KPa) higher for similar loads.

Table 4. Measured deflection of a sample of ten truck tires for eight different loading conditions at a constant inflation pressure of 75 psi (0.52 MPa) for bias-ply tires and 95 psi (0.66 MPa) for radial tires. Deflection rate estimated using linear regression curve fitting.

Load, lb (kg)	TIRE DESIGNATION									
	A	B	C	D	E	F	G	H	I	J
	Tire Deflection, inches*									
5300 (2404)	X	X	X	X	X	X	X	X	1.43	1.46
5120 (2322)	X	X	X	X	X	X	X	X	1.40	1.47
4950 (2245)	X	X	X	X	X	X	X	X	1.37	1.44
4760 (2159)	1.19	1.09	1.18	1.14	1.15	1.18	1.17	1.22	1.33	1.40
4580 (2077)	1.14	1.05	1.15	1.11	1.11	1.15	1.13	1.17	1.30	1.36
4380 (1987)	1.12	1.01	1.12	1.06	1.07	1.13	1.10	1.13	1.26	1.32
4180 (1896)	1.10	0.98	1.08	1.02	1.04	1.11	1.05	1.09	1.22	1.28
3970 (1801)	1.05	0.95	1.04	0.98	1.00	1.13	1.02	1.06	1.17	1.23
3760 (1706)	1.01	0.93	1.01	0.95	0.96	1.11	0.98	1.03	1.13	1.20
3570 (1619)	0.98	0.89	0.98	0.90	0.92	1.09	0.95	0.99	X	X
2650 (1202)	X	X	X	X	X	X	X	X	0.89	0.97
2380 (1080)	0.85	0.65	0.75	0.68	0.78	0.69	0.91	0.64	X	X
Deflection Rate, inches per 1000 pounds load	0.14	0.18	0.18	0.19	0.16	0.19	0.11	0.24	0.20	0.20

X - No test conducted at this load.

* To minimize the number of values shown in this table, the results are given only in inches. To convert to centimeters multiply by 2.54 cm/in.

was inflated to the maximum rated T&RA inflation pressure and mounted on the testing machine. A compressive load corresponding to the maximum rated T&RA load was applied to the tire and the deflection was measured. This deflection was used as the reference value for maintaining constant tire deflection for the other test loads. As the load was reduced to the other load conditions, the tire inflation pressure was reduced to maintain constant deflection. The results of this test are given in Table 5.

d. Tire Footprints

In addition to the deflection and inflation pressure measurements, tire footprints were made for several of the load and inflation pressure conditions. Printing ink was applied to the surface of the tire in the contact region and a sheet of recording paper was placed on the loading surface of the testing machine. Compressive loads were applied to the tire and an inked print (footprint) of the contact area of the tire was obtained. Footprints of tire C for several load and inflation pressure conditions are shown in Figure 5.

2.3 Discussion of Test Results

a. Varying Load and Inflation Pressure -- T&RA

The data given in Table 3 indicate that in general the tire deflection is approximately constant for the range of loads and inflation pressures recommended in the T&RA tables. This is shown by the narrow range of standard deviations listed in the lower portion of Table 3. Also listed in this table are the mean values for the T&RA recommended load and inflation pressure conditions. For this range of loads, the mean deflections for the bias-ply tires range from 1.07 to 1.19 in. (2.72 to 3.02 cm) with a range of standard deviations from 0.01 to 0.07 in. (0.03 to 0.18 cm). For the two radial tires tested, the mean deflections are larger than for the bias-ply tires -- 1.47 and 1.50 in. (3.73 and 3.81 cm) for tires I and J, respectively. Although larger, the deflection for the two radial tires is still approximately constant for the range of loads tested. Thus, the SAE J57a alternatives of adjusting the inflation pressure according to the T&RA tables can be assumed to give approximately constant tire deflection for loads greater than 75 to 80 percent of the maximum rated load.

The variations which were measured can be easily understood when one considers that the T&RA load/inflation pressure tables are generated using an empirical equation -- designed to provide constant tire deflection -- that expresses tire load as a function of inflation pressure, tire and rim dimensional characteristics and an appropriate load factor based on the general type of tire construction and usage (single or dual) [15]. This

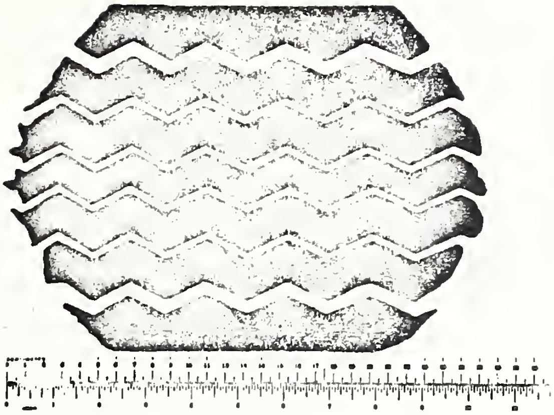
Table 5. Measured inflation pressure required to maintain constant tire deflection under different loading conditions for a sample of ten truck tires. The mean and standard deviations are for the eight bias-ply test tires.

Reference Deflection* in. (cm)	TIRE DESIGNATION										Bias-Ply Tires Only Mean (Standard Deviation)	T&RA Tables	
	A 1.19 (3.02)	B 1.09 (2.77)	C 1.18 (3.00)	D 1.14 (2.90)	E 1.15 (2.92)	F 1.18 (3.00)	G 1.17 (2.97)	H 1.22 (3.10)	I 1.43 (3.63)	J 1.46 (3.71)		Bias-Ply	Radial
Load, lb (kg)	Tire Inflation Pressure, psi**												
5300 (2404)	X	X	X	X	X	X	X	X	95	95	X	90	95
5120 (2322)	X	X	X	X	X	X	X	X	92	93	X	85	90
4950 (2245)	X	X	X	X	X	X	X	X	89	90	X	80	85
4760 (2159)	75	75	75	75	75	75	75	75	86	86	75	75	80
4580 (2077)	71	71	72	70	72	71	72	71	82	82	71.3 (0.7)	70	75
4380 (1987)	68	68	68	68	68	69	69	68	79	79	68.3 (0.5)	65	70
4180 (1896)	63	64	63	64	64	64	65	64	75	76	63.9 (0.6)	60	65
3970 (1801)	59	59	60	60	60	60	61	60	70	71	59.9 (0.6)	55	60
3760 (1706)	55	55	55	56	58	56	57	57	66	66	56.1 (1.1)	50	55
3570 (1619)	51	51	52	52	50	53	53	53	X	X	51.9 (1.1)	50	55
2650 (1202)	X	X	X	X	X	X	X	X	43	43	X	50	55
2380 (1080)	29	29	30	30	31	31	30	31	X	X	30.1 (0.8)	50	55

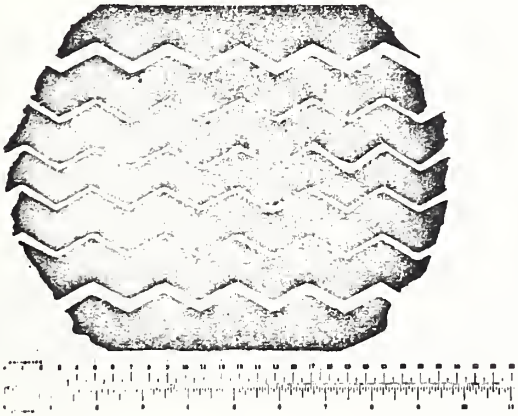
X - No Test conducted at this load.

* Reference deflection corresponds to deflection at maximum rated load and inflation pressure: 4760 lb (2159 kg) and 75 psi (0.52 MPa) for the bias-ply tires and 5300 lb (2404 kg) and 95 psi (0.66 MPa) for the radial tires.

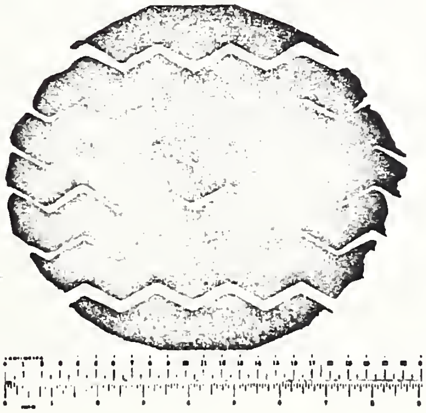
** To minimize the number of values shown in this table, the results are given only in psi. To convert to Pascals multiply by 6894.8 Pa/psi.



(a) 4760 lb (2159 kg), 75 psi (0.52 MPa)



(b) 3570 lb (1619 kg), 50 psi (0.34 MPa)



(c) 2380 lb (1080 kg), 50 psi (0.34 MPa)

Figure 5. Footprints of tire C (bias-ply rib) for various load and inflation pressure conditions based on T&RA recommendations.

equation is applied to a wide variety of tire types produced by the different manufacturers. Thus, it is not surprising that there are slight variations of the actual measured deflections using the T&RA tables.

b. Constant Inflation

As expected, tire deflection increases with tire load. The constant inflation pressure data given in Table 4 show that the increase of deflection with load, or deflection rate, is approximately constant over the load range of interest. The linear regression curve fit indicates an increase of deflection with load ranging from 0.11 to 0.24 in. per 1000 lb load (0.28 to 0.70 cm per 453.6 kg). The deflection rate is slightly larger for the two radial tires than for most of the bias-ply tires -- an average value of 0.20 versus 0.17 in. per 1000 lb (0.51 versus 0.44 cm per 453.6 kg) for radial versus bias-ply. Other comparisons -- new versus recap bias-ply and new rib versus new cross-bar bias-ply -- show little difference in the deflection rate based on the averages for these groupings.

c. Constant Deflection

In general, the inflation pressures required to maintain constant tire deflection shown in Table 5 do not agree with the corresponding T&RA recommendations. The measured inflation pressures are greater than those recommended by T&RA with the difference between the average and T&RA values increasing from the pre-established value of zero at the maximum recommended conditions to over 6 psi (41.4 KPa) for the bias-ply tires and 11 psi (75.8 KPa) for the radial tires at 3760 lb (1706 kg). As mentioned in the discussion of Section 2.3a, the T&RA load/inflation pressure tables are derived from an empirical load equation designed to provide constant tire deflection. Since this equation is applied to a wide variety of tire types, it is not surprising that there are variations between the recommended and measured inflation pressures.

Another possible explanation for the higher inflation pressures pertains to the techniques used in conducting this portion of the test. For the T&RA deflection measurements (Table 3), the load was removed between the different load settings, while for the constant deflection measurements (Table 5), it was not. As a consequence of not removing the load, the friction between the tire and loading plate prevented the tire footprint from reconforming. As a result, the tire deflections were larger for the same load conditions. For example, consider tire C at a load of 4380 lb (1987 kg). From Table 3, the inflation pressure and deflection are 65 psi (0.45 MPa) and 1.13 in. (2.87 cm), respectively, whereas from Table 5 they are 68 psi (0.47 MPa) and 1.18 in. (3.00 cm). Thus, rather than a lower inflation pressure for a larger deflection as would be expected, the inflation pressure is higher. The mechanism which causes this to occur is illustrated in Figure 6. When the load is removed, the inflation pressure decreased and a smaller load reapplied to the tire, points A and B change to the positions shown on the right. If the load is not removed, points A and

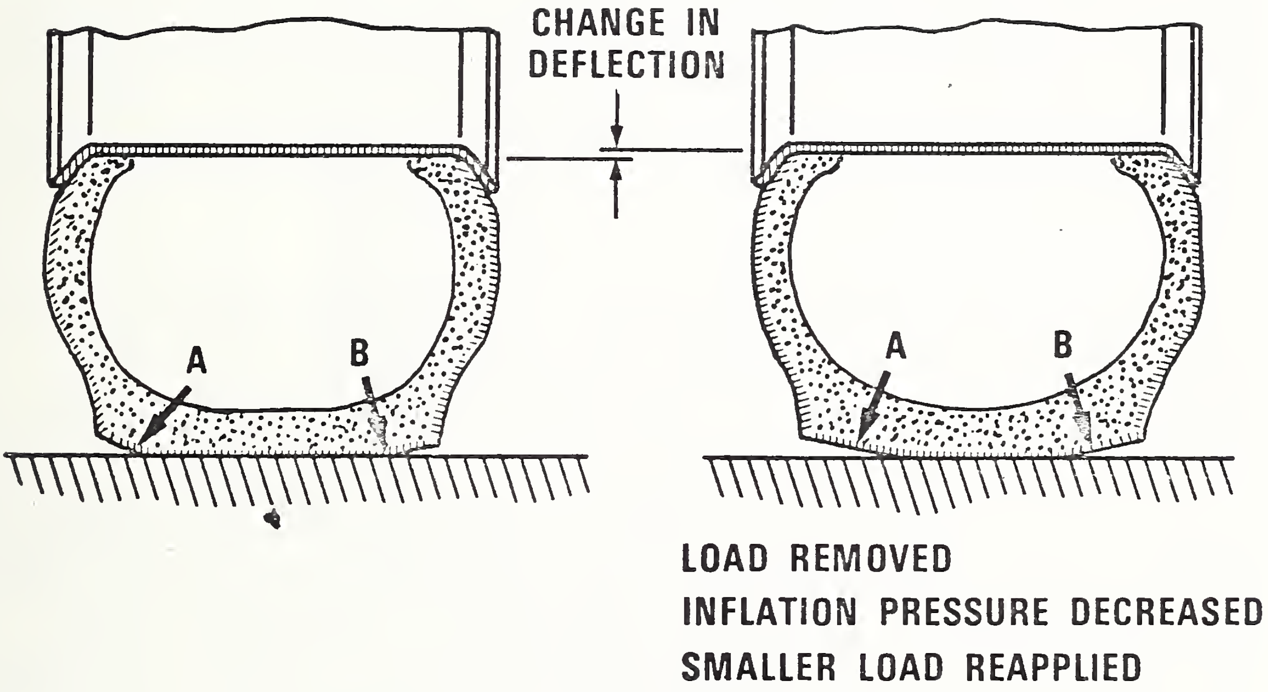


Figure 6. Sketch of tire cross section illustrating the mechanism causing the constant deflection tire inflation pressures to be higher than the T&RA recommended values.

B tend to stay in contact with the loading surface because of friction. As a result, higher inflation pressures are required to maintain the same deflection.[6]

Even if these variations do exist, this is not necessarily a problem. Although a strict comparison of the data shown in Tables 3 and 5 cannot be made because of the differences in the test procedures discussed above, these data indicate that relatively large changes in inflation pressure on the order of 3 to 5 psi (20.7 to 34.5 KPa) result in relatively small changes in tire deflection on the order of 0.02 to 0.05 in. (0.05 to 0.13 cm). Thus, even though adjusting the inflation pressure according to T&RA recommendations might not truly provide constant tire deflection, the variation of tire deflection from that at the maximum recommended conditions would be relatively small. This would be acceptable provided that the tire sound levels are not significantly affected by these small changes of tire deflection. Also, this would indicate that adjustment of the inflation pressure within ± 2 psi (± 13.8 KPa) would be adequate. This tolerance would greatly simplify setting up the proper test conditions when conducting measurements in the field.

d. Tire Footprints

Tire footprints, such as those shown in Figure 5, were obtained for the load and inflation pressure conditions listed in Table 6. In this table the gross contact areas -- the area inside the perimeter of the contact patch including the open tread elements -- are given for each of these footprints. These gross contact areas were measured using a rolling disk planimeter.

The tire footprints shown in Figure 5 correspond to 100, 75 and 50 percent of the maximum rated load with T&RA recommended inflation pressures of 75, 50 and 50 psi (0.52, 0.34 and 0.34 MPa), respectively. The first two load and inflation pressure conditions give approximately the same tire deflection and as shown by the data in Table 6 approximately the same overall contact patch area -- 65.8 and 64.7 in.^{2} (424.5 and 417.4 cm^2). Reduction of the load to 2380 lb (1080 kg) while holding the inflation pressure at 50 psi (0.34 MPa) results in a much smaller tire deflection and a corresponding decrease in the gross contact area to 52.4 in^2 (338.1 cm^2).

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[6] This hypothesis was suggested by Dr. George R. Thurman formerly of the Firestone Tire and Rubber Company (retired) [16]. Dr. Thurman had noticed similar discrepancies when conducting deflection measurements and found that if the tire/loading plate interface was lubricated, these differences were for all practical purposes eliminated. Since this was suggested after the tests had been completed and the tires returned, this hypothesis could not be verified.

Table 6. Gross contact areas for various load and inflation pressure conditions.

LOAD, lb (kg)	INFLATION PRESSURE, psi (MPa)	TIRE DESIGNATION A	B	C	D	E	F	G	H	I+	J+	TEST CONDITION
		GROSS CONTACT PATCH AREA, square inches*										
5300 (2404)	90 (0.62)	X	X	X	X	X	X	X	X	73.7	69.0	T&RA
4760 (2159)	75 (0.52)	79.5	67.3	65.8	70.7	69.5	71.4	69.7	74.9	73.4	70.9	
3970 (1801)	55 (0.38)	X	X	X	X	X	X	X	X	74.6	72.4	
3570 (1619)	50 (0.34)	75.3	65.9	64.7	66.2	68.6	69.9	65.7	72.1	X	X	
2650 (1202)	50 (0.34)	X	X	X	X	X	X	X	X	58.1	56.5	
2380 (1080)	50 (0.34)	55.7	49.1	52.4	50.8	50.9	55.6	51.4	55.0	X	X	
4760 (2159)	75 (0.52)			65.8								CONSTANT DEFLECTION
4180 (1896)	63 (0.43)			65.2								
3570 (1619)	52 (0.36)			61.9								
2380 (1080)	30 (0.21)			59.2								
	Tire C Tire I											
5300 (2404)	X 95 (0.66)			X						73.7		CONSTANT INFLATION
5120 (2322)	X 95 (0.66)			X						71.4		
4760 (2159)	75 (0.52) 95 (0.66)			65.8						67.4		
4380 (1987)	X 95 (0.66)			X						64.7		
4180 (1896)	75 (0.52) X			63.5						X		
3970 (1801)	X 95 (0.66)			X						59.9		
3570 (1619)	75 (0.52) X			57.4						X		
2650 (1202)	X 95 (0.66)			X						46.1		
2380 (1080)	75 (0.52) X			43.6						X		

X - No test conducted at this load.

*To minimize the number of values shown in the table, the results are given only in square inches. To convert to square centimeters multiply by 6.45 cm^2/in^2

+T&RA tests were conducted using the inflation pressures recommended for radial tires which are 5 psi (34.5 KPa) higher for similar loads.

For constant tire deflection the gross contact area decreases slightly for the two smaller loads, but it is essentially constant -- within ± 6 percent of the mean value of 63.0 in^2 (406.6 cm^2). This agrees with the results presented in reference [17] which indicate that if inflation pressure and load are simultaneously varied to maintain constant tire deflection, the contact area of the tire will remain effectively constant. [It should be noted that when the tire footprints are made the load is removed so that a piece of recording paper can be placed between the loading plate and tire. Thus, the problem of tire adhesion to the loading plate affecting the footprint, as illustrated in Figure 6, is not a problem.]

For constant inflation pressure and varying load, the gross contact area for tire C (bias-ply rib) decreases linearly with decreasing load from 65.8 $in.^2$ (424.5 cm^2) at 4760 lb (2159 kg) to 43.6 $in.^2$ (281.3 cm^2) at 2380 lb (1080 kg). Based on linear regression curve fitting, this decrease is approximately 10 $in.^2$ per 1000 lb load (64.5 cm^2 per 453.6 kg). The same is also true for Tire I (radial rib) where the gross contact area linearly decreased by approximately 10 $in.^2$ per 1000 lb load (64.5 cm^2 per 453.6 kg).

The objective of this portion of the program was to investigate the relationship between load, inflation pressure and tire deflection for a sample of truck tires. The significance of these data depends upon how the measured sound levels vary with these parameters. The acoustic data are presented in the next section.

3. ACOUSTICAL MEASUREMENT PROGRAM

The operational procedures and measurement/analysis instrumentation utilized in this load/deflection study were similar to that used in previous DOT/NBS truck tire noise studies. Data were obtained for a set of rib and of cross-bar tires of bias-ply design -- tires A and B of Table 1, respectively.

The test procedure utilized was essentially identical to that specified in SAE J57a; however, the following exceptions should be noted:

- "Fast" meter response was utilized.
- The hard surface (vehicle path and measurement area) was sealed asphalt.
- The distance between the point of entrance and point of exit of the test section was 600 feet (182.9 m).
- Mud flaps were left on the vehicle during testing.

Detailed descriptions are provided of the vehicle configurations, test tires, the field test site utilized for data acquisition and the operational test procedure in Appendix B.

3.1 Acoustical Measurement Results

Measurements were made for test runs with the load and inflation pressure conditions shown in Table 7. To reduce the total number of test runs, fewer load conditions were tested than were discussed in Section 2. The inflation pressure data shown for the constant deflection conditions are the values given in Table 5 for tires A and B. For these tests the inflation pressures were set to the desired value and the vehicle run for a minimum of ten miles to allow the tires to warm up. The vehicle was then stopped and the inflation pressures were again adjusted to the desired value. Immediately following this, the acoustic measurement test runs were made. A minimum of two test runs were made for each of these conditions.

The data for these test runs, which consisted of the maximum A-weighted sound level for each coastby, are presented in Tables 8 and 9 for tires A and B, respectively. The data for each run are adjusted to 50 mph (80.5 km/hr) using a 40 log V relationship between sound level and vehicle speed [18] and then averaged for each test condition.

The data for the conditions of constant tire deflection and T&RA recommended inflation pressure are plotted in Figure 7 as the maximum A-weighted sound level versus tire load in terms of percent of maximum rated tire load. As can be seen in Figure 7, the results obtained following the T&RA recommendations are quite similar to those obtained by maintaining constant tire deflection for both types of tire. For the rib tire (tire A), the test results at the alternate load/ inflation pressure conditions are within ± 0.5 dB of the sound level at maximum rated load and inflation pressure for loads greater than 75 percent, indicating little sensitivity to load or inflation pressure. For the cross-bar tire (tire B) the data are within ± 1.5 dB of the sound level at maximum rated load and inflation pressure. Thus, both alternative loading procedures can introduce variations relative to the values at the maximum rated load and inflation pressure.

As an alternative to adjusting the inflation pressure to correspond to either T&RA recommendations or constant tire deflection, measurements were made for constant inflation pressure and varying load. These data are plotted in Figure 8. The variations of the sound levels from the values at the maximum rated load and inflation pressure are +0.2 to -0.3 dB for tire A and 0 to -0.7 dB for tire B for loads greater than 70 to 75 percent of the maximum rated load. These variations are less than those observed for similar loading when the inflation pressures were adjusted. Thus it appears that based on this set of data, if reduced loading is necessary to

Table 7. Nominal and actual load and inflation pressure conditions utilized in the load deflection study.

Load, lb*							Tire Inflation Pressure, psi**			
Total Gross Vehicle Weight	Steering Axle	Drive Axle	Actual Load Per Test Tire		Nominal Load Per Test Tire		T&RA Tables	Constant Inflation Pressure	Constant Tire Deflection	
			lb	Percent Maximum Rated Tire Load	lb	Percent Maximum Rated Tire Load			Tire A	Tire B
25,854	6,684	19,170	4793	100.7	4760	100.0	75	75	75	75
24,343	6,840	17,503	4376	91.9	4380	92.0	65	75	68	68
22,852	7,020	15,832	3958	83.2	3970	83.4	55	75	59	59
21,539	7,234	14,305	3576	75.1	3570	75	50	75	51	51
16,390	6,920	9,470	2368	49.7	2380	50.0	50	75	29	29

* To convert the load in pounds to kilograms divide by 2.2046 lb/kg.

** To convert psi to Pascals multiply by 6894.8 Pa/psi.

Table 8. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for coastbys at a nominal speed of 50 mph (80.5 km/hr) over an asphalt surface for tire A (bias-ply rib tire). These data are adjusted to exactly 50 mph (80.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then averaged for the two test runs.

LOAD PER TIRE lb (kg)	TEST RUN NUMBER	TIRE & RIM ASSOCIATION RECOMMENDATIONS					CONSTANT DEFLECTION					CONSTANT INFLATION [75 psi (0.52 MPa)]			
		Inflation Pressure psi (MPa)	Vehicle Speed mph (km/hr)	Maximum A-Weighted Sound Level, dB re 20 μPa			Inflation Pressure psi (MPa)	Vehicle Speed mph (km/hr)	Maximum A-Weighted Sound Level, dB re 20 μPa			Vehicle Speed mph (km/hr)	Maximum A-Weighted Sound Level, dB re 20 μPa		
				Measured	Adjusted to 50 mph (80.5 km/hr)	Average of runs			Measured	Adjusted to 50 mph (80.5 km/hr)	Average of runs		Measured	Adjusted to 50 mph (80.5 km/hr)	Average of runs
4793	1	75 (0.52)	50 (80.5)	74.3	74.3	74.2	75 (0.52)	50 (80.5)	74.3	74.3	74.2	50 (80.5)	74.3	74.3	74.2
(2174)	2		50 (80.5)	74.2	74.2			50 (80.5)	74.2	74.2		50 (80.5)	74.2	74.2	
4376	1	65 (0.45)	50 (80.5)	74.4	74.4	73.8	68 (0.47)	50 (80.5)	74.8	74.8	74.7	49 (78.9)	74.2	74.6	74.5
(1985)	2		51 (82.1)	73.6	73.3			49 (78.9)	74.2	74.6		51 (82.1)	74.6	74.3	
3958	1	55 (0.38)	50 (80.5)	73.6	73.6	73.7	59 (0.41)	49 (78.9)	74.0	74.4	74.1	50 (80.5)	75.0	75.0	74.4
(1795)	2		50 (80.5)	73.8	73.8			50 (80.5)	73.8	73.8		50 (80.5)	73.8	73.8	
3576	1	50 (0.34)	49 (78.9)	73.2	73.6	74.3	51 (0.35)	50 (80.5)	74.4	74.4	74.3	50 (80.5)	74.2	74.2	74.0
(1622)	2		50 (80.5)	75.0	75.0			50 (80.5)	74.2	74.2		51 (82.1)	74.0	73.7	
2368	1	50 (0.34)	50 (80.5)	74.8	74.8	73.9	29 (0.20)	49 (78.9)	71.8	72.2	72.6	49 (78.9)	74.2	74.6	74.5
(1074)	2		50 (80.5)	73.0	73.0			49 (78.9)	72.6	73.0		50 (80.5)	74.4	74.4	

Table 9. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), for coastbys at a nominal speed of 50 mph (80.5 km/hr) over an asphalt surface for tire B (bias-ply cross-bar tire). These data are adjusted to exactly 50 mph (80.5 km/hr) using a 40 log V relationship between sound level and vehicle speed and then averaged for the two test runs.

LOAD PER TIRE lb (kg)	TEST RUN NUMBER	TIRE & RIM ASSOCIATION RECOMMENDATIONS					CONSTANT DEFLECTION					CONSTANT INFLATION [75 psi (0.52 MPa)]			
		Inflation Pressure psi (MPa)	Vehicle Speed mph (km/hr)	Maximum A-Weighted Sound Level, dB re 20 μPa			Inflation Pressure psi (MPa)	Vehicle Speed mph (km/hr)	Maximum A-Weighted Sound Level, dB re 20 μPa			Vehicle Speed mph (km/hr)	Maximum A-Weighted Sound Level, dB re 20 μPa		
				Measured	Adjusted to 50 mph (80.5 km/hr)	Average of runs			Measured	Adjusted to 50 mph (80.5 km/hr)	Average of runs		Measured	Adjusted to 50 mph (80.5 km/hr)	Average of runs
4793	1	75 (0.52)	50 (80.5)	80.8	80.8	80.4	75 (0.52)	50 (80.5)	80.8	80.8	80.4	50 (80.5)	80.8	80.8	80.4
(2174)	2		50 (80.5)	80.0	80.0			50 (80.5)	80.0	80.0		50 (80.5)	80.0	80.0	
4376	1	65 (0.45)	49 (78.9)	78.6	79.0	79.2	68 (0.47)	50 (80.5)	79.4	79.4	79.2	49 (78.9)	79.0	79.4	79.7
(1985)	2		49 (78.9)	79.0	79.4			50 (80.5)	79.0	79.0		50 (80.5)	80.0	80.0	
3958	1	55 (0.38)	49 (78.9)	79.6	80.0	79.8	59 (0.41)	48 (77.3)	79.2	79.9	81.1	49 (78.9)	80.4	80.8	80.4
(1795)	2		49 (78.9)	79.2	79.6			50 (80.5)	81.2	81.2		50 (80.5)	80.0	80.0	
3576	1	50 (0.34)	48 (77.3)	80.4	81.1	82.0	51 (0.35)	48 (77.3)	81.4	82.1	81.8	49 (78.9)	79.8	80.2	79.6
(1622)	2		49 (78.9)	82.4	82.8			49 (78.9)	81.0	81.4		51 (82.1)	79.4	79.1	
2368	1	50 (0.34)	50 (80.5)	80.2	80.2	79.8	29 (0.20)	48 (77.3)	78.0	78.7	79.9	52 (83.7)	79.6	78.9	78.8
(1074)	2		50 (80.5)	79.4	79.4			48 (77.3)	80.4	81.1		50 (80.5)	78.8	78.8	

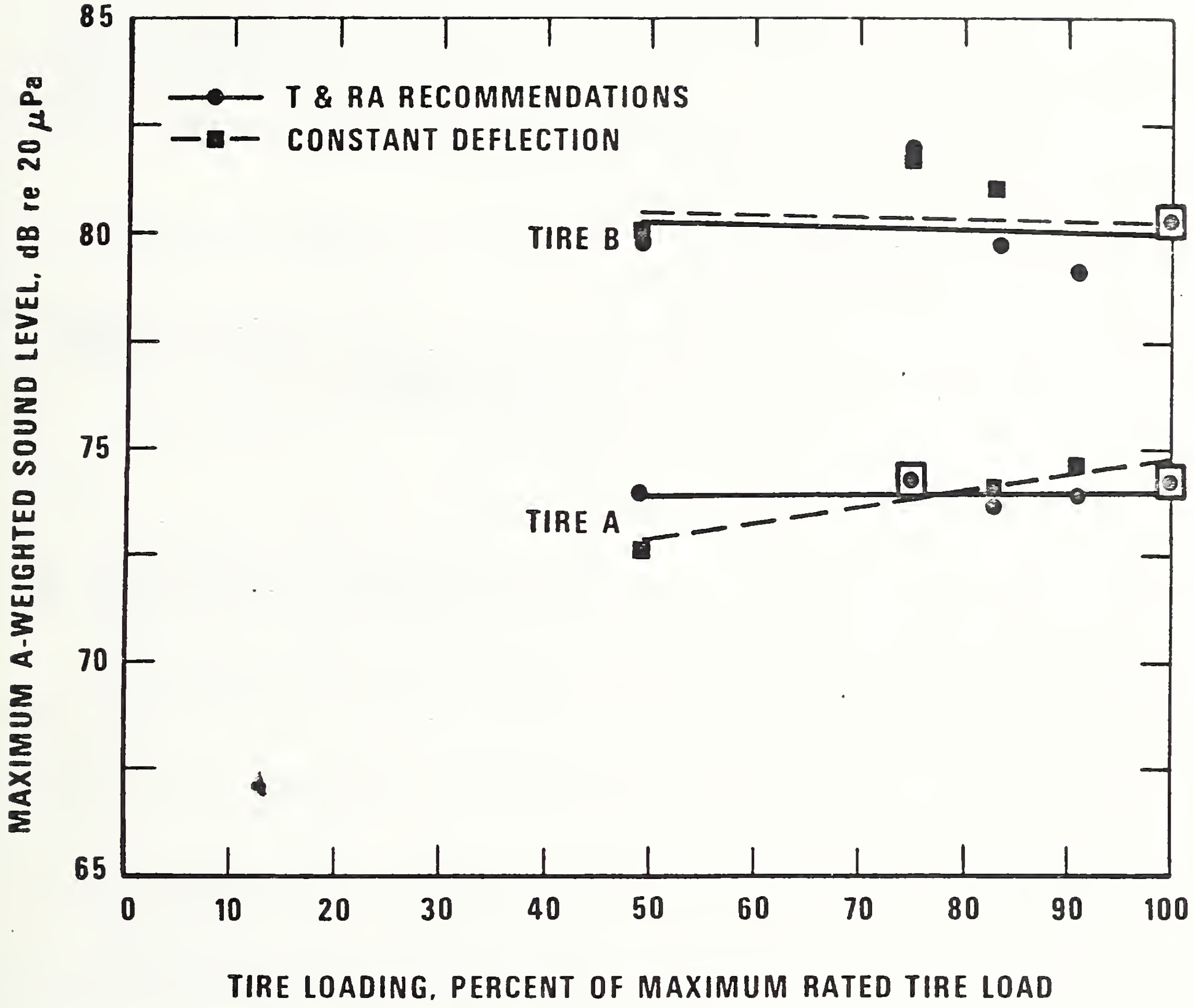

Figure 7. Maximum A-weighted sound levels, as measured at 50 feet (15.2m), versus tire load for various inflation pressures. These data correspond to vehicle coastbys at 50 mph (80.5 km/hr) on an asphalt surface.

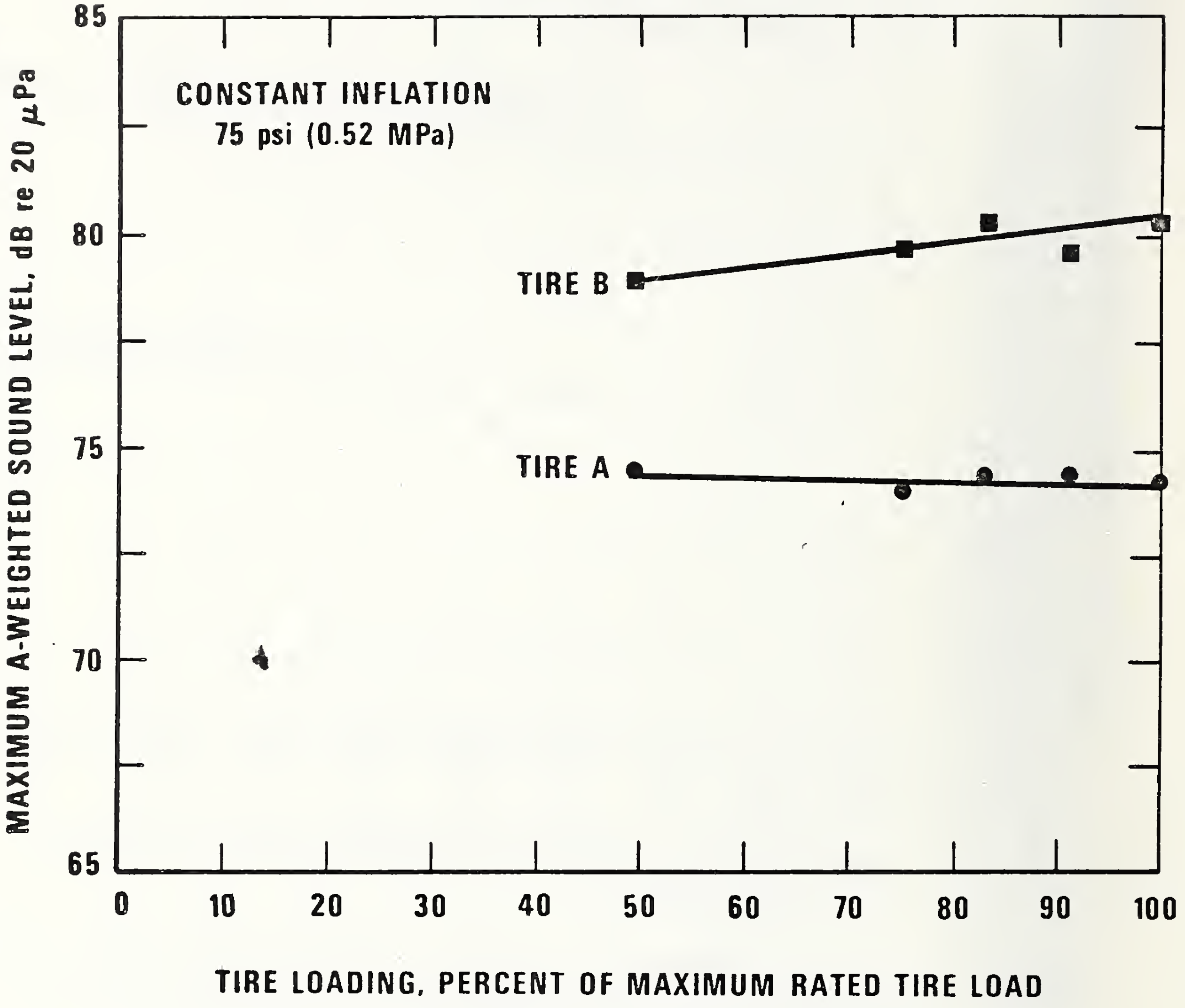

Figure 8. Maximum A-weighted sound levels, as measured at 50 feet (15.2 m), versus tire load for constant inflation pressure. These data correspond to vehicle coastbys at 50 mph (80.5 km/hr) on an asphalt surface.

comply with local load limits, testing can be performed using the maximum inflation pressure without encountering serious errors, provided that the loads are greater than 70 to 75 percent of the maximum rated tire load. This would be more convenient and practical since this essentially represents the typical in-service case where the load varies between trips but the tire inflation pressure is maintained at a constant value.

3.2 Conclusions

Based on the data presented in this report the following conclusions can be made:

- For tire loads greater than 70 to 75 percent of the maximum rated loads, smaller variations of the measured sound level were observed when maintaining constant inflation pressure than when adjusting the inflation pressure to correspond to either T&RA recommendations or constant tire deflection.

- The load/inflation pressure adjustments recommended in SAE J57a -- constant tire deflection and T&RA recommendations -- induced variations in the resulting sound level from those at the maximum rated load and inflation pressure on the order of ±0.5 dB for the bias-ply rib tire and ±1.5 dB for the bias-ply cross-bar tire which were tested. Thus, use of these alternative loading conditions can introduce variations relative to the values at the maximum rated load and inflation pressure.

- The T&RA tables give load and inflation pressure combinations which give approximately constant tire deflection.

- Tire deflection is relatively insensitive to small changes of inflation pressure. Changes in inflation pressure from 3 to 5 psi (20.7 to 34.5 KPa) produce changes in tire deflection on the order of 0.02 to 0.05 in. (0.51 to 1.27 mm).

4. APPENDIX A. SAE RECOMMENDED PRACTICE FOR MEASUREMENT OF TRUCK TIRE NOISE[7]

SOUND LEVEL OF HIGHWAY TRUCK TIRES—SAE J57a

SAE Recommended Practice

Report of Vehicle Sound Level Committee approved July 1971 and last revised June 1976. Approved by American National Standards Institute November 1976. Rationale Statement available

1. Introduction—This SAE Recommended Practice establishes a test procedure for measuring the sound level produced by tires intended primarily for highway use on motor trucks, truck tractors, trailers and semitrailers, and buses. The procedure provides for the measurement of the sound generated by a set of test tires, mounted on the rear axle operated at 80 km/h (50 mph) and at maximum rated tire load.

Specifications for the instrumentation, the test site, and the operation of the test vehicle are set forth to minimize the effects of extraneous sound sources and to define the basis of reported sound levels.

Factors influencing sound level measurement and reference to sound levels are given in the Appendix.

2. Instrumentation—The following instrumentation shall be used for the measurements as required:

2.1 A sound level meter which satisfies the Type 1 requirements of American National Standard Specification for Sound Level Meters, S1.4-1971.

2.1.1 As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter may be used with a magnetic tape recorder and/or a graphic level recorder or other indicating instrument, providing the system meets the requirements of SAE J184, Qualifying a Sound Data Acquisition System, with slow response specified in place of fast response as applicable to paragraph 3.6 therein.

ϕ 2.2 An acoustical calibrator, having an accuracy of ±0.5 dB, for establishing the calibration of the sound level meter and associated instrumentation.

ϕ 2.3 An anemometer having an accuracy of ±10% at 19 km/h (12 mph).

3. Test Site

3.1 The test site shall be located on a flat area which is free of reflecting surfaces (other than the ground), such as parked vehicles, trees, or buildings within 30 m (100 ft) of the measurement area.

3.2 The vehicle path shall be relatively smooth, semipolished, dry, Portland cement concrete which is free of extraneous surface material.

3.3 The microphone shall be located 15 m (50 ft) from the centerline of the vehicle path at a height of 1.2 m (4 ft) above the ground plane. The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path. See Fig. 1.

3.4 The test zone extends 15 m (50 ft) on either side of the microphone point along the vehicle path. The measurement area is the triangular area formed by the point of entrance into the test zone, point of exit from the test zone, and the microphone.

3.5 The measurement area should be surfaced with concrete, asphalt, or similar hard material and, in any event, shall be free of snow, grass, soil, ashes, or other sound-absorbing materials.

3.6 The ambient sound level (including wind effects) at the test site shall be at least 10 dB below the level of the test vehicle operated in accordance with the test procedure.

3.7 The wind speed in the measurement area shall be less than 19 km/h (12 mph).

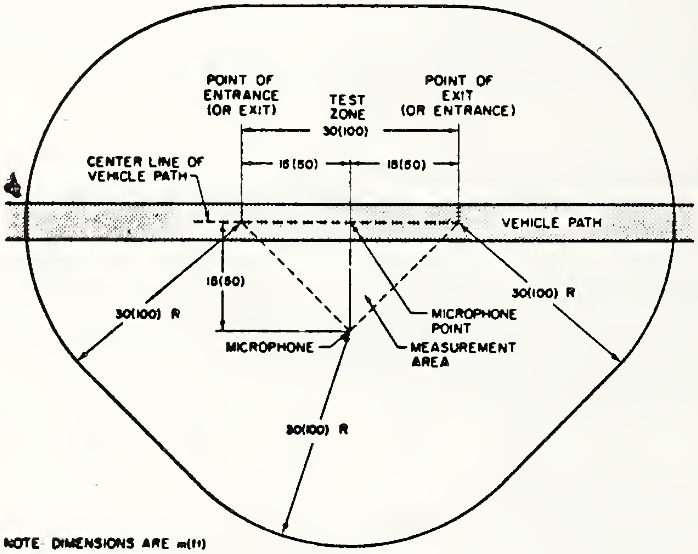

FIG. 1—TEST SITE (SEE PARAGRAPH 3). (VEHICLE MAY BE RUN IN EITHER DIRECTION)

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4. Test Vehicle

4.1 The vehicle shall be a motor truck equipped with two axles (a nonpowered steering axle and a powered axle).

4.2 The vehicle shall have a platform, rack, or van body capable of retaining the loading or ballast. This body shall have an essentially flat and horizontal undersurface, and be mounted such that this surface has a 230 ± 100 mm (9 ± 4 in) clearance with the tire fully loaded. This body shall be nominally 2440 mm (96 in) in width and extend a minimum of 910 mm (36 in) rearward of the rear (powered) axle centerline.

4.3 Mud flaps should be removed at the test site, if permissible.

5. Tires

5.1 Tires used for dual installations shall be dual mounted (four tires) on the rear axle for testing. Tires used in single installations (wide base) shall be mounted singly. A tire used as both duals and singles may require test at both dual and single mounting. The sound level reported must be identified as to type of mounting.

5.2 The tires shall be inflated to the maximum pressure and loaded to the maximum load specified by the Tire and Rim Association for continuous operation at highway speeds exceeding 80 km/h (50 mph).

5.2.1 If local load limits will not permit full rated load, the test may be conducted at the local load limit with inflation pressure reduced to provide a tire deflection equal to the maximum load and inflation pressure, provided the load is not less than 75% of the maximum rated load.

As an alternative, the pressure in the tires can be adjusted to correspond to the actual load following the appropriate load/pressure tables in the Tire and Rim Association Yearbook. Because the choice of procedure may cause small differences in level, such levels shall not be reported unless they are identified with the percent load used.

5.3 Quiet tires are recommended for use on the front axle.

6. Procedure

6.1 The test vehicle shall be operated in such a manner (such as coasting) that the sound level due to the engine and other mechanical sources is minimized throughout the test zone. The vehicle speed at the microphone point shall be 80 km/h (50 mph).

6.2 The sound level meter shall be set for slow dynamic response and the A-weighting network. The observer shall record the highest level attained during each pass of the test vehicle, excluding readings where known acoustical interferences have occurred.

6.2.1 Alternatively, each pass of the test vehicle may be recorded on magnetic tape and subsequently analyzed with a sound level meter and/or graphic level recorder.

6.3 There shall be at least three measurements. The number of measurements shall equal or exceed the range in decibels of the levels obtained.

6.4 The sound level reported shall be the average of the two highest readings which are within 2 dB of each other.

7. General Comments

7.1 It is recommended that technically competent personnel select the equipment to be used for the test measurements and that these tests be conducted only by persons familiar with the current techniques of sound measurement.

7.2 All instrumentation should be operated according to the practices recommended in the operating manuals or other literature provided by the manufacturer. All stated precautions should be observed. Some specific items for consideration are:

7.2.1 Specifications for orientation of the microphone relative to the ground plane and the source of sound should be adhered to. (Assume that the sound source is located at the microphone point.)

7.2.2 Proper signal levels, terminating impedances, and cable lengths should be maintained on all multi-instrument measurement systems.

7.2.3 The effect of extension cables and other components should be taken into account in the calibration procedure.

7.2.4 The position of the observer relative to the microphone should be as recommended.

7.3 Instrument manufacturer's recommended calibration procedure and schedule for individual instruments should be employed. Field calibrations should be made immediately before and after testing each set of tires.

7.4 Not more than one person, other than the observer reading the meter, shall be within 15 m (50 ft) of the vehicle path or the microphone, and that person shall be directly behind the observer reading the meter, on a line through the microphone and the observer.

7.5 The sound level of the tires being tested is valid only when the sound level of the vehicle equipped with quiet tires is at least 10 dB below that of the vehicle equipped with test tires. The sound levels obtained with this procedure may be used for a relative ranking of the test tires, if the sound level of the vehicle equipped with the quietest tires available is 3-10 dB lower than when equipped with the tires being tested.

8. Reference Material—Suggested reference material is as follows:

8.1 ANSI S1.1-1960 (R1971), Acoustical Terminology

8.2 ANSI S1.2-1962 (R1971), Physical Measurement of Sound

8.3 ANSI S1.4-1971, Specification for Sound Level Meters

8.4 SAE Recommended Practice J184, Qualifying a Sound Data Acquisition System

8.5 Tire and Rim Association Yearbook

8.6 SAE Publication SP-373, Truck Tire Noise

8.7 G. R. Thurman, "Effect of Road Surface and Bed Clearance on Truck Tire Noise." Paper 740607 presented at SAE West Coast Meeting, Anaheim, California, August 1974

The ANSI documents are available from the American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.

APPENDIX

A1. An A-weighted sound level not exceeding 85 dB, determined in accordance with this recommended practice, is consistent with present best current practice for cross ribbed tires in normal states of wear. It is general experience that the sound level of unworn tires is significantly less than that of worn tires.

A2. Road surfaces are known to significantly affect the sound levels generated by highway truck tires. Rib type tires generally produce lower sound levels on smooth surfaces than on surfaces having a textured finish such as that brushed in during construction. Differences as great as 5 dB have been observed between sound levels obtained on very smooth and coarse concrete surfaces for tires producing relatively low levels of sound. For cross-ribbed tires, however, generated sound levels have been found to not differ by more than approximately 1 dB for given tire types on a variety of Portland cement concrete surfaces judged to be relatively smooth. For these reasons, the vehicle path description in paragraph 3.2 is sufficient to provide for reproducible sound levels for cross-ribbed tires, within the expected accuracy of such measurements (±1 dB), and to provide surface-dependent relative sound levels for rib type tires.

A3. Persistence of tire sounds after the passage of the vehicle and the tonal components of these sounds are properties of certain types of tires which tend to occur concurrently. Both are factors that direct attention to the sound, and are important determinants of the acceptability of the sound.

5. APPENDIX B. ACOUSTICAL MEASUREMENT TEST PROGRAM

The operational procedures and measurement/analysis instrumentation utilized in this load/deflection study were similar to that used in previous DOT/NBS truck tire noise studies. In the following sections detailed descriptions are provided of the vehicle configurations, test tires, field test site utilized for data acquisition and the operational test procedure.

5.1. Field Test Site

The dynamometer course at the U.S. Army Proving Ground located in Yuma, Arizona, was selected as the test site for the acoustical data acquisition phase of the program. Utilization of this site was arranged through agreement with the U.S. Army Test and Evaluation Command, Aberdeen Proving Ground, Aberdeen, Maryland.

The dynamometer course is approximately 2 miles (3219 m) long with 500 foot (152.4 m) radius turn-arounds at each end. The roadway is 30 feet (9.1 m) wide, near-level (0.8 percent grade) and is surfaced with a high strength asphalt. A 600-foot (182.9 m) test section was established at the southwest end of the course. A maintenance shelter and storage building located adjacent to the dynamometer course were used to store test tires and as the area where the tires were mounted on the test vehicles. Figure B-1 shows an overall view of the test site with the location of the test section and maintenance facilities noted. A photograph showing the surface details of the dynamometer course is presented in Figure B-2.

To comply with the measurement area requirements of SAE J57a (see Appendix A), an asphalt pad was constructed adjacent to the dynamometer course roadway. This triangular-shaped pad consisted of three rectangular sections of asphalt each 3 inches (7.6 cm) thick, 10 feet (3.0 m) wide and 600, 400, and 200 feet (182.9, 121.9, and 61.0 m) long, respectively. The pad was allowed to cure for two weeks after construction and then was sealed using a commercial driveway sealer. Figure B-3 is a photograph showing the test section on the dynamometer course roadway and the measurement area pad.

5.2. Test Tires

A set of four bias-ply rib tires (tire A) and a set of four bias-ply cross-bar tires (tire B) were tested in the acoustical measurement portion of this program. These were the same types of tires as listed in Table 1. The test tires were always mounted on the drive axle of the test vehicle. Rib tires, which had a characteristic tire noise level that was known to be as low as or lower than that of the two sets of test tires, were mounted on the steering axle. The characteristic tread patterns for the test tires are shown in

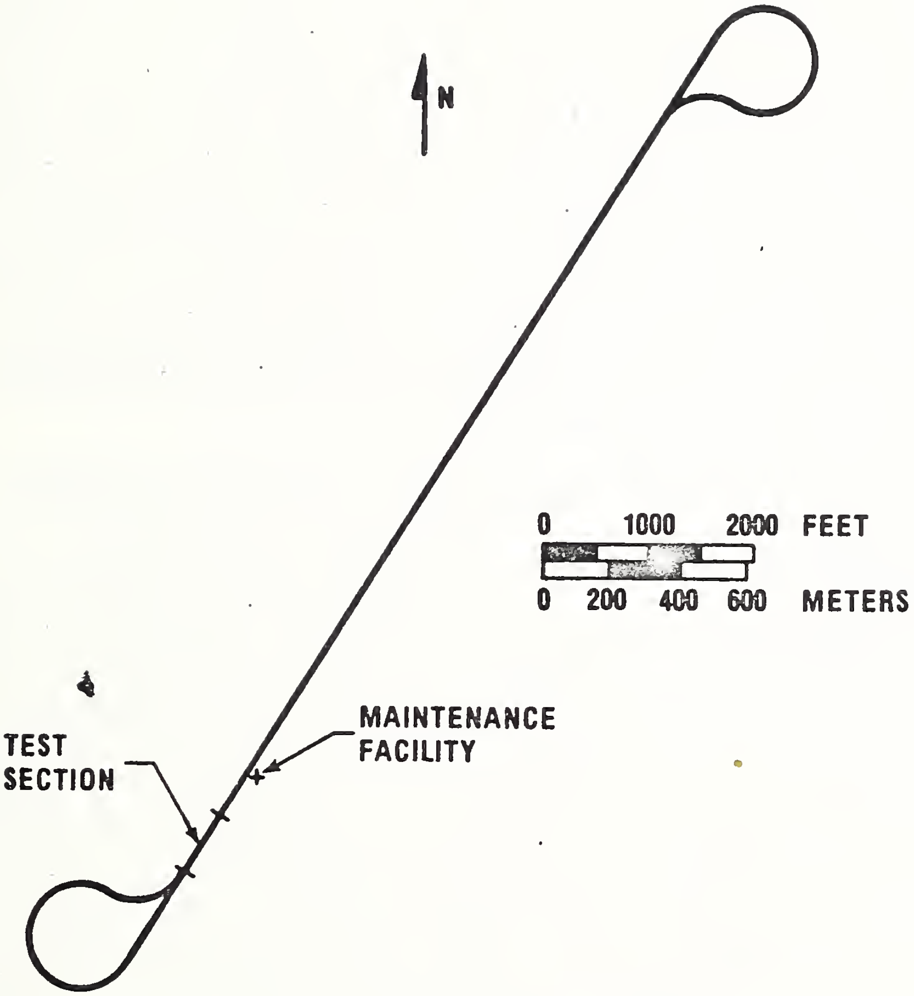


Figure B-1. Plan of dynamometer course at the U. S. Army Yuma Proving Ground, Yuma, Arizona, showing the location of the test section and maintenance facility.

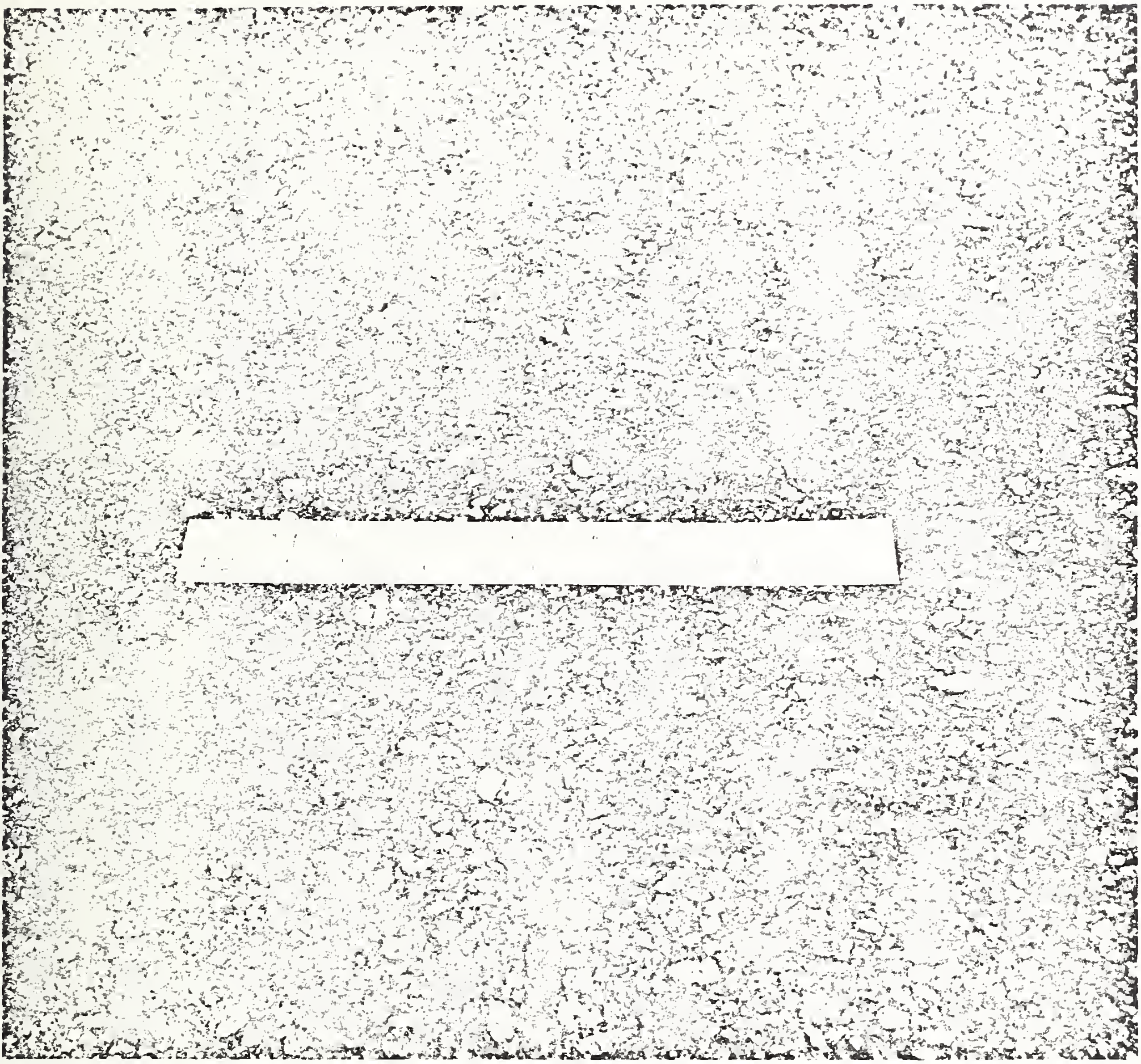


Figure B-2. Pavement surface details of the dynamometer course.

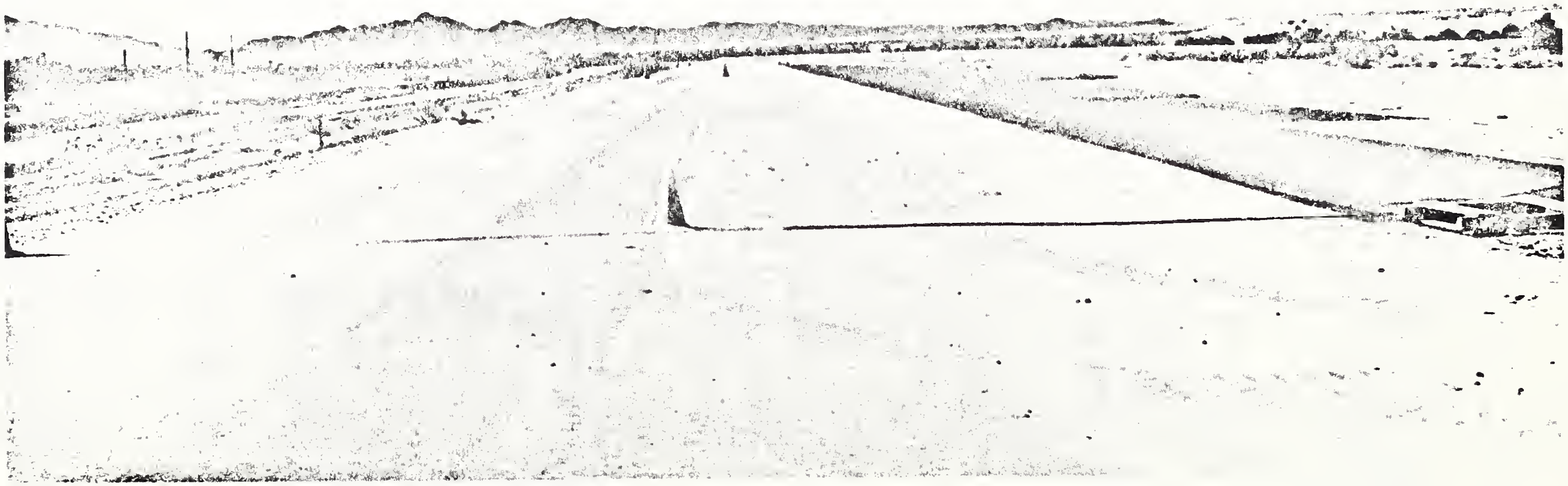
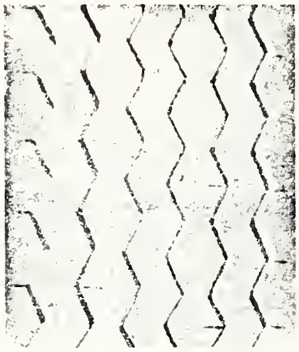


Figure B-3. A view of the test section established on the dynamometer course roadway and the measurement area pad.

Figure B-4. The average tread depth[8] and average Shore hardness[9] for these tires are also indicated.

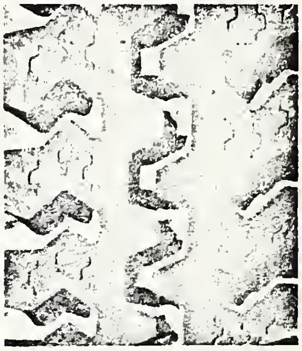
For these tests the inflation pressures were set to the desired value and the vehicle run for a minimum of ten miles to allow the tire to warm up. The vehicle was then stopped and the inflation pressures were again adjusted to the desired value to maintain constant tire deflection. Immediately following this, the acoustic measurement test runs were made.

TIRE A



- New bias-ply rib
- Average tread depth -- 16/32 inch
- Average Shore hardness - 50

TIRE B



- New bias-ply cross-bar
- Average tread depth -- 29/32 inch
- Average Shore hardness - 64

Figure B-4. Characteristic tread element pattern, average tread depth, and average Shore hardness for the test tires.

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[8] Tread depth measurements were taken at four equally spaced locations around the tire circumference. The device utilized for this measurement was simply a depth gage with 1/32 inch graduations. The operator located the depth gage over a major groove (not over sipes or other small grooves), depressed the probe into the groove, and noted the tread depth directly from the instrument.

[9] The Shore hardness of the tread rubber was determined by ASTM test method D2240-68 [19]. A type A durometer (for soft materials) was utilized in the following manner: the durometer was held in a vertical position with the point of the indentor at the center of the tread face. The presser foot was applied to the specimen as rapidly as possible without shock, keeping the foot parallel to the specimen surface. The scale was read five seconds after the presser foot was in firm contact with the specimen. The reported values represent the average for readings taken at approximately the same four locations as the tread depth measurements.

5.3. Test Vehicle

The test vehicle utilized in this study was an International Harvester[10] Model 1700 4 x 2[11] single-chassis truck with a conventional cab. This vehicle was equipped with 10-hole Budd wheels, 392 CID gasoline engine, 5-speed transmission and 2-speed axle. All tests were run in a coastby mode at 50 mph (80.5 km/hr). An overall view of the vehicle is shown in Figure B-5. The loading conditions of the test vehicle and the tire inflation pressures are listed in Table 7 in Section 3.1.

5.4. Test Procedure

The test procedure utilized was essentially identical to that specified in SAE J57a; however, the following exceptions should be noted:

- "Fast" meter response was utilized.
- The hard surface (vehicle path and measurement area) was sealed asphalt.
- The distance between the point of entrance and point of exit of the test section was 600 feet (182.9 m).
- Mud flaps were left on the vehicle during testing.

The components of the data acquisition and recording instrumentation, plus the automatic tape recorder control and elapsed time system utilized are shown in Figure B-6.

Three tape switches -- one immediately before the test section and one each at the beginning and end of the test section -- were used to start and stop the recorder and to mark the data tapes to designate the start and end of data. The tape switches at the beginning and end of the test section were also used to control an elapsed time system which provided a direct readout of average vehicle speed in miles per hour.

The acoustic measurement system consisted of a one-inch condenser microphone, a battery-operated microphone power supply (to supply the polarization voltage to the microphone), a step attenuator which provided the capability for selection of gain over a range of 60 dB in 10 dB steps, and a

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[10] The commercial vehicles utilized are identified in this report in order to adequately describe the vehicles on which the test tires were mounted throughout this program. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that these vehicles were necessarily the best available for the purpose.

[11] The nomenclature 4 x 2 relates to the number of wheel positions -- 4, and the number of driven positions -- 2, but has no relationship to the number of tires -- 6. Therefore, a 6 x 6 would have 10 tires mounted at 6 wheel positions, 6 of which are driven.

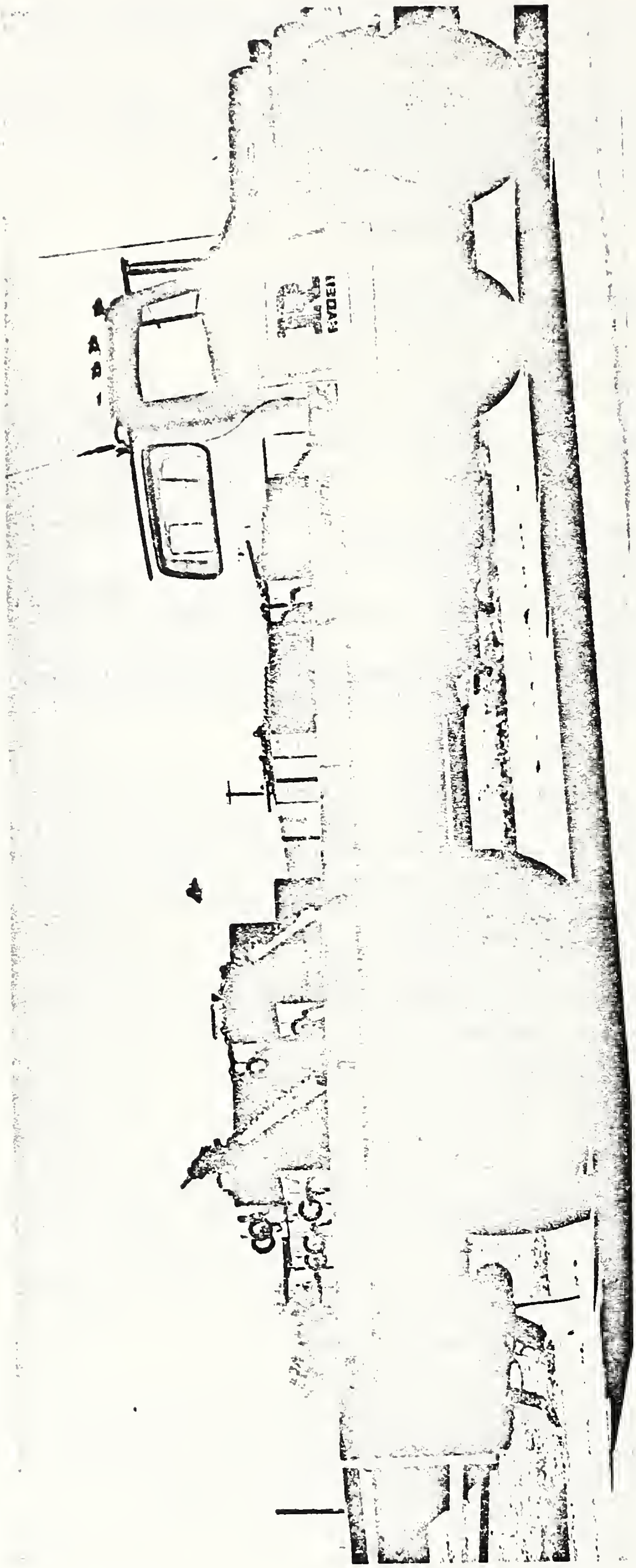

Figure B-5. View of test vehicle used in load/deflection study.

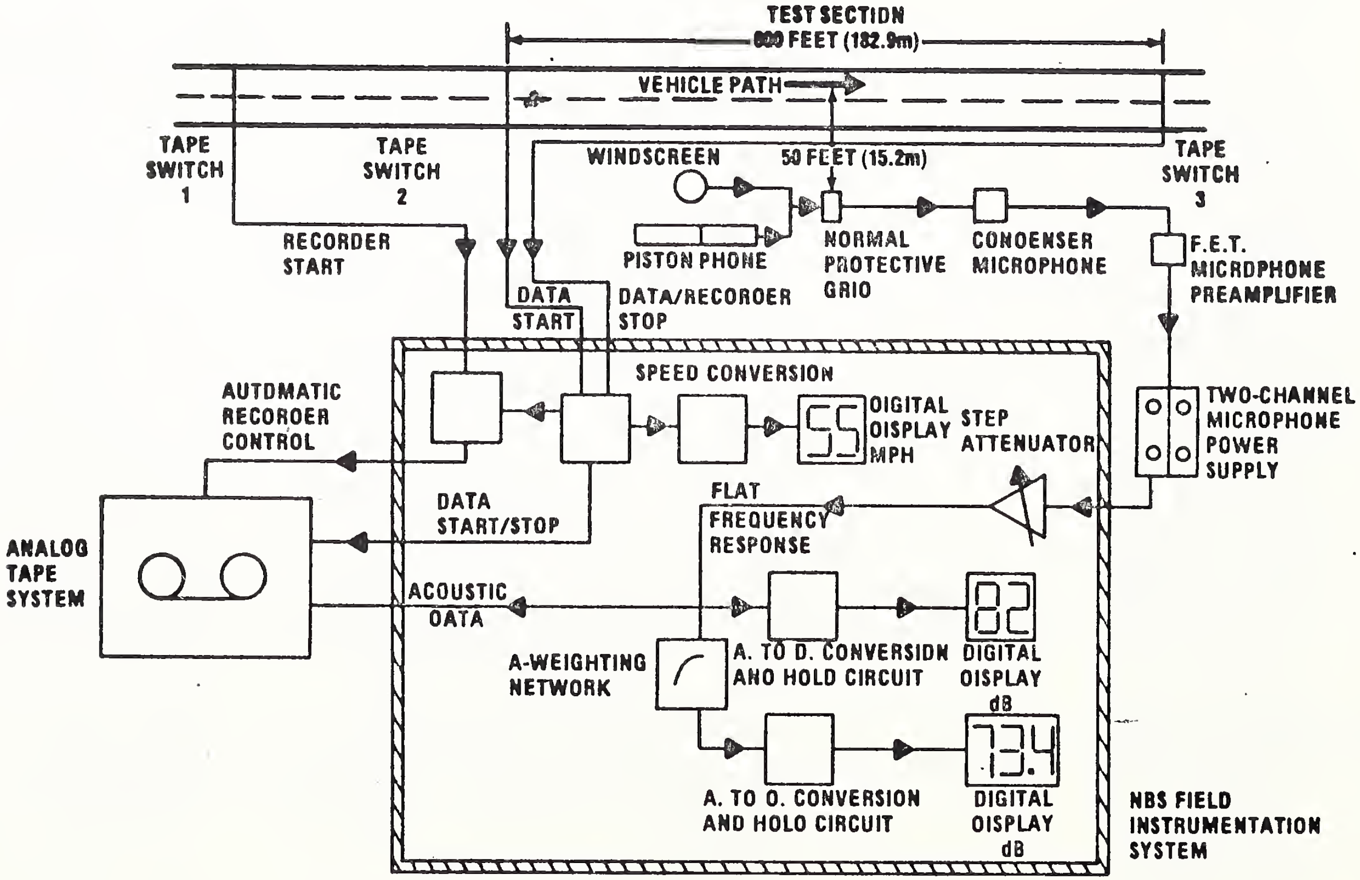

Figure B-6. Data acquisition and recording instrumentation plus automatic tape recorder control and elapsed time system.

tape recorder with two direct record analog data channels and one "FM" timing channel. The system included both a flat frequency response hold capability -- which provided an indication as to whether or not a tape channel had saturated (saturated runs were repeated) -- and an A-weighting hold capability -- which provided a direct reading, in the field, of the maximum A-weighted sound level observed during a passby without having to return to the laboratory for analysis of the tapes. The measurements were performed out-of-doors; therefore, a windscreen was placed over the microphone to reduce the noise produced by wind passing over the microphone grid. A hand-held rotating vane anemometer was used to measure wind speed. No measurements were made for wind speeds greater than 12 mph (19.3 km/hr). A single point calibration utilizing a pistonphone which produced a 124 dB sound pressure level (re 20 μPa)[12] at a frequency of 250 Hz was used for system calibration in the field. Calibration tones were recorded on the data tape once each hour as well as at the beginning and end of each data tape. Figure B-7 shows the microphone location and associated instrumentation in the field at the Yuma Proving Ground test site.

Once the data had been recorded, the analog tapes were returned to the National Bureau of Standards for reduction and analysis. Figure B-8 identifies the equipment which was utilized for analysis purposes. Each tape was played back a channel at a time through the real-time analyzer. An interface-coupler was necessary to make the real-time analyzer compatible with a mini-computer. When a timing signal appeared on the analog tape, the computer was instructed to start sampling the digital data from the real-time analyzer. A real-time analyzer time constant of 0.2 second above 200 Hz and one which below 200 Hz increased linearly to 3.15 seconds at 12.5 Hz was utilized to obtain the root-mean-square (rms) value of the level. Once all data had been analyzed, the computer stored the data and dumped it onto digital magnetic tape. This tape was formated to be acceptable to the large NBS computer which was utilized for further analysis. For the purposes of this report only the maximum A-weighted sound level data are discussed. One-third octave band data were also obtained but are not reported here.

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[12] A pistonphone generates a reference sound pressure of 124 dB (re 20 μPa) only at the standard atmospheric pressure of 760 mm Hg. For ambient pressure conditions other than standard the actual level will vary from the reference value of 124 dB (e.g., 760 ± 10 mm Hg corresponds to 124 ± 0.1 dB). Because the magnitude of this departure from the reference level was small for the range of ambient pressure conditions at the Yuma test site, no corrections were made to the data.

Figure B-7. Overall view of the microphone location with the test vehicle. The tripod-mounted microphone was located 50 feet (15.2 m) from the centerline of vehicle travel along a line perpendicular to the vehicle path.

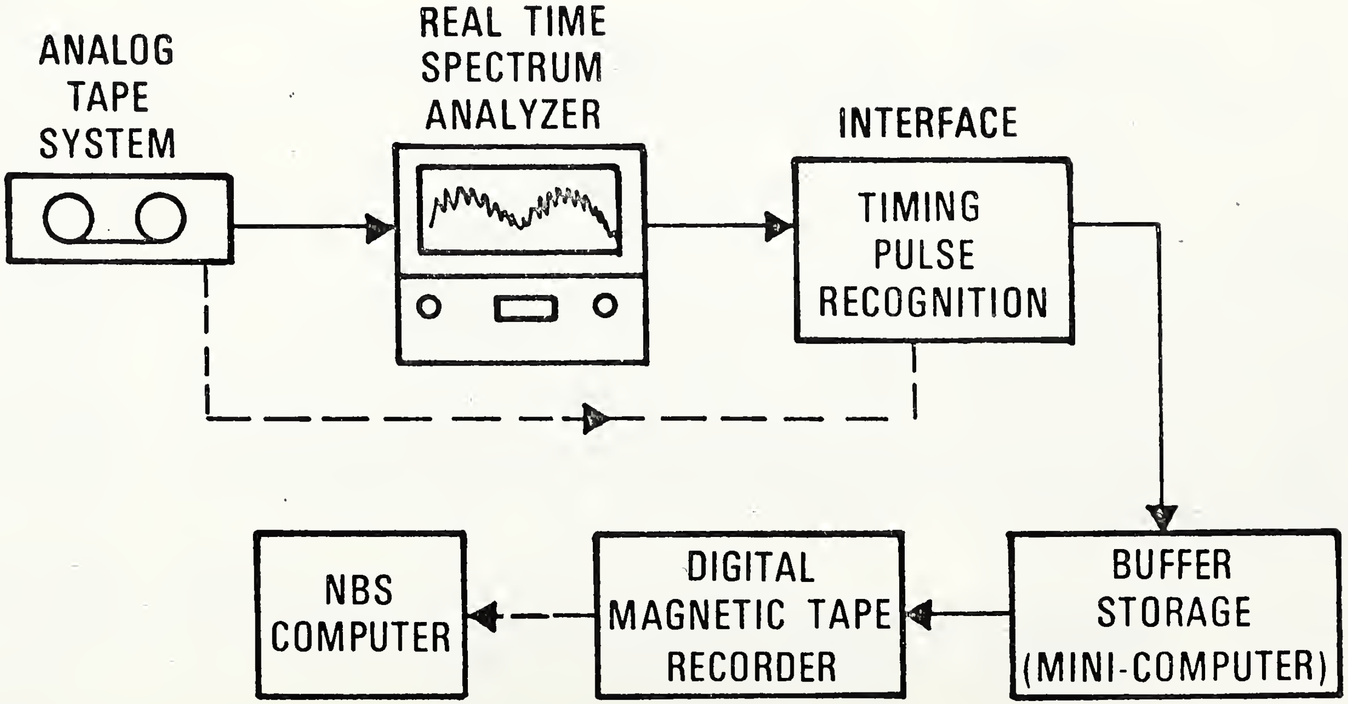

Figure B-8. Data reduction and analysis system.

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