HSRI TIRE TEST PROGRAM
FOR
CALSPAN TIRF VALIDATION

UM-HSRI-PF-73-5

July 3, 1973

PREFACE

The tire traction test results reported herein were obtained by the University of Michigan Highway Safety Research Institute (HSRI) in cooperation with the Motor Vehicle Manufacturers Association and the Rubber Manufacturers Association.

The HSRI Mobile Tire Tester was used in acquiring these traction test data according to the Calspan Run Schedule* prescribed for the Calspan MVMA/RMA TIRF Validation Program. The HSRI data will be placed in context with similar data obtained by other organizations operating a tire test facility for the purpose of examining the validity of tire traction data acquired by the new Calspan Corporation Tire Research Facility (TIRF).

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*Included in a document titled "Tire Test Program" distributed January 1973 by the Vehicle Safety Research Department of the Motor Vehicle Manufacturers Association.

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BREAK-IN PROCEDURE

100 miles at 60 mph on full-size automobile weighted 1250 lb/wheel. Tire pressure at 26 psi.

The break-in of the HSRI tires was performed by Ford Motor Company while breaking in their own Calspan TIRF validation tires.

TEST SURFACE DESCRIPTION

The Calspan TIRF validation tire test program was conducted at the Bendix Automotive Development Center, New Carlisle, Indiana.

The dry tests were run on an asphalt section of the main test loop. The dry asphalt test section showed ASTM skid numbers of 1.075 peak and .745 slide.

The wet testing was performed on the jennite-surfaced skid pad watered to approximately .02 inches with the mobile tire tester's on-board watering system. The wet jennite test section showed ASTM skid numbers of .631 peak and .362 slide.

The preceding ASTM skid numbers were measured by the Ford Motor Company traction trailer.

Free-Rolling Lateral Force F_y (lb)
Aligning Moment M_z (ft·lb)

TIRF validation data taken on wet jennite

(Firestone) JR78-15 (6.0 inch rim)

1200 lb, 28 psi, 20 mph

α	F_y	M_z
-2	+603	-4
0	+29	+3
+2	-431	-22
6	-761	-126
10	-818	-170
16	-875	-163
20	-804	-192

1200 lb, 28 psi, 60 mph

α	F_y	M_z
-2	+522	+15
0	+135	+15
+2	-430	0
6	-709	-133
10	-732	-133
16	-660	-133
20	-617	-111

(General) G78-15 (5.5 inch rim)

1200 lb, 28 psi, 20 mph

α	F_y	M_z
-2	+388	-19
0	+9	0
+2	-368	+15
6	-646	-90
10	-708	-133
16	-674	-152
20	-646	-154

1200 lb, 28 psi, 60 mph

α	F_y	M_z
-2	+330	-10
0	-	-
+2	-287	-15
6	-468	-96
10	-545	-126
16	-545	-89
20	-517	-118

Note: All tests run at zero inclination angle (γ=0).

Free-Rolling Lateral Force F_y (lbs)
Aligning Moment M_z (ft·lb)
TIRF validation data taken at 40 mph on dry asphalt

(General) G78-15 (5.5 inch rim)

800 lb, 28 psi

α	F_y	M_z
-2	+431	-30
0	+183	+4
+2	-224	-4
6	-623	-74
10	-769	-155
16	-804	-192
20	-834	-207

2000 lb, 28 psi

α	F_y	M_z
-2	+396	-93
0	+57	-13
+2	-273	+71
6	-817	+68
10	-1103	-112
16	-1350	-251
20	-1520	-

1200 lb, 28 psi

α	F_y	M_z
-2	+474	-55
0	+163	-10
+2	-200	+36
6	-760	-52
10	-990	-141
16	-1132	-274
20	-1120	-259

1200 lb, 32 psi

α	F_y	M_z
-2	+483	-59
0	+172	0
+2	-192	+7
6	-752	-81
10	-975	-160
16	-1120	-281
20	-1090	-229

Note: All tests run at zero inclination angle (γ=0).

Free-Rolling Lateral Force F_y (lb)
Aligning Moment M_z (ft·lb)
TIRF validation data taken at 40 mph on dry asphalt

(Firestone) JR78-15 (5.0 inch rim)

800 lb, 28 psi

α	F_y	M_z
-2	+494	-
0	+106	+10
+2	-287	-9
6	-660	-111
10	-741	-163
16	-746	-195
20	-704	-188

2000 lb, 28 psi

α	F_y	M_z
-2	+560	-163
0	+72	+52
+2	-402	+77
6	-1119	+37
10	-1390	-163
16	-1490	-269
20	-1590	-340

1200 lb, 28 psi

α	F_y	M_z
-2	+560	-200
0	+135	0
+2	-359	+36
6	-860	-126
10	-947	-178
16	-975	-244
20	-947	-251

1200 lb, 32 psi

α	F_y	M_z
-2	+600	-74
0	+129	+15
+2	-373	0
6	-875	-114
10	-1012	-195
16	-1019	-244
20	-1032	-274

Note: All tests run at zero inclination angle (γ=0).

Straight-Ahead Longitudinal Force F_x (lb)

TIRF validation data taken at 20 mph, 1600 lb, and 28 psi

Brake/Drive Testing on Wet Jennite

G78-15			JR78-15		
Slip	Brake	Drive	Slip	Brake	Drive
.2	1026	1171	.2	1130	985
.4	1111	1061	.4	1120	921
.6	1063	954	.6	1070	805
.8	982	852	.8	930	645
1.0	821	772	1.0	720	600

Brake Testing on Dry Asphalt

G78-15

Slip	Brake
.2	1410
.4	1315
.6	1250
.8	1125
1.0	1000

Note: All tests run at zero inclination angle (γ=0).

TREAD TEMPERATURE OBSERVATIONS

The surface temperature of the crown rib was continuously monitored with a Sensors, Inc., infrared radiometer, model ATR 1061-S. At the beginning of each test run, the tread surface temperature was the ambient air temperature which ranged from 50°F to 70°F.

The wet pavement tests produced no increase in tread temperature.

The dry pavement free-rolling tests resulted in the following maximum temperatures after about 10 seconds contact time.

Slip Angle	Max. Temp.
6°	90°F
10°	150°F

The dry pavement locked-wheel tests (straight-ahead) resulted in a localized "hot spot" at about 190°F and a circumferentially average tread temperature of about 120°F.

It should be noted that the loaded test tire is lowered to the test surface just prior to actual data taking and is immediately raised after the test surface transit. Considerable convection cooling takes place (particularly when the raised test tire is wet) as the mobile tire tester moves along the approach roads. Inflation pressure in the test tire remains fairly constant.

TREAD WEAR MEASUREMENTS

The following tables list the new tire groove depths and the groove depths upon completion of the wet and dry test procedures. A single G78-15 and a single JR78-15 tire was used throughout the entire testing program. The worn groove depths thus reflect wear from both wet and dry testing.

The groove depths are given in inches.

General G78-15 Belted-Bias

	Leading* Shoulder	Crown		Trailing Shoulder	
	Groove 1	Groove 3	Groove 4	Groove 6	
At Medalion	.450	.375	.375	.445	New
	.440	.360	.355	.435	Worn
180° Away	.450	.380	.370	.445	
	.430	.370	.350	.440	

Firestone JR78-15 Steel-Belted Radial

	Leading* Shoulder	Crown		Trailing Shoulder	
	Groove 1	Groove 2	Groove 3	Groove 4	
At Medalion	.400	.363	.363	.400	New
	.340	.320	.335	.390	Worn
180° Away	.400	.363	.363	.400	
	.365	.335	.340	.390	

*The leading shoulder (groove 1) is forewardmost in the contact region when the tire is operated at a slip angle and may be expected to receive the most wear. A slightly asymmetric wear pattern is evident as the tires were tested only at positive slip angles of 6, 10, 16, and 20 degrees (in addition to zero and ±2 deg).

FORCE MEASUREMENT PRECISION

The precision of a force measurement made with the HSRI Mobile Tire Tester is determined by the following analysis.

A physical quantity $f(x,y)$ calculated from the measurements of the independent variables, x and y, will be in error due to uncertainties dx and dy in the measurement of x and y. The error in the physical quantity is

$$df = f(x+dx,\ y+dy) - f(x,y) \tag{1}$$

The imprecise value can be expressed by a Taylor's series expansion about the true, and unkrown, value of the desired physical quantity.

$$\begin{aligned} f(x+dx,\ y+dy) &= f(x,y) \\ &+ \frac{\partial f}{\partial x} dx + \frac{1}{2} \frac{\partial^2 f}{\partial x^2} dy^2 + \ldots \\ &+ \frac{\partial f}{\partial y} dx + \frac{1}{2} \frac{\partial^2 f}{\partial y^2} dy^2 + \ldots \end{aligned} \tag{2}$$

Retaining the first order terms in the expansion (2) allows the measurement error (1) to be expressed as

$$df = \frac{\partial f}{\partial x} dx + \frac{\partial f}{\partial y} dy \tag{3}$$

A mobile tire tester force measurement is the product of two independent variables, each of which involve some uncertainty.

$$F = a \cdot C \tag{4}$$

In the above,

F = longitudinal or lateral force measurement

a = amplitude of trace on chart recorder

C = chart recorder calibration factor

In view of Equation (3), the force measurement error is

$$dF = Cda + adC \tag{5}$$

The error equation (5) will be evaluated for the following typical maximum values.

C_x = 370 lb/in (longitudinal force calibration)

C_y = 390 lb/in (lateral force calibration)

a = 3 in

da = .02 in (estimated accuracy of reading visicorder chart paper with steel rule with .01 inch graduations)

The estimated error in calibration, dC, is calculated as the standard deviation of the slope of a least squares straight line through a series of calibration points. The equation for calculating the standard deviation of the slope of a least squares line is

$$dC = \sigma = \sqrt{\frac{\sum_{i=1}^{n} (da_i)^2}{n-2}} \times \sqrt{\frac{n}{n \sum_{i=1}^{n} F_{c_i}^2 - \left(\sum_{i=1}^{n} F_{c_i}\right)^2}} \tag{6}$$

where

n = number of calibration points

F_c = applied calibration force

da = error in reading the applied calibration (chart recorder resolution; .02 inches)

The substitution of mobile tire tester calibration data into Equation (6) results in

$$dC_x = 2.46 \qquad \text{and} \qquad dC_y = 2.89$$

The uncertainty in the measurements of F_x and F_y can now be calculated from Equation (5). The results are

$$dF_x = 7.40 + 7.38 = 14.78 \text{ lb}$$

$$dF_y = 7.80 + 8.67 = 16.47 \text{ lb}$$

This is the precision of longitudinal and lateral force measurements made with the HSRI Mobile Tire Tester.

SLIP ANGLE SETTING ACCURACY

To investigate the accuracy of the mobile tire tester slip angle indicator, a set of small angle free-rolling tests were run at low speed with a special test tire believed to be free from lateral force development by tire nonuniformity. This calibration tire was borrowed from Ford Motor Company.

The lateral force versus small slip angle data found with the calibration tire (Fig. 1) should be used in correcting the free-rolling lateral force data measured for the G78-15 and JR78-15 tires.

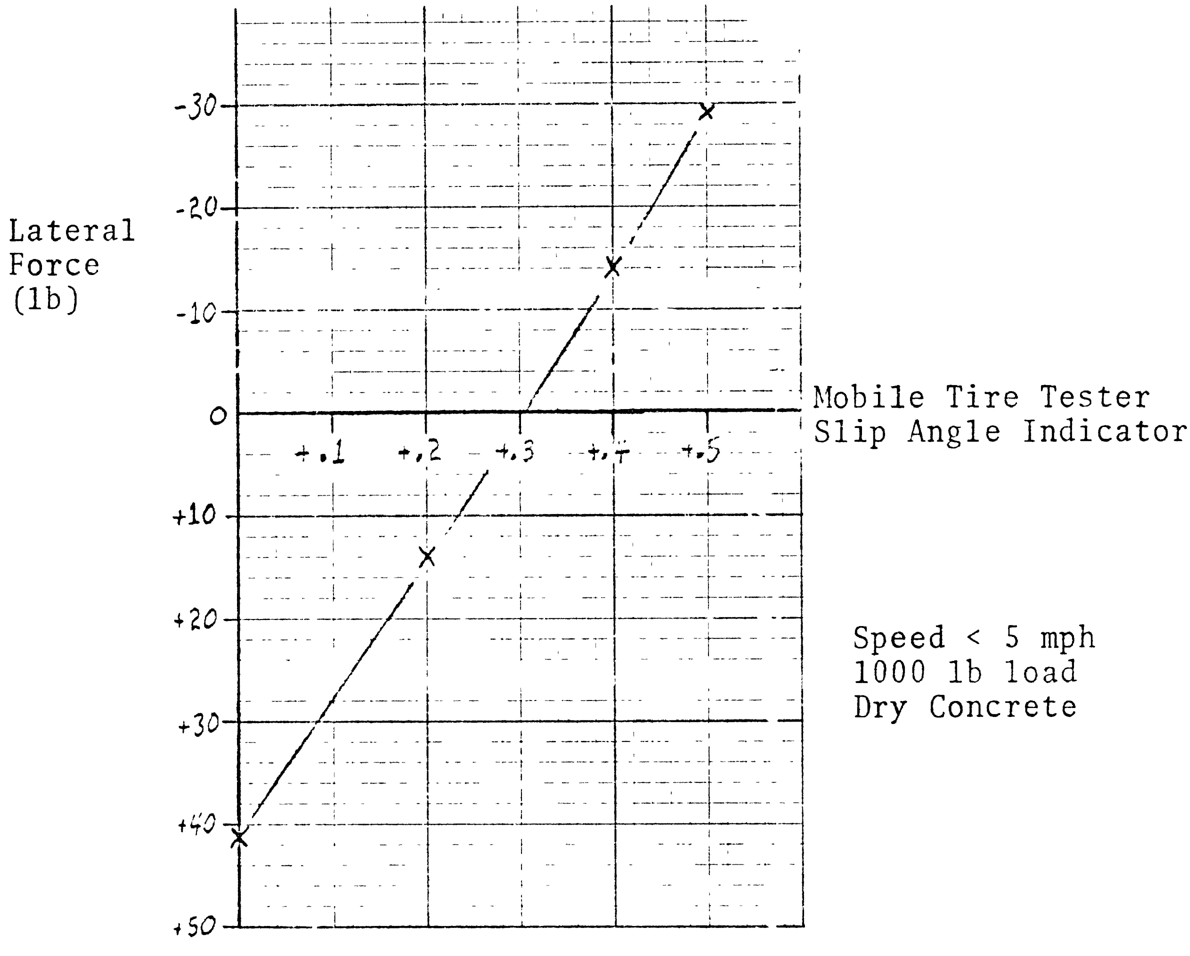

Figure 1. Calibration of the mobile tire tester slip angle indicator using a certified zero lateral force tire from Ford Motor Company.

MEASUREMENT OF VEHICLE VELOCITY AND TIRE ROTATIONAL VELOCITY

The test transit or vehicle velocity is controlled by an engine governor which limits the diesel engine driving the mobile tire tester to 2100 rpm. The transit velocity is maintained by driving the engine up against the governor while in the transmission gear giving the desired velocity at 2100 rpm. The following table gives the truck velocities in each gear as recorded by a fifth wheel speedometer. The additional drag due to lowering the test

MOBILE TIRE TESTER GEAR SELECTIONS AND RESULTING VELOCITIES AT 2100 rpm

Gear	Truck Velocity (mph)
1	9.4
2	12.8
3	14.0
4	19.0
5	23.8
6	29.2
7	39.0
8	49.8
9	60.0

wheel and operating the test wheel hydraulic motor drive/brake is negligible. Truck velocity is controlled to within 1%. The 4th, 7th, and 9th gears are used for the 20, 40, and 60 mph tests.

The test wheel rotational velocity is measured by a DC tachometer and recorded on chart paper with the output of the traction force transducers. The amplitude scale on the chart paper allows the test wheel speed to be read to an accuracy of .2 mph.

The longitudinal wheel slip (brake and drive) is computed by ratioing the test wheel tachometer signal between the free-rolling and locked wheel values. It is believed that the lock-unlock cycle time is of sufficient duration to consider the traction force versus longitudinal slip data as representative of steady-state conditions.