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A Temperature Study of Pneumatic Tires During Highway Operation

Army Tank-Automotive Command

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Army Materials and Mechanics Research Center

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TECHNICAL REPORT NO. 11716

A TEMPERATURE STUDY OF PNEUMATIC TIRES DURING HIGHWAY OPERATION

U.S. ARMY TANK AUTOMOTIVE COMMAND LABORATORIES

DECEMBER, 1972

by DAVID K. WILBURN

TACOM

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MOBILITY SYSTEMS LABORATORY

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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13. ABSTRACT

Automotive pneumatic tire and road surface temperatures are measured using infrared sensory non-contact techniques. A highway test vehicle implemented with on-board dual system temperature averaging and high speed circumferential profiling instrumentation package is described. Infrared techniques used for generating "tire temperature histories" are discussed in terms of highway performance factors. The influencing effects of road surface and air temperature, air flow and solar load are shown. Circumferential high resolution temperature profiles are also shown for defect induced tires relative to sensing the development and location of the defect under actual highway conditions of operation. Average tread and sidewall temperatures are plotted for new and worn 2-ply and 4-ply bias-belted tires for variations of load, speed, inflation, balance and camber. A comparison is made between the temperatures generated in tires operated under highway conditions and the same tire run on the dynamometer drum tester. The results of the overall program are based on approximately 5000 miles of highway testing performed on 10 test tires of various types.

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APPROVED PEMA PROJECT AMCMS 728012.16

PHYSICAL SCIENCE BRANCH
CONCEPT & TECHNOLOGY DIVISION
RESEARCH, DEVELOPMENT AND ENG. DIR.
U.S. ARMY TANK-AUTOMOTIVE COMMAND

TABLE OF CONTENTS

FORWORD

This program is a Production Engineering Measures Project (PEMA) funded thru the Army Materials and Mechanics Research Center, AMXMR-QA. The project was performed totally in-house within the Concepts and Technology Division by the Physical Science Branch.

Inquiries may be directed to the Commander, U.S. Army Tank-Automotive Command, Warren, Michigan or thru the Army Materials and Mechanics Research Center, Watertown, Massachusetts.

LIST OF FIGURES

LIST OF FIGURES - Continued

LIST OF TABLES

PROGRAM HISTORY

During fiscal year 1970, the Physical Science Branch of TACOM reported on an experimental infrared tire diagnostic program.[1] The object of the task was to determine if latent or developing (real) defects could be sensed in terms of a detail characteristic circumferential temperature profile generated in the tire during exercise by drum test. The potential of the IR technique aroused interest within the automotive and highway safety community and generated several individual commercial and government sponsored projects all utilizing infrared as a measurement media in various schemes of employment,[2,3,4]. As a result of the continued interest in infrared methods of tire temperature and "hot-spot" (defect) location, a second phase tire test program was authorized and funded by the Army Materials and Mechanics Research Center to be performed at the Tank-Automotive Command. As described in this report.

RECOMMENDATIONS

It is recommended that consideration be given relative to implementing appropriate military tire specifications with an infrared test clause as a means of:

(1) Providing an expanded examination capability for detection of latent and real manufactured defects in test tires subject to drum performance evaluations.

(2) Establish limiting maximum operating temperatures for tires undergoing drum tests at rated loads and maximum speeds.

This recommendation is based on the results of tests described in this report, TACOM Report TR1154, and state-of-the-art capabilities developed within the infrared non-destructive testing community on pneumatic tires.

SUMMARY

1. Tire tread and sidewall temperatures increase with a decrease in tire inflation pressure. The temperature increase is greater in the sidewall area than in the tread.

2. Tire tread and sidewall temperatures increase with increasing load. The temperature increase is greater in the sidewall area than in the tread.

3. Tread temperature is strongly influenced by road surface temperature. Tire tread temperature increases in proportion to increases in road surface temperature.

4. Sidewall temperature is strongly influenced by air temperature and solar load (sun exposure). Sidewall temperatures increase in proportion to increases in air temperature and solar load.

5. For normal inflation pressures, sidewall temperature decreases slightly with speed, for speeds up to 8C mph. In comparison, tread temperature increases slightly with speed, for speeds up to 80 mph.

6. Out-of-balance tires produce a "heat pulse" in the area of the high balance node. The differential temperature of the heat pulse was proportional to the amount of out-of-balance and increased with increasing unbalance. Out-of-balance could not be detected by the "average temperature" measuring method.

7. Out-of-caster (wobble) produced a slight increase in average tread temperature, but could not be detected as a "hot spot" in any localized area of the tire.

8. Four ply tires generated higher temperatures in both sidewall and tread than 2 ply tires.

9. Worn tires (1/8 inch tread depth or less) generated lower tread and sidewall temperatures in comparison to normal tread debth tires of the same type.

10. Defects of ply separation built into two test tires were detected by the high speed temperature profiling system. The averaging tire temperature system did not sense the presence of the defects in terms of an overall increase or decrease in nominal operating temperature.

11. Two additional used tires of unknown condition were examined by the high speed profiling system for the presence of defects. A small area of temperature discontinuity was detected in one tire and was subsequently verified as a cord rupture and tread unbond by tire sectioning.

12. Nominal tread and sidewall temperatures observed in a tire during highway operation is not reproduced for drum test operation for similar speeds and loads.

INTRODUCTION

Military Specification MIL-T-12459C outlines both road service tests, (paragraph 4.5.8) and indoor drum endurance tests (paragraph 4.5.6). Any hidden defects after the road service, indoor drum or plunger test (paragraph 4.5.3) are determined by cutting the tire into specified sections for visual inspection. There is currently no requirement in the specification for temperature measurements to be made during drum test or road service test operations. Needle thermocouple (puncture) temperature measurements are made occasionally, but are not a specification requirement. Similarily, there are no-non-destructive testing procedures used to inspect test tires after drum or road service operation which would be in lieu of or supplemental to the visual inspection after sectioning.

Infrared non-contact temperature measurement techniques are now available that would allow established IR test procedures to be applied on a routine basis as a specification requirement for:

(1) Monitoring average tire temperatures during drum or road service tests to determine compliance against a specified maximum limiting temperature.

(2) Monitoring the circumferential temperature profile of a tire during drum tests to determine the presence of "hot or cold" areas which would indicate the existence of a developing failure.

A recent study of tire failures indicated that excessive temperature build-up is a major cause of blow-outs and tread/body separation.[5] The report noted that tires become critically unsafe when rubber temperatures reach 280°F, and "explosive" at 300°F.

A technique of measuring average tires temperatures is simple and reliable and could easily be applied as a specification test to verify the acceptability of tires in production or new changes in design or construction, and, to determine the effects of loading, speed, and inflation. Measurement of tire temperature during drum test does not, however, reproduce thermally the conditions that occur when the same tire is operated in road service. The conventional drum test apparatus can not create environmental conditions of:

(1) Road temperature variations

(2) Air ambient variations

(3) Air flow

(4) Solar load

(5) Radiative transfer

The highway tests described in this report were conducted to determine:

(1) The feasibility of monitoring tire temperatures by infrared means from a test vehicle during actual highway operation.

(2) Relationship between temperature histories of tires operated "on the road" as compared to drum operation.

(3) What environmental conditions are important in influencing the temperature of a tire.

(4) The feasibility of sensing defects latent or developing in a tire during actual highway operation (safety oriented).

Appendix A exhibits the P-16 (funding support document) for this program which outlines the initial objects and purpose of the overall project.

RESULTS

Instrumentation and Test Vehicle

A commercial passenger car was utilized as a self-contained test bed for all highway performance operations.

To bring the test vehicle up to known good condition, it was outfitted with new shock absorbers, drive shaft universals, ball joints, and brakes, cylinder and drums. The front end was rebuilt and re-aligned and all tires were balanced dynamically before use.

The instrumentation signal analysis and readout equipment was mounted in the rear seat area and its power supplied by solid-state inverters mounted in the trunk. The vehicle is pictured in Figure 1. An outrigger platform was designed to mount two temperature sensing heads; one "looked" vertical at the center of the tread area, and the second "looked" horizontal at the sidewall area. Each instrument (radiometer head) could be positioned to scan across the width of the tread or from bead edge to shoulder. The outrigger platform was affixed to the left front fender as shown in Figure 2. The instrumentation bay (rear seat area) is shown in Figure 3.

All read-out instruments were positioned to allow an observer riding in the rear jump seat to monitor the output functions.

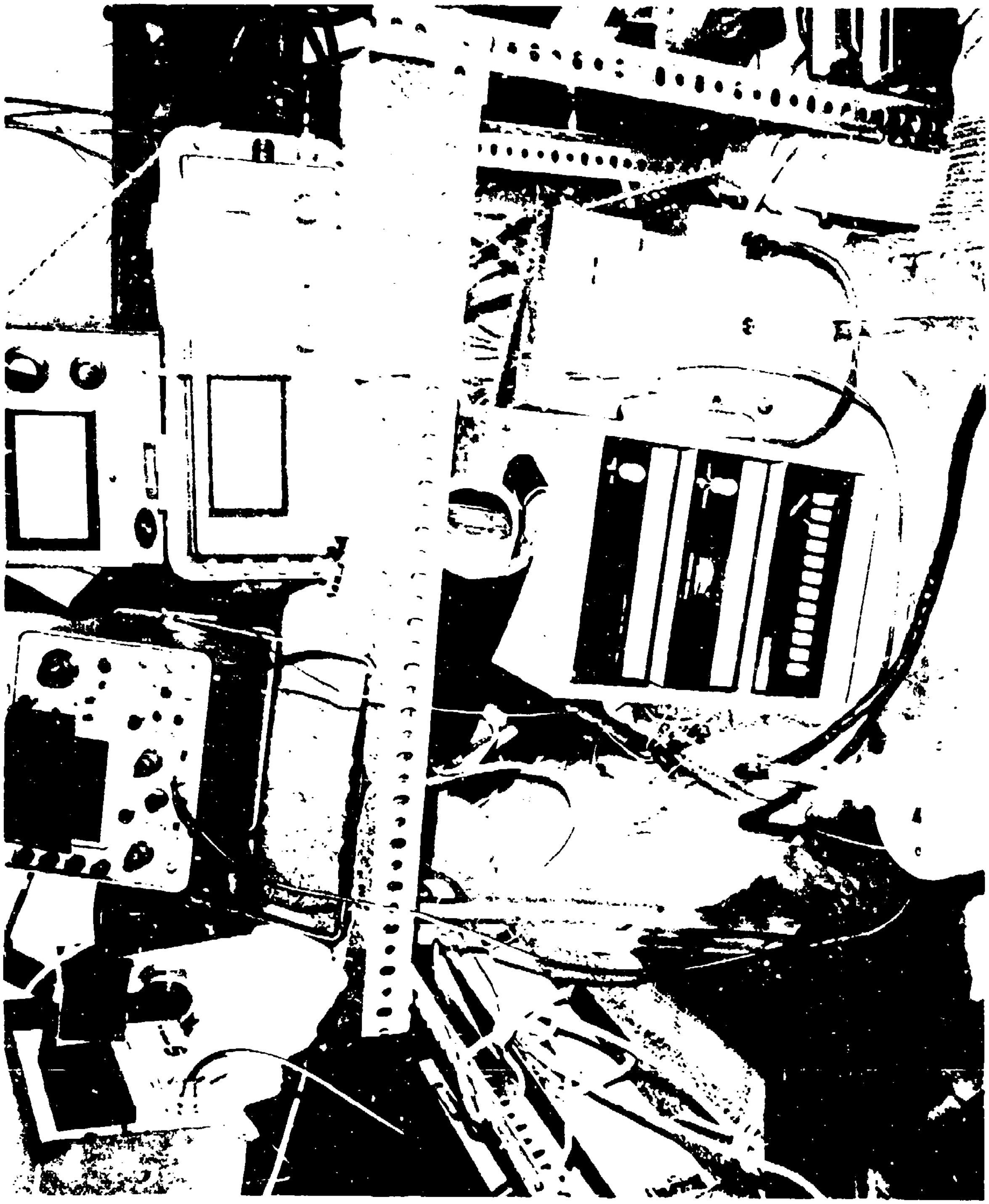
The instrumentation used during the road test operation is listed in Table I. All instruments are commercially available as off-the-shelf items. The optical and electrical properties of the remote temperature sensing devices are listed in Table II.

TEST VEHICLE

FIGURE 1

PLATFORM FOR MOUNTING RADIOMETER HEADS

FIGURE 2



INSTRUMENT AREA IN TEST CAR

FIGURE 3

The pyranometer cell is shown mounted in the roof of the car in Figure 3. To monitor road surface temperature, an infrared thermometer was mounted vertically to view the road surface thru a hole cut in the rear floor panel.

No particular problems were encountered in the operation of any on-board instrumentation. Calibration of all temperature measuring devices was accomplished in the laboratory and verified with a portable black body reference with an accuracy of $\pm$ 1^{o}C.

TABLE I

TEST INSTRUMENTATION SUMMARY USED

FOR HIGHWAY OPERATION

INSTRUMENT DESCRIPTION	MODEL NO.	MANUFACTURER	PURPOSE	UNITS OF MEASURE	RANGE	READOUT
1. Radiation Thermometer	PRT-5	Barnes Eng.	Tread Temperature	^{o}F	20 to 600^{o}F	Analog
2. Temperature Radiometer	1061	Sensors, Inc.	Sidewall Temperature	^{o}F	-76 to 932^{o}F	Digital
3. Infrared Thermometer	IT-2	Barnes Eng	Road Surface Temp	^{o}F	-32 to 150^{o}F	Analog
4. Thermocouple Indicator	DS500-T3	Doric Scientific	Air Temperature(s)	^{o}F	-100 to 2500F	Digital
5. Pyranometer	68	Yellow Springs Inst. Co.	Vertical Solar Load	Cal/cm^2/min.	0 to 2	Analog
6. Heat Probe	H-1	International Inst. Co.	Solar Load on Tire Sidewall	Watts/cm^2	0 to 0.015	Analog
7. Track Test 5th Wheel	-	Track Test	Vehicle Speed	mph	0 to 80	Analog
8. Tire Defect Sensor(s)	804	Sensors, Inc.	Circumferential Temp.	.01V/^{o}F	--	Oscilloscope
9. Oscilloscope	422	Tektronix	Temperature Profiles	Voltage vs Time	.001V to 200V	CRT
10. Oscilloscope Camera	--	Tektronix	Record CRT Trace	-	--	Film

TABLE II

OPTICAL AND ELECTRICAL CHARACTERISTICS

OF TEMPERATURE SENSING SYSTEMS

INSTRUMENT	TIME CONSTANT	WAVELENGTH PASS-MICROMETERS	ACCURACY °F	FIELD OF VIEW ON TIRE	SENSING DETECTOR	REFERENCE CAVITY TEMPERATURE
PTR-5 Radiation Thermometer	.5 Sec	8-14	0.35	0.35 x 0.35"	Thermistor	113°F
IT-2 IR Thermometer	.5 Sec	8-13	1.50	0.75 x 0.75"	Thermistor	113°F
1061 Temp. Radiometer	.5 Sec	0.8-40	1.0	0.47 x .2"	Thermopile	Not Used
804 Defect Sensor	50 Micro Sec.	0.8-40	1.0	0.5 x 0.5"	Thermopile	Not Used

TABLE III

IDENTIFICATION OF TEST TIRES AND ASSIGNMENT SCHEDULE

TIRE IDENTIFICATION	TEST ASSIGNMENT	MILES DRIVEN	PLYS	CONSTRUCTION	SIZE	CONDITION RECEIVED	MILES ON TIRE AT START OF TEST	REMARKS
1. KT15782	Average Temperature	1509	2	Bias Belted	8:15-15	New	-	
2. KT15B02	Profiles	1272	2	Bias Belted	8.15-15	New	-	
3. 10019	Average Temperature	1331	4	Bias Belted	8:25-15	Used	5,000	
4. 3NM3226	Average Temperature	770	2	Bias Belted	678-15	Used	22,000	Polyglass 1/8" tread depth.
5. P00961RN	Profiles	47	4	Bias Belted	8:25-15	Used	1,500	Nylon with built-in detect
6. PO15310AN	Profiles	26	4	Bias Belted Hi-Traction	G78-15 tread	Used	1,500	Nylon with built-in detect
7. KT15B0H	Average Temperature	55	2	Bias Belted	8:15-15	New	-	Inflation tests at low psi.
8. 8254X398	Averaging & Profiles	60	4	Bias Belted	8:15-15	Used	1,000	
9. 10019X	Averaging	100	4	Bias Belted	8:25-15	Used	1.500	
10. 10019Y	Averaging	100	4	Bias Belted	8:25-15	New		

PYRANOMETER PHOTOCELL MOUNTED
ON ROOF OF TEST VEHICLE

FIGURE 4

INFRARED THERMOMETER POSITIONED TO VIEW ROAD SURFACE

FIGURE 5

PROCEDURES AND MEASUREMENTS

The measurement phase of the road test program was carried out during a scheduled series of expressway operations performed in the Detroit Michigan local area. The test vehicle with driver and observer was operated on a 250 mile course in accordance with a pre-determined operation plan. The driver maintained the desired speed by means of the 5th wheel speed indicator while the observer performed the scheduled measurements.

Although two basic types of temperature tests were conducted, including (1) Average sidewalls and tread operating temperatures, and, (2) Circumferential profile temperature, a standard set of support data was acquired for both. This data consisted of:

(1) Vertical Solar Load on Road Surface

(2) Road Surface Temperature

(3) Horizontal Solar Load on Tire

(4) Air Temperature, Tire Area

(5) Free Air Temperature, Front Left Fender

(6) Road Temperature, 6 Inches Above Road Surface

(7) Temperature, Roof of Test Vehicle

(8) Tire Inflation Pressure

(9) Road Surface Type

(10) Time

(11) Speed

(12) Load on Tire in Pounds.

(13) Mileage, Accumulated and Total

As prescribed by the program outlined, the specific tests performed were:

(1) Average tread and sidewall temperatures as a functions of:

 (a) Road temperature

 (b) Solar load

(c) Speed

(d) Inflation pressure

(e) Load, pounds

(f) Air ambient

(g) Balance

(h) Caster

(i) Road type

(j) Tire construction

(k) Tire wear conditions

(2) Circumferential temperature profile relative to detection and location of tire defects.

All tests were performed on clear dry pavement during daylight hours under typical urban traffic conditions.

TEST TIRES

A description of the tires selected for road operations and identification of test assignment for each tire is shown in Table III.

All tires were run on standard passenger car 15-inch rims. Tires which were subject to low inflation tests were not assigned additional tests due to the possibility that the previous under inflation may have injured the tire.

RESULTS OF TEMPERATURE TESTS:

Results of "average" surface temperature tests are shown in a series of graphs, Figures 6 thru 19, as follows:

Figure	
6	SPEED VERSUS SIDEWALL AND TREAD TEMPERATURE TEST TIRE # 1
7	INFLATION VERSUS SIDEWALL AND TREAD TEMPERATURE FOR CONSTANT SPEED. TEST TIRE # 7
8	LOAD ON TIRE IN POUNDS VERSUS SIDEWALL AND TREAD TEMPERATURE TEST TIRE # 8
9	TREAD AND SIDEWALL VERSUS ROAD TEMPERATURE FOR 50 MPH SPEED
10	ROAD SURFACE TEMPERATURE VERSUS FREE AIR TEMPERATURE
11	COMPARISON, 2-PLY AND 4-PLY BIAS BELTED; SPEED VERSUS SIDEWALL/TREAD TEMPERATURE TEST TIRES # 3 & 4
12	COMPARISON, 2-PLY WORN TO 1/16 TREAD DEPTH. TEMPERATURE SIDEWALL AND TREAD VERSUS SPEED. TEST TIRES # 4 & 1
13	SPEED VERSUS TEMPERATURE OF SIDEWALL FOR VARIOUS ROAD TEMPERATURES. TEST TIRE # 8
14	SIDEWALL VS. PSI INFLATION PRESSURE FOR 40, 50, AND 70 MPH. TEST TIRE # 7
15	TREAD TEMPERATURE VS. SPEED FOR TIRE INFLATION PRESSURES OF 14, 20, 26 and 30 PSI. TEST TIRE # 7
16	SIDEWALL TEMPERATURES VS. SPEED FOR TIRE INFLATION PRESSURES OF 14, 20, 26 and 30 PSI TEST TIRE # 7
17	TREAD TEMPERATURE VS. TIRE INFLATION PRESSURES FOR SPEEDS OF 70, 50 and 40 MPH. TEST TIRE # 7

Figure

18 COMPARISON; SIDEWALL TEMPERATURE FROM DRUM TEST VS. HIGHWAY OPERATION

19 COMPARISON; LOAD ON TIRE VERSUS TEMPERATURE OF SIDEWALL FOR DRUM TEST AND HIGHWAY CONDITIONS

RESULTS OF TEMPERATURE PROFILING TESTS

Results of the circumferential profiling studies are shown in Figures 19 thru 22 as follows:

Figure

20 CIRCUMFERENTIAL TEMPERATURE PROFILE OF TREAD AND LEFT SIDEWALL; TEST TIRE NO. 6 WITH BUILT IN DEFECT*

21 CIRCUMFERENTIAL TEMPERATURE PROFILE OF TREAD AND LEFT SIDEWALL. TEST TIRE NO 5 WITH BUILT-IN DEFECT. **

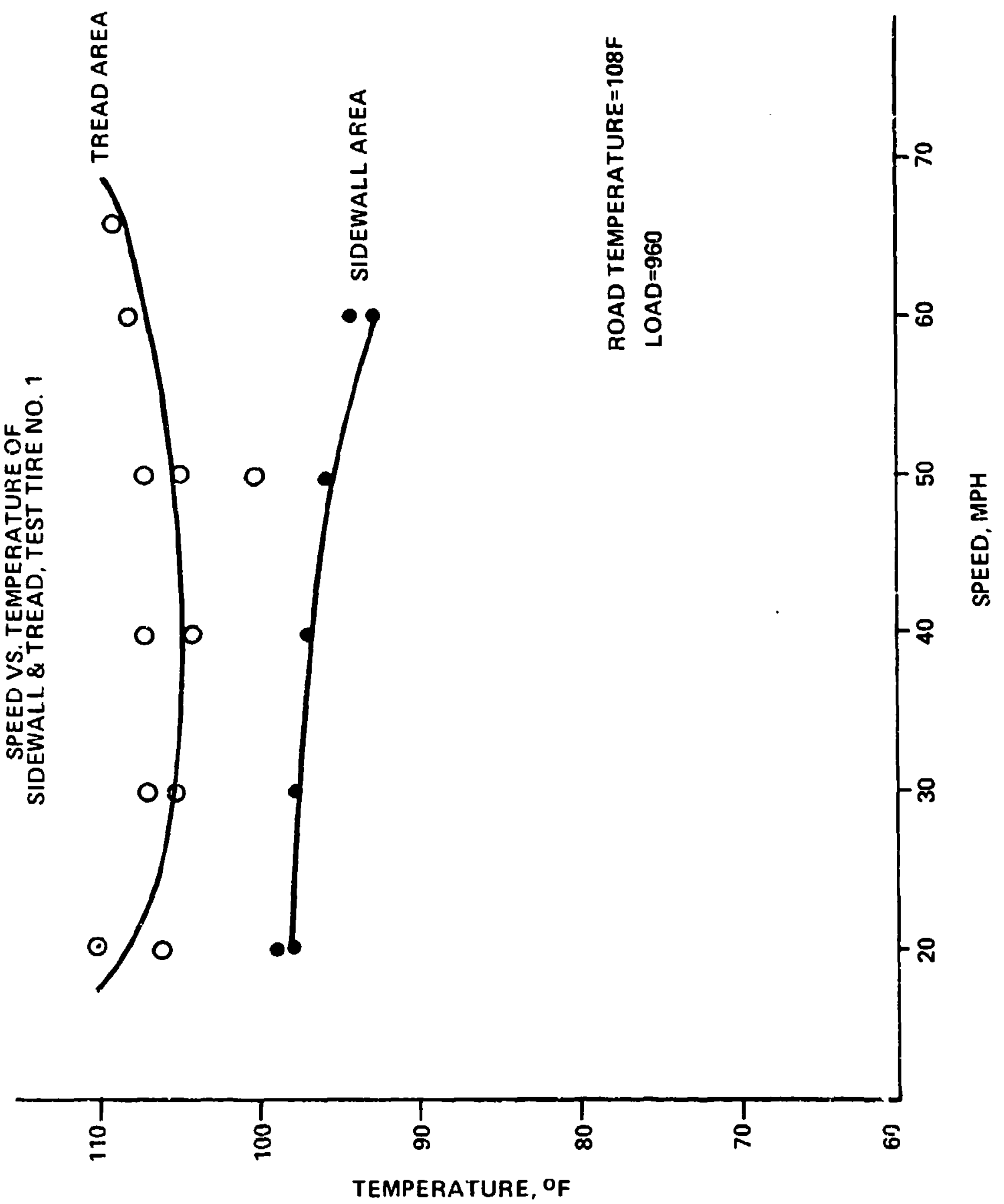
22 CIRCUMFERENTIAL TEMPERATURE PROFILE OF TREAD AREA ILLUSTRATING TIRE UNBALANCE. 5 OZ. OUT OF BALANCE AT 180°. TEST TIRE NO. 1

23 CIRCUMFERENTIAL TEMPERATURE PROFILE OF TREAD AREA. TEST TIRE # 2 ILLUSTRATING DETECTION OF TREAD/PLY SEPARATION

Manufactureres Description of Built-In Defect:

* Ply separation in shoulder opposite serial placed on either side of tread splice produced by 1/2 x 1/2 inch piece of diaphram stock.

** Ply separation in shoulder opposite serial placed on either side of tread splice produced by 1/2 x 1/2 inch piece of aluminum metal foil.



SPEED VS. TEMPERATURE OF
SIDEWALL & TREAD, TEST TIRE NO. 1
TREAD AREA
SIDEWALL AREA
ROAD TEMPERATURE=108F
LOAD=960
110
100
90
80
70
60
TEMPERATURE, °F
20
30
40
50
60
70
SPEED, MPH

FIGURE 6

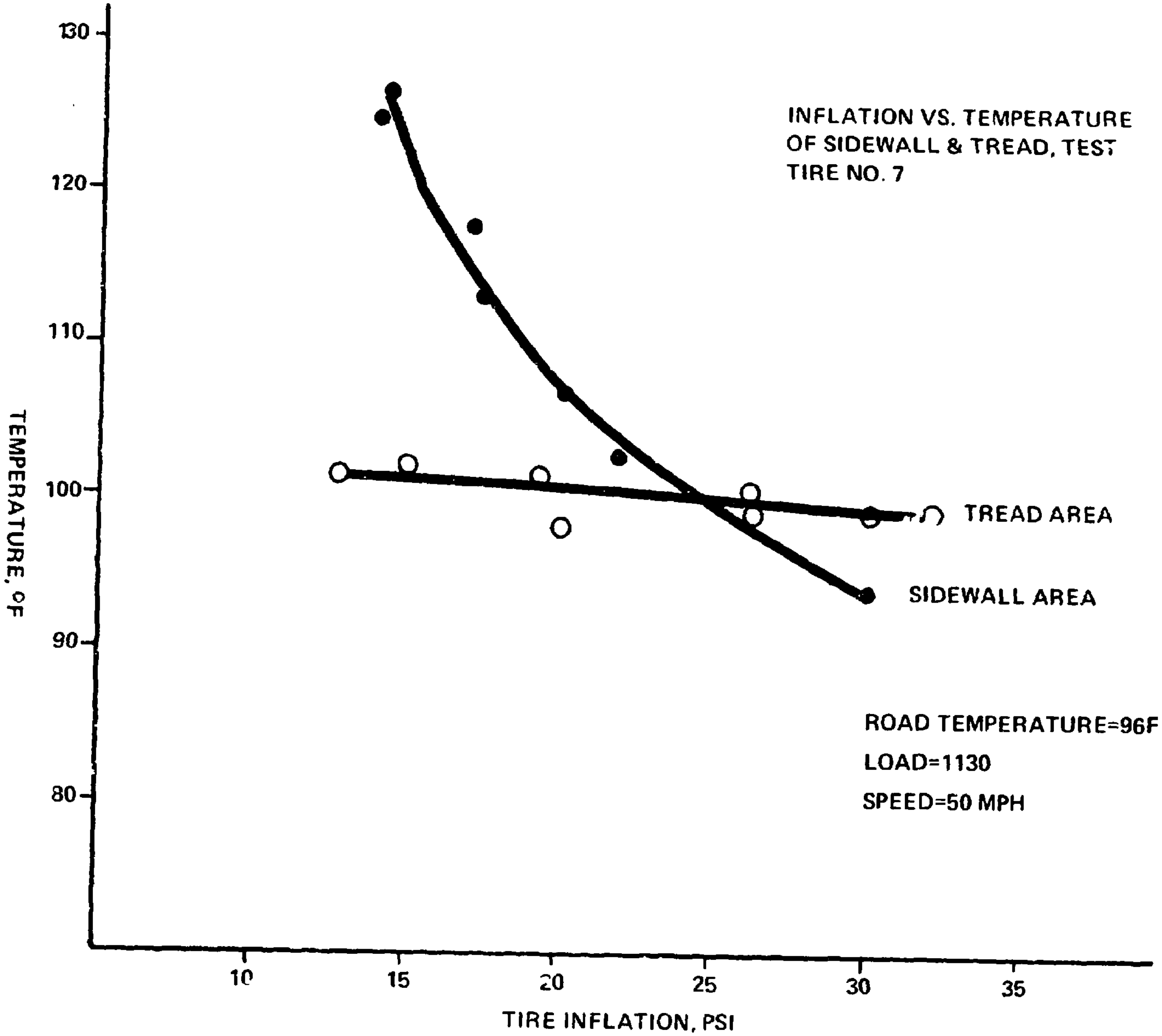

INFLATION VS. TEMPERATURE
OF SIDEWALL & TREAD, TEST
TIRE NO. 7
TREAD AREA
SIDEWALL AREA
ROAD TEMPERATURE=96F
LOAD=1130
SPEED=50 MPH
TEMPERATURE, °F
130
120
110
100
90
80
10
15
20
25
30
35
TIRE INFLATION, PSI

Figure 7

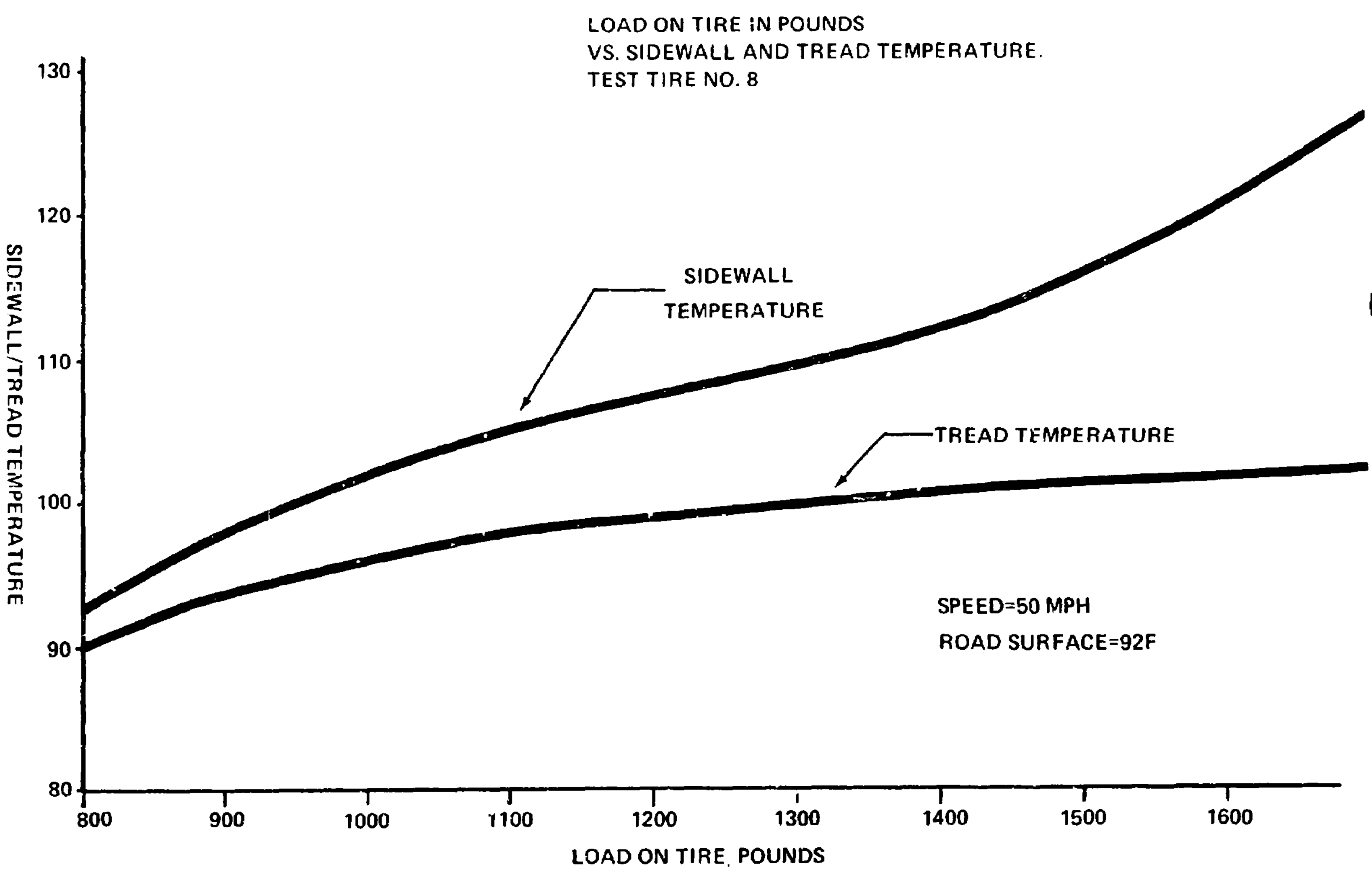

LOAD ON TIRE IN POUNDS
VS. SIDEWALL AND TREAD TEMPERATURE.
TEST TIRE NO. 8
SIDEWALL
TEMPERATURE
TREAD TEMPERATURE
SPEED=50 MPH
ROAD SURFACE=92F
130
120
110
100
90
80
SIDEWALL/TREAD TEMPERATURE
800
900
1000
1100
1200
1300
1400
1500
1600
LOAD ON TIRE, POUNDS

FIGURE 8

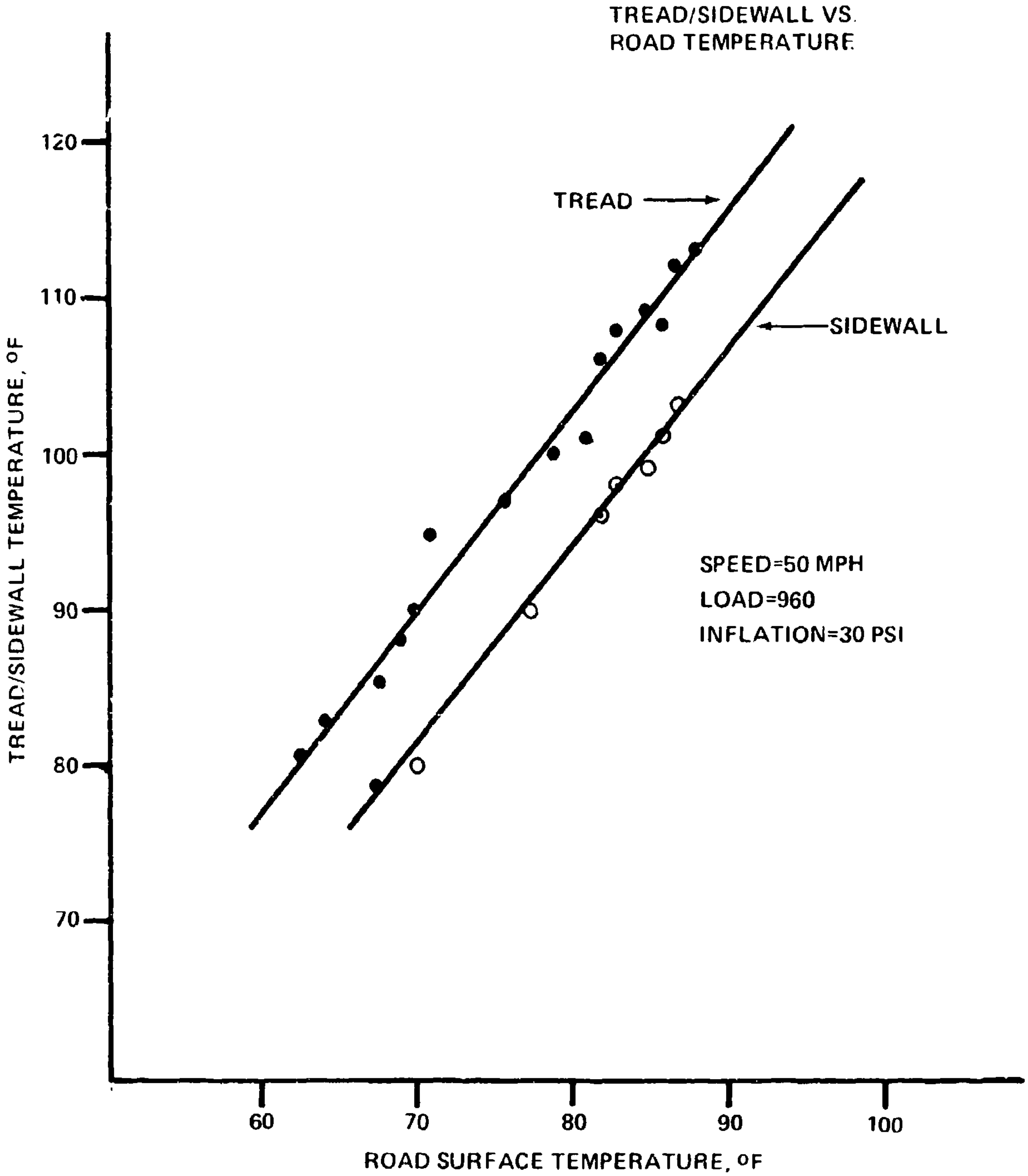

TREAD/SIDEWALL VS.
ROAD TEMPERATURE
TREAD
SIDEWALL
SPEED=50 MPH
LOAD=960
INFLATION=30 PSI
TREAD/SIDEWALL TEMPERATURE, °F
120
110
100
90
80
70
60
70
80
90
100
ROAD SURFACE TEMPERATURE, °F

Figure 9

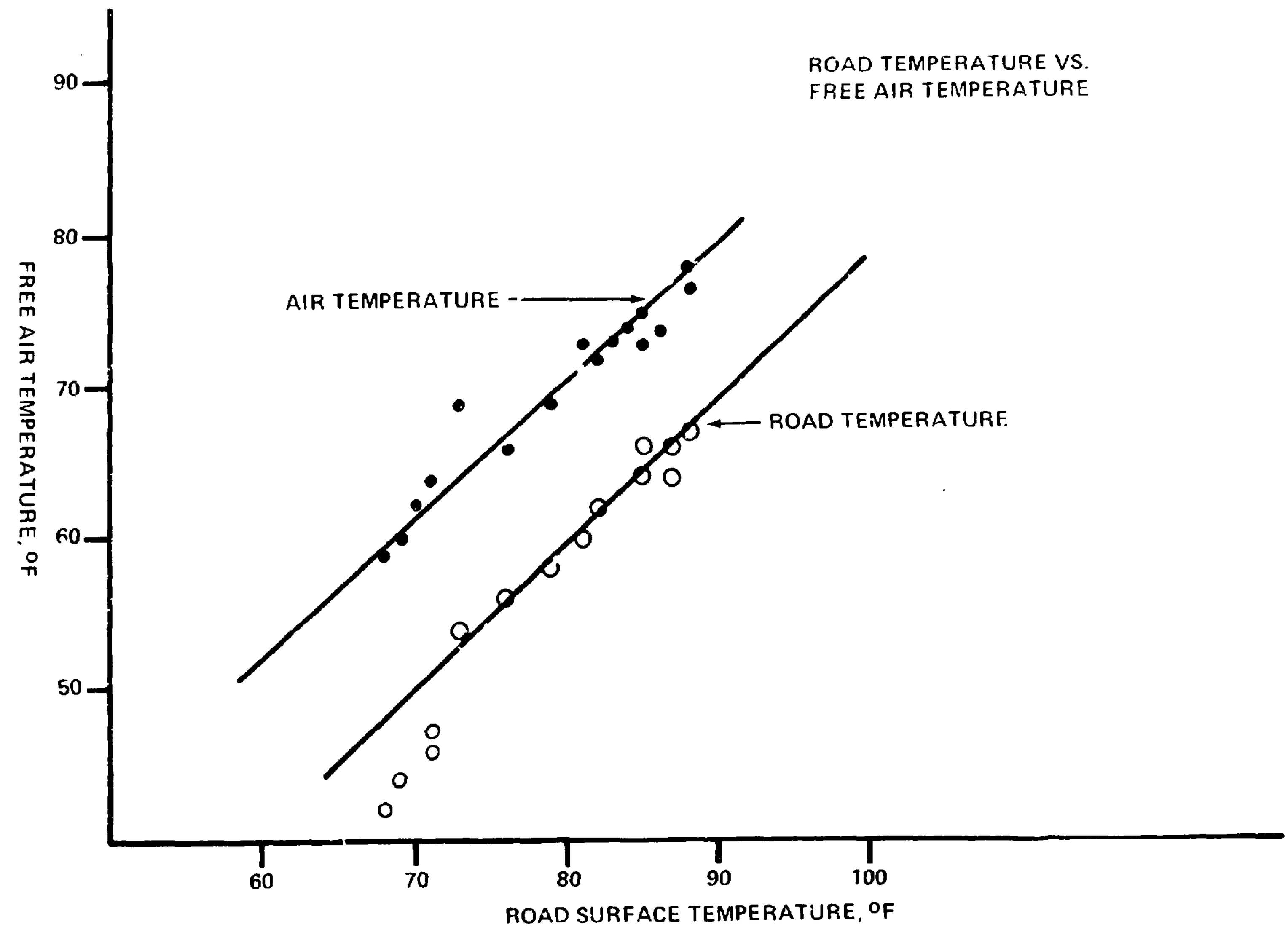

ROAD TEMPERATURE VS.
FREE AIR TEMPERATURE
AIR TEMPERATURE
ROAD TEMPERATURE
FREE AIR TEMPERATURE, °F
90
80
70
60
50
60
70
80
90
100
ROAD SURFACE TEMPERATURE, °F

FIGURE 10

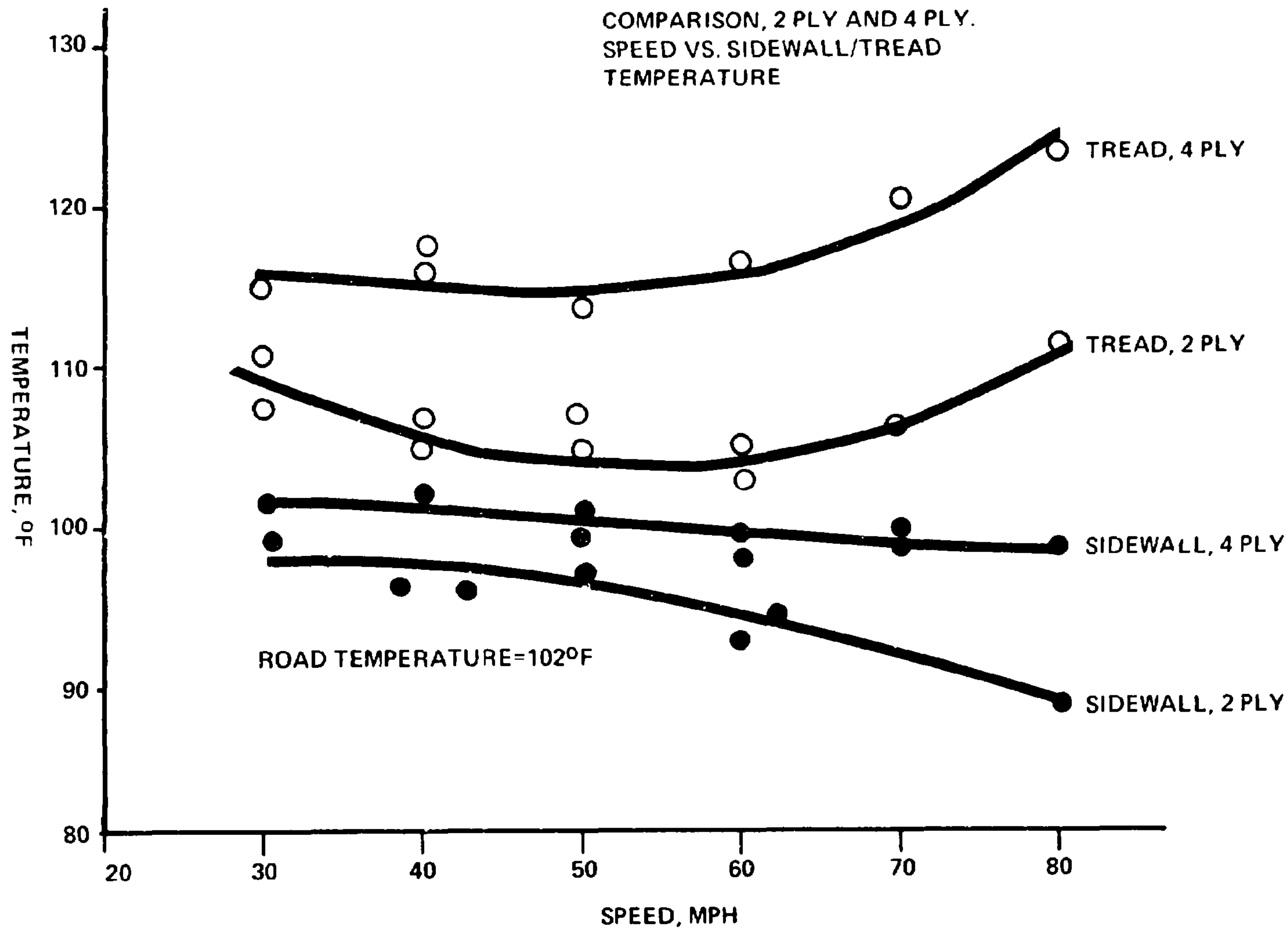

COMPARISON, 2 PLY AND 4 PLY.
SPEED VS. SIDEWALL/TREAD
TEMPERATURE
TREAD, 4 PLY
TREAD, 2 PLY
SIDEWALL, 4 PLY
SIDEWALL, 2 PLY
ROAD TEMPERATURE=102°F
TEMPERATURE, °F
130
120
110
100
90
80
SPEED, MPH
20
30
40
50
60
70
80

FIGURE 11

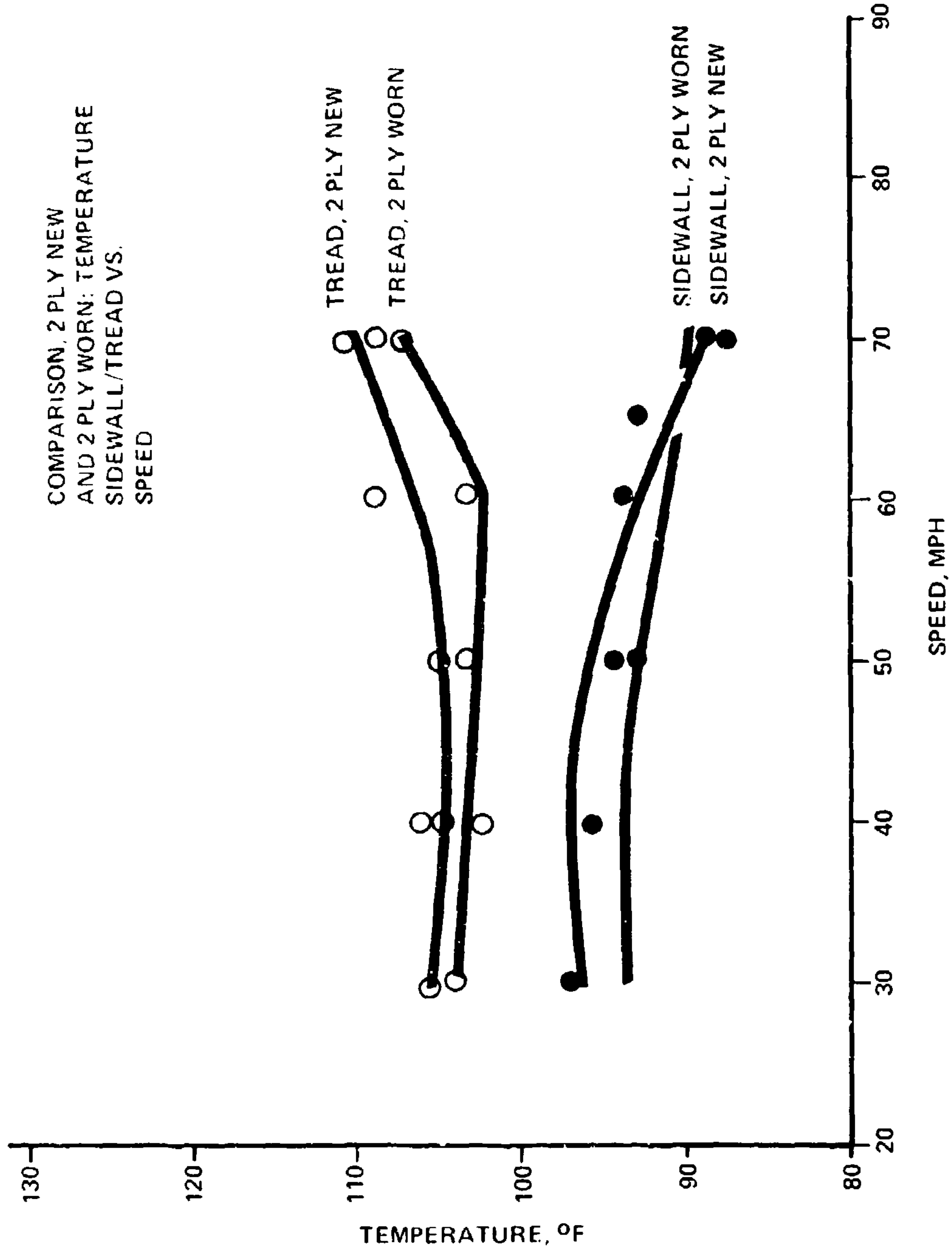

COMPARISON, 2 PLY NEW AND 2 PLY WORN: TEMPERATURE SIDEWALL/TREAD VS. SPEED
TREAD, 2 PLY NEW
TREAD, 2 PLY WORN
SIDEWALL, 2 PLY WORN
SIDEWALL, 2 PLY NEW
130
120
110
100
90
80
TEMPERATURE, °F
20
30
40
50
60
70
80
90
SPEED, MPH

FIGURE 12

SPEED VS TEMPERATURE
SIDEWALL FOR VARIOUS
ROAD SURFACE TEMPERATURES

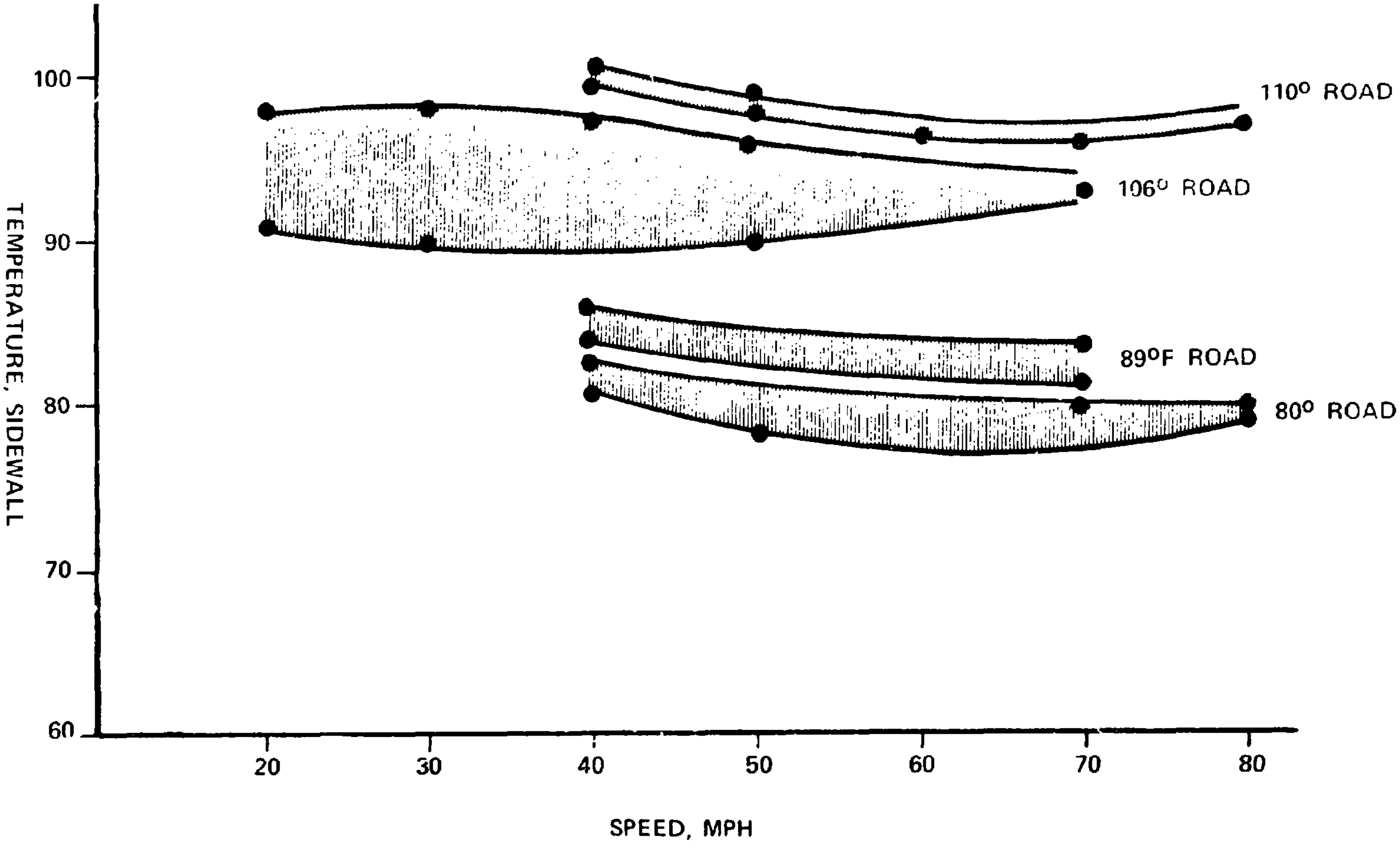


FIGURE 13

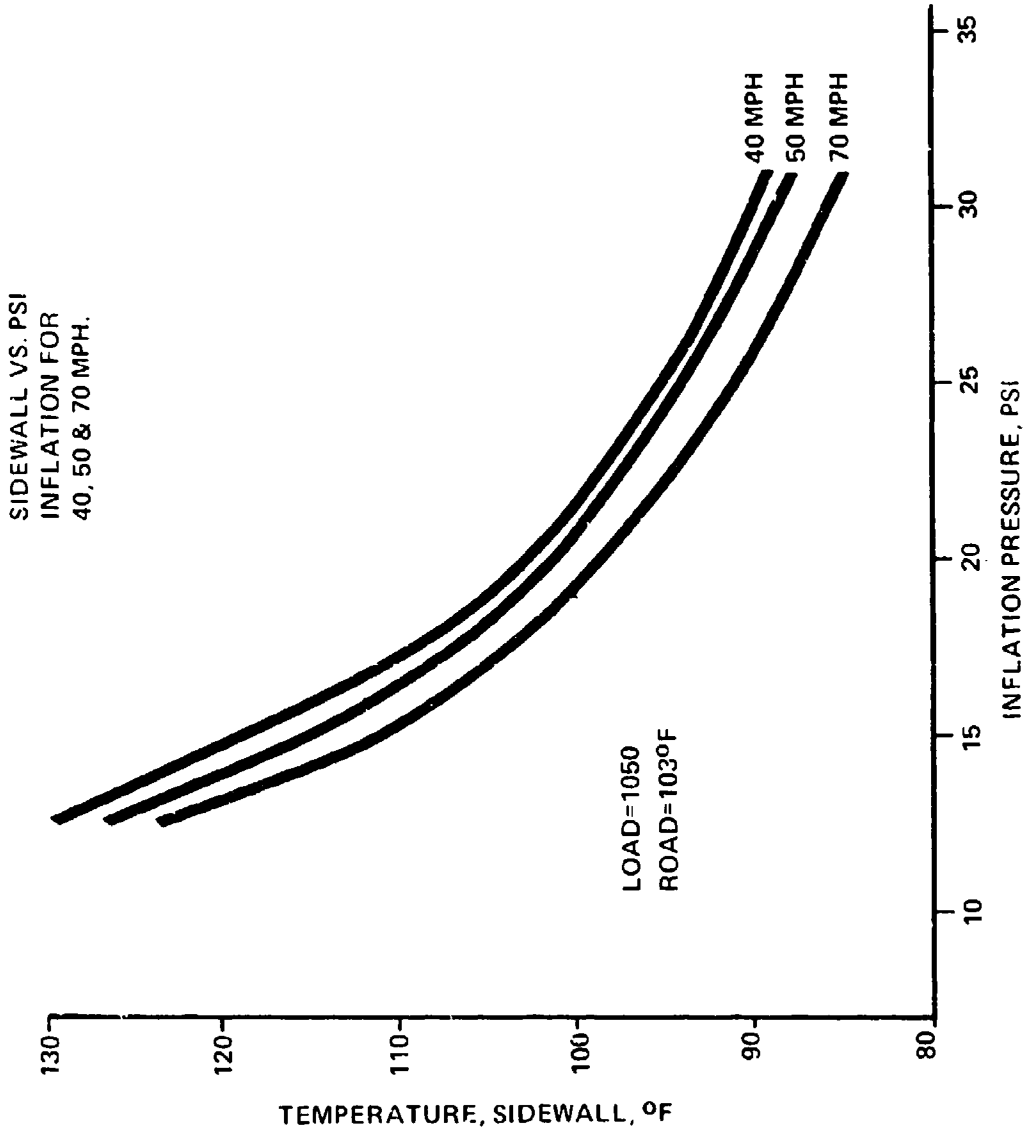

SIDEWALL VS. PSI
INFLATION FOR
40, 50 & 70 MPH.
LOAD=1050
ROAD=103°F
40 MPH
50 MPH
70 MPH
130
120
110
100
90
80
TEMPERATURE, SIDEWALL, °F
10
15
20
25
30
35
INFLATION PRESSURE, PSI

FIGURE 14

TREAD TEMPERATURE VS. SPEED
FOR TIRE PRESSURES OF
14, 20, 26 & 30 PSI

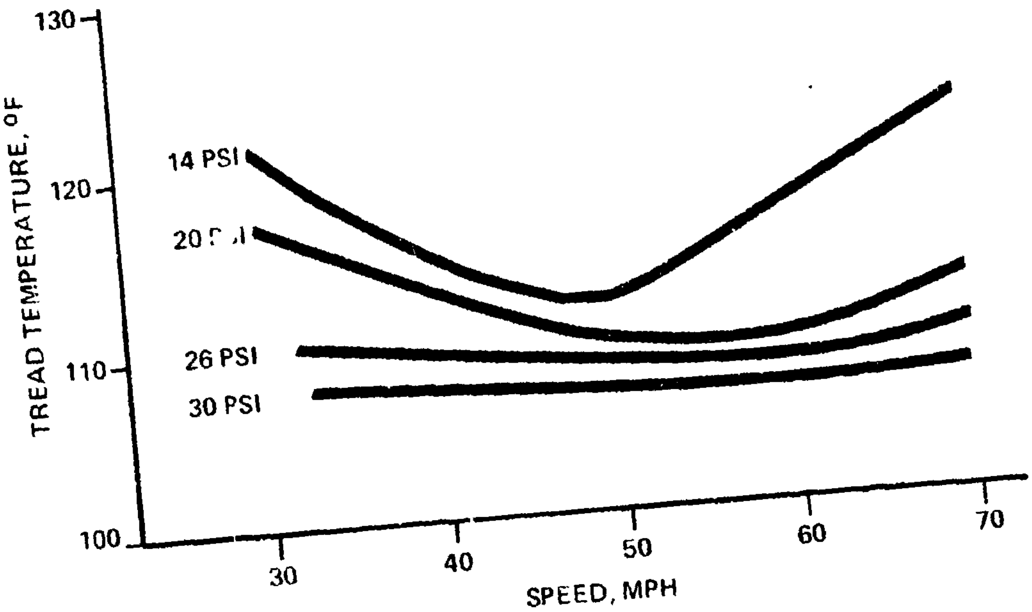
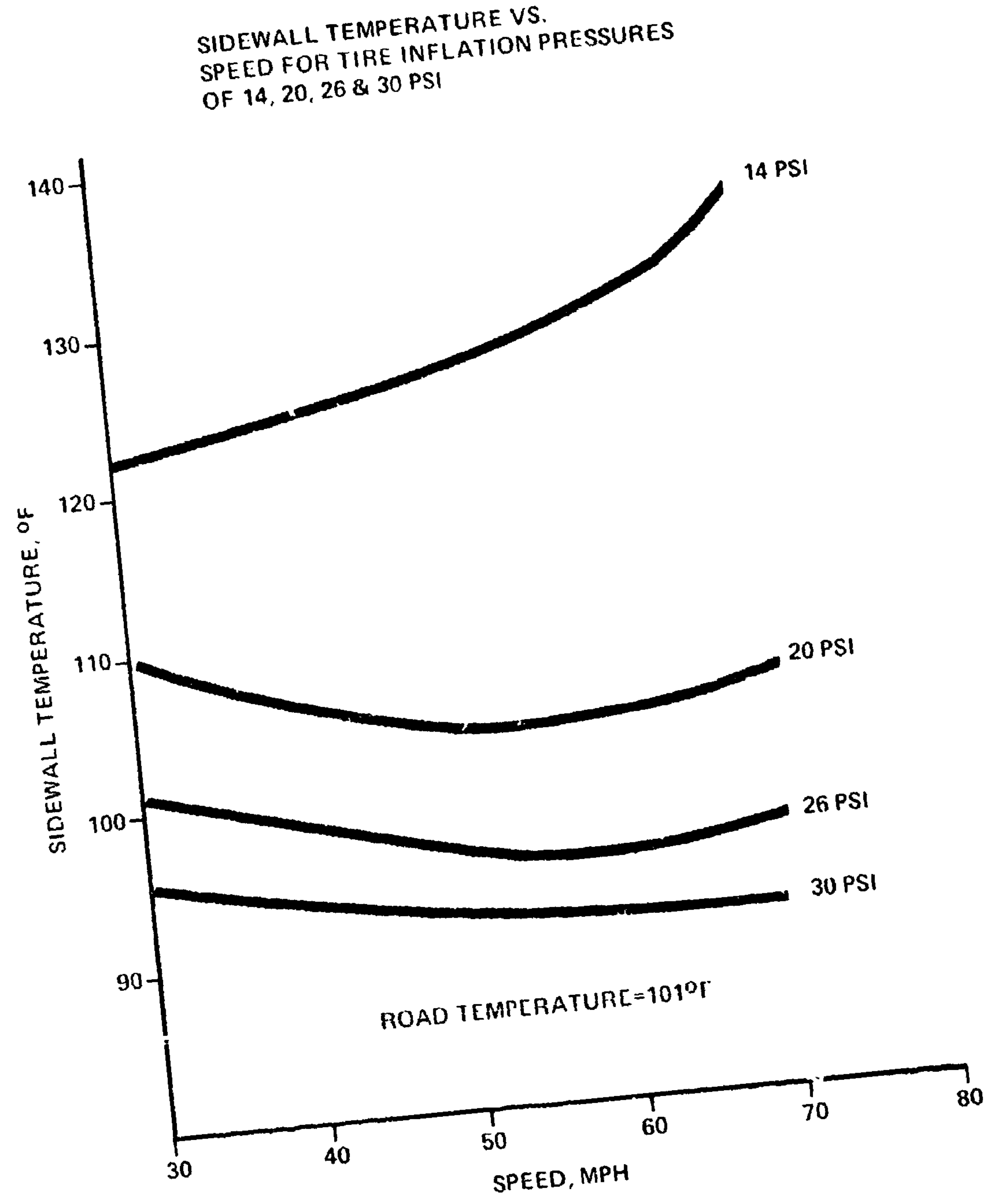


FIGURE 15



SIDEWALL TEMPERATURE VS.
SPEED FOR TIRE INFLATION PRESSURES
OF 14, 20, 26 & 30 PSI
140
130
120
110
100
90
SIDEWALL TEMPERATURE, °F
14 PSI
20 PSI
26 PSI
30 PSI
ROAD TEMPERATURE=101°F
30
40
50
60
70
80
SPEED, MPH

FIGURE 16

TREAD TEMPERATURE VS.
TIRE INFLATION PRESSURES
FOR SPEEDS OF 70, 50 & 40
MPH.

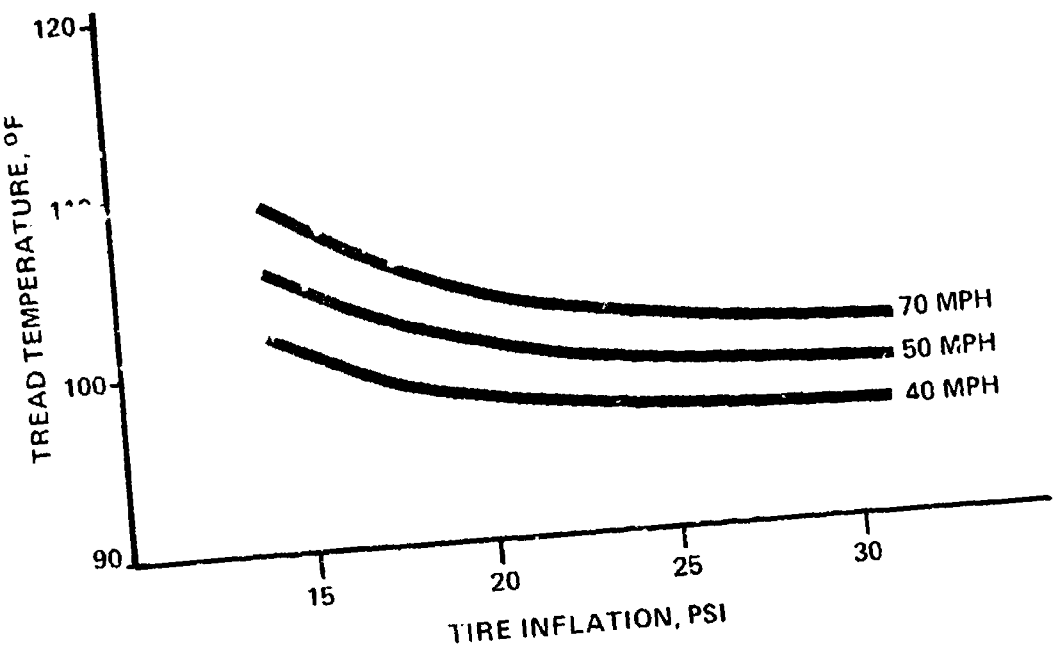
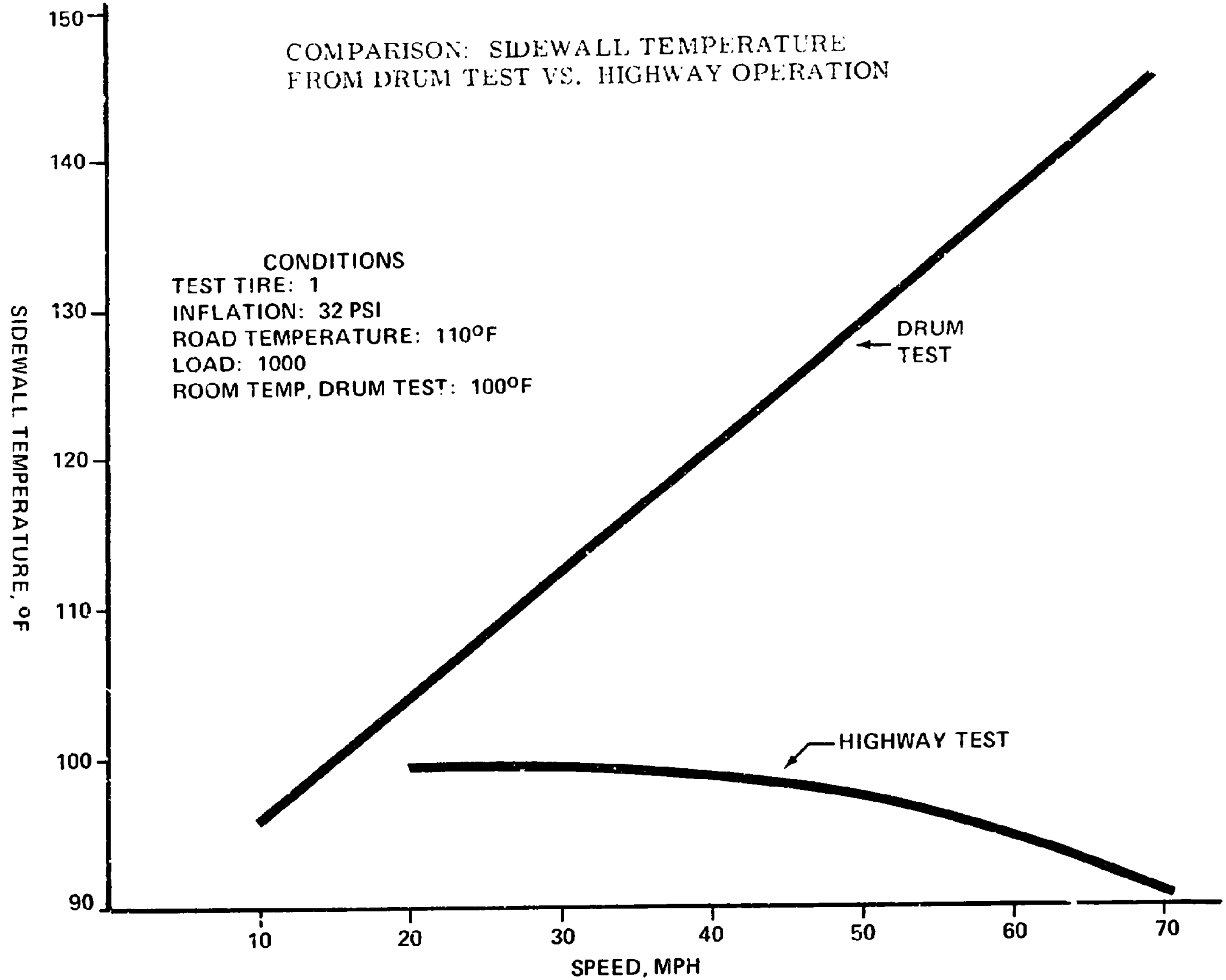
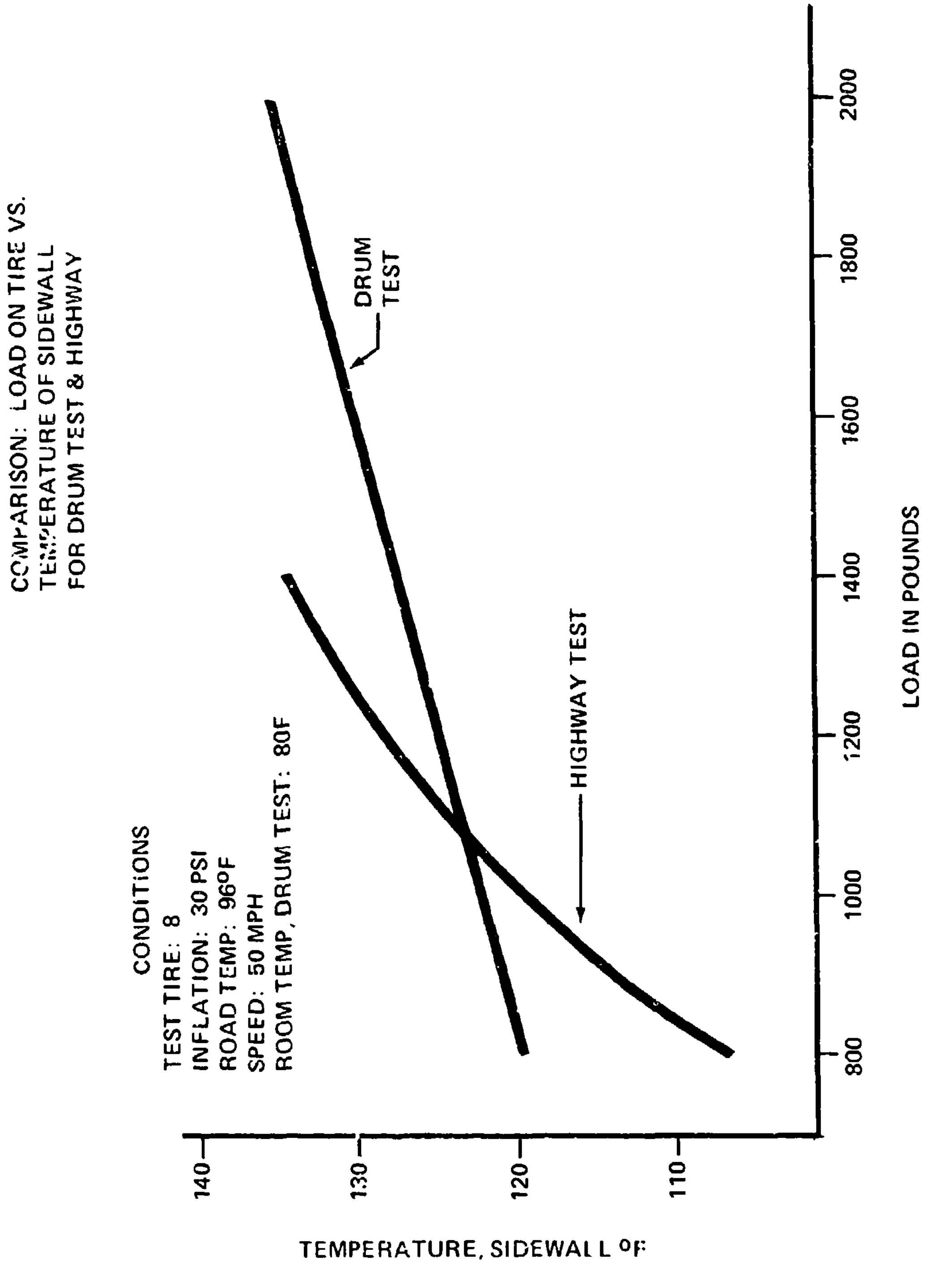


FIGURE 17



COMPARISON: SIDEWALL TEMPERATURE
FROM DRUM TEST VS. HIGHWAY OPERATION
CONDITIONS
TEST TIRE: 1
INFLATION: 32 PSI
ROAD TEMPERATURE: 110°F
LOAD: 1000
ROOM TEMP, DRUM TEST: 100°F
DRUM TEST
HIGHWAY TEST
SIDEWALL TEMPERATURE, °F
150
140
130
120
110
100
90
10
20
30
40
50
60
70
SPEED, MPH

FIGURE 18



COMPARISON: LOAD ON TIRE VS.
TEMPERATURE OF SIDEWALL
FOR DRUM TEST & HIGHWAY
CONDITIONS
TEST TIRE: 8
INFLATION: 30 PSI
ROAD TEMP: 96°F
SPEED: 50 MPH
ROOM TEMP, DRUM TEST: 80F
DRUM TEST
HIGHWAY TEST
140
130
120
110
TEMPERATURE, SIDEWALL °F
800
1000
1200
1400
1600
1800
2000
LOAD IN POUNDS

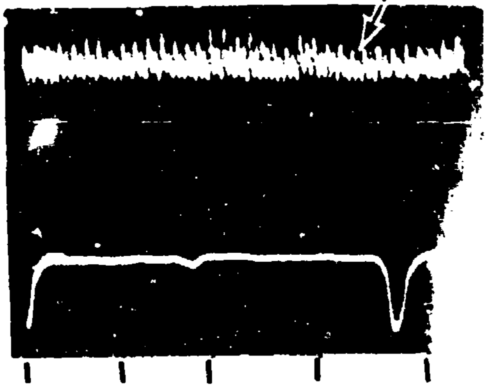
FIGURE 19

CIRCUMFERTIAL TEMPERATURE
PROFILE, TEST TIRE NO. 6

TEST CONDITIONS

50 MPH
1000 LOAD
32 PSI
CEMENT
ROAD=105°F
AIR=80°F

TREAD MODULATION PATTERN

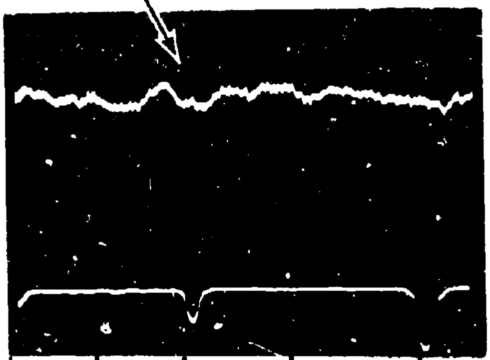


.05V/DIV. VERT.
5 MS/DIV. HORZ.

0 90 180 270 360

DEGREES ROTATION
TREAD

DEFECT AREA



.05V/DIV. VERT.
5MS/DIV. HORZ.

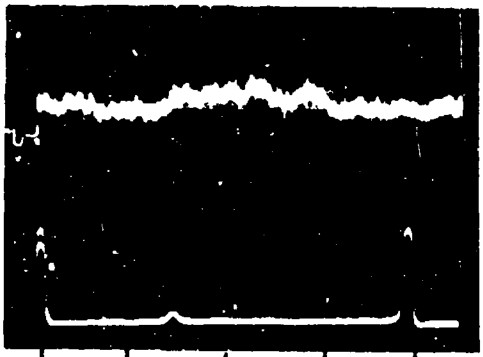
0 90 180 270 360

DEGREES ROTATION
SIDEWALL

FIGURE 20

CIRCUMFENTIAL TEMPERATURE
PROFILE, TEST TIRE NO. 5

TEST CONDITIONS
50 MPH
1000# LOAD
32 PSI
CEMENT
ROAD=108F
AIR=74F

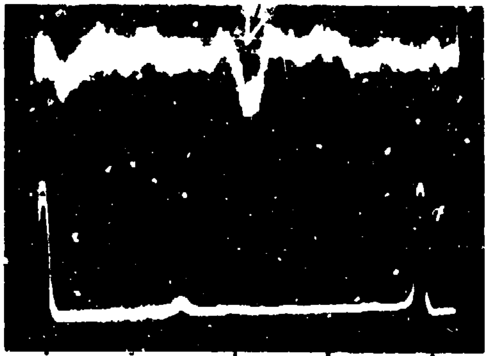


.05V/DIV. VERT.
5MS/DIV. HORZ.

0 90 180 270 360

DEGREES ROTATION
TREAD

DEFECT AREA



.02V/DIV. VERT.
5MS/DIV. HORZ.

0 90 180 270 360

DEGREES ROTATION
SIDEWALL

FIGURE 21

CURCUMFERENTIAL TEMPERATURE
PROFILE OF OUT OF BALANCE
CONDITION, TEST TIRE NO. 1

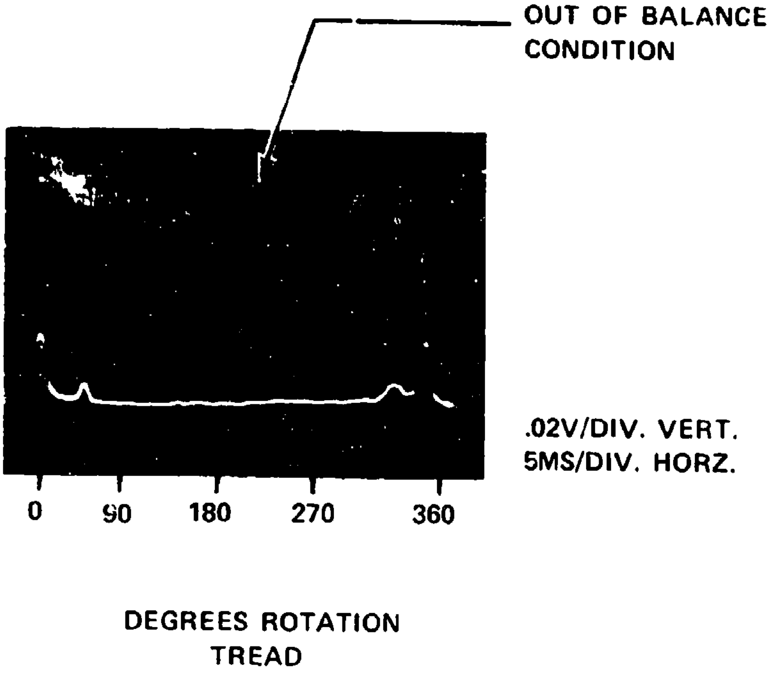
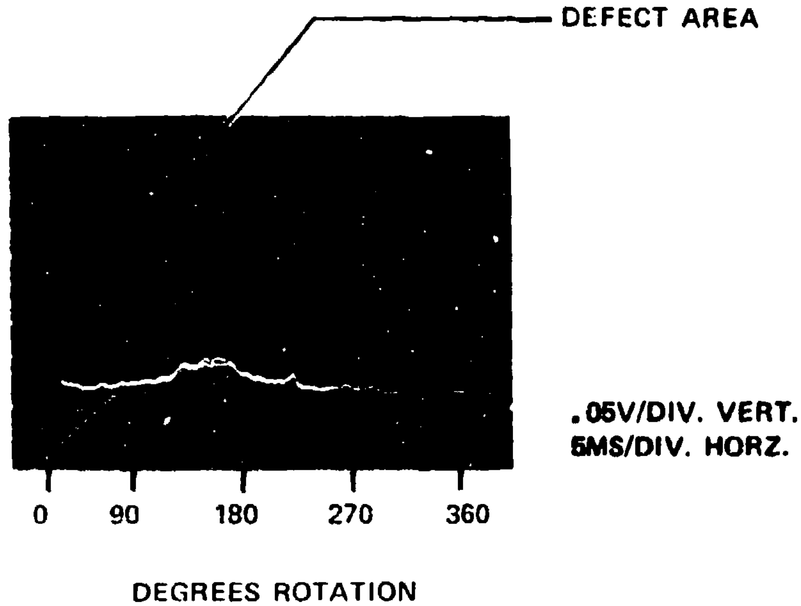


FIGURE 22

CIRCUMFERENTIAL TEMPERATURE PROFILE
OF TREAD AREA, TEST TIRE NO. 2



CONDITIONS OF TEST

70 MPH
1000 LOAD
30 PSI
CEMENT
ROAD=119°F
AIR=88°F

Figure 23

DISCUSSION OF RESULTS

Tire surface temperature can be measured routinely using "averaging" type radiation thermometers such as the devices described in Table I, item 1, 2, and 3. No operational problems occurred utilizing the instrumentation on the outrigger or in the drum room test cell. The data described in this report represents maximum expressway speeds of 80 mph under typical midwest summer conditions.

Road surface temperature, free air temperature, and direct solar heating of tire surfaces influence tire operating temperatures more, under some conditions, than speed or load. Developed tread and sidewall temperatures are directly related to road surface temperature as can be seen in Figure 9, and, road surface temperature is a function of air temperature and solar load as shown in Figure 10.

The road surface heated by solar radiation can therefore be warmer or cooler than free air temperature. After these influencing effects were measured and understood, tire temperature data taken under any environmental condition could be normalized to a standard condition or referenced to a desired road/air temperature combination for data comparison purposes.

The three most important operational factors affecting the temperature of a tire under highway performance are inflation, load and speed, in order of importance. Inflation affects sidewall temperature more than tread temperatures as can be seen in Figure 7. This indicates that the road is able to conduct more heat away from the tread than the sidewall which is interfaced to the cooling air. And, as speed decreases, sidewall temperature increases since there is less available cooling air.

Next in importance is load. As load increases, sidewall and tread temperatures increase (Figure 8) Tread temperature again is influenced more by road surface temperature than from heating as a result of load. The effects of the load are predominantly seen as an increase in sidewall temperature. As the rated load of 1650 pounds is reached, sidewall temperature starts to increase at a more rapid rate indicating the importance of following loading recommendations.

Speed produces the least effect in tire temperature. As speed increases from 30 to 80 mph, a slight cooling effect is noticed in the sidewall area as opposed to a slight heating effect for the tread area (Figure 6).

Tread temperature is less affected by a speed as shown in Figure 17.

Sidewall cooling is a result of the increased air flow at higher speeds. Tread heating at higher speeds is a result of increased friction between road and tire offsetting the cooling effects of ram air.

Effects of inflation, load and speed also can work in combination. As speed increases and road temperature increases, Figure 13 illustrates a corresponding increase in sidewall temperature. Since speed affects tread temperature more than sidewall, Figure 15 shows the effects of speed on tread for reduced inflation pressures. This indicates that low inflation pressure produces elevated tread temperatures as speed increases, especially as compared to a normal inflation pressure which shows little change in tread temperature with increase in speed. Figure 16 shows the same conditions of inflation and speed for the sidewall.

A comparison was also made between operating temperatures of 2-ply and 4-ply tires and new thread and worn (1.8 inch depth) tires (Figures 11 and 12). In general, 2 ply tires run cooler than 4 ply, and worn tires run cooler than new tread tires.

Figures 18 and 19 compare the temperature generated in a tire undergoing highway operation to the same tire run on a drum test machine. It is interesting to note that an entirely different tire temperature history is produced for drum test operations as compared to highway operation. Sidewall temperature increases linearly as a function of speed and load. This is due to the absence of cooling air and effects of the road interface. A temperature "specification" clause in the drum test would therefore require a different set of limiting temperatures as opposed to a road test specification. Since there are few environmental effects to consider when measuring tire temperatures during drum test, operating temperatures for variations in load, speed and inflation can be measured and reproduced with much more accuracy as compared with the highway test.

Temperature monitoring of tires during highway operation also has merit as a means of indicating low inflation, overloading and possible out-of-balance or wobble. For an absolute measure of these conditions, compensation would be required for environmental conditions such as road and air temperature which would act as a thermal bias overriding the effects of low inflation, overload, etc. For example, in the specific case for tire specimen number 8, Table IV shows an expected temperature change in degrees F for various problem conditions as noted:

TABLE IV

TEMPERATURE CHANGES MEASURED IN TEST TIRE NO. 8 FOR LOW INFLATION, OVERLOAD, WOBBLE & OUT OF BALANCE CONDITIONS

^{o}F/500# Overload	^{o}F/5 psi Underflation	^{o}F/5 OZ. Out of Balance	^{o}F/1/8 inch Wobble
18.0	5.5	1.5	1

Tire defects other than massive failures would not normally be detected by the average temperature measuring technique. For this reason, high speed temperature profiling radiometers are used to sense circumferential instantaneous temperature and predict failure based on "hot" or "cold" spots. This technique was first evaluated and reported on in reference 1 and subsequently used in this program to determine if on-board vehicle instrumentation of this type could be used on the highway to monitor tire condition during "real life" conditions. No particular problems were associated with the operation of the instrumentation. Figure 19 indicates a confirmed detection of the built-in defect in Test Tire # 5. Figure 20 indicates a marginal detection of the built-in defect in Test Tire # 6. A summary of the sensory voltages produced in the detection of these faults is shown in Table V.

TABLE V

SIGNAL VOLTAGES SENSED IN DETECTION OF BUILT IN DEFECTS FOR TEST TIRES 5 & 6

	Voltage of Signal Produced by Defect	Millisecond Width of Defect Pulse
Test Tire # 6	+0.2	3
Test Tire # 5	-0.4	2

The thermal modulation effect produced by the tread pattern in military tires and reported on in reference 1 was not observed in the highway tires. Test tire # 6 having a "high traction tread" produced a slight modulation of the circumferential temperature profile as seen in Figure 20, but did not disturb the normal tread profile.

The circumferential profiles of Figure 20 thru 22 were not calibrated in terms of "temperature of defect". This type of calibration is possible but was not warranted for purposes of this test. As indicated in Table V, the defect area was described in terms of a voltage differential between the signal generated by the defect and adjacent "sound" surface.

REFERENCES

1. An Infrared Diagnostic Technique for Evaluation of Automotive Tires, TR11154, December 1970. AD719692. D. K. Wilburn, U. S. Army Tank-Automotive Command, Warren, Michigan 48090.

2. Surface Temperature of Running Tires Using Infrared Scanning, SAE Report No. 700475, May 1970. Firestone Tire and Rubber Co., Akron, Ohio.

3. Thermal Analysis of a Rolling Tire; SAE Report No. 700474, May 1970. B. F. Goodrich Company, Akron, Ohio.

4. Tire Performance Simulator, Rubber World, V158, # 2, May 1968.

5. Labels and Crayons Reduce High Speed Tire Failure, Autoproducts, September 1970.

EXHIBIT P-16 (Part I)　　　　DATE　24 January 1971

PRODUCTION ENGINEERING MEASURES (PEM) PROJECT

RCS CSGLD 1125 (RI)

1. Project No. ____________ 2. PEMA ____________ 3. Cost ________

4. Title. Infrared Road Testing of Pneumatic Tires

5. Facility. U.S. Army Tank Automotive Command, ATTN: AMSTA-RGD. Warren, Michigan 48090

6. Purpose. To apply infrared tire diagnostic techniques devised during FY70 project on tire diagnostics to evaluation of pneumatic tires during road (vehicle) operation. Previous R&D effort has developed infrared instrumentation and techniques to diagnose pneumatic tires during dynamometer operation. The same instrumentation and techniques will be utilized for the road operation tests. Utilization of the infrared method of tire diagnostics as an on-board tire sensory system for road operations is proposed as the most direct and scientific method of studying the following tire performance and endurance factors:

   a. Relationship of road temperatures to tire operating temperature.

   b. Thermal effects of road hazards on tire temperature profiles.

   c. Comparison of tire dynamometer temperature data to road operational data for comparative tires, speeds and loads.

   d. Study of impact energy on tire failures.

7. Objective/benefits.

   a. This program will support all wheeled vehicles using pneumatic tires. It will also aid the army tire procurement/development program by supplying basic operational data on actual tire performance versus dynamometer testing techniques.

   b. The goal of this program will be to supply data to be used in the development of an infrared specification test for pneumatic tires.

8. Item(s) supported. Military tires, general purpose, cross-country and passenger, sizes 14-inch to 28-inch.

9. Current and projected requirements. Specification requirements for destruction of the tire after dynamometer operation as a means of visually determining tire integrity. The infrared method of diagnostics during dynamometer operation would reduce the number of sound tires destroyed for inspection purposes.

10. Description of work.

    a. Infrared tire analysis is a method of measuring the temperature profile and thermal pattern generated by a tire under load and in operation. Unique temperature patterns are analyzed in terms of tire defects. USATACOM in Report TR11154 describes the results of the infrared diagnostic tests run on the dynamometer.

    b. The proposed continuation effort will utilize the techniques, equipment and technical lessons learned and apply this to the road where the IR equipment will be carried on-board the test vehicle to analyze the effects of road operation on tire integrity.

11. End products from project. See Inclosure 1.

12. Detailed cost summary. See Inclosure 2.

13. Time phasing. See Inclosure 3.

14. Related efforts. See Inclosure 4.

15. Remarks. None.

END PRODUCTS FROM PROJECT

The end product will be a formal technical report incorporating data obtained, interpretating and analysis. Secondary results will be seen in the concept of an IR specification for tire testing.

DETAILED COST SUMMARY

COST BY ITEM*

	Government	Contractor	Total
Equipment design	$ 745.00	0	$ 745.00
Equipment fabrication	1,777.00	"	1,777.00
Equipment installation	573.00	"	573.00
Pilot production lines		"	
Procurement packages		"	
Equipment acquisition		"	
Other (Travel)	500.00	"	500.00
TOTAL	$ 3,595.00	0	$ 3,595.00

COST BY TYPE*

	Government	Contractor	Total
Direct material	$ 1,200.00	0	$ 1,200.00
Contracted work		"	
Direct manufacturing labor	21,502.00	"	21,502.00
Other factors		"	
Profit or fee		"	
TOTAL	$ 22,702.00	0	$ 22,702.00

EXPENDITURE BY FISCAL YEAR

	Prior FY		Budget FY		Future FY
	FY 69	FY 70	FY 69	FY 70	FY 71
PEMA	$0	$44K	$0	$44K	$26K
R&D	$0	$0	$0	$0	$0

* Including O. M. of A. Current hourly average rate is $ 28.67/hr.

TIME PHASING

Design and construction of test rig	Jul. 71 - Sep. 71
Calibration and instrumentation	Sep. 71 - Oct. 71
Initial road operations	Oct. 71 - Nov. 71
*Road program	Apr. 72 - Jul. 72
Report	Aug. 72 - Sep. 72

* Road operations must be conducted during nominal summer conditions, +45 to +85^{o}F.

RELATED EFFORTS

None in-house. Several infrared dynamometer test operations in progress by tire manufacturers and Dept. of Transportation. Close coordination maintained at DOT.