Tire Parameter Determination:
Volume I – Summary
NTIS, November 1976

PB 263 440

DOT HS-802 086

TIRE PARAMETER DETERMINATION
Volume I-Summary

Contract No. DOT-HS-4-00923
November 1976
Final Report

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Washington, D.C. 20590

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. DOT HS-802 086	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TIRE PARAMETER DETERMINATION Volume I - Summary		5. Report Date November 1976
		6. Performing Organization Code
7. Author(s) D. J. Schuring		8. Performing Organization Report No. ZM-5563-T-1
9. Performing Organization Name and Address Calspan Corporation 4455 Genesee Street Buffalo, New York 14221		10. Work Unit No.
		11. Contract or Grant No. DOT-HS-4-00923
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration U.S. Department of Transportation Washington, D.C. 20590		13. Type of Report and Period Covered Final Report 7/1/74 - 12/31/75
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Program Objective: To generate a comprehensive body of the major force and moment characteristics of passenger car and light truck tires currently distributed in USA, and to present them in a form suitable for vehicle handling computer simulations.

Major Program Elements: (1) Ranking of tire construction and performance parameters with respect to their influence on vehicle handling and control, to prevent testing for second and third order effects; (2) Selection of about 400 tires representing the current population of OE and replacement tires in USA; (3) Proof of good correlation between tire data measured on Calspan's Tire Research Facility and corresponding data measured on a passenger car; (4) Preparation of an empirical tire model; (5) Development of a test program; (6) Presentation of test results in a form readily applicable to tire studies and computer modeling.

Volume I - Summary
Volume II - Technical Report, Part 1 (Test Methodology)
Volumes III through IX - Technical Report, Part 2 (Tire Test Data)

17. Key Words Tires, cornering properties, braking properties, test equipment, computer models.	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified

Form DOT F 1700.7 (8-69)

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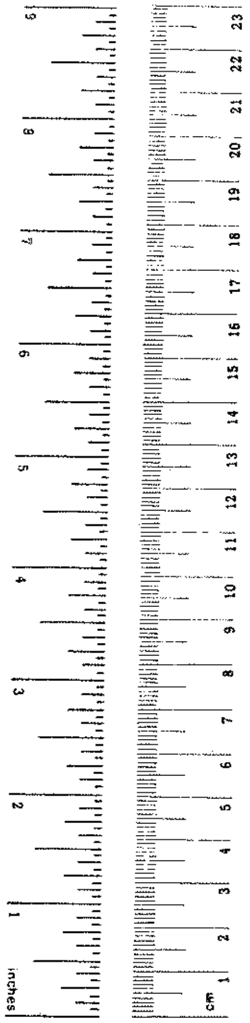
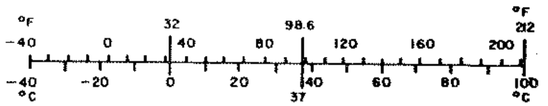
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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



PREFACE

The work reported herein was performed by the Calspan Corporation for the National Highway Traffic Safety Administration (NHTSA) under Contract No. DOT-HS-4-00923 during the period from 1 July 1974 to 31 December 1975. The NHTSA contract technical manager was Mr. Manuel J. Lourenco of the Office of Operating Systems Research, Research Institute. The project engineer was Dr. Dieterich J. Schuring of the TIRF Center of Calspan. The test program was performed under Mr. Ignaty Gusakov, Technical Manager, TIRF Center; data processing was handled by Mr. Dennis T. Kunkel.

The complete project is reported in nine separate volumes.

Volume I - Summary Report
Volume II - Technical Report, Part 1 (Test Methodology)
Volumes III through IX - Technical Report, Part 2 (Tire Test Data)

This volume contains a concise summary of the test methodology and of the major conclusions of the program.

This report has been reviewed and approved by

K. D. Bird

K. D. Bird, Director
TIRF Center

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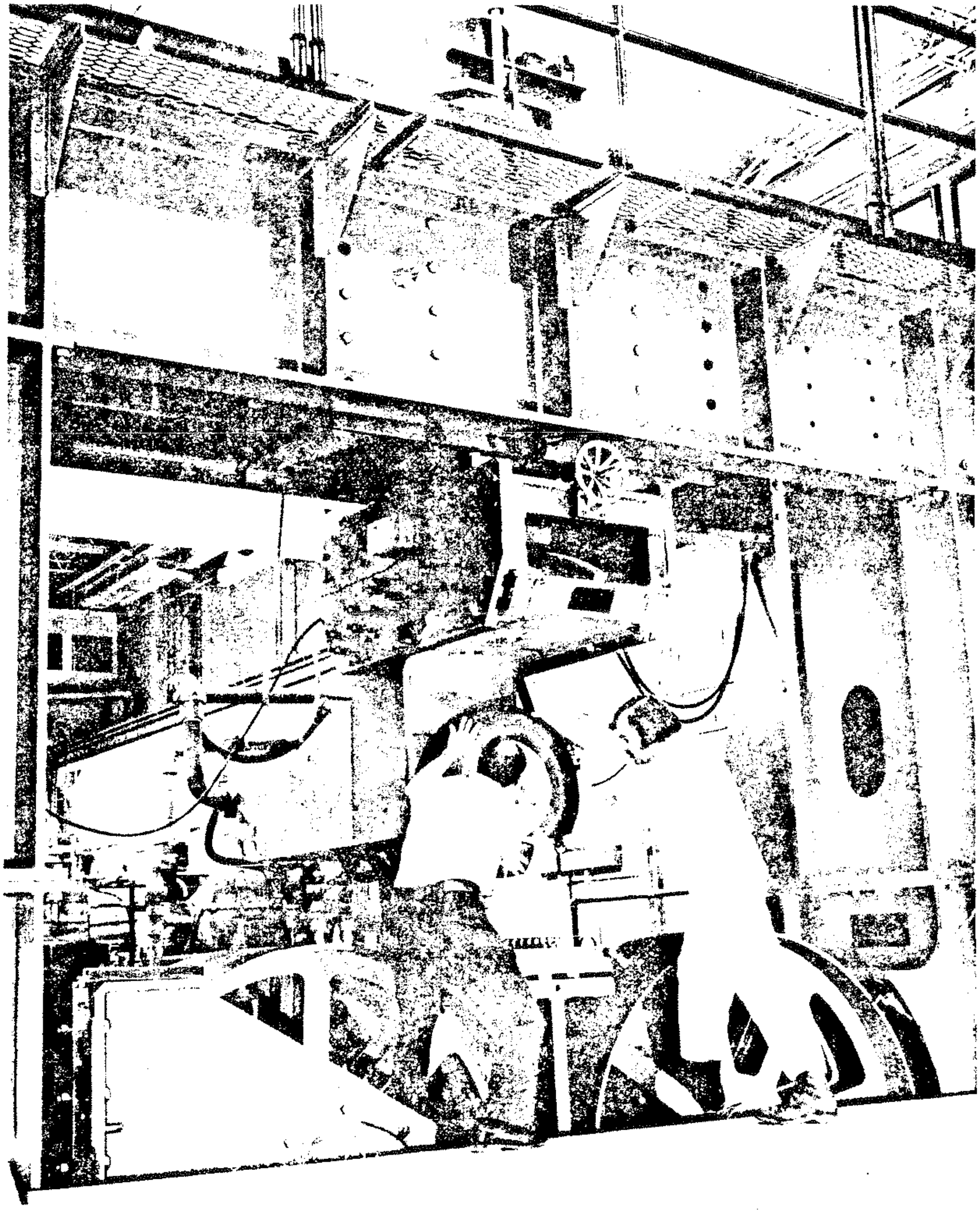


CALSPAN TIRE RESEARCH FACILITY (TIRF)

1.0 INTRODUCTION

This short report gives an overview of a test program conducted on Calspan's Tire Research Facility (TIRF) to generate the major force and moment characteristics of currently manufactured tires. The forces and moments and their derivatives were to be used as realistic tire input information for complex vehicle computer modeling.

Computer models such as the NHTSA/APL Hybrid Computer Vehicle Handling Model have been advanced to the point where complicated handling and stability situations can be simulated realistically, provided sufficient up-to-date, quantitative tire data are available. However, existing tire data proved to be seriously lacking in accuracy and parameter range, as well as in their ability to reflect the performance characteristics of the current tire population. Over the past decade, tire designs have undergone many changes in construction (four ply, two ply), cord materials (nylon, rayon, polyester), construction type (bias ply, bias belted, radial ply), belt materials (fiberglass, steel, high performance organic), aspect ratio (from 84 or higher to 50), etc., and it is expected that these changes will continue, promoted by regulatory safety considerations, the energy shortage with its trend toward smaller cars, economic reasons (elimination of the spare tire), and the usual competitive forces of the market place. The tire test methodology developed in this program is applicable to any tire designs contemporary as well as new ones as they are produced.

The objective of this program – the generation of a body of contemporary tire data that could be readily used in sophisticated computer simulation and that would realisitically represent the road performance of tires of all sizes and types covered by FMVSS 109 and 119 (with the exception of large truck tires) – called for the development of a comprehensive test methodology. It entailed

- Ranking of tire parameters with respect to their importance in vehicle handling and control, to prevent testing for second and third order effects and to keep the investigation focussed on the parameters of critical importance. The term "parameter" covers here both tire design parameters (such as size, construction type, and cord material) as well as tire performance parameters (such as cornering stiffness, aligning torque, and slide braking coefficient).

- Selection of about 400 tires from currently available tire types. The selected sample had to represent the current distributions of critical design and construction parameters as well as their anticipated changes in the near future.

- Proof of good correlation between tire performance data measured on Calspan's Tire Research Facility and corresponding data obtained from a passenger car on the road.

- Preparation of an empirical tire model for computer use that would realistically express the critical performance parameters of each individual tire tested.

- Design of a tire test program that would permit rapid acquisition of all tire data of importance on TIRF.

- Development of a test technique that would assure consistent, good quality of all data measured.

- Presentation of test results in a form readily applicable to tire studies and computer modeling.

- Conclusion and recommendations for future research.

Each of these points is treated in a separate section of the Technical Report, Part I. Part II, containing Volumes III through IX , presents the test results.

2.0 RANKING AND SELECTION OF TIRE PARAMETERS

There are two basic types of tire parameters that are influencing vehicle stability and control: design and construction parameters, and performance parameters.

The design and construction of tires cannot be fully described without a detailed analysis of all their physical and chemical properties – a very costly and time-consuming procedure. To keep identification efforts on a reasonably low level, we restricted ourselves to those design and construction descriptors that are directly accessible, i.e., to data molded on sidewalls, listed in tire specifications, and available from simple tire measurements.

An extensive evaluation of pertinent literature showed that, with respect to handling and control of passenger cars, these design factors could be divided into those of primary and secondary importance, Table 1.

Tire Design and Construction Parameters	
Primary	Secondary
Construction Type	Number of Plies
Aspect Ratio	Tread Contour
Load Range (if applicable)	Tread Pattern (Dry)
Rated Load	State of Wear (Dry)
Cord Material	
Wheel Dimensions	
Tread Compound (If available)	
Tread Pattern (Wet)	
State of Wear* (Wet)	

*Of increasing importance at increasing tread loss

TABLE 1 TIRE DESIGN AND CONSTRUCTION PARAMETERS AND THEIR ESTIMATED INFLUENCE ON VEHICLE HANDLING

An evaluation of the importance of tire performance parameters with respect to vehicle stability and control resulted in Table 2, with three levels of influence. From Tables 1 and 2, the most important parameters were combined into Table 3, to serve as major input in the actual tire test program.

Tire Performance Parameters		
Primary	Secondary	Tertiary
Normal Force, F_z	Overturning Moment, M_x	Rolling Resistance Moment, M_y
Longitudinal Force, F_x	Inclination Angle, γ	Loaded Radius, R_L
Lateral Force, F_y	Road Speed (Dry), v	Road Skid Number (Dry) SN
Aligning Torque, M_z	Water Thickness,** δ	Temperature,* θ
Slip Angle, α		
Longitudinal Slip, s		
Inflation Pressure, p		
Road Skid Number (Wet), SN		
Road Speed (Wet), v		

* Not subject to systematic study in this program

**Up to definite limits where the effects then become of primary importance

TABLE 2 TIRE PERFORMANCE PARAMETERS AND THEIR ESTIMATED INFLUENCE ON VEHICLE HANDLING

Test Parameters		
Design and Construction	Performance and Operation	
Construction Type	Normal Force,	F_z
Aspect Ratio	Slip Angle,	α
Load Range (Truck Tires)	Longitudinal Slip,	s
Rated Load	Inclination Angle,	γ
Cord Material	Inflation Pressure,	p
Wheel Diameter	Road Speed (Wet),	v
State of Wear	Road Skid Number (Wet),	SN
Tread Pattern (Wet)	Water Thickness,	δ

TABLE 3 PARAMETERS OF TIRE DESIGN AND CONSTRUCTION, AND PERFORMANCE AND OPERATION, SELECTED FOR TESTING

3.0 SELECTION OF A REPRESENTATIVE TIRE SAMPLE

The program Work Statement called for testing a tire sample of about 400 passenger car, multipurpose, and light truck tires. Selection of the sample was to be guided by the

- Scope of tires covered by FMVSS 109 and 119
- Distribution of tire designs and sizes currently manufactured
- Future trends in tire development

An extensive survey was made of current OE and replacement tires distributed in the USA, with the help of statistical publications of RMA, T&RA, tire companies, etc. Future trends were factored in by a comparative analysis of past and current market distribution. As a result, a tire matrix of about 380 tires evolved, representing all of the important (important, with respect to vehicle performance) tire features and trends of the near future tire population in USA. Table 4 shows the distribution of construction types; Table 5, the distribution of cord materials; Table 6, the distribution of tire sizes. In all three tables, percentages estimated for 1976 (in parentheses) are compared with those of actually procured tires. In general, there is close agreement between the distributions desired and those achieved.

	Passenger Car			Light Truck and Mobile Home
Construction	Highway	Snow	Total	
Bias Ply	19.0 (15.4)	1.9 (1.8)	20.9 (17.2)	7.1 (7.6)
Bias Belted	25.1 (28.5)	1.1 (1.2)	26.2 (29.7)	0.5 (0.7)
Radial Ply	38.4 (40.1)	5.3 (2.5)	43.7 (42.6)	1.6 (2.1)
	82.5 (84.0)	8.3 (5.5)	90.8 (89.5)	9.2 (10.4)

TABLE 4 DISTRIBUTION OF PASSENGER CAR,
LIGHT TRUCK AND MOBILE HOME
TIRES (IN %) - Construction Types
( ) - Estimated for 1976
Open Numbers - procured and tested
Total number of tires procured - 378

	Cord Material	Passenger Car		Light Truck and Mobile Home	
		Carcass	Belt	Carcass	Belt
Bias Ply	Polyester	12.7 (10.2)		0.3 (1.5)	
	Nylon	5.6 (6.0)		6.9 (6.0)	
	Rayon	2.6 (1.1)			
	HP Organic			— (0.21)	
Bias Belted	Polyester	24.3 (26.0)		— (0.3)	
	Nylon	1.9 (1.5)		0.5 (0.4)	
	Rayon	— (2.1)	— (2.2)		
	Fiberglass		22.5 (27.4)		0.5 (-)
	Steel		3.7 (-)		– (0.7)
Radial Ply	Polyester	23.5 (33.3)		0.8 (0.1)	
	Nylon	0.3 (0.7)		— (1.7)	
	Rayon	19.8 (5.4)	9.8 (3.5)		
	Fiberglass	— (1.0)	— (3.7)		
	Steel		32.8 (32.5)	0.8 (—)	1.6 (2.0)
	HP Organic	— (2.3)	1.1 (3.0)	— (0.2)	

TABLE 5 DISTRIBUTION OF PASSENGER CAR, LIGHT TRUCK AND MOBILE HOME TIRES (IN %) - Cord Materials
( ) - Estimated for 1976
Open Numbers - procured and tested
Total number of tires procured - 378

	Wheel Diam. in	Aspect Ratio (Passenger Car)					
		Balloon	Metric	60	70	78	84
Bias Ply	12	0.3 (-)					
	13	1.3 (1.3)		0.3 (-)	0.5 (0.3)	2.9 (2.1)	
	14	2.1 (2.4)		0.3 (0.3)	1.6 (0.5)	5.6 (6.4)	
	15	1.1 (0.8)		0.3 (-)	0.5 (-)	4.2 (3.7)	
Bias Belted	12						
	13				0.5 (0.5)	1.1 (1.3)	
	14			1.1 (-)	2.4 (1.9)	9.8 (9.8)	
	15			1.1 (-)	0.3 (0.3)	9.5 (13.6)	0.5 (-)
Radial Ply	12		0.3 (-)				
	13		3.4 (3.7)	0.3 (-)	1.3 (1.6)	1.6 (1.3)	
	14		2.9 (1.9)		5.3 (4.3)	6.9 (5.9)	
	15		2.6 (3.5)		5.6 (10.9)	13.5 (12.2)	

		Load Range	
		C	D
Light Truck + Mobile Home	14	0.3 (0.3)	0.3 (-)
	14.5		— (1.4)
	15	3.4 (3.0)	0.5 (0.3)
	16	1.3 (1.5)	1.6 (1.6)
	16.5	0.5 (0.6)	1.3 (1.1)

TABLE 6

DISTRIBUTION OF PASSENGER CAR, LIGHT TRUCK AND MOBILE HOME TIRES (IN %) - <u>Size</u>

( ) - Estimated for 1976
Open Numbers - procured and tested
Total number of tires procured - 378

4.0 TIRF/ROAD CORRELATION STUDY

The program called for a demonstration of the degree of agreement achievable between tire force and moment data measured on TIRF and corresponding data measured on a passenger car on the road. Before commencing the correlation testing, a review of pertinent literature was made to

- check the state-of-the art of measuring tire performance data "on the road"
- ascertain the degree of agreement achieved between corresponding tire performance data measured on various indoor and outdoor facilities including passenger cars
- delineate the level of effort necessary to establish reliable correlations between tire performance data measured on TIRF and on a passenger car.

It was concluded from this review that no inherent systematic deviations existed between corresponding tire data measured on the various indoor and outdoor test facilities but that there were severe limitations for most road machines (particularly in passenger cars) caused by data scatter (noise) and lack of proper instrumentation.

Following the review, a three-step test program was set up to include

- TIRF/passenger car steady-state correlation tests
- TIRF/passenger car nonsteady-state correlation tests
- TIRF-simulated transient tire tests.

In the steady-state tests, a 1973 Ford Galaxie was instrumented at its right rear wheel position with a Lebow three-axis force sensor and a GM-developed vehicle slip angle transducer, and run on a 400-ft diameter circle at speeds from zero up to the limit of adhesion. A large range of tire forces and corresponding vehicle slip angles were covered and recorded. A series of "steer" corrections had to be applied to the measured vehicle slip angles to reduce them to equivalent tire slip angles. In addition, the tire camber angle, which could not be measured, had to be estimated.

For comparison, the same tire (G78-14 bias belted) used for vehicle tests was run under similar conditions on TIRF. Figure 1 shows lateral force and tire slip angle data measured on TIRF under the same loads and camber angles as experienced on the vehicle. Corresponding vehicle data are presented in two bands (indicating vehicle data scatter) for two extreme sets of "steer" corrections. In view of the many uncertainties and experimental errors involved in the vehicle tests, the agreement between vehicle and TIRF tests must be considered good.

In the nonsteady-state tests, the instrumented Ford Galaxie was driven through a modified double-lane change type test course with tire forces, lateral acceleration, speed, vehicle slip angle, etc. recorded throughout the maneuvers. More than 20 runs were made at different speeds with different tires. Three tires, size G78-14, were tested: a bias ply, a bias-belted, and a radial ply tire. "Steer" corrections and camber angle estimates were applied to the vehicle raw data in the same manner as they were in the steady-state tests, to relate the tire forces directly to tire slip and inclination angles.

The same tires used in vehicle tests were tested on TIRF in steady-state fashion, under similar slip angle - camber angle - load - speed conditions, and the results compared with vehicle test results. Of 21 vehicle runs, 7 had to be excluded from comparisons because of malfunctionings of the vehicle slip meter. Five runs showed very good correlation with TIRF data over the whole slip angle range between ±6°, and nine runs showed good correlation over large parts of the range except for some deviations at the extreme ends. The deviations were assumed to be a consequence of the often poor performance of the slip meter, which according to its manufacturer was not intended to be used for dynamic measurements. Figure 2 shows typical "good" correlation results.

Transient tire tests were performed on TIRF to explore the influence of slip angle and load rates on tire response. Both input variables were changed simultaneously so as to simulate in real time the maneuvers performed in the nonsteady-state vehicle tests. Vertical force and slip angle recordings of a few typical, but severe, vehicle runs were introduced into the TIRF control system and applied to three tires identical with those used in nonsteady-state tests. The transient lateral force response of these tires (transient, because of the high-rate changes of slip angle and load in the simulations) was then compared with their steady-state response (also measured on TIRF in separate tests). Figure 3 shows that as the simulation proceeds, the transient lateral force performs a number of hysteresis-like loops — a consequence of the lagging response of tires to rapid changes of slip angle and load. The lag results in severe force offsets of up to ±90 lb (offsets, with respect to the steady-state response), with conceivably significant consequences for the dynamic behavior of vehicles in rapid maneuvers.

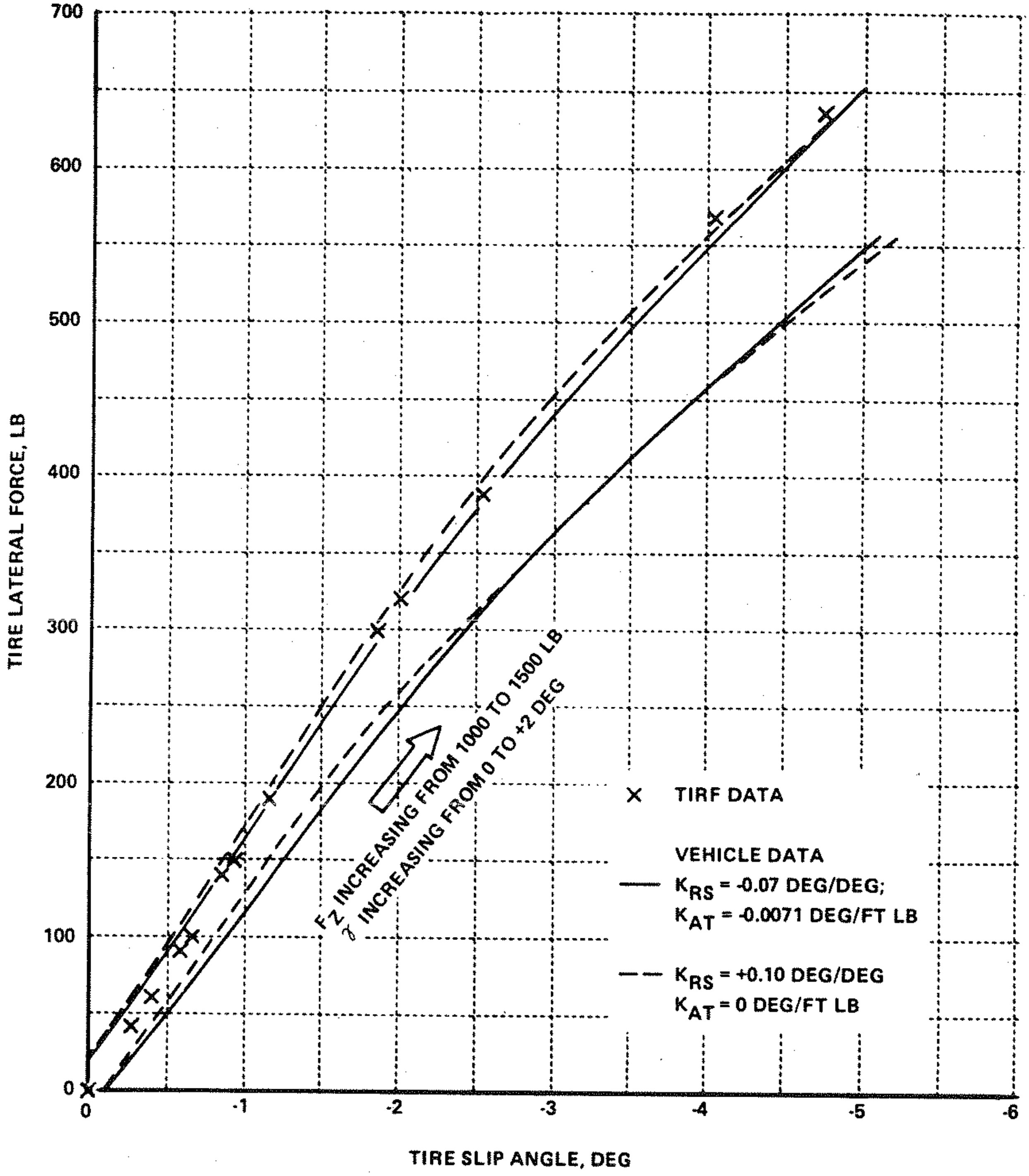


Figure 1 TIRE SLIP ANGLE VS LATERAL FORCE

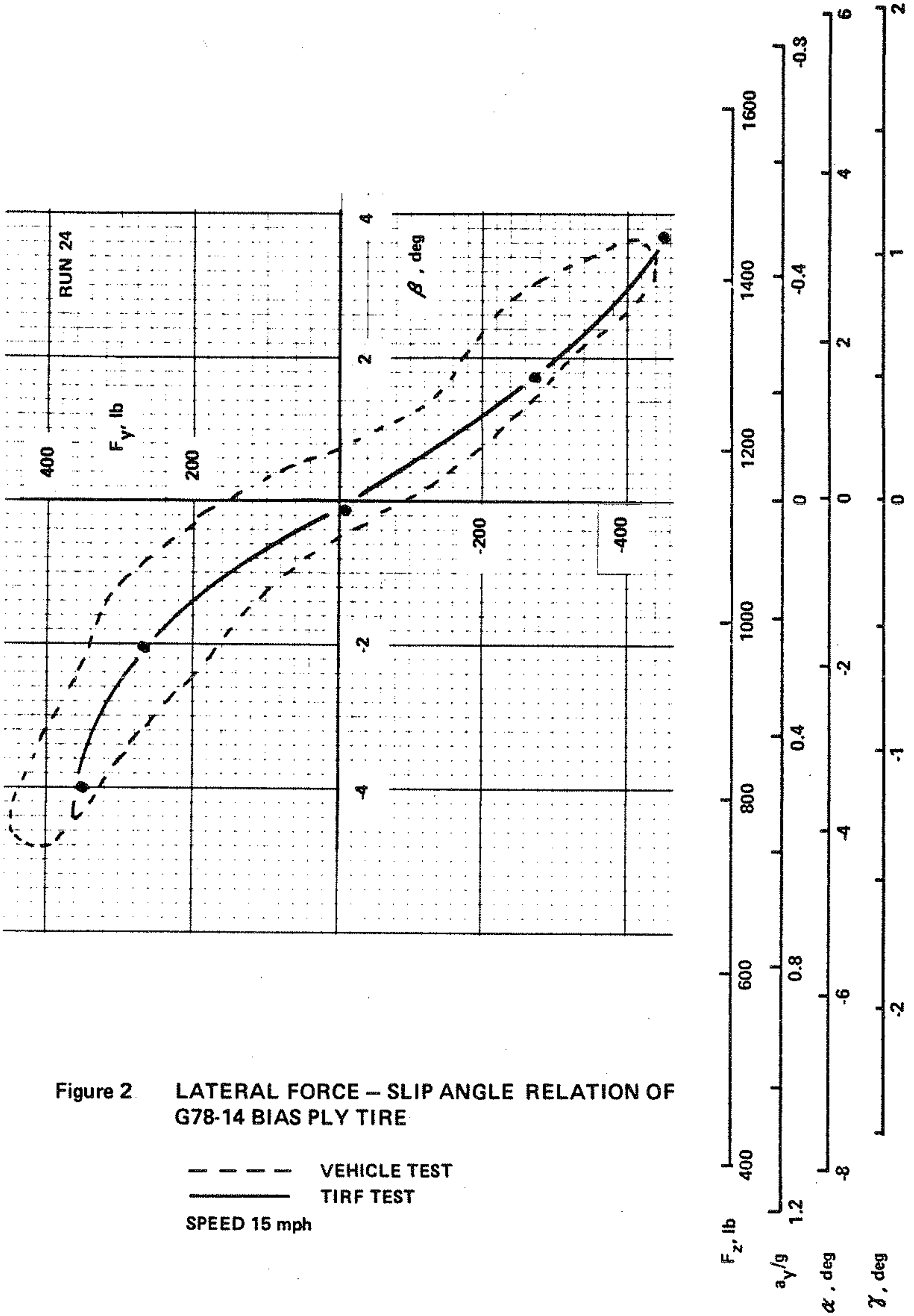


Figure 2 LATERAL FORCE – SLIP ANGLE RELATION OF G78-14 BIAS PLY TIRE

– – – – VEHICLE TEST
———— TIRF TEST

SPEED 15 mph

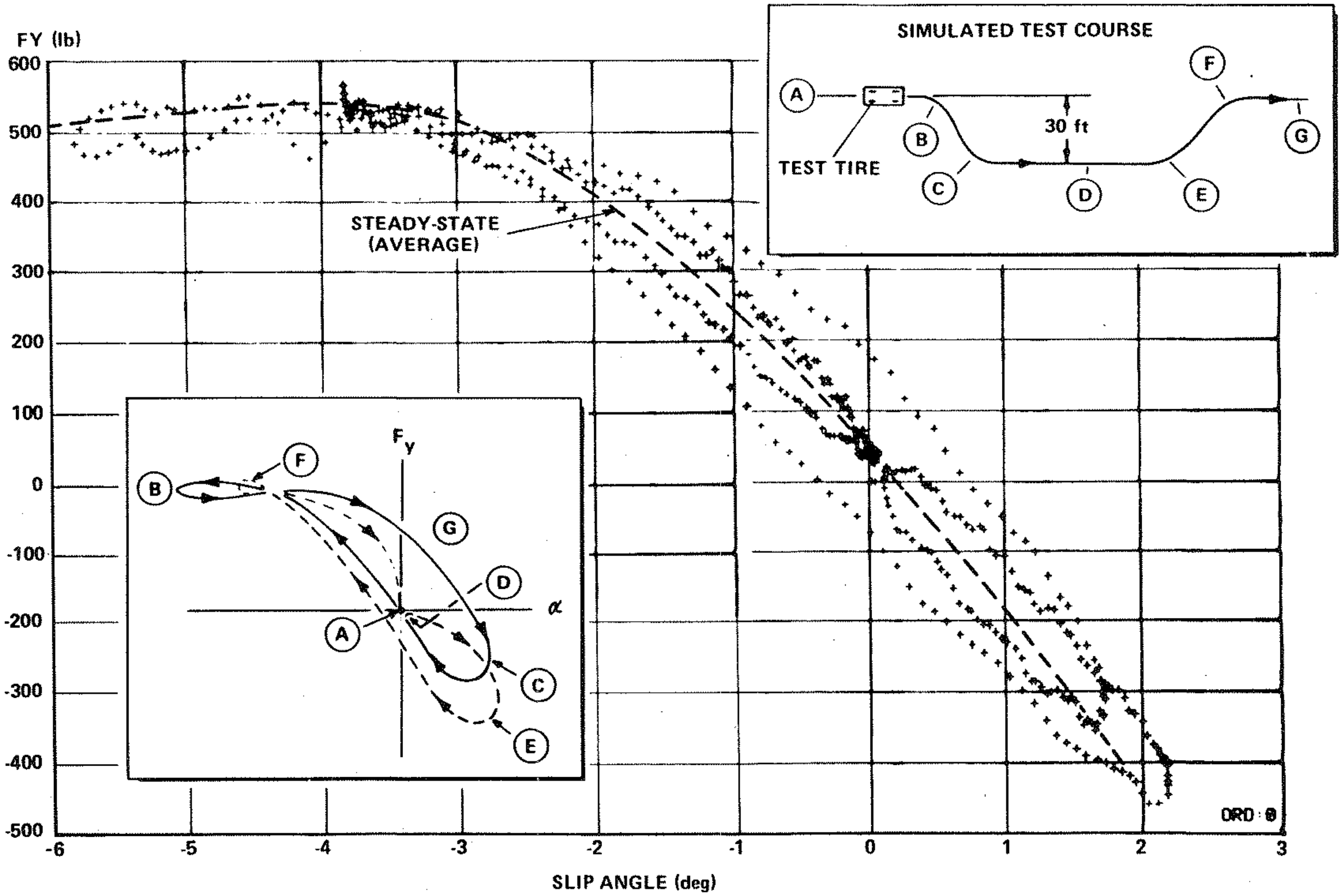


Figure 3 LATERAL FORCE RESPONSE OF GR 78-14 TIRE IN ACCIDENT AVOIDANCE MANEUVER, SIMULATED ON TIRF

5.0 EMPIRICAL TIRE MODEL

One of the major objectives of this program was to compact for each tire tested the vast amount of experimental data measured on TIRF into a manageable number of model constants. The constants would serve to describe the tire force and moment characteristics in form of a few mathematical equations. The equations have been developed over the past ten years or so by Calspan; they are under continuous development. For this program, equations were available for

- Cornering stiffness as function of load (constants A_0, A_1, A_2)
- Camber stiffness as function of load (constants A_3, A_4)
- Peak lateral force coefficient as function of load (constants B_1, B_3, B_4)
- Peak braking coefficient as function of load (constants P_0, P_1, P_2)
- Slide braking coefficient as function of load (constants S_0, S_1, S_2)
- Longitudinal slip at peak braking force as function of load (constants R_0, R_1)
- Overturning moment as function of vertical load, lateral force, and inclination angle (constants C_1, C_2, C_3)
- Aligning torque as function of vertical load, lateral force, and inclination angle (constants K_1, K_2, K_3)

These eight equations contain 22 coefficients. A data reduction computer program was developed permitting computation of all coefficients from the raw data recorded on TIRF.

6.0 TEST PROGRAM

Table 3 lists nine independent parameters (eight performance parameters plus state of wear). If each of these nine parameters was varied in only five steps, the total number of possible tests for a single tire would be astronomically high. Hence, an informed choice of test combinations was mandatory for reducing the number of tests per tire to tractable proportions.

The tests were divided into two groups — basic tests applied to all tires, and special tests applied to a selected small number of tires. Since this program is primarily concerned with dry road tire performance, all tests involving wet surfaces were delegated to special tests. Also, since on dry roads the tire parameters are not very susceptible to pressure changes between 24 and 32 psi, pressure was not treated as a variable in the basic tests. This then left four independent parameters for the basic tests – normal force, slip angle, inclination angle, and longitudinal slip.

The special tests included the effects of five more independent performance parameters: inflation pressure p, road speed v (for wet tests), road skid number SN (for wet tests), water thickness, and state of wear. Since road speed and skid numbers concern only wet tests, however, these two parameters could be held at constant levels during dry tests. Hence, for special dry tests, only the inflation pressure and the state of wear was varied (besides F_z, α, γ, s).

The basic program was designed to secure information about the effects of design and construction parameters (listed in Table 3) on tire performance; it was performed on all tires. The tests included variations of normal force F_z, slip angle α, inclination angle γ, and longitudinal slip s. The rest of the independent parameters was held constant – p at 24 psi cold, v at 30 mph, SN at 75. These levels were considered representing normal driving conditions. It was found expedient to divide the basic tests into two groups – cornering runs and braking runs. A cornering run would produce approximately 360 data points from which the model constants for cornering and camber stiffnesses, peak lateral force coefficient, overturning moment and aligning torque could be derived. A braking run would generate about 480 points, from which the model constants for peak and slide braking coefficients, and the longitudinal slip values at peak braking force could be derived for four loads. Table 7 shows more specifics of the basic program.

The special programs were designed to inquire into the effects of speed (dry and wet surfaces), of water depth and surface roughness, of tread depth (wet and dry surfaces), of pressure (dry surface) and of lateral force in the presence of driving and braking (wet surface)— on tire performance for a small number of selected tires. Table 8 indicates the scope of the special tests. With the exception of the cornering/braking interaction tests, all tires were subjected to the basic cornering and braking runs. The cornering/braking interaction tests were added to explore the performance range between pure braking and pure cornering.

Before commencement of the cornering test, each tire was subjected to a 20 sec break-in and warm-up run at ±10 deg slip angle. In this way, temperature and pressure changes during a test were kept small.

Prior to the tests on TIRF, all tires were inspected for defects and nonuniformity. The tires were shipped to the Transportation Systems

Test	Vertical Load, F_z	Slip Angle, α deg	Inclination Angle, γ deg	Longitudinal Slip, s %	No. of Set Points	
(γ)	A1	0	$-2 \rightarrow +2$	0	35	cornering run
(α/γ)	T&RA	$0 \rightarrow 16$	$6 \rightarrow 0$	0	96	
(α)	A2	$2 \rightarrow -20$	0	0	228	
(s)	A3	0	0	$0 \rightarrow -100$	≈ 480	braking run

TABLE 7 BASIC TEST SCHEDULE

Load (A1)	50%, 75%, 100%, 125%, 150% T&RA
Load (A2)	50%, 75%, 100%, 125%, 150%, 175% T&RA
Load (A3)	75%, 100%, 125%, 150% T&RA

Parameter	Speed mph	Water Depth, mil	Surface SN	Tread Depth %	Pressure psi
Speed, dry*	5, 30, 60	0	30	100	24
Speed, wet	10, 30, 50, 70	20	30	100	24
Water depth and surface roughness	30	10, 20, 40	30, 50	100	24
Tread depth, dry*	30	0	30	100, 70, 30, 0	24
Tread depth, wet	30	20	30	100, 70, 30, 0	24
Pressure, dry	30	0	30	100	18, 25, 32
F_x/F_y interaction, wet	20	20	30	100	24

TABLE 8 SPECIAL TEST PROGRAM

*Note that the combinations of 30 mph, 24 psi, SN 30, and 100% tread depth apply to all of the tires tested in the basic program.

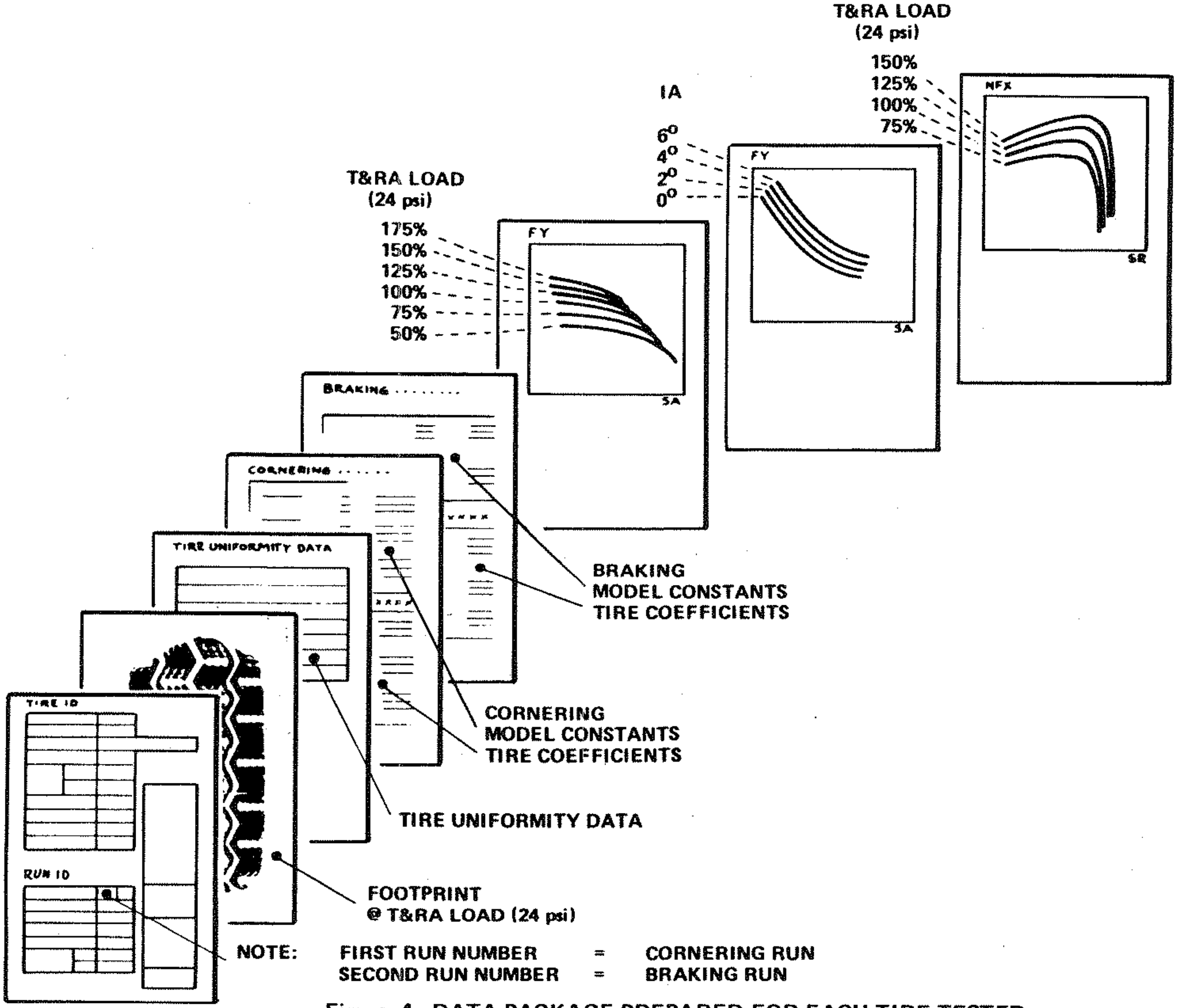
Center of DOT for x-ray and holographic tests and then shipped back to Dunlop Tire and Rubber Company in Buffalo and tested for radial and lateral force variations (in accordance with SAE Recommended Practice J332a). Following tests on TIRF, the tires were shipped back to TSC for post-test inspection.

7.0 PRESENTATION OF TEST RESULTS

For each tire tested, a data package was prepared containing (Figure 4)

- A list of tire identification data, such as size, brand name, and cord material; and a list of run identification data such as run number, road speed, and design load
- A tire footprint
- Tire Uniformity data
- A list of cornering computer model constants and tire coefficients, such as cornering stiffness, camber stiffness and pneumatic trail
- A list of braking computer model constants and tire coefficients, such as peak braking coefficient, and braking stiffness
- A plot of lateral force versus slip angle at various loads
- A plot of lateral force versus slip angle at various camber angles
- A plot of braking force coefficient versus slip ratio at various loads.

The results of the cornering/braking interaction runs were presented in form of computer plots. In addition, all raw data were listed out on standard computer printout sheets for each cornering and braking run.



NOTE: FIRST RUN NUMBER = CORNERING RUN
SECOND RUN NUMBER = BRAKING RUN

Figure 4 DATA PACKAGE PREPARED FOR EACH TIRE TESTED.
FOR EXPLANATIONS, SEE SECTION 8.0, VOLUME II

8.0 CONCLUSIONS AND RECOMMENDATIONS

It can be concluded that the objective of this program — development of a body of contemporary passenger and light truck tire data suitable for use in complex vehicle handling models — has been satisfied. For each of the approximately 380 tires tested, a large number of computer model constants and performance coefficients were generated that would allow modeling the major tire force and moment characteristics such as cornering stiffness, camber stiffness, aligning torque, and peak and slide braking coefficients. The tires tested represented current distributions of constructions, sizes, load ranges, aspect ratio, and cord materials. Verification tests performed on a passenger car indicated good correlation between TIRF and road performance data.

The results of the program suggest three fruitful areas of further research.

- A statistical analysis of tire data generated in this program, to provide direct inputs in many safety-related studies lacking proper tire data
- An extension of the tire test program to include truck tires
- An investigation of the influence of transient tire properties on vehicle handling, as pointed out at the end of Section 4.0.

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