U.S. Department of Transportation

National Highway Traffic Safety Administration

Memorandum

131718

Subject: ACTION: Ex Parte Memorandum, Report on Meeting with Goodyear, and Docket Submission Regarding Tires and Low Tire Pressure Monitoring Systems

Date: MAY 21 2001

From: William H. Walsh
Associate Administrator
for Plans and Policy

Reply to Attn. of:

To: Docket

Thru: John Womack
Acting Chief Counsel

NHTSA-00-8572-26

Please submit the attached information to Docket #8572.

On April 6, 2001, representatives from Goodyear Tire & Rubber Company (William Hopkins, Sam Landers, Dennis O'Connor, John Rumel, James Whiteley, Dale Freygang, and Mark Burtschi) made a presentation to representatives from Plans and Policy of NHTSA (William Walsh, James Simons, Lawrence Blincoe, Jonathan Walker, and Steve Peirce). The first Attachment labeled "H.R. 5164" is that presentation.

Subsequently, there have been follow up calls and inquiries made from James Simons to William Hopkins and from Lawrence Blincoe to Sam Landers to further NHTSA's understanding of the information presented and in some cases to request specific information and numbers that were used in developing the presentation. Attached are two faxes from Sam Landers to Lawrence Blincoe providing additional requested information.

Over the phone Sam Landers clarified that you would substitute the slip coefficient for Mu * E in the equation on Chart 8 of the first attachment when you are estimating stopping distance for non-ABS vehicles. In addition, Sam Landers clarified that surface definitions are more indicative of the age and use of the surface than the materials noted.

Attachments

#

Get it together!
SAFETY BELTS SAVE LIVES

GOODYEAR

H.R.5164

Transportation Recall Enhancement, Accountability, and Documentation

Docket # 8572

SEC. 13. TIRE PRESSURE WARNING

GOODYEAR

Meeting Purpose

Answer Questions Given to Goodyear

- Motor Vehicle Safety
  - Tire Failures
  - Vehicle Control
- Fuel Economy
- Tread Life
- Consumer Response
- Maintainability
- Tire Sales
- Cost / Benefit Analysis

Low Pressure Monitor Systems

GOODYEAR

Motor Vehicle Safety Tire Failures

- Tires ~~may~~ do fail due to blowouts, de-beading, or belt separations. Low tire pressure ~~may~~ do contribute to an increase in the incidence of these types of failures :
  - What are the annual incidence and/or rate of failures for these problems?
  - What portion of these failures occur due to low tire pressure?
  - Are these failure impacts different for different vehicle types, different quality tires, or different inflation settings?

GOODYEAR

TREAD Act Overview

		Tire Pressure Monitor	FMVSS Update	Labeling	Reporting Requirements
		D8572	**D8011**	**D8296**	**D8677**
Customer Satifaction		**X**	**X**	**X**	**X**
Safety	Braking Traction	**X**	**X**		
	Handling	**X**	**X**		
	High Speed	**X**	**X**		
	Durability	**X**	**X**		
	Bead Retention	**X**	**X**		
Value	Tire Cost	**X**	**X**	**X**	**X**
	Fuel Efficency	**X**	**X**		
	Tread Life	**X**	**X**		

GOODYEAR

EARLY WARNING SYSTEM -PROPOSAL

- EFFICIENT FORMATS FOR ANALYSIS OF KEY ELEMENTS FOR WARNING OF SAFETY ISSUES
- INCLUDES:
  - FORMAT FOR INJURIES (INCLUDING FATALITIES) AND LAWSUITS
  - FORMAT FOR PROPERTY DAMAGE CLAIMS AND WARRANTIES
- FOR INJURIES AND LAWSUITS, ANALYSIS CAN BE BY TIRE SIZE / TYPE, BY VEHICLE, BY PRODUCTION LOCATION, BY LOCATION OF THE INCIDENT, ETC.
- FOR PROPERTY DAMAGE AND WARRANTIES, ANALYSIS CAN BE BY TIRE SIZE / TYPE, BY YEAR OR MOST RECENT QUARTER, BY PRODUCTION LOCATION, BY RATE VERSUS PRODUCTION, BY AREA OF TIRE, e.g. CROWN, ETC.
- BASED ON DATA FROM A TECHNICAL ANALYSIS OF TIRES INVOLVED IN ADJUSTMENTS AND CLAIMS AND BASED ON INDUSTRY CONCENSUS

Vehicle Control

- **Stopping Distance**
  - Do you have any studies / models that directly relate tire pressure to vehicle stopping distance?
  - How do traction ratings correspond to actual deceleration or stopping distance?
- **Handling**
  - Do you have any studies/models that directly relate tire pressure to vehicle handling capability?
  - How do handling ratings correspond to real world vehicle control or crash avoidance?
- Does low tire pressure impact handling and stopping distance in a different way if only one tire is low, as opposed to all tires losing pressure at a relatively constant rate?

Vehicle Control :

Low Tire Pressure Vehicle **Stopping**

- Predictive Models
- Low Inflation Stopping Effects
- Example Data
  - Dry
  - Wet
  - Deep Water

Vehicle Stopping Distance Model

Change in Kinetic Energy = Braking Energy

$0.5 \times (MV_1^2 - MV_2^2) = \text{Braking Force} * \text{Stopping Distance}$

$V_2 = 0$ For Complete Stop

$F = Ma$

$a = g * Mu * E$

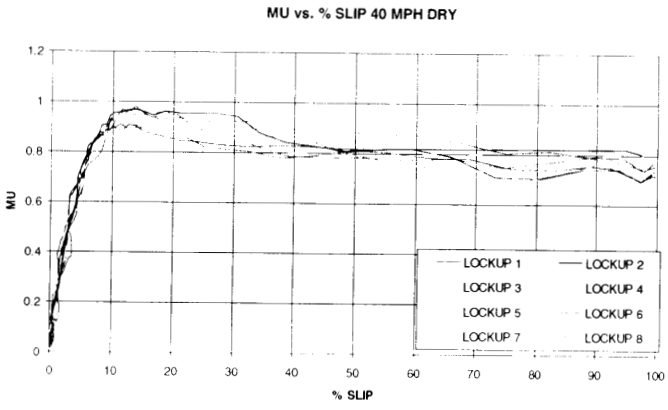
Mu = Tire Peak Mu

E = ABS Braking Efficiency

g = Gravity Constant

$$\text{Stopping Distance} = \frac{V_1^2}{2 * g * Mu * E}$$

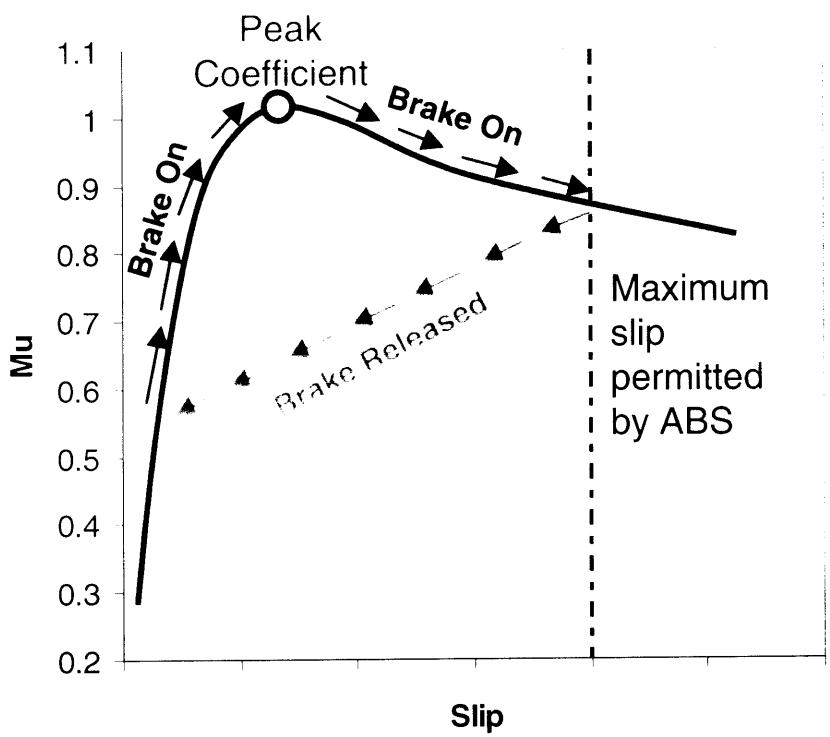
Mu, Tire Traction Test



Data Collection

- Trailer is loaded as required, and leveled.
- 10 lock-ups are performed per test condition.
- All 4 channels are sampled at 100 points per sec.
  - Tire Load
  - Tire Braking Force
  - Vehicle Speed
  - Tire Speed
- Data is downloaded to mainframe computer.
- Mu vs. Slip curve, peak Mu, and slide Mu are calculated.

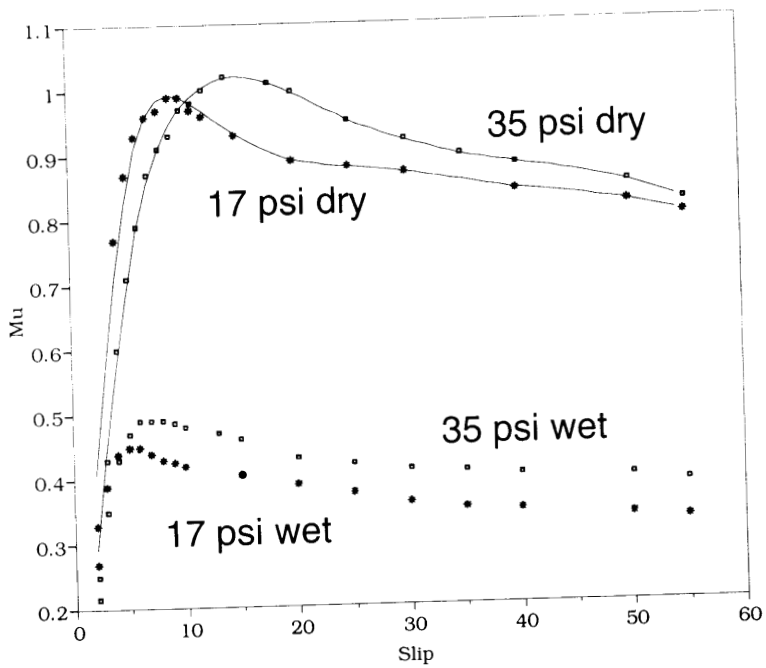
E, ABS Braking Efficiency



- Locked wheel slipping traction is lower than a tires peak traction
- ABS brake systems pulse the brakes on and off to keep the traction nearer to the peak
- The efficiency, E, of the ABS brake system is the effective % of the peak

Inflation Effect on Traction

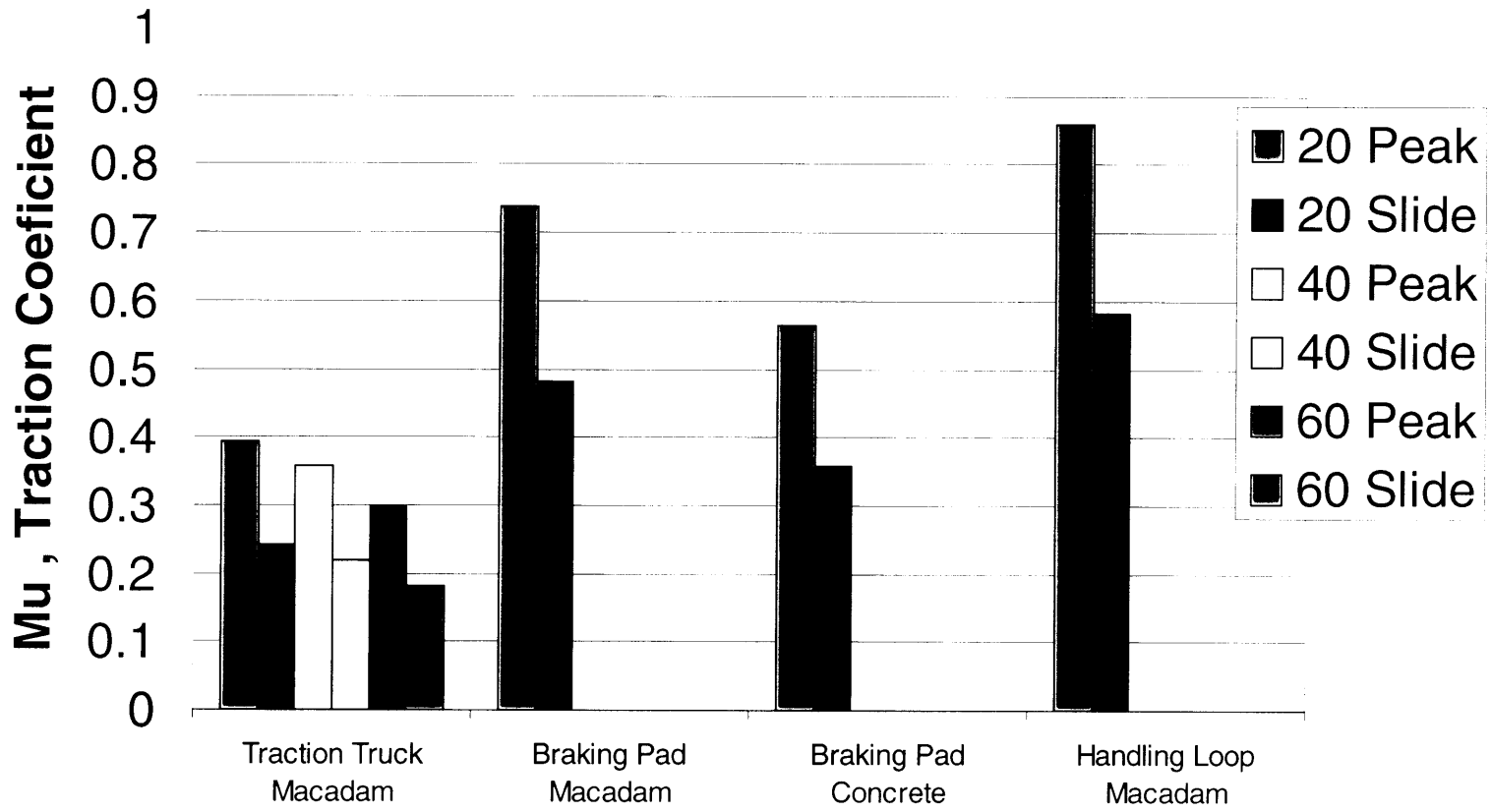
40 mph traction trailer test
Smooth macadam surface



- The peak traction is slightly lower when inflation pressure is reduced
- The Mu vs Slip curve becomes steeper due to a lower tire stiffness with lower inflation pressure
- Braking distances increase with lower pressure
- Braking distances are strongly influenced by test surface coefficients

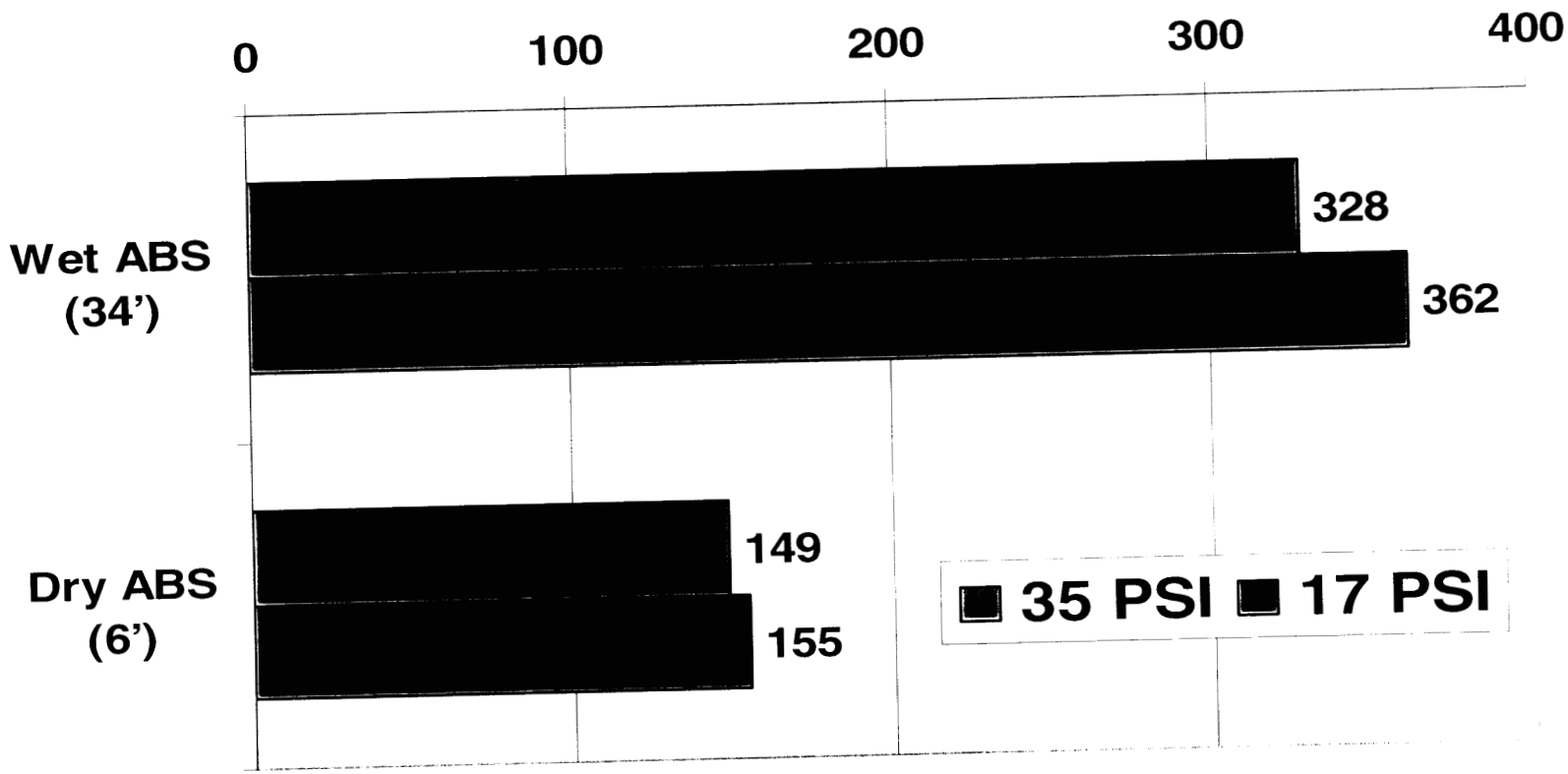
Test Surface Coefficients

(SRTT & 0.050" water depth)



Wet Stopping Distance (calculated)

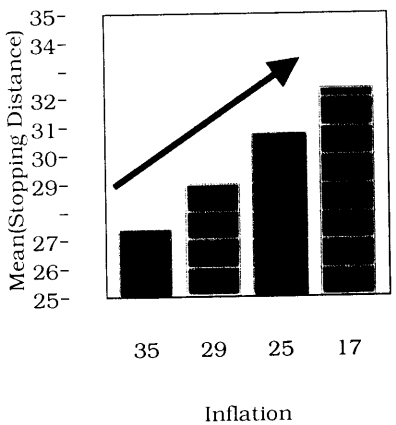
(Stop From 60 MPH In Feet)



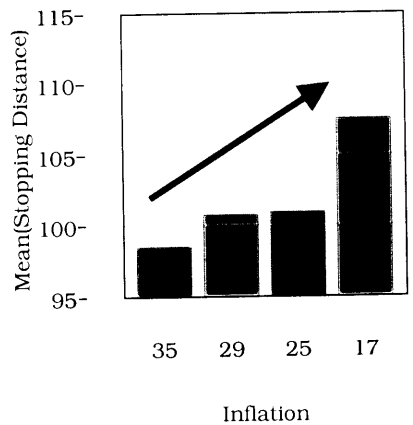
Wet Stopping Distance (actual)

(0.050" water depth)

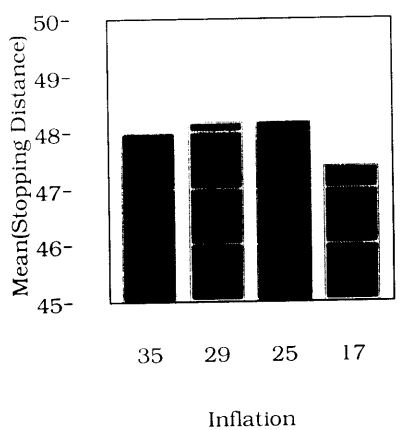
25 MPH, Macadam



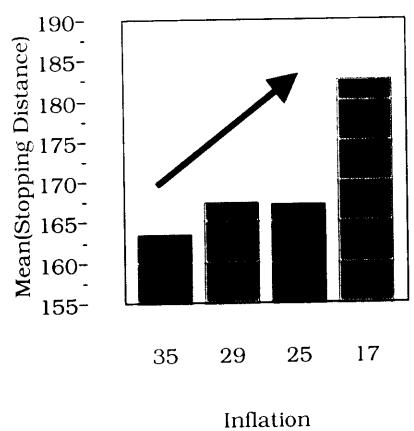
45 MPH, Macadam



25 MPH, Concrete



45 MPH, Concrete



- With the exception of low speed on smooth concrete, there is a significant increase in stopping distances at reduced inflation pressure
- Lower inflation increases hydroplaning potential at higher speeds

Rain Condition Equivalents

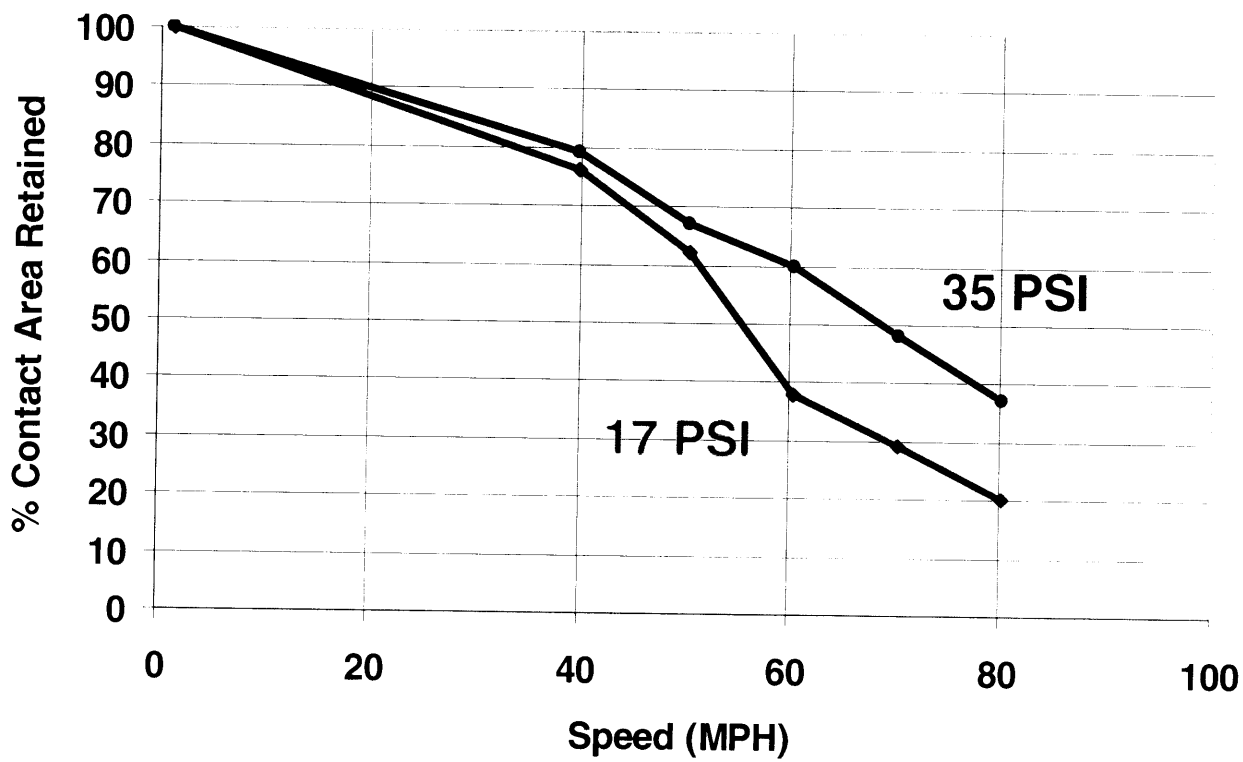
Road Conditions		Current Tests
Dry Roads	0.000	Dry Trailer Traction
Drizzle / Light Rain (0.50 inches / hour)	0.020	QGL Wet Trailer Traction
Extended Shower (1.00 inches / hour)	0.050	Trailer Traction, Vehicle Handling, Cornering, Stopping Distance
Heavy Downpour (4.0 inches / hour)	0.080	Glassplate Hydroplaning
	0.110	
Severe Local Storm (10.0 inches / hour)	0.140	
Standing Water / Poor Drainage	0.170	
(worn highway ruts)	0.200	
	0.230	Vehicle Deep Water Hydroplaning
	0.260	
	0.290	
	0.320	European Auto Magazines (Vehicle tests)
	0.350	(8-9 mm / 0.330")
	0.380	
	0.410	
	0.440	
	0.470	
	0.500	
Flooded Conditions	0.600	

Tire Hydroplaning (0.230" water depth)

	CONSTR SERIAL	SPEEDS (km/h)					
		2	64	81	97	113	129
35 psi	6X7522-R 2						
35 psi	6X7522-R 3						
17 psi	6X7522-R 2						
17 psi	6X7522-R 3						

~60% Greater Road Contact At Low Speed
~40- 50% Less Road Contact Retained At Freeway Speeds
Center Portion Of Tread Totally Lifted Out Of Contact

Low Pressure Hydroplaning



~40-50% less road contact retained at freeway speeds

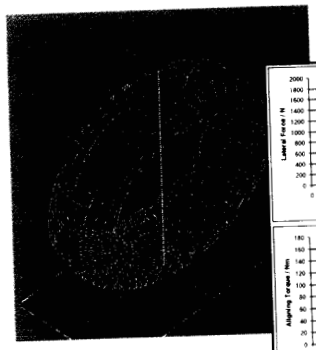
Vehicle Control :

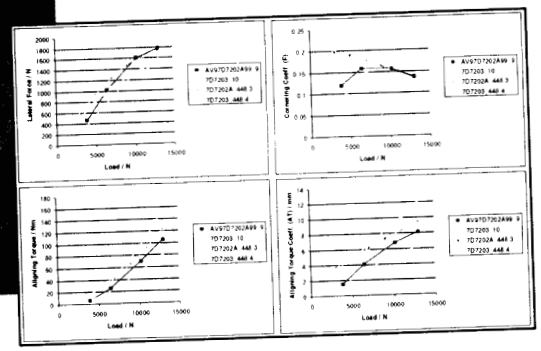
Low Tire Pressure Vehicle **Handling**

- Predictive Models
- Vehicle Handling Considerations
- Low Inflation Handling Effects
- Example Data
  - Off-Ramp, Constant Turn
  - Evasive Maneuver, Transient

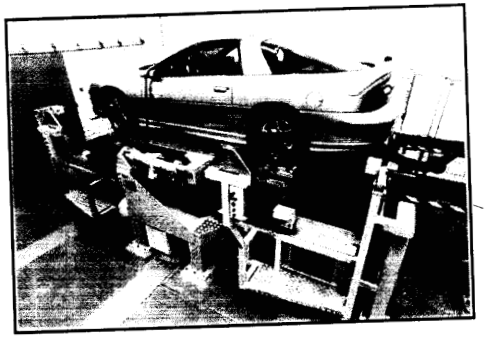
Vehicle Handling Prediction

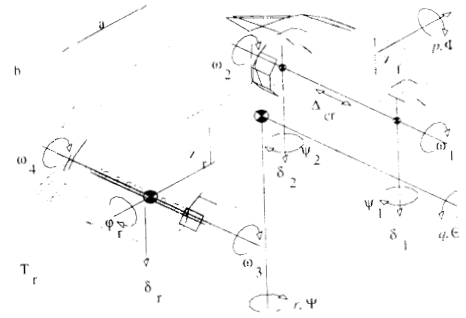
F & M Data/SSM



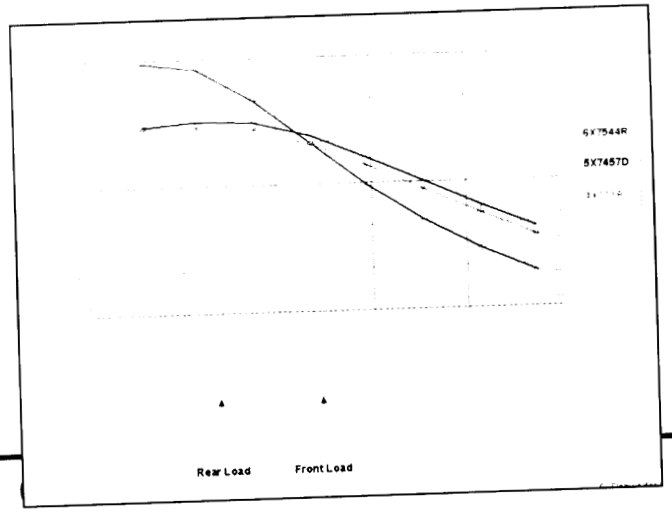


Vehicle Data

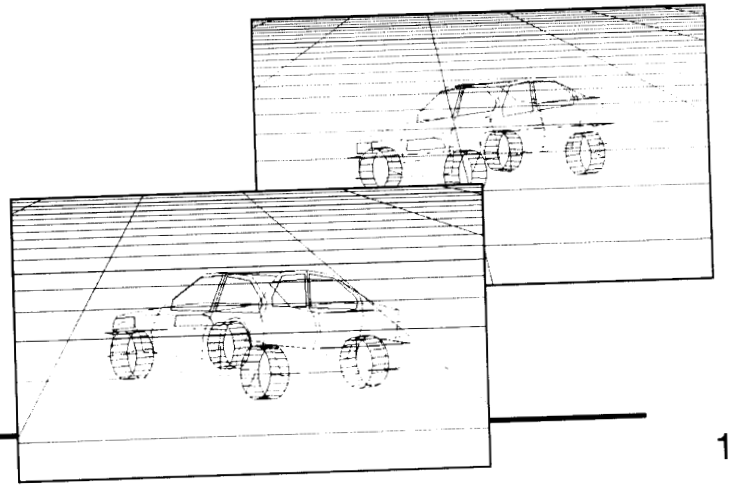




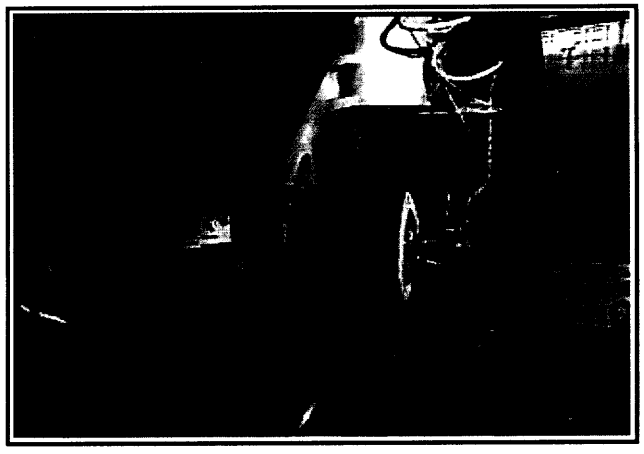
Static Understeer Analysis

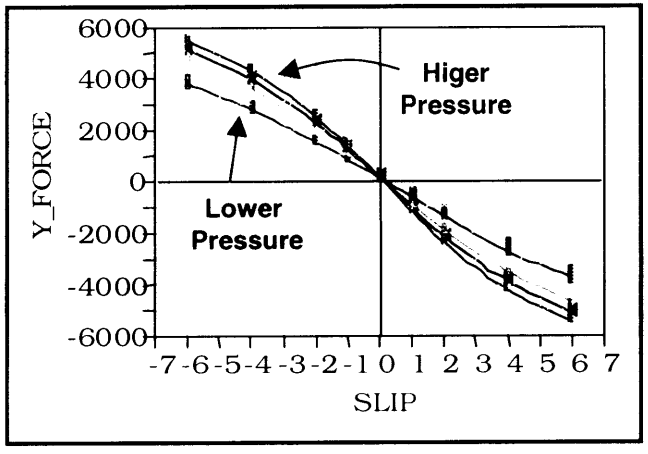


Vehicle Handling Performance Model



Low Pressure Cornering Force

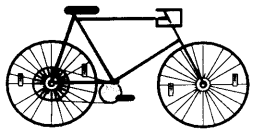




- Tires create a lateral force (Y_Force) when steered to a slip angle
- Low tire pressure generates lower cornering power because of reduced tire stiffness (lower cord tensions)
- A greater steering angle is required to generate the same cornering force

Simple Bicycle Handling Model

Steady State Cornering Steer Angle



$$\gamma = 57.3\frac{l}{R} + \left(\frac{w_f}{c_f} - \frac{w_r}{c_r}\right)\frac{v^2}{gR}$$

where

γ = steer angle

l = wheel base

R = turn radius

w = weight on axle

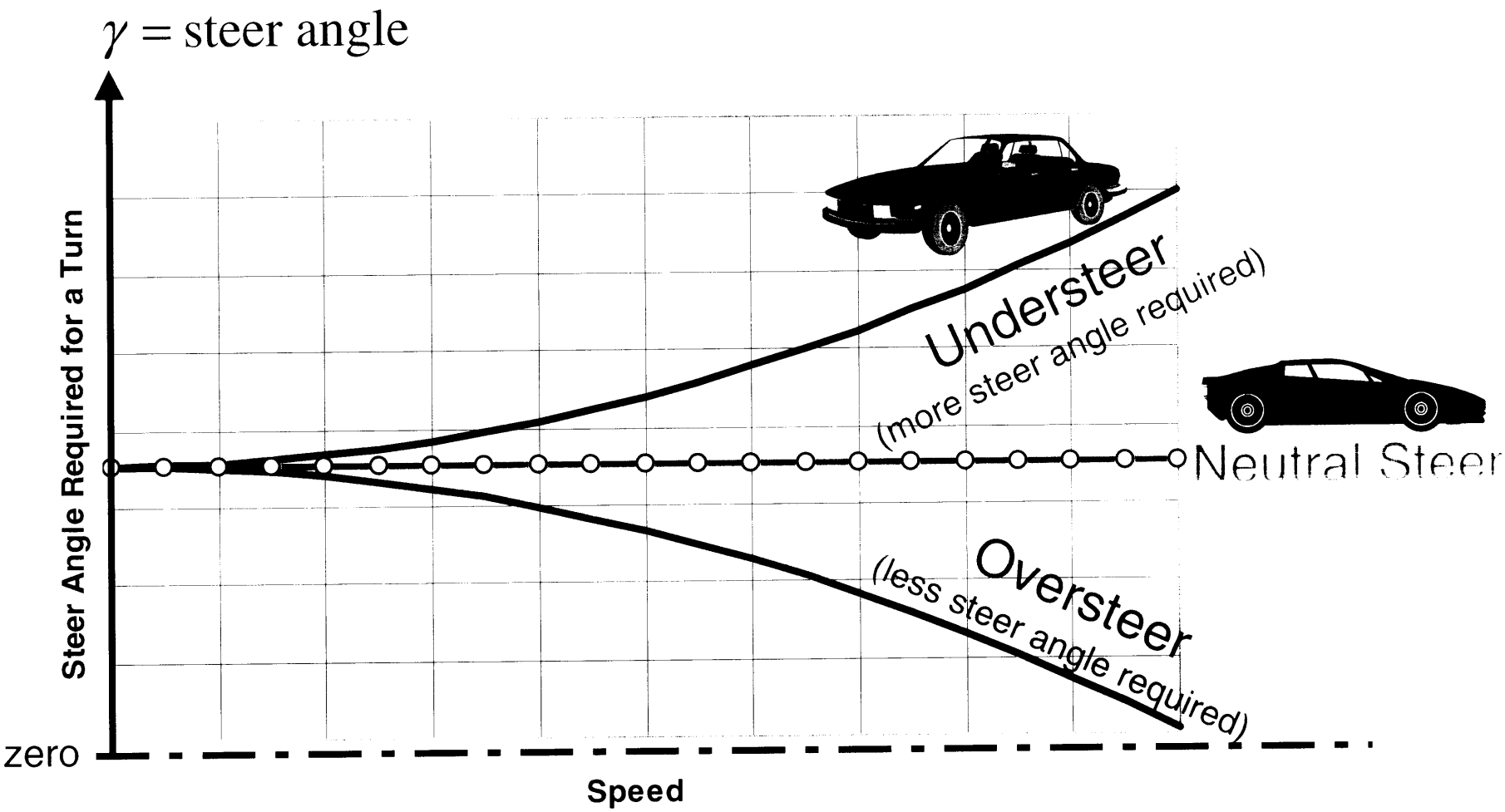
c = tire cornering stiffness

v = speed

g = gravitational constant

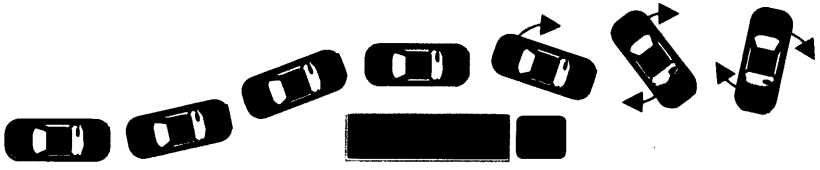
- The simple bicycle model considers only weight distribution and tire properties.
- In real vehicles, steering is also affected by :
  - tire aligning torque
  - tire camber
  - vehicle roll steer
  - lateral force and aligning torque deflection steer
- Vehicle is understeer when the steer angle increases with speed
- Vehicle is oversteer when the steer angle decreases with speed

Vehicle Steering Characteristics



Low Pressure Handling Considerations

Lane Change Maneuver
Oversteer Effect

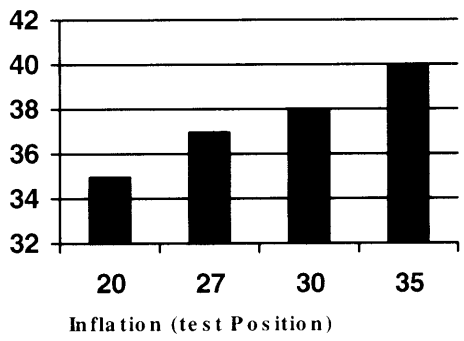


Expressway Off-Ramp
Understeer Effect

- **Lane Change Maneuver**
  - Excessive oversteer will cause a vehicle to be unstable and overly sensitive to steering input
  - Low Rear Tire - Oversteer Effect
- **Off-Ramp Maneuver**
  - Excessive understeer will cause a vehicle to want to go straight and be unable to steer a tight radius
  - Low Front Tire - Understeer Effect

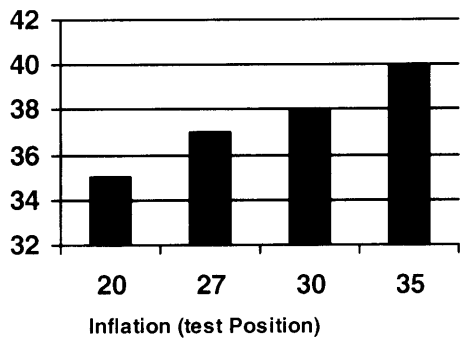
Off-Ramp Maximum Speed (mph)

All 4 Tires

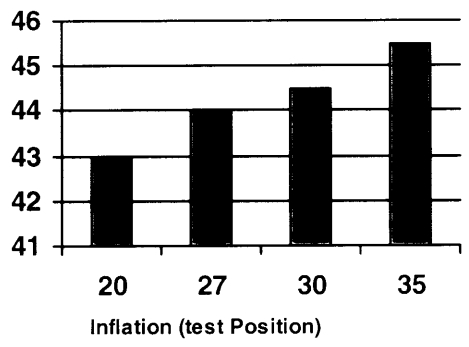


- Off-ramp maximum speed is significantly reduced with reduced inflation
- The trends are essentially the same no matter where the low pressure tire is located

Left Front

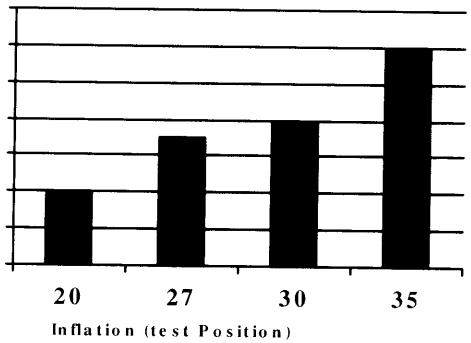


Left Rear



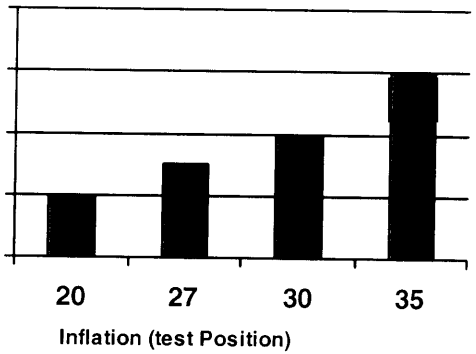
55 mph Lane Change Drivability

All 4 Tires

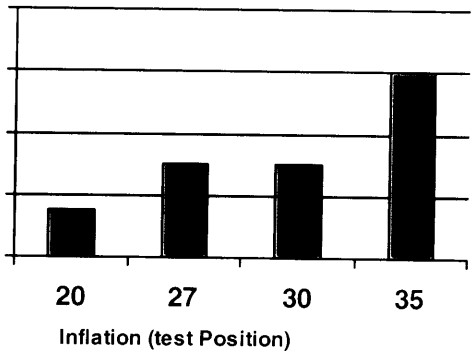


- Lane change drivability is significantly reduced with reduced inflation
- The trends are essentially the same no matter where the low pressure tire is located

Left Front



Left Rear



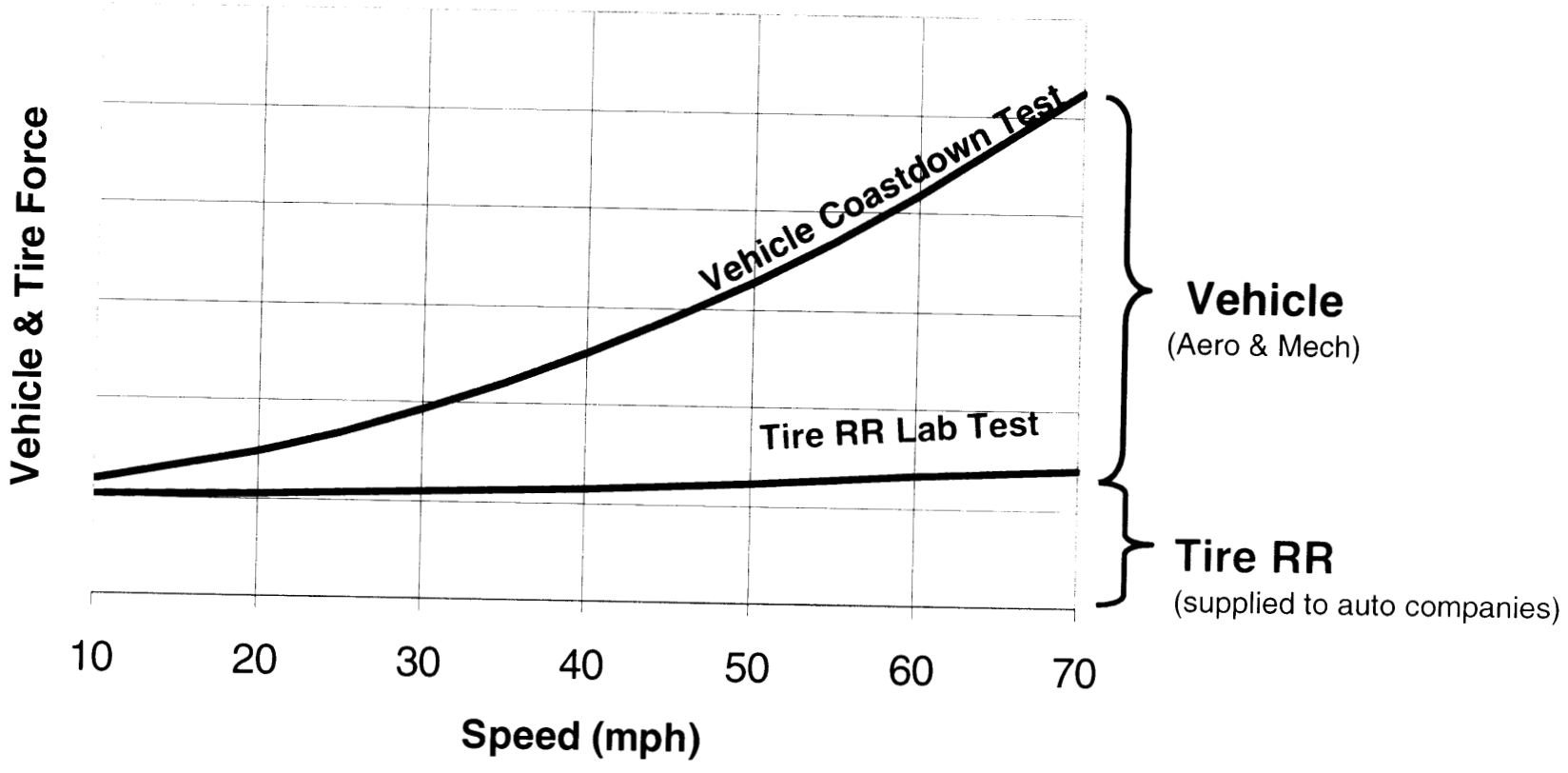
Fuel Economy

- Do you have any models that directly relate tire pressure to fuel consumption?
- In a 1978 report by the Aerospace Corporation, it was found that for radial tires there was a 1% decrease in fuel economy for each 3.33 psi decrease in tire pressure.
  - If you do not have a specific model, do you have any newer estimate of this impact?
  - Do you agree with the 1978 estimate?
  - Would the relationship be linear, or would it vary for different inflation pressures?
- Are these fuel economy impacts different for different vehicle types, different quality tires, or different inflation settings?
- Does low tire pressure impact fuel economy in a different way if only one tire is low, as opposed to all tires losing pressure at a relatively constant rate?

Low Pressure Fuel Efficiency

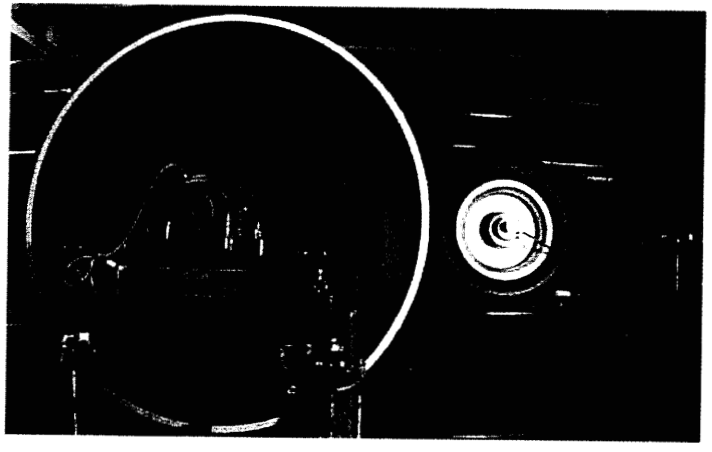
- Low tire pressure significantly increase the rolling resistance forces of tires
- Tire rolling resistance consumes 4 to 10% of a vehicles fuel depending on :
  - Vehicle weight and engine and driveline efficiency
  - Vehicle accessories and aerodynamics
  - Driving speed, acceleration rate, breaking frequency
- Automobile companies are required to provide C.A.F.E. fuel economy estimates for all new vehicles
- Goodyear does not have the vehicle information to project the fuel efficiency impact for the overall fleet

Data for C.A.F.E. Vehicle Model

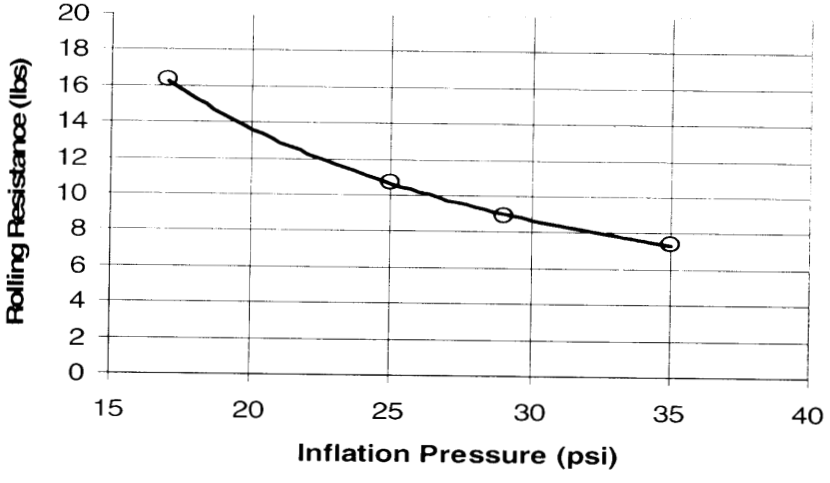


Tire Rolling Resistance Data

(supplied to vehicle manufacture for C.A.F.E. calculation)



- Tires are rotate at a controlled load and speed steps against a flywheel of a Rolling Resistance machine.



	Inflation	RR
standard	35	7.4
placard	30	8.7
- 6 psi	24	11.1
- 10 psi	20	13.6
1/2 std	17	16.3

Contribution of Tire RR to Fuel Economy

REF : Automotive Engineering International / February 98

ENERGY DERIVED FROM FUEL → 100%

ROLLING LOSSES +

	URBAN	HIGHWAY
	12.6% -	20.2%
AERODYNAMICS	2.6%	10.9%
INERTIA	5.8%	2.2%
TIRE ROLLING RESISTANCE	**4.2%**	**7.1%**

VEHICLE LOSSES +

70.2% - 76.2%

- THERMODYNAMIC
- DRIVE-LINE LOSSES
- FRICTION
- ACCESSORIES
- VIBRATIONS

STAND-BY LOSSES

17.2% - 3.6%

- IDLING
- BRAKING

Hypothetical Auto C.A.F.E. Estimate

CITY CYCLE, $mpg_{city} = 22.2 - 0.107 \times RR_{tire}$

psi	Tire RR	mpg@psi	% tire	miles/yr	gal/yr	$/g	$/yr	added cost
35	7.4	21.4	3.6%	12,000	561.6	$ 1.50	**$ 842.41**	$ (5.52)
30	8.7	21.2	**4.2%**	12,000	565.3	$ 1.50	**$ 847.93**	$ -
24	11.1	21.0	5.4%	12,000	572.3	$ 1.50	**$ 858.44**	$ 10.51
20	13.6	20.7	6.6%	12,000	579.6	$ 1.50	**$ 869.44**	$ 21.51
17	16.3	20.4	7.9%	12,000	587.8	$ 1.50	**$ 881.70**	$ 33.77

HIGHWAY CYCLE, $mpg_{hiwy} = 38.8 - 0.317 \times RR_{tire}$

psi	Tire RR	mpg@psi	% tire	miles/yr	gal/yr	$/g	$/yr	added cost
35	7.4	36.5	6.0%	12,000	329.1	$ 1.50	**$ 493.61**	$ (5.64)
30	8.7	36.1	**7.1%**	12,000	332.8	$ 1.50	**$ 499.24**	$ -
24	11.1	35.3	9.1%	12,000	340.1	$ 1.50	**$ 510.13**	$ 10.89
20	13.6	34.5	11.1%	12,000	347.8	$ 1.50	**$ 521.75**	$ 22.50
17	16.3	33.6	13.3%	12,000	356.6	$ 1.50	**$ 534.96**	$ 35.72

COMBINED CYCLE, $mpg_{comb} = 0.55 \times mpg_{city} + 0.45 \times mpg_{hiwy}$

psi	mpg city	mpg hiwy	mpg comb	miles/yr	gal/yr	$/g	$/yr	added cost
35	21.4	36.5	28.2	12,000	426.1	$ 1.50	**$ 639.16**	$ (6.00)
30	21.2	36.1	**27.9**	12,000	430.1	$ 1.50	**$ 645.16**	$ -
24	21.0	35.3	27.4	12,000	437.8	$ 1.50	**$ 656.68**	$ 11.52
20	20.7	34.5	26.9	12,000	445.9	$ 1.50	**$ 668.86**	$ 23.70
17	20.4	33.6	26.4	12,000	455.1	$ 1.50	**$ 682.60**	$ 37.44

Domestic Sales Weighted MPG Average

Hypothetical LT C.A.F.E. Estimate

CITY CYCLE, $mpg_{city} = 16.4 - 0.079 \times RR_{tire}$

psi	Tire RR	mpg@psi	% tire	miles/yr	gal/yr	$/g	$/yr	added cost
35	7.4	15.9	3.6%	12,000	757.0	$ 1.50	$ 1,135.43	$ (7.44)
30	8.7	15.7	**4.2%**	12,000	761.9	$ 1.50	**$ 1,142.87**	$ -
24	11.1	15.6	5.4%	12,000	771.4	$ 1.50	**$ 1,157.03**	$ 14.17
20	13.6	15.4	6.6%	12,000	781.2	$ 1.50	**$ 1,171.86**	$ 28.99
17	16.3	15.1	7.9%	12,000	792.3	$ 1.50	$ 1,188.38	$ 45.51

?

HIGHWAY CYCLE, $mpg_{hiwy} = 28.8 - 0.235 \times RR_{tire}$

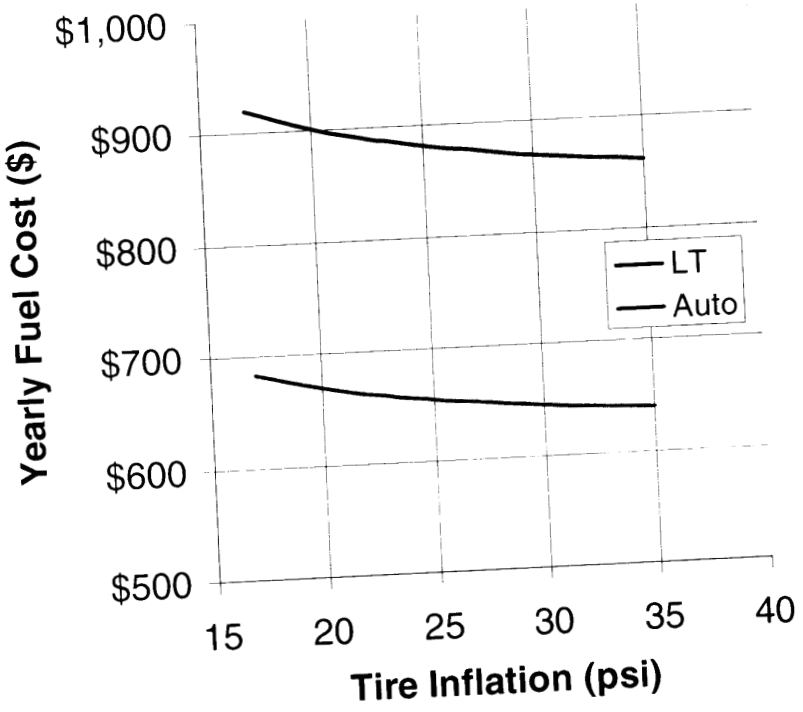
psi	Tire RR	mpg@psi	% tire	miles/yr	gal/yr	$/g	$/yr	added cost
35	7.4	27.1	6.0%	12,000	443.5	$ 1.50	$ 665.30	$ (7.60)
30	8.7	26.8	**7.1%**	12,000	448.6	$ 1.50	**$ 672.89**	$ -
24	11.1	26.2	9.1%	12,000	458.4	$ 1.50	**$ 687.57**	$ 14.68
20	13.6	25.6	11.1%	12,000	468.8	$ 1.50	**$ 703.23**	$ 30.33
17	16.3	25.0	13.3%	12,000	480.7	$ 1.50	$ 721.03	$ 48.14

COMBINED CYCLE, $mpg_{comb} = 0.55 \times mpg_{city} + 0.45 \times mpg_{hiwy}$

psi	mpg city	mpg hiwy	mpg comb	miles/yr	gal/yr	$/g	$/yr	added cost
35	15.9	27.1	20.9	12,000	574.3	$ 1.50	$ 861.48	$ (8.08)
30	15.7	26.8	**20.7**	12,000	579.7	$ 1.50	**$ 869.57**	$ -
24	15.6	26.2	20.3	12,000	590.1	$ 1.50	**$ 885.09**	$ 15.52
20	15.4	25.6	20.0	12,000	601.0	$ 1.50	**$ 901.51**	$ 31.95
17	15.1	25.0	19.6	12,000	613.4	$ 1.50	$ 920.03	$ 50.46

Domestic Sales Weighted MPG Average

Hypothetical C.A.F.E. Yearly Estimates



For autos with a combined MPG average of 27.9

- At 6 psi underinflation
  - + 7.8 gal more gas
  - + $11.52 greater cost
- At 10 psi underinflation
  - + 15.8 gal more gas
  - + $23.70 greater cost

For light trucks with a combined MPG average of 20.7

- At 6 psi underinflation
  - + 10.4 gal more gas
  - + $15.52 greater cost
- At 10 psi underinflation
  - + 21.3 gal more gas
  - + $31.94 greater cost

Fuel Economy

- Do you have any models that directly relate tire pressure to fuel consumption?
- In a 1978 report by the Aerospace Corporation, it was found that for radial tires there was a 1% decrease in fuel economy for each 3.33 psi decrease in tire pressure.
  - If you do not have a specific model, do you have any newer estimate of this impact?
  - Do you agree with the 1978 estimate?
  - Would the relationship be linear, or would it vary for different inflation pressures?

$(20.7 - 20.0)/20.7 = 3.38\% = 10$ psi

$1\% = 2.96$ psi

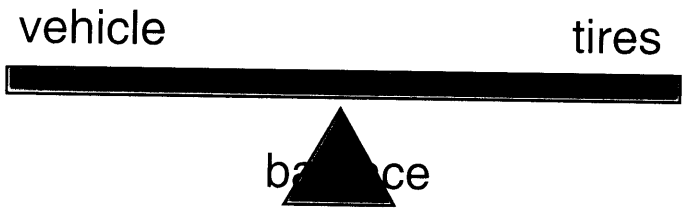
- Are these fuel economy impacts different for different vehicle types, different quality tires, or different inflation settings?
- Does low tire pressure impact fuel economy in a different way if only one tire is low, as opposed to all tires losing pressure at a relatively constant rate?

GOODYEAR

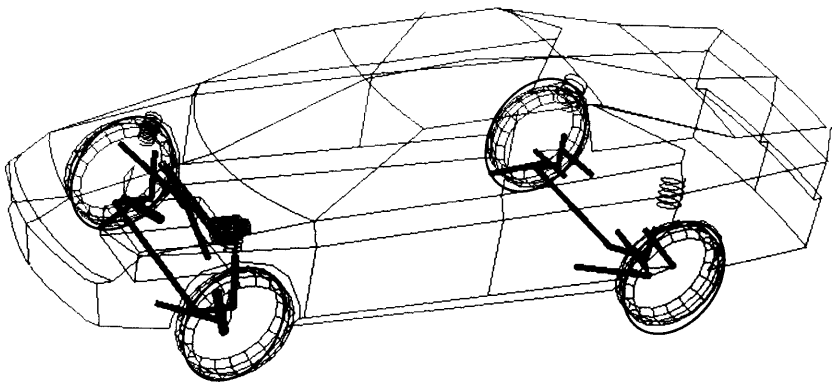
Tread Life

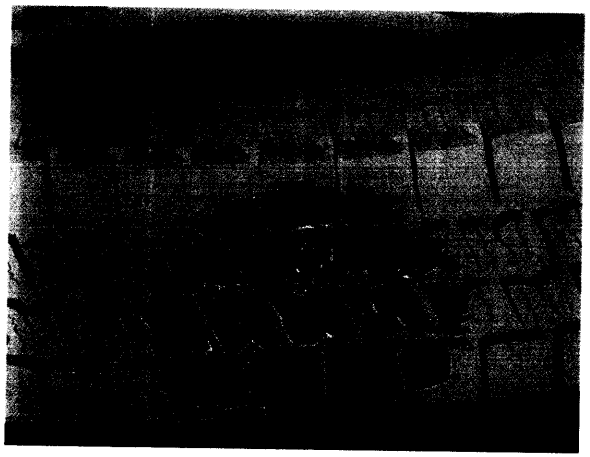
- Driving at lower inflation pressure would impact the rate of treadwear on vehicles. This could cause tires to wear out earlier than necessary and decrease tire life.
  - Does Goodyear have any studies that directly measure the impact of treadwear due to underinflated tires?
  - What is the average tread life of tires?
  - What is the average cost?
  - Do you have data that could be used to describe a matrix of tread life by tire sales?
  - Are these tread life impacts different for different vehicle types, different quality tires, or different inflation settings?
  - Are they different for OEM tires than for aftermarket tires?

Tire Critical to Vehicles



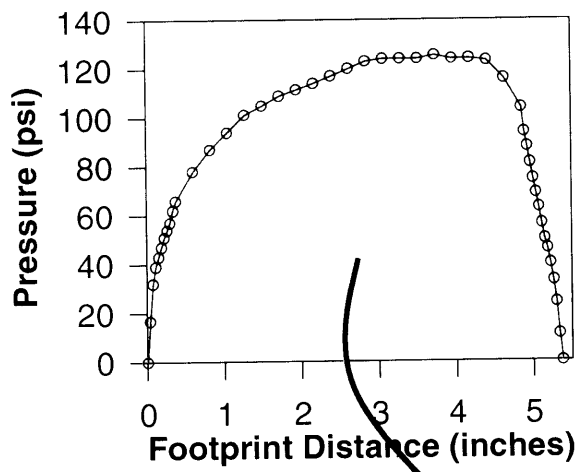
- Tires are one of the most important parts of the complex vehicle system

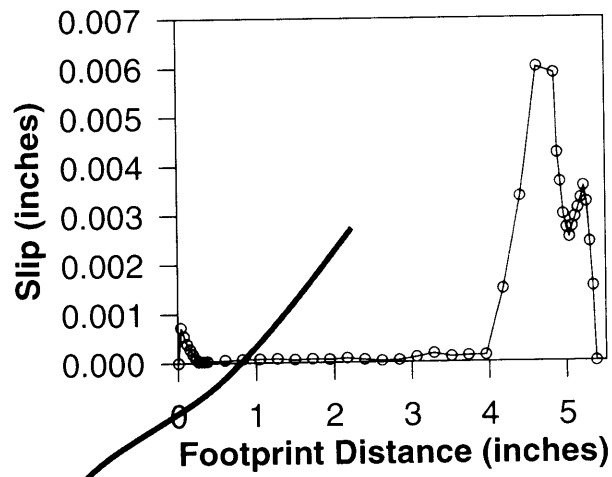




A tire's footprint must transmit all the vehicle forces to the road

Simplified Tire Wear Mechanics

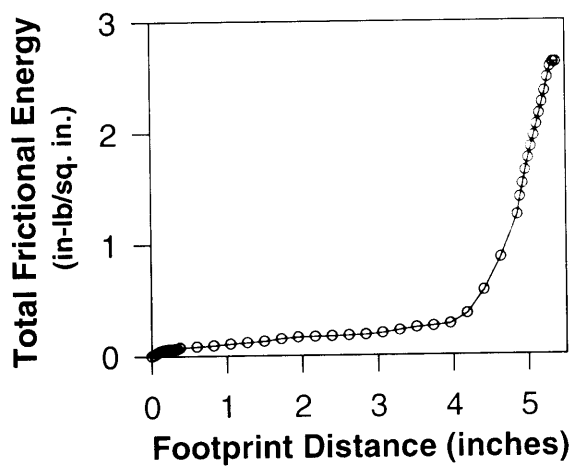




Slip increases with cornering, traction, and braking

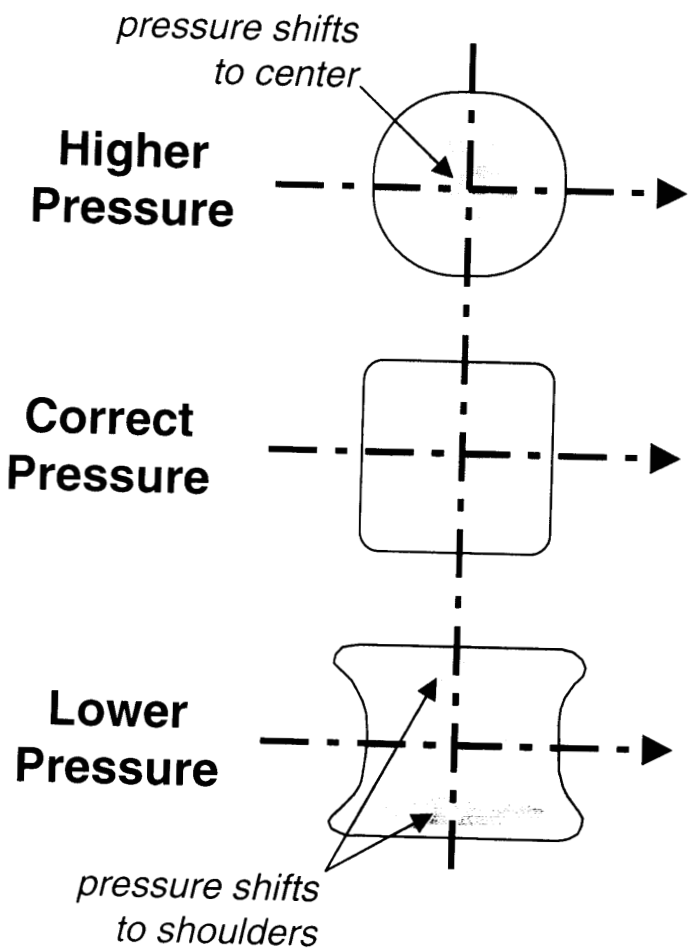
$$FE = \Sigma\,(\mu_i * P_i * s_i) =$$

Coefficient of Friction



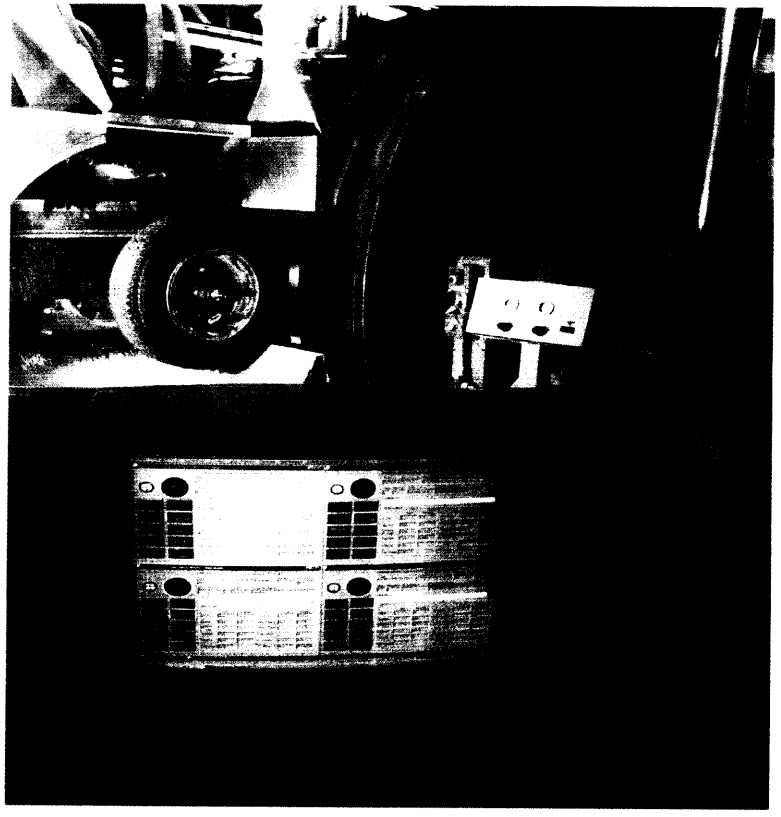
Actual wear depends on the compound abradability

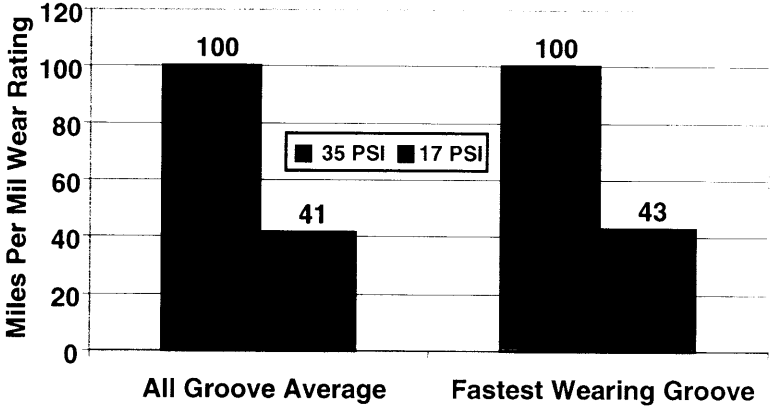
Tire Pressure and Footprint Mechanics



- footprint is smaller and rounder with higher contact pressures
- footprint is the correct size and shape with a more uniform contact pressure
- footprint is longer in the shoulder with lower contact pressures

Laboratory Fast Wear Test





- Laboratory wear simulates a fast wear condition with city cycle cornering, braking, and acceleration
- About a 58% loss in treadwear was measured at 17 psi inflation pressure

Low Pressure Treadwear Estimation

Highway Treadwear

- Highway driving is slow wear primarily from straight ahead driving with little braking or cornering
- Inflation pressure does not significantly effect the wear when driving straight ahead
- About a 10% loss in highway treadwear could be expected by dropping the inflation pressure from 35psi to 17psi

City Treadwear

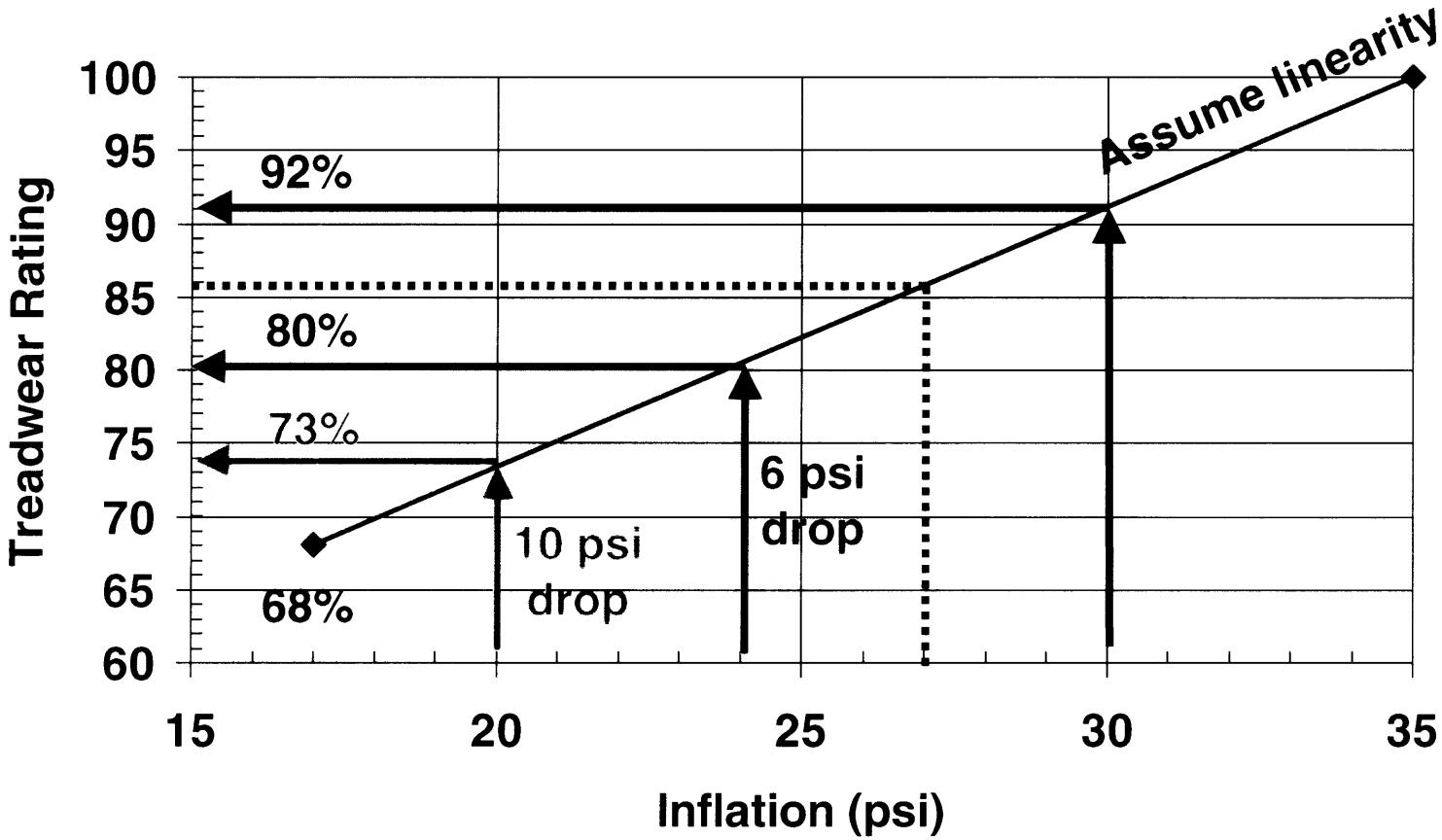
- City driving is fast wear primarily from increased braking or cornering
- Inflation pressure has a significant effect on wear when braking and cornering
- Up to a 50% loss in city treadwear could be expected by dropping the inflation pressure from 35psi to 17psi

45% x 90%

68%
Treadwear
at 17 psi

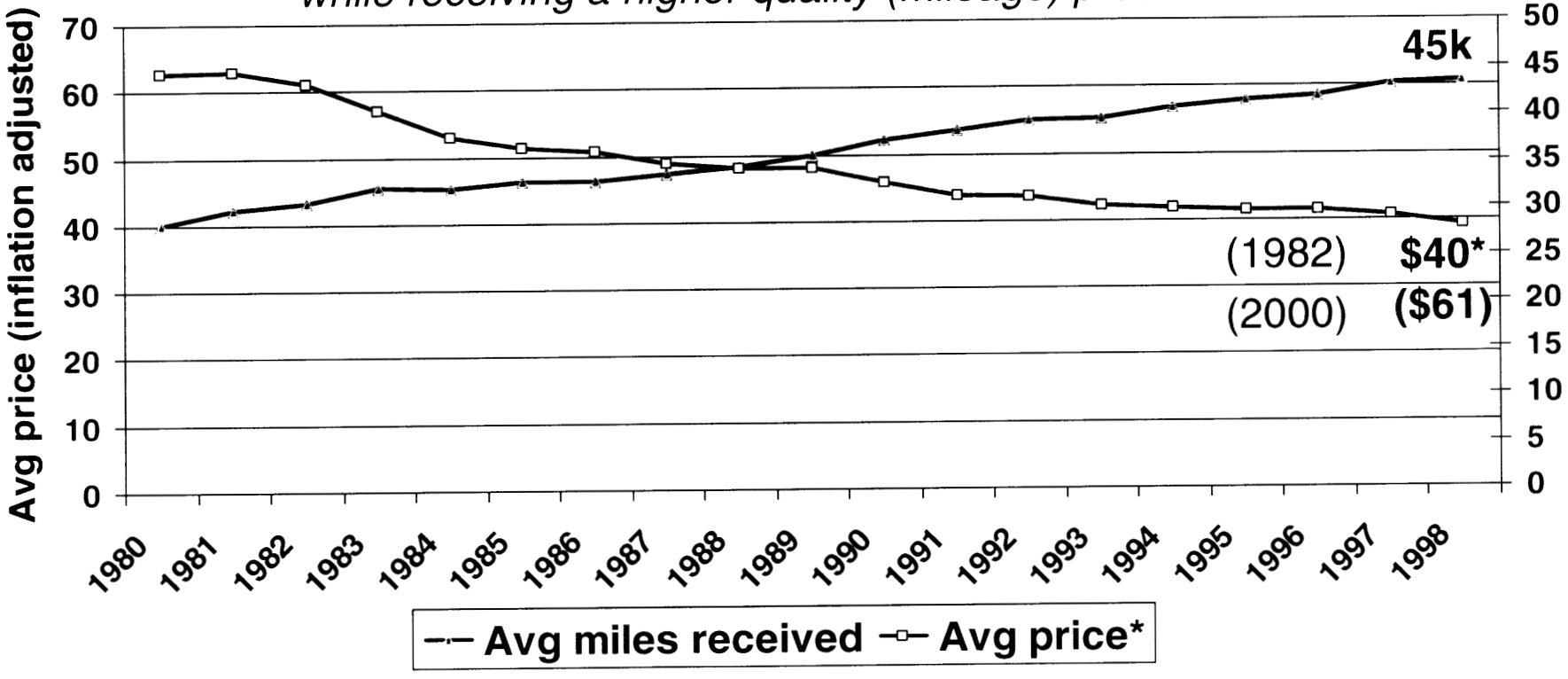
55% x 50%

Low Pressure Treadwear Impact



Industry Average Mileage and Transaction Price (auto tires)

Consumers continue to pay a lower price for tires while receiving a higher quality (mileage) product.



Source: GY Mgmt Information

*Avg price adjusted for inflation - Base Yr 82-84= 100

Treadwear Loss / Tire Use Costs

	% TW	TW	Miles / Yr	% / Yr	Tire Cost	Tire $ / Yr
[redacted]						
[redacted]						
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
24 psi	80%	41,860	12,000	29%	$ 244.00	$ 69.95
20 psi	73%	38,198	12,000	31%	$ 244.00	$ 76.65
17 psi	68%	35,581	12,001	34%	$ 244.00	$ 82.30

assumptions : 45,000 mi average treadwear occurs at -3 psi underinflation from placard of 30 psi

- A 6 psi drop in inflation pressure from placard (30 psi) will result in a tire use cost increase of $9.13 a year (15%)
- A 10 psi drop in inflation pressure from placard (30 psi) will result in a tire use cost increase of $15.83 a year (26%)
- Faster wearing tires will have to be replaced more frequently increasing the number of scrap tires

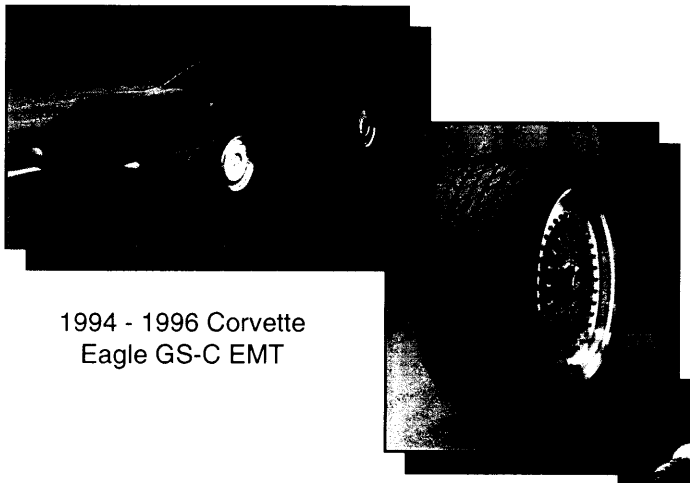
Consumer Response

- In order to determine the actual impact of tire pressure monitoring systems, we will have to estimate the reaction of consumers.
  - Do you have or know of any studies that indicate what the response of consumers will be to tire pressure information?

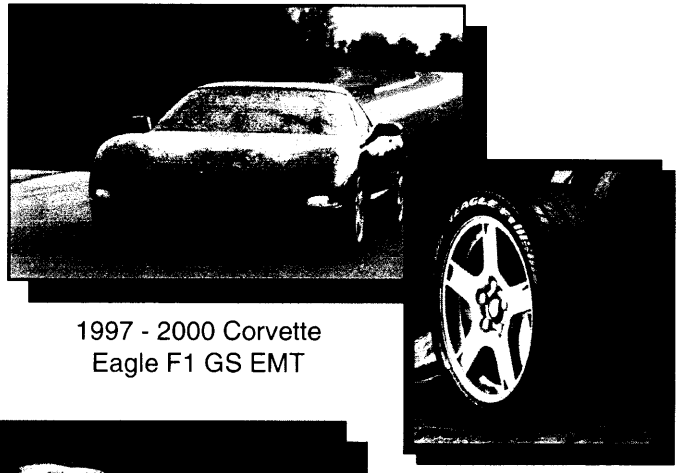
Maintainability

- TPM systems will be installed in new vehicles, but in order for the systems to work for the life of the vehicle they will have to be remounted when tires are replaced.
  - Do you know of any studies or information that would help to determine the rate at which these systems will be maintained so that they will function properly throughout the life of the vehicle?

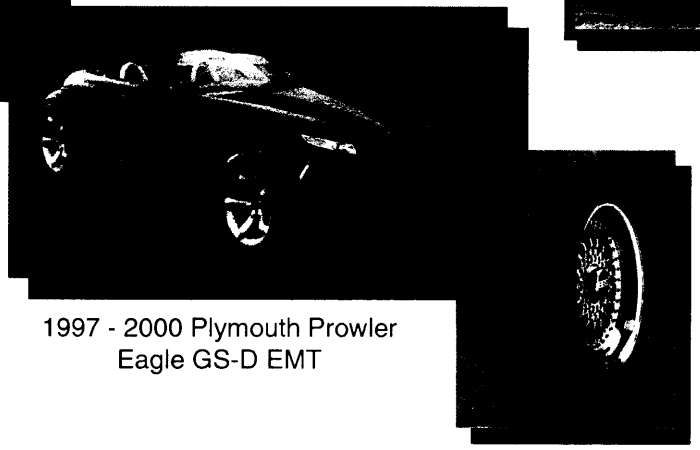
Goodyear Experience



1994 - 1996 Corvette
Eagle GS-C EMT



1997 - 2000 Corvette
Eagle F1 GS EMT



1997 - 2000 Plymouth Prowler
Eagle GS-D EMT

Over Half Million EMT (Run-Flat) Tires Supplied

All Vehicles with EMT Tires Must Have LPMS

Corvette LPMS History

- 89 Corvette ZR1 std with Epic tire warning
  - Piezo-electric power (inconsistent)
  - Mounted by steel strap in wheel well
  - One level warning (25 psi)
  - Complaints from warning level being too close to placard (30 psi)
- 94 Corvette EMT as option with Epic / Smartire LPMS
  - 10 year Nicad battery powered w/ motion sensor
  - Two level alert / warning (35 psi placard, 25 psi alert, 5 psi flat tire)
- 97 Corvette EMT as std with Schrader LPMS
  - Integrated into valve
  - Nicad battery powered

Consumer Requirements

Possible Tire Inflation Loss	Rate of Change	Tires Effected	Safety Concern	Cost Concern
Normal Air Loss (diffusion)	**Months**	**All 4**	**Yes**	**Yes**
Natural Pressure Variations (weather)	**Days**	**All 4**	**No**	**No**
Slow Air Loss Due to Road Hazard (nail)	**Hours**	**One**	**Yes**	**No**
Fast Air Loss Due to Road Hazard (impact)	**Minutes**	**One**	**Yes**	**No**

A LPMS should :

- Alert the driver of a normal air loss in all 4 tires for proper maintenance, maximum safety, and optimum operating cost
- Ignore natural variations due to natural causes
- Warn the driver of an air loss in any one tire so that appropriate action can be taken to minimize safety concern

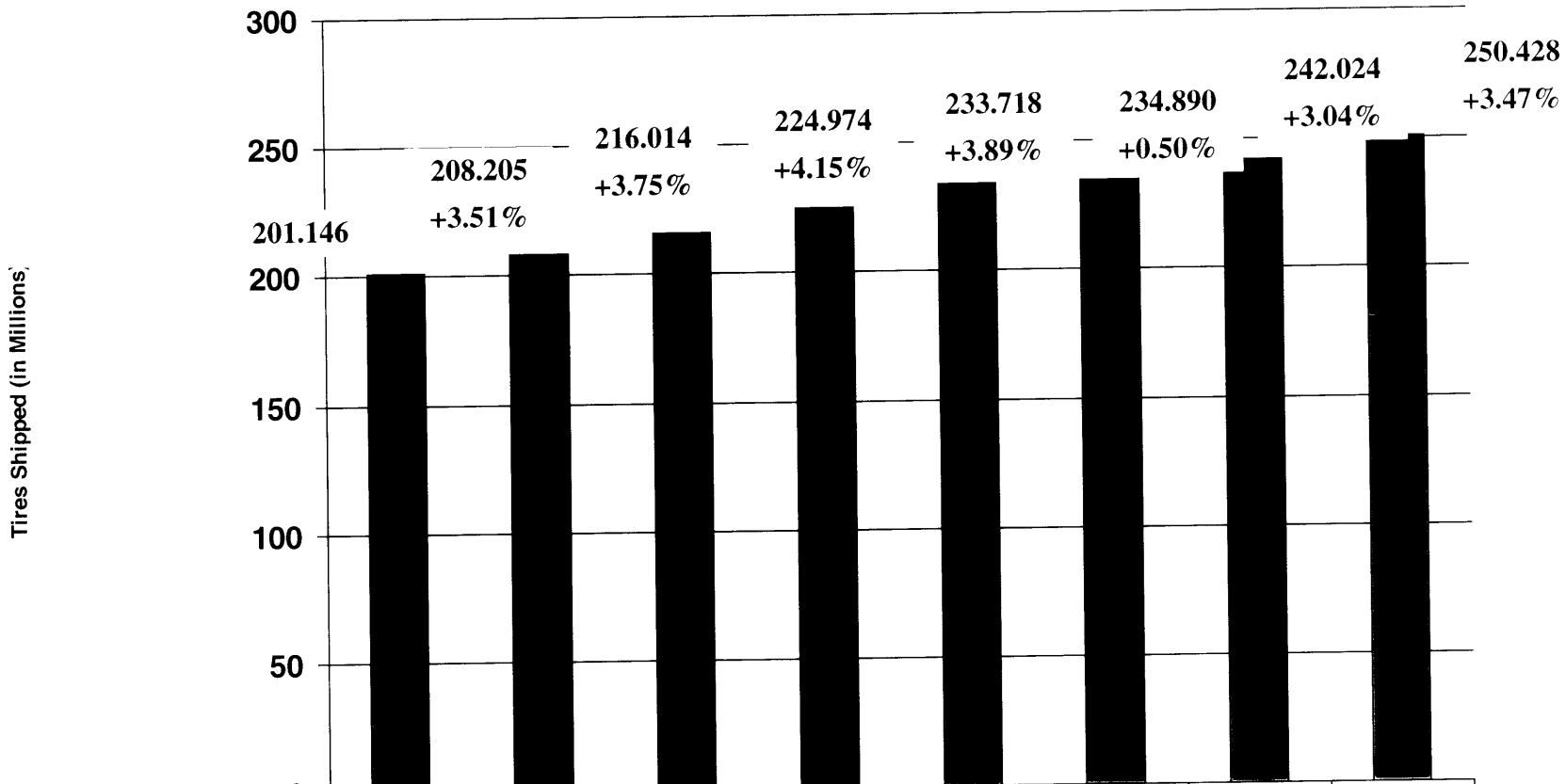
RMA Position on Tire Pressure Monitor/Warning Systems

- A Tire Pressure Monitor System/Low Tire Pressure Warning System (TPMS/LTPWS) must indicate to the operator when any (one or more) is **underinflated** when the actual inflation pressure falls below the placard pressure specified by the vehicle manufacturer.
- A TPMS/LTPWS must warn the operator when any tire (one or more) is **significantly underinflated** when the actual inflation pressure falls below the minimum inflation pressure specified by tire industry standardizing body (TRA, ETRTO, JTMA, etc) required to carry the actual load the individual tire is supporting, or the maximum load to be applied to the tire as determined by the vehicle manufacturer, or 150 kPa, (22 psi) whichever is larger.
- For vehicles equipped with run-flat tire systems, a TPMS/LTPWS must also provide warning to the operator when **the run-flat mode or condition** is reached and is being utilized on any tire (one or more).

Tire Sales

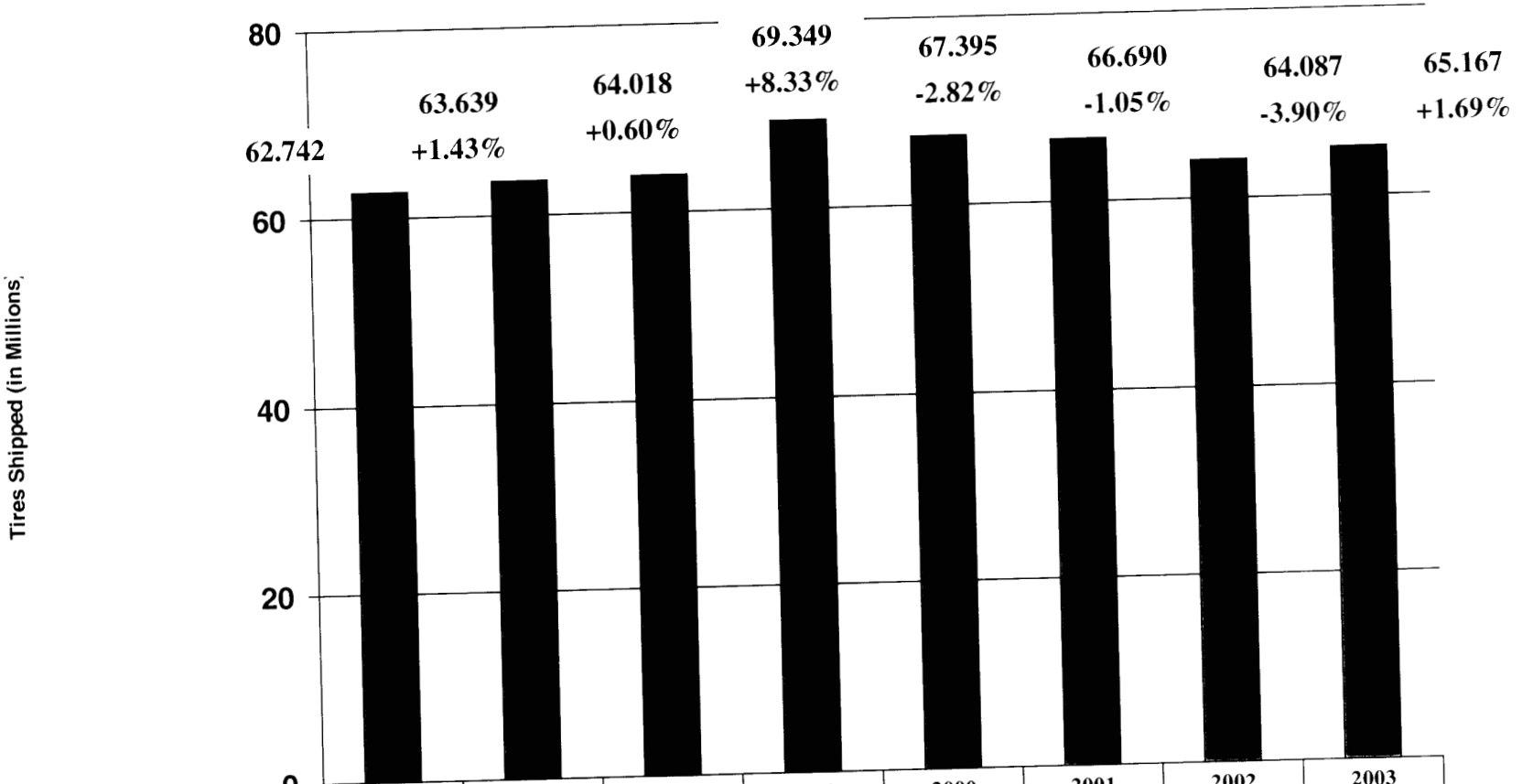
- In order to measure the impacts of TPM devices we will need to know the size of the tire market.
  - How many tires are sold in the U.S. annually?
  - What portion of these are light truck tires and what portion are passenger car tires? What portion are aftermarket vs. OEM?
  - What portion of each market are radials?

UNITED STATES CONSUMER TIRE MARKET REPLACEMENT



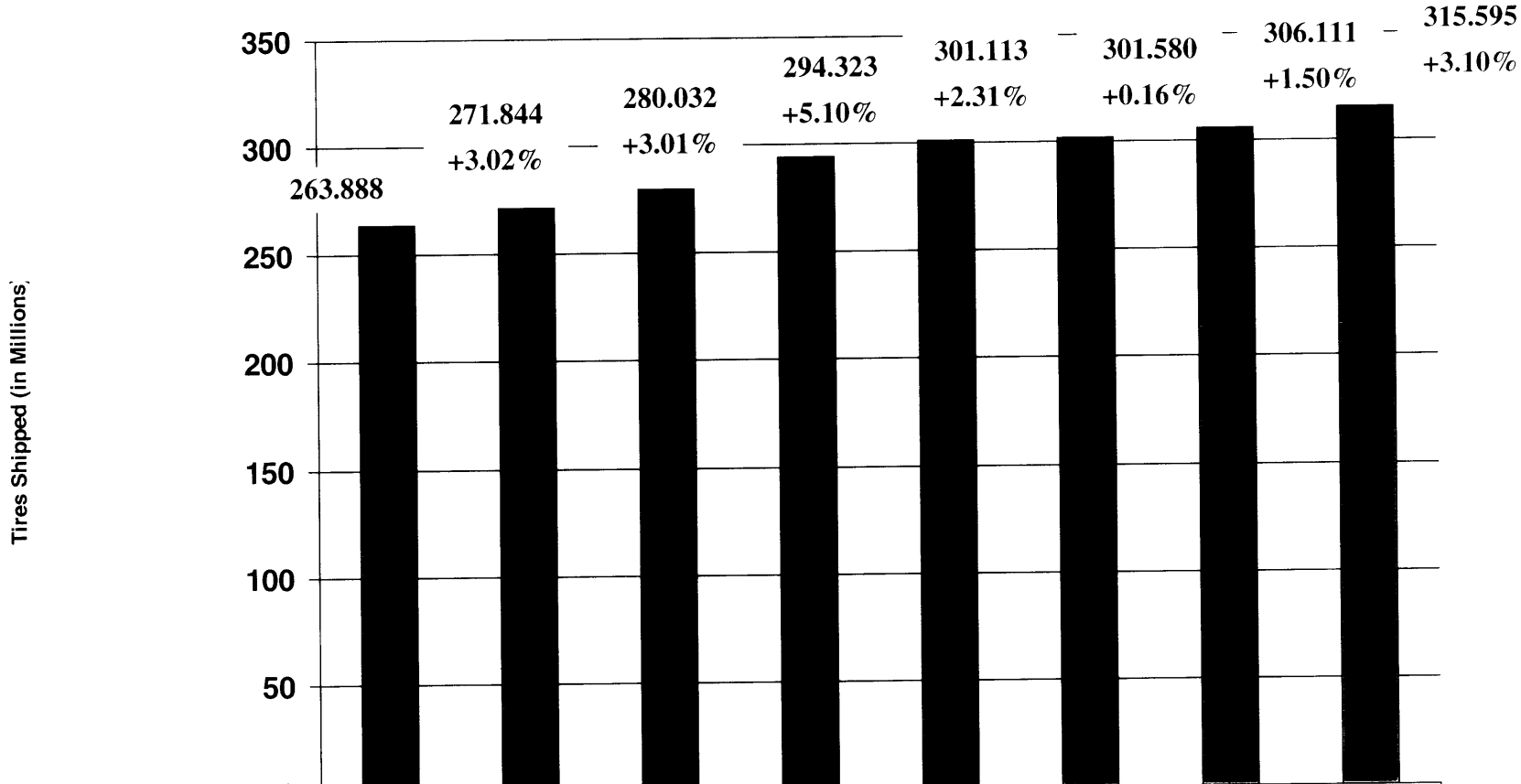
	1996	1997	1998	1999	2000	2001	2002	2003
■ Auto Bias & LT Bias	2.676	2.818	2.464	1.994	1.758	1.550	1.300	1.050
■ P-Met on LT & RLT	33.896	38.431	42.568	49.233	58.743	57.350	62.815	69.281
■ Broad Market & Performance	164.574	166.956	170.982	173.747	173.217	175.990	177.909	180.097

UNITED STATES
CONSUMER TIRE MARKET
OE



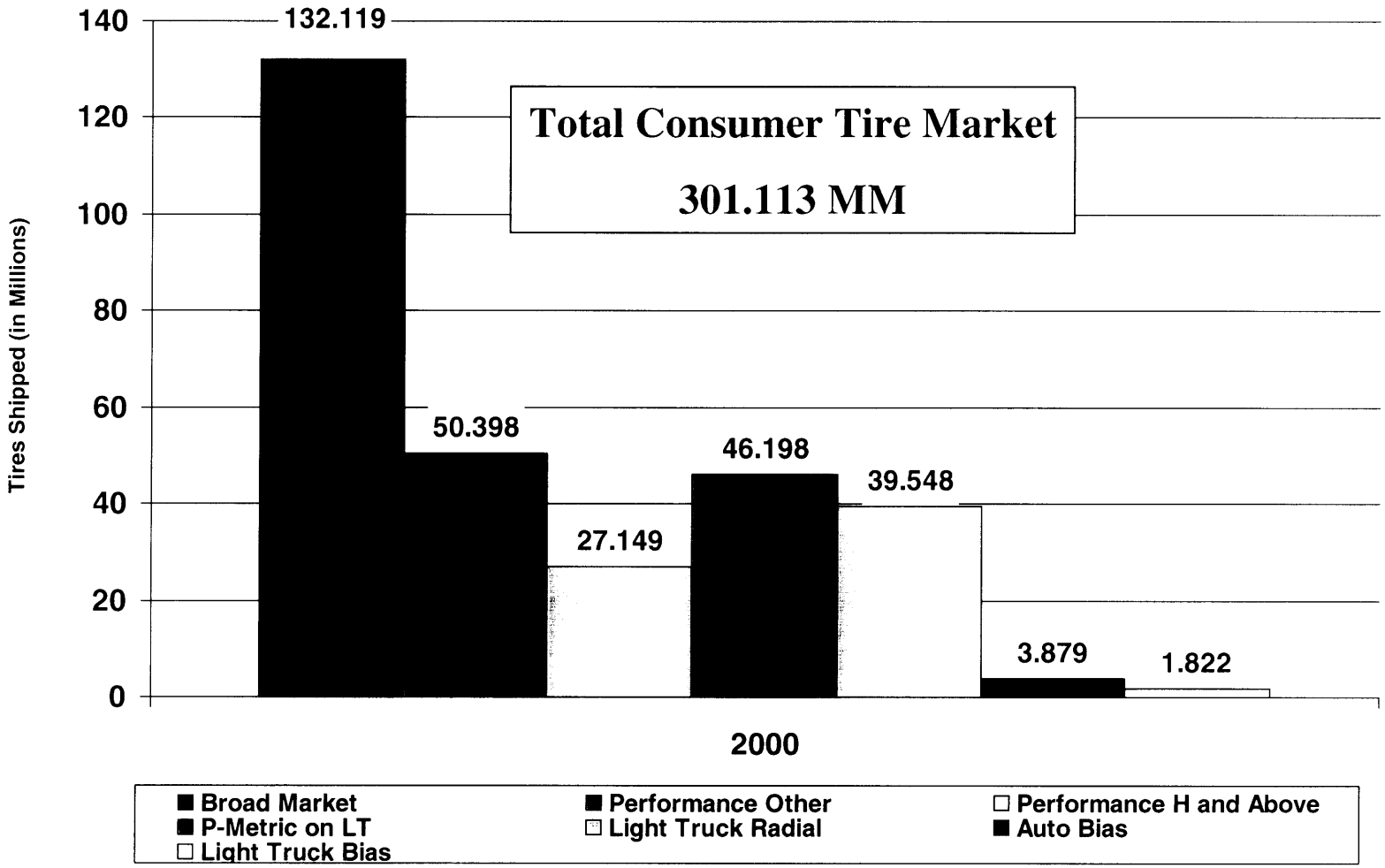
	1996	1997	1998	1999	2000	2001	2002	2003
Auto Bias & LT Bias	5.510	5.278	4.688	4.000	3.943	3.725	3.588	3.312
P-Met on LT & RLT	16.055	19.438	22.702	26.369	27.003	26.815	25.795	28.110
Broad Market & Performance	41.177	38.923	36.628	38.980	36.449	36.150	34.704	33.745

UNITED STATES
CONSUMER TIRE MARKET
OE + REPLACEMENT



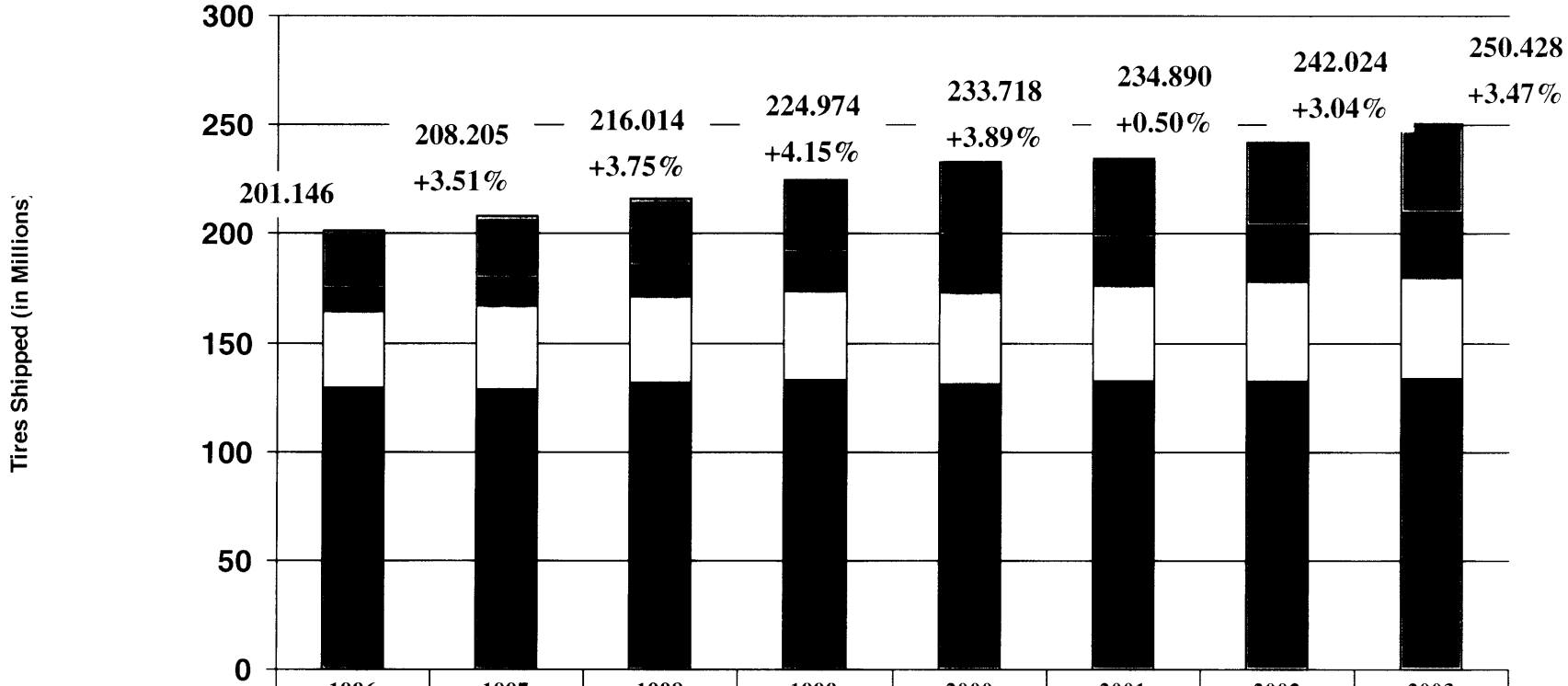
	1996	1997	1998	1999	2000	2001	2002	2003
Auto Bias & LT Bias	8.186	8.096	7.152	5.994	5.701	5.275	4.888	4.362
P-Met on LT & RLT	49.951	57.869	65.270	75.602	85.746	84.165	88.610	97.391
Broad Market & Performance	205.751	205.879	207.610	212.727	209.666	212.140	212.613	213.842

UNITED STATES - YEAR 2000
CONSUMER TIRES BY MARKET SEGMENT
OE + REPLACEMENT



UNITED STATES CONSUMER TIRE MARKET

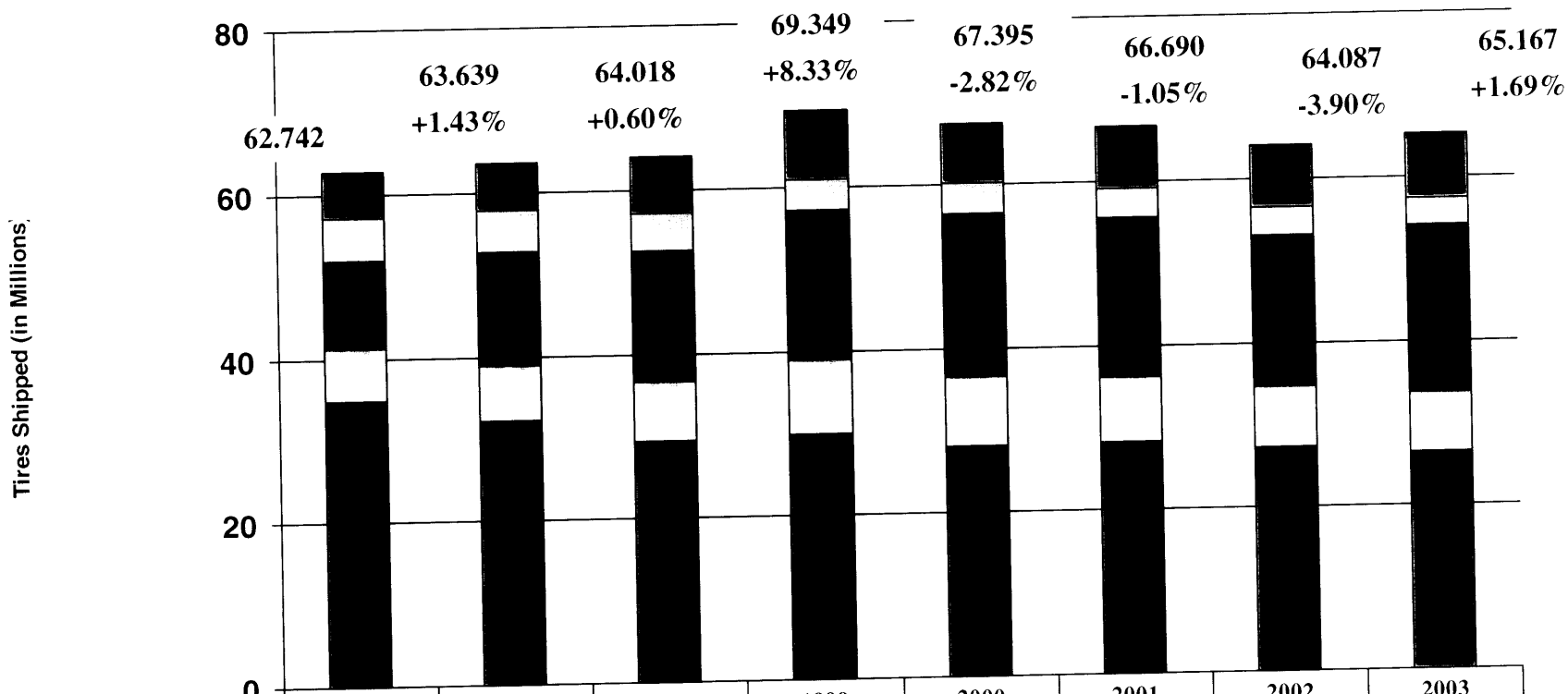
REPLACEMENT



	1996	1997	1998	1999	2000	2001	2002	2003
□ Bias LT	2.025	2.301	2.132	1.621	1.698	1.500	1.250	1.000
■ Radial LT	24.167	26.032	28.359	31.482	32.467	34.780	37.120	39.430
□ Auto Bias	0.651	0.517	0.332	0.373	0.060	0.050	0.050	0.050
■ P-Metric on LT	9.729	12.399	14.209	17.751	26.276	22.570	25.695	29.851
□ Performance Other	35.463	37.902	39.070	40.588	41.970	43.434	45.389	46.660
■ Performance H+	15.639	15.143	17.088	19.768	21.578	24.244	25.941	27.497
■ Broad	113.472	113.911	114.824	113.391	109.669	108.312	106.579	105.940

UNITED STATES CONSUMER TIRE MARKET

OE

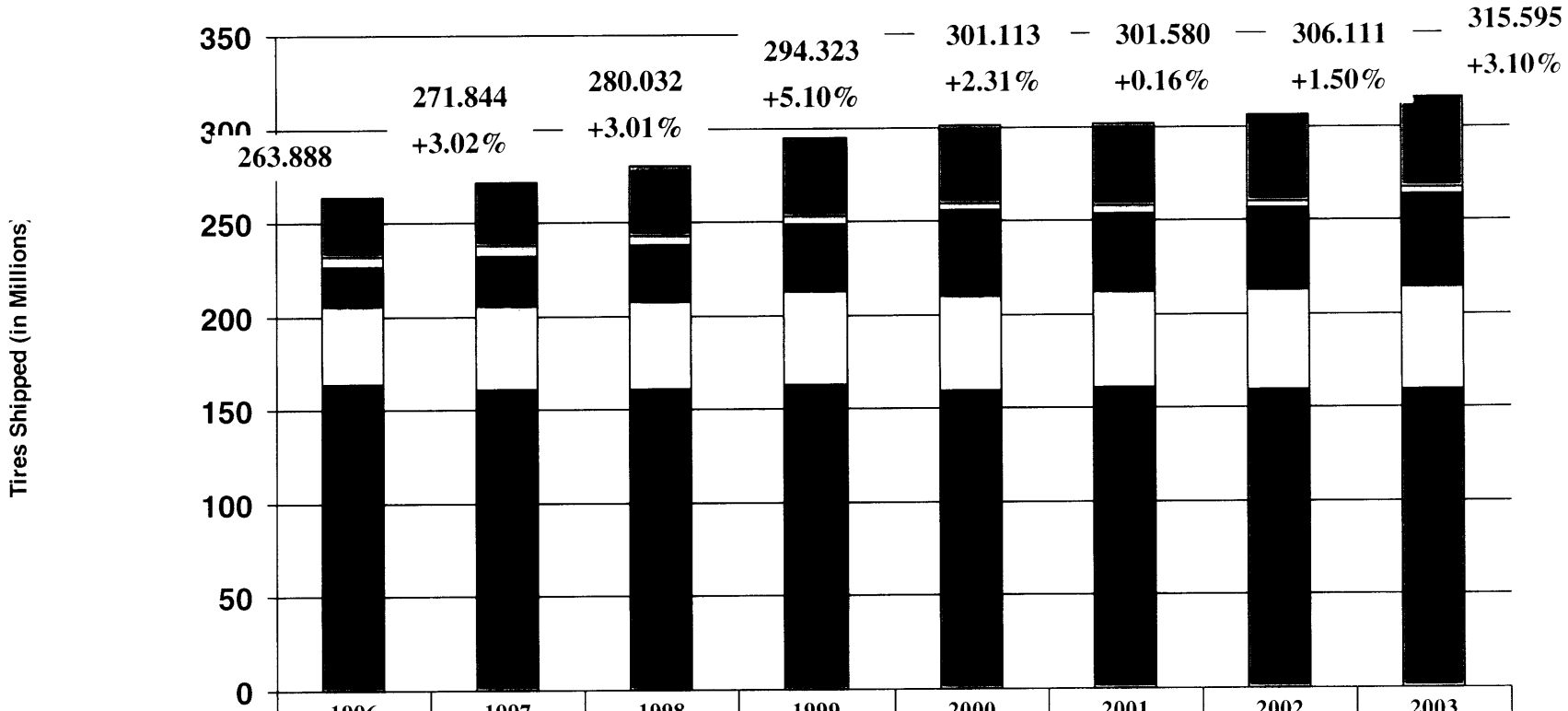


	1996	1997	1998	1999	2000	2001	2002	2003
Bias LT	0.353	0.242	0.169	0.144	0.124	0.115	0.110	0.105
Radial LT	5.297	5.612	6.721	8.203	7.081	7.485	7.425	7.805
Auto Bias	5.157	5.036	4.519	3.856	3.819	3.610	3.478	3.207
P-Metric on LT	10.758	13.826	15.981	18.166	19.922	19.330	18.370	20.305
Performance Other	6.331	6.718	7.206	9.087	8.428	7.888	7.506	7.304
Performance H+	5.332	3.808	3.678	4.219	5.571	5.712	5.898	6.221
Broad	29.514	28.397	25.744	25.674	22.450	22.550	21.300	20.220

04/06/01

UNITED STATES CONSUMER TIRE MARKET

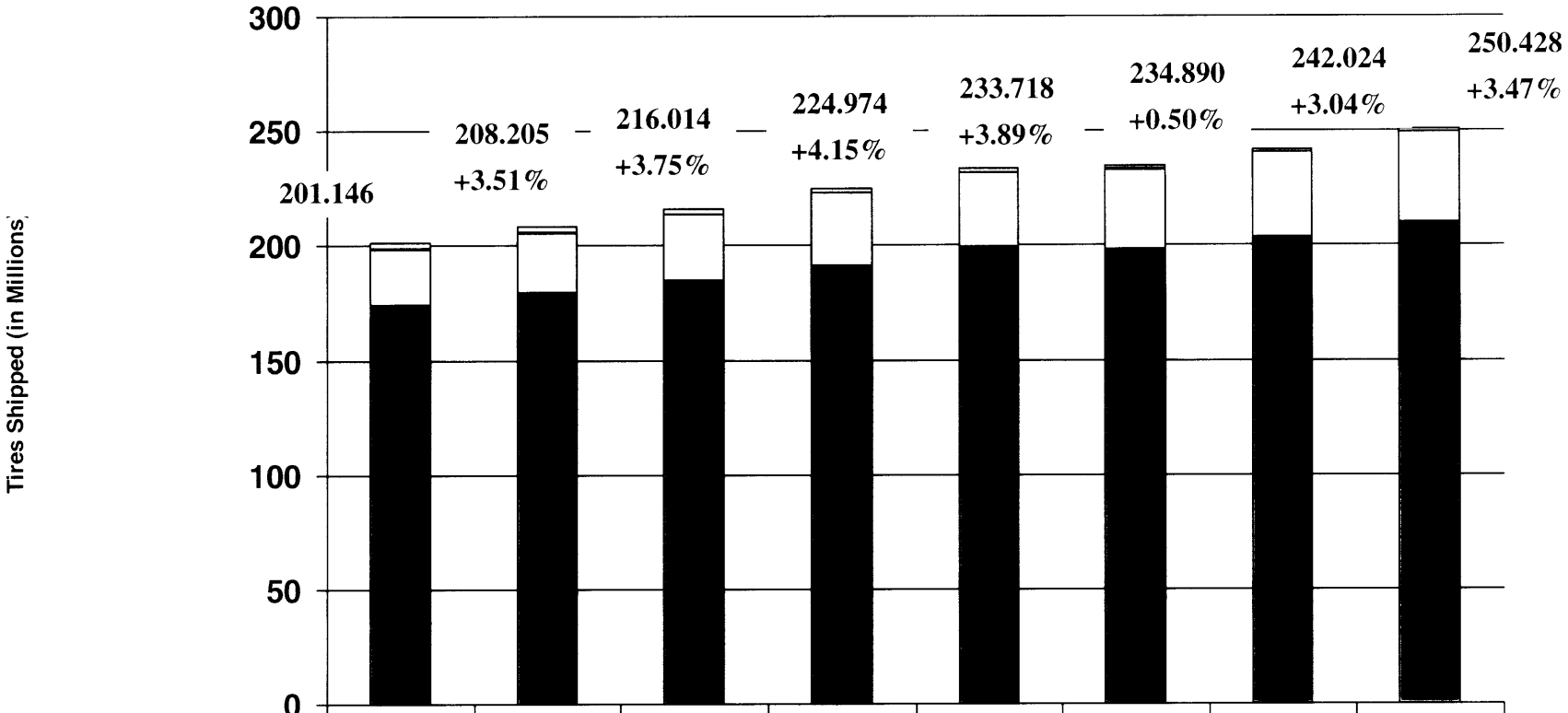
OE + REPLACEMENT



	1996	1997	1998	1999	2000	2001	2002	2003
Bias LT	2.378	2.543	2.301	1.765	1.822	1.615	1.360	1.105
Radial LT	29.464	31.644	35.080	39.685	39.548	42.265	44.545	47.235
Auto Bias	5.808	5.553	4.851	4.229	3.879	3.660	3.528	3.257
P-Metric on LT	20.487	26.225	30.190	35.917	46.198	41.900	44.065	50.156
Performance Other	41.794	44.620	46.276	49.675	50.398	51.322	52.895	53.964
Performance H+	20.971	18.951	20.766	23.987	27.149	29.956	31.839	33.718
Broad	142.986	142.308	140.568	139.065	132.119	130.862	127.879	126.160

UNITED STATES
CONSUMER TIRE MARKET

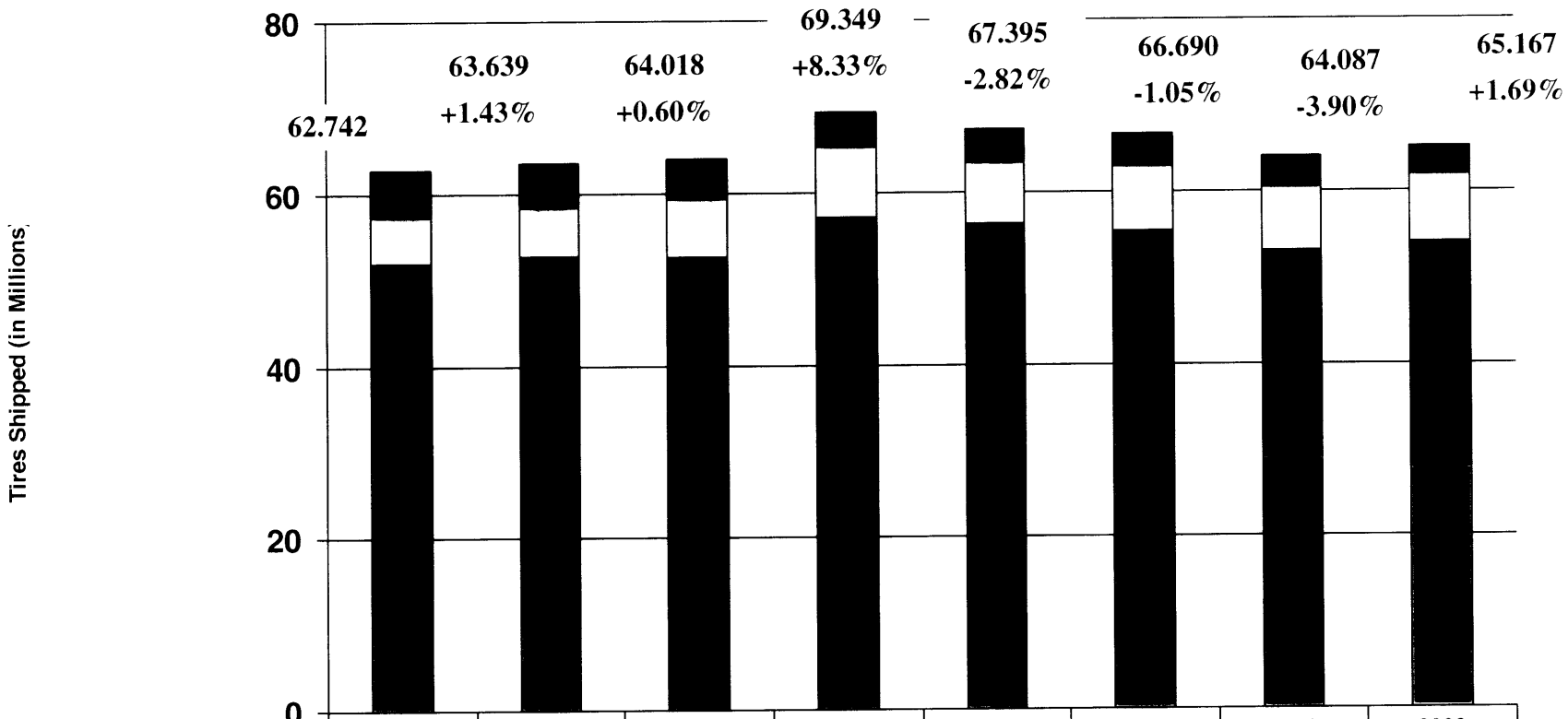
REPLACEMENT



	1996	1997	1998	1999	2000	2001	2002	2003
□ Light Truck Bias	2.025	2.301	2.132	1.621	1.698	1.500	1.250	1.000
■ Auto Bias	0.651	0.517	0.332	0.373	0.060	0.050	0.050	0.050
□ Light Truck Radial	24.167	26.032	28.359	31.482	32.467	34.780	37.120	39.430
■ P-Metric on LT	9.729	12.399	14.209	17.751	26.276	22.570	25.695	29.851
■ H/V/W/Z Speed Rated	15.639	15.143	17.088	19.768	21.578	24.244	25.941	27.497
■ S/T/all other non-Speed Rated	148.935	151.813	153.894	153.979	151.639	151.746	151.968	152.600

UNITED STATES
CONSUMER TIRE MARKET

OE



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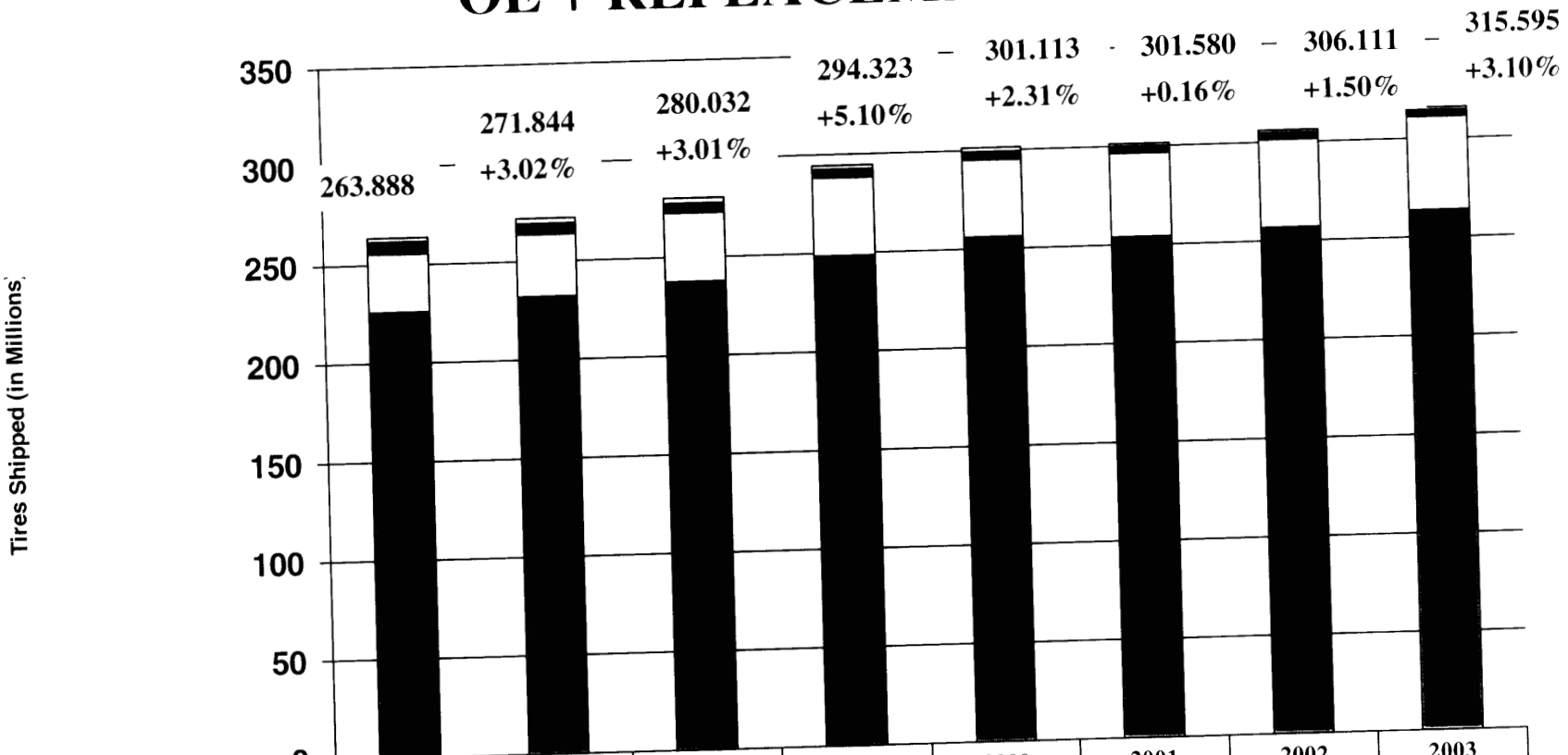
□ Light Truck Bias	0.353	0.242	0.169	0.144	0.124	0.115	0.110	0.105
■ Auto Bias	5.157	5.036	4.519	3.856	3.819	3.610	3.478	3.207
□ Light Truck Radial	5.297	5.612	6.721	8.203	7.081	7.485	7.425	7.805
■ P-Metric on LT	10.758	13.826	15.981	18.166	19.922	19.330	18.370	20.305
■ H/V/W/Z Speed Rated	5.332	3.808	3.678	4.219	5.571	5.712	5.898	6.221
■ S/T/all other non Speed Rated	35.845	35.115	32.950	34.761	30.878	30.438	28.806	27.524

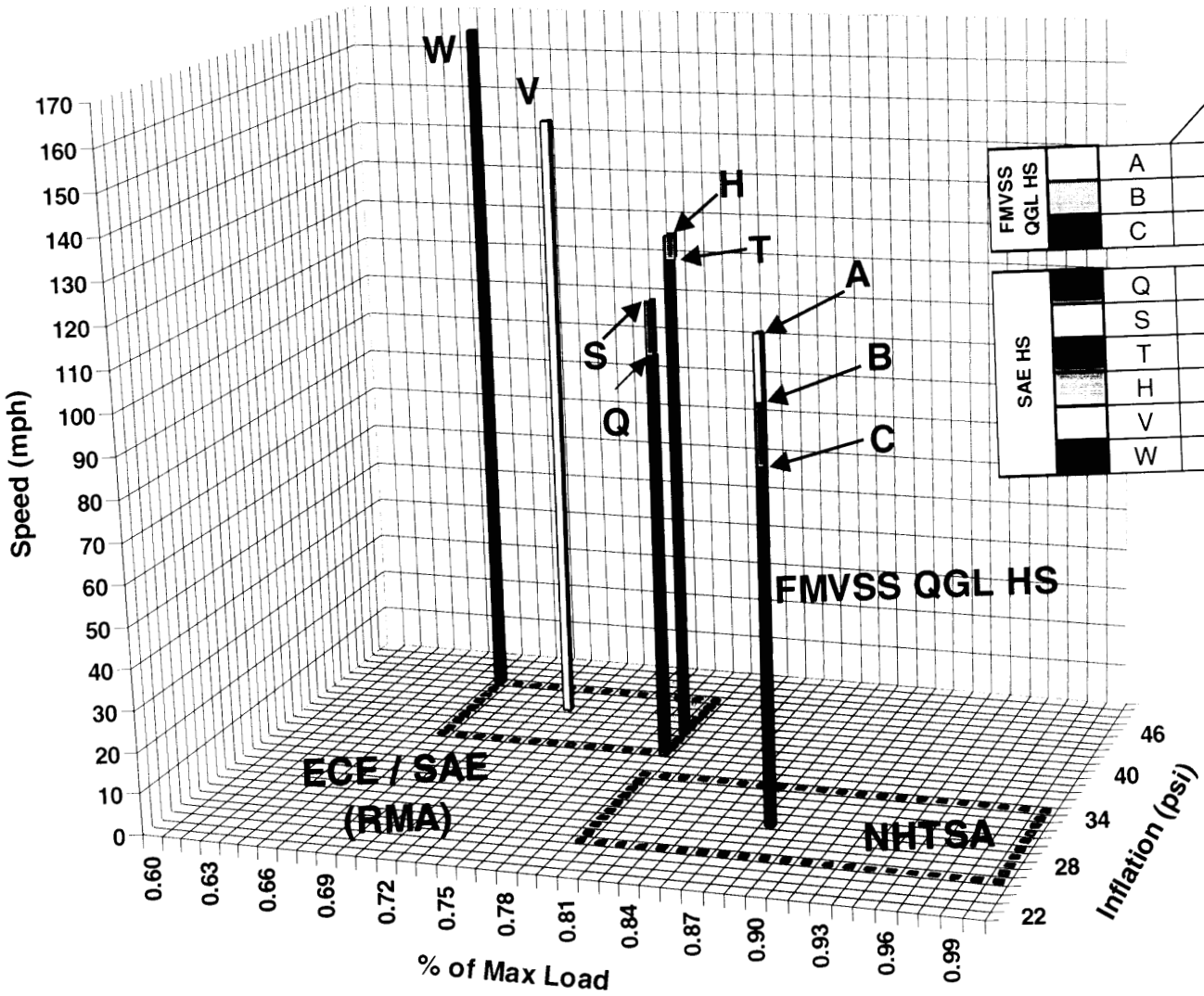
UNITED STATES CONSUMER TIRE MARKET

OE + REPLACEMENT



	1996	1997	1998	1999	2000	2001	2002	2003
□ Light Truck Bias	2.378	2.543	2.301	1.765	1.822	1.615	1.360	1.105
■ Auto Bias	5.808	5.553	4.851	4.229	3.879	3.660	3.528	3.257
□ Light Truck Radial	29.464	31.644	35.080	39.685	39.548	42.265	44.545	47.235
■ P-Metric on LT	20.487	26.225	30.190	35.917	46.198	41.900	44.065	50.156
■ H/V/W/Z Speed Rated	20.971	18.951	20.766	23.987	27.149	29.956	31.839	33.718
■ S/T/all other non Speed Rated	184.780	186.928	186.844	188.740	182.517	182.184	180.774	180.124

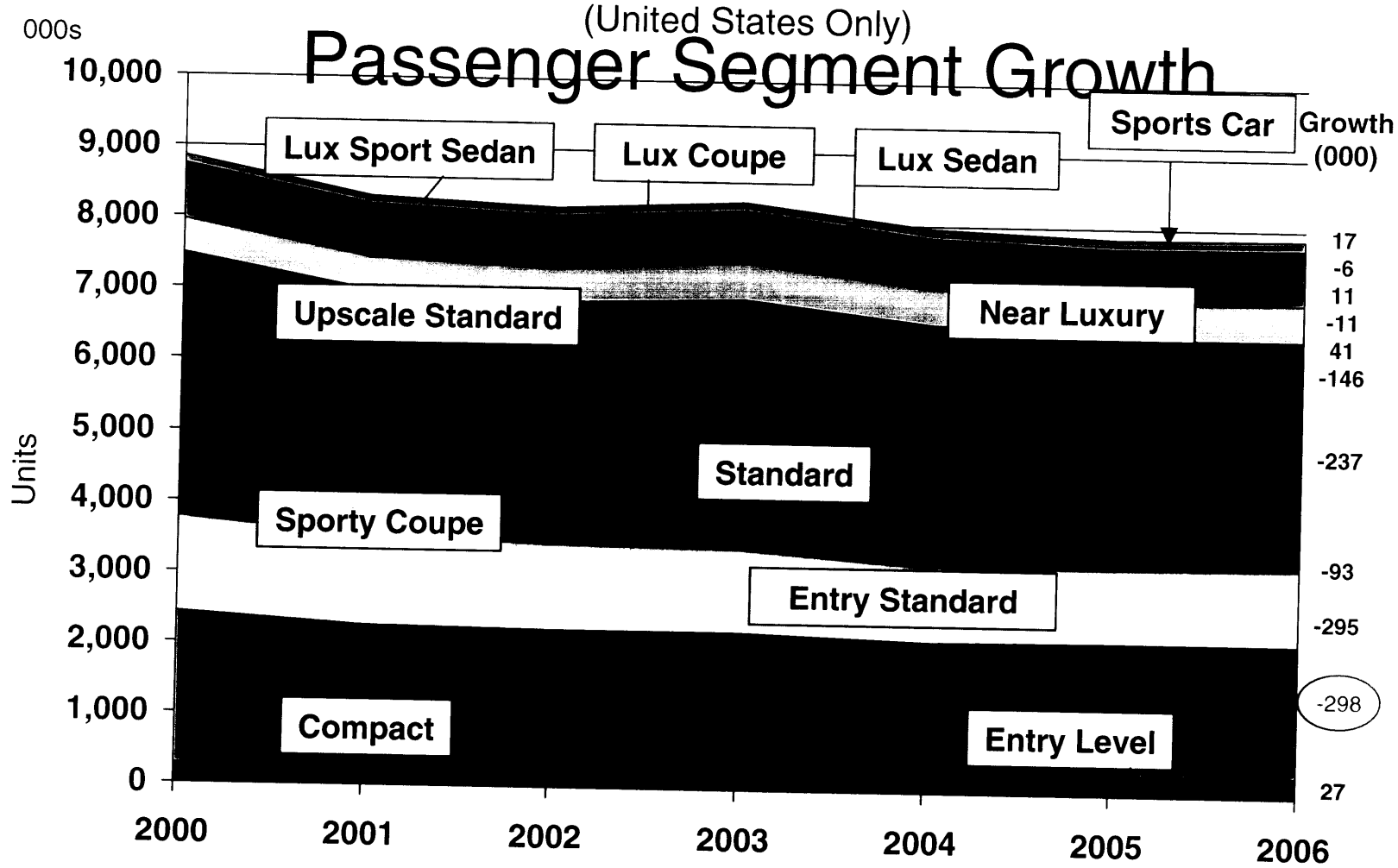
Tire Speed Ratings



		Speed (mph)	% of Max Load	Inflation (psi)
FMVSS QGL HS	A	115	88%	32
	B	100	88%	32
	C	88	88%	32
SAE HS	Q	99	80%	38
	S	112	80%	38
	T	118	80%	41
	H	130	80%	41
	V	149	73%	44
	W	168	68%	46

Passenger Segment Growth

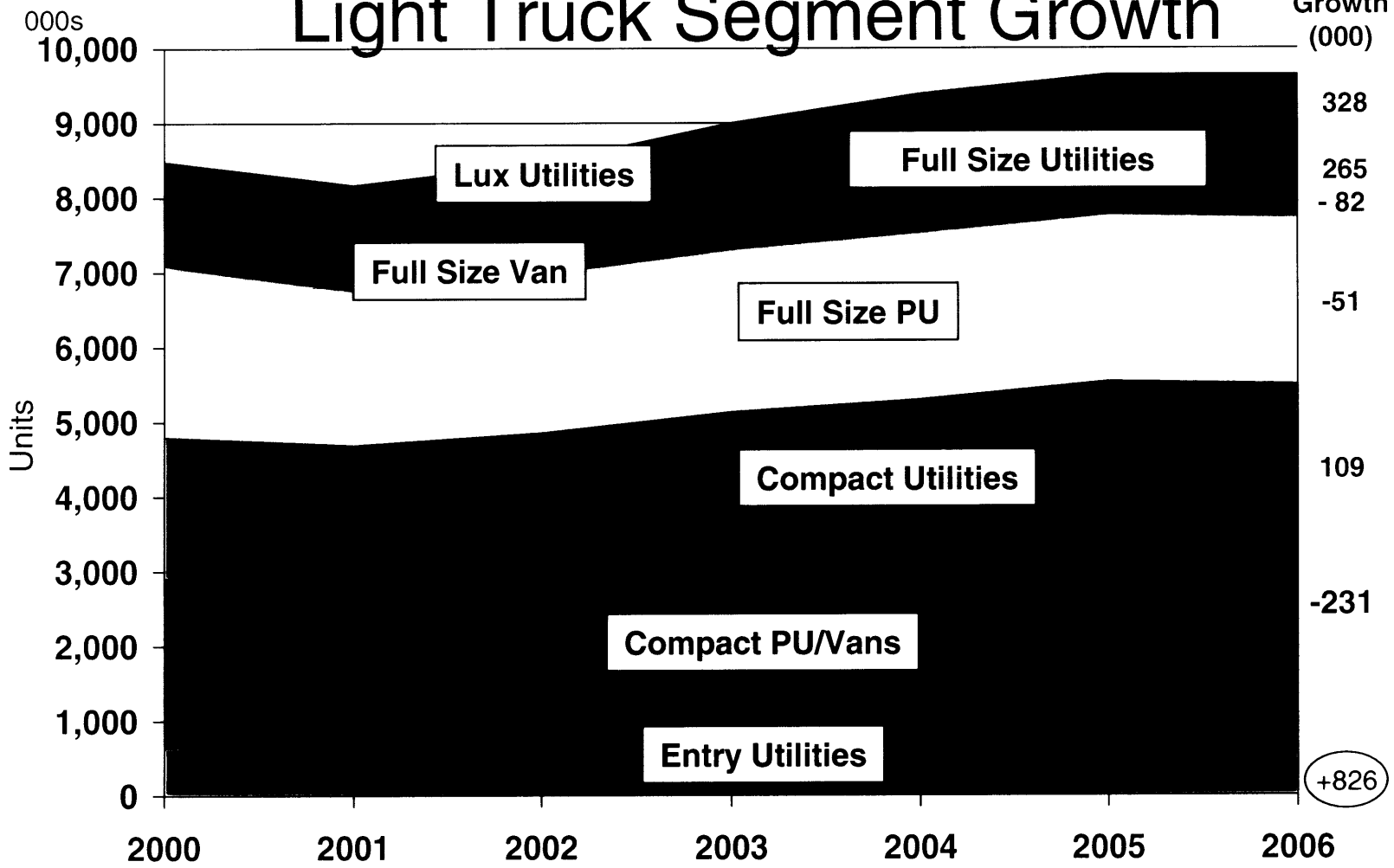
(United States Only)



Source: DRI North American Light Vehicle Fcst Rept, pg 142, March 2001

(United States Only)

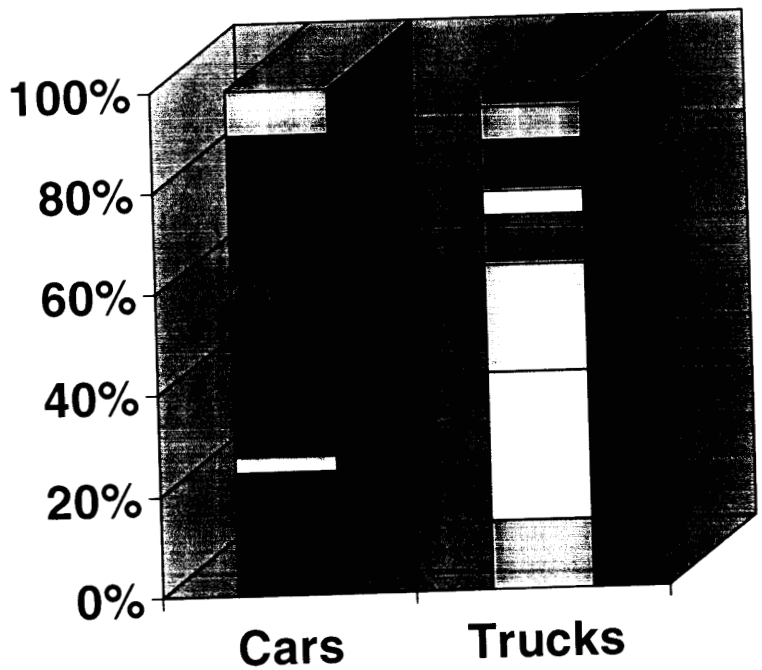
Light Truck Segment Growth



Source: DRI North American Light Vehicle Fcst Rept, pg 164, Mar 2001

Cars and Light Trucks within Segments

United States - 2000



Luxury Utilities	303,989
Full Size Vans	414,097
Full Size Utilities	665,240
Full Size Pickups	298,339
Entry Utilities	637,110
Compact Vans	1,382,484
Compact Utilities	1,893,237
Compact Pickups	883,744
Upscale Standard	805,893
Standard	2,276,194
Sporty Coupe	634,902
Sport Car	106,851
Near Luxury	469,452
Luxury Sport Sedan	344,416
Luxury Sedan	360,137
Luxury Coupe	82,237
Entry Standard	1,356,147
Entry	273,089
Compact	2,145,514

Trucks

Cars

Cost / Benefit Analysis

- In your presentation you stated that the added cost/year of tires set 6 psi below placard was $49, and the cost for tires set 10 psi below placard was $96.
  - Can you provide the details of these calculations?

Jointly Develop a Cost / Benefit Analysis

- Safety
  - Stopping Distances
  - Vehicle Handling
  - High Speed Capability
  - Tire Durability
- Economic
  - Fuel Consumption
  - Treadwear
  - Tire Costs

GOODYEAR

Recommendation

- Adopt RMA under inflation definitions and use flexibility of current tire industry standards
  - Pressure
  - Sizing
- Review tire applications by vehicle segment - establish minimum standard pressure reserve
- Consider all aspects of tire performance and the specific Tread Act rule making
- Work with OEM's and NHTSA to jointly develop the best proposal for consumers

GOODYEAR TECHNICAL CENTER AKRON

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AKRON, OHIO 44309-3531

Fax Cover Sheet

To: LARRY BLINCOE
NHTSA

From: SAM LANDERS
GOODYEAR

Number of Pages Submitted: 3

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Sam Landers **04/10/2001 09:13 AM**

To: lblincoe@nhtsa.dot.gov
cc: Bill Hopkins/NA/GDYR@GOODYEAR (bcc: Sam Landers/NA/GDYR)
Subject: Traction Data

Larry,

The following data was used to generate chart #12,"Test Surface Coefficients (SRTT & 0.050" water depth)":

Traction Truck Macadam	20 mph	Peak/Slide=	0.393/0.243
Traction Truck Macadam	40 mph	Peak/Slide=	0.357/0.220
Traction Truck Macadam	60 mph	Peak/Slide=	0.298/0.182
Braking Pad Macadam	20 mph	Peak/Slide=	0.738/0.481
Braking Pad Concrete	20 mph	Peak/Slide=	0.564/0.357
Handling Loop Macadam	20 mph	Peak/Slide=	0.859/0.582

Our test department is currently retrieving similar data for dry conditions. I will forward it as soon as they give it to me.

Do you have the book titled "Mechanics of Pneumatic Tires" by Samuel K. Clark published by the U.S. Department of Transportation, National Highway Traffic Safety Administration? This is an older book (~1985) but an excellent reference that has much of the information you are looking for. It maybe out of print. Page 607 addresses braking distance and includes the equation we presented on page 8 of our presentation. Please note that the coeficient of friction changes with slip velocity. The coeficient of friction used in the equation should be the average for the speed range experienced during the stop. Our test department advises using the average of 20, 40, and 60 mph coeficients of a stop from 60 mph.

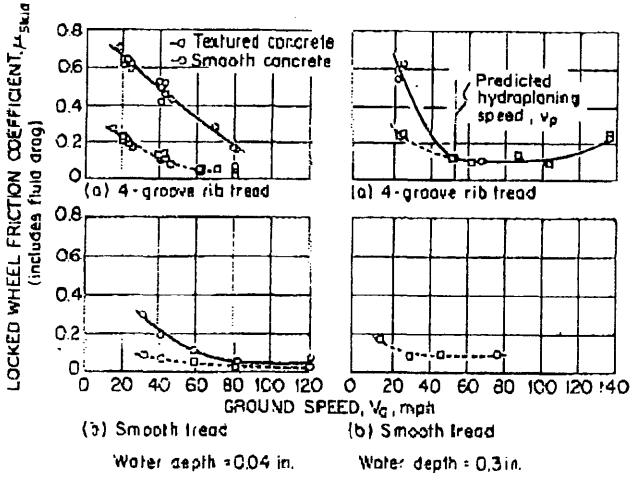
On page 325 of the Clark book, an equation for the onset of hydroplaning is presented. Hydroplaning speed (mph) = 10.35 x SQRT[inflation pressure(psi)]. This equation assumes that the water depth exceeds the capability of the tread design to remove the water. The amount of tread design void volume, the groove configuration, and how much the tire is worn determines its anti-hydroplaning capability.

Regards, SAM

Mechanics of Pneumatic Tires

Editor
Samuel K. Clark
University of Michigan
Ann Arbor, Michigan 48109

U.S. Department of Transportation
National Highway Traffic Safety Administration
Washington, D. C. 20590



GURE 5.90. *Effect of tread design, runway surface texture, and speed on the locked wheel friction coefficient, μ_{Skid}, developed on a flooded runway.*
6.50 – 13 passenger car tire; vertical load = 835 lb; tire pressure = 27 lb/in² [33].

As might be expected, the role of the various design variables is somehat different in thick film wet traction than in dynamic hydroplaning, nce in the pure hydroplaning case the tread surface cannot contact the vement so that tread compound and pavement micro-texture have little fluence, while they have considerable effect on the wet traction forces ailable prior to hydroplaning.

Full dynamic hydroplaning occurs when the amount of fluid encounred by the tire exceeds the combined drainage capacity of the tread patn and the pavement macrotexture. It occurs in deep fluid layers, usually eater than 2.0 mm, where fluid mass effects are dominant. As a tire oves through a thick fluid layer, the momentum of the fluid is changed hich causes a reaction force on the tire tread surface. The pressures so ilt up on the tire surface are sufficient to bend the tread region inwards d upwards from the pavement allowing a progressive persistance with creasing speed of the fluid film from the front, through the middle along e centerline, to the rear of the footprint. Since tire deformation is related the imbalance between the external and internal pressures acting on the e carcass, Horne [33] discovered that the following formula gives the apoximate speed at which a tire will dynamically hydroplane.

$$V_H = 1.8\sqrt{P} \tag{5.17}$$

ere V_H is the threshold speed for hydroplaning in *m/s*, and p is tire intion pressure in kilopascals. Comparison of this equation with experint is given in Figure 5.91 and is seen to be excellent. The approximate eed levels at which various ground vehicles will be susceptible to dymic hydroplaning are shown in Figure 5.92. Note that eq. 5.17 applies ly when the requirements are met on the fluid depth, tire tread pattern, d pavement macro-texture. In general the potential for dynamic hydroning is increased by little pavement macrotexture with few interonnected drainage paths, shallow tread depth, poor tread pattern design,

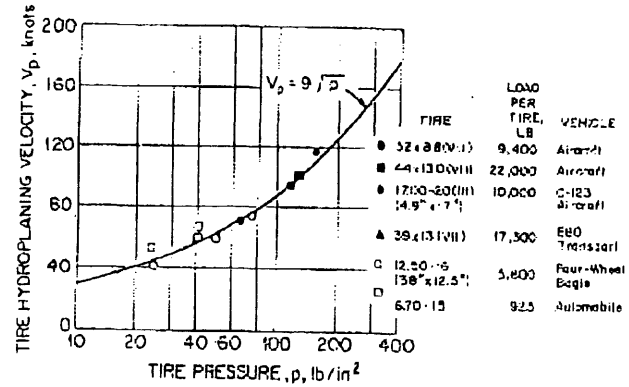


FIGURE 5.91. *Experimental and calculated tire-hydroplaning velocities [33].*

deep fluid layers, wide, low inflation pressure tires, and high vehicle speeds [6], [33], [106].

It is convenient to present the influence of the various variables on dynamic hydroplaning speeds by use of a Table 5.7, which attempts to condense the results of a great deal of research into an extremely concise form. In doing so, however, many of the nuances of the rather extensive literature are lost, and the serious reader should avail himself of the original papers used here as sources. For example, the influence of tread depth is quite strong in hydroplaning. As tread depth decreases the speed and water depth necessary for hydroplaning are both reduced, as is shown in Figure 5.93. The results of one investigation on the interaction of inflation pressure, load and speed is given in Figure 5.94, which clearly demonstrates that the onset of hydroplaning can be load dependent as well. However, the relationship between load and hydroplaning potential or wet traction capability is quite complex [7, 106, 111, 112]. Increases in load under dry conditions produce increases in the length of the contact region

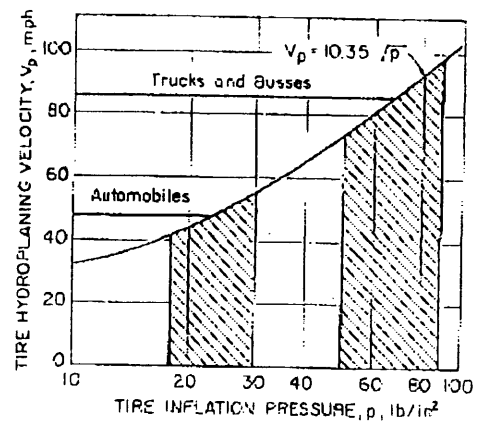


FIGURE 5.92. *Susceptibility of some ground vehicles to hydroplaning. [6].*

04/10/01 TUE 14:20 FAX 888 307 1920 GOODYEAR PLC GROUP 004

04/10/01 TUE 14:19 FAX 888 307 1920 GOODYEAR PLC GROUP 003

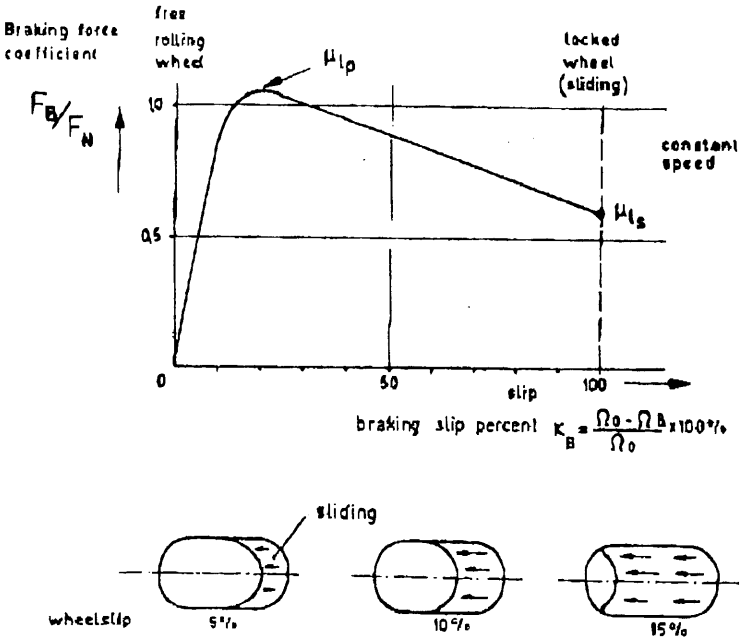


FIGURE 8.2.66. *The relation between braking force coefficient and braking percent slip.*

The difference in behavior of a radial ply and bias ply tire is clearly monstrated in figure 8.2.67 at a constant speed of 40 km/hr. [70]. It is en that the position of the peak coefficient μ_{lp} is often very difficult to de- mine since the curves are sometimes rather flat. Similar results are also ten obtained on wet surfaces [71].

. Effective radius

Returning to figures 8.2.61 and 8.2.62, the stretch of the tread elements t before contact, as measured from the photograph, appears to be ap- oximately 10 percent. Assuming again no sliding in the front part of the ntact zone, the same reasoning as in the free rolling case (sec. 8.2.3) re- lts in: $V = 1.1V_w$, that is $R_e = 1.1R$, showing an increase in effective dius compared with the free rolling condition ($R_e = 0.96R$) and a de- ase in angular velocity Ω [70].

The slip ratio may be defined to be:

$$\kappa_B = \frac{\Omega_o - \Omega_B}{\Omega_o} = \frac{R_{eB} - R_{eo}}{R_{eB}}$$

ere R_{eo} = effective radius at free rolling
R_{eB} = effective radius at braking.

Wet road measurements

Distance method [72]

The locked wheel "sliding" friction coefficient is determined during the speed interval under investigation.

The calculation of this friction value, sometimes called "braking coefficient" is based on the accurate measurement of the skid distance s and the speed V. It follows that:

$$\mu_{ls} = \frac{V_1^2 - V_2^2}{2gs}$$

where V_1 = initial velocity
V_2 = final velocity
g = gravitational constant.

Due to the erroneous assumption in the above formula of a constant deceleration over the speed interval (μ being speed dependent) it is rather difficult to compare results obtained with different tires on various road surfaces. Although standard vehicles are used, a large number of tests are required to arrive at an acceptable accuracy of the averaged μ_{ls} values. This is usually done at speed increments of about 10 km/hr. in the required speed range of the test vehicle.

b. Deceleration method

As discussed in chapter 6, the braking performance of tires can also be measured by the deceleration of the vehicle. In this method only the front wheels of the test vehicle are braked in order to maintain directional stability of the vehicle at all speeds [73].

Both the peak value of the braking force coefficient μ_{lp}, and the locked

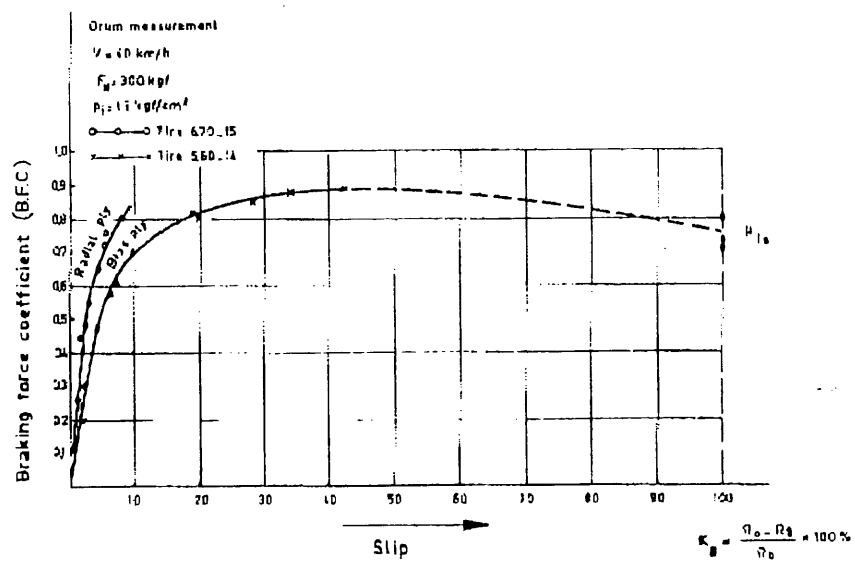


FIGURE 8.2.67. *Comparison of the braking force coefficient-braking slip relationships of a radial ply and bias ply tire at constant drum speed.*

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Fax Cover Sheet

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From: SAM LANDERS
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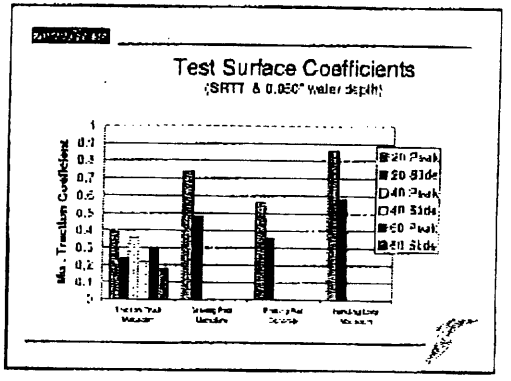
The following spreadsheet is the traction truck data from chart 12 →

CONSTR	INFL	WATER	Speed	Peak Mu	Slide Mu
SRTT	35	wet 0.05"	20	0.393	0.243
SRTT	35	wet 0.05"	40	0.357	0.220
SRTT	35	wet 0.05"	60	0.298	0.182



These numbers are lower than the more recent test below
Changes are probably due to a recent resurfacing

The following spreadsheet is recent traction trailer data for the SRTT industry standard tire.

CONSTR	INFL	WATER	Speed	Peak Mu	Slide Mu
SRTT	35	dry	40	0.949	0.660
SRTT	35	dry	60	0.936	0.646
SRTT	35	wet 0.05"	20	0.503	0.278
SRTT	35	wet 0.05"	40	0.454	0.244
SRTT	35	wet 0.05"	60	0.343	0.182

The following spreadsheet is average traction numbers for a typical OE base tire
This is the same tire presented last week and used for the regression equations to follow

CONSTR	INFL	WATER	Speed	Peak Mu	Slide Mu
Test Tire	17	dry	40	0.995	0.700
Test Tire	17	wet 0.05"	20	0.491	0.283
Test Tire	17	wet 0.05"	40	0.448	0.234
Test Tire	17	wet 0.05"	60	0.338	0.129
Test Tire	35	dry	40	1.036	0.700
Test Tire	35	wet 0.05"	20	0.561	0.340
Test Tire	35	wet 0.05"	40	0.499	0.285
Test Tire	35	wet 0.05"	60	0.352	0.207

RAW DATA (WET TRACTION TRUCK)

Dash	P	V	VSQRD	Peak Mu	Slide Mu
6315	17	20	400	0.498	0.281
6316	17	20	400	0.483	0.284
6315	17	40	1600	0.447	0.231
6316	17	40	1600	0.449	0.236
6315	17	60	3600	0.328	0.13
6316	17	60	3600	0.348	0.128
6317	35	20	400	0.572	0.343
6318	35	20	400	0.55	0.337
6317	35	40	1600	0.491	0.281
6318	35	40	1600	0.506	0.289
6317	35	60	3600	0.343	0.203
6318	35	60	3600	0.36	0.21

REGRESSION EQUATIONS

Inflation is in psi, speed is in mph

Peak Mu = 0.4374907 + (0.0024907 x inflation) + (0.0030750 x speed) - (0.000095 x speed^2)

Slide Mu = 0.2339537 + (0.0034537 x inflation) + (0.0003625 x speed) - (0.000049 x speed^2)

The following two pages show statistics for regression

04/11/2001 10:10 AM

DataTable=1K204 T98,Fit Model=

Least Squares Fit

Response Peak Mu

Summary of Fit

RSquare	0.968081
RSquare Adj	0.956111
Root Mean Square Error	0.017629
Mean of Response	0.447917
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.07540275	0.025134	80.8771
Error	8	0.00248617	0.000311	Prob > F
C. Total	11	0.07788892		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00167267	0.000836	6.1684
Pure Error	6	0.00081350	0.000136	Prob > F
Total Error	8	0.00248617		0.0350
				Max RSq
				0.9896

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.4374907	0.041138	10.63	<.0001
P	0.0024907	0.000565	4.40	0.0023
V	0.003075	0.002181	1.41	0.1963
VSQRD	-0.000095	0.000027	-3.52	0.0078

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
P	1	1	0.00603008	19.4036	0.0023
V	1	1	0.00061751	1.9870	0.1963

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
VSQRD	1	1	0.00385067	12.3907	0.0078

Response Slide Mu

Summary of Fit

RSquare	0.991449
RSquare Adj	0.988243
Root Mean Square Error	0.007617
Mean of Response	0.246083
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.05381875	0.017940	309.1921
Error	8	0.00046417	0.000058	Prob > F
C. Total	11	0.05428292		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00037067	0.000185	11.8930
Pure Error	6	0.00009350	0.000016	Prob > F
Total Error	8	0.00046417		0.0082
				Max RSq
				0.9983

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2339537	0.017775	13.16	<.0001
P	0.0034537	0.000244	14.14	<.0001
V	0.0003625	0.000943	0.38	0.7106
VSQRD	-0.000049	0.000012	-4.23	0.0029

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
P	1	1	0.01159408	199.8262	<.0001
V	1	1	0.00000858	0.1479	0.7106
VSQRD	1	1	0.00104017	17.9275	0.0029

Surface	INFL	V	Calculated Peak Mu	Surface Adjustment	Adjusted Peak Mu	E	Calculated Stop Dist	Actual Stop Dist	Actual / Calc
Braking Pad Concrete	35	25	0.542	2.000	0.271	80%	44.79	48.00	1.07
Braking Pad Concrete	29	25	0.527	2.000	0.264	80%	46.06	48.20	1.05
Braking Pad Concrete	25	25	0.517	2.000	0.259	80%	46.94	48.20	1.03
Braking Pad Concrete	17	25	0.497	2.000	0.249	80%	48.82	47.40	0.97
Braking Pad Concrete	35	45	0.471	2.000	0.235	80%	167.15	163.60	0.98
Braking Pad Concrete	29	45	0.456	2.000	0.228	80%	172.64	167.40	0.97
Braking Pad Concrete	25	45	0.446	2.000	0.223	80%	176.49	167.20	0.95
Braking Pad Concrete	17	45	0.426	2.000	0.213	80%	184.75	182.60	0.99

I Hope this is everything you asked for – any problems, give me a call

Sam