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MEASUREMENT OF CRASH AVOIDANCE CHARACTERISTICS OF VEHICLES IN USE

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16. Abstract

The primary purpose of this study was to collect information on the condition of lighting equipment, rearview mirrors, and tires on a nation-wide sample of vehicles in use. In order to more adequately represent cars of the future, the sample was restricted to vehicles built in 1979 and later. As a result, the data may not be completely representative of the current vehicle population.

The results of the study indicate that headlamps are often badly out of aim. About 60% of the vehicles sampled had one or more low-beam units aimed outside of SAE limits. Aim worsens as vehicles age, at least for the first four years. With the exception of side marker lights, all other lights and signals on the vehicles inspected were about 98% operational. Side marker lights were about 90% operational. The condition of all lighting equipment was better in states having motor vehicle inspection programs.

The rearview mirrors in the sample were generally in good physical condition. Their aim was quite variable. However, in general, the mirrors were aimed to provide a reasonably good view of important areas to the rear.

About 90% of the tires in the sample were found to be free of defects. Average tread depth, except for new cars, was about 0.21 inch, with a standard deviation of about 0.07 inch. On average, tires were inflated to within 2-3 psi of the pressure recommended. However, the standard deviation was about 6 psi.

A study was also run of the effects of vehicle loading on vertical headlamp aim. These results suggest that fuel levels will alter aim by about 0.2 degree on average. Full-passenger or full-rated loads have a much greater effect, altering pitch by as much as 1-1.5 degrees.

Literature surveys were also run on aerodynamic effects, and equipment for cleaning headlamps and maintaining their aim under different loading conditions. Summaries of the findings are presented.

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The purpose of this study was to obtain information about the condition of certain important items of safety equipment (i.e., lighting equipment, tires, and rearview mirrors) from vehicles in use. Specifically, the following data were obtained:

1. Headlamps:
    a. Condition
    b. Aim
    c. Intensity reduction due to dirt
2. General condition of other lighting equipment
3. Rearview mirrors
    a. Number and type
    b. Condition
    c. Horizontal and vertical field of view
4. Tires
    a. Condition
    b. Tread depth
    c. Inflation pressure

A study was also run to estimate the effects of different levels of passenger and baggage load on vertical headlamp aim. In addition, information was secured concerning aerodynamic effects on vehicle pitch and equipment available for cleaning headlamps and maintaining correct vertical aim under different loading conditions.

The information regarding the condition of safety equipment was obtained at 20 different sites in the United States. These sites were selected to provide a representative sample of cars, vans, and pickup trucks manufactured from 1979 to 1984. The sample was restricted in this way so that it would more adequately depict vehicles of the future.

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However, some of the analyses may not be completely representative of the current vehicle population. Data on lighting equipment and mirrors were collected from one sample of nearly 1,000 vehicles at service stations scattered throughout each site. Tire data were taken from another sample of about 1,000 vehicles that had been parked for at least one hour at a variety of locations such as schools, factories, and employee sections of shopping centers. Because the vehicles in the sample were relatively new, their condition may be better than that of the general vehicle population.

About 99% of the headlamps in the sample were found to be working and free of defects. On average, headlamps in the sample were found to be aimed down about 0.15 degree. The standard deviation of aim was about 0.9 and 0.8 degree for the vertical and horizontal dimensions respectively. The aim of new (1984 model) vehicles was relatively good, with about 60% of them having both lamps aimed within SAE specifications. However, after four years only about 30% of vehicles had both lamps aimed within SAE specifications. Vehicles in states having periodic motor vehicle inspection (PMVI) programs had somewhat lower aim variance and were more likely to have both headlamps aimed within SAE specifications than those not in PMVI states.

About 98% of the front and rear marker lamps in the sample were operational. Side marker lamps were in somewhat poorer shape. About 87% of those at the front and 94% of those at the rear were working on the vehicles in the sample. Side marker lights may not receive much maintenance. Only 0.5% of those on new vehicles were not working. This figure steadily increased, reaching 15% on vehicles that were six years old. All marker lights were more likely to be working in states having PMVI than states without.

Brake and turn signals were found to be working about 98% of the time. Once again, the incidence of working units was higher in PMVI states.

All the vehicles in the sample had an interior mirror and an outside mirror on the driver's side. About 2/3rds of the sample also had an outside mirror on the passenger side, most of which were convex. Fewer than 10% of the sample had more than three mirrors. Those that did had so-called "button" convex mirrors either mounted on the face of one or both exterior mirrors or attached near it.

Most of the mirrors in the sample were in good physical shape and were aimed to provide a reasonable field of view for the driver. However, some mirrors were fogged, cracked or missing altogether. And some mirrors were so badly aimed that they provided virtually no useful information.

About 10% of the tires in the sample were found to have defects of one kind or another. The most common defects were uneven tread wear and weather checking.

For all but the newest vehicles in the sample, tread depth averaged about 0.21 inch, with a standard deviation of about 0.07 inch. Current-model vehicles averaged about 0.28 inch, with a standard deviation of about 0.04 inch.

Tire pressure in the sample averaged about 31 psi, with a standard deviation of about 6 psi. The mean was slightly higher and the standard deviation slightly lower on the newest cars in the sample. When measured and recommended pressures were compared it was found that, on average, pressures were generally within one psi of recommended values. Rear tires tended to be slightly underinflated. Front tires, on the older vehicles in the sample, tended to be overinflated by 2 to 3 psi, on average.

The loading study was carried out on a selected sample of 20 vehicles. The model years were 1979 to 1984. Each was measured with the fuel tank empty and then full. Weight was added to each of the seated positions (150 pounds each) and to the baggage area to bring it to full-rated load. Pitch readings were taken after each load increment. Pitch changes associated with fuel alone ranged from 0 to 0.4 degrees, with a median value of 0.2 degrees. Pitch changes going from driver-only to full-rated load ranged from about 0.6 to 1.5 degrees, with a median of 1.1 degrees. Going from driver-only to a full passenger load produced pitch changes from about 0.5 to 1.0 degree, with a median of 0.7 degree.

The available data indicate that aerodynamic effects on most newer vehicles are slight. At 55 mph the pitch change for almost all vehicles investigated fell between plus and minus 0.25 degree. For many vehicles the change was 0.1 degree or less. The only vehicles exhibiting a significantly greater effect were those having large frontal areas (e.g. a pickup truck with a camper).

Means for cleaning headlamps have been available for a number of years. Originally these systems used wiper-washer arrangements that were simply scaled-down versions of those used on windshields. This is still a popular solution. More recently systems have been produced that utilize high-pressure jets to blast the lens clean. By eliminating the wiper mechanism, such systems should be significantly less costly.

Maintaining proper vertical aim under varying load conditions is another area that has long been of concern. The solutions fall under two headings, leveling the whole car and leveling just the lamps. There are a variety of ways, both manual and automatic, of achieving each. Car leveling systems have important advantages in terms of driver control and occupant comfort. Maintaining proper headlamp aim is not a primary concern. However, such systems are relatively expensive. Lamp leveling systems can be mechanical, electrical, hydraulic or pneumatic. Many of these have been used in production vehicles in recent years and have been shown to be effective and reliable. In general, they are significantly less expensive than car leveling systems.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This report describes work carried out to provide information concerning three important vehicle safety systems: headlamps, rearview mirrors, and tires. The bulk of the information was collected in a nation-wide study of the condition of these systems on vehicles in use. Other information was obtained through literature surveys, information from manufacturers of vehicles and components, and special investigations. In this portion of the report we will provide background information in each of the areas of concern. Later section will describe the methods, results, and conclusions of the investigation.

1.1 Headlamps

1.1.1 General. Recent work carried out for the National Highway Traffic Safety Administration (NHTSA) at the University of Michigan (Olson and Sivak, 1983) made it clear that low-beam headlamps are inadequate for reliably revealing common, low-contrast objects at anything other than very low speeds. The test on which this conclusion is based was run under ideal conditions (i.e., no glare, all glass clean and clear, lamps in perfect aim, correct voltage, and alerted subjects). Matters are seldom so well arranged in the real world, and the result is oftentimes reduced visibility.

In 1971 Yerrell reported a study of headlamp glaring and illuminating intensities. The data were taken surreptitiously from passing cars at a number of sites in Great Britain and on the continent. The results show great variability in both measures. Some cars had a quarter or less of the allowable maximum illuminating intensities and some cars had several times the allowable maximum glare intensities. There are several reasons for the scatter in Yerrell's results. Some of the more important are:

a. Misaim

b. Dirt accumulations

c. Wrong voltage to the lamp

d. Inappropriate use of high beams

e. Production variance

Yerrell's date are now rather old, and they are based on a sample of British and European vehicles. However, there is reason to believe that these problems persist at the present time, and in the United States. To the degree they do, they represent significant problems for and limitations to headlamp performance. The study to be described sought to supply information on some of these issues.

1.1.2 Headlamp Aim. The low-beam of motor-vehicle headlamps is shaped to provide maximum seeing illumination to the driver of the vehicle to which it is mounted and minimum glare to oncoming drivers. Very small changes in aim can make a substantial difference in the quality of performance it delivers.

The problem is that these carefully-designed devices must operate under conditions that make accurate aiming very difficult. For example, Olson and Mortimer (1974) analyzed various sources of misaim and available data on the extent of each. The following sources were identified:

Attributable to the lamp:

a. Misorientation of the aiming plane.

b. Non-parallel mounting and aiming planes.

c. Changes associated with aging.

Attributable to the vehicle:

a. Lamp mounting mechanism.

b. Dog tracking (i.e., tracking axis and longitudinal axis not parallel)

c. Matchboxing (i.e., paired lamps not on a line perpendicular to the longitudinal axis)

d. Load (fuel, passengers and baggage)

e. Vehicle defects (e.g., broken or sagging springs)

Attributable to the aiming process:

a. Problems in finding the longitudinal axis of the vehicle

b. Aimer out of calibration

c. Human factors (e.g., poor training, carelessness).

The data collected by Olson and Mortimer suggest that one of the major contributors to aim variance is in the aiming process itself. In a small-scale survey of service outlets in one area it was found that the chance of having all four lamps on the test vehicle aimed within SAE specifications was less than 50–50. In some cases the already badly misaimed lamps on the test vehicle were made worse by the service technician.

The available data indicate that headlamp aim is often seriously deficient. For example, vehicle inspection programs, some of them in place for 50 years or more, show lamp aim to be the most common reason for rejection (Terry, 1973; Heath, 1973).

McCutcheon and Sherman (1968) examined vehicle inspection results from four states. They found, uniformly, that headlamp aim was by far the most common problem, accounting for about 20% of all defects found.

The largest survey of headlamp aim has been reported by Hull et al. (1972). They measured the aim of lamps on about 500 cars at two service station in Austin, Texas (an inspection state). Another sample of about 500 cars were measured at two service stations in Kansas and Missouri (both non-inspection states). The data were taken in such a way that the effects of passenger and baggage loads were not considered.

On average, the results indicate that the lamps were aimed slightly down, with a standard deviation of about 0.8 degree in both vertical and horizontal dimensions. Aim worsened with vehicle age and was slightly better in the vehicle inspection areas.

Although the Hull et al. data were taken in a very limited geographic area and at only four high-volume service stations, they have been the best information on headlamp aim available. A significant problem is that they were collected in 1972, and vehicles have changed a great deal in the period since. Up-to-date information, including the effects of representative passenger and baggage loads, would provide valuable data to guide future research.

1.1.3 Load. Headlamps are aimed at the factory with the car in an empty state (no driver, passengers or baggage). In most vehicles, persons in the front seat alter the pitch of the vehicle very little. However, back seat passengers, baggage in the trunk and fuel levels can change vertical aim to a significant degree.

There have been two loading studies carried out on samples of U. S. vehicles (Hull et al., 1972; Olson and Mortimer, 1974). Each used a relatively small sample of vehicles and added weight progressively, checking aim at regular intervals. The results of each of these studies indicate that going from a driver-only to a full-rated load condition will change vertical headlamp aim by more than a degree in every vehicle checked.

Devices to compensate for vehicle load, either by changing headlamp vertical aim, or by returning the entire vehicle to a level state, have been available for many years. At the simplest level, the driver is provided with a lever or knob on the dash that allows him/

her to alter the aim of the lamps when the car is heavily loaded. The problem is that the driver may forget to reset the lamps when the load is removed.

Fully automatic aim adjusters have been developed to provide greater accuracy under load and eliminate the possibility of driver error. Unfortunately, they are a great deal more expensive than the manual type.

Load leveling systems have been standard equipment on some cars and optional on others for a number of years. They are not thought of primarily as aim compensation systems, although that is an acknowledged benefit. Both manual and automatic systems are available, the latter being relatively expensive.

1.1.4 Dirt on Headlamps. Especially in bad weather, headlamps can become very dirty very quickly. Although this fact has long been recognized, documentation of the extent to which dirt reduces lamp output has been done only relatively recently.

The main study is that of Rumar (1974). Three weather conditions were studied: dry, wet, and slushy. In dry weather Rumar found that nearly half the cars surveyed had sufficient dirt to reduce illuminating intensities in the central portion of the high beam by about 20 However, in the wet, the situation became worse, with about 33% of the cars having a loss of 55–60%. In slushy conditions about 25 of the cars had a loss of 80%

Other data have been reported by Cox (1968), who measured two lamps judged by him to be "moderately dirty" and "very dirty" respectively. The reduction in intensity averaged about 50% in the former case, and about 90% in the latter.

In recognition of this problem lens cleaning systems have been developed and marketed in countries other than the U.S. for some years. There are two types available. The oldest is an adaptation of the wiper-washer system used on windshields. More recently, another system has been developed that uses a high-pressure spray. The latter would probably work better on U.S. headlamps, where wiper operation is made difficult by the presence of the aiming studs.

1.2 Other Factors

1.2.1 Rearward Field of View. There have been several good studies of rear vision on various types of vehicles (e.g. Ford Motor Co., 1972; Burger, et al., 1980; Sugiura et al., 1979). As a result of this work rear vision provided to drivers has improved significantly in recent years.

However, what is provided and what use is made of it by ordinary vehicle operators may be two different matters. There are no data indicating how well people aim the mirrors on their vehicles, and what fields of view are actually available. One of the purposes of this study was to obtain that information.

1.2.2 Tires. The tire is probably the most important safety-related component of the motor vehicle because it is a major element in the vehicle's (1) braking system, (2) steering system, (3) suspension system, and (4) drive system. The tire is also one of the vehicle components that is most in need of driver attention in terms of: (1) inflation pressure maintenance, (2) proper loading, and (3) periodic replacement, in order to ensure continuous, high quality performance.

As a tire rolls under load the sidewalls flex, causing an energy input to the carcass and a resulting buildup of heat. Excessive flexing due to low pressures or overloading can increase this heat buildup to the detriment of tread life and fuel economy. In the extreme, failure to maintain proper inflation pressure or overloading of tires can result in sudden and total failure. Accordingly, tire manufacturers, in conjunction with the Tire and Rim Association, rate the load-carrying capacity of all sizes of tires as a function of inflation pressure. Vehicle manufacturers include these tire load ratings in establishing recommended inflation pressures, as well as gross axle and vehicle load ratings, for their products.

Tire inflation pressure, loading, and tread depth also contribute significantly to the handling and braking performance of a vehicle. Inflation pressure and loading are dominant factors in establishing the so-called cornering stiffness of the pneumatic tire, which is a key parameter in determining the handling characteristics of a vehicle. Relative under-inflation and/or overloading of rear tires reduces effective rear cornering stiffness, tending to produce an oversteering and potentially unstable vehicle. Conversely, relative underinflation and/or overloading of the front tires tends to produce an understeering effect, which can lead to sluggish directional response.

Tread depth is primarily at issue on wet (or snow-covered) roads. A major reason for tread grooving is to provide a mechanism to allow surface water to escape from the tire/road contact area. As tread depth decreases, fluid pressure in the contact patch may increase to the point where hydroplaning of the tire occurs. In this case, the tire separates from the roadway, riding instead on a thin film of water. The result is a drastic reduction in tire-to-road friction, with a consequent reduction in both braking and handling capability.

Over the past two decades, several researchers have produced evidence indicating that motorists in general are not as aware of the safety significance of proper tire maintenance as they should be. These researchers have consistently found that a significant portion of the tires in use on passenger cars are poorly maintained or misused by virtue of improper inflation pressures, overloading, and/or insufficient tread depth.

In 1964, Olson and Bauer reported on a survey of 405 cars parked in the employee parking lots of the General Motors Technical Center. They found that 60% of these cars had one or more tires inflated at least 5 psi above or below the manufacturer's recommended inflation pressure. Some tires were as much as 14 psi in error.

In the summer of 1968, Erlich and Jurkat examined the tires of 4,502 vehicles in use at 137 service stations in the eastern part of the U.S. They found that approximately 18% of the tires examined had less than 1/16 inch of tread remaining; that some 6.5% of the tires were overloaded; that overloading occurred more frequently on rear tires and more frequently on station wagons and light trucks; and that overloading conditions were, in part, due to underinflation. In the following winter, these same investigators expanded their study through the examination of an additional 199 vehicles. For this sample, average tread depth was found to be greater, apparently because of the large number of snow tires in use. However, overloading of tires, especially rear tires, was more frequent.

In 1970, Harvey and Brenner expanded on the analysis of the data generated by Erlich and Jurkat as well as data produced by Baker et al. Harvey and Brenner found that vehicles involved in accidents tend to have more worn tires than those of the general population and that, in particular, heavily worn (less than 1/16th inch tread) rear tires are significantly related to accident experience. They also found that more than 25% of cars in use had at least one seriously underinflated (i.e., 4 psi or more below recommended pressure) tire.

Scott and Compton also highlighted the safety significance of tire factors in a 1978 report. In this study, they found several tire factors to be significantly different between vehicles in general and those involved in accidents. Their findings included: (1) The mean inflation pressure of vehicles in accidents was significantly lower than that of non-accident vehicles; (2) vehicles in accidents had significantly higher differential pressures among their own various tires than did non-accident vehicles; (3) mixing of tire construction types was overrepresented among accident-involved vehicles; (4) tread depths of 2/32nds inch or less were over-involved in accidents on wet roads.

In 1978, Viergutz, Wakely, and Dowers reported on the inflation pressures found in a sample of vehicles in the Chicago area. Approximately 2,000 vehicles were examined during the summer and an additional 400 during the winter. It was found that 10% of the tires were underinflated by at least 6 psi, and 10% were overinflated by at least 3.5 psi. An average of one tire per car was underinflated by 3 to 6 psi in the summer and 5 to 8 psi in the winter.

Such findings are not limited to the U.S. In 1972, Lowne reported on some 2,000 cars observed in England and Scotland during 1969 and 1970. He found that 9% of the cars had at least one tire with tread depth of less than 1mm (1/25th inch) and that 13% of the cars had inflation pressure errors exceeding 8 psi in one or more tires. Attwood and Williams (1978) examined 2,980 tires on vehicles in use in Canada. They found that over 70% were underinflated and that 37% were underinflated by 4 psi or more. Almost 90% of the vehicles examined had at least one underinflated tire and 60% had one or more tires underinflated by at least 4 psi.

In sum, while tires are an important piece of safety equipment on a vehicle, it seems clear that they are often given far less attention than would be desirable.

1.2.3 Aerodynamic Effects. There is very little discussion of aerodynamic effects on vehicle pitch in the literature. However, it seems clear that, for "pre-energy crisis" vehicles, the influence of aerodynamic drag, acting above the ground plane, dominated the influence of aerodynamic effects on pitch. Thus, for example, Huculak (1978) observes that most passenger cars pitch up with increasing speed, and he cited an example of 0.25 degree at 50 mph.

But, radical changes in the aerodynamic aspects of passenger car design have taken place in recent years, and it may be that this rule no longer holds true. As more attention is paid to the reduction of drag, aerodynamic lift (which may have rearward bias, and thus a front-down pitch influence) becomes more important. Data exist in the literature (e.g., Roussillon, 1983 and Ruckhein et al., 1983) to indicate that some modern passenger cars may actually pitch down at speed, particularly when wind direction is at a zero yaw angle (straight onto the longitudinal axis of the vehicle).

Conversely, vehicles such as vans and pickup trucks, due to their large frontal area, high profiles and high drag coefficients, can be expected to pitch up at speed to a greater extent than the quoted 0.25 degree. The expected high pitch of these vehicles would be mitigated somewhat, due to the higher suspension stiffnesses typically employed in these vehicles.

2.0 FIELD STUDY

2.1 Method

2.1.1 Introduction. The field study was designed to gather information about the in-use characteristics of key vehicle safety systems. Specifically, these were:

1. Headlamps
   a. Horizontal and vertical aim
   b. General condition
2. Condition and operation of other lighting equipment.
3. Tires
   a. Pressure
   b. Tread depth
   c. General condition
4. Rearward field of view
   a. Number and type of mirrors installed
   b. Condition of each mirror
   c. Horizontal and vertical field of view

The study was conducted in a way designed to obtain a broad and representative sampling of vehicles within the contiguous 48 states.

2.1.2 Areas Sampled. The data were collected at twenty sites. These sites were selected from the national sample of Primary Sampling Units (PSU's), developed for the National Highway Traffic Safety Administration's (NHTSA) National Accident Sampling System (NASS). While the NASS sample design used 50 PSU's, these had been selected in phases, with each phase drawn to be independently representative of the United States. Thus, use of the twenty PSU's in the first two phases of the NASS sample design was felt to provide an appropriate set of geographic areas representative of urban and rural areas throughout the country.

In alphabetical order, the sample areas were as follows:

ALABAMA: St. Clair and Shelby counties (Birmingham SMSA)

ARIZONA: Yuma county

ARKANSAS: Ashley, Chicot, Desha, Drew and Lincoln counties

CALIFORNIA: Contra Costa county (San Francisco SMSA)

COLORADO: Gilpin and Jefferson counties (Denver SMSA)

FLORIDA: Fort Lauderdale and Hollywood

ILLINOIS: Chicago

MICHIGAN: (3) Berrien county

Genesee county (Flint)

Muskegon county

MISSOURI: Saint Louis City

NEBRASKA: Douglas county (Omaha)

NEW JERSEY: Bergen county (New York SMSA)

NEW YORK: Ulster county

NORTH CAROLINA: Cleveland and Rutherford counties

PENNSYLVANIA: (3) Delaware county (Philadelphia SMSA)

Erie county

Lackawanna county (Scranton)

TEXAS: Dallas county (excluding Dallas)

WASHINGTON: Island, San Juan, and Skagit counties

Nine of the twenty sites are in states that have periodic motor vehicle inspection (PMVI). This percentage (45%) corresponds closely to the national percentage of states with PMVI (50 %).

2.1.3 Vehicles. The vehicle population has been in a period of transition for some time now, in response to increasing fuel prices and Government-mandated fuel economy standards. There can be little doubt that personal vehicles of the future will be much smaller and lighter than those of the past. This fact raised a problem concerning the composition of the sample. If a cross section of all vehicles was measured, it would include a significant number of the older, large type. If these differed from the newer type of vehicle in ways that would affect some of the variables of concern, and it seemed reasonable that they would, this would limit the usefulness of the data in the future. On the other hand, restricting the range of the sample to relatively new vehicles could introduce another type of bias, because they may enjoy better maintenance than do older vehicles.

On balance, it was finally decided to restrict the sample to vehicles manufactured from 1979 to 1984 (the model year current at the time the data were taken). As a check on age-related trends, the data were analyzed on a model-year basis in most cases.

2.1.4 Sampling Method. Data on lighting equipment and rearward field of view were taken in service stations. Service stations were ideal for several reasons. Some of the more important of these were:

1. Every vehicle needs fuel, and the need is in direct proportion to the level of use the vehicle experiences.

2. Working in a service station means the vehicles are brought to the survey site by operators who are already willing to accept a delay while fueling. It was expected they would also be willing to accept a small additional delay to aid the survey and/or find out something about the condition of their vehicle.

3. Service stations are found everywhere, meaning that areas representing various socio-economic levels, types of traffic, and urban-rural mixes can be readily sampled.

The chief problem associated with using service stations is that a systematic bias in fuel levels can be expected. That is, it seems reasonable to assume that drivers generally choose to enter a service station because they are low on fuel. Thus, taking data on vehicles entering a service station would result in a sample having fuel levels lower than average. It is also probable that the variance in fuel levels would be less than that of the general population. Waiting until the fueling is completed would produce a bias in the opposite direction. Available data (Hull, Hemion, and Cadena, 1972; Olson and Mortimer, 1974) indicate that fuel levels have a significant effect on vertical aim, so the problem was potentially serious.

The information on aim as a function of fuel levels is fairly old and, given that the vehicle population has changed significantly since these data were collected, it was thought worthwhile to examine the question again. Initially, a small-scale study was run on eight cars. All the vehicles were six years old or less. They were selected to represent the spectrum of available vehicles from large to sub-compact. With the permission of their owners, each car was brought into the Institute garage area, parked in a marked position, and the vertical aim measured with mechanical aimers while the fuel tank was near empty. The car was then taken to a nearby service station and the tank filled. With that completed, it was returned to the garage area, parked in the same spot and the vertical aim measured again.

The largest change in vertical aim measured in any of the vehicles was 2 inches at 25 feet (about 0.4 degree). Most were less than that. Many cars changed as little as 1 inch at 25 feet, empty to full. The results of this test suggest that newer vehicles, such as were measured in this survey, are less affected by fuel levels than those measured in previous surveys, and that no serious problems would result from taking data in filling stations.

More complete data concerning the effect of fuel level on vertical aim were taken as a part of a survey of the effects of vehicle loading. The results of this work is described in Section 3 of this report. Briefly, these data, collected on twenty vehicles, confirm the results of the smaller study. Vertical aim change associated with going from empty to full ranged from 0 to about 0.4 degree, with a median change of 0.2 degree.

The original plan was to take aim measurements twice, once in the "as is" condition after the vehicle entered the station, and again when the fueling was completed. The difference, considered along with the amount of fuel taken on and the tank's capacity, would provide all the information needed to correct for fuel bias. However, this approach proved impractical, because few people were willing to delay the start of the fueling long enough to allow it to be done. As a result most data were taken after fueling was complete.

The interest in this study was in measuring population aim resulting from all causes. Thus, aim measurements were taken with all passengers and baggage in place. For the same reason, measurements were taken at all times of the day, on weekends, and at locations calculated to produce both local and long-distance traffic.

Tire data were taken on a different sample of cars in various parking lots (e.g. schools, factories, employee sections of shopping centers). This was done for two reasons. First, there was concern that taking tire data on the lighting sample would require additional time and may lead to a high level of refusals from vehicle operators. It may have caused problems with service station managers as well, if they felt the investigators were impeding flow through their station. Second, tire pressure increases as the tire heats up during normal operation. Measuring tire temperature and correcting the reading to "cold pressure" is a cumbersome process at best. It was much simpler to take pressure data on cars that had been sitting long enough that the tires had cooled to the ambient temperature. Based on information obtained during the pilot phase, this cooling process required a minimum of one hour.

Tire pressure is also affected by the ambient temperature. This means that if an operator checked his/her tire pressures last on a relatively warm day and we measured them at a time when temperatures were significantly colder, the readings would be lower. However, there was no way to correct for his type of problem. Vehicle operators should check their pressures regularly. Doing so would correct for seasonal temperature variations. Hence, the data that will be reported are based on readings taken at a variety of ambient temperatures.

Measures of the field of view provided by rear view mirrors were taken on the same cars as were used for the lighting data. Not all of these drivers were willing to take the additional time for the mirrors measurement. In general, about two persons in three participated.

Every effort was made to arrive at a data base that was representative of automobiles in the U.S. in general. Using the PSU's was a good start. However, on arriving in a particular PSU, the field team selected sites for data collection that provided broad representation within it. Data were collected during the day, evenings, and weekends to obtain a balanced sample of all drivers and vehicles.

Defining what was required to get a proper sampling was fairly easy. However, it was necessary to gain access to the vehicles in service stations and parking lots, and this required the cooperation of certain key individuals. In most cases, service stations managers were willing to allow our team to set up on their premises. Once set up, almost all drivers of vehicles in which we were interested were willing to participate in the study. Hence, there were no particular difficulties in meeting the sampling objectives for lighting and rearward field of view data. More difficulty was encountered in gaining access to parked cars for the tire data. In particular, many industrial concerns were unwilling to allow access to their employees' cars. Schools and shopping centers were much more cooperative, and, with their help and a great deal of searching for industrial parking lots, a satisfactory sample was obtained for the tire data.

2.1.5 Equipment. Headlamp aim was measured with mechanical aimers (Hopkins Model B4A). A photograph of one of these units is shown in Figure 1. The calibration of the aimers were checked on a daily basis when lamp aim data were being taken.

Tire pressure was measured in kilopascals (1 psi = 6.9 kPa) using a precision Schrader instrument, shown in Figure 2. Pressure was measured twice at each tire. If the two readings differed by more than 10 kPa, a third reading was made.

Tire tread depth was measured using one of the two instruments shown in Figure 3. In either case readings were made to the nearest 1/32nd of an inch. Readings were made in each groove at two opposite points on each tire, care being taken to avoid the wear bars.

Temperature of the air and tire sidewalls were made using an Omega Model 727C thermocouple of the type shown in Figure 4. Tire sidewall temperatures were taken and compared with air temperature to ensure that the car had been standing for a long enough period of time for the tires to cool down to ambient or nearly so. If the reading indicated that the tires were still warm, further measurements were not conducted on the vehicle.

The rearward field of view was measured using the special device shown in Figure 5. This consisted of a vertical panel eight feet tall, supported in a movable stand. The numbers on the panel were spaced four inches apart, corresponding to one degree at the viewing distance used (19 feet). Horizontal distance was measured using a Rolatape Measure-Master Model MM10, which was attached to the base of the device.

Data were entered and stored in a Radio Shack Model 100 portable computer, such as that shown in Figure 6. The unit had been programmed to prompt for information, and check to be sure entries were within specified limits.

As the study was designed to cover all parts of the country, it was also designed to include all types of weather. Data collection began in the winter and ran through the summer. The investigators encountered abundant snow and rain, especially in the first three months, and a variety of temperatures, precipitation, dust, etc. after that. This was particularly important for the measurement of headlamp dirt levels. While no data were taken in the midst of a rain or snow storm, the investigators went to work as soon as it was over. This provided good exposure to the effect of wet roads on headlamp dirt levels.

2.1.6 Procedure. Upon arrival in a given test area, the first day or so was spent looking for promising sites and approaching individuals for permission to use their property or to gain access to vehicles on their property. Once this had been done, the actual measurement work could begin.

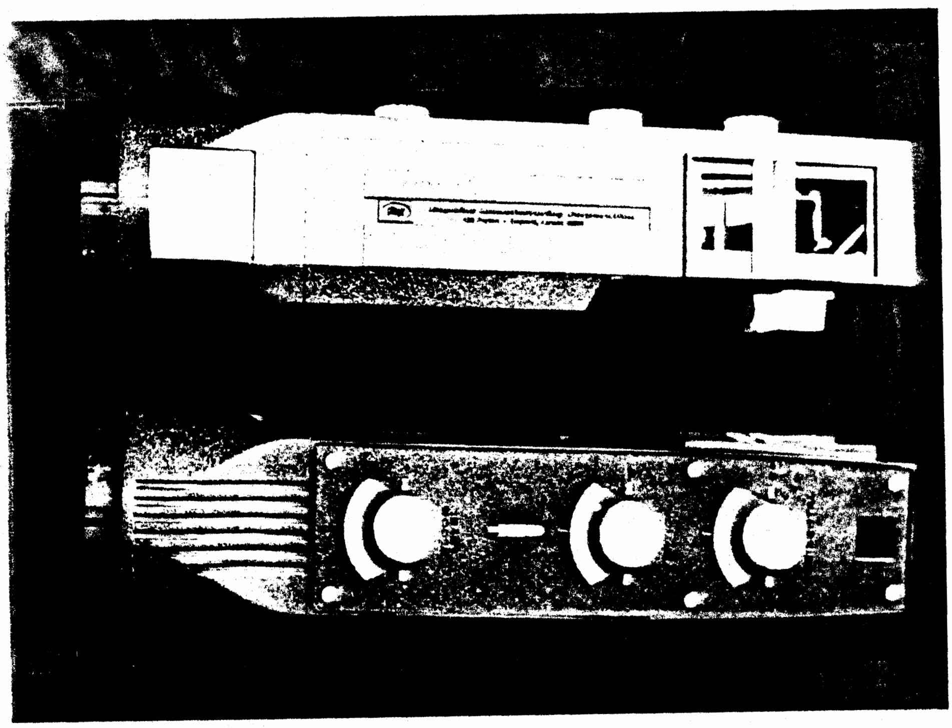

Figure 1. Photograph of headlamp aimers used in survey.

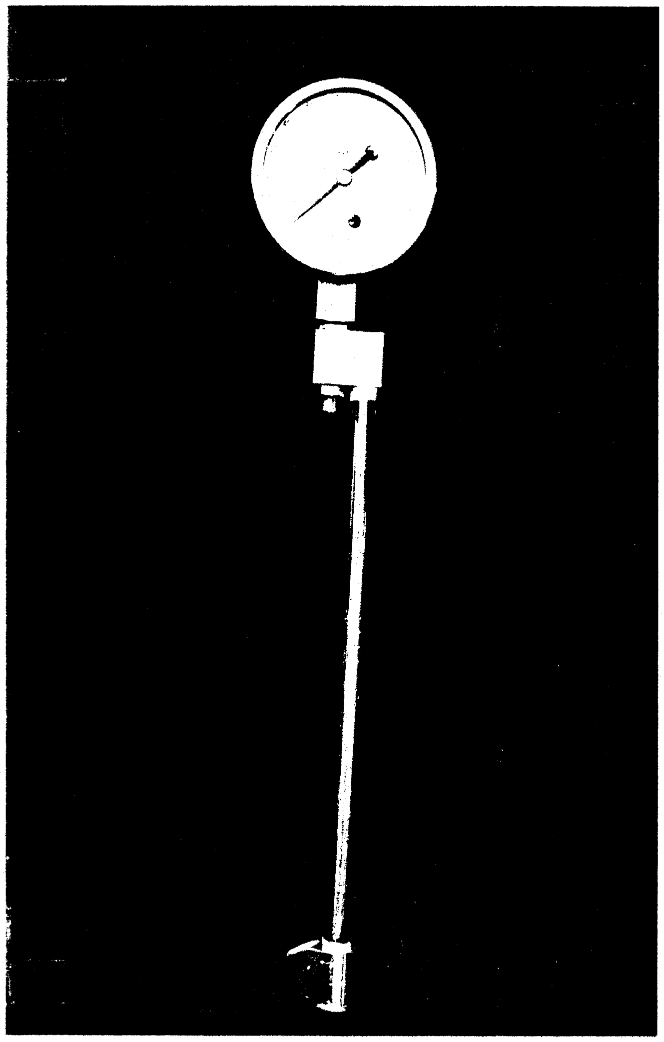

Figure 2. Photograph of tire pressure gauge.

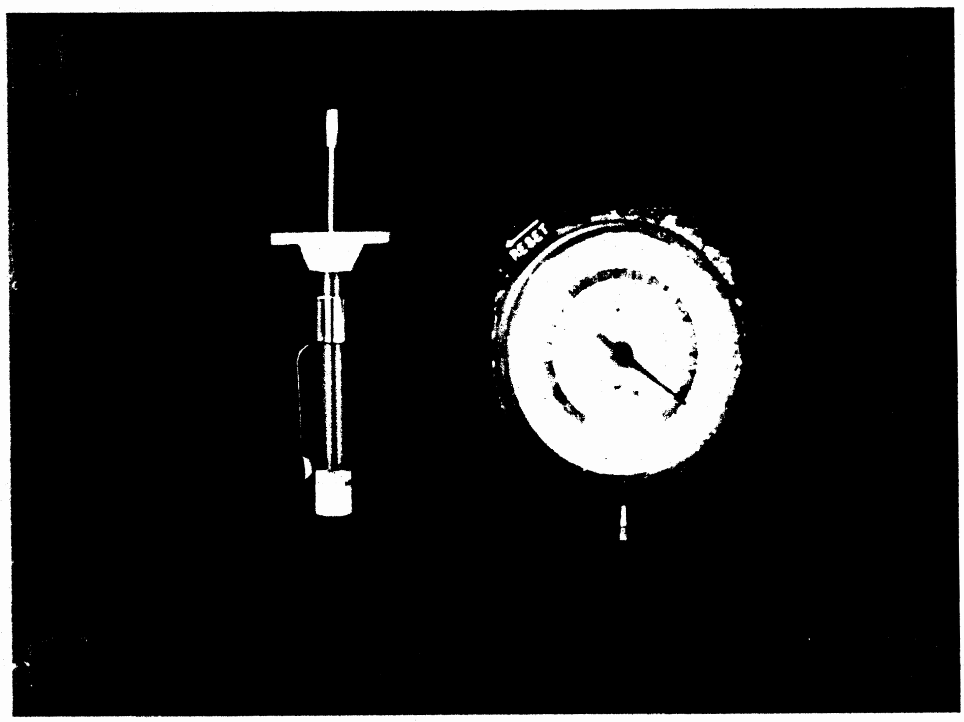

Figure 3. Photograph of tread depth gauges used in survey.

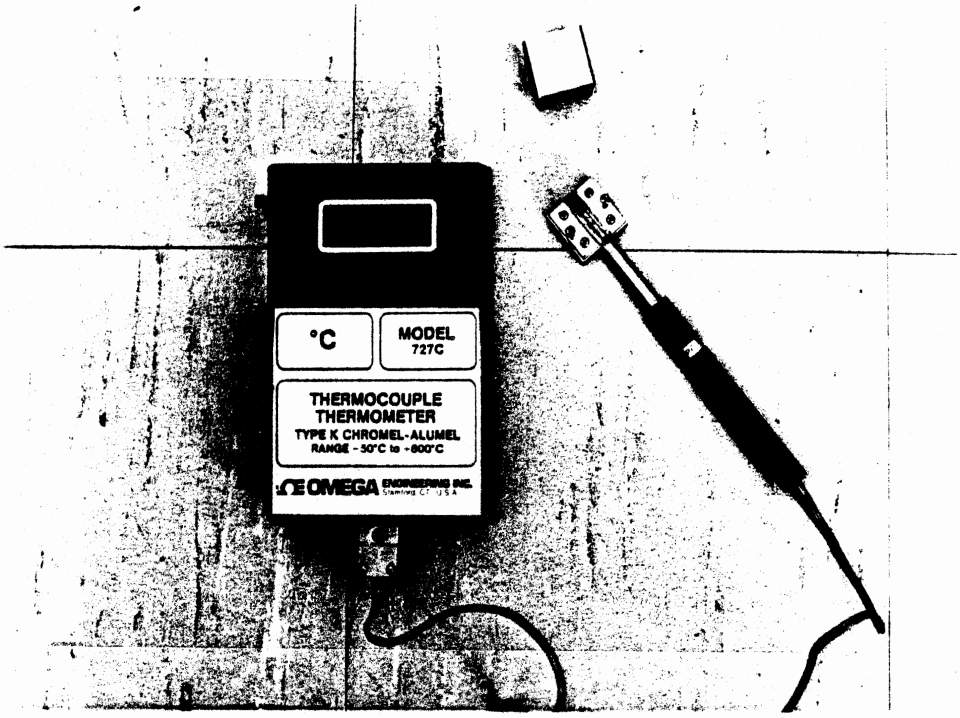

Figure 4. Photograph of thermocouple used in survey.

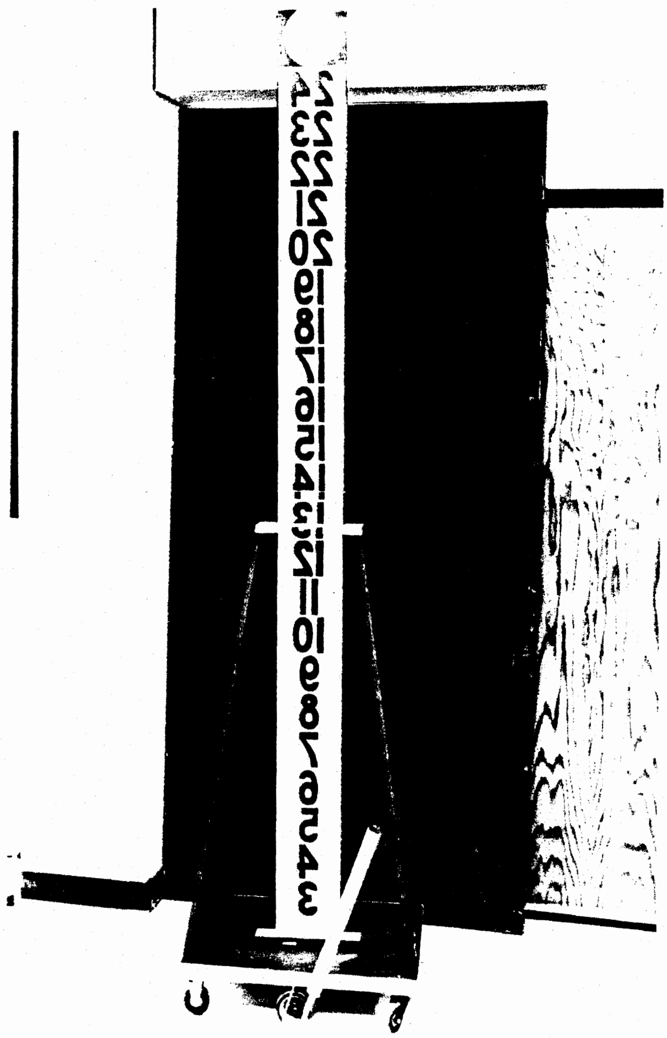

Figure 5. Photograph of device used to measure field of view.

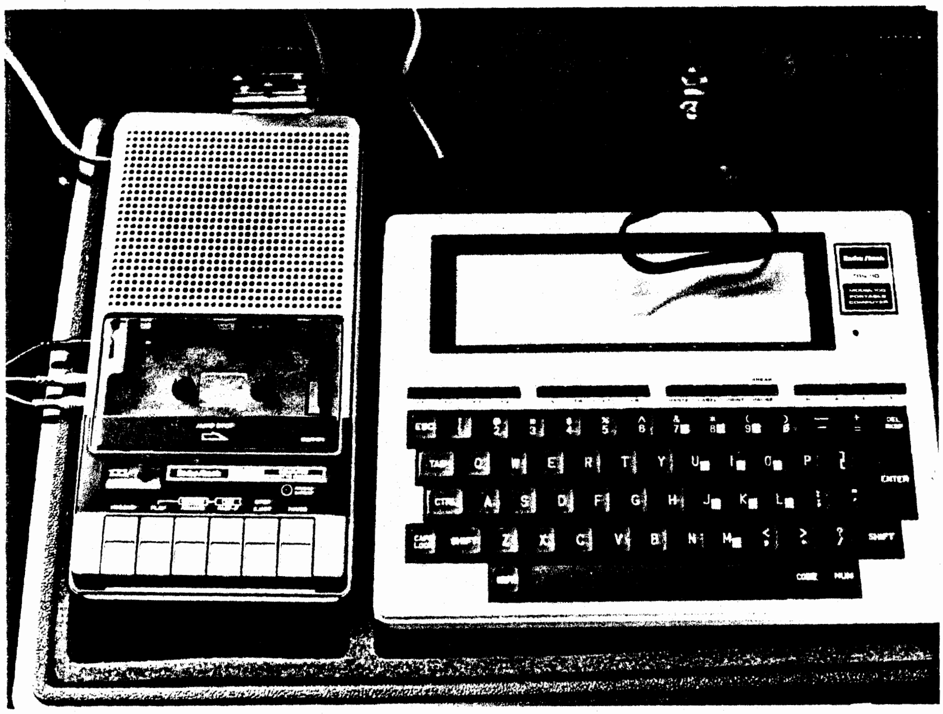

Figure 6. Photograph of Model 100 computer used to collect and store field data.

After setting up at a service station, and measuring the ground slope in the area where aim checks were to be run, the team looked for entering vehicles that met the sample criteria (passenger car, pickup truck or van, six years or less old). The driver was approached and asked if he/she would be willing to participate in the survey. They were also told that the measurements could be accomplished in the time it required to fill their tank. Almost everyone agreed.

While the car was being fueled one surveyor circled the car inspecting the other lamps (i.e., front and side markers and taillamps). Each lamp was categorized under one of the following headings:

Intact and working

Intact and not working

Not intact (e.g. broken lens) and working

Not intact and not working

At the appropriate time the driver was asked to step on the brakes and turn on the turn signals so they could be evaluated as well. When the fueling process was completed, headlamp aim was measured.

Additional information taken on each car was year, make, model, number and location of passengers, an estimate of baggage load, fuel level entering and leaving and fuel taken on.

At the conclusion of the activities just described the driver was asked if he/she would be willing to spend an extra five to ten minutes in the field-of-view measurement. Five dollars was offered as an inducement. Those who were willing were directed to another position in the service station complex. Markings had been laid out earlier to indicate the long axis of the vehicle, the mirror position, and the track for the measurement device (19 feet back of the mirror position). The type (flat or convex) and position of each mirror was noted. The subject was instructed to look into the mirror while maintaining a normal driving position and call off the highest and lowest numbers he/she could see on the vertical panel.

To start the investigator determined a reference line. This corresponded to the left edge of the vehicle as seen by the driver in the left-side outside rearview mirror. The vertical panel on the measuring device was set at this point and top and bottom readings taken. The investigator then moved the device as far left as possible for it still to be seen in the left edge of the outside mirror on the driver's side and noted the horizontal distance.

Once again the driver called out the top and bottom readings. The interior and right-side exterior mirrors were measured in the same way.

Tire data were taken from parked vehicles. The team arrived at a time calculated to ensure that most of the cars would have been parked for at least one hour. The ambient temperature was noted at the start and again at intervals of one-half hour. The team then began to move down the line of vehicles, looking for those that met the sample criteria. When one was located a temperature reading was made on one of the tires. If it was essentially ambient the measurement process was initiated. First the year, make and model of the car was noted, as well as its mileage. Then the make, model and size of each tire was recorded, along with the tread depth and tire pressure. An assessment was made of the tire condition as well, looking for uneven tread wear, cuts, bruises, bulges and evidence of ply separation.

2.2 Results

2.2.1 General Characteristics of the Sample.

A total of 964 vehicles were included in the sample. In terms of model years, these were distributed as follows:

1978 and earlier – 34

1979 – 228

1980 – 121

1981 – 136

1982 – 134

1983 – 156

1984 – 155

Of the total 326 were in states having periodic motor vehicle inspection (PMVI), and 638 were in states that did not have PMVI.

2.2.2 Lighting Equipment

2.2.2.1 Headlamps.

Each headlamp in the sample was examined for several possible problems, as noted in Table 1. Only about one percent of the lamps were found to have any of the listed defects. It should be noted that the lamps having cracked lenses and condensation inside were working.

TABLE 1

FREQUENCY WITH WHICH VARIOUS HEADLAMP DEFECTS WERE FOUND IN THE SAMPLE

	None	Lens Cracked	Not Working	Lamp Missing	Improperly Installed	Conden-sation Inside
Frequency	1922	3	7	1	3	2
Percent	99.1	0.2	0.4	0.1	0.2	0.1

Note: Lamps having cracked lenses and condensation inside were working.

A category of special interest to the investigators was "improperly installed." This covers a variety of problems (e.g. a type 1 [high beam] lamp installed in a low-beam position). However, only three cases were found in the sample. One of these was a rectangular lamp that had been installed upside down; the other two were round lamps that had been installed at an angle. In all probability, most of the lamps in this sample were still original equipment. The incidence of this and other problems may increase as vehicles age.

Table 2 provides an overview of the condition of aim of the vehicles in the sample. On average, the vertical aim was slightly down and the horizontal aim was virtually perfect. However, the standard deviations for each measure are large, about 0.9 degree for the vertical and 0.8 degree for the horizontal.

It will be recalled that the aim data were collected in service stations, after the refueling process had been completed. Thus, this sample is biased in that the average fuel levels were probably greater than that of the general vehicle population. As a result, the sample's mean headlamp vertical aim is somewhat high. The vehicles in the sample were not all full at the time the measurements were taken, because many of the participants had purchased fixed amounts of fuel. However, the mean was about 7/8 full at the time of the measurement. If we assume that the "average" vehicle on the road has about 1/2 tank of fuel, the data collected in the loading survey and described in Section 3.0 suggest that the difference in vertical aim between the population sampled and the general vehicle population would be about 0.1 degree. On that basis the expected mean vertical aim for the general vehicle population would be about 0.25 degree down.

TABLE 2

CONDITION OF AIM OF VEHICLES IN SAMPLE

Headlamp	Vertical Aim (Degrees)		Horizontal Aim (Degrees)	
	Mean	SD	Mean	SD
Driver's Side	0.12 Down	0.90	0.04 Right	0.80
Passenger Side	0.17 Down	0.90	0.04 Left	0.77

It is more difficult to estimate the effect of the sampling method on the standard deviation. Most cars in this sample were between full and 1/2 at the time the measurements were taken, with a large number being full. We do not know the distribution of fuel levels in the population of vehicles on the road. However, it may be reasonable to assume that about 2/3rds of them have between 3/4 and 1/4 tank. If this is true, the data from the fuel loading study we conducted imply a standard deviation of about 0.1 degree associated with fuel levels alone. While the standard deviation in vertical aim caused by fuel levels would have been less in this survey sample, it appears that it probably would not have made a very great difference. As an approximation, it may be appropriate to increase the standard deviation for vertical aim from 0.9 to about 1.0 degree to account for this effect.

Because mechanical aimers were used, the aim data are truncated at plus or minus 10 inches at 25 feet, the limit to which the aimers could be adjusted. This raises a question concerning the interpretation of the standard deviation data shown in Table 2. Table 3 shows the actual percent of lamps in the sample that were within plus or minus 4 inches at 25 feet (the current SAE standard) for both horizontal and vertical dimensions. Also shown is the standard deviation that would be inferred from these percentages. It is apparent from these data that the distributions are not strictly normal, since these inferred standard deviations are smaller than those calculated based on the entire sample. However that may be, it is noteworthy that about two-thirds of the lamps were within aim specifications vertically, and about three-quarters were within specifications horizontally.

TABLE 3

PERCENT OF ALL LAMPS TESTED AIMED WITHIN
$\pm$ 4 INCHES AT 25 FEET

Side	Vertical	Horizontal
Driver	65	75
Inferred Standard Deviation in. at 25 ft (deg.)	4.28 (0.82)	3.48 (0.66)
Passenger	64	76
Inferred Standard Deviation in. at 25 ft (deg.)	4.37 (0.83)	3.40 (0.65)

Table 4 shows the aim data stratified by vehicle model year. These data suggest that aim deteriorates slightly for the first few years that a particular model year is on the road, and then stabilizes. As an example, note that for 1984 vehicles (which would have averaged about six months old at the time the data were taken) the mean aim was close to perfect and the standard deviations were about 0.75 degree vertically and 0.5 degree horizontally. For 1983 models a down bias is first evident and the standard deviation for both dimensions increases. From that point on the down bias remains at about the same level (with the exception of the 1981 model year), but the standard deviation of aim increases until, about in the 1981 model year, it reaches an apparent maximum level.

Table 5 shows the aim data comparing vehicles in states with and without PMVI. The mean aim of lamps in both areas is good. However, the standard deviation of aim in PMVI areas is slightly less.

Table 3 showed that about 65% of headlamps were within SAE specifications vertically and 75% were within specifications horizontally. Combining the two dimensions, we found that 54.6% of the low beams on the driver's side and 55.1% of the low beams on the passenger side were within plus or minus 4 inches at 25 feet in both horizontal and vertical dimensions. Assuming that the two distributions were independent, this implies that about 30% of cars would have both lamps aimed within SAE specifications. However, the actual percentage of cars having both lamps aimed within SAE specifications was 40.1

TABLE 4

CONDITION OF AIM OF VEHICLES IN SAMPLE, CLASSIFIED BY MODEL YEAR

Year	N	Headlamp	Vertical Aim (degrees)		Horizontal Aim (degrees)	
			Mean	SD	Mean	SD
1978 and Earlier	34	Driver's Side	0.04 Down	0.85	0.12 Left	1.01
		Passenger Side	0.23 Down	0.92	0.11 Right	0.96
1979	228	Driver's Side	0.15 Down	0.96	0.10 Right	0.88
		Passenger Side	0.26 Down	0.96	0.05 Left	0.81
1980	121	Driver's Side	0.25 Down	0.97	0.01 Right	0.92
		Passenger Side	0.27 Down	0.99	0.05 Right	0.98
1981	136	Driver's Side	0.05 Down	1.02	0.04 Right	0.96
		Passenger Side	0.03 Down	0.99	0.01 Left	0.88
1982	134	Driver's Side	0.16 Down	0.80	0.09 Right	0.74
		Passenger Side	0.23 Down	0.80	0.06 Left	0.70
1983	156	Driver's Side	0.16 Down	0.81	0.07 Right	0.63
		Passenger Side	0.21 Down	0.80	0.10 Left	0.62
1984 (current)	155	Driver's Side	0.04 Up	0.77	0.03 Left	0.53
		Passenger Side	0.01 Down	0.76	0.06 Left	0.53

TABLE 5

CONDITION OF AIM OF VEHICLES IN SAMPLE IN STATES WITH AND WITHOUT PERIODIC MOTOR VEHICLE INSPECTION

Headlamp	Inspection States				Non-Inspection States			
	Vertical Aim (degrees)		Horizontal Aim (degrees)		Vertical Aim (degrees)		Horizontal Aim (degrees)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Driver's Side	0.11 Down	0.83	0.03 Left	0.76	0.12 Down	0.93	0.08 Right	0.81
Passenger Side	0.15 Down	0.85	0.11 Left	0.66	0.19 Down	0.92	0.00	0.82

in this sample. The two distributions turned out not to be independent. If the low beam on the driver's side was within specifications, in 73.6% of the cases the one on the passenger side was as well.

Table 6 lists the percent of lamps within SAE specification as a function of model year. Nearly 60% of current-model vehicles had both low-beam lamps aimed within specifications. However, after four years this percentage was cut about in half. The data for the oldest vehicles in the survey (1979 and 1980 models) suggest that the percent of vehicles having both low-beam lamps within SAE specifications stabilizes at about 25–30% after four years.

TABLE 6

PERCENT OF CARS HAVING DRIVER'S SIDE, PASSENGER SIDE AND BOTH LOW-BEAM HEADLAMPS AIMED WITH SAE SPECIFICATIONS ($\pm$ 4 INCHES AT 25 FEET) AS A FUNCTION OF MODEL YEAR

Model Year	Driver's Side	Passenger Side	Both
1979	43.3	46.8	28.1
1980	47.9	42.1	26.4
1981	47.8	48.5	32.4
1982	59.7	59.7	45.5
1983	63.7	63.7	52.9
1984 (current)	67.9	68.6	57.7

Table 7 shows the percent of lamps within SAE specifications as a function of whether they were subject to periodic inspections. The probability of finding one or both lamps within plus or minus 4 inches at 25 feet was appreciably higher in states having PMVI.

2.2.2.2 Marker lamps. As described in the Method section, the condition of all lamps on the vehicle, except for the headlamps, was classified under four headings. First it was determined whether the unit was intact. ("Not intact" meant anything from a

TABLE 7

PERCENT OF CARS HAVING DRIVER'S SIDE, PASSENGER SIDE AND BOTH LOW-BEAM HEADLAMPS AIMED WITHIN SAE SPECIFICATIONS ($\pm$ 4 INCHES AT 25 FEET) IN STATES WITH AND WITHOUT PMVI

States	Driver's Side	Passenger Side	Both
Inspection	58.4	62.1	45.3
Non-Inspection	52.6	51.5	37.5

crack in the lens to the unit being destroyed or missing.) Then it was noted whether the lamp was working.

Table 8 lists the condition of the front marker lights for all vehicles in the sample. Over 98% were found to be intact and working. Only five lamps were not intact and 31 (about 1.6% were not working.

TABLE 8

CONDITION OF FRONT MARKER LIGHTS IN SAMPLE

Condition		Number	Percent
Intact	Working	1907	98.3
	Not Working	28	1.4
Not Intact	Working	2	0.1
	Not Working	3	0.2

Table 9 lists the condition of front marker lights in PMVI and non-PMVI areas. Given that only about two percent of the units in this sample were defective, large differences could not be expected. However, the percent of front marker lamps that were both intact and working was slightly higher in the PMVI areas.

TABLE 9

COMPARISON OF CONDITION OF FRONT MARKER LIGHTS IN STATES WITH AND WITHOUT PERIODIC MOTOR VEHICLE INSPECTION

Condition		Inspection States	Non-Inspection States
Intact	Working	652 (99.3%)	1255 (97.7%)
	Not Working	4 (0.6%)	24 (1.9%)
Not Intact	Working	0	2 (0.2%)
	Not Working	0	3 (0.2%)

The general condition of the rear presence lamps is considered next in Table 10. Many cars have multiple rear lamps (up to four on each side for the cars in this sample). Multi-unit systems were considered bulb by bulb in this survey, and are coded numerically in Table 10. Unit 1 was the outermost or uppermost lamp (or the only lamp on many cars). Unit 2 was the lamp closest to it, and so on. It is clear from Table 10 that only about 2.0 to 2.7% of these units were not working on the vehicles in the survey

Table 11 divides the data from Table 10 into PMVI and non-PMVI areas. Once again, the differences are small but consistent. The incidence of non-working units is slightly lower in areas having PMVI.

Side marker lights are considered in Table 12. This table lists the condition of lights at each of the four corners of the vehicle. As in other cases most of the lights were working. However, where headlamps and front and rear marker lamps were 98 to 99% operational, side marker lights are considerably more likely not to be working. Additionally, for some reason, the side marker lights in front were about twice as likely not to be working as those in the rear.

TABLE 10

CONDITION OF REAR PRESENCE LAMPS OF VEHICLES IN SAMPLE

Condition		Location of Presence Lamp			
		1	2	3	4
Total Lamps		1628	1116	478	48
Intact	Working	1589 (97.6%)	1087 (97.4%)	465 (97.3%)	48 (100%)
	Not Working	34 (2.1%)	28 (2.5%)	13 (2.7%)	0
Not Intact	Working	5 (0.3%)	1 (0.1%)	0	0
	Not Working	0	0	0	0

Note: Lamp locations are coded as follows: Number 1 is outermost or uppermost, number 2 is next to it, and so on. These data sum together paired lamps from each side of the vehicle.

TABLE 11

CONDITION OF REAR PRESENCE LAMPS IN STATES WITH AND WITHOUT PERIODIC MOTOR VEHICLE INSPECTION

Condition		Inspection States				Non-Inspection States			
Total Lamps		Location of Presence Lamps				Location of Presence Lamps			
		1	2	3	4	1	2	3	4
		542	368	142	12	1086	748	336	36
Intact	Working	531 (98.0%)	360 (97.8%)	140 (98.6%)	12 (100%)	1058 (97.4%)	727 (97.2%)	325 (96.7%)	36 (100%)
	Not Working	8 (1.5%)	8 (2.2%)	2 (1.4%)	0	26 (2.4%)	20 (2.7%)	11 (3.3%)	0
Not Intact	Working	3 (0.5%)	0	0	0	2 (0.2%)	1 (0.1%)	0	0
	Not Working	0	0	0	0	0	0	0	0

TABLE 12

COMPARISON OF CONDITION OF SIDE MARKER LIGHTS AT ALL FOUR CORNERS OF CARS IN THE SAMPLE

Condition		Front		Rear	
		Left	Right	Left	Right
Intact	Working	848 (87.4%)	848 (87.4%)	919 (94.7%)	909 (93.7%)
	Not Working	116 (12.0%)	119 (12.3%)	49 (5.1%)	56 (5.8%)
Not Intact	Working	4 (0.4%)	1 (0.1%)	1 (0.1%)	1 (0.1%)
	Not Working	2 (0.2%)	2 (0.2%)	1 (0.1%)	4 (0.4%)

The condition of side marker lights as a function of vehicle age is considered in Table 13. Only about 0.5% of side marker lights on current-model cars were not working. However, this total increases steadily each year and, after six years, over 15% of side marker lights were not working.

Table 14 categorizes the condition of the side marker lights by PMVI and non-PMVI areas. The same trend is evident as in other equipment already covered, that is, lamps are more likely to be functioning in PMVI areas. This is further emphasized in Table 15, which is a breakdown of the "intact-not working" category for side marker lamps at the front and rear of the car in PMVI and non-PMVI areas.

2.2.2.3 Brake and turn signals The general condition of brake lamps on vehicles in the sample is summarized in Table 16. About 98% of these units were found to be working.

As in the case of rear presence lamps, brake lamps are often made up of units having more than one bulb. As many as four bulbs per side were found on cars in this sample. These were coded numerically, using the same logic as in the presence lamps. Table 17 summarizes the results of the survey for brake lamps, presenting data for PMVI

TABLE 13

COMPARISON OF CONDITION OF SIDE MARKER LIGHTS
AS A FUNCTION OF VEHICLE MODEL YEAR

Model Year	Intact		Not Intact	
	Working %	Not Working %	Working %	Not Working %
1979	84.1	15.2	0.4	0.3
1980	86.8	12.8	0	0.4
1981	88.4	10.8	0.2	0.6
1982	94.0	5.8	0	0.2
1983	97.3	2.5	0.2	0
1984 (current)	99.4	0.5	0.2	0

TABLE 14

COMPARISON OF CONDITION OF SIDE MARKER LIGHTS IN STATES
WITH AND WITHOUT PERIODIC MOTOR VEHICLE INSPECTION

Condition		Inspection States	Non-Inspection States
Intact	Working	1221 (93.1%)	2302 (89.7%)
	Not Working	83 (6.3%)	257 (10.0%)
Not Intact	Working	5 (0.4%)	2 (0.1%)
	Not Working	3 (0.2%)	6 (0.2%)

TABLE 15

COMPARISON OF "INTACT-NOT WORKING" CATEGORY FOR SIDE MARKER LAMPS ON THE FRONT AND REAR OF CARS IN THE SAMPLE

Location on Vehicle	Inspection States	Non-Inspection States
Front	59 (9.0%)	176 (13.7%)
Rear	24 (3.7%)	81 (6.3%)

TABLE 16

CONDITION OF BRAKE LIGHTS ON VEHICLES IN SAMPLE

Condition		Number	Percent
Intact	Working	3824	97.8
	Not Working	81	2.1
Not Intact	Working	7	0.2
	Not Working	0	0

and non-PMVI states separately. The percentages are close to those found for rear presence lamps, that is 1.4% and 2.4% of brake lamps were not working in PMVI and non-PMVI areas respectively.

Turn and brake filaments are the same in many cars. Hence, in most cases when the brake filaments were out, the turn signals did not work either. However, there were four instances when brake lamps were out and the turn signals still worked. All of these were foreign-made vehicles with separate, amber turn signals. In one such vehicle the left

TABLE 17

CONDITION OF BRAKE LAMPS IN STATES WITH AND WITHOUT PERIODIC MOTOR VEHICLE INSPECTION

Condition		Inspection States				Non-Inspection States			
		Location of Brake Lamp				Location of Brake Lamp			
Total Lamps		1	2	3	4	1	2	3	4
		656	450	152	14	1284	924	394	38
Intact	Working	645 (98.3%)	441 (98.0%)	150 (98.7%)	14 (100%)	1252 (97.5%)	901 (97.5%)	383 (97.2%)	38 (100%)
	Not Working	8 (1.2%)	8 (1.8%)	2 (1.3%)	0	30 (2.3%)	22 (2.4%)	11 (2.8%)	0
Not Intact	Working	3 (0.5%)	1 (0.2%)	0	0	2 (0.2%)	1 (0.1%)	0	0
	Not Working	0	0	0	0	0	0	0	0

turn signals did not work, but the brake lights did. In two instances where brake and turn filaments were the same the turn signals did not work (perhaps due to a failed flasher) while the brake signals did.

2.2.2.4 Conclusions – Lighting equipment In general, the lighting equipment on the vehicles in this survey were functioning with a high level of reliability. Headlamps are probably the most important item of lighting equipment on a vehicle and, to best serve their purpose, they must not only function, they must be aimed properly. To aid in maintaining proper aim, standards have been promulgated by the SAE, and have been adopted by the Federal Government in Federal Motor Vehicle Safety Standard (FMVSS) 108. To meet the standard the lamps must be within plus or minus 4 inches at 25 feet (about 0.8 degree) of perfect aim.

On new cars in the sample, about 60% had both lamps aimed within SAE specifications. Considering the fact that the data presented include a number of sources of aim variance not within the control of the manufacturer (e.g. fuel, passenger and baggage loads), this indicates that the headlamps of new cars delivered to customers are likely to be aimed within specifications. However, the situation seems to deteriorate markedly as the vehicles age. Within four years, only about 30% of the vehicles measured had both lamps aimed within specifications. This means the visibility provided by headlamps is reduced on average as the vehicle ages. It also means that other drivers will encounter high levels of glare more frequently. Both of these are undesirable effects, and further efforts should be made to minimize them.

On the positive side, based on a comparison with data collected about twelve years ago by The Southwest Research Institute (Hull et al., 1972), it appears that headlamp aim may have improved. The SWRI data are nominally very similar to those presented here, i.e., a slight down bias and a standard deviation of about 0.75 degree. The difference is that the SWRI data do not include the effects of passengers, baggage and fuel.

The aim data from the study of Hull et al. are used for the "random misaim" input to the CHESS headlighting evaluation model (Bhise et al., 1977). The authors altered the mean and standard deviation of the original data to allow for fuel, passenger and baggage loading, arriving at a mean vertical aim of 0.73 degree up and a standard deviation of 1.55 degrees. Horizontal aim has a mean of 0.08 degree and a standard deviation of 0.86 degree. If these estimates are accurate, headlamp aim has improved considerably in the last 12 to 13 years. It also seems clear that motor vehicle inspection programs have a beneficial effect, since the data from this survey consistently show a higher percentage of lights operating and better headlamp aim in states having such programs.

2.2.3 Rearward Field of View

2.2.3.1 General. A total of 620 vehicles were included in the sample for field of view. As many as five mirrors were found on some of these. All had an inside mirror and an outside mirror on the driver's side. Most (413 or 67%) also had an outside mirror on the passenger side. A small number of vehicles also had short-radius convex mirrors (sometimes called "button" mirrors) either stuck on the outside mirrors on one or both sides or attached near them.

The following is a description of the condition of the mirrors in the sample:

1. Outside, driver's side. Total of 620. Of these 614 appeared ok, 1 was frosted, 4 were cracked, and 1 was broken off. One mirror was convex, the rest were flat.
2. Inside mirror. Total of 620. Of these 617 appeared ok, 2 were frosted, and 1 was broken off. All were flat.
3. Outside, passenger side. Total of 413. Of these 1 was missing the mirror surface, 1 was frosted, 6 were cracked, and 3 were broken off. A total of 181 were flat and 228 were convex (the shape of the surface could not be determined on the 4 where the mirror or glass was missing).
4. Button mirror, driver's side. Total of 41. All appeared ok.
5. Button mirror, passenger side. Total of 22. All appeared ok.

2.2.3.2. Field of View. In the presentations to follow two reference points will be used. For horizontal measures the reference will be the left edge of the vehicle as seen by the driver in the left outside rear-view mirror. This will be called "0." Readings to the left of this point will be shown as negative, those to the right as positive. For vertical readings the reference point will be the ground plane at a point 19 feet back of the mirror.

In interpreting the vertical data it should be mentioned that one degree is equal to four inches at 19 feet. The vertical dimension from the ground to the center of the outside mirrors on about 90% of the cars in this sample ranged from 35 to 40 inches. Thus, for example, an up-angle reading for the lower edge of the mirror of 12 to 13 degrees on a car means that the mirror was set so that the lowest angle of view was approximately parallel to the ground.

Figure 7 shows the distribution of the horizontal field of view provided by the outside rear view mirrors on the driver's side of the vehicles sampled. The two symbols (X and O) represent the horizontal limits as provided by the right and left edges of the mirror respectively. The limit distributions provided by the two edges of the mirrors are plotted separately. In the vehicles sampled, the field of view left of the car provided by this mirror ranged from 0 degrees to about 25 degrees, with a median of about 13 degrees. The median position of the right edge of the mirror was just about on the reference line; that is, it showed only a glimpse of the left side of the vehicle. A small fraction of these mirrors were turned in so far that a substantial portion of the field was occupied by the side of the car. About half the mirrors were turned out so that the side of the car would not be visible. In extreme cases they were turned out as much as 10 degrees from the reference point.

The vertical field of view provided by the driver's-side outside mirror is summarized in Figure 8. In this case the two symbols (X and O) represent the vertical limits as provided by the bottom and top edges of the mirror respectively. Based on these data, the vertical field of view ranged from about 7 to 10 degrees. The bulk of the mirrors appear to have been moderately well aimed, showing the road no closer than 19 feet back, and including at least the horizon in the top portion.

The horizontal field of view provided by the interior mirrors in the sample is shown in Figure 9. This field of view averaged about 25 degrees in width, and typically overlapped the view provided by the driver's-side exterior mirror substantially.

The horizontal field of view in an interior mirror is typically limited by the size of the rear window. However, in some vehicles, especially station wagons, parts of the side windows were included as well. The field of view in such vehicles included all that could be seen in the mirror, not just that visible through the rear window.

The vertical field of view provided by the interior mirrors is shown in Figure 10. This field was typically only about 5 degrees high. Most of the mirrors were aimed to take in all of the height of the rear window, so most of the variation shown is attributable to different vehicle configurations and driver eye height.

The horizontal field of view provided by the passenger-side outside mirrors is shown in Figure 11. The considerable variation in horizontal spread is possibly attributable to the mix of flat and convex mirrors. Note that the overlap in coverage with the interior mirror

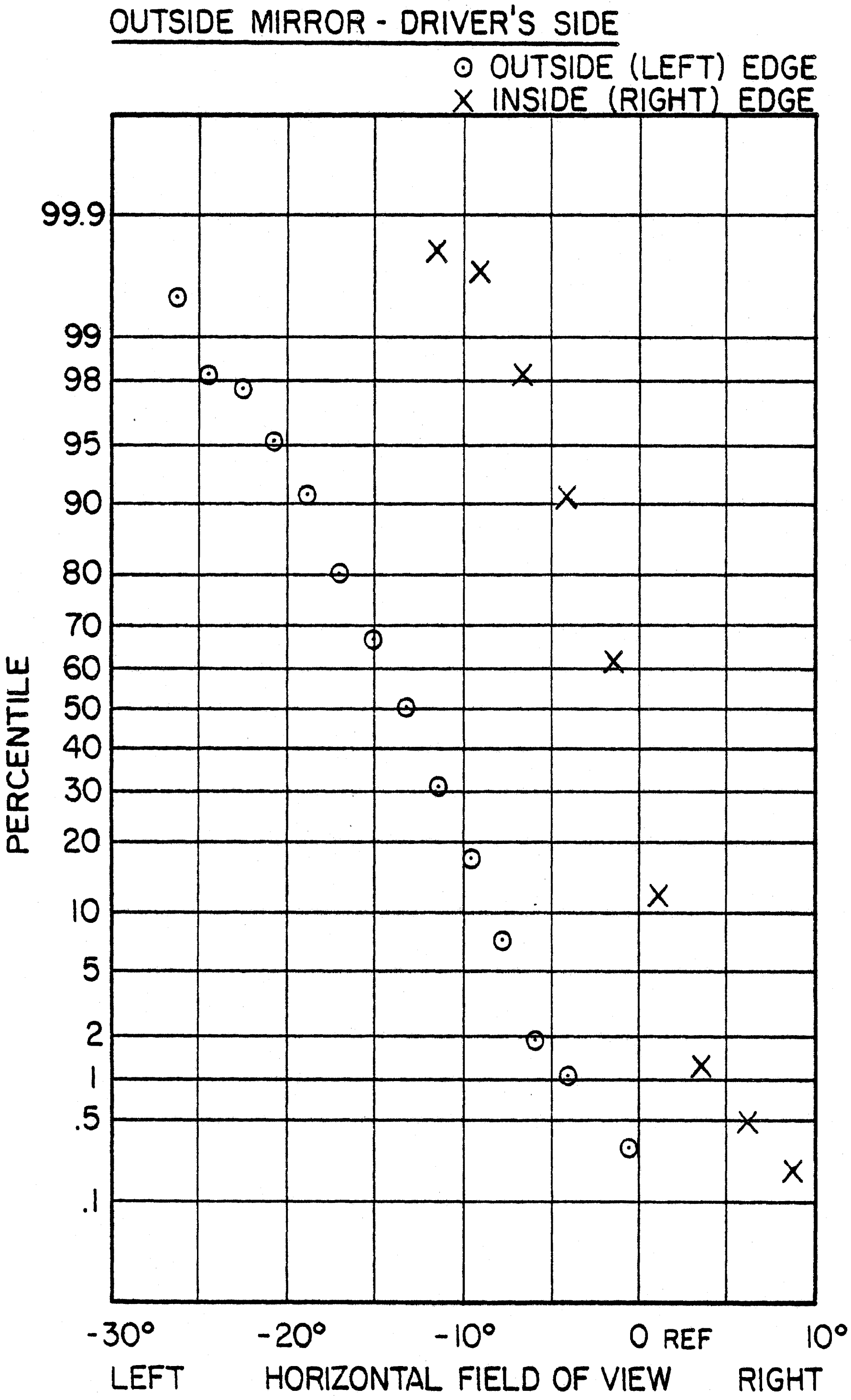

Figure 7. Horizontal field of view measured in the driver's side outside mirrors.

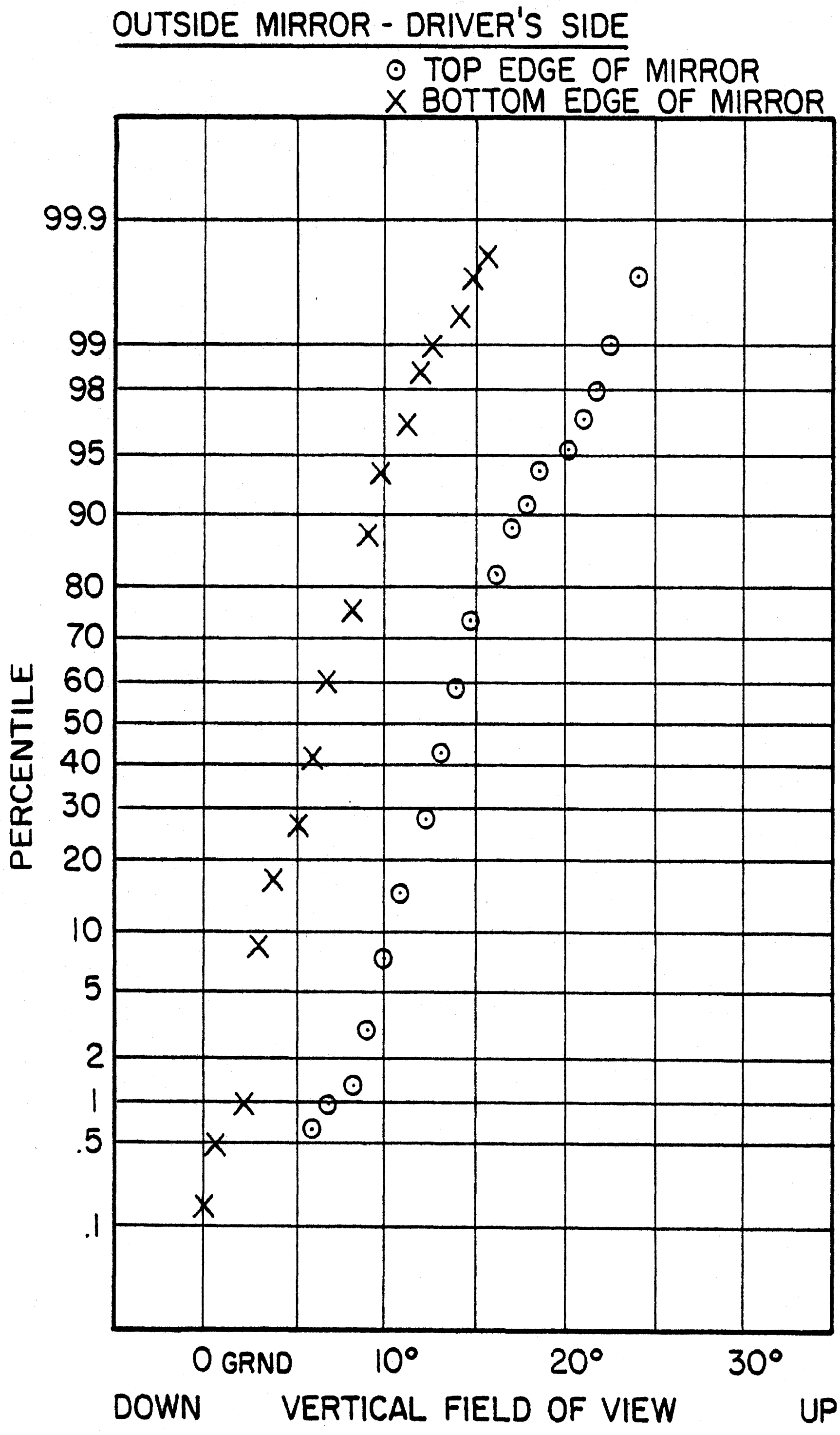

Figure 8. Vertical field of view measured in the driver's side outside mirrors.

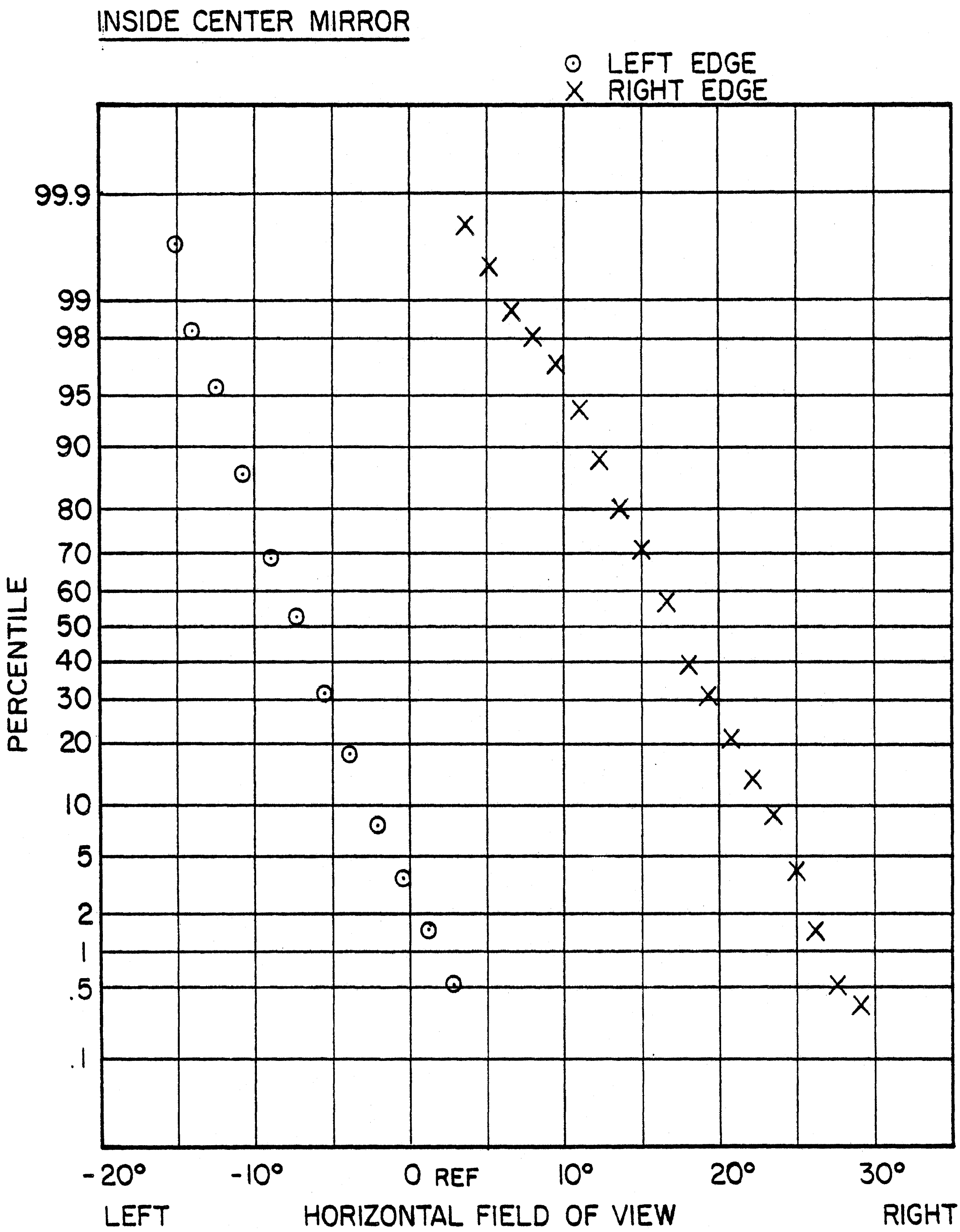

Figure 9. Horizontal field of view measured in interior mirrors.

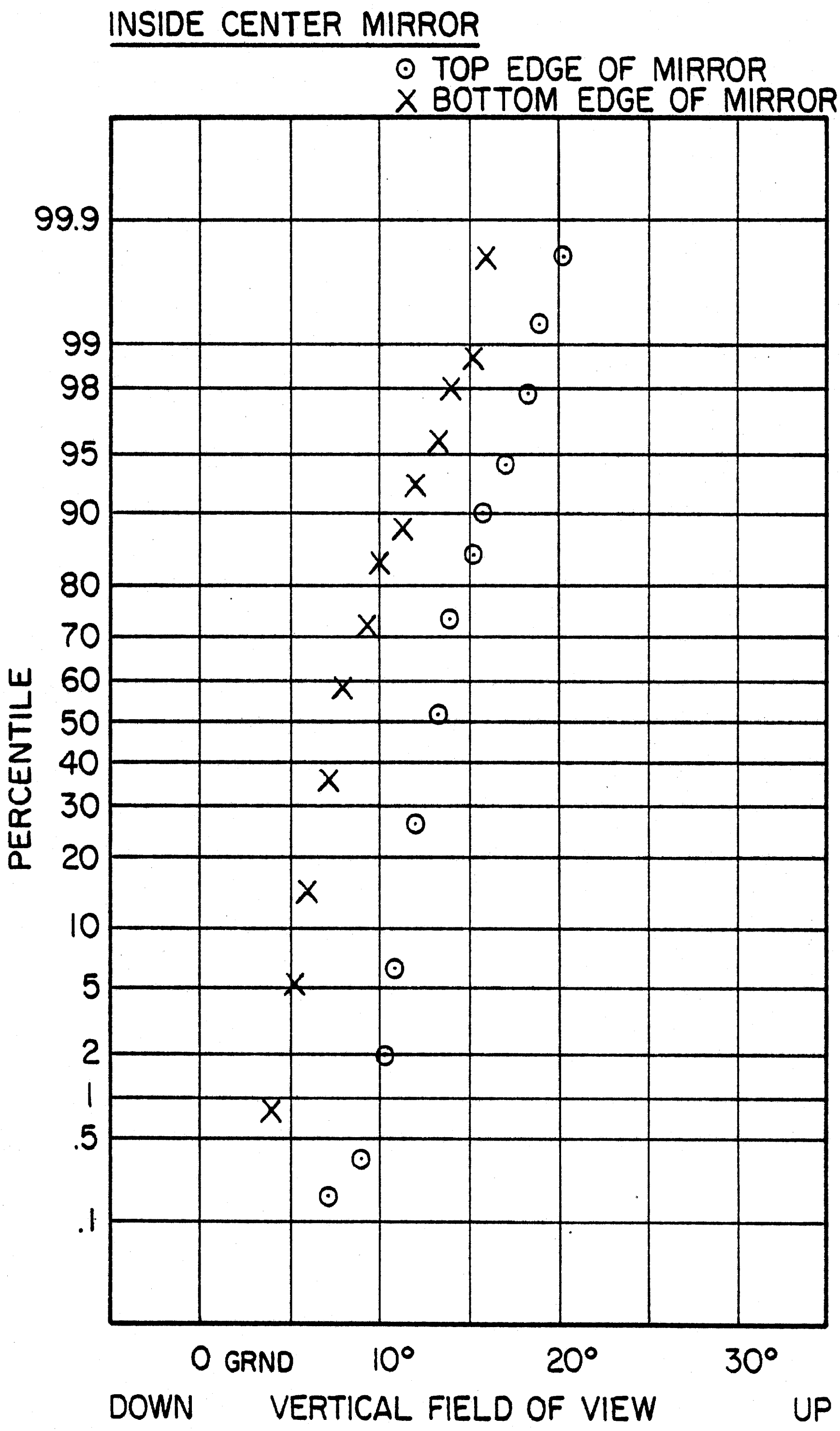

Figure 10. Vertical field of view measured in interior mirrors.

seems less for this mirror than for the one on the driver's side. Figure 9 shows that the median rightmost coverage provided by the interior mirror was about 17 degrees, which is close to the median leftmost coverage provided by this mirror. Thus, it appears that, as used by most people, the passenger-side rearview mirror provides a significant improvement in the right-side field of view.

The vertical coverage provided by the passenger-side mirror (Figure 12) is almost identical to that provided by the driver's-side mirror (Figure 8). This is an interesting finding, and it suggests that drivers do generally pay attention to their mirrors, aim them in a reasonable way and aim mirrors on the opposite side of the car using the same criteria.

Figure 13 is a plot of the median horizontal field of view from each of the three mirrors as it would appear on a representative late-model sedan (1984 Ford Tempo). There is considerable overlap in the coverage. It appears from this projection that the horizontal gain on the left side from this configuration is rather marginal, amounting to about two feet at one car length. The gain on the right side is somewhat greater. Clearly, the main benefit from the outside mirrors is in revealing objects close to and off to the side of the vehicle.

2.2.3.3 Conclusions – Field of View. The results of this survey indicate that a large percentage of drivers have their rearview mirrors aimed in a reasonable way. That is, outside mirrors are generally oriented to show close to the side of the vehicle in the inside edge, and the inside mirror is close to being centered on the rear window. There are numerous notable exceptions. These people must never use the mirrors or are satisfied with very little information about what is going on behind their own vehicle.

As typically aimed, there is a great deal of overlap in the fields of view provided by the three mirrors with which most vehicles in the sample were equipped, and coverage to adjacent lanes close to the vehicle is limited. There would seem to be some merit in encouraging drivers to aim their outside mirrors so as to provide better coverage in these important areas.

2.2.4 Tires

2.2.4.1 General condition. Table 18 is a listing of defects found in the tires inspected. About 90% of the tires had no visible defects. Uneven tread wear and weather checking account for the bulk of observed defects.

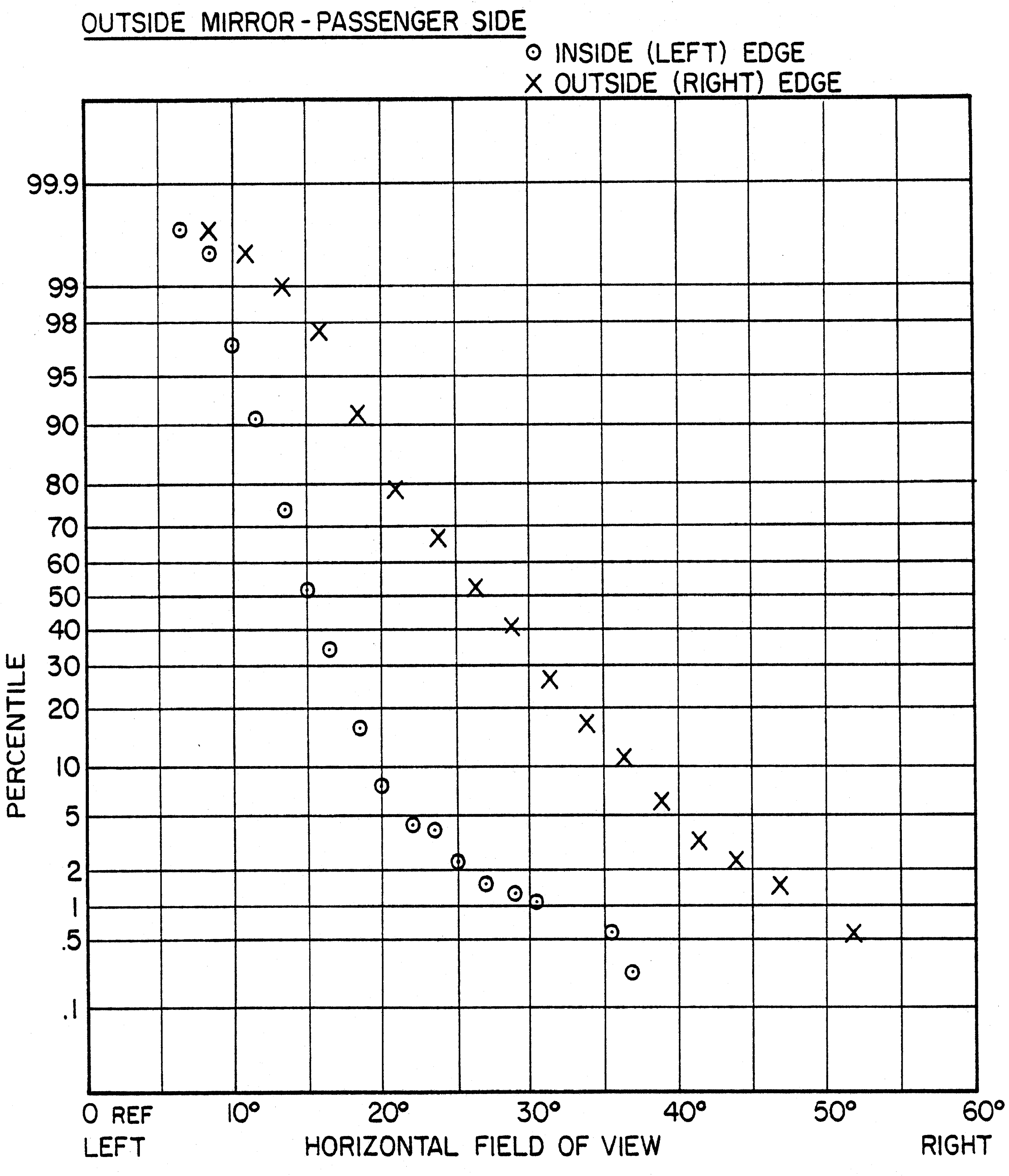

Figure 11. Horizontal field of view measured in the passenger side outside mirrors.

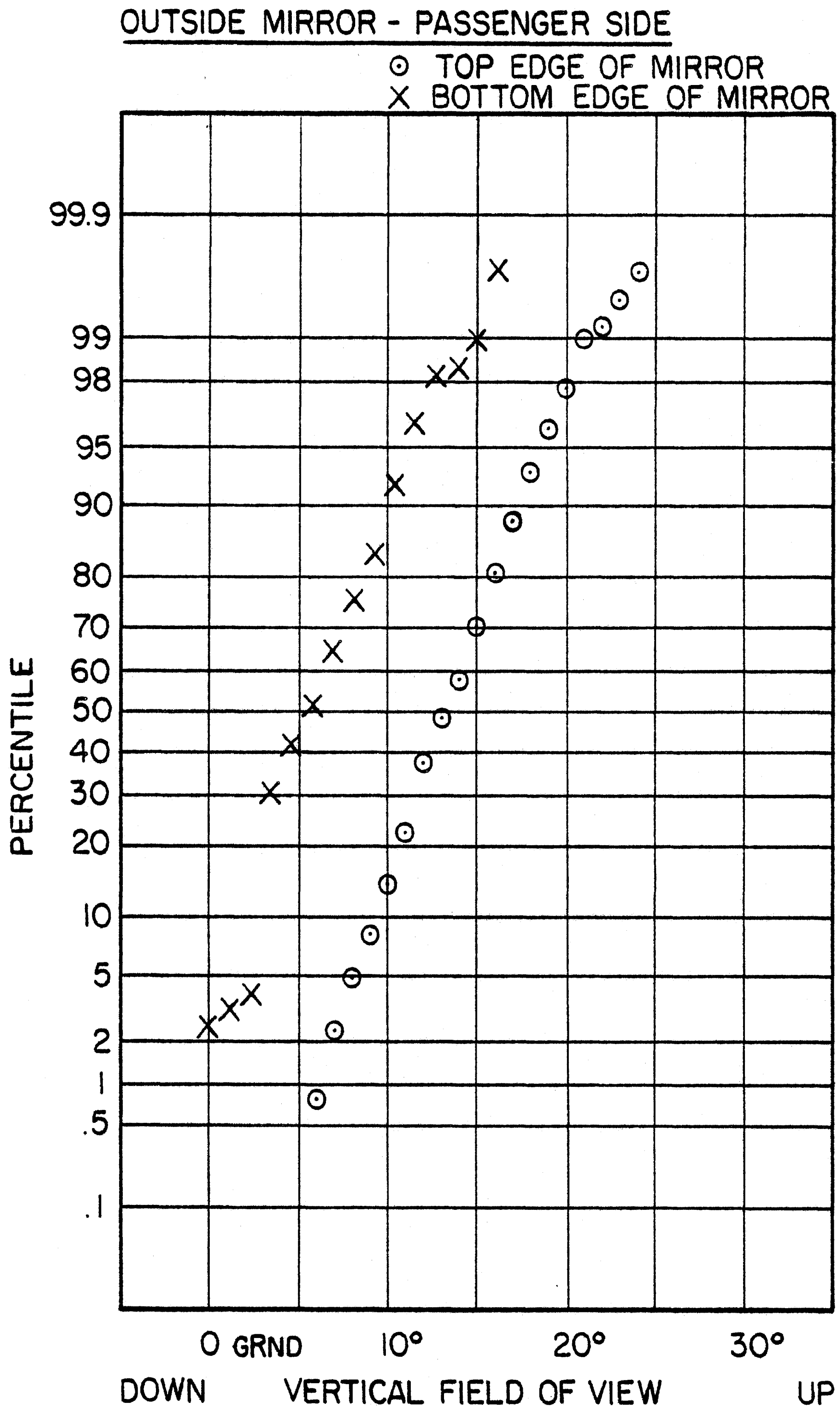

Figure 12. Vertical field of view measured in the passenger side outside mirrors.

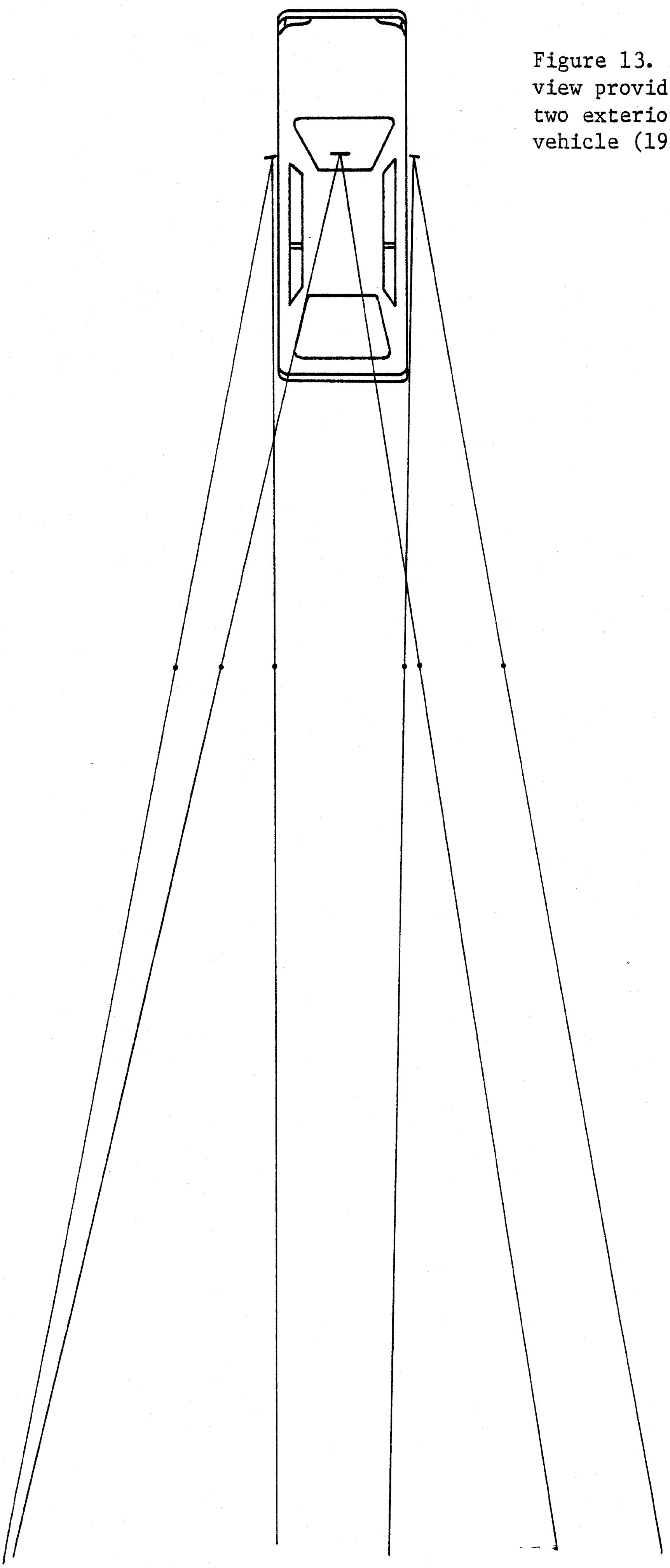

Figure 13. Median fields of view provided by interior and two exterior mirrors on a small vehicle (1984 Ford Tempo).

TABLE 18

LISTING OF VARIOUS DEFECTS FOUND IN TIRES IN SAMPLE

	DEFECTS								
	None Visible	Sidewall Gouges	Tread Gouges	Sidewall Bulges	Tread Cupping	Tread Worn in Center	Tread Worn on One Edge	Tread Worn on Both Edges	Weather Checking
Number of Tires	3416	55	2	17	6	25	103	56	96
Percent	90.5	1.5	0.1	0.5	0.2	0.7	2.7	1.5	2.5

Since these inspections were done with the car sitting on the ground, some defects were easier to spot than others. For example, localized defects such as tread gouges had a good chance of being out of sight on the ground or under the fenders. Similarly, sidewall defects on the inside of the tire would be likely to be overlooked. Hence, such defects are probably underrepresented in the sample.

2.2.4.2 Tread depth. Tread depths were measured at two points in each groove in each tire. It was not unusual to find differences from groove to groove. However, for purposes of the analyses to follow, a mean tread depth was calculated for each tire.

Table 19 lists the mean and standard deviation of tread depth for each wheel, categorized by vehicle model year. The current model (1984) vehicles in the sample had, on average, greater tread depth and less variability in tread depth than other model years. The 1983 vehicles averaged less tread than the 1984's, but slightly more than older vehicles. Starting with 1982 model vehicles, mean tread depth ranges only from 0.19 to 0.21 inch, with no indication of any trends. However, the standard deviation of tread depth does seem to increase slightly each year from 1982.

One question of interest was whether tread depth differs front-to-rear as a function of which axle is driven. Table 20 summarizes these results for front, rear, and four-wheel drive vehicles. Statistical tests (Mann-Whitney U) were run on these data as well. The four-wheel and rear-wheel drive vehicles had tread depth differences that were not significant ($p > 0.05$). On the other hand, front-wheel drive vehicles averaged less tread on the front wheels than on the rear ($p < 0.01$).

2.2.4.3 Inflation. The general information on tire pressure of the vehicles in this sample is summarized in Table 21. The mean inflation of all tires was about 31 psi, with a standard deviation of about 6 psi.

Table 22 summarizes the tire pressure data by vehicle model year. The current model vehicles averaged slightly higher pressures, and the standard deviations were slightly lower. From 1983 back, there is no apparent trend in either the mean or standard deviation of inflation pressure.

There is considerable variability in recommended tire pressures from vehicle to vehicle. Hence, mean tire pressures do not mean a great deal. Table 23 shows mean differences from recommended tire pressures. These data were arrived at by subtracting recommended from measured pressures. Thus, a negative sign indicates underinflation.

TABLE 19

TREAD DEPTH (in inches) OF VEHICLES IN SAMPLE, CLASSIFIED BY MODEL YEAR

Year	n	Measure	Front		Rear	
			Left	Right	Left	Right
1979	173	Mean SD	021 0.072	0.21 0.082	0.21 0.094	0.20 0.093
1980	170	Mean SD	0.20 0.081	0.19 0.079	0.20 0.080	0.20 0.083
1981	169	Mean SD	0.20 0.072	0.20 0.069	0.20 0.071	0.20 0.071
1982	142	Mean SD	0.20 0.062	0.19 0.068	0.21 0.064	0.20 0.065
1983	171	Mean SD	0.22 0.070	0.22 0.071	0.24 0.070	0.24 0.070
1984 (current)	119	Mean SD	0.28 0.42	0.28 0.045	0.29 0.038	0.29 0.038

TABLE 20

FRONT AND REAR TIRE TREND DEPTH (in inches) AS A FUNCTION OF DRIVE TYPE

Drive Type	Total Vehicles	Mean Tread Depth		Level of Significance
		Front	Rear	
Rear-Wheel Drive	543	0.218	0.221	$p>0.05$
Front-Wheel Drive	326	0.194	0.208	$p<0.01$
Four-Wheel Drive	85	0.270	0.269	$p>0.05$

TABLE 21

MEANS AND STANDARD DEVIATION OF TIRE PRESSURE FOUND IN SAMPLE VEHICLES

		Left	Right
Front	PSI	31.8	31.4
	SD	6.15	5.75
Rear	PSI	30.6	30.6
	SD	5.91	6.35

There are some interesting trends suggested in Table 23. First, the newest cars (1984 models) seem to have the best-maintained tire pressures, as measured by both the mean departure from recommended values and the variability of that measure. Second, the rear tires in the sample tend to be underinflated, although this is most pronounced in the 1981–83 models. Third, front tires tend to be underinflated in 1983–82 models, but the trend is toward overinflation in the oldest models sampled (i.e., 1980–79).

TABLE 22

TIRE PRESSURE (in PSI) OF VEHICLES IN
SAMPLE< CLASSIFIED BY MODEL YEAR

Year	n	Measure	Front		Rear	
			Left	Right	Left	Right
1979	173	Mean	31.7	31.2	30.3	30.8
		SD	6.6	6.5	6.9	7.7
1980	170	Mean	31.4	31.0	30.2	29.9
		SD	5.4	6.0	5.1	5.6
1981	169	Mean	31.8	30.7	30.8	30.1
		SD	5.5	5.2	6.3	6.1
1982	142	Mean	32.0	31.3	29.9	30.2
		SD	8.3	5.3	5.5	6.3
1983	171	Mean	31.5	31.4	30.2	29.9
		SD	5.8	6.0	5.6	6.2
1984 (current)	118	Mean	83.2	33.1	33.2	33.6
		SD	4.8	5.0	5.0	4.9

TABLE 23

DIFFERENCE BETWEEN MEASURED AND RECOMMENDED TIRE PRESSURES (in PSI) OF VEHICLES IN SAMPLE, CLASSIFIED BY MODEL YEAR

Year	n	Measure	Front		Rear	
			Left	Right	Left	Right
1979	172	Mean SD	2.8 7.0	2.3 6.7	−0.6 7.0	−0.1 7.8
1980	170	Mean SD	2.1 6.1	1.7 7.1	−0.3 6.3	−0.6 7.0
1981	168	Mean SD	0.8 5.9	−0.3 6.1	−1.2 7.4	−1.8 6.5
1982	139	Mean SD	−0.4 9.0	−1.0 6.1	−2.9 6.3	−2.7 7.4
1983	169	Mean Sd	−0.9 6.2	−1.0 6.2	−3.1 6.7	−3.5 7.0
1984 (current)	117	Mean SD	0.9 4.9	0.8 5.1	−0.1 4.8	0.4 4.7

Note: The n in this table differs in some years from the n in other tables because recommended tire pressures could not be obtained for some cars. Positive values indicate overinflation, negative values underinflation.

2.2.4.4 Conclusions – Tires. The results of this survey show considerable variability in both tread depth and inflation pressure. Neither result was unexpected. However, while variation in tread depth does not necessarily indicate a safety problem (although there were several very bald tires in the sample), improper tire pressure can have a significant effect on vehicle response characteristics, and can make it more difficult to control the vehicle under conditions of high lateral acceleration. Whether the problem comes from carelessness or lack of knowledge on the part of the owner, poor service personnel, poor equipment, or some combination of all these factors cannot be determined. However, it seems apparent that, while tires are among the most important items of safety equipment on a vehicle, they are also among the most neglected.

3.0 THE EFFECT OF LOAD ON VEHICLE PITCH ANGLE

3.1 Introduction

Because car bodies sit on springs, and because the headlamps are attached to the sprung portion of the vehicle, the amount and distribution of load within a vehicle can have a significant effect on vertical headlamp aim.

This problem has been studied to a limited degree by Hull et al. (1972) and Olson and Mortimer (1974). In each case the investigators selected a small sample of vehicles and loaded them systematically, checking the effect on pitch angle at each stage. The findings indicated that the vertical aim of headlamps might go up by as much as 1.5 degrees, when going from a driver-only to a full-rated load condition. The change in pitch associated with fuel level was typically between 0.25 and 0.50 degree.

The data just cited are more than ten years old. In the interim very significant changes have taken place in motor vehicles. What effect these changes would have on the question of interest here is uncertain. Therefore, a study was carried out to provide the necessary data.

3.2 Method

3.2.1 Vehicles. Twenty vehicles were used in this study. These are listed in Table 24. An effort was made to obtain as broad a sampling as possible of different makes, models, body styles, and types in the years from 1979 to 1984 (the same years as the field survey).

3.2.2 Procedure. Vehicles were solicited from staff members of the University of Michigan Transportation Research Institute. An attempt was made to obtain each volunteered vehicle when its fuel tank was relatively empty. Actual fuel levels at the time each vehicle was checked ranged from less than one-quarter to half full.

A concern was whether the tendency of independently-suspended wheels to move laterally under load would affect the results. The fact that the wheels could not do so under the conditions of this test might affect suspension deflection and bias the results. To check this a car was set up with its front wheels on an air bearing. Measurements were made of changes in pitch angle associated with placing 200 pounds of weight on the radiator. This was done with the air on, which allowed the wheels to move laterally, and with the air off. The measurement was repeated three times under each condition. The mean change with the air on was 59 minutes and with the air off was 55 minutes. This

TABLE 24

LISTING OF VEHICLES MEASURED IN LOADING STUDY

Make	Model	year	Body Style	Passengers	Full Rated Load (lbs.)	Fuel Capacity (gallons)
AMC	Spirit	1980	2 dr Sedan	4	775	21.0
Buick	Park Avenue	1983	4 dr Sedan	6	1100	24.0
Chevrolet	Caprice Classic	1983	Station Wagon	8	1200	22.0
Chevrolet	Chevette	1980	4 dr Sedan	4	700	12.5
Chevrolet	Monza	1979	2 dr Sedan	4	725	18.5
Dodge	Caravan	1984	Van	7	1200	15.0
Dodge	Daytona	1984	2 dr Sedan	4	715	14.0
Ford	Club Wagon	1979	Van	8	1700	40.1
Ford	Escort	1982	2 dr Sedan	4	650	11.3
Honda	Accord	1983	4 dr Sedan	5	850	15.8
Mercury	Topaz	1984	4 dr Sedan	5	850	14.0
Mercury	Zypher	1979	2 dr Sedan	5	850	18.0
Oldsmobile	Cutlass	1979	4 dr Sedan	6	1100	18.0
Pontiac	Bonneville	1979	4 dr Sedan	6	1100	21.0
Pontiac	Phoenix	1980	2 dr Sedan	5	886	14.0

LISTING OF VEHICLES MEASURED IN LOADING STUDY (continued)

Make	Model	year	Body Style	Passengers	Full Rated Load (lbs.)	Fuel Capacity (gallons)
Pontiac	2000	1983	4 dr Sedan	5	880	14.0
Renault	Alliance	1983	2 dr Sedan	5	850	12.5
Toyota	Long Bed	1980	Pickup Truck	2	1000	16.0
Toyota	Tercel	1982	2 dr Sedan	5	800	11.9
VW	Rabbit	1981	2 dr Sedan	4	785	10.0

difference (4 minutes, or 0.067 degree) was considered small enough to be ignored, especially so since the maximum loading in this test would be on the rear axle.

Each vehicle was brought to the Institute garage area and parked in a specified location. Basic information concerning make, model, year, seated positions, load limits, and fuel capacity was recorded and the tires were checked and set to the pressure specified by the manufacturer.

Pitch readings were made with an inclinometer accurate to within one minute of arc. A position was marked with chalk on the doorsill for this instrument, so that it would always be in the same position. The first reading was made with the vehicle empty and the fuel at a low level. The vehicle was then taken to a nearby service station and the tank filled. After being returned to the Institute and parked in the same position, the pitch angle of the vehicle was checked again.

At this point the passenger loading test began. Weight (150 pounds) representing the driver was placed on the seat and the rear suspension was agitated by raising and lowering the bumper gently. A reading was made using the inclinometer. Weight was then added to the other seated positions, one at a time, in the following order: right front passenger, center front passenger (if any), right rear, left rear and center rear (if any), with the pitch angle being checked each time. If there were more than two seats (as in vans), these were treated in the same way as the back seat in sedans. Finally, weight was added to the trunk to bring the vehicle to its full-rated load.

A second test was of driver plus simulated baggage. All weights except those representing the driver were removed and pitch angles were measured with 100, 200, and 300 pounds in the trunk. An exception was a large van and a pickup truck, where as much as 700 pounds was added to the cargo area. As a final check all weight except that representing the driver was removed and a reading made with the inclinometer. This was compared with the first such reading to verify accuracy.

3.3 Results

The fraction of the fuel tank that was filled at the time of the test was calculated, and this value used to estimate the pitch change that would have come about had the tank been empty and then filled completely. These data are plotted in Figure 14. This is a normal probability plot, showing percentiles versus pitch change from the empty condition. The 5th to 95th percentile range is from almost 0 to about 0.4 degree. There are no data on population fuel levels. However, if we assume that the average car on the road has about half a tank of fuel and that about 2/3rds of the cars on the road have between 1/4 and 3/4 tank of fuel, then the standard deviation in vertical aim due to fuel levels would be about 0.1 degree, based on these data.

Figure 15 is a normal probability plot of the pitch change associated with going from a driver-only to a full-rated load condition. The mid-90th percentile range in this instance is almost one degree, from about 0.6 to 1.5 degrees. Based on these data, the headlamps of cars operating under full-rated load conditions would be aimed from about 0.6 to 1.5 degrees up relative to the driver-only condition.

The pitch change associated with going from driver-only to full passenger load is shown in Figure 16. The two data points on the left side of the figure are from a two-passenger pickup truck and a large van. Eliminating these, the mid-90th percentile range is about 0.5 degree. These data indicate that the headlamps of cars operating under full passenger load conditions will be aimed up from about 0.5 to 1.0 degree relative to the driver-only condition.

Based on data obtained from accident-involved vehicles (CPIR Revision 3, January, 1980), almost 85% of vehicles have no more than two occupants. Figure 17 shows the pitch change associated with going from driver only to driver plus one passenger (located in the right front seat). The distribution of change is small and nearly symmetric about zero degrees. The largest change was 0.15 degree down and the range is through zero to about 0.1 degree up.

While it seems clear that the effects associated with usual passenger loads are small, it is probable that in many cases cars with one or two passengers are carrying significant baggage. Figure 18 shows the effects of adding 100 pounds or a full trunk load (generally 300 pounds, but as much as 700 pounds for the pickup truck and the large van) to a vehicle otherwise occupied only by a driver. The smaller load would raise headlamp aim anywhere from 0.1 to 0.5 degree. The larger load, as expected, would raise headlamp aim much more. The range for this sample of vehicles was from about 0.5 to 1.4 degrees.

One of the major changes that has occurred in the vehicle population since the previous loading studies were carried out is the increase in the number of smaller cars. Thus, one matter of interest was differences between large and small cars in the sample. To provide some guidance on this question the cars were ranked in terms of full-rated load, after eliminating the pickup truck and two vans. The four smallest and four largest were selected for comparison. All were sedans, except for one 8-passenger station wagon in the large group.

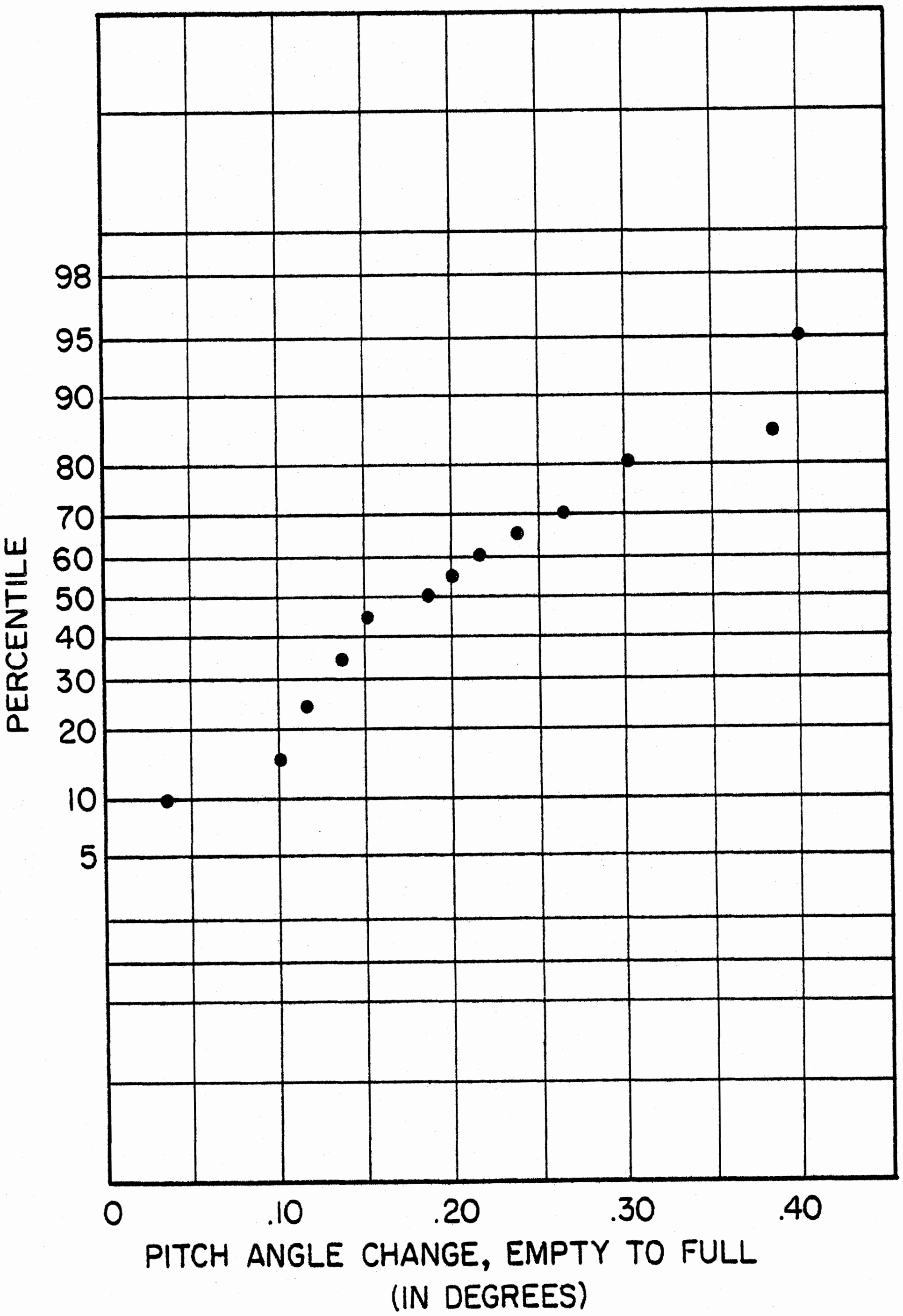

Figure 14. Pitch angle change, empty to full.

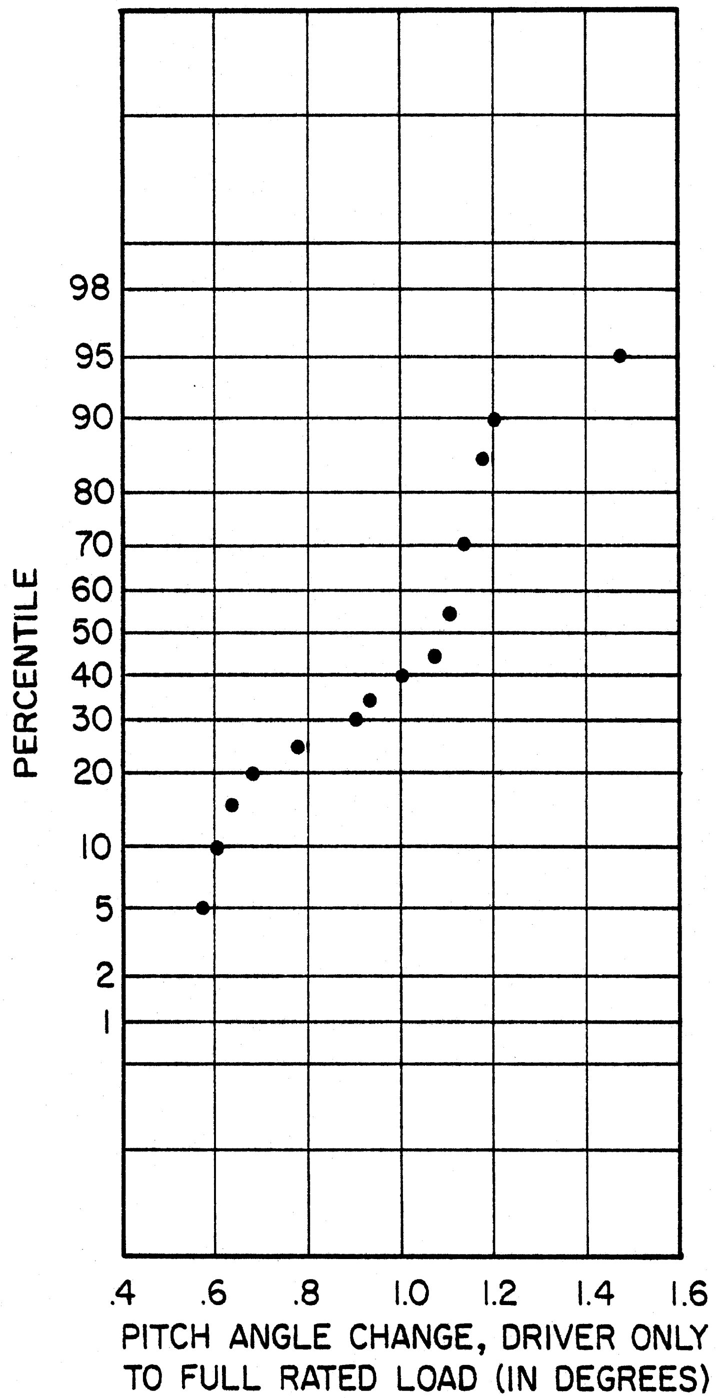

Figure 15. Pitch angle change, driver only to full rated load.

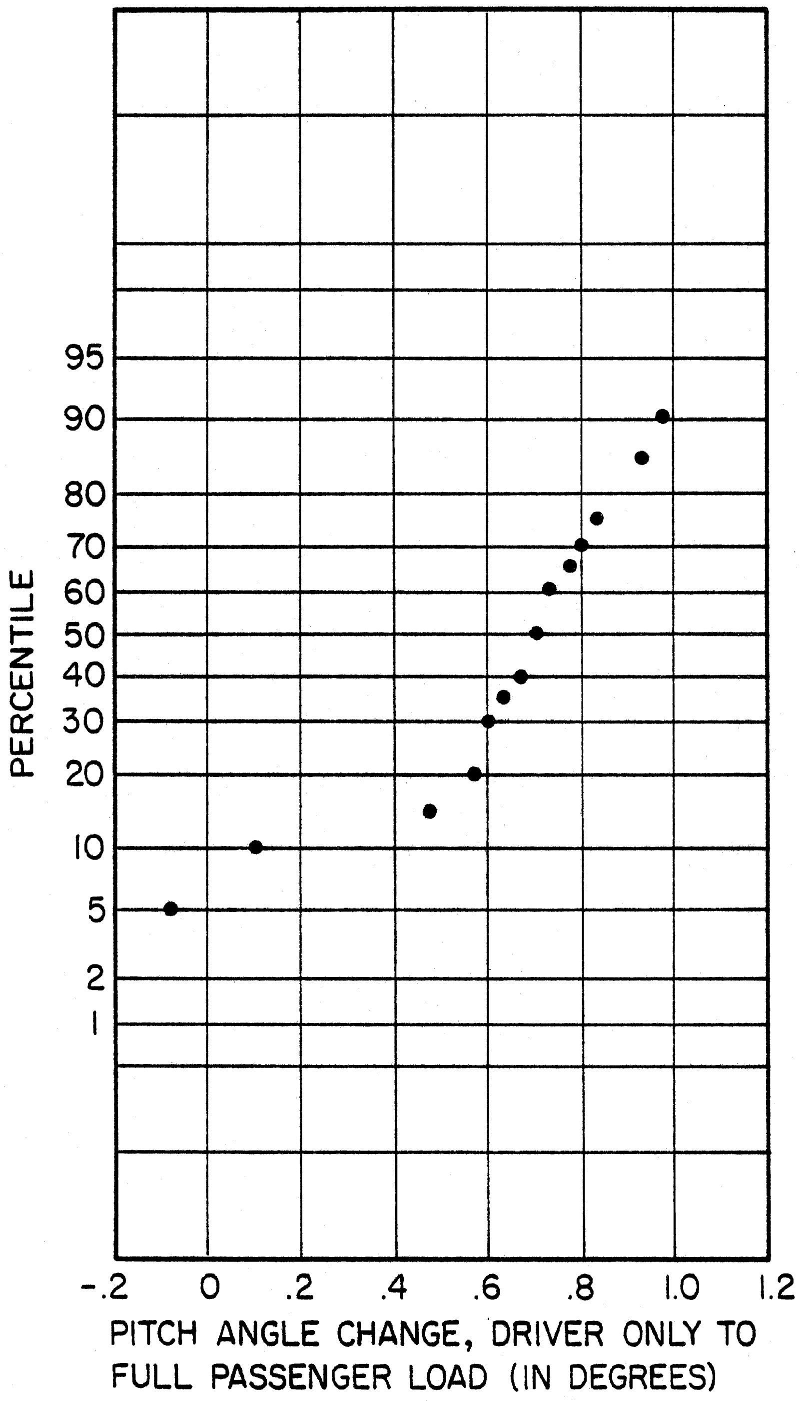

Figure 16. Pitch angle change, driver only to full passenger load.

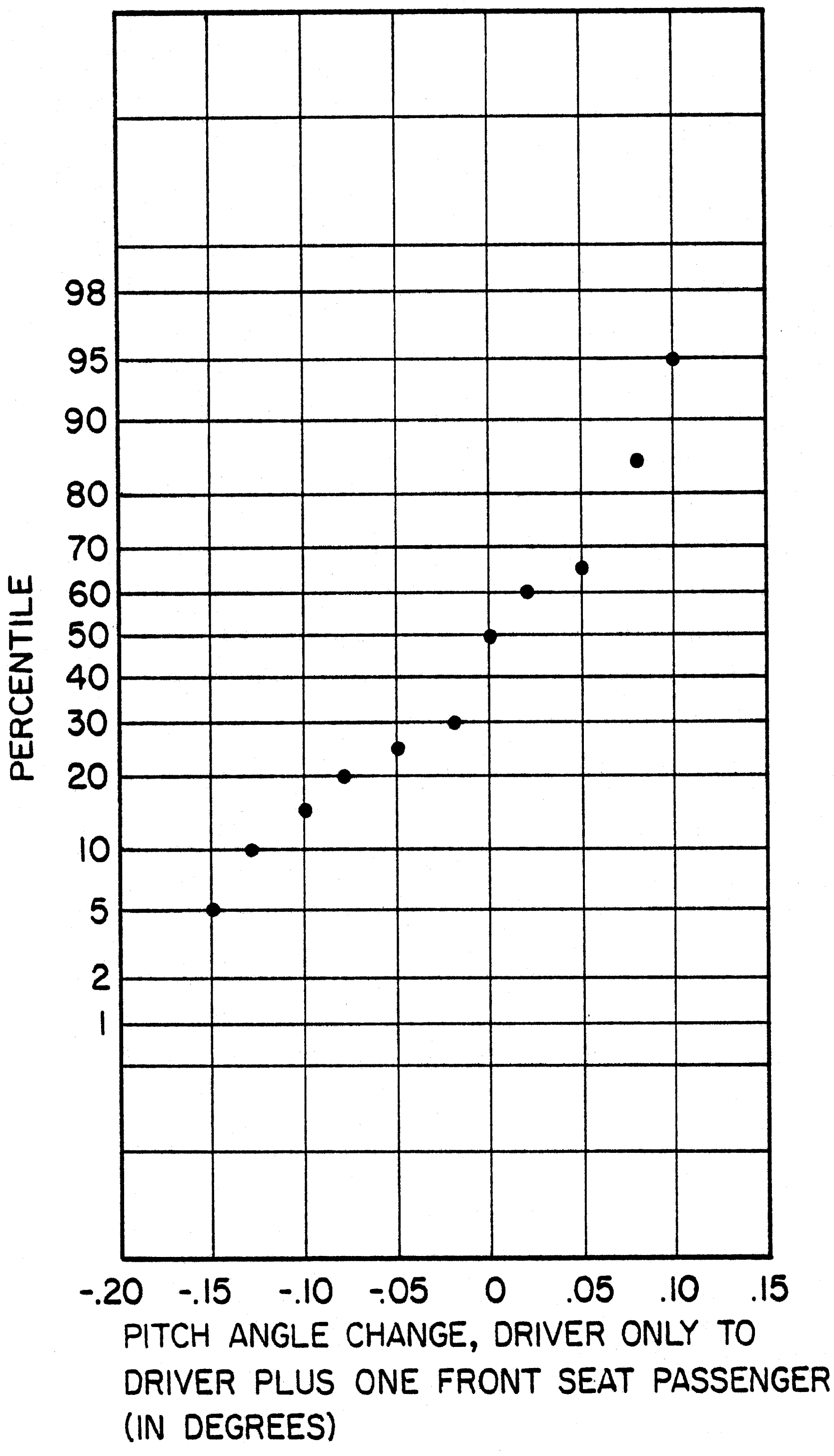

Figure 17. Pitch angle change, driver only to driver plus one front seat passenger.

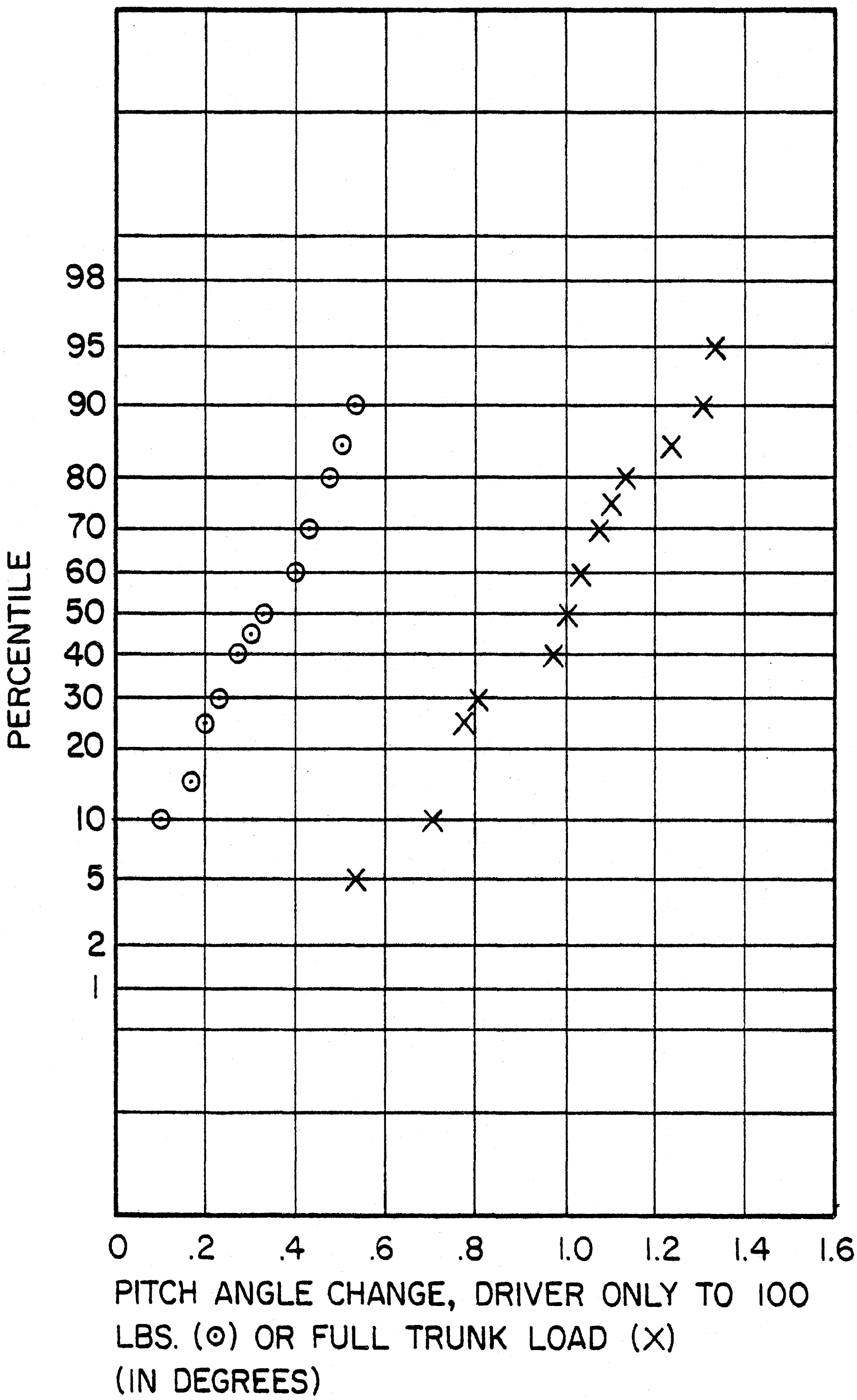

Figure 18. Pitch angle change, driver only to]00 lbs. (o) or full trunk load (x).

Three comparisons were run. The first was for change from driver only to full-rated load. For the small cars this averaged 53 minutes (the mean full-rated load for these four vehicles was 715 pounds). For the large cars the average change was 65 minutes (the mean full-rated load was 1125 pounds).

The next comparison was for change from driver only to full passenger load. Four passengers in the small cars resulted in an average change of 37 minutes. For the large cars the average change was 44 minutes. However, this included 8 passengers in the station wagon, which was equivalent to full-rated load for that vehicle. If each of the larger cars was restricted to 6 passengers, the average change was 36 minutes.

The last comparison was for the effects of fuel load. Going from empty to full (average of 13 gallons) changed the pitch angle in the small cars by an average of 14 minutes. The same process (average of 21 gallons) changed the pitch angle in the large cars by an average of 15 minutes.

3.4 Discussion

The results of this study have provided some indication of the vehicle population variance in vertical headlamp aim arising from various loading conditions. It is apparent that the variance is relatively small, except for extreme conditions (e.g. heavy loads). CPIR data suggest that such conditions may occur only about 5% to 10% of the time.

It also appears that, while large and small cars differ greatly in how much they can carry, they differ very little in the effects of loading on vertical headlamp aim.

Comparing the results of this investigation with earlier work, it appears that there have been significant improvements. For example, Hull et al. (1972) report vertical aim changes at full-rated load for eleven vehicles ranging from 1.42 to 1.65 degrees. In the present study the largest change measured was 1.44 degrees at full-rated load, and the median was about 1.04 degrees. Similarly, Olson and Mortimer (1973) measured aim changes associated with fuel levels in a sample of four vehicles. The changes in vertical aim ranged from 0.29 to 0.69 degree. In the present study only 20% of the vehicles measured fell into this range. The median change was about 0.2 degree.

4.0 THE EFFECT OF AERODYNAMICS ON VEHICLE PITCH

4.1 Introduction

It is known that aerodynamic pressures acting on a vehicle at speed can induce pitch attitude changes in the vehicle and, consequently, have some influence on headlight aim. The purpose of this part of the research program was to evaluate that potential through analytical means.

While there is little discussion of the influence of aerodynamics on vehicle pitch in the literature, it is safe to say that for "pre-energy crisis" vehicles, aerodynamic drag, acting above the ground plane, had sufficiently strong effect to cause most vehicles to pitch, front up, while traveling at speed. Thus, for example, Huculak (1978) states that most passenger cars pitch up with increasing speed and he cited an example of 0.25 degree at 50 mph. Recent designs have resulted in radical changes in the aerodynamics of passenger cars, however. It could be that the efforts to reduce drag in the interest of fuel economy may also reduce aerodynamic-induced pitch.

4.2 Method

To investigate these questions, a simple mathematical model was developed, and parameter data derived from the literature and obtained from vehicle manufacturers were applied to calculate vehicle pitch. That activity is now considered.

Aerodynamic pressures acting on a vehicle at speed result in three forces (drag, lift, and lateral forces) and three moments (pitch, roll, and yaw) acting on the vehicle. By convention, these forces and moments are defined with respect to an axis system whose origin is in the ground plane at mid-wheelbase. The free-body diagram of Figure 19 is illustrative, in the pitch plane. This figure shows the aerodynamic forces of drag (F_D) and lift (F_L) and the aerodynamic pitch moment (M_p) acting at the reference origin. The front and rear differential tire loads (F_F and F_R) and the drive thrust, which all are required to react the aerodynamic loads are shown.

Using the principles of statics, it can be readily shown that

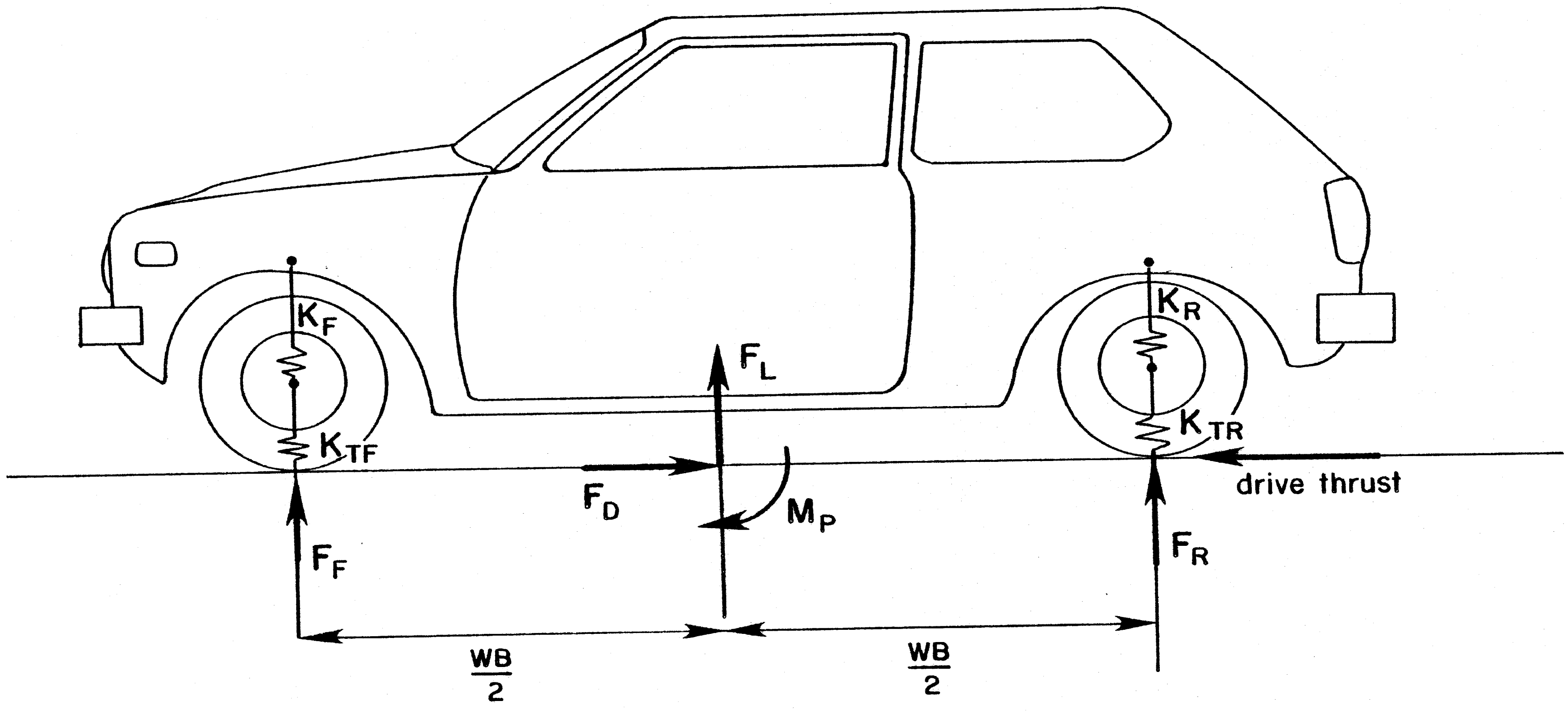

Figure 19. Vehicle model for pitch response to aerodynamic forces.

$$F_F = \frac{1}{2}\left[-F_L - \frac{M_P}{WB}\right] \tag{1}$$

$$F_R = \frac{1}{2}\left[-F_L - \frac{M_P}{WB}\right] \tag{2}$$

where WB is the wheelbase of the vehicle.

To first order, the pitch attitude change of the vehicle due to aerodynamic forces will result from the suspension load changes implied by Equations (1) and (2) acting on the compliant suspension and tire elements. That is

$$\Delta\theta = \frac{F_F(1/K_R + 1/K_{TR}) - F_F(1/K_F + 1/K_{TF}}{WB} \tag{3}$$

$\Delta\Theta$ is the pitch change in radians (front up being positive)

K_F is the front suspension vertical spring rate (sum of two sides)

K_R is the rear suspension vertical spring rate (sum of two sides)

K_{TF} is the front tire vertical spring rate(sum of two sides)

K_{TR} is the rear tire vertical spring rate (sum of two sides)

We complete the mathematical picture by introduction of the conventional definitions of the aerodynamic coefficients of lift and of pitch moment, namely:

$$C_L \equiv F_L \frac{2_g}{\rho A V_2} \tag{4}$$

$$C_{PM} \equiv \frac{M_P}{WB} \frac{2_g}{\rho A V_2} \tag{5}$$

where

Equations (1) through (5), then, constitute the mathematical model used in this project to examine the influence of aerodynamic forces on vehicle pitch. We note that the model is, of course, approximate. It ignores, for example, the influence of drive thrust, which, acting

C_L is the aerodynamic lift coefficient

C_{PM} is the aerodynamic pitch moment coefficient

ρ is the air density

A is the frontal area of the vehicle

V is the relative air speed to the vehicle

through the drive axle suspension geometry, may generate small vertical suspension displacements, independent of vertical load conditions. Small influences of vehicle roll (which may be coupled to pitch due to an inclined roll axis) are also ignored.

Vehicle parameter data, needed to make representative calculations, were obtained from several sources. Aerodynamic data giving C_L and C_{PM} as a function of wind yaw angle for twelve vehicles were obtained from the literature. Data for six of these came from full-scale wind tunnel testing by Hogue (1980), while the data for the other six came from scale model testing by Zellner (1982). These twelve vehicles had model-year identifications distributed over the years 1969 through 1980. Additionally, upon request, Ford Motor Company provided data describing a representative sample of six 1983 model year vehicles. Chrysler Corporation also provided data for a sample of six 1984 vehicles. Tire and suspension rate data were obtained from (1) UMTRI's own files, (2) the literature, in particular published MVMA specifications, and (3) Ford and Chrysler (provided along with aerodynamic data). We note that, in several cases, suspension and/or tire data specifically for the vehicle model of interest were not available. In such cases, data for a vehicle of similar type, size, and weight were used. Thus we emphasize that the numerical results presented below should be taken, as a group, to be indicative of the general magnitude of the influence of aerodynamic forces on vehicle pitch. They should not be considered as necessarily accurate for each of the individual vehicle models identified.

4.3 Results

There are, of course, an unlimited number of "test" conditions, composed of vehicle speed and wind conditions, under which the sample vehicles could be evaluated. We have arbitrarily chosen five conditions as described in Table 25. In all five, the vehicle travels at 55 mph. The first condition is still air and the next two are 10 and 20 mph head winds, respectively. The last two conditions prescribe 10 and 20 mph side winds, respectively. The table indicates the resulting relative wind speed and yaw angle.

Table 26 shows the predicted pitch angle change due to aerodynamics, for the sample vehicles, under the reference conditions. We see that the earlier example of 0.25 degree at 50 mph appears to be much more an "upper bound" than a "typical" value. Indeed, only one passenger car approaches 0.25 degree at a wind speed of 55 mph. Interestingly, four passenger cars actually pitch down, indicating (1) low drag, (2) a rearward center of action of lift, and/or (3) a relatively compliant rear suspension/stiff front suspension.

Table 25

AERODYNAMIC "TEST" CONDITIONS

Condition No.	Vehicle Speed (mph)	Headwind (mph)	Sidewind (mph)	Resultant Wind Speed (mph)	Resultant Wind Direction (deg)
1	55	0	0	55	0
2	55	10	0	65	0
3	55	30	0	75	0
4	55	0	10	55.9	10.3
5	55	0	20	58.5	20.0

Pickup trucks and vans also generally show low pitch response. While these vehicles, of course, have less advantageous aerodynamic properties, their higher stiffness suspensions, designed for load-carrying capacity, seem to provide the necessary offsetting influence. Only the Micro Bus and the pickup equipped with a camper body show pitch response in the range of 0.3 degree at 55 mph. The Micro Bus, being a rather light van, does not have as stiff a suspension as the other vans. The camper-equipped pickup suffers from high magnitude and high elevation of the camper drag.

In general, these calculations show that aerodynamic influences on pitch are not highly significant in modern passenger vehicles and light trucks. Apparently, recent improvements in aerodynamic properties obtained for fuel economy reasons, have served to lessen aerodynamic pitch response relative to older vehicles.

Table 26

CALCULATED VEHICLE PITCH DUE TO AERODYNAMICS

Vehicle	Data Source	Pitch Angle, Deg* At Indicated Test Conditions**				
		1	2	3	4	5
1975 Fiat X1/9	1	−.03	−.04	−.06	−.01	NA
1977 Honda Accord	1	−.03	−.05	−.06	.00	.03
1974 Chev Monte Carlo	1	.17	.23	.31	.14	.12
1972 Chev Station Wagon	1	.02	.02	.03	.04	.07
1976 VW Micro Bus	1	.30	.42	.56	.50	.74
1976 Ford Econoline Van	1	.13	.18	.24	.09	.05
1980 Chev Citation	2	−.13	−.18	−.23	−.13	−.14
1978 Ford Fairmont Sedan	2	−.08	−.12	−.16	−.08	−.06
1978 Ford Fairmont Wagon	2	.01	.01	.02	.02	.05
1978 Ford F250 Pickup with Camper	2	.33	.46	.61	.35	.39
1984 Chrysler Laser XE Turbo	3	.05	.07	.10	.06	NA
1984 Dodge Daytona Turbo Z	3	.03	.04	.05	.04	NA
1984 Chrysler E-Class Sedan	3	.24	.33	.44	.30	NA
1984 Dodge 350 Maxi Van SE	3	.08	.11	.15	.10	NA
1984 Dodge Ram Van	3	.04	.06	.08	.05	NA
1984 Dodge D150 Swept Side Pickup	3	.10	.14	.18	.13	NA
1983 Ford Crown Victoria	3	.17	.23	.31	.17	.16
1983 Ford Escort 3 Door	3	.00	.01	.01	.03	.07
1983 Ford LTD	3	.08	.11	.15	.10	NA
1983 Ford F-100 Pickup	3	.10	.14	.18	.11	.14
1983 Econoline Van	3	.04	.05	.07	.05	.06
1983 Ford Ranger Pickup	3	.03	.04	.06	.06	.08

* Positive direction is front up, rear down.
** See Table 1 for definitions of conditions.
1 Aerodynamic data from full scale wind tunnel tests by Hogue (1980).
2 Aerodynamic data from scale model wind tunnel tests by Zeller (1982).
3 Aerodynamic data from manufacturers.

5.0 HEADLAMP DIRT EFFECTS AND CLEANING SYSTEMS

5.1 Introduction

Among the many hazards to efficient headlamp operation are contaminants that lodge on the lamp lens. Included among these are dirt, ice, snow, and slush. Such coatings absorb and scatter illumination from the lamp. Visibility distance is reduced and, in some cases, glare to oncoming drivers is increased.

Probably the best documentation of the degree to which various contaminants affect headlamp performance has been provided by Rumar (1970), who measured changes in high-beam light output of vehicles in service stations under various weather conditions. His data are reproduced in Figure 20. In dry weather the bulk of vehicles showed a reduction of 20% or less. However, under wet and slushy conditions the percentage loss increased dramatically. Rumar also made estimates of the loss in visibility distance associated with various levels of light reduction. These data are reproduced in Figure 21. Note that for levels less than 20% there was a slight gain in visibility distance with low beams. This is due to scatter, which results in some additional illumination being directed above horizontal toward the target. Glare would be increased for the same reason. Similar results have been reported by Schmidt-Clausen (1978).

Headlamp cleaning devices are common in Europe, and standards have been developed to evaluate the adequacy of various designs. The first such standard was published in Sweden, effective in 1971 (Swedish Standard SMS 2983). This resulted, after some modifications, in the International Standard ISO 3267, effective in 1975. The latter standard is currently being modified. The Economic Commission for Europe (ECE) became involved in writing standards for headlamp cleaners as well. The result of their work is ECE Regulation No. 45, effective in 1981.

5.2 Effects of Dirt on Photometric Output

As noted in the Introductory section, various investigators have studied the effects of lens contaminants on headlamp output. However, these studies used relatively large samples and simple photometry. It was thought worthwhile to study a smaller sample, using detailed photometry based on the test points specified in FMVSS 108.

Three lamps were selected for the measurements. All were from vehicles owned and operated by UMTRI staff members. All were from two-lamp systems (i.e., large round or rectangular units). Two of them (identified as lamps 1 and 2 in the following

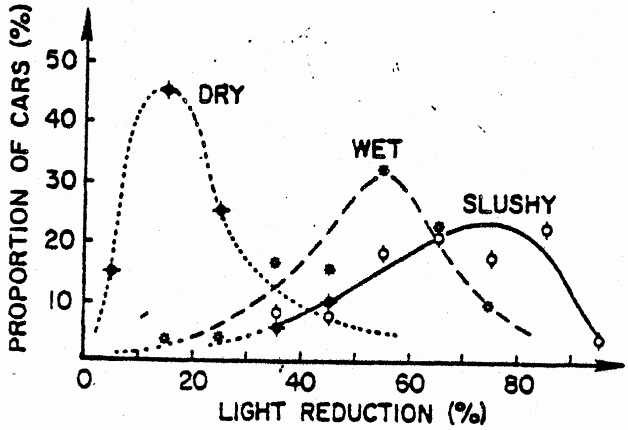

Figure 20. Proportion of cars at gas stations having various degrees of light reduction in the central part of the high beam caused by dirt under three road conditions.

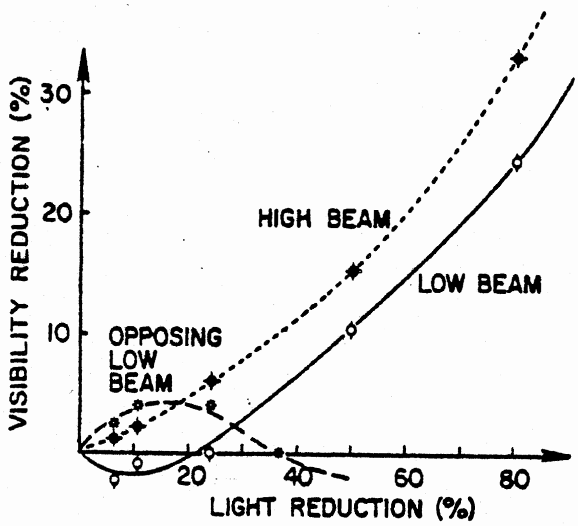

Figure 21. Visibility reduction caused by light attenuation due to dirt for three conditions obtained in controlled experiments.

tables) were judged "very dirty" by the experimenter. The third lamp was judged "moderately dirty."

After removal, the lamps were carefully packaged and sent to Guide Lamp Division of General Motors Corporation for photometry. At Guide the lamps were photometered as received, then cleaned and photometered again.

The results of the photometry are shown in Tables 27 and 28. Each table shows the points measured, the specifications for each point from FMVSS 108, and the results of the photometry. (Note that there are no specifications for the 1D, V and H, 2R points in the low-beam listing.)

Table 27 is for the low beams. At most test points, dirt resulted in an increased output in the glare zone (i.e., above horizontal), and reduced output below horizontal. For the two dirtier lamps (1 and 2) the reductions in illumination projected below horizontal were often 30 to 50%, and sometimes more. Both of these lamps were slightly under spec at the min-max point (0.50, 1.5R) when clean, but, when dirty, lamps 1 and 2 failed 6 and 3 test points respectively. Lamp 3 shows the same general pattern as the first two, but failed only one test point when dirty.

Table 28 lists the results obtained for the high beams on the same three lamps. The increased scattering effect of dirt seen with the low beams is nowhere in evidence here, dirt reduces output at all of the points measured.

The practical effects of dirt levels such as measured on the worst of the three lamps tested can be estimated from data supplied by Rumar (1970). These suggest that losses in nighttime visibility distance would average about 20%. This, coupled with the increased glare provided oncoming drivers, creates a situation of some concern. In the next section means for solving this problem will be discussed.

5.3 Cleaning methods

In recognition of the problem of maintaining reasonable light output under adverse driving conditions, headlamp cleaning systems have been developed. The first headlamp cleaners were used in Europe. Standards were promulgated for these devices as well. The first was the Swedish standard SMS 2983. This formed a basis for the international standard, ISO 3267, which is being revised at the present time. The Economic Commission for Europe has also prepared a standard for headlamp cleaners, ECE Regulations No. 45, dated July 1, 1981.

TABLE 27

RESULTS OF PHOTOMETRY (in candelas) ON THREE HEADLAMPS MEASURED BOTH DIRTY AND CLEAN. LOW BEAMS.

Points Measured	Specifications		Lamp 1		Lamp 2		Lamp 3	
	Max	Min	Dirty	Clean	Dirty	Clean	Dirty	Clean
10U,5L	125		201*	61	193*	97	135*	101
1.5U,1R	1400		1003	1050	799	582	689	617
1U,1.5L	700		641	438	657	434	537	450
0.5U,1.5L	1000		715	528	763	573	692	610
0.5U,1R	2700		1385	1825	1530	1815	1620	1625
0.5D,1.5L	2500		963	1019	1190	1250	1620	1555
0.5D,1.5R	20000	8000	3485*	7865*	4740*	7965*	8725	10110
1D,6L		750	612*	795	910	1105	1050	1090
1.5D,9L		750	546*	925	1115	1655	1015	1100
1.5D,2R		15000	6640*	18750	11750*	21850	16300	20600
1.5D,9R		750	1375	3020	1495	2085	2755	3505
2D,15L		700	391*	860	777	1280	840	955
2D,15R		700	1000	2385	1350	2225	1930	2320
4D,4R	12500		3285	8550	7195	12200	6140	8250
1D,V			2660	5645	3745	6120	7495	7910
H,2R			2095	3805	2790	4205	3815	4090

*Out of specifications

TABLE 28

RESULTS OF PHOTOMETRY (in candelas) ON THREE HEADLAMPS MEASURED BOTH DIRTY AND CLEAN. HIGH BEAMS.

Points Measured	Specifications		Lamp 1		Lamp 2		Lamp 3	
	Max	Min	Dirty	Clean	Dirty	Clean	Dirty	Clean
2U,V		1000	4070	7685	11500	21550	5835	6930
1U,3L		2000	3740	9050	6325	11150	9250	11000
1U,3R		2000	4905	12500	10900	19900	8700	11350
H,12L		750	1105	2400	2170	3550	1875	2255
H,9L		1500	1595	3690	2320	3765	2560	3100
H,6L		3250	2835*	7575	2505*	3845	3950	4685
H,3L		10000	5635*	17500	5945*	10500	11100	13650
H,V	75000	20000	10350*	31700	13650*	24900	15350*	20100
H,3R		10000	6605*	19300	10550	18450	12450	16450
H,6R		3250	3080*	7890	3365	5150	4825	6310
H,9R		1500	2050	4885	3020	4895	3020	3770
H,12R		750	1610	3860	2790	4755	2680	3345
1.5D,9L		1500	1610	3615	1600	2195	2015	2455
1.5D,V		5000	7095	20200	8850	14650	11100	14700
1.5D,9R		1500	2225	5535	2140	3160	2175	2740
2.5D,12L		750	1130	2250	1020	1285	995	1200
2.5D,V		2500	4225	9400	4225	6200	5720	7545
2.5D,12R		750	1480	2985	1305	1745	1015	1225
4D,V	5000		2150	3125	1610	1775	1945	2310

*Out of specifications.

The first headlamp cleaner was essentially a miniature version of the windshield cleaning system incorporated into most cars. That is, each lamp was equipped with a spray nozzle and wiper. These were activated at the same time as the windshield cleaning system.

The wiper system worked well on the large, relatively flat and smooth surfaces common on European lamps. Cars using U.S. headlamps presented more of a problem. These lamps came in two sizes, there could be either one or two to a side, they had a convex shape, and they were equipped with aiming studs that made operating a wiper blade difficult. More recently, rectangular headlamps have come into use in the U.S. These are relatively flat, but still have aiming studs. In addition, current Federal regulations prohibit a parked wiper blade from obstructing light from the lamp.

In addition to the difficulties enumerated above, the wiper-washer system is relatively complex and expensive. Because of this, there has been considerable interest in developing an alternative that would be simpler and perhaps work better on sealed-beam headlamps. The solution has been to clean with fluid alone. In these systems a nozzle directs a spray of cleaning solution over the surface of the lamp, loosening and washing away whatever deposits may be present. Such systems have been described by Hella (1979) and Valeo Lighting (1983). It is not clear whether or when these systems will move into production.

5.4 Conclusion

Dirt on headlamps results in significant alterations to the beam pattern, increasing glare and reducing seeing illumination. As a result, cleaning systems have been developed.

Headlamp cleaning systems of the wiper-washer type have been in use for a number of years, and seem to do the job very effectively. However, in the hope of reducing costs and providing something that would work more readily on U.S. headlamps, a high-pressure spray system has been developed by at least two manufacturers. This may prove to be the more effective approach, but it has yet to be adopted by any vehicle manufacturer.

6.0 HEADLAMP LEVELING

6.1 Introduction

In Section 3 of this report data are presented showing the effect of various levels of passenger, fuel, and baggage load on vehicle pitch angle. Headlamps are typically aimed based on a driver-only condition. This is reasonable, given that most driving is done with only a driver and perhaps a front seat passenger. As is made clear in Section 3, almost any additional loading on most vehicles causes them to pitch up. For example, going from a driver-only to a full-rated-load condition could raise the headlamp aim by as much as 1.5 degrees. The median change for the vehicles sampled was about one degree and the minimum was about 0.6 degree.

Causing the headlamps to be misaimed up as much as indicated for some of the heavily-loaded conditions in the loading study would greatly increase glare to oncoming drivers. Because of this there has long been concern about how this problem might be remedied. In this section of the report we will review work on means for compensating for vehicle loading effects.

Broadly speaking, there have been two general approaches to the problem. One of these is to level the whole vehicle, the other is to adjust the headlamps in some way to compensate for the change in pitch angle. These will be dealt with separately.

6.2 Car Leveling Systems

Systems that maintain the vehicle at a constant attitude regardless of load have been in use for years. However, maintaining proper vertical aim of the headlamps is a fringe benefit and not the principle reason for their use. The main reason for considering level control systems is to provide a better compromise between ride comfort and attitude control. Opting for ride comfort means that lower rate springs must be used, and this results in several problems at high load levels (Meller, 1978).

1. Large static wheel deflections
2. Large variation in vehicle natural frequency
3. Large variation in camber angle when considering independent suspensions.
4. Reduced roll stiffness
5. Greatly reduced ground clearance

There are a variety of means for achieving attitude control. These have been reviewed by Hegel (1973). Briefly, these are as follows:

1. Full air suspension. Full air suspensions were introduced on several vehicles in the 1958 model year. An air spring, occupying about the same space as the coil spring it replaced, was used at all four wheels. A system for sensing and correcting pitch changes was included, and air was supplied by an engine-driven compressor. According to Hegel, these systems were removed from the market due to cost and reliability problems.

2. Air-hydraulic suspension. Like the air suspension, air-hydraulic systems use a compressible gas for the spring element. However, a hydraulic fluid is also used, communicating with the compressible gas by means of a bladder or piston-type accumulator. Vehicle attitude is sensed and hydraulic fluid added or bled off as required. A hydraulic pump is required to power the system. This system is more compact and flexible than the air suspension, however, it is the most expensive of the levelling systems.

3. Hydraulic auxiliary systems. In this approach a device similar to a conventional shock absorber is employed. However, its working fluid can be pressurized by a pump-accumulator system. In this way the device provides lifting capability while still functioning as a shock absorber. Unlike the first two approaches, and like the others still to be described, this is an auxiliary system, so a failure will not prevent the vehicle from being operated. However, it does require a pump and accumulator for the hydraulic fluid. The working pressure is relatively high, so care must be used to guard against leaks.

4. Hydraulic auxiliary (self-pumper). The general principle of this system is the same as the one just discussed, except that the up and down motion of the suspension is utilized as a power source, eliminating the need for a separate pump. All of the other elements, i.e. accumulator, height sensing mechanism, etc. are required, however. The device is relatively complicated, and there is the disadvantage that the car must be driven some distance before it can correct for pitch error.

5. Air shock absorbers. These are shock absorbers that have been modified by adding an auxiliary air system. Increasing pressure in the air chamber will cause the shock to extend, adding to the lifting capability of the suspension.

Air shocks are relatively inexpensive and have proven a popular solution to the problem of attitude control.

All of the attitude control systems we have discussed are automatic. That is, the pitch angle is sensed and a power source utilized to restore the null condition with no intervention from the driver. However, air shocks can functional manually, and are apparently often used that way. In the simplest case the driver must observe the vehicle to determine whether the pitch angle is correct and either add or bleed off air to compensate if it is not. Air can be added with a manual pump, but it is much easier if done at a service station. Electric or vacuum driven pumps can be added to such systems, making it far easier for the driver to add air if required. Such an approach may work fairly well for occasional loads such as a trailer. It is probably not an effective way of compensating for day-to-day variations in vehicle loading.

6.3 Headlamp Leveling Systems

Systems for leveling the whole car in response to load changes are fairly complex and expensive. Because of this, there has been considerable interest in developing systems that adjust the aim of the headlamps alone. Over the years a number of such systems have been developed. Originally, all were mechanical, employing direct lever and/or cable links to adjust vertical aim. More recently the trend seems to be toward using air (or vacuum), hydraulic, or electric power to move the lamps.

Headlamp adjusting devices may be either manual, in which the driver is required to sense the aim error and make the appropriate adjustment, or automatic. In either case the source of power at the lamps can be the same.

Apparently, the earliest headlamp control system was manually-adjusted, and mechanical. A dash-mounted lever was used to set the lamps to one of three positions, normal, or two levels of aim down. Like other manual systems, it relied on the driver to determine when and what changes were required. Its main virtues were that it was simple and relatively inexpensive.

Mechanical systems evolved that were rather sophisticated. Figure 22 is a diagram of a fully automatic mechanical system developed by Lucas-Martin (Rayner, 1972). Deflection is measured at both ends of the vehicle and an "integrator" is used to combine these signals and adjust the lamps.

Three types of manual control systems are diagrammed in Figures 23 through 25 (Hella, 1983). The first of these (Figure 23) is hydraulic. Turning the knob clockwise in

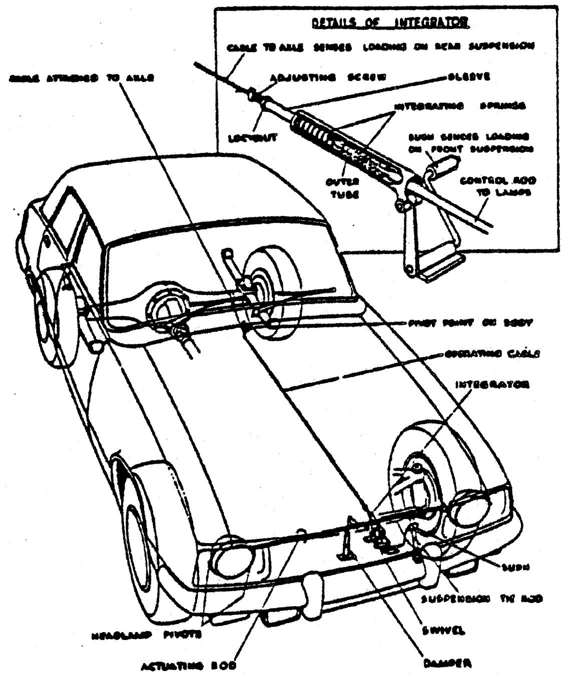

Figure 22. Diagram of mechanical leveler system that senses deflection at both axles.

the driver's compartment causes fluid to be displaced within the control cylinder, pushing out the pistons located at each headlamp, and raising the aim of the beam. Rotating the knob in the opposite direction reverses the process and the aim is depressed.

Figure 24 is a schematic of a pneumatic system. This one uses engine vacuum, variations using positive pressure are also possible. In this case vacuum is regulated by a lever-operated cam.

A stepped electrical system is shown in Figure 25. The knob in the driver's compartment would have three or four steps shown, coded in some way to represent the type of loading condition appropriate for each.

Fully automatic leveling systems are diagrammed in Figures 26 through 28. The first two sense deflections at both axles, the last one only at the rear. Figure 26 shows an electric system. Sensors feed deflection information into to an actual-value transmitter. After a delay, an electric motor is switched on, driving in one direction or the other, as appropriate, to adjust the lamps. The system diagrammed in Figure 27 is a hydraulic version.

Figure 28 shows a hydraulic system that senses deflection only at the rear axle.

6.4 Conclusion

It is not clear that misaim due to vehicle loading is a major source of aim variance in the population of vehicles on the road. However, there is no question that loading can alter vertical aim significantly. The usual load effects cause lamp aim to be raised. This may increase visibility distance for the driver of the affected vehicle, but it will also increase glare for other drivers.

There are a wide variety of solutions to this problem, and they have been available in some cases for a number of years. Vehicle leveling systems have been standard equipment in some (relatively expensive) vehicles for years. They may enjoy greater popularity in the future as vehicles become smaller. Manual aim compensating systems have also been used on some vehicles. Whether they or the automatic systems will enjoy greater use in the future is uncertain. Cost-benefits is one issue that has not been addressed in any of the literature we have reviewed. It would be difficult to establish that a favorable ratio existed for aim compensation systems.

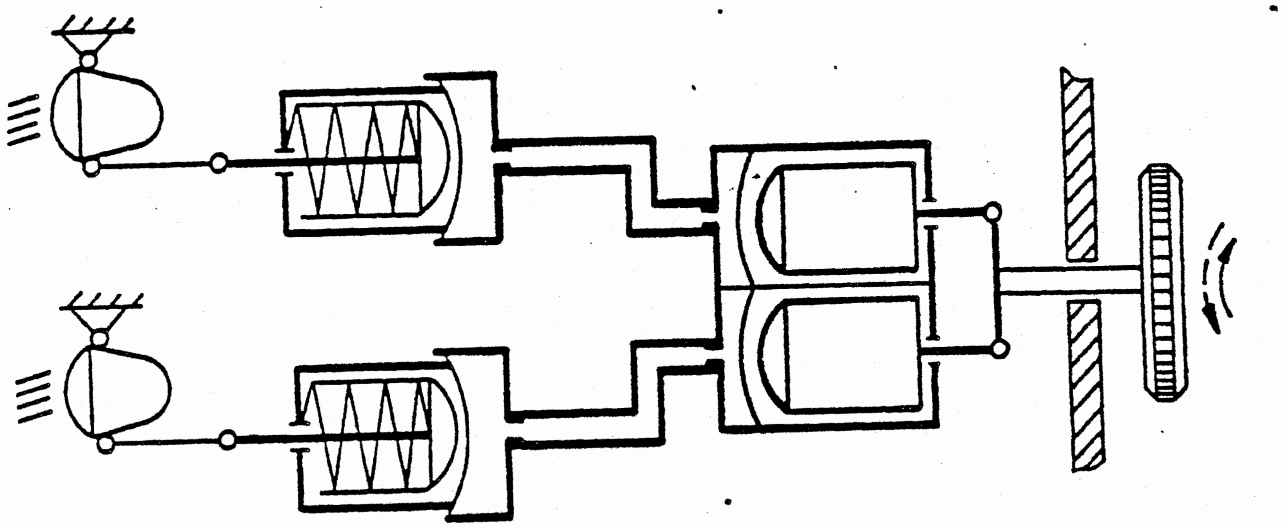

Figure 23. Schematic of manual hydraulic headlamp leveling system.

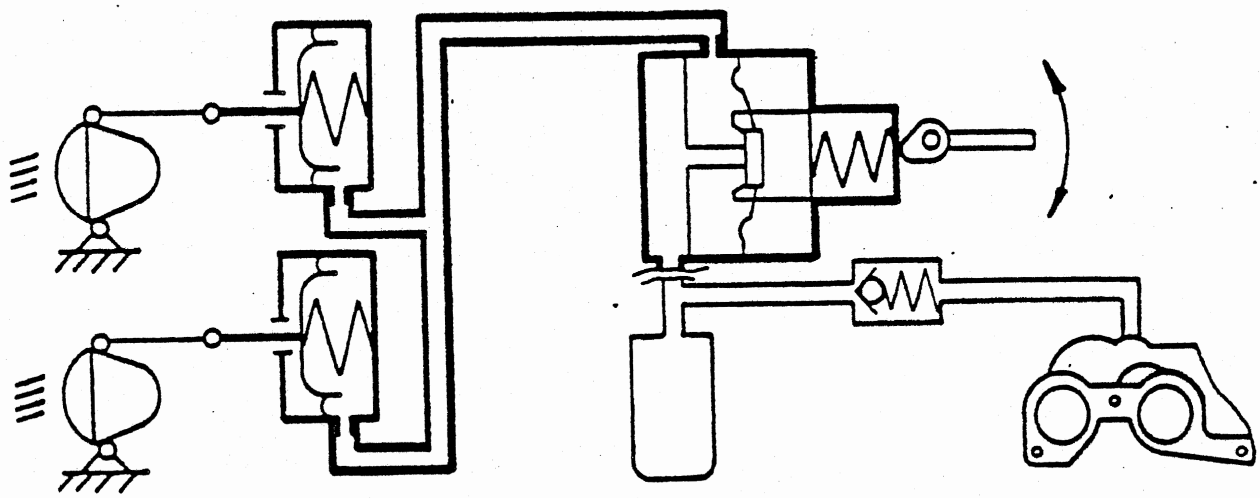

Figure 24. Schematic of manual pneumatic headlamp leveling system.

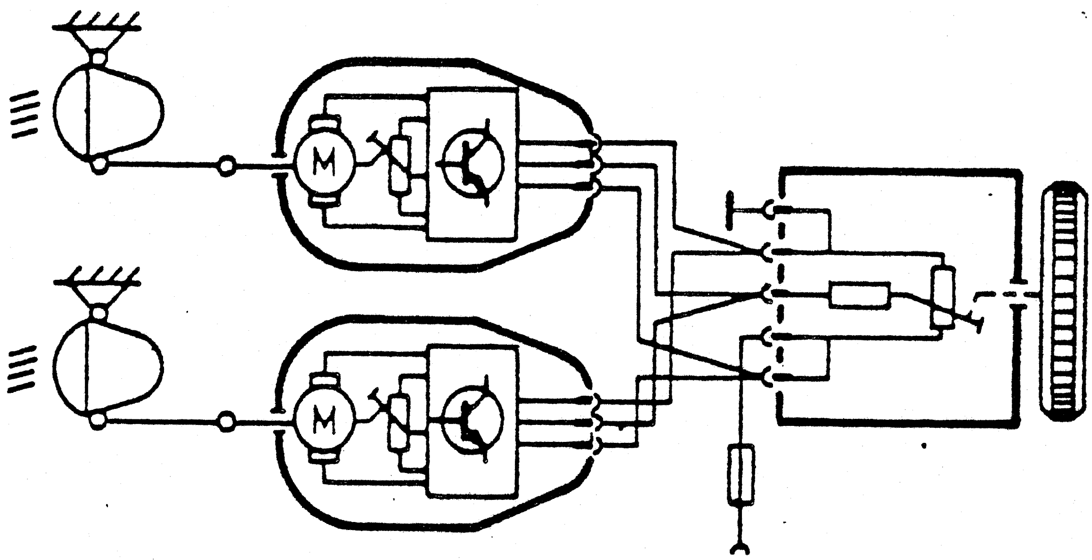

Figure 25. Schematic of manual electric headlamp leveling system.

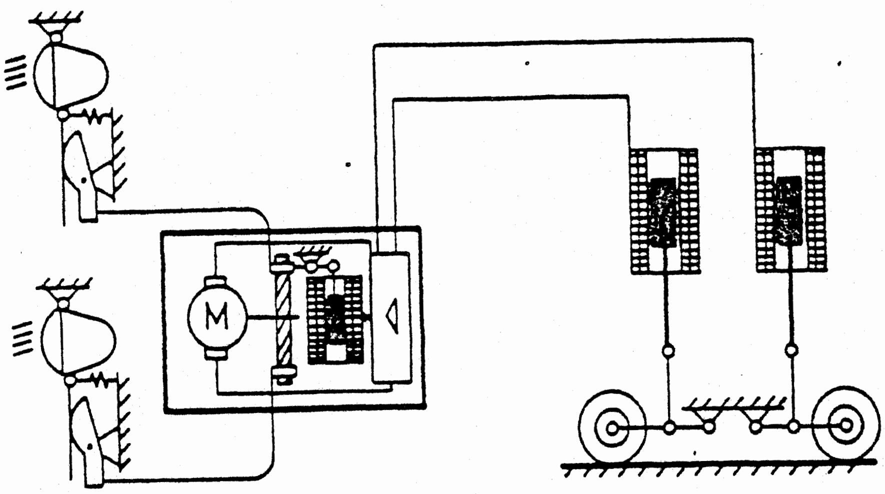

Figure 26. Schematic of automatic electric leveling system, with pitch being sensed at both axles.

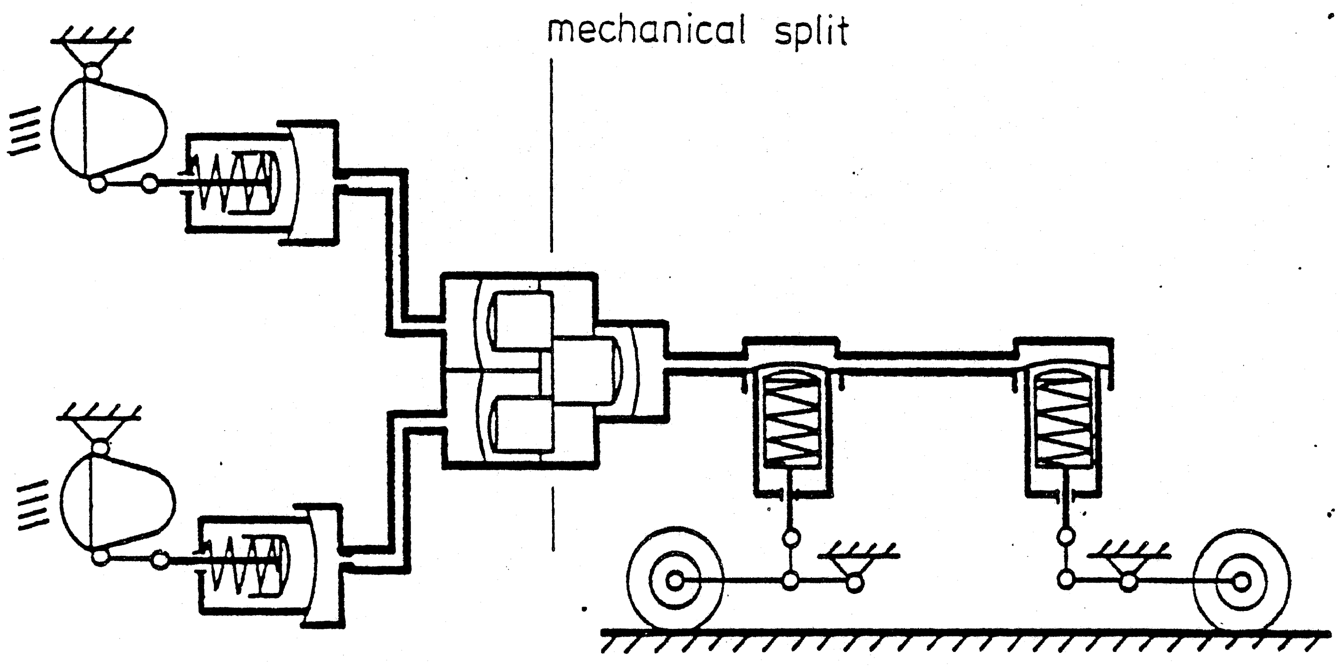

Figure 27. Schematic of automatic hydraulic leveling system, with pitch being sensed at both axles.

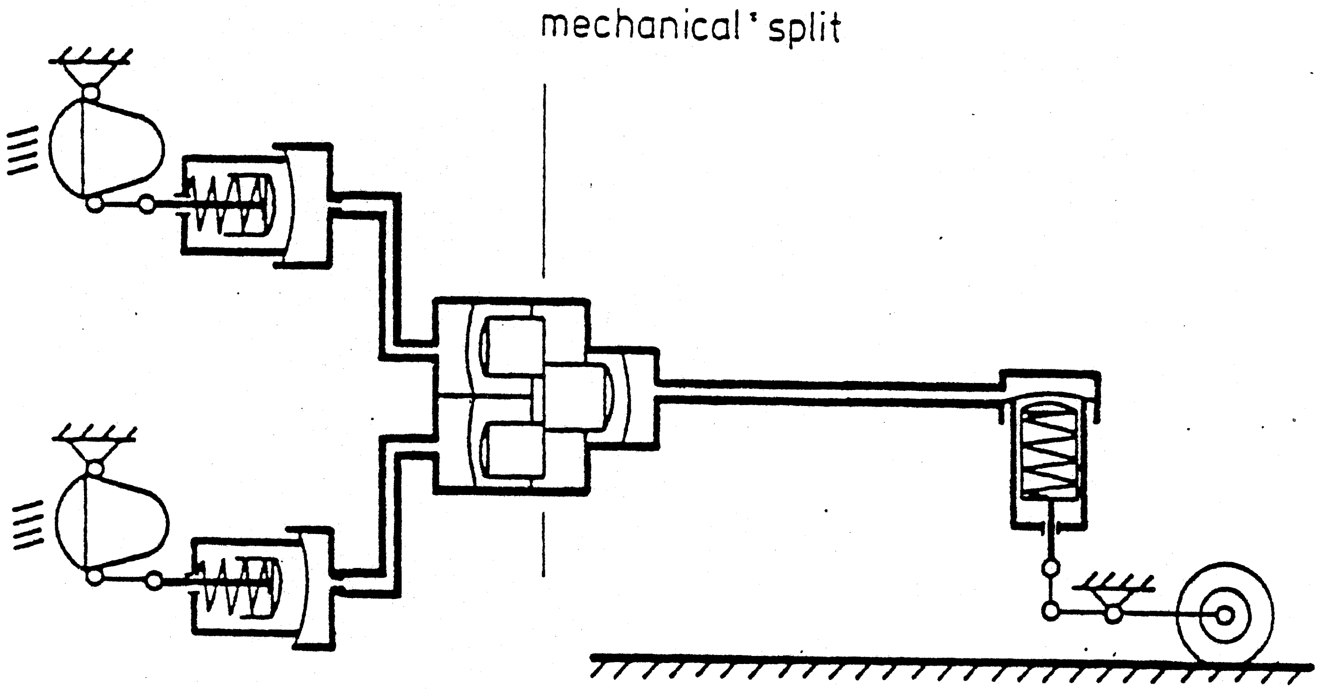

Figure 28. Schematic of automatic hydraulic leveling system, with pitch sensed at rear axle only.

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