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INVESTIGATION OF SOME FACTORS AFFECTING THE AIM OF HEADLAMPS

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16. Abstract

A review of factors that are likely to contribute to misaim of headlamps is followed by a series of studies to evaluate the role of some of the factors. These include headlamp aiming methods and devices; the quality of aiming by service stations, repair shops, and dealer service departments; the effect of vehicle service on aim; and the effect of vehicle loading.

It was concluded that improved training of service personnel in the use and maintenance of aimers is needed. Mechanical aimers offer greater reliability than other types. Ways need to be found to reduce the errors in locating the vehicle's long axis before other methods can be recommended. Since factory aim is generally better than in the service trade, it may be suggested that new car aim should be checked out but not disturbed unless a large error is found.

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FOREWORD AND ACKNOWLEDGEMENTS

This research program, concerned with determining some of the sources of misaim of headlamps in the motor vehicle population, is one in a series of HSRI studies concerned with headlighting performance, sponsored by the Motor Vehicle Manufacturers Association.

This report is issued under the general contract title: "Passenger Car and Truck Lighting Research: Headlighting Phase 2, Headlight Aim, Beam Selection and Beam Switching." A subsequent report will describe the studies conducted on the problems of multibeam switching. Additional reports in another contract in this series are concerned with development of a headlamp field test evaluation methodology, beam evaluations in terms of seeing distance, and development of a mathematical model to predict the seeing distance in opposed and unopposed traffic night driving conditions.

During the conduct of this work periodic meetings were held with the MVMA Lighting Committee, headlighting research task force, consisting of Mr. G. Gardner and Mr. R. Rossio, chairman; Mr. P. Lorenz; Mr. P. Maurer; and Mr. B. Preston. The formal and informal discussions with the members of the task force were helpful and they contributed to this study.

The cooperation of a number of automobile dealers in Ann Arbor, in the factory aim study, and of Whit's Truck Rental and Killins Cement Co., in the truck aim study, is greatly appreciated.

The following members of the Human Factors Department at HSRI participated in this study: Ms. Janice Smith, Mr. Samuel Sturgis, Mr. Corwin Moore and Mr. David Post.

ABSTRACT

A review of factors that are likely to contribute to misaim of headlamps is followed by a series of studies to evaluate the role of some of those factors.

Headlamp aiming methods are evaluated in terms of the variability in aim introduced by subtasks such as: the use of the sights used for finding the vehicle's long axis, finding the long axis of the vehicle, and aiming the lamps. Differences were found in the effectiveness of the sights, and finding the long axis was dependent on the availability of a prominent hood centerline on the vehicle. The photometric device provided lower variability in aiming a headlamp than a visual machine, with the latter less effective than the use of a large aiming screen. When the errors due to use of a sighting device and finding the vehicle's long axis are included, both the photometric and the visual machines introduce considerable errors, particularly in the horizontal. On the easiest to aim cars, with clearly defined centerlines, the photometric and visual machines, respectively, would allow about 95% and 50% of the aim of headlamps to fall in the SAE specifications.

The quality of headlamp aiming by service stations, repair shops and dealer service departments was found to be a contributor to poor aim, since only 38% of the outlets aimed all four lamps on a test car to within specifications. By comparison, a survey of the headlamp aim of new cars on dealers' lots, in as-received condition, showed that at worst 35% and at best 95% of the cars on any one lot were within specification.

The effect of vehicle service on aim was investigated by periodically checking the aim of a sample of vehicles. Most of the change in aim occurred in the first two months of the eight-month survey, and amounted to a standard deviation in aim of 0.3°

vertically and 0.2° horizontally for passenger cars. The changes in headlamp aim that occurred in a sample of trucks over a period of six months was larger than found for the automobiles.

Vehicle loading effects were found to be substantial, and usually raised the beam.

It was concluded that improved training of service personnel in the use and maintenance of aimers is needed. Mechanical aimers offer greater reliability than other types. Ways need to be found to reduce the errors in locating the vehicle's long axis, before other methods can be recommended. Since factory aim is generally better than in the service trade, it may be suggested that new car aim should be checked but not disturbed unless a large error is found.

Other factors, such as alignment problems caused by radial tires, interference of bezels, and reduction in the friction of headlamp aim adjusting mechanisms, are discussed.

INTRODUCTION: PROBLEMS IN AUTOMOBILE HEADLAMP AIM

The inability to correctly aim headlamps and maintain that aim is perhaps the major impediment to headlighting improvements for motor vehicles. Clearly, improvements in the beam intensity distribution will result in little benefit in visibility or adequately control glare to oncoming drivers, unless the light is projected in the intended direction when installed on operating motor vehicles.

That misaim of headlamps on vehicles is common has long been known. For example, the PMVI program in Virginia started in 1932. Over the years, the Virginia inspectors have rejected nearly 60% of vehicles for faulty aim, and another 14% for needed lamp repairs (Terry, 1973). While the percentages vary from one PMVI jurisdiction to another, the usual finding is that lamp misaim is the most common reason for rejection.

Heath (1973) has recently summarized the problems with lamp aiming in the early years. The introduction of mechanically aimable headlamps in 1955 was a major improvement since it made possible a quick, accurate and inexpensive aiming system. In spite of this, misaimed headlamps are still a significant problem. In recent years there have been some serious efforts to identify major sources of misaim variance and evaluate various aiming techniques (e.g., Jehu, 1954a; Finch et al., 1969; Hull et al., 1972; and Walker, 1972). It is apparent that there are many sources of lamp misaim, some of which still lie in the aiming equipment. The situation is such that motorists are often placed in the vexing position of having lamps rejected as misaimed by an inspection station, but considered within limits by the service facility to which they were taken for correction. This problem has been well summarized by Murphy (1973), who presents figures showing the probability of a lamp, set to specific degrees of misaim by a mechanical aimer, being accepted as within limits when inspected by other methods. In the worst case, his data indicate that a lamp which is misaimed by 2.5 inches horizontally at 25 feet would be rejected (i.e., judged to be misaimed by more than 4 inches) 25% of the time when checked by one optical device.

Murphy's data are based on close to ideal conditions. Add to them variance associated with load, miscalibrated equipment, careless operators, etc. and the situation should deteriorate even more.

The data reported in this paper are intended to supplement those already published by others. Some of the studies are replications of work reported by others, but with changes which it is hoped will add value to their interpretation. Some of the other studies have not been reported elsewhere, to our knowledge.

SPECIFICATIONS AND PROCEDURES FOR HEADLAMP AIMING

The information on specifications and procedures for headlamp aiming in the United States is contained in SAE Standards J599 and J602 and SAE Recommended Practice J600.

J599 (currently 599c, as revised in April, 1972) contains the basic information regarding method of aim (visual), positioning of high intensity zones, and inspection limits for standard high and low beams as well as symmetrical fog lamps. Included in the tabled summary are recommended limits and settings for mechanical aimers as well. Under Equipment the standard recommends that mechanically aimable lamps be aimed with mechanical aimers, and suggests visual aiming as an alternative.

The SAE Recommended practice J600 (currently 600a, last revised in November, 1963) is concerned with headlamp aiming machines other than mechanical devices. It defines a laboratory test procedure which measures the ability of such devices to aim various types of lamps within limits as stated in J600. Among the specifications given in J600 which are pertinent to the subject of this report are:

a) Alignment with the long axis of the vehicle within 0.1 degree (about 0.5 inch at 25 feet).

b) All normal driving lamps, which includes standard high and low beams and auxilliary driving and meeting lamps should be aimable so that they do not vary more than 1 inch at 25 feet vertically and 2 inches at 25 feet horizontally when aimed by experienced personnel.

J602 (currently 602a, last revised in July, 1970) is concerned with mechanical aiming devices. As does J600, it defines laboratory procedures for determining accuracy within limits as specified in the standard. The standard calls for vertical aim control within 0.5 inch at 25 feet and horizontal aim within 1.0 inch at 25 feet.

FACTORS AFFECTING HEADLAMP AIM

As already indicated, there are a number of sources of headlamp aim variance. These can be grouped as: factors associated with (1) the headlamp itself, (2) the vehicle, and (3) aiming techniques and devices.

Relative to the tolerances suggested in SAE J599c (±4 inches at 25 feet both vertically and horizontally) many of the factors are probably minor. However, as shall be shown later, some are quite significant. When all sources of variance are summed the total is considerable and it is easy to understand why headlamp misaim is such a common problem.

LAMP FACTORS

1. MISORIENTATION OF THE AIMING PLANE. The intention of the lamp manufacturer is to define the aiming plane so that a line from the lamp center and normal to the plane would pass through the HV point appropriate for that beam as defined in J599c.

Most if not all manufacturers and most service outlets utilize mechanical aimers. Such devices assume proper orientation of the aiming plane. There is some variability in the orientation of the aiming plane, although the amount is not known precisely. Finch et al. (1969), in a test using 79 representative headlamp units, reported that about two-thirds of his sample could meet photometric requirements if the aiming planes were reoriented. However, his data are not presented in a way that allows an estimate of the variance.

2. BEAM PATTERNS. As described in SAE J599c, visual aiming requires positioning of a high intensity zone relative to horizontal-vertical references. The most critical beam to aim is the low or meeting beam and the more nearly the actual projected beam approaches a sharply-defined, rectangular pattern, the easier it is to aim. In fact, the edges of the high intensity zone are normally rather fuzzy and often not flat. Variations in beam pattern certainly complicate the problem of aiming lamps visually, although the precise extent is unknown. As will be shown later, visual aiming is relatively less accurate than other methods. However, the studies reported here, as well as those reported elsewhere, confound beam pattern differences with other sources of variance.

3. DIFFERENCES BETWEEN BEAM AND MOUNTING PLANE. Many motorists and, as will be shown, many service people, apparently assume that a nonfunctional bulb can be replaced without reaiming.

In fact, it is highly unlikely that the new lamp will have exactly the same aim as the old one. For those lamps where the relationship between beam and aiming plane is determined by moving the filament, the variance will probably be less than for lamps where the same end is accomplished by grinding the aiming bosses. However, in either case a new lamp should be aimed after installation.

Some indication of the extent of misaim attributable to this source can be obtained from the data reported by Finch et al. (1969), who found that about half of their 140-lamp sample would have been outside the California Lamp Adjusting Station tolerances if they were used to replace a correctly aimed unit. (Pertinent tolerances, at 25 feet, were between 0.5" down to 3.5" down for both type 1 and 2 units, and between 1.0" left to 4.0" right for type 2 and 4.0" left to 4.0" right for type 1 units.)

Hull et al. (1972) have also investigated this problem. The lamps on 27 vehicles were set to 0-0 using mechanical aimers and then replaced with new bulbs. The aim of the new units were then checked. They report standard deviations of 2.4 and 1.9 inches at 25 feet for the horizontal and vertical dimensions, respectively, for the newly installed lamps. Twelve percent of their sample was outside the limits of 4 inches at 25 feet.

4. CHANGE AS A FUNCTION OF USE. It would be expected that as lamps are burned and exposed to vibration in use, the aim and/or beam pattern may change due to changes in the relationship between the filament and reflector, filament deposits on reflector and lens, and aging of the filament. Finch et al. (1969) report very substantial changes in photometric performance for a sample of lamps after 90 days of service. However, many of these test cars were in service with the California Highway Patrol and, as such, were likely exposed to hard service. His

data may represent an overestimate of what would be encountered in a sample of vehicles opposed to normal service.

Hull et al. (1972) also report data related to this problem. Their sample of six lamps were photometered and were each used for 20 to 65 hours in normal service. Photometric checks afterward revealed shifts in the point of maximum intensity averaging less than 0.5 degree. The maximum change was one degree. The authors concluded that there was no significant change in aim as a function of service.

What constitutes a significant change in aim is, of course, debatable. In our judgment, the fact that approximately half the sample of lamps showed an aim change in service of 0.5 degree (about 2.6 inches at 25 feet) or more would make it one of the more important sources of aim variance.

It should be noted too that changes in aim of this type cannot be corrected by use of mechanical aimers. Thus, the data suggest that mechanical aimers are of less value in checking or aiming older lamps.

CAR FACTORS

1. LAMP MOUNTING MECHANISM. All American-built cars mount headlamps in the same basic way. The bulb is clamped into a bowl-shaped stamping by means of a retaining ring. This stamping contains notches to assure that the appropriate bulb is installed in the correct orientation. The whole assembly of retaining ring, bulb and stamping is secured to another stamping by means of two screws and a spring in tension. There are three points of contact between the two stampings, and the lamp assembly can be rotated right-left and up-down by means of the two screws. For purposes of this discussion the mechanism serves two important functions, lamp aim and aim maintenance.

When in good condition the mechanism is a crude, though effective means of adjustment. As the vehicle ages, dirt and rust accumulate on the bearing points, with a consequent increase in friction. It is easily possible for a careless or untrained service person to make a lamp adjustment so that only friction between the stampings is opposing the tension spring. Under such conditions vibrations of normal service will quickly cause the lamp to go out of adjustment.

The ability of the system to maintain an aim setting depends on its structural integrity. Some authors (e.g., Finch et al., 1969) have complained that the mechanism is insufficiently sturdy for its purpose. A fuller examination of this problem will be reported later in this paper.

2. DOG TRACKING. The tracking axis of a vehicle is normally perpendicular to the rear axle. When the rear axle is not perpendicular to the long axis of the car the tracking axis and long axis will not be the same. In extreme cases this condition, called "dog tracking," can be readily noted while following an affected vehicle, although dog tracking to such an extent would normally result from collision damage. Virtually all aiming techniques assume that the tracking axis and the long axis are parallel. To the extent that the vehicle dog tracks the lamps will be misaimed laterally.

An indication of the variance attributable to dog tracking in normal production vehicles is given in a study reported by Walker (1972). Measurements of dog tracking were taken on twenty-five, 1970 model vehicles. The results were reported in terms of lamp misaim in inches at 25 feet. Of this sample, 44% dog tracked to an extent that produced a misaim of less than one inch. Eighty percent tracked to produce a misaim of less than two inches. The worst misaim in this sample was about four inches.

Thus, it would appear that dog tracking is a significant problem in lamp aim, with perhaps 20% of new cars affected to an extent which produces a misaim of two or more inches. If the sample had been drawn from older vehicles the problem might have been shown to be substantially more serious.

Unfortunately, correcting for dog tracking is not simple. The most expedient procedure requires a dynamometer, a most unlikely piece of equipment for a service outlet to have. Very simple, inexpensive compensation techniques must be developed before most service outlets can be expected to acquire them. In the meantime, at least some manufacturers are employing aiming procedures which compensate for dog tracking. At present a new car which dog tracked significantly but had correctly set headlights would be misaimed at almost any service outlet and could well fail at an inspection station.

3. MATCHBOXING. By design, paired headlamps are intended to be positioned in a line perpendicular to the long axis of the vehicle. The condition when they are not is called "matchboxing." Mechanical aimers make a lateral setting with reference to a line parallel to the headlamp aiming plane and are affected by matchboxing.

The extent to which matchboxing contributes to headlamp misaim has not been identified precisely. Walker (1972) reports a study of matchboxing and dog tracking on 50 cars, but the data are not separated. However, the investigation of dog tracking effects mentioned above, also reported by Walker, does make possible a very rough approximation of the magnitude of matchboxing. Walker reports a standard deviation of 1.23 for the two sources combined and 0.98 (the 0.62 reported in the paper is apparently in error) for dog tracking alone. Assuming the two test vehicle populations to be comparable, a standard deviation of about 0.74 inches at 25 feet is indicated for matchboxing.

By this approximation, matchboxing would appear to affect perhaps one car in a hundred more than ±2 inches. Thus, as best as can be ascertained, matchboxing appears to be a problem of somewhat less consequence than dog tracking. However, it is a significant additional source of error for those aiming techniques affected by it.

4. STATIC LOADING. As the headlamps are attached to the sprung mass of the vehicle, any change in the vehicle attitude around the pitch axis, however arrived at, will change the vertical aim of the headlamps. While matters such as broken springs and badly underinflated tires can affect aim in the same way, the most common problem is load.

Typically, a full-size American-built sedan is rated at 1100 pounds load (900 pounds in passengers and 200 pounds baggage).

Probably most miles are driven with one or two passengers in front and little or no baggage; however, a variety of other combinations are encountered, including substantial overloads.

In the usual instance the lamps are set for a "normal" load condition and other conditions result in reduced lamp effectiveness and/or increased annoyance to other drivers.

There are a number of ways, varying in complexity, in which this problem can be solved.

A. Manual Adjustment by the Driver. Using a calibrated screw, lever or some other device, it could be possible for the driver to adjust his lamps manually to compensate for load conditions. However, systems which require drivers to: (1) understand the need and, (2) be willing to learn how and when to do something are fated to low levels of proper use. It can be argued that, so long as it is not possible to abuse the system (i.e., aim the lights too high), such a device will help those who choose to use it properly and hurt no one.

Simple, two-level manual compensators are used on some European cars. Their general use may aid the problem of vertical misaim due to load.

B. Automatic Lamp Adjustment. Devices which automatically reaim the headlights to compensate for vehicle loading overcome the primary objection to manual systems (low use levels or misuse). They do so at appreciably higher cost, however. Automatic lamp aiming systems are available at present (Hull et al., 1972) and seem to work adequately well. Whether their universal use can be justified on a cost-benefit basis remains to be established.

C. Automatic Vehicle Trim Adjustment. Some vehicles are equipped with systems which maintain a level trim regardless of load. Many vehicles can be so equipped at the owner's option. Manual trim adjustment options are also available, accomplished by adding air to the rear shock absorbers. Solving the lamp misaim problem being here discussed is one of the benefits provided by such systems.

Most cars on the road today are without vertical aim compensation of any kind and load variations are potentially a very significant source of lamp misaim. Some documentation of the extent of the problem has been produced by Hignett (1970) for British cars and by Hull et al. (1972) for a sample of domestic and foreign vehicles in the United States. A later section of this paper will describe another survey conducted on some vehicles in this country.

5. DYNAMIC LOADING. Changes in pitch angle associated with dynamic forces acting on the vehicle can be considerable. Short-term changes resulting from road geometry, etc. are of little consequence. However, Hull et al. (1972) found upward shifts of 0.5 degree or more lasting 12 seconds during hard acceleration of

their test vehicle. Such an aim change would increase the discomfort experienced by oncoming and preceding drivers.

6. TIRES. Walker (1973) has reported measures of side forces produced by some tires. Many tires produce lateral forces in straight ahead driving, causing the vehicle to dog track to some extent. The effect is generally negligible. Recent measures have shown that some tires produce lateral forces of up to 75 pounds, which could bring about a lateral misaim of about an inch at 25 feet in a full-size sedan.

AIMING FACTORS

Aim variance associated with the aiming process itself arises from two sources: (1) the device and/or procedure employed and (2) the person doing the aiming. Under (1) are specific problems such as devices which are difficult to use or call for much subjective judgment, devices which are out of calibration, instructions which are inadequate, ambiguous, or difficult to understand and facilities which are not appropriate to the device in use. Under (2) are problems such as inadequate training, poor motivation and supervision, and lack of feedback.

1. ERRORS ASSOCIATED WITH AIMING DEVICES OR PROCEDURES. Three devices were evaluated in the program conducted by HSRI. They represented the three possible aiming methods (visual, mechanical and photometric) and, in addition, account for the great bulk of aimers sold in this country.

In general, the three devices were judged to have no serious design defects that would make intended use unduly difficult. In addition, all were accompanied by instructions which were comprehensive and reasonably understandable.

The visual and photometric devices were far more expensive than the mechanical aimers, representing from five to ten times the capital investment. They were also much heavier and bulkier, complicating the storage problem. Such machines are best used in an application where they need not be moved more than a few feet between runs, as in a regular vehicle inspection lane.

More detailed information regarding the devices and their use will be given in a later section.

2. ERRORS DUE TO THE SERVICE PERSON. The extent of the error in headlamp aim specifically attributable to the service person's lack of skill, carelessness, lack of training, etc. is difficult to identify. But, the service trade survey conducted by HSRI and reported in this paper shows that the quality of headlamp aim service is poor, and that a considerable proportion of the error can be traced to the operator, since the mechanical aiming equipment that was generally used is very accurate when it is used properly.

A major indirect contributor to poor service trade aiming may be lack of feedback. Unless his lamps are misaimed so as to cause glare to oncoming drivers, the driver can only judge aim by the appearance of the beam on the road. Since most drivers have not been specifically shown a properly aimed beam pattern, and since such factors as ambient lighting and dirt on the lenses blur the pattern even if the driver knows what it is supposed to look like, customers' complaints of poor aiming are probably rare. This suggests that service trade aiming should be better in states having PMVI since a misaimed lamp should result in rejection and a complaint from the customer. However, there are no data concerning quality of service in states with and without PMVI.

RELIABILITY AND VALIDITY OF AIMING DEVICES

INTRODUCTION

There are three means of aiming headlamps, visual, photometric and mechanical, and all devices described as "headlamp aimers" fit into one of these three categories.

Headlamp aim criteria are visual (SAE J599c), that is, instructions refer to the positioning of a high intensity zone. Hence, all devices, whatever the principle of operation, must aim the beams so that they meet visual criteria.

The simplest but most subjective procedure is to follow SAE specifications and aim the headlights on a screen 25 feet in front of the vehicle. Since few service outlets would have this kind of space available for aiming headlamps the visual device evaluated in this study (see Figure 1) allows the same procedure to be accomplished in a far more restricted space. Basically, the device uses a condensing lens to focus a reduced image of the beam on a miniature screen. The screen is suitably marked to indicate where the image should be positioned (Figure 2). Prior to use, the slope of the floor must be determined and the optical axis of the device aligned with the long axis of the car. The unit is located in front of each lamp with the aid of a probe, which can be raised out of the way afterwards. For high beam an alternative photometric method is provided. To use this the operator moves a mask into position until a white dot is centered on the HV point. The lamp is then adjusted until a maximum reading is obtained on the candlepower meter provided.

Photometric aim devices seek to eliminate the subjectivity involved in lamp aim by replacing human perceptual judgments with a photocell or array of photocells. The Ford Mark III (Walker, 1972) is an example of a photoelectric aimer which is apparently very accurate. However, in its present form, it is not suited for use in a service facility.

The photometric machine tested (Figure 3) is designed for use in a service facility, and bears some resemblance to the

Figure 1. Visual aimer in use.

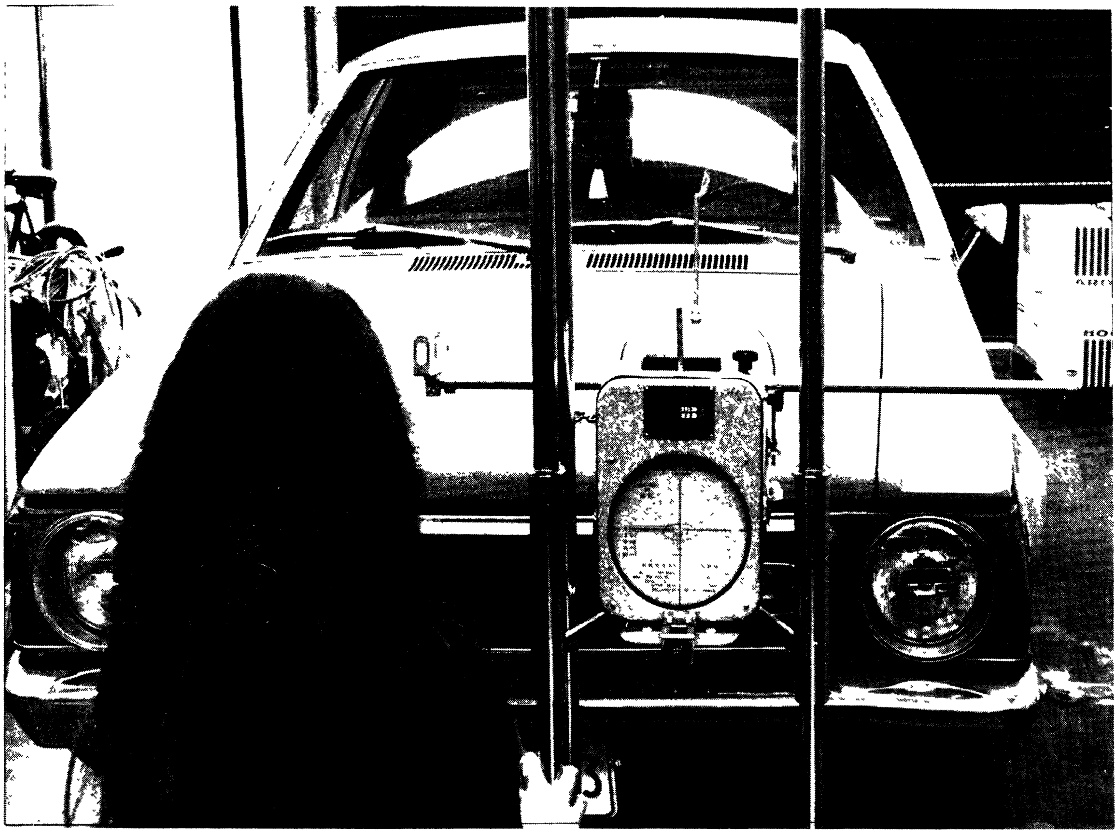


Figure 2. Screen markings on visual aimer.

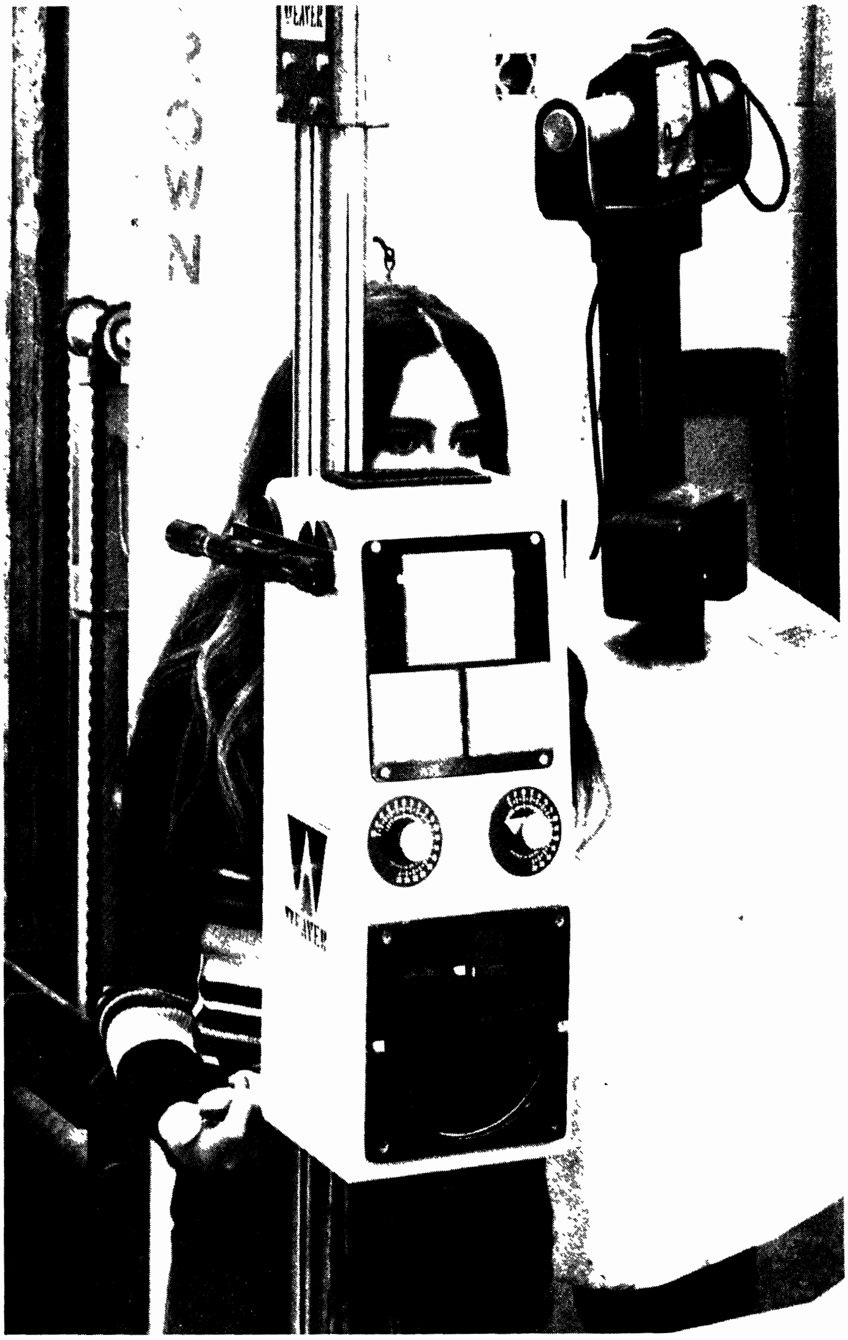


Figure 3. Photometric aimer in use.

visual machine. The light is focused on a photocell and the operator adjusts the lamp using two meters, one for horizontal and the other for vertical aim. Like the visual machine, the operator must determine the slope of the floor and align the device with the long axis of the car. The device is positioned in front of a lamp by moving it sideways and up and down until a maximum candlepower reading is obtained.

Mechanical aimers eliminate the two major subjective aspects of headlamp aiming: locating the vehicle centerline and positioning the beam. The units that were tested are first attached to the lamps by suction cups acting on the lenses, and the adjusting screws turned to center the bubble in a spirit level and align a split image for measuring the vertical and horizontal aim, respectively. As with the other two devices, the slope of the floor must be known but it is not necessary to make an alignment with the long axis of the vehicle.

Hull et al. (1972) have assessed the reliability of mechanical aimers. They report standard deviations (in inches at 25 feet) of 0.31 and 0.43 for horizontal and vertical aim, respectively. These values imply that more than 95% of aims would be within ±1 inch at 25 feet both horizontally and vertically.

The visual, photometric and mechanical aimers do not compensate for dog tracking. In addition, the mechanical aimers are affected by matchboxing and misorientation of the aiming plane.

All three devices can be used for inspection or adjustment; that is, they can either show the extent of misaim or be used to aim headlamps.

The studies to be described are designed to examine specific sources of variance associated with the use of, primarily, the visual and photometric aimers, in order to identify specific problem areas.

I. SIGHTING DEVICES

BACKGROUND. The visual and photometric aimers tested are equipped with sights which are intended to be used in aligning the unit with the long axis of the vehicle (Figure 4). In the case of the visual machine the sight consists of two wires, about six inches apart. In the case of the photometric machine, the sight consists of a yoke and blade device, the components being about 5 1/4" apart. Inspection of the unit led to a question as to the accuracy with which the sights could be used. Accordingly, the first study estimated variance associated with the use of the sighting device alone.

METHOD. Ten subjects participated in this study. They were instructed to align the sights as carefully as possible with a prominent vertical black line on a wall 25 feet away (Figure 5). The machines were set on blocks to prevent shifting. To reduce irrelevant cues, reference scales on the visual device were removed and a three-bladed adjusting knob on the photometric device was replaced with a circular knob. Measurements of the alignment were made by the experimenter after each sighting with a telescopic rifle sight, to the nearest one-eighth inch.

Each subject made ten sightings with each machine. After each sighting the actual aim was read and the machine misaligned. Conventional statistical balancing techniques were employed to cancel learning effects.

RESULTS. For each subject and sighting device the standard deviation of the alignments was computed. Mean standard deviations were obtained of 0.2 and 0.5 inch at 25 feet for the sights of the photometric and visual machines respectively. The difference in the mean variability of alignments between the two units was statistically significant ($p \leq 0.01$).

Figure 4. Sighting to align the visual and photometric aimers.

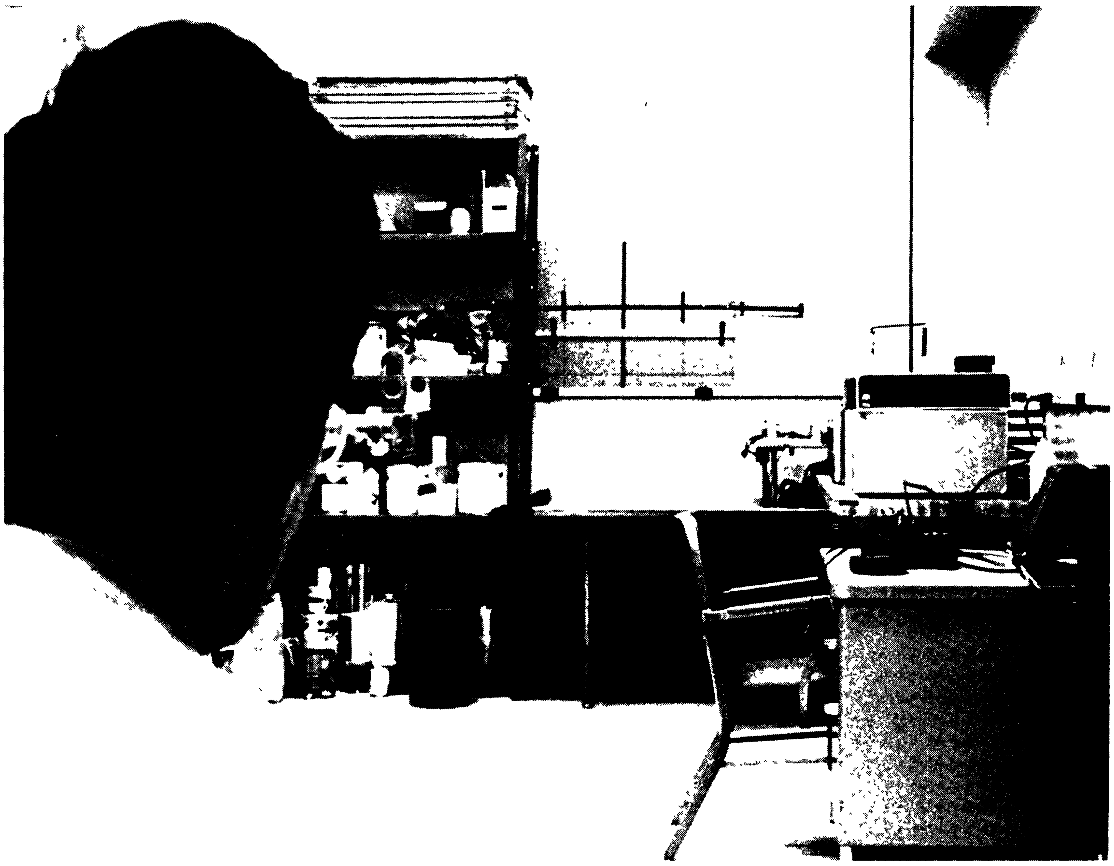


Figure 5. Subject sighting on target in sight accuracy test.

DISCUSSION. It is apparent that the variance associated with the sights, especially the one on the visual machine, is sufficiently great so as to make the 0.1 degree (0.5 inch at 25 feet) tolerance specified in SAE J600a not achievable 100% of the time under ideal circumstances.

Since the longitudinal axes of motor vehicles are not specified with near the clarity of the target in this case, the variance in actual practice can be expected to be far greater. This problem is explored in detail in the next section.

II. LOCATING VEHICLE LONG AXIS

BACKGROUND. Once the subject vehicle is in place the first task with either the visual or photometric aimers under evaluation is to align the optical axis of the aimer with the long axis of the vehicle. The instructions for both machines make reference to this problem and recommend use of hood centerlines, hood ornaments, rearview mirrors, centers of windows, etc.

Walker's (1972) data suggest that a substantial percentage of alignments with either device would be outside the tolerances given in SAE J600a. Walker reports standard deviations (in inches at 25 feet) of 1.25 and 1.94 for the photometric and visual aimers respectively. These tests involved single measures by a single individual on a number of cars. The cars were run on dynamometer rollers and deviations were measured from the tracking axis rather than the longitudinal axis. Thus, the results are confounded with dog tracking. Dog tracking as a source of error in lamp aim has already been discussed, and a standard deviation of about 1.0 inch in 25 feet was indicated for new cars.

METHOD. Because the alignment of these aimers with the vehicle appears to be a potentially large source of error, a study was designed to supplement the data reported by Walker.

In this study five vehicles were employed, each selected to provide different visual references, typical of those found in the automobile population. The cars were:

1. 1969 VW "Beetle"
2. 1971 Gremlin
3. 1972 Ford, 4-door sedan
4. 1971 Plymouth station wagon
5. 1970 VW van

The first task was to find the long axis for each car to be used in the test. The cars were set on a level floor and a plumb bob dropped to the floor from each end of both axles. These points were marked and a chalk line used to extend the line thus defined past the front and rear bumpers. The mid-point between the lines was determined by measurement at each bumper and a mark was made on the bumper surface.

The facility where the test was conducted was set up as in Figure 6. The tracks on which the aimers moved laterally were attached to the floor parallel to the door at the far end. The rearmost track was 25 feet from the door. A tape measure, reading distance in inches from the right wall was attached to the door.

When a car was brought into the room the reference marks on the bumper were used to define a line which was extrapolated to the door at one end of the room and the rear track at the other. Dimensions A and B were measured and remained constant during each test. After each aim setting a rifle scope attached to the aimer was used to read dimension C on the door, while dimension D, the lateral position of the aimer on the track, was determined directly with a tape measure. If the alignment of the aimer is exactly parallel to the long axis of the car, then:

$$(A-C) = (B-D)$$

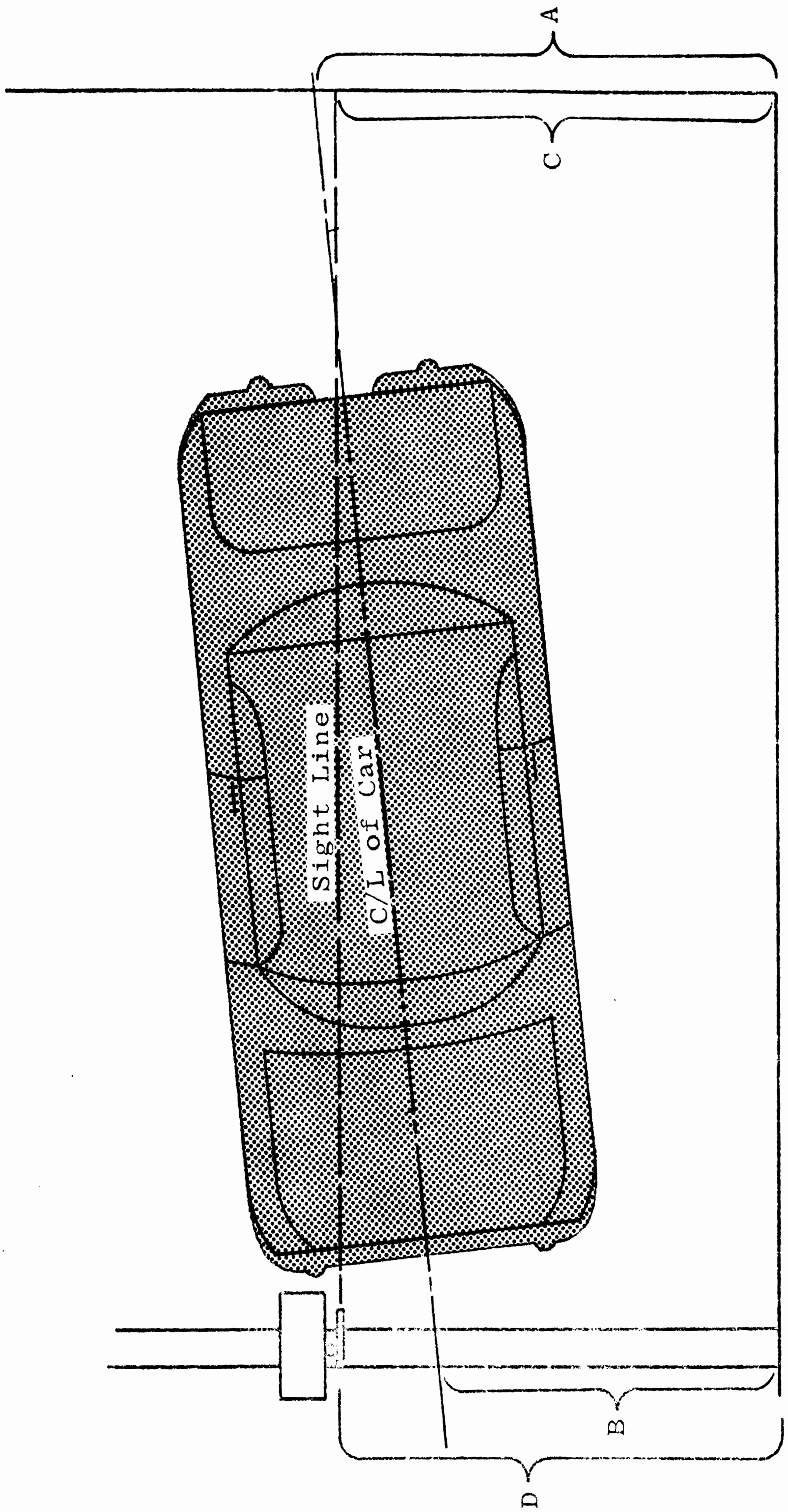


Figure 6. Geometry employed in study to determine the accuracy with which the long axis of vehicle can be located with the sights provided on the visual and photometric aiming devices.

Therefore, the extent of misalignment, in inches at 25 feet, was obtained directly by measuring all quantities in inches and taking the difference:

(A-C) - (B-D) = Error in Alignment

A total of ten subjects made five alignments with each aimer on each car. When a subject started the study the purpose was explained to him and the use of the aimer demonstrated. The various strategies he might use in finding the long axis were outlined and he was invited to proceed. The order in which cars were presented was varied to balance learning effects.

RESULTS. The standard deviations associated with the two aimers for each of the five vehicles are given in Table 1. Also

TABLE 1. Standard Deviations of Misalignment of Headlamp Aiming Devices With the Long Axis of Representative Cars.

Cars	Aimer	Standard Deviation (Inches at 25 Feet)	Two Standard Deviations (Inches at 25 Feet)
Ford Sedan	Photometric	1.65	3.30
	Visual	2.34	4.68
VW Beetle	Photometric	1.89	3.78
	Visual	3.28	6.56
Plymouth Sedan	Photometric	2.24	4.48
	Visual	5.27	10.54
AM Gremlin	Photometric	2.69	5.38
	Visual	3.73	7.46
VW Van	Photometric	8.39	16.78
	Visual	8.58	17.16

shown are the two standard deviation values, which are interpreted as the limits within which 95% of the cases will be found.

DISCUSSION. Three points are worth noting as regards the results of this study:

First, it is apparent that the alignment can be made more readily on some cars than on others. Those cars associated with the lowest variance had prominent hood centerlines and all subjects used these. By contrast, the van was a puzzle to most subjects and a variety of strategies were employed.

Second, the visual unit was harder for the subject to use than the photometric unit, as measured by the higher variances associated with it. [Walker (1972) reports a similar trend.] These differences are significant ($p \leq 0.01$) level, and are greater than can be accounted for by the differences in sight performance described in the preceding study. The authors can offer no explanation for this disparity at this time.

Third, and most important, the variance associated with aligning an aiming unit with the long axis of a car is such that relatively few such alignments would fall within the 0.1 degree suggested in SAE J600a, even on the easiest car measured. Especially on the more difficult car measured, a substantial percent of these lateral alignments would be expected to fall outside the ±4 inches at 25 feet tolerance specified in SAE J599c.

The actual lamp aim variance produced by these machines is the sum of the variance due to the sight, alignment with the vehicle, and aiming of the lamp itself. The latter factor will now be considered.

III. ACCURACY OF HEADLAMP AIM USING VARIOUS TECHNIQUES

BACKGROUND. The ultimate test of any headlamp aiming device is how well it can position the beam of a headlamp. The fact that there are other sources of aim variance associated with the device is not as important, since it may be possible to improve these problems. However, if the aiming technique itself is poor, then the device is of little or no value. This study was designed to estimate the variance associated with repeated headlamp aims made by a number of relatively inexperienced subjects.

Assessments of the accuracy of aiming techniques have been reported by at least two investigators.

Walker (1972) evaluated the accuracy of visual aim using a screen at 25 feet, and a visual aimer apparently identical to that used in this study. He also evaluated a photometric aimer different from that employed in this study. A number of different types of makes of bulbs were used in each study. Seven experienced subjects participated in the evaluation of a screen at 25 feet, while the number of subjects is not specified for the other studies. Walker's results are reproduced in column 1 of Table 2.

Hull et al. (1972) have also reported the results of evaluations, in this case including: visual, screen at 25 feet; visual machine; photometric machine and a mechanical aimer. All devices were apparently the same as were used in this study. The lamps were mounted on a car and five observers were used. The effects of alignment of the aimers (excluding the mechanical device) with the car are included in the standard deviations reproduced in column 2 of Table 2. Because the data were not separated by type of bulb, they are all shown under the 5 3/4" single filament condition.

METHOD. Three representative headlamps were used, a 5 3/4" Type I and Type II and a 7" Type II. These were mounted in a solid fixture which permitted them to be rotated vertically and

TABLE 2. Standard Deviations of Aim Achieved Using Three Aiming Techniques on Three Types of Headlamps. Data are inches at 25 feet.

Bulb and Method		Previous Studies		Present Study		
		1 Walker Aim Only[1]	2 Hull et al. Aim + Alignment	3 Aim Only[1]	4 Aim + Alignment	5 2 SD Limits
5 3/4" Type I						
Screen at 25 feet	H	1.14	1.34	1.23		
	V	0.60	0.88	0.59		
Photometric	H	1.50	0.89	0.36	1.68	3.36
	V	0.80	0.49	0.36		
Visual	H	1.90	1.36	2.24	3.24	6.48
	V	1.10	1.03	1.24		
Visual w/ photometric ops.	H		1.04	0.91	2.52	5.04
	V		0.89	0.46		
5 3/4" Type II (Low Beam)						
Photometric	H	2.70		0.52	1.73	3.46
	V	1.30		0.29		
Visual	H	2.60		1.87	3.00	6.00
	V	1.70		1.36		
7" Type II (Low Beam)						
Screen at 25 feet	H	1.65		1.17		
	V	1.10	0.81			
Photometric	H			0.43	1.70	3.40
	V			0.17		
Visual	H			2.54	3.46	6.92
	V			1.15		

[1] Excludes error due to alignment of aimer to the lamp.

horizontally (see Figure 7). Visual aiming, using an aiming screen at 25 feet was compared with the two aiming devices.

The headlamp fixture was anchored to a heavy table and care taken to be sure the center of the lamp corresponded to the H-V point on the aiming board. The tracks for the machines were attached to the floor parallel to the board and a distance from the fixture adequate to allow proper operation (Figure 8). Each device was then set up and properly adjusted horizontally and vertically. These controls were then taped over to prevent further adjustment. A number of checks were run to be sure the devices were aligned properly before starting the study. Each lamp was installed in the fixture and checked with a spot aimer to be sure it was seated properly. A tape measure was attached to the aiming board and readings of horizontal and vertical alignment were taken with a rifle scope attached to the aiming fixture. Nine subjects participated in the study, each taking five aims with each technique with each lamp. In addition, five aims were taken with the 5 3/4" Type I lamp using the visual aimer photometrically.

RESULTS. The results of the study are summarized in column 3 of Table 2. There are large and statistically significant differences ($p \leq .01$) between techniques, with the variability in lamp aim being least for the photometric device and greater for the visual device. Stability in horizontal aim was more difficult to achieve than vertical aim on all lamps. The 5 3/4" Type II lamp had lower variance than either the 5 3/4" Type I or 7" Type II, although these differences may reflect peculiarities in the individual bulbs.

In column 4 of Table 2 is shown the expected standard deviation in lamp aim for each bulb and device, derived by summing the variances associated with alignment of the long axis and headlamp

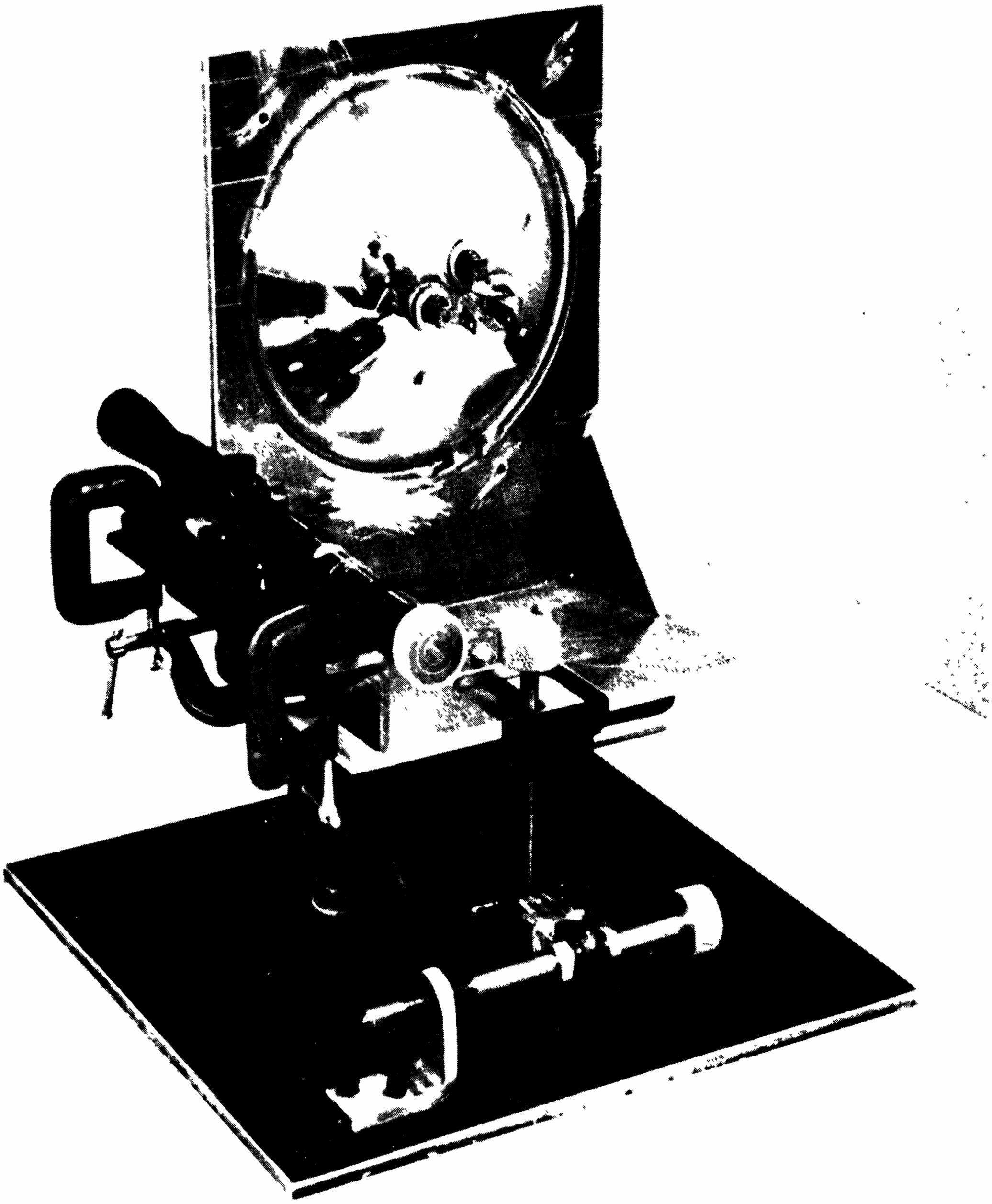


Figure 7. Headlamp fixture used in aiming study.

Figure 8. The two aiming machines in use in the aiming study.

aiming, assuming for the former value the lowest variance found in the sample of five cars examined in the study described in the preceding section.

In column 5 of Table 2 are shown the two standard deviation values for each case. These values are interpreted as the limits within which 95% of the cases will be found.

DISCUSSION. An inspection of the first three columns of Table 2 shows good agreement among the values reported from the different studies. The only significant disagreement concerns the photometric aimer evaluated by Walker, which was a different machine than that evaluated in the other two studies. It might also be argued that the values reported by Hull et al. are low, considering that they supposedly included alignment with the vehicle. As the procedures employed are not clear and the vehicle itself not described, no comment can be offered on this point.

Two points are worth noting from the results of these studies:

First, there are very substantial differences among aimers in the accuracy with which headlamps can be aimed, when subtasks such as alignment with the vehicle are excluded. The field photometric device appears to be much the best of those tested, approximating the mechanical aimer in repeatability. Conventional visual aiming using an aiming screen is next best, though significantly poorer than the photometric machine. The visual machine is the poorest of those tested.

Second, devices which require alignment with the long axis of the vehicle by visual means suffer serious losses in accuracy. Thus, the photometric device tested, according to the data reported in this study, is capable of aiming headlamps within ±1 inch at 25 feet vertically or horizontally more than 95% of the time. However, in practice this substantial performance is degraded in horizontal aim so that only on cars where a clear centerline is available could it be expected that more than 95% of aims would fall within ±4 inches. Under the same conditions, with the visual machine it would be expected that about 75% of the lamps aimed would be within the ±4 inch horizontal tolerance.

The results of this and the other studies cited make it clear that headlamp aiming techniques available today (except mechanical) are of low reliability. To the extent that such devices are used for field aiming and inspection of headlamps, a substantial aim variance of headlamps in service must be expected.

The studies just described were run under laboratory conditions where sources of variance such as miscalibration or misuse of equipment, operator carelessness, etc. should have been minimal. What the situation is in actual field practice is the subject of the next study.

SERVICE TRADE LAMP AIMING

BACKGROUND. When a motorist takes his car into a service facility to have the lamps aimed, how well will the job be done? This was the basic question which the survey conducted in this phase sought to answer. In addition, information was desired as to the type of equipment used, the length of time the equipment had been owned, familiarity with it, the frequency with which it was used and attitudes toward "selling" aiming.

METHOD. All service stations, garages and automobile dealerships who claimed to be able to aim headlamps in the Ann Arbor area were surveyed. Twenty-four service stations and garages and eight dealerships were included. A full-size station wagon equipped with a conventional four-headlamp system was employed. Using a level floor and mechanical aimers each of the lamps was first misaimed in a specified manner, as shown in Figure 9. The car was then taken to one of the service outlets where the driver complained that his lamps seemed to be aimed badly, and requested them to be checked and remained as necessary. When possible the driver observed the aim process. Afterwards the serviceman who did the work was queried to obtain information related to his experience and practice in headlamp aiming. The car was then returned to the HSRI garage and the aim checked at the same spot and with the same equipment as used to misalign it initially.

RESULTS. Figure 9 shows the resulting aims of the four lamps on the test car. It is apparent that in most cases the aim was improved, though in some cases it was made worse. The data are shown in the form of a cumulative frequency distribution in Figure 10. The probability of all four lamps being within the 4" x 4" SAE recommendations was less than 0.4. (Twelve of the 32 outlets aimed all four lamps within SAE specifications.) There were 18% of the lamps misaimed more then 4" left or right, 26% misaimed more than 4" up or down, and 35% were misaimed in excess of 4" either horizontally and vertically, or both.

There was relatively little variability in equipment used by the various outlets. In three instances no equipment was used. In three other cases optical aimers were used. All other outlets employed mechanical aimers. In general the operators who were observed seemed to be adequately familiar with their equipment, although some misconceptions were noted (e.g., biasing a mechanical aimer down and to the right or turning on lights to use a mechanical aimer).

Most of the outlets checked did little headlamp aiming; "one a month or less" being the usual response to that question. In a few instances operators claimed to aim "several per week" and one claimed "one or two per day." There was no relationship between claimed frequency and accuracy.

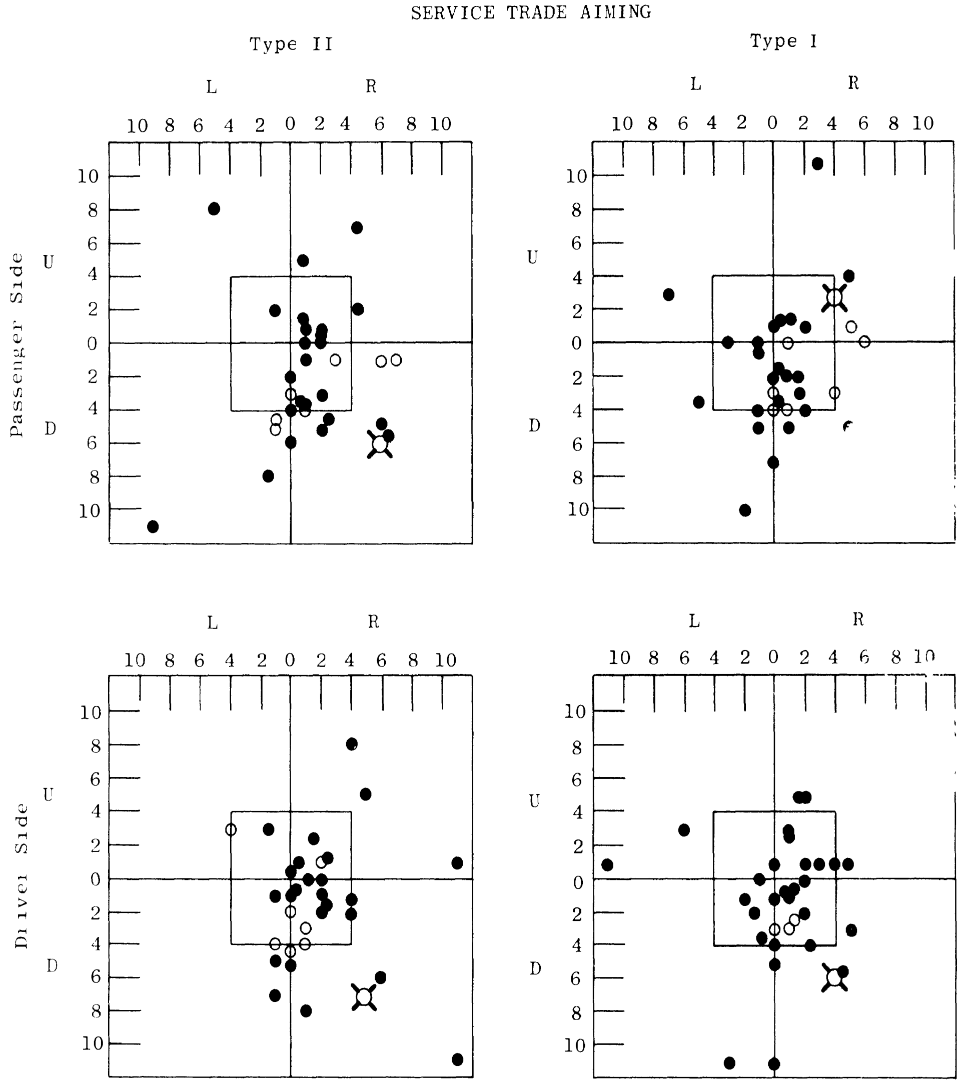


Figure 9. Headlamp aims of test car resulting from the efforts of 32 service outlets. Initial misaim indicated by X for each lamp.

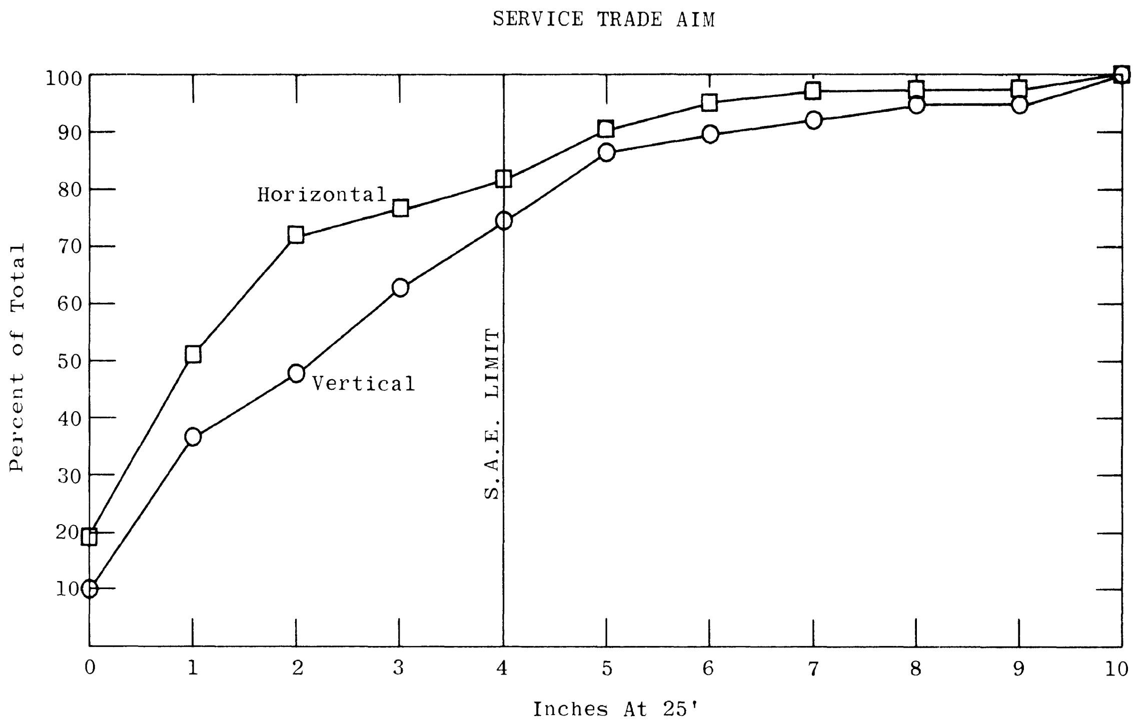


Figure 10. Cumulative frequency distributions of headlamp aims resulting from service trade survey.

Few of the agencies suggested aiming when cars were in for other service; the impression was gained from these conversations that aiming was a service that is hard to sell. Similarly, only a few of the agencies suggested aiming when selling a headlamp. The comment was frequently received that reaiming was not necessary unless the aiming screws were accidentally turned while attempting to remove or replace the lamp.

DISCUSSION. This survey is based on a small number of service outlets in a limited area. However, unless the Ann Arbor area is decidedly worse than the national average, it is apparent that accurate headlamp aiming is a service not readily available to the motorist. Further, the results of this survey provide reason to believe that poor quality service could be a significant source of variance in the headlamps of cars on the road.

As already noted, mechanical aimers are capable of a high degree of repeatability. Substantial difference on the same lamps from different sets of mechanical aimers can only be due to differences in calibration and/or methods. All of the lamps that were aimed within specification were aimed with mechanical units but so were some of those that were outside the specifications, including a few which were beyond the range of our instrument (±10 inches at 25 feet). The problems associated with obtaining accurate, consistent performance in the field even with simple equipment and procedures is well illustrated by these data.

Among differences in methods one would list carelessness in stabilizing the headlamp units, i.e., removing the effects of friction in the headlamp adjusting mechanism. Indications from the aim maintenance study to be described later are that this could be a significant source of variance. Were it a problem with the service personnel surveyed in this study the aim would be expected to be off in the direction of pull of the spring, which, for the vehicle tested, would be down for all units and to the right for the passenger side Type II and the driver side Type I, and to the left for the others. While the units are biased down, they tend to be biased also to the right in all cases. Thus, there is no consistent evidence of carelessness in stabilizing the units.

FACTORY AIM

BACKGROUND. The survey to be described sought an indication of the quality of headlamp aim provided by the factory.

The resources available for this study allowed a check on only a small number of vehicles in a limited geographical area. Obviously this represents a tiny fraction of 1972 cars and a very small sample of production lines as well. Consistent results, good or bad, across all makes and models checked would provide a strong indication of the state-of-the-art. Particular groups of cars which differed from general practice would not necessarily indicate an overall trend.

METHOD. Eight dealerships were surveyed, six in Ann Arbor and two in Plymouth, Michigan. In each case the dealership's management was approached and the purpose of the survey explaimed. Cooperation was generally excellent.

Cars which had been prepared for delivery (a procedure which normally includes a check of the aim of headlamps) were excluded from the study. Cars were checked as they stood on the dealer's lot. The ground slope was measured for each car and mechanical aimers used for the checks.

Twenty or more cars were checked at each site visited, except for two where there were fewer than that number available. Four GM dealers were visited, two Ford, one Chrysler and one American Motors. A total of 153 cars were checked, and a total of 428 lamps.

RESULTS. The results of the survey are given in the form of cumulative frequency distributions in Figure 11. These data are for individual lamps. Horizontal aim was somewhat better than vertical with at least 90% of the lamps at any dealership being within ±4 inches at 25 feet, as recommended by SAE. With the exception of one dealership, at least 84% of lamps were in specification vertically as well.

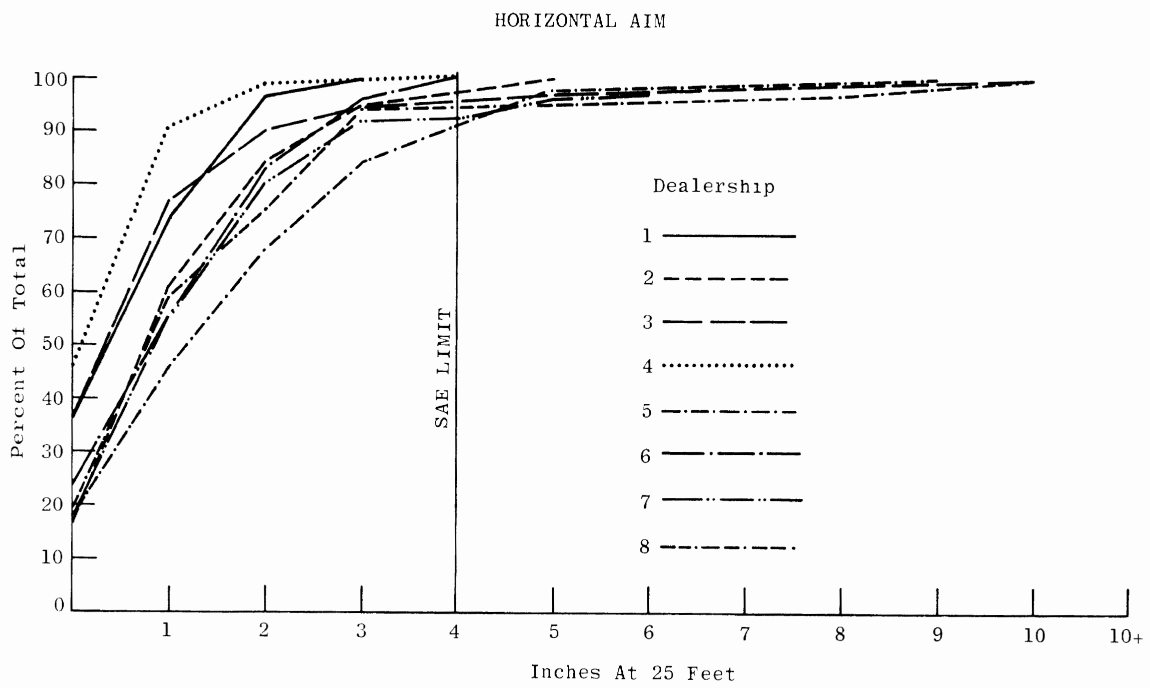
If having one or more lamps out of SAE specification would "fail" a car the percent of failures were: dealer 1, 14%; dealer 2, 50%; dealer 3, 25%; dealer 4, 5%; dealer 5, 65%; dealer 6, 14%; dealer 7, 40%; and dealer 8, 30%. Overall, 28% of the vehicles had at least one lamp outside the SAE tolerance.

DISCUSSION. The results of this survey indicate that most headlamps are aimed within SAE specifications at the factory. Comparing the results of this and the service trade aiming study gives reason to believe that the manufacturers may be doing a better job of lamp aiming than many of their dealers. Unless dealerships can upgrade their headlamp aiming capability it is questionable whether they should attempt to change factory aim settings.

AIM AS A FUNCTION OF SERVICE: AUTOMOBILES

BACKGROUND. This study sought to provide information regarding the stability of headlamp aim on a sample of passenger cars of various ages in normal service.

Efforts with similar intent have been reported elsewhere. For example, Finch et al. (1969) checked changes in aim on a sample of 20 vehicles after 90 days service. Nearly half the lamps in his sample were found to be outside California Adjusting Station tolerances at the end of the test period.



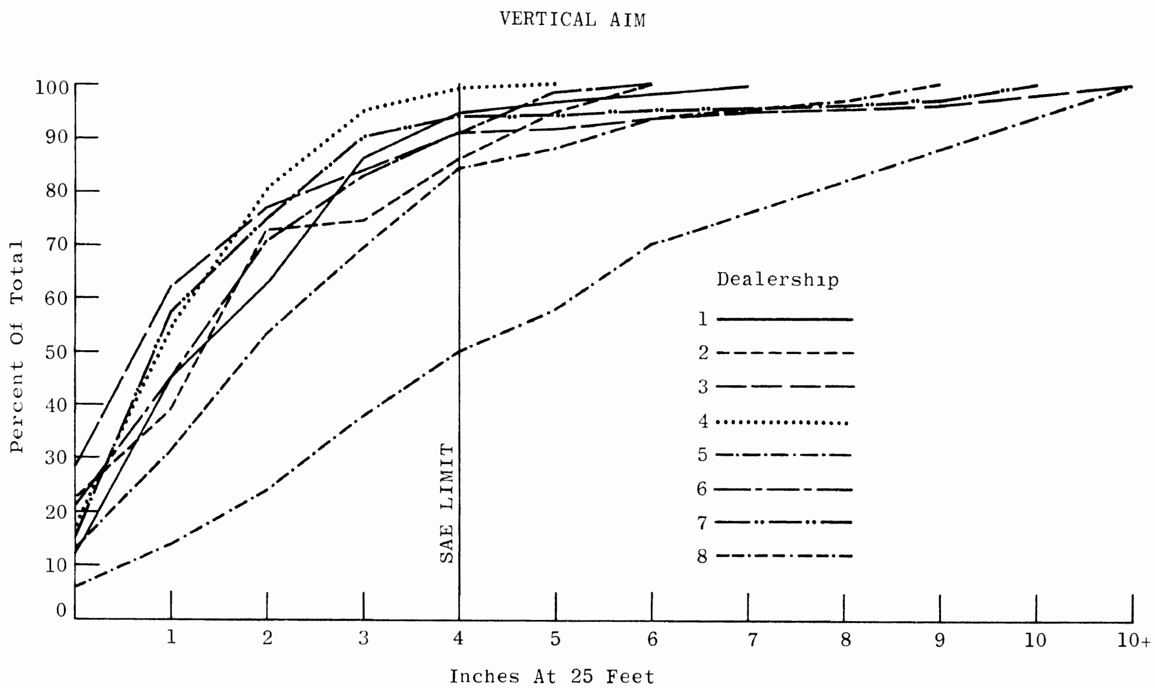


Figure 11. Results of new car aim study.

Hull et al. (1972) report a similar study on 26 vehicles. The time span is not given but the cars were driven from about 800 to 6500 miles before rechecking. The investigators report standard deviations for all lamps of 0.5 and 1.1 inches at 25 feet for horizontal and vertical aim variability, respectively. These results are appreciably better than those reported by Finch et al. The substantial differences in the results of these two studies indicates a need for further data.

METHOD. Volunteers willing to have their cars tested in a year-long program were solicited from HSRI staff. Forty-four vehicles were originally entered into the sample. Each owner was given a letter explaining the purpose of the study and asking that he notify the experimenter if he replaced a headlamp, experienced sheet metal damage, broken springs or anything else that might change the lamp aim.

In addition each owner was given a brief questionnaire designed to provide some information relating to his experience with headlamp aiming.

Initial Aiming. All aiming was done on a flat concrete floor in the HSRI garage area. The slope of the floor was carefully measured and all aiming was done with mechanical aimers which were checked regularly for calibration.

Each car was driven into the aiming area, rocked to settle the suspension and the lamps cleaned. The odometer readings and gas levels were noted as well as anything unusual (such as air suspension or heavy trunk loads) which might affect aim.

The lamps were checked for aim as received and this information recorded. The lamps were then reaimed to "0-0" on the mechanical aimers. Care was taken that the final adjustment involved tightening the adjusting screws and the units were perturbed by tapping the aimers and fenders to try to settle them into position.

Where necessary, bezels were reinstalled and the aim checked again. It was frequently noted that installation of the bezels resulted in a slight shift in aim (although one lamp was moved 4" up to 8" right due to bezel interference). For this reason subsequent measurements were recorded as changes from the "bezels on" value rather than the intended 0-0.

Follow-Up Checks. The aim condition of the subject vehicles were checked at intervals of approximately two, five, eight and twelve months.

The follow-up checks were made using the same space, equipment and procedures as the initial check except that the bezels were not removed. The cars were checked with the same gasoline levels as they had for the first check and accumulated mileage noted. The mileage recorded was quite variable. From one check to another it ranged from about 300 miles to more than 6000. Total mileage accumulated over the test period ranged from about 3500 to more than 23,000.

RESULTS. The attrition rate of the sample was much higher than anticipated, with the result that fewer than half of the cars completed all four measures. A much better representation (33 cars) completed the first three checks, so the results were tabulated based on this sample over an eight-month period.

The results of this study, based on a sample of 33 cars, are summarized in Table 3. Shown are values (in inches at 25 feet) for one standard deviation for 5 3/4" and 7" bulbs. There were 60 of the former on 15 sample cars and 36 of the latter on 18 sample cars.

TABLE 3. Variability in Headlamp Aim Over Time of a Sample of Automobiles in Normal Service.

		Standard Deviation of Sample (in. at 25 ft.)	
		5 3/4" bulbs	7" bulbs
As received	V	4.2	3.6
	H	4.5	5.2
After aim	V	0.7	0.6
	H	1.2	0.7
Changes from "after aim" condition:			
Two months	V	1.6	1.7
	H	1.2	0.9
Five months	V	1.4	1.8
	H	0.8	0.9
Eight months	V	1.5	2.4
	H	0.8	2.5

In Table 3, "as received" shows the condition of lamps as they were first measured before aiming. After they had been aimed and the bezels reinstalled there was still appreciable scatter, as shown in the "after aim" values. The listings reported for the check intervals of 2, 5 and 8 months, show standard deviations of change from the "after aim" condition. These values would be "0" had the readings stayed the same as they were after the bezels had been installed.

The results indicate that there was a change in aim after the first two-month period but little or no change thereafter with the exception of the 7" bulbs in the last check period. Actually, the change for the 7" bulbs at the eight-month check was largely attributable to very substantial changes on the part of two cars in the sample. The rest of the cars continued to show little or no change. Indeed, if the two cars in question are removed from the sample the standard deviation for the H dimension at eight months drops to 1.00.

The response to the questionnaire submitted to the participants are summarized in Table 4. A substantial number of the subjects had some experience related to headlamp aim, either by having lamps aimed or inspected for aim. Relatively few of the cars in this sample had ever been aimed by their present owners, however.

TABLE 4. Results of Survey on Headlamp Aim Experience Given to Participants in Lamp Aim Studies.

	Yes	No
Have you ever had the lamps aimed on this car?	3 7%	41 93%
Have you ever had the lamps aimed on any car?	27 61%	17 39%
Have you ever been stopped for vehicle inspection in Michigan?	2 5%	42 95%
If yes, did your headlamps pass?	2 100%	
Have you ever lived in a state that had compulsory vehicle inspection?	11 25%	33 75%
If yes, did your headlamps ever fail to pass inspection?	3 27%	8 73%

DISCUSSION. The results of this survey are at variance with the results and conclusions presented by Finch et al. (1969) and in support of Hull et al. (1972). The data from this study indicate a short-term change with good stability thereafter. This suggests that a significant part of the aim change reported by other investigators may, in fact, result from aiming procedures which produce an unstable condition in the lamp fixture. Experience suggests that methods which require care and fussing on the part of service personnel are unlikely to yield consistently good results. However, if a redesign can be effected in the lamp support system which reduces the probability of instability in the mechanism after the adjusting screws have been moved, it may result in a significant improvement in the stability of aim of headlamps in service.

AIM AS A FUNCTION OF SERVICE: TRUCKS

BACKGROUND. This study sought to provide information regarding the stability of headlamp aim on a sample of trucks in a variety of service applications.

Work of this type has not been reported elsewhere, to the authors' knowledge. Hull et al. (1972) investigated the aim condition of a sample of 363 heavy duty trucks of various makes and types. They found that about 50% of all the lamps were outside SAE limits. They did not, however, check aim change over time.

Trucks, in general, are driven more miles per unit time, and see harder service than passenger cars. This would be expected to result in a higher incidence of misaim for trucks.

METHOD. The sample of trucks checked in this study were drawn from two sources, a truck rental agency and a transit-mix concrete company. Five types of vehicles were available from the rental agency: small vans, and single-axle trucks with box-bodies of 12, 16, 18 and 20 foot lengths. The cement hauling firm had a half-ton pickup truck and eighteen twin axle transit-mix trucks.

The trucks in this survey were exposed to a wide variety of service (especially the rental units), generally short hauls at low to medium speed. No long-haul trucks were included. The rental units were driven an average of about 10,000 miles during the test period, the transit-mix trucks were in operation from 500 to 1700 hours.

Both agencies were very cooperative with the survey personnel, providing paved and sheltered places for the measurements. The general procedure was the same as employed in the automotive aim maintenance study. Each truck was checked for initial condition and the lamps set to 0-0 using mechanical aimers. The lamps were checked again about six months later using the same equipment and location. About 50 trucks were included in the original sample.

RESULTS. For a variety of reasons, about half the trucks were lost from the sample during the test period. Unfortunately, all but three of the transit-mix trucks were converted to a third "tag axle" arrangement during this period. Since this would change their vertical aim by an unknown amount, they were dropped from the study. Other trucks were sold or suffered crash damage. The final sample consisted of 26 units, with 52 headlamps.

The initial check found, as did Hull et al. (1972) that half the lamps were outside SAE specifications in at least one dimension. The standard deviation (in inches at 25 feet) were 4.4 vertically and 3.0 horizontally. In this sample, the lamps tended to be up (average of 2.5 inches) and to the left (average of 0.5 inch).

In the follow-up check about six months later, about 15% of the sample were outside SAE specifications. The standard deviation for the vertical dimension was 3.1 inches and for the horizontal dimension it was 3.0 inches. The aim bias was now down (average of 1.4 inches) and to the right (average of 0.8 inch).

DISCUSSION. The results of this survey support the idea that aim change as a function of service is more of a problem with trucks than automobiles. The standard deviation for this sample of trucks was about twice as great vertically and three times as great horizontally as the sample of cars described in Table 3.

In the preceeding chapter on stability of automobile headlamp aim the fact that almost all change occurred in the first check period led to the suggestion that poor aiming technique (i.e., failing to turn the adjusting screws to properly tension the spring) may be a major source of aim variance. Because only one check was made, and that after an appreciable time period, the extent to which the variance measured in this study can be attributed to poor aiming technique cannot be estimated. The evidence does suggest, however, that improvements in lamp mounting mechanism for trucks leading to improved resistance to vibration, etc. may significantly reduce aim variance in this type of vehicle.

VEHICLE LOADING

BACKGROUND. This study sought some indication of the effect of vehicle loading on headlamp aim. The intent was to estimate the effect of various loading configurations up to full-rated load on lamp aim.

METHOD. Seven vehicles were selected for the study. They were intended to be representative of the types of vehicles found on the roads today. Each car was moved to a specific position on a ramp facing into a darkened room. A spot aimer was used (Figure 12) and focused on a screen 25 feet from the lamp (Figure 13). A first measurement was taken with a full gas tank and 150 lbs in the drivers' seat. All other measures were referenced to this one. Two readings had to be taken each time; the height of the spot on the screen and the height of the aimer.

The loadings were increased one "passenger" (150 lbs) at a time, first in the front and then in the back seat. Finally, the luggage space was loaded in 50 lb increments (200 lb increments in the case of the pickup truck) to capacity. Weights were then removed, beginning with the rear seat and ending with full luggage load and "driver." After each change the car was rocked from both sides and bounced at all corners in an effort to equalize the suspension. In addition, the cars were occasionally moved back and forth ten feet or so to permit the tires to equalize side forces associated with suspension deflection. This latter precaution did not result in discernable changes, however.

RESULTS. A summary of the results of this study is presented in Table 5 which compares deflections associated with different vehicles for comparable conditions. The values shown are changes from the driver (150 lbs) only--full gas tank condition.

Also shown in Table 5 are results from comparable cars and conditions reported by Hull et al. (1972). Hull reports pitch changes as a function of load condition but does not describe the baseline condition. Thus, the data may not be strictly comparable. However, for the Mustang and station wagon the agreement is good. The Plymouth in Hull's report showed greater deflection than the one measured in this study. There is quite substantial disagreement concerning the VW, however. This may well have come about if the entire 206 pound "trunk" load in the data reported by Hull were placed in the front storage compartment.

Figure 12. Spot aimer in use in the study of effects of vehicle loading on aim.

Figure 13. Set-up used in vehicle loading study.

TABLE 5. Headlamp Aim Change As A Function of Vehicle Loading.

Change (inches at 25 feet) up or down (+ or -) from 150 pound driver - full gas condition.

Condition	VW bug	Mustang	Plymouth	Sta. Wgn.	Camaro	Pontiac	Pick up (1000#)
Gas Tank Empty							
No Occupants	+2.5	-2.0	-1.5	-1.3		-3.3	
Gas Tank Full							
No Occupants	+1.0	+0.3	0.0	+0.3	+0.3	+0.3	0.0
300# - Front	-0.5	0.0	0.0	+0.3	-0.3	0.0	+0.3
300# - Front & 300# - Rear	+0.3	+2.8	+1.8	+1.0	+2.3	+1.3	
Full Passenger Load	+0.3	+2.8	+2.5	+0.8	+3.3	+1.3	+0.3
Full Rated Load	+1.5(-1.9)[1]	+6.5(+7.0)	+5.8(+8.2)	+4.3(+4.9)	+5.3	+3.3	+5.8
300# - Front Full Trunk Load	-0.5[2](-4.6)	+3.5(+4.0)	+2.8	+4.3(+3.7)	+3.3	+3.3	+5.8
150# - Front Full Trunk Load	-0.5	+4.5	+3.0	+4.8	+3.5	+3.5	+6.8

[1]Values in ( ) are those reported by Hull (1972).

[2]Trunk load was split evenly between front and rear compartment number of pounds.

The worst condition tested was 100 lbs in front plus driver, which produced a change from the baseline condition of 1 1/2 inches at 25 feet.

DISCUSSION. The results reported make clear the fact that vehicle loading is a major source of headlamp aim variance of cars. Since the most usual change is upwards, this will result in substantial increases in glare for other drivers.

CONCLUSIONS

A number of factors have been found to be significant contributors to headlamp aim variance. Based on the findings of these studies, the following factors appear to be of greatest consequence.

LAMP FACTORS

There is very little evidence available on lamp factors. The data which have been reported by Finch et al. (1969) and Hull et al. (1972) suggest that beam changes as a function of use may be a significant source of aim variance. Unfortunately, a reasonable estimate of the variance associated with this factor cannot be made on a basis of the available evidence, but it would appear to be one of the more significant factors. More data are needed to clarify this matter.

VEHICLE FACTORS

Virtually all the vehicle factors mentioned appear to be significant sources of aim variance. The lamp mounting mechanism, the target of frequent criticism, appears capable of retaining a setting well enough to not warrant inclusion as a major source of aim variance, at least in passenger cars. However, the evidence suggests that it is difficult to achieve a stable setting when the aim must be changed. Dog tracking, matchboxing and the tracking effects of certain tires are all significant factors in horizontal aim variance, and pitch changes resulting from static loads and acceleration forces can produce very significant vertical aim variance.

AIMING FACTORS

The following is a brief summary of the various aiming techniques together with the virtues and short-comings of each.

VISUAL AIMING. Visual aiming requires no equipment (although it is facilitated by a screen with adjustable H and V reference lines), and is unaffected by matchboxing and misorientation of beam and aiming plane. It requires about 45 feet of space in a dark area, is affected by dog tracking and locating the longitudinal axis of the vehicle. The aiming is a subjective process which results in a low level of reliability.

VISUAL AIMING - MACHINE. This technique saves space as compared to basic visual aiming, but requires a bulky and fairly costly piece of equipment. Other factors remain the same except the reliability seems, if anything, worse.

PHOTOMETRIC AIMING. This technique is unaffected by matchboxing and misorientation of the beam and aiming plane. The reliability is much better than the two preceding methods and about equal to mechanical aiming. The equipment, however, is bulky and fairly costly; in addition, accuracy is affected by dog tracking and locating the longitudinal axis of the vehicle.

MECHANICAL AIMING. This technique is fast, simple and equal to photometric techniques in reliability. No estimate of the longitudinal axis is required. The equipment is inexpensive, light and easily stored. Overall accuracy is affected by dog tracking, matchboxing and misorientation of the aiming plane and beam.

All the techniques have various flaws, which must be considered in addition to human factors as significant sources of variance. The most accurate aiming technique would appear to be the photometric, except for the problem of locating the vehicle long axis. Further work to solve this problem might be worthwhile.

Jehu (1954b) has described an aiming device which had been specially modified to reduce a number of sources of aim error. Noteworthy is the means employed to obtain alignment with the vehicle long axis, an adaptation from a tester manufactured by Cibié. Basically, this technique uses a metal bar, perpendicular to the optical axis of the aimer, which is brought into contact with the front wheels of the vehicle. Jehu reports a standard deviation for alignment with the long axis of about two inches at 25 feet using this technique. This compares favorably with the results reported in this paper for the photometric aimer on the easiest vehicles. There are no data on the relationship of such factors as dog tracking and matchboxing to alignments achieved in the manner described. The primary virtues of the technique, if it is sufficiently accurate, are that it is very fast and nearly fool proof. It would add appreciably to the bulk of the aimer, however.

In sum, there are a number of sources of aim variance, some of which are quite significant and for many of which compensation cannot be readily provided. The following suggestions are offered which may aid the situation:

1. Ways should be found to reduce the variance associated with locating the long axis of the vehicle for those techniques which require it. This could be done by installing permanent marks on the vehicle at the time of manufacture or devising a simple and more effective alignment technique which is part of the aimer. The method suggested by Jehu (1954b) and described above might be investigated as a possibility.

2. Design changes to reduce the friction in the headlamp adjusting mechanism would be desirable. A general increase in the structural rigidity of the headlamp support mechanism would undoubtedly aid the problem as well, but appears to be of less consequence.

3. Ways must be found to encourage proper use of mechanical aimers and keep them in calibration. Proper use may be facilitated by printing the basic procedural steps on the side of the aimer unit, so that it is always clearly visible to the service personnel.

The need for periodic calibration checks should be stressed in the descriptive literature for these units to discourage buyers from acquiring aimers without the calibration device. Alternatively, it may be possible to include with each set of aimers a very simple, inexpensive check device. As an example, this could take the form of mouldings in the shape of a headlamp lens, which could be permanently affixed to a wall in the shop. By noting the settings required to get proper "aim" when the units were first acquired, changes in calibration could be readily detected on subsequent checks.

4. Vertical aim compensation would be a desirable feature for automobiles. As already noted, this is available in a variety of forms at present. Since trim changes around the pitch axis appear to be a major source of vertical aim variance, significant improvements in lamp aim of vehicles on the road could be achieved in this way.

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