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An Eyellipse for Rear Seats with Fixed Seat Back Angles

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ABSTRACT

This paper describes the development of the fixed seat eyellipse in the October 2008 revision of SAE Recommended Practice J941. The eye locations of 23 men and women with a wide range of stature were recorded as they sat in each of three second-row bench seats in a laboratory mockup. Testing was conducted at 19-, 23-, and 27-degree seat back angles. Regression analysis demonstrated that passenger eye location was significantly affected by stature and by seat back angle. The regression results were used to develop an elliptical approximation of the distribution of adult passenger eye locations, applying a methodology previously used to develop the driver eyellipse in SAE J941-2002.

INTRODUCTION

The eyellipse is a statistical construct that represents the distribution of vehicle occupants' eye locations as an ellipse, or ellipsoid in three dimensions (1, 2). The eyellipse was introduced by Meldrum (3), who observed that the distribution of a large number of measured driver eye locations was similar to a three-dimensional multivariate normal distribution. A bivariate normal distribution is frequently depicted using an ellipsoid centered on the mean of the distribution. The ellipsoid can be computed to enclose a specified percentage of the distribution density, for example, 95%. Meldrum exploited the "cutoff" characteristic of the density ellipsoid to obtain a result more useful for vision analysis. Tangents to any bivariate normal density ellipse divide the distribution into a constant fraction. Equivalently, as shown in Figure 1, a "cutoff" ellipse can be constructed such that all tangents to the ellipse divide the distribution into constant fractions.

The cutoff ellipse provides greater utility for vision analyses than does the density ellipse. Consider a design criterion to ensure a minimum upward vision angle for drivers. Using a 95% cutoff ellipse, Figure 1 shows a schematic side-view analysis of upvision angle. The figure shows that 95% of drivers have an upvision angle at least as larger as the angle of the tangent.

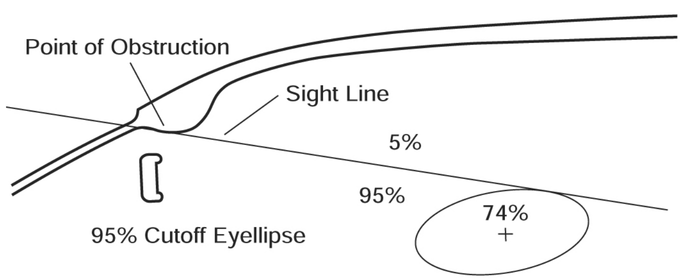

Figure 1. Conducting an upward vision analysis with a side-view 95% cutoff driver eyellipse. The eyellipse encloses approximately 74% of driver's eyes in side view, but 95% of driver's eyes lie below the tangent to point of obstruction.

SAE Recommended Practice J941 presents eyellipses for drivers in passenger cars and light trucks (SAE Class A vehicles) as well as heavy trucks (Class B vehicles). The original eyellipse (3), which applied only to Class A vehicles, was based on eye locations measured statically using stereo-photogrammetry. The eyellipse was enhanced with other data to provide for greater seat track adjustability and head turn (2). Yet, among other limitations, the original eyellipse was based on data obtained using fixed seat back angles and did not provide configurability for population anthropometry.

In 2002, a new edition of J941 was adopted that introduced an entirely new eyellipse model based on driver eye locations from 33 vehicles (4). The model allows specification of single-gender stature distributions and gender mix and takes into account the effect of steering wheel position (see J941, Appendix A).

Because the earlier version of J941 used seat back angle as an input, the model was frequently used to estimate driver eye and head locations in rear seats with fixed seat back angles. However, the model was neither developed nor validated for this purpose.

Both the driver and fixed-seat eyellipses in J941 have been used to create head contours for use in evaluating headroom. The contours, described in SAE J1052, were computed as ellipsoidal approximations to the head distributions associated with the eyellipse.

The current paper describes the development of the rear-seat eyellipse model included in Appendices B and C of the October 2008 revision of J941. The practice refers to a "fixed-seat" eyellipse, since the model is applicable to seats without adjustments. Since these seats are typically available only in the second and more-rearward rows of passenger vehicles, the model is also referred to as a rear-seat eyellipse.

METHODS

As part of a larger study of rear-seat accommodation, the postures of 13 women and 10 men were measured in a laboratory mockup. The subjects ranged in stature from 1470 to 1924 mm. The median body mass index was 26.3 kg/m2. The test conditions are described in Reed et al. (7). The second-row seats of three vehicles (two passenger cars and one minivan) were mocked up in the laboratory such that the back angles could be manipulated. The seat height (H30) was 270 mm. Testing was conducted with back angles (SAE J1100 dimension A40, measured with the SAE J826 H-point machine) of 19, 23, and 27 degrees. A FARO Arm coordinate digitizer was used to record the three-dimensional locations of body landmarks. The eye location was estimated in sideview from the X (fore-aft) coordinate of the infraorbitale landmark and the Z (vertical) coordinate of the ectocanthus (corner of eye) landmark.

A regression analysis was conducted to predict eye location with respect to seat H-point as a function of stature and seat back angle (SAE A-40). For ease of modeling, eye location was predicted as the length and angle with respect to vertical of a sideview vector from H-point to eye. Following Manary et al. (4), the residual variance from the regressions was retained to for use in modeling.

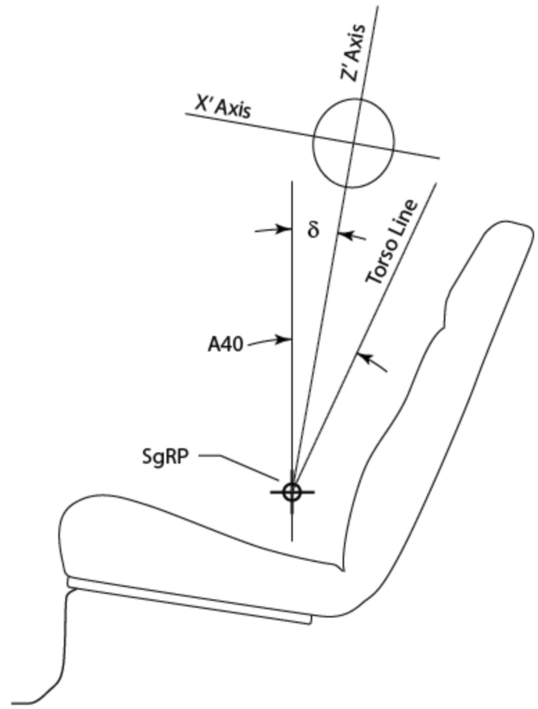

Figure 2. Schematic of fixed-seat eyellipse.

RESULTS

REGRESSION ANALYSIS

The side-view angle of the H-point-to-eye vector was given by the regression equation:

$$\delta = 0.698*(A40) - 9.09, \quad R^2 = 0.43, \text{RMSE} = 2.63 \qquad [1]$$

where δ is the vector angle and A40 is the seat back angle (see Figure 2). The root mean square error (RMSE) is the standard deviation of the residual variance from the regressions. The height of the eye above the H-point along the vector was given by:

$$h = 67.0 + 0.351*S - 1.613*(A40), \quad R^2 = 0.83, \text{RMSE} = 19.6 \qquad [2]$$

where h is the vector distance and S is stature, both in mm. Note that the H-point-to-eye distance is slightly smaller with increased seat back angle.

MODEL DEVELOPMENT

Flannagan et al. (5) introduced a methodology for conducting accommodation analyses that exploits the observations that stature is approximately normally distributed within large single-gender adult populations, many functional anthropometric measures of interest are linearly related to stature, and the residuals of linear regression analyses of such data are usually normally distributed. In the current data, the relationship between delta and seat back angle was approximately linear, as was the relationship between stature and H.

Following Flannagan et al., an estimate of the distributions of delta and H were obtained by convolving single-gender normal distributions of stature by the observed linear relationships between stature and the outcome measures, while retaining the residual variance. These calculations exploit the fact that a linear function of a normal distribution is itself a normal distribution with readily computed parameters (mean and variance).

The mean male and female statures are denoted S_M and S_F, respectively, and the corresponding standard deviations are σ_M and σ_F.

Step 1. Compute Z′ axis angle
The Z′ axis lies at the angle delta with respect to vertical, calculated using equation 1.

Step 2. Compute single-gender mean locations on Z′
The male and female mean eye locations are obtained from equation 2:

$$h_M = 67.0 + 0.351 S_M - 1.613\ (A40) \quad [3]$$

$$h_F = 67.0 + 0.351 S_F - 1.613\ (A40) \quad [4]$$

Step 3. Compute male and female standard deviations on Z′
The standard deviations of single-gender eye locations on Z′ are computed from the single-gender stature standard deviations, the slope of the stature effect in equation 2, and the residual from equation 2.

$$s_M = \sqrt{0.351^2 \sigma_M{}^2 + 19.6^2} \quad [5]$$

$$s_F = \sqrt{0.351^2 \sigma_F{}^2 + 19.6^2} \quad [6]$$

where sm and sf are the standard deviations of male and female eye location along the Z′ axis.

Step 4. Compute Z′ axis length
The Z′ eyellipse axis length is computed so that tangents perpendicular to the Z′ axis cut off the desired percentage of the combined male and female population of eye locations. Given a desired cutoff quantile q (e.g., 95%), the following equations must be solved for C_U and C_L respectively the upper and lower cutoff values of h:

$$1-q = p_M\, \Phi((C_U - h_M)/s_M) + (1 - p_M)\, \Phi((C_L - h_F)/s_F) \quad [7]$$

$$q = p_M\, \Phi((C_U - h_M)/s_M) + (1 - p_M)\, \Phi((C_L - h_F)/s_F) \quad [8]$$

where p_M is the fraction of males in the population and Φ is the cumulative standard normal distribution, e.g., $\Phi(1.64) = 0.95$. These equations must be solved iteratively to determine the cutoff values for the selected value of q. Then

$$Z' \text{ axis length} = C_U - C_L. \quad [9]$$

Step 5. Compute X′ axis length
The angle of the H-point to eye vector with respect to vertical is independent of stature and normally distributed with a standard deviation of 2.63 degrees (the residual from equation 1). The X′ axis will span an angular range given by

$$X'\text{angle} = 2\ (2.63)\ \Phi^{-1}(q) \quad [10]$$

where is the inverse standard normal distribution, e.g., $\Phi^{-1}(0.95) = 1.64$. Approximating the axis length by the chord length,

$$X' \text{ axis length} = (C_U - C_L)/2\ (\pi/180)\ (X'\text{angle}) \quad [11]$$

Step 6. Compute Y axis length
The width of the eyelipse is taken to be the same as the width of the Class A driver eyellipse in J941. As a function of eyellipse cutoff quantile q,

$$Y \text{ axis length} = 2\ (31.65)\ \Phi^{-1}(q) \quad [12]$$

Step 7. Compute cyclopean centroid location
The eyellipse centroid for a single cyclopean eyellipse lies on the seat position centerline at a distance $(C_U - C_L)/2$ up the Z′ axis from the seating reference point (SgRP). Relative to the SgRP on seat centerline,

$$X_c = (C_U - C_L)/2 \sin(\delta) \quad [13]$$

$$Y_c = 0 \quad [14]$$

$$Z_c = (C_U - C_L)/2 \cos(\delta) \quad [15]$$

Separate eyellipses for the left and right eyellipses are located 32.5 mm on either side of the occupant centerline, following the J941 recommended estimate of 65 mm for interpupillary distance

DISCUSSION

The centroid of the fixed-seat eyellipse model described here is about 20 mm lower and 10 mm forward of the previous model (J941-2002), depending on back angle. The 2002 model was developed based on driver data, which may account for some of the difference. The centroid of the 2008 fixed seat eyellipse is fairly close to the centroid of the pre-2002 fixed seat eyellipse.

The current model has less applicability than the driver eyellipse. One important application of the fixed seat eyellipse is the derivation of head contours to assess occupant clearance to the headliner in rear seats (see SAE J1052 and J1100). The model can be also used to assess the visibility of rear-seat entertainment displays.

J941 Appendix B presents a fixed-seat eyellipse based on U.S. adult stature data from the 1990 National Health and Nutrition Examination survey. The model presented here, which is reproduced in J941 Appendix C, can be used with any adult population stature distributions.

The statistical model underlying this eyellipse is based on a relatively small sample of subjects, compared with the hundreds of subjects used to develop the driver eyellipse. However, the regression methodology applied here is statistically powerful, under the normal distribution assumptions that have been validated using the much larger driver datasets. Doubling or tripling the same size would be unlikely to shift the mean locations substantially; the biggest effect would likely be to expand or contract the axes, which are based on residual variance estimates.

The current model is based on static laboratory data. Manary et al. (3) reported that driver eye locations averaged about 10 mm lower after driving for approximately 15 minutes. If a similar dynamic affect applies to passenger data, the model might be biased high.

About half of rear-seat passengers are age 12 and younger (6), but the current model applies only to adults. Huang and Reed (6) introduced a method for weighting child anthropometric data to obtain representative distributions for rear seat assessment. A similar methodology could be applied to obtain an eyellipse for a rear seat population of both adults and children. Head locations for children with a range of body size sitting with and without belt positioning boosters were previously published (9).

The current model does not represent the effects of headroom restriction or seat height. Headroom restriction would likely reduce the vertical extent of the eyellipse by constraining high head positions. Seat height might affect seat back angle if it causes occupants to shift in the seat to obtain more comfortable foot positions. Body mass index (BMI) was not a significant predictor of head location in this dataset, but a population with a substantially different distribution of BMI might have a different head location, particularly because increased BMI is associated with more-forward hip locations (8).

The model presented here does not attempt to represent the variability in passenger head location that would result from atypical or asymmetric postures. Rather, the model represents nominal, sagittally symmetric postures that result when subjects are asked to “sit normally.” In general, eye location distributions in real vehicles driven on-road would be larger, representing greater variance in eye location. Nonetheless, the current model is a reasonable representation of the distribution of eye locations that passengers could normally achieve, and hence is useful for assessments of vision and head clearance.

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