The Anthropometry of Forest Machine Operators in the Southern USA

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Anthropometric dimensions critical to the design of operator workspaces and cab access in grapple skidders were collected from a sample of Southern United States loggers. The data were then compared to existing SAE and ILO anthropometric recommendations and data. Results indicated that southern grapple skidder operators are generally taller in stature, sitting height and seated eye height than the worldwide population measured to determine the SAE and ILO guides. Southern operators are also heavier than subjects measured for the SAE recommendations.

Keywords: *anthropometry, grapple skidders, forestry workers, forest machine operators, forestry equipment operators, forestry ergonomics.*

INTRODUCTION

General

Grapple skidder operators, like operators of most forest harvesting equipment, are subjected to substantial environmental and postural stresses. The eventual effects of these stresses on the health of operators is a topic of major importance to the forestry profession, and concrete answers depend on focused and long-term research.

It is recognized that the postural stresses operators experience are due, in large part, to mismatches between the physical dimensions (size, weight, height, reach distance, etc.) of the operators and the corresponding layout and dimensions of operators' workplaces in the forest harvesting machinery. Reduction of these problems is one of the goals behind the current efforts of equipment manufacturers to appropriately incorporate ergonomic design features into the operator compartments of their products.

Incorporation of ergonomic considerations during equipment design, however, cannot be achieved in the absence of reliable anthropometric data about operator populations. Equipment designers rely on the research community to develop reliable anthropometric data and to advise them when specific populations are significantly different.

The primary United States anthropometric design reference for off-highway work machines (which includes construction, agricultural, and forest equipment) is the Society of Automotive Engineers (SAE) Recommended Practice J833 [9]. In 1989, substantial revisions made SAE J833 technically equivalent to the International Standard ISO 3411 (Human physical dimensions of operators and minimum operator space envelope). The SAE document provides data for a worldwide operator population using dimensions of a 5th percentile female, 50th percentile composite, and 95th percentile male in sitting and standing positions. The ISO document which is the basis for SAE J833, notes that the anthropometric data are a combination of national datasets to approximate the worldwide male operator population. There is no mention of female operators in the ISO standard.

The International Labour Office (ILO) also publishes a collection of anthropometric data that could be used in the design of work machines [5]. These data are organized on a regional basis with North America being one of 20 regional categories. The North American table does not differentiate by ethnic or racial origin and is drawn from 33 sources, 22 of which were published prior to 1980.

Equipment designers use anthropometric data in four basic ways. Clearance dimensions, such as doorways and access openings, are established based on the 95th percentile values. Reach dimensions, such as control and handhold locations, are established based on 5th percentile values. Adjustable design elements such as seat adjustment ranges are designed to accommodate the range of users from 5th to 95th percentiles. Finally, fixed dimensions that must accommodate a range of users can be designed around the average, or 50th percentile, values. Thus, the basic anthropometric data in SAE J833 affect design values specified in other standards.

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For example, stature, sitting height, shoulder breadth, and chest depth of a 95th percentile male are used to establish minimum design values in several SAE documents. SAE Recommended Practice J154 [8] specifies a minimum interior space envelope for machine enclosures. SAE Recommended Practice J925 [11] lists minimum service access dimensions and is also referenced for the dimensions of emergency exits in SAE Recommended Practice J1084 [12]. The 95th percentile male is also used as the basis for defining deflection limiting volume, the critical performance criterion for evaluating rollover protective structures.

Operator weight is a design parameter used in standards relating to seat design and whole-body vibration evaluation. SAE Recommended Practice J1163 [13] establishes the datum Seat Index Point (SIP) on the basis of a 75 kg operator (50th percentile male). The SIP is the reference point for hand and foot control locations specified in SAE Recommended Practice J898 (10). The seat vibration performance evaluation method outlined in SAE Recommended Practice J1384 (14) specifies 5th and 95th percentile operator body weights.

Objective

The objective of this research was to collect anthropometric data from a sample of Southern United States loggers for critical operator dimensions and compare the collected data to existing physical dimensions.

Background

Vik [16] stated that "The design of the operator's workplace on a forestry machine requires consideration of the size of the potential operator." The primary sources of anthropometric data are measurements taken for military applications, but a few special studies of select groups exist. A study by Casey [2] revealed that the anthropometry of agricultural workers (a population that may be similar to forest workers) is not well represented by anthropometric data typically available to designers. He found that male farm equipment operators are significantly heavier than the population represented by anthropometric standards.

Bellinger [1] found that operators of agricultural equipment significantly deviate from what designers consider to be the average man. Therefore, designers should, during the initial planning stages of the design process, consider the population that will actually be operating the machine.

Contemporary anthropometric standards are important in designing machines to fit the population that will be required to operate them. Male agricultural workers do not appear to be well represented by current anthropometric standards [2]. This study was designed to investigate whether existing design references accurately represent forest equipment operators.

METHODS

General

Data were collected during December 1991 and January 1992 at 7 randomly selected logging sites typical of those found in East Central Alabama and West Central Georgia (USA). Although anthropometric data are usually obtained from semi-nude individuals, subjects were measured in their work clothes and shoes due to practical constraints of the field environment. Participants were generally clothed in two layers of clothing since the temperature ranged from 10° to 18.5° centigrade [50°-65°F] while measurements were being collected.

Participants

A total of 47 adult male individuals were measured. All of them were either full- or part-time skidder operators. Twenty-six operators were African-American and 21 were Caucasian. All of the subjects measured were fully clothed and wearing work boots. They were asked to remove their coats while being measured. The average age was 36 years. The youngest driver was 23 while the oldest was 54.

Experimental Methods

The data were collected using the following equipment:

1. Anthropometer—A standard GPM (Martin Type) scale anthropometer to obtain limb, height and body measurements.

2. Bathroom Scale—A standard bathroom scale to obtain the approximate weight of each operator.

3. Wooden Stool—A wooden stool 40.64 cm. [16 in.] high with a seat 29.21 cm. [11.5 in.] wide, and

46.99 cm. [18.5 in.] long was used while taking seated measurements of each subject.

4. Plywood Platform—A plywood board 0.91 m. [3 ft.] long, 0.91 m. [3 ft.] wide, and 1.91 cm. [0.75 in.] thick served as a flat surface while obtaining standing measurements, seated measurements, and weights of the operators.

Anthropometric measurements were taken before midday. In all cases the skidder operators had been working from 1 to 3 hours before measurements were obtained. A total of 16 measurements, illustrated in Figure 1, along with body weight were taken from each participant. Body landmarks were located by palpation techniques. These dimensions were specifically selected because of their direct application to workplace design.

The measurement procedure began by recording total body weight as the operator stood on the weighing scale. Each subject was then asked to stand in a natural erect posture on the plywood platform as 8 standing measurements were recorded. Eight seated measurements were then taken as operators sat on the wooden stool. The same anthropometer, scale, stool, and platform were used to measure each subject.

Statistical Procedure

A subjective analysis of the data indicated that the skidder operator measurements were closely grouped and normally distributed. This was verified by calculations of arithmetic means and standard deviations for the 17 anthropometric measurements. Thus, for statistical analysis purposes the data were assumed to be normally distributed.

The mean and the standard deviation were then utilized to determine the number of measurements required to obtain a 95% confidence level in the observed anthropometric data. The following formula and procedure [7] were used to determine the number of observations needed to obtain a confidence level of 95%.

$$N = (st/kx)^2$$

where

N = The number of observations required.
s = The sample standard deviation of the data.
t = 2.06 for 95% confidence.

Table 1. Clothing correction factors for selected measurements.

Measurement	Correction Factor—cm [in.]
+Stature	2.54 [1.0]
+Foot Width	0.76 [0.3]
+Foot Length	2.95 [1.2]
+Sitting Height	0.25 [0.1]
+Seated Eye Height	0.25 [0.1]
+Seated Shoulder Height	0.25 [0.1]
+Popliteal Height	2.54 [1.0]
*Shoulder Breadth	0.61 [0.24]
*Chest Depth	1.04 [0.41]
*Hip Breadth	1.42 [0.56]
*Buttock—Knee Length	0.51 [0.20]
+Weight—kg [lb.]	2.73 [6]

\+ Source: Damon, Albert et al. *The Human Body in Equipment Design.* Massachusetts: Harvard University Press, 1966.

* Source: Van Cott, Harold P. and Robert G. Kinkade, eds. *Human Engineering Guide to Equipment Design.* Washington, D.C., 1972.

Note: The above factors should be added to measures taken from nude or semi-nude subjects to compensate for the effects of clothing. Conversely, the factors can be subtracted from dimensions taken from clothed subjects in order to make comparisons with measures taken from nude or semi-nude subjects.

Table 2. Field measurements of grapple skidder operators.

Measurement—cm. [in.]	**Percentiles** 5th	50th	95th
Thumbtip Reach	77.26 [30.42]	83.59 [32.91]	89.91 [35.40]
Sitting Height	78.79 [31.02]	89.25 [35.14]	99.72 [39.26]
Seated Eye Height	64.61 [25.44]	75.74 [29.82]	86.86 [34.20]
Forearm-Hand Length	46.48 [18.30]	50.11 [19.73]	53.74 [21.16]
Shoulder Breadth	40.28 [15.86]	47.67 [18.77]	55.06 [21.68]
Seated Shoulder Height	56.15 [22.11]	61.56 [24.24]	66.97 [26.37]
Hip Breadth	31.67 [12.47]	37.76 [14.87]	43.86 [17.27]
Buttock - Popliteal Length	44.75 [17.62]	49.88 [19.64]	55.01 [21.66]
Buttock - Knee Length	56.89 [22.40]	62.50 [24.61]	68.12 [26.82]
Popliteal Height	43.15 [16.99]	46.81 [18.43]	50.46 [19.87]
Foot Width	9.80 [3.86]	10.94 [4.31]	12.09 [4.76]
Foot Length	28.44 [11.20]	30.42 [11.98]	32.41 [12.76]
Stature	169.77 [66.84]	179.80 [70.79]	188.82 [74.34]
Weight-kg [lbs.]	60.33 [133.00]	89.81[198.00]	119.30[263.00]
Chest Depth	20.01 [7.88]	25.37 [9.99]	30.73 [12.10]
Elbow Rest Height	15.77 [6.21]	22.27 [8.77]	28.77 [11.33]
Forearm Grip Distance	35.28 [13.89]	38.60 [15.20]	41.93 [16.51]

k = An acceptable percentage of the actual mean. In this case k was set to 0.05.

x = Mean or arithmetic average of the data. This is also the 50th percentile for the distribution.

The 5th and 95th percentile estimates of each of the anthropometric measures were calculated using the assumption that the data were normally distributed.

The experimental data were collected from clothed subjects in natural, relaxed sitting or standing postures. Thus, adjustments were necessary to make credible comparisons between experimental results and the ILO and SAE references. The ILO data, for example, are based on semi-nude subjects sitting or standing in erect postures. Therefore, for comparison with the ILO data, the experimental data were adjusted by subtracting appropriate cloth-

Table 3. Anthropometric measures of grapple skidder operators adjusted for clothing and posture.

Measurement—cm [in.]	Percentiles 5th	50th	95th
Thumbtip Reach*	77.26 [30.42]	83.59 [32.91]	89.91 [35.40]
Sitting Height	83.10 [32.72]	93.57 [36.84]	104.03 [40.96]
Seated Eye Height	68.13 [27.14]	80.06 [31.52]	91.18 [35.90]
Forearm-Hand Length*	46.48 [18.30]	50.11 [19.73]	53.74 [21.16]
Shoulder Breadth	39.67 [15.62]	47.06 [18.53]	54.45 [21.44]
Seated Shoulder Height	60.47 [23.81]	65.88 [25.94]	71.29 [28.07]
Hip Breadth	30.25 [11.91]	36.34 [14.31]	42.44 [16.71]
Buttock - Popliteal Length*	44.75 [17.62]	49.88 [19.64]	55.01 [21.66]
Buttock - Knee Length	56.38 [22.20]	62.00 [24.41]	67.61 [26.62]
Popliteal Height	40.61 [15.99]	44.27 [17.43]	47.92 [18.87]
Foot Width	9.04 [3.56]	10.18 [4.01]	11.32 [4.46]
Foot Length	25.40 [10.00]	27.38 [10.78]	29.36 [11.56]
Stature	169.26 [66.64]	179.29 [70.59]	188.31 [74.14]
Weight-kg [lbs.]	57.15 [127.00]	86.4 [192.00]	115.65 [257.00]
Chest Depth	18.97 [7.47]	24.33 [9.58]	39.69 [11.69]
Elbow Rest Height*	15.77 [6.21]	22.27 [8.77]	28.77 [11.33]
Forearm-Grip Distance	35.28 [13.89]	38.60 [15.20]	41.93 [16.51]

* Not adjusted for clothing or slump.

ing allowances (Table 1) and adding factors for "postural slump." Stature was increased by 2.03 cm [0.8 in.] and sitting height, seated eye height, and seated shoulder height were increased by 4.57 cm [1.8 in.] [3]. The SAE data, on the other hand, are based on lightly clothed operators sitting or standing in erect postures. Thus, for comparison with the SAE data, the experimental results were only adjusted for postural slump.

RESULTS AND DISCUSSION

General Findings

The 5th, 50th and 95th percentile measures calculated from the experimental data are presented in Table 2. These data are not corrected for clothing or "postural slump." The measures presented in Table 3 (except fore arm-hand length, thumbtip reach, buttock-popliteal length, elbow rest height and forearm grip distance) were adjusted to account for both of those factors.

Adjusted Data vs. SAE and ILO Data

The experimental data, adjusted only for postural slump, are compared to the SAE reference values in Table 2 and the differences are illustrated in Figure 2. Table 5 and Figure 3 make similar comparisons between the experimental data adjusted for clothing and slump and the ILO reference values. However, measurements for forearm-hand length, thumbtip reach, chest depth, foot width, seated shoulder height, buttock-popliteal length, elbow rest height, and weight were not included in the ILO database.

The ILO reference values compared favourably to the individuals measured in this study with the exception of sitting height, seated eye height, and shoulder breadth. For these three dimensions the 50th percentile values were comparable, but the operators exhibited a wider range. Thus, 5th percentile operators were smaller than the ILO data for these dimensions while 95th percentile operators were larger.

Comparisons between the skidder operators and SAE reference values revealed substantive differences. For all dimensions, the average value of the operators was larger than the 50th percentile SAE value. At least 7 measures (thumbtip reach; sitting height; seated eye height; shoulder breadth; seated shoulder height; stature and weight) showed significant differences in either 5th or 95th percentile values. The smaller skidder operators for instance, were over 16 cm [6.0 in.] taller than the 5th percentile SAE value for stature. Similarly, the larger operators were 21 kg [46 lbs] heavier than the 95th percentile SAE value for weight.

The above comparisons are not unexpected given the populations defined by the various databases. The ILO data describes a North American male industrial population and fits the observed operator data fairly well. The SAE data, on the other hand, describe a worldwide industrial population. In fact, the SAE document claims to include females in the database (although the ISO document that SAE J833 is derived from specifies male-only values). Compared to a worldwide average, North American operators will tend to be larger.

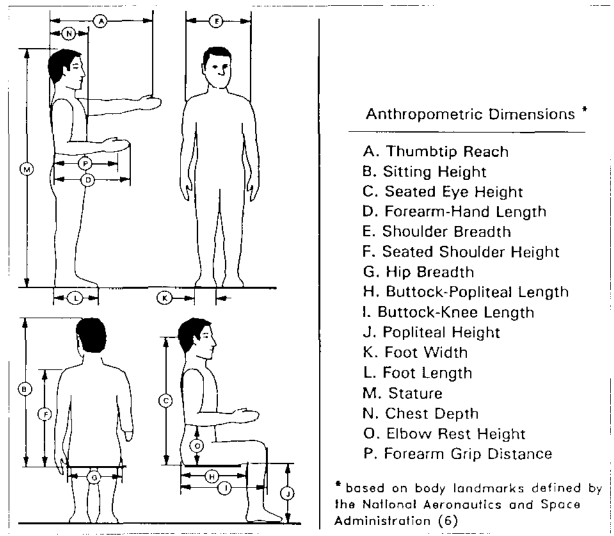

Figure 1. Anthropometric dimensions used in the study.

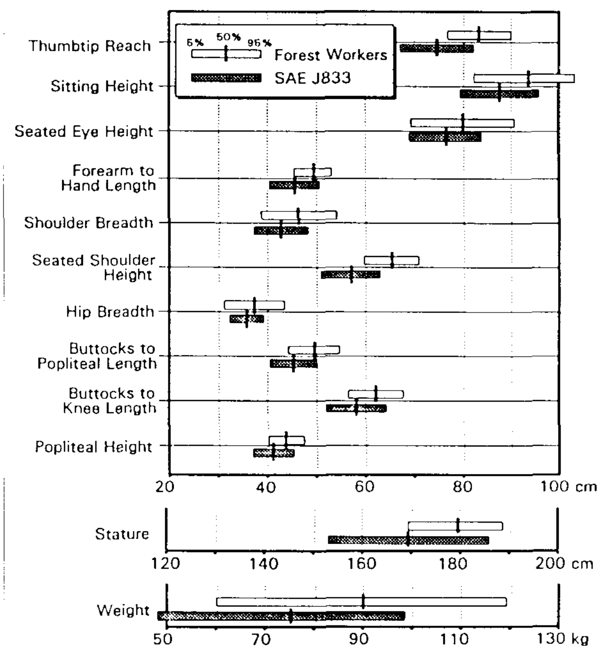

Figure 2. Comparison of adjusted forest worker anthropometry with SAE J833 data.

Table 4. Adjusted skidder operator data vs. SAE data. Difference: Operator—SAE J833.

Anthropometric Dimension	5th Percentile cm	[in.]	50th Percentile cm	[in.]	95th Percentile cm	[in.]
Thumbtip Reach	9.67	[3.81]	8.4	[3.34]	7.32	[2.88]
Sitting Height	3.56	[1.40]	5.9	[2.33]	8.29	[3.26]
Seated Eye Height	-0.41	[-0.16]	3.4	[1.34]	7.24	[2.85]
Forearm-Hand Length	5.48	[2.16]	4.1	[1.62]	2.75	[1.08]
Shoulder Breadth	2.58	[1.02]	4.5	[1.80]	6.57	[2.59]
Seated Shoulder	9.33	[3.67]	8.7	[3.44]	8.15	[3.21]
Hip Breadth	-0.83	[-0.33]	1.7	[0.70]	4.37	[1.72]
Buttock - Popliteal Length	3.85	[1.52]	4.1	[1.65]	4.52	[1.78]
Buttock - Knee Length	4.50	[1.77]	3.9	[1.54]	3.32	[1.31]
Popliteal Height	3.31	[1.30]	2.7	[1.09]	2.23	[0.88]
Shoe Width	0.80	[0.32]	0.6	[0.25]	0.49	[0.19]
Shoe Length	3.45	[1.36]	1.9	[0.76]	0.41	[0.16]
Stature	16.77	[6.60]	10.30	[4.05]	2.82	[1.11]
Weight—kg [lbs.]	12.18	[26.92]	16.59	[36.67]	21.00	[46.42]

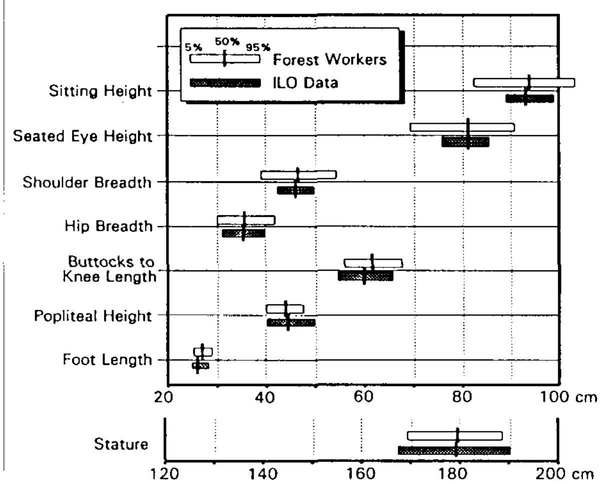

Figure 3. Comparison of adjusted forest worker anthropometry with ILO data.

Forest equipment cabs designed using SAE anthropometric data would not be optimum for operators in the Southern United States. The observed differences could hinder visibility, result in cramped work spaces, or increased seat damage and maintenance. The results could be a reduction in operator safety, increased fatigue and reduced efficiency. These undesired effects could be even more pronounced in the winter months when the use of bulky clothing further distorts differences between actual operator anthropometry and commonly used design standards.

CONCLUSIONS AND RECOMMENDATIONS

It is imperative that equipment designers have good anthropometric data in order to design machines that properly accommodate their users. The results of this study suggest that current SAE design data do not accurately reflect the size of forest equipment operators in the Southern United States. The study subjects were generally taller and heavier than the SAE design reference. The ILO reference, while providing a better fit to the subject population, has limited value for design since it is restricted in the number of anthropometric dimensions.

The results of this study also illustrate the difficulty of designing equipment for the global market. Specifying operator dimensions based on the SAE/ISO international anthropometry would not fully accommodate the user population that was sampled in this study. Yet equipment designers must provide

Table 5. Adjusted skidder operator data vs. ILO data. Difference: Operator—ILO data.

Anthropometric Dimension	5th percentile cm	[in]	50th percentile cm	[in]	95th percentile cm	[in]
Sitting Height	-5.89	[-2.32]	0.58	[0.23]	5.02	[1.98]
Seated Eye Height	-7.06	[-2.78]	-0.93	[-0.37]	5.18	[2.04]
Shoulder Breadth	-2.33	[-0.92]	1.06	[0.42]	4.44	[1.75]
Hip Breadth	-0.73	[-0.29]	1.34	[0.53]	2.43	[0.96]
Buttock - Knee Length	1.39	[.55]	2.00	[0.79]	1.62	[0.64]
Popliteal Height	0.22	[.09]	-.22	[-0.09]	-2.08	[-0.82]
Foot Length	0.40	[0.16]	0.88	[0.35]	0.86	[0.34]
Stature	2.26	[0.89]	0.30	[0.12]	-1.67	[-0.66]

designs for worldwide use. Equipment designers should consider the possibility that specific national worker populations (such as North American forest equipment operators) may be poorly represented by global averages. Critical clearance design values such as emergency exit and access dimensions may need to be designed for the 99th percentile global operator. Similarly critical reach design values such as control placement may need to be designed for the 1st percentile global value. If designing for an appropriately large range of operator sizes is prohibitive, designers must give consideration to the implications of their selection of anthropometric data.

Forest equipment designed using SAE standards would not fully accommodate the user population that was sampled in this study. However, because this project was limited to a small region of the United States, further anthropometric research should be conducted on a broader sample of forest equipment users to determine whether the data repre sent the larger population. If there are significant regional differences between the primary wood-producing regions of the United States, these should be noted and eventually reflected in appropriate design recommendations.

ACKNOWLEDGEMENTS

The authors thank the U.S. Forest Service and the Department of Industrial Engineering, Auburn University, for supporting this research and Ms. B. Swanson for typing the manuscript.

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