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COMFORT AND CONVENIENCE SPECIFICATIONS FOR SAFETY BELTS: SHOULDER BELT FIT, PRESSURE AND PULLOUT FORCES

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This study is an extension of an earlier study titled "Development of Specifications For Passive Belt Systems" (Contract DOT-HS-7-01617).

16. Abstract

A three-part study was conducted to further define comfort requirements for seat belt systems with respect to shoulder belt fit, shoulder belt contact pressure, and 3-point restraint system pullout forces. Objective of the belt-fit portion of the study was to determine how much an originally-proposed shoulder belt crossing specification could be modified (to make it less restrictive on the vehicle designer) if a somewhat smaller segment of the user population was accepted as the criterion for design. As a result, a new compliance envelope was developed and is herein proposed. The objective of the shoulder belt pressure portion of the study was to verify (or modify) the upper pressure criterion limit derived in the original study, using a larger sample of test subjects. The results essentially confirmed those of the original study. Purpose of the shoulder belt pullout force portion of the study was to develop a criterion value for inclusion in the new comfort rulings if this appeared desirable. The value found proved to be essentially the same as one developed in an earlier study of active belt system comfort ("Sources and Remedies For Restraint System Discomfort and Inconveniences," DOT-HS-230-3-674, Final Report dated October 1974).

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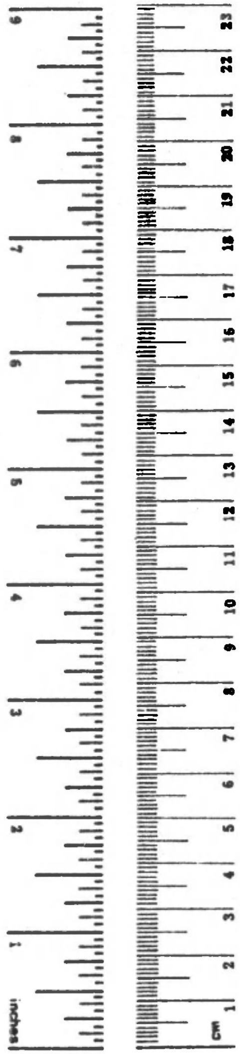
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

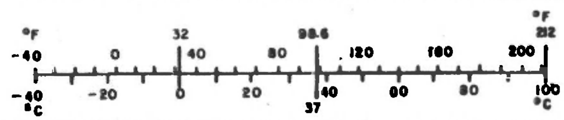
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Introduction

Opinion surveys taken over the past several years indicate that a prime reason many people give for not wearing seat belts is that they are inconvenient to don and doff and uncomfortable to wear.

Two previous NHTSA-sponsored studies have attempted to determine the reasons for this discomfort and to develop performance specifications designed to minimize such problems in future seat belt designs.

The first such study, entitled, "Sources and Remedies for Restraint System Discomfort and Inconveniences" (DOT-HS-230-3-674), examined a variety of three-point, active seat belt systems typical of the 1973-74 time period to determine why such systems elicited so many comfort and convenience complaints. The result was a number of recommendations for improving belt system geometry, design and location of buckling hardware, and retraction force limits to minimize webbing pressure discomfort.

The second study, "Development of Specifications for Passive Belt Systems" (DOT-HS-7-01617), examined the applicability of the previous recommendations to passive seat belt systems being proposed for vehicles of the 1980 time frame. As a result of this second study several recommendations were made regarding "belt fit" and webbing pressure limits in order to provide information that could be used in proposed modifications of the Federal Motor Vehicle Safety Standard (FMVSS) 208.

Recommendations in both of the above studies were based on the objective of "fitting" at least 90 percent of the user population, defined as a range of users from the 5th percentile female through the 95th percentile male. These recommendations placed considerable constraint on the automobile industry in applying the recommended specifications across all vehicle models. They also placed a particularly difficult requirement on designers with respect to passive belt systems. In the latter case, belt system installation is constrained by the ultimate positioning of one end of the belt system on the door. And in some cases, because of a particular body style, available anchoring points are not always compatible with the geometric requirements of the belt webbing for meeting the recommended shoulder belt comfort pattern.

Anxious to avoid placing unnecessary constraints on vehicle body styles, yet well aware of the importance of making sure belt systems are as comfortable as they can be made within these practical considerations, NHTSA sponsored the present study in order to re-examine the critical comfort aspects of shoulder belt fit and occupant torso contact pressure. Since impending changes to FMVSS 208 will also cover active belt system design, a third shoulder belt consideration also was reexamined during the study, namely, the force necessary to pull the latchplate from its stowed position and insert it in the buckle. Although pull-out force recommendations were developed in the prior study, belt configurations at that time differed from currently designed systems (i.e., the stowed latchplate position was on the outboard side of the occupant near his or her hip, whereas current latchplate stowage positions are now above the occupant's shoulder, typically mounted on a B-pillar).

Purpose of Study

The purpose of this study, therefore, has been to extend our knowledge about fitting occupants and to specify webbing retractor force (upper) limits to ensure that both the "wearing pressure" and the "webbing pull-out" forces required to don an active belt system are acceptable to the majority of potential belt wearers.

One result of the previous passive belt study was the development of a special "fit" compliance envelope specification (see Appendix A). A procedure was developed whereby a rectangular compliance envelope is marked on the chest of a 50th percentile anthropomorphic dummy (Part 527) representing the acceptable chest and shoulder crossing pattern for the full range of anticipated users from the 5th percentile female through the 95th percentile male. This envelope necessarily is restrictive in that, if a planned shoulder belt installation is anchored in such a way that the webbing does not cross the test dummy's chest within the marked compliance envelope, one can expect that smaller or larger wearers will experience various levels of discomfort and annoyance. That is, the webbing probably will ride against the neck, across a sensitive portion of the inboard breast, and/or will tend to fall off the outboard shoulder, especially following a forward- or sideward-reaching activity.

However, recognizing the potential problem manufacturers may experience in anchoring passive seat belts in such a way that both comfort and safe restraint can be provided simultaneously, the question has been raised, "How much of the user population might be less well-fitted if the proposed compliance envelope were to be slightly enlarged to fit a wider range of vehicle body configurations and belt anchoring constraints?"

Thus, a major purpose of this study was to determine what (if any) modifications could be made to the proposed compliance envelope to fit various, smaller population groups, viz., 10th percentile female-90th percentile male, 15th percentile female-85th percentile male, and/or 20th percentile female-80th percentile male.

The second part of the study involved an expansion of the information base obtained during the two previous studies relative to shoulder belt pressure and pull-out force, the purpose being to increase the reliability or credibility of the previous findings by increasing the data base upon which force criteria are based. This was considered important principally because of the subjective nature of these data and the need to sample a greater number of subject opinions.

1.0 General Methodology

1.1 Approach

The general approach taken in this study was similar to that of previous studies. This was important from a methodological point of view since a primary objective of these experiments was to extend the knowledge previously accumulated.

A few modifications, noted below, are discussed in terms of the three individual experiments conducted.

a. Shoulder Belt Fit Experiment - In the active belt system study mentioned previously, a mockup was used to evaluate various seat belt webbing geometries. In the passive belt study, webbing geometry was studied in an actual automobile. Each method has benefits and drawbacks. However, the governing factor in the present study was the need to have as precise control over geometric variation and measurement as possible, hence a mockup was used since it provides greater flexibility and simplicity (see Figure 1).

The general approach taken was to start with an optimized belt geometry and then determine how great a departure from this ideal configuration various user percentile categories would find acceptable, the principal concern being shoulder belt fit.

b. Shoulder Belt Contact Force Experiment - The primary purpose of this experiment was to acquire additional force acceptance data since the earlier study utilized a limited number of subjects. The same mockup (Figure 1) was used. Although in the passive belt study force acceptance was studied in both an actual automobile (wherein subjects rode in the vehicle over a controlled course) and also in a static mode (where subjects merely sat in the car and evaluated belt pressures), comparison of these results showed that the resulting subjective judgments were the same regardless of the mode in which the data were taken. Based on this finding the present experiment was conducted using the static (i.e., mockup) mode. The same experimental methodology was used as in the previous studies namely, the "Method of Limits." This approach involves exposing subjects to both an ascending and descending series of belt pressures until (in each case) the subject selects the force level s/he judges acceptable. The point at which these two judgments of acceptability cross over is considered the subject's acceptance level.

c. Shoulder Belt Pull-Out Force Experiment - The purpose

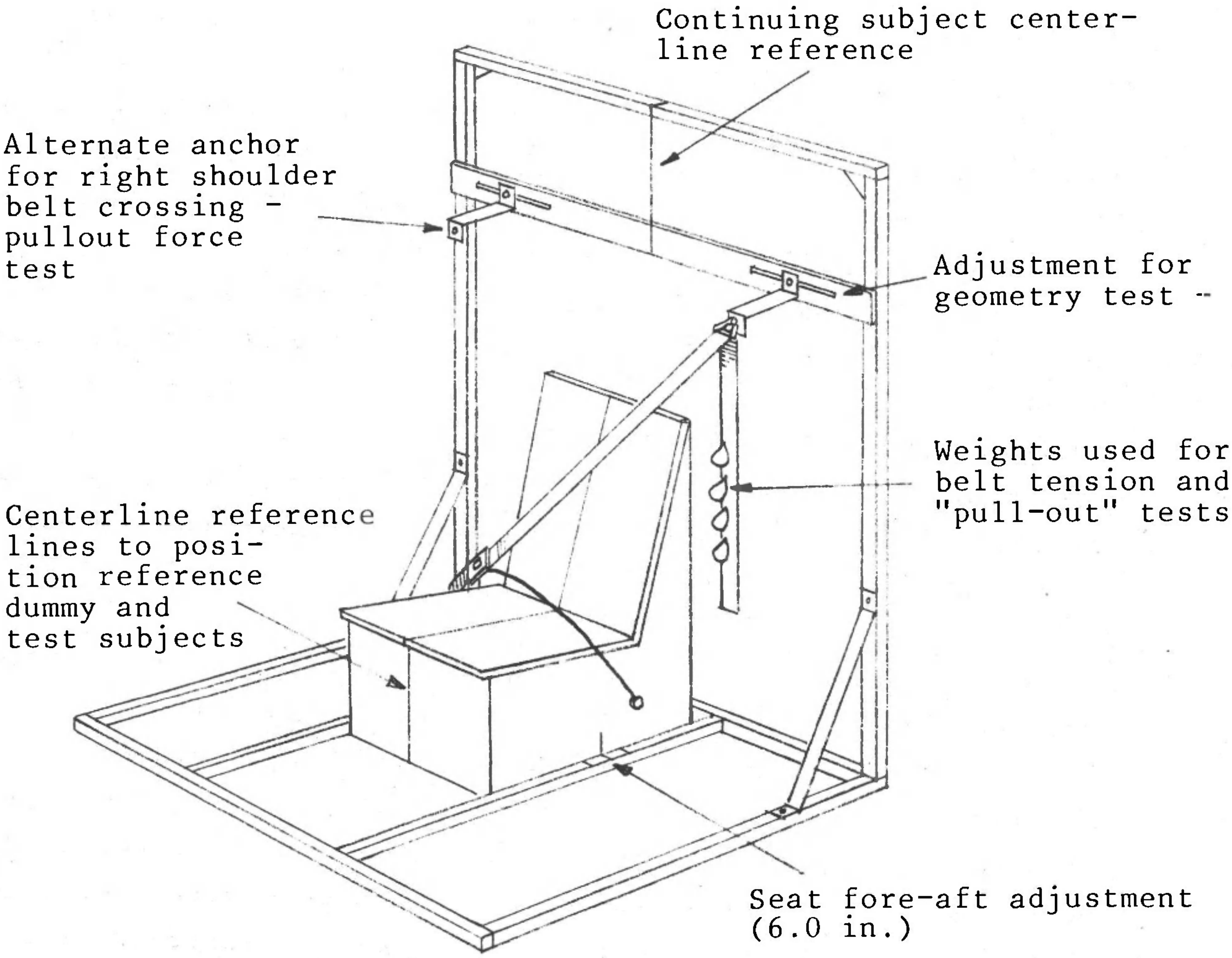


Figure 1 - General Apparatus Used for Tests

of this experiment was to determine the maximum force belt users will accept relative to the task of pulling the latchplate from its stowed position for the purpose of buckling up. In the earlier (active) belt study, a similar experiment was conducted, however at that time seat belts were configured differently than they are at present. That is, in the earlier configurations it was the practice to locate the latchplate alongside the occupant's seat. Today, latchplates are located above the occupant's shoulder, generally on the vehicle's B-pillar.

The experimental method used in this study was similar to that noted above for the pressure experiment, namely, the method-of-limits approach. One additional variable was also introduced for this study: subjects were tested for both over-the-right and over-the-left shoulder belt pull, typical of the difference between dirver and passenger belt system installations.

1.2 Test Apparatus

The principal apparatus used for all three experiments was, as noted, the mockup illustrated in Figure 1.

A three-point seat belt system was simulated by mounting a D-ring above and behind either the subject's right or left shoulder as required. Actual webbing was used for the shoulder belt. An off-the-shelf latchplate and buckle were used together with a short length of webbing with flexible stiffener for anchoring the buckle segment to the seat. Instead of an actual lap belt, however, a bungee cord was used in order to avoid the necessity for mounting a retractor on the outboard side of the seat. And instead of using a retractor to supply force at the upper end of the shoulder belt, weights were hung on the free end of the shoulder belt. This not only provided simulation of a retracting force for the belt-fit experiment but also provided a simple method for sampling various force levels for the other two experiments (i.e., by adding or removing weights, specific contact and/or pull-out force conditions could easily be simulated).

Other features of the mockup shown in the illustration (e.g., referencing marks) were used to assist the experimenter in positioning subjects in a centered and erect position in the seat. These reference marks also were used to align a 35mm camera used to capture key belt-fit film records.

1.3 Test Subjects

Two categories of subjects were used during the study. For the belt-fit experiment, subjects were chosen to represent specific anthropometric classifications. That is, since our objective was to determine whether belt-fit geometries were different for each of the subject size categories, two subjects were selected for each of the following size/sex categories:

a. Females:
   - Two 10th percentile
   - Two 15th percentile
   - Two 20th percentile

b. Males:
   - Two 90th percentile
   - Two 85th percentile
   - Two 80th percentile

Percentiles were based on sitting height as defined in the 1960 HEW survey (see Table 1).

The critical percentile dimension used was sitting height, although it is recognized that using just two subjects in each sitting-height category does not necessarily represent all other possible differences in anthropometric variation that might influence belt-fit effectiveness (i.e., differences in shoulder width, chest depth, breast configuration, etc.).

For the force experiments, a partially random sampling approach was taken in selecting subjects. For the belt contact force experiment, 30 females and 30 males were randomly chosen since the nature of the test involved subjective response to a phenomenon that can only be measured by allowing the subjects to experience and compare different contact forces. This sample provided an effective range of characteristics as these might influence

Table 1 - Basic U.S. Adult Anthropometric Reference

Percentile	Standing Height		Sitting Height	
5	63.6	59.0	33.2	30.9
10	64.5	59.8	33.8	31.4
20	66.0	61.1	34.4	32.2
30	66.8	61.8	34.9	32.6
40	67.6	62.4	35.3	33.1
50	68.3	62.9	35.7	33.4
60	68.8	63.7	36.0	33.8
70	69.7	64.4	36.5	34.2
80	70.6	65.1	36.9	34.6
90	71.8	66.4	37.6	35.2
95	72.8	67.1	38.0	35.7

Basic Percentile Dimensions of
U.S. Adult Population
(18 to 79 years)

H. W. Stoudt, et al., Weight, Height and Selected Body Dimensions of Adults, United States 1960-1962. Public Health Service Publication No. 1000, ser. 11, no. 8

individual judgments of pressure acceptability--male vs. female, small vs. large people, sensitive vs. relatively insensitive people, and younger vs. older persons. (See Tables 2 and 3.)

For the pull-out force experiment, 25 small and (apparently) weaker female subjects were selected. The rationale for this selection was based on the assumption that people with these characteristics ordinarily would be the ones who might object most to high pull-out forces. In addition these also represented the group that would be most disadvantaged in terms of awkwardness in reaching for and pulling a latchplate from a position above and behind their shoulder (the current latchplate position for active belt systems).

As indicated by Table 4, however, there was some departure from this objective due to the difficulty of obtaining the desired subjects within the time frame of the experiments.

Although in previous studies subjects typically have been selected on the basis of having a valid driver's license, in the present case no attempt was made to select drivers only, since the questions under investigation applied equally to vehicle passengers and drivers.

Specific subject sample characteristics for each of the above experiments are discussed in greater detail in the following experiment descriptions.

2.0 Experiment 1: Shoulder Belt Fit

2.1 Test Procedure

a. Mockup Preparation - A baseline belt configuration was set up representing the originally proposed compliance pattern established to accommodate 5th-percentile female through 95th-percentile male belt users (see Appendix A). This was done by placing a marked, 50th percentile dummy in the seat, adjusted to a mid-position (see Figure 2). A reference scale (marked in 1/2-inch increments) was placed above the upper shoulder belt anchor point, its zero, center point opposite the mid-shoulder point on the dummy. This baseline belt configuration represented a precisely-centered belt within the aforementioned compliance envelope marked on the dummy.

Table 2 - Male Subject Distribution by Stature, Age and Weight For the Contact Force Experiment

Stature	Age	Weight
5' 4"	62	110 lbs
5 6	23	150
5 6	23	175
5 7	16	145
5 7	19	138
5 7	20	150
5 7	64	144
5 8	36	130
5 8	62	190
5 8 3/4	19	139
5 9	20	160
5 10	20	160
5 10	23	150
5 11	20	150
5 11	20	160
5 11	20	160
5 11	21	200
5 11	28	170
6 0	21	180
6 0	22	220
6 0	23	145
6 0	25	160
6 0	44	160
6 1	17	165
6 1	20	177
6 1	39	207
6 2	20	170
6 2	24	165
6 3	21	170
6 3	24	185

Table 3 - Female Subject Distribution by Stature, Age and Weight For the Contact Force Experiment

Stature	Age	Weight
4' 11"	41	90 lbs
5 0	23	117
5 0	65	98
5 1	40	150
5 1	60	99
5 1½	46	140
5 2	26	130
5 2	27	165
5 2	28	120
5 2	33	140
5 2	45	137
5 3	20	137
5 3	20	115
5 3	20	120
5 3	25	150
5 3	30	136
5 4	17	130
5 4½	28	125
5 5	17	120
5 5	18	125
5 5	19	135
5 5	22	133
5 5½	22	126
5 6	29	150
5 6½	17	125
5 6½	25	159
5 7	35	135
5 8	27	150
5 8	48	200
5 8½	35	115

Table 4 - Female Subject Distribution by Stature for Pullout Experiment

Stature	Age	Weight
4' 10½"	61	105 lbs
4 11	52	119
4 11	51	98
5 0	42	115
5 0	45	105
5 3/4	50	130
5 1	51	135
5 1	52	110
5 1½	39	108
5 1½	51	112
5 1½	57	120
5 1½	60	200
5 1½	73	125
5 2	36	83
5 2	39	104
5 2	47	90
5 2	61	95
5 2	74	147
5 2½	65	165
5 2 3/4	59	120
5 3	53	113
5 3	57	128
5 3	60	113
5 4	54	135
5 4	61	127

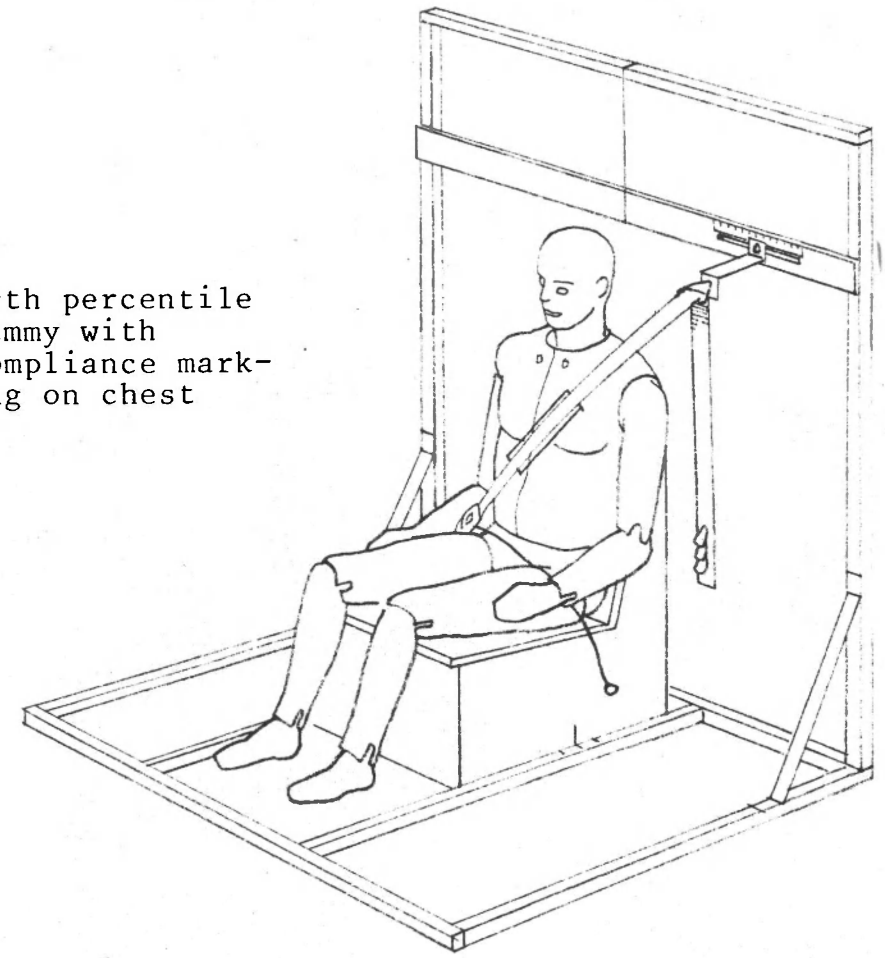


Figure 2 - Baseline Belt Configuration

b. Subject Measurement - Following removal of the test dummy, subjects were seated one at a time in the mockup and asked to don the belt system. Female subjects were seated with the seat in the most forward position; male subjects were seated in the most aft position. Seat adjustment range was 6-inches, three inches forward or aft of the mid position used in establishing the baseline belt configuration.

As each subject was properly positioned (i.e., sitting erect and aligned with mockup vertical reference marks), the upper shoulder belt anchor was shifted first inboard, then outboard, to locate the lateral limits acceptable for the particular subject. These limits represented positions of the belt that were just short of creating the pre-established problems of causing the webbing to touch the subject's neck, lie across or lift a breast, and/or fall off the subject's shoulder. In the last case subjects were asked to lean forward and back as well as side to side several times to determine whether the belt would remain on the shoulder when subject returned to his or her original erect and vertically-aligned position. When both experimenter and subject were satisfied that proper limits had been reached for both inboard and outboard shifts of the belt, the positions of the anchor point relative to the zero reference were recorded and later plotted on a graphic chart on which the original compliance envelope also was shown. This method allowed us to plot inboard and outboard edges of the belt acceptable to each subject and thus illustrate how much each percentile-subject's acceptance limits varied from the original compliance envelope.

2.2 Test Results

Results of individual subject "fittings" are presented in the form of graphic plots of inboard and outboard belt limits with reference to the originally proposed compliance envelope (designed to accommodate 5th percentile female through the 95th percentile male user population).

Figure 3 is a plot of the mean shoulder belt inboard and outboard limits for the two 10th percentile female subjects.

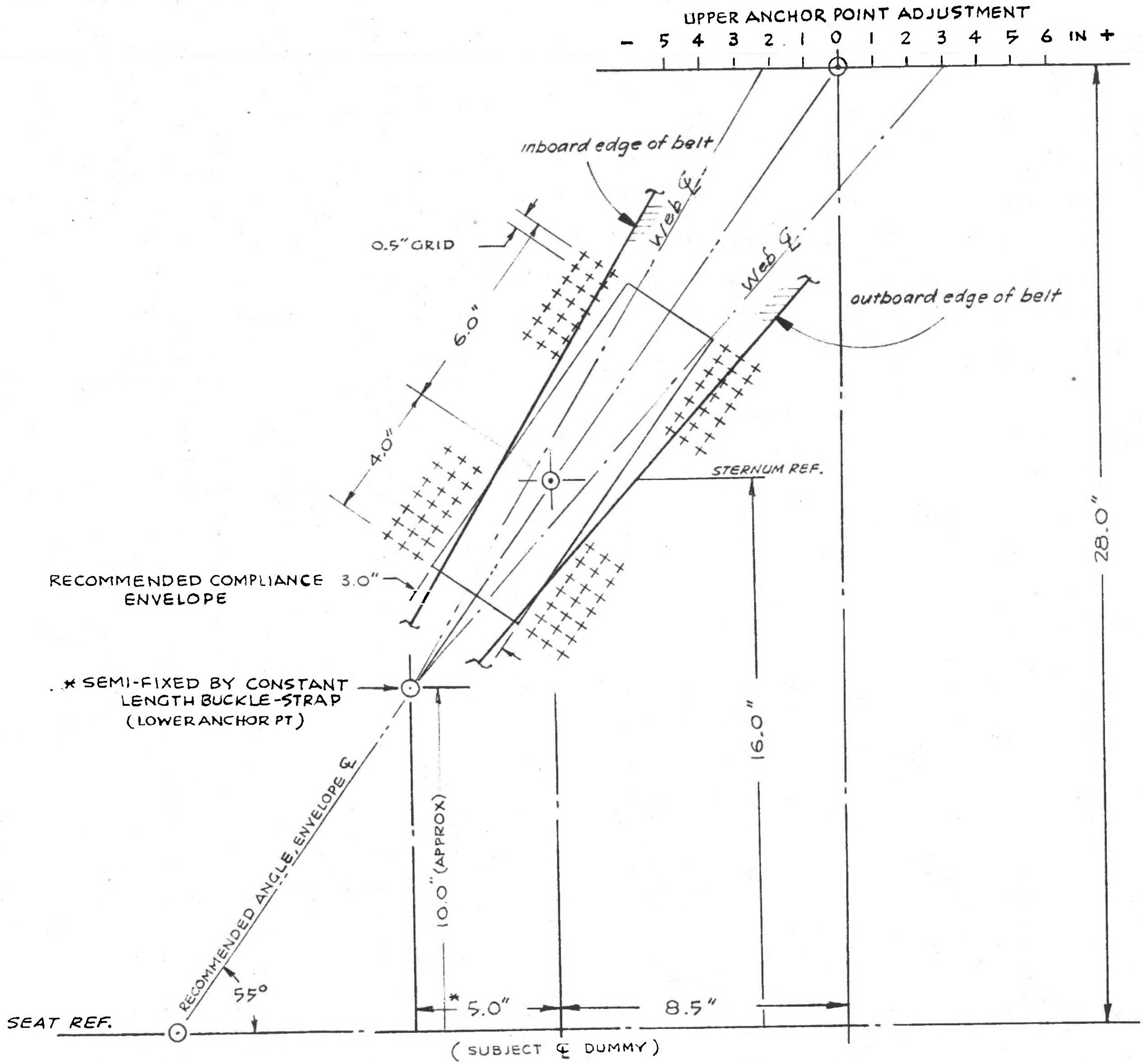


Figure 3 - Mean Acceptable Range of Belt Positions (10th Percentile Composite)

This plot shows that the belt could be moved approximately 1/2-inch closer to the neck (as compared to the originally proposed compliance envelope borders), and approximately 1-inch closer to the shoulder and still be acceptable to this percentile group.

Figure 4 provides a similar plot for the 15th percentile female subjects. It shows that, for this group, the belt could be moved approximately 1/2-inch closer to the neck and slightly more than 1/2-inch closer to the shoulder.

Figure 5 provides a plot of the 20th percentile female subjects. It shows that, for this group, the belt could be moved slightly less than 1/2-inch closer to the neck and 1/2-inch closer to the shoulder.

Although it would seem reasonable to expect the foregoing series of plots to show a systematic progression of variation toward the neck and/or shoulder as subject size increased, the results contradict such an assumption. This undoubtedly is due to anatomic variations among subjects. That is, subject sitting height alone does not account entirely for how a belt may fit. Although it is possible that a systematic progression might accrue if a much larger sampling of each percentile group was made and averaged, this still may not be of practical significance due to the variation introduced by different female undergarments. (This effect was apparent not only in this experiment but has been noted in numerous earlier experiments.)

Figures 6 through 8 show plots for the three male subject groups. Figure 8 for the 90th percentile male subject group shows that the belt can be moved approximately 1-1/2 inches closer to the neck and slightly less than 1/2-inch closer to the shoulder.

Figure 6 shows that for the 80th percentile male group, the belt could be moved about 1-1/2 inches closer to the neck and 1/2-inch closer to the shoulder.

Figure 7 shows that for the 85th percentile male group, the belt could be moved about 1-3/4 inches closer to the neck, but could not be moved toward the shoulder at all.

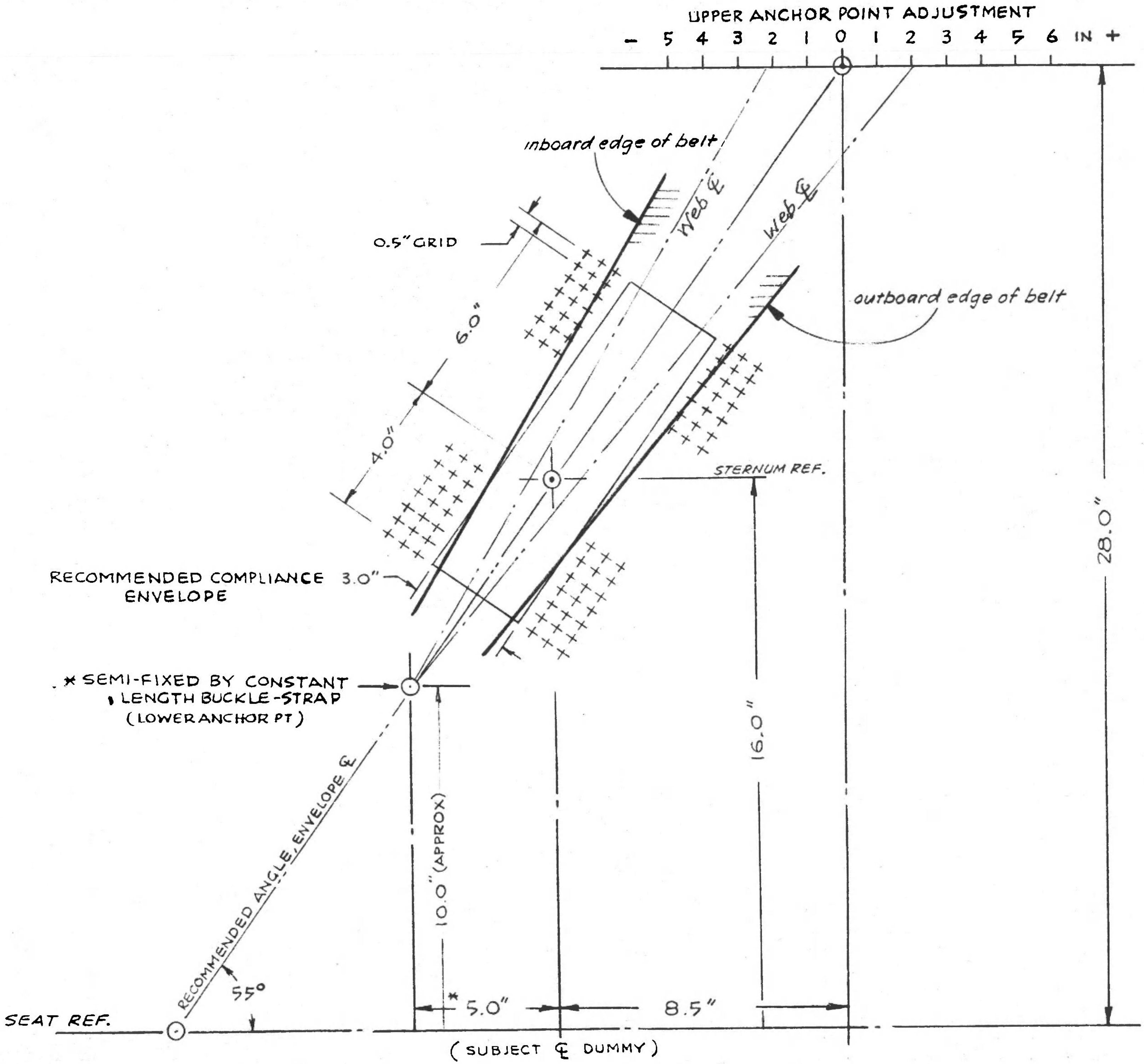


Figure 4 - Mean Acceptable Range of Belt Positions (15th Percentile Composite)

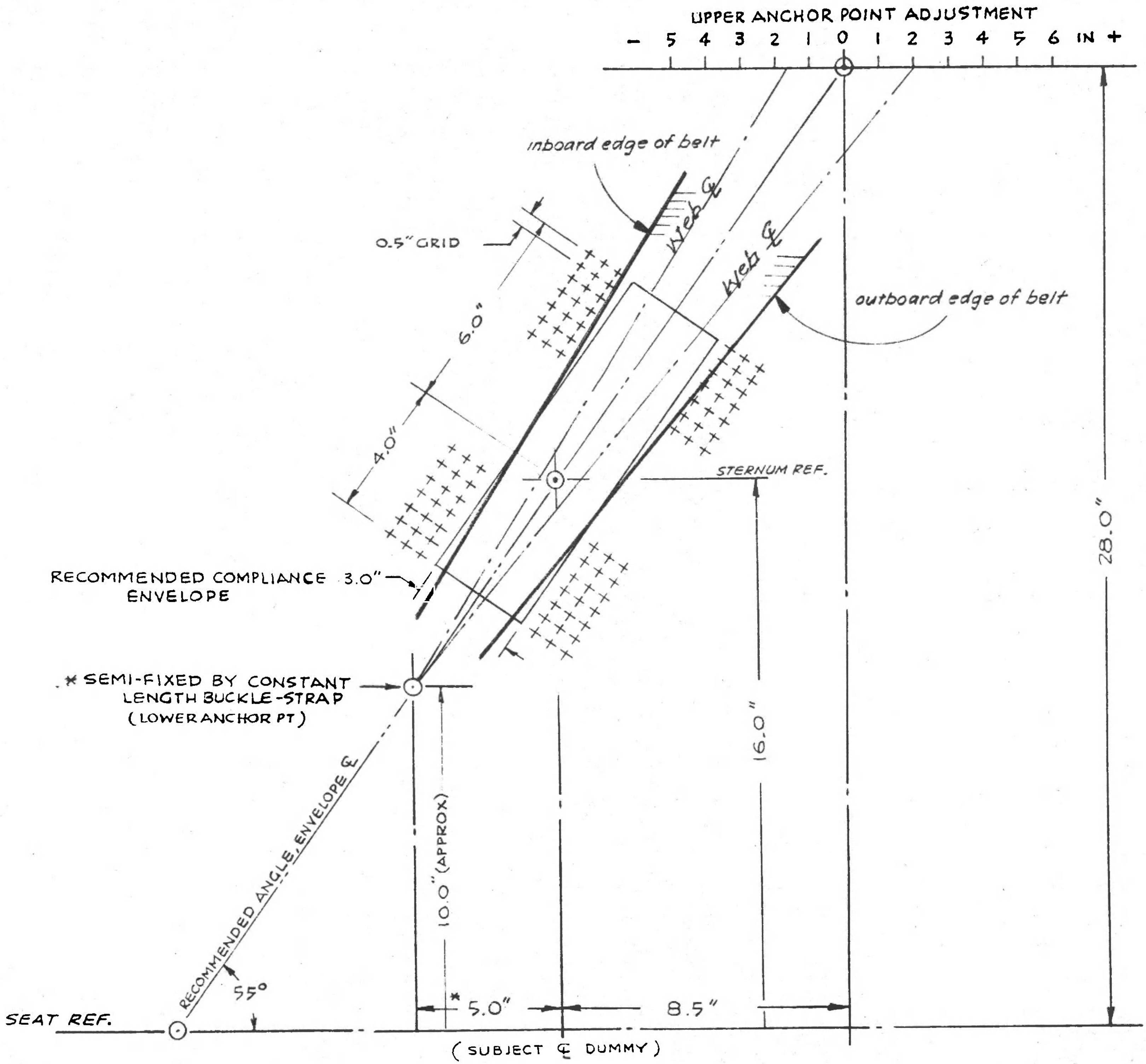


Figure 5 - Mean Acceptable Range of Belt Positions (20th Percentile Composite)

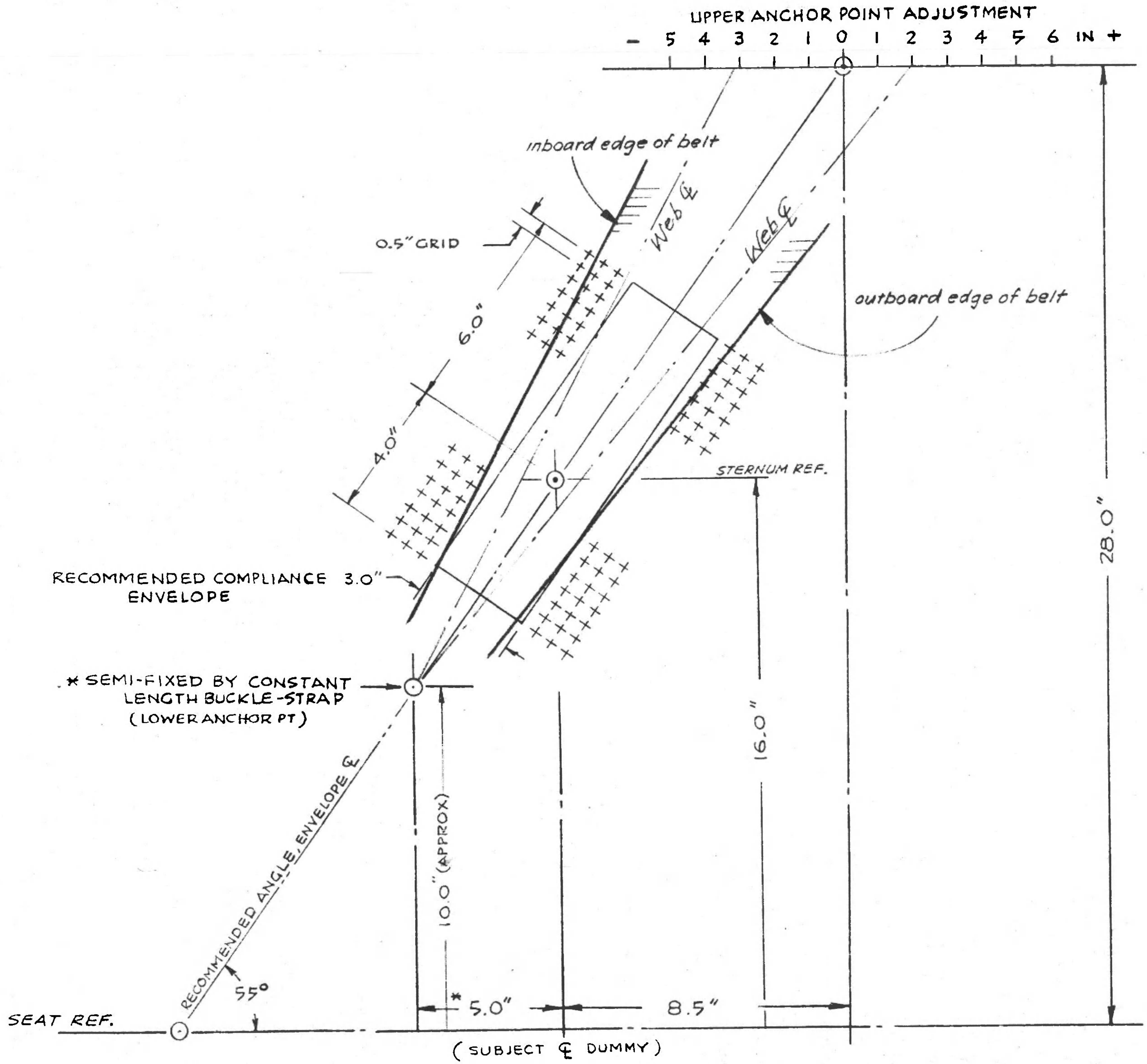


Figure 6 - Mean Acceptable Range of Belt Positions (80th Percentile Composite)

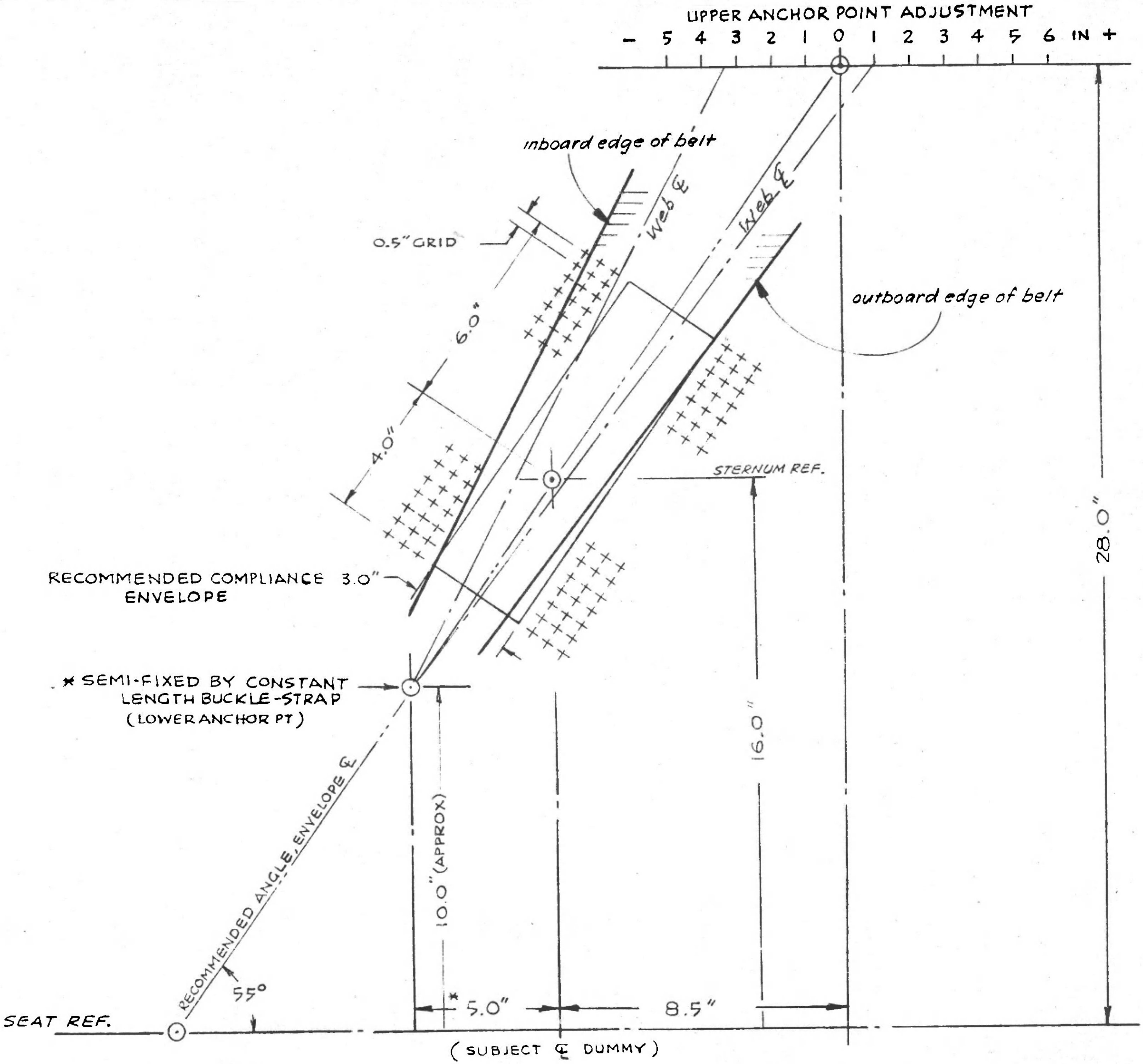


Figure 7 - Mean Acceptable Range of Belt Positions (85th Percentile Composite)

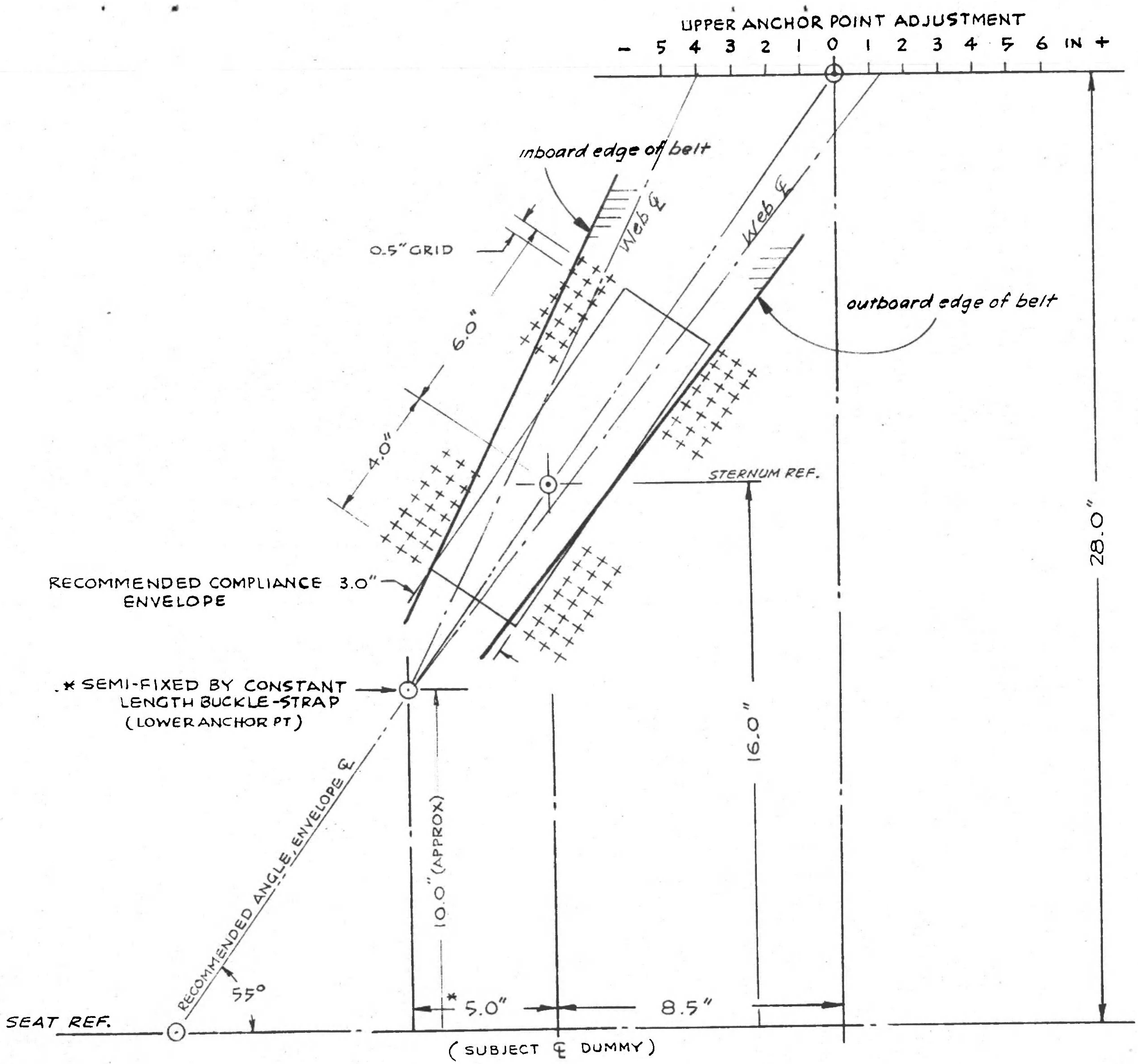


Figure 8 - Mean Acceptable Range of Belt Positions (90th Percentile Composite)

Again, the assumption that there should be some systematic variation as one proceeds from the 90th to the 80th percentile subject size is not borne out by the test results. In the case of males one cannot blame inconsistencies on undergarments. Therefore it can be assumed that true anatomical variables introduce unique, individual fit variations. Among these probably are shoulder slope, width, depth, and possibly postural irregularities (e.g., spine/neck curvature).

2.3 Discussion

In order to interpret the implications of the foregoing plots it is desirable to compare the limiting subject sample ranges. This serves to provide a general indication as to which end of the sample creates the limiting factor for either the inboard or outboard relaxation of original compliance envelope borders.

In Figure 9, the sample range represented by the 10th percentile female through the 90th percentile male is shown. This plot indicates that female anthropometry sets the limit for moving the belt closer to the neck, while male anthropometry sets the limit for moving the belt toward the shoulder. An interesting point to note also is the fact that both male and female samples could not tolerate widening of the original envelope at the bottom.

In Figure 10, the sample range represented by a 15th percentile female through an 85th percentile male is shown. This plot indicates that the female again sets the limit in terms of possible movement of the belt closer to the neck, whereas the male again establishes the limit for moving the belt toward the shoulder.

In Figure 11, the sample range represented by a 20th percentile female through an 80th percentile male is shown. This plot indicates that the female once again sets the limit in terms of possible movement of the belt closer to the neck; but in this case both male and female require essentially the same limiting parameter for possible outboard movement of the belt.

If one were to take the inboard and outboard limits of both the 10th percentile female and the 90th percentile male

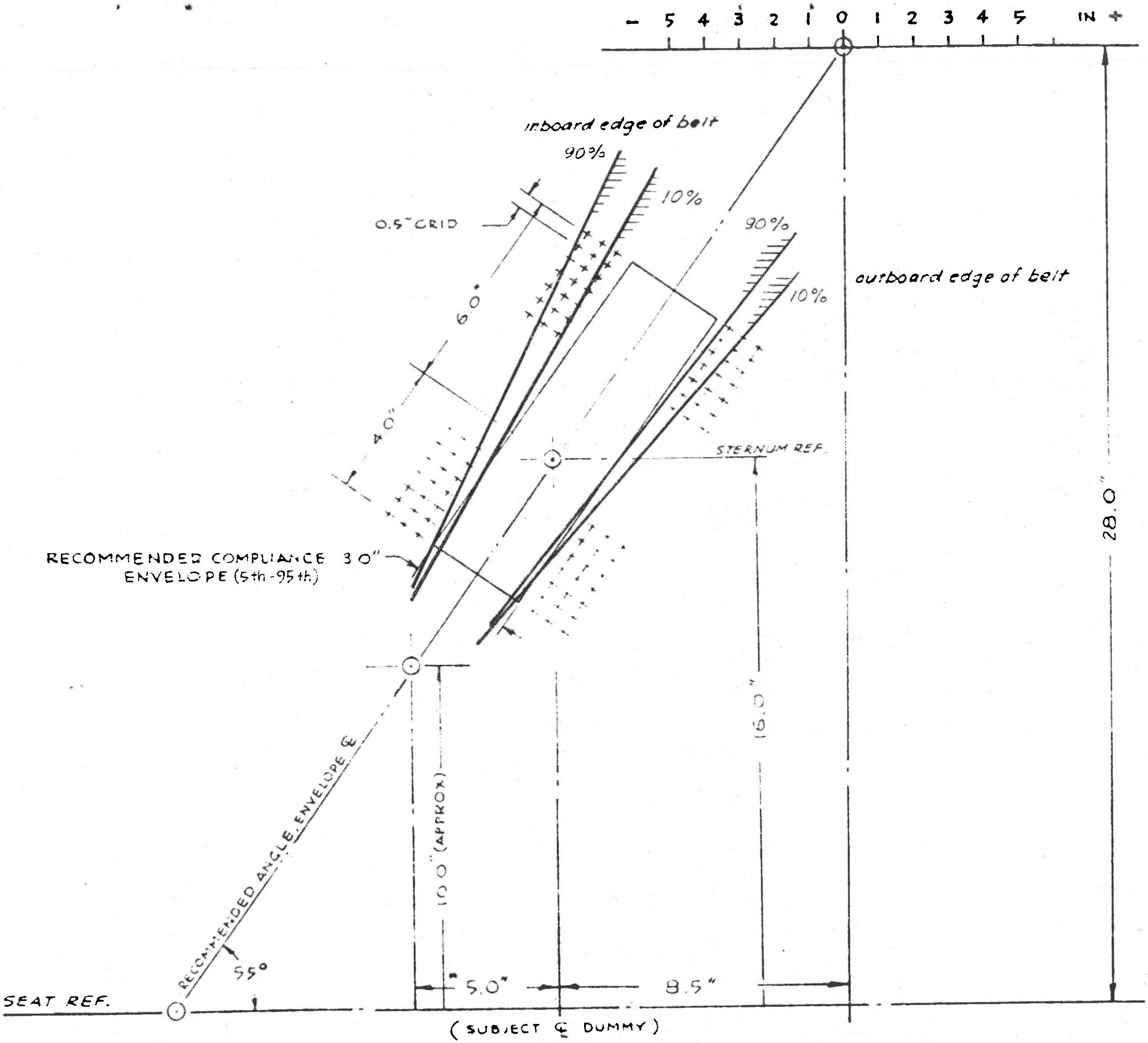


Figure 9 - Sample Belt Geometry Range: 10th Percentile Female Through 90th Percentile Male

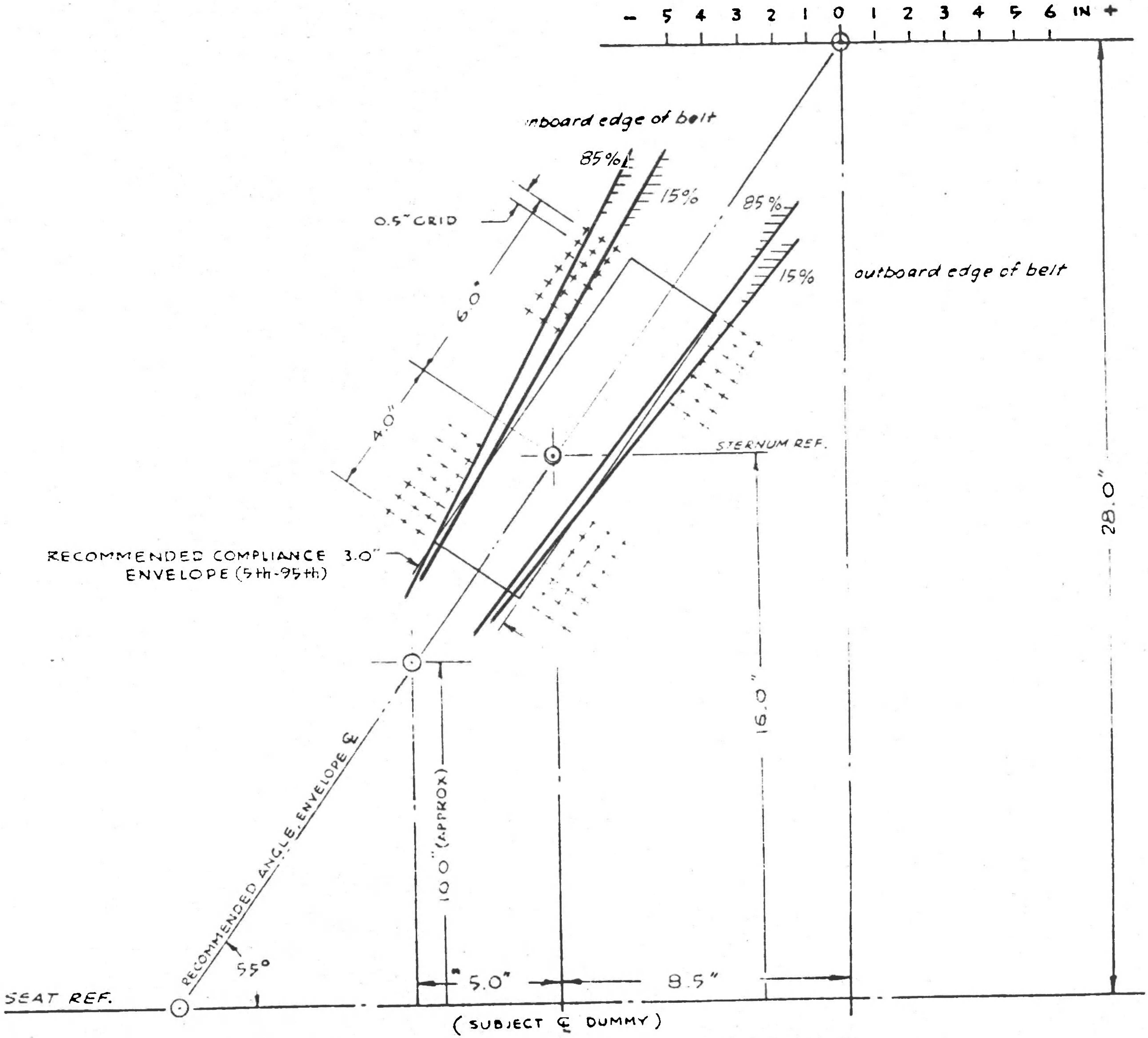


Figure 10 - Sample Belt Geometry Range: 15th Percentile Female Through 85th Percentile Male

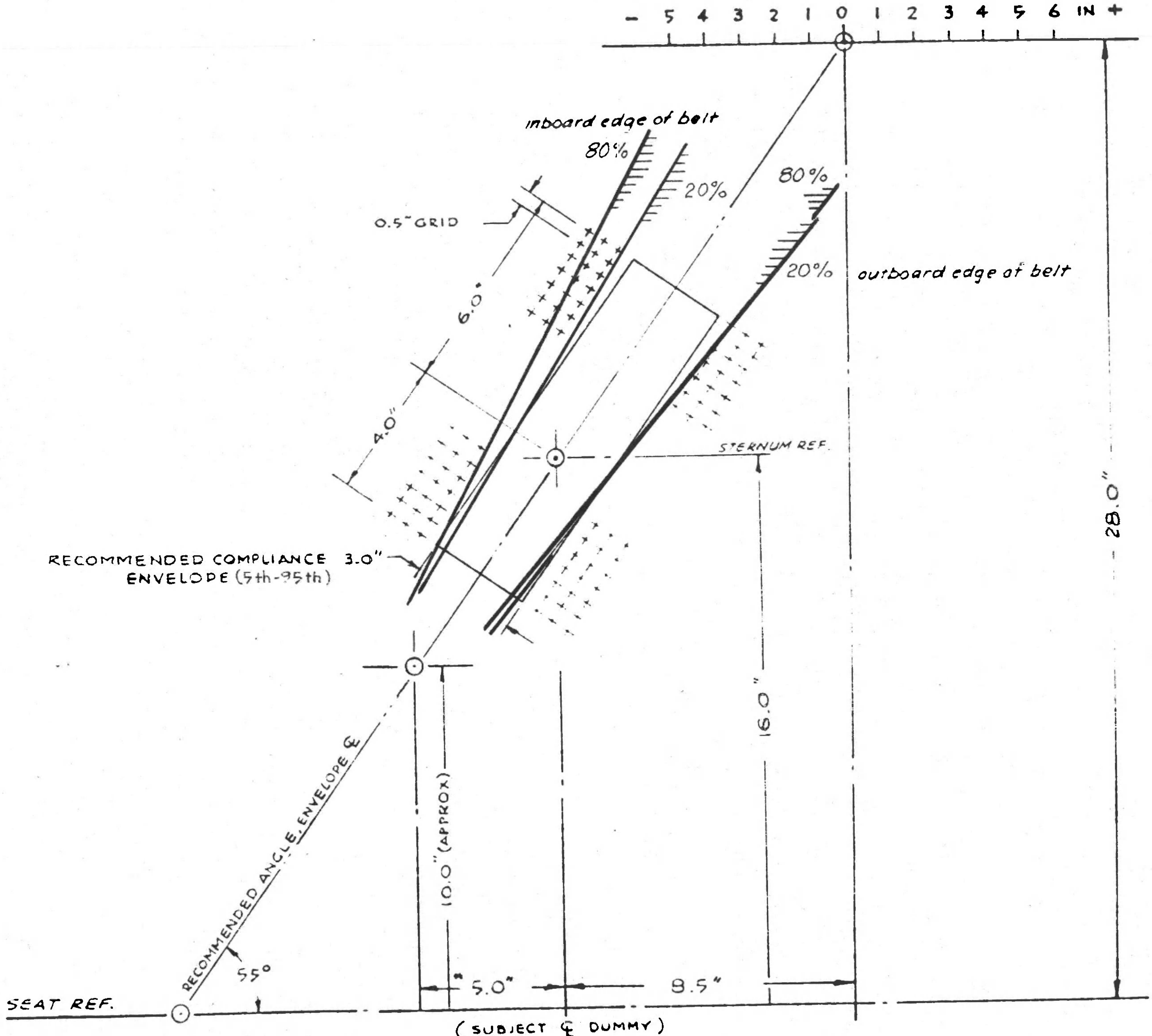


Figure 11 - Sample Belt Geometry Range: 20th Percentile Female Through 80th Percentile Male

plots and construct an envelope about the original compliance envelope sternum reference, a wedge-shaped envelope would be created as shown in Figure 12. Then if one were to "inlay" a 2-inch simulated belt within this envelope, first rotated to the outboard limits of the envelope, then to the inboard limits, it is possible to see how much leeway a designer has with respect to installing a shoulder belt and still be within acceptance limits of a user population that is 10 percent less than the original envelope required to fit the 5th to 95th percentile range. This is illustrated in Figure 13.

Since each of the illustrations in this figure represents a shift in the belt as it crosses the general sternum area, it is possible to consider whether the envelope could be shortened and still represent the limits within which a belt must fit in order to accommodate the new user population (e.g., 10th percentile female-90th percentile male). This is illustrated in Figure 14. Now we have a new "wedge-shaped" envelope that is only 6-inches long, the upper edge being 4-inches across and the lower edge 3-inches across.

Although one could construct similar envelopes for each of the other population ranges, due to the irregularities noted before nothing seems to be gained. That is, the 10th-90th range essentially encompasses the others, thus indicating that if one wishes to relax the original compliance envelope the most practical course is to use the new wedge-shaped envelope which, based on data from this study, will accommodate at least 80 percent of the expected user population.

It should be noted, however, that the graphic plots presented above reflect only in a general way the behavior of a belt on any actual subject. That is, these plots are "flattened" (2-dimensional) representations of information that actually is curvilinear (i.e., the belt fit involves webbing configurations

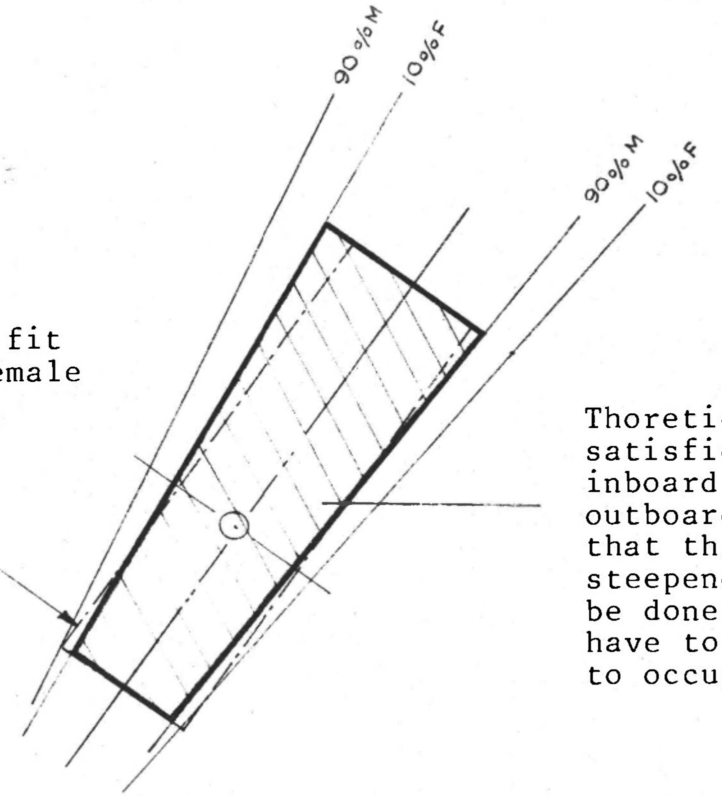
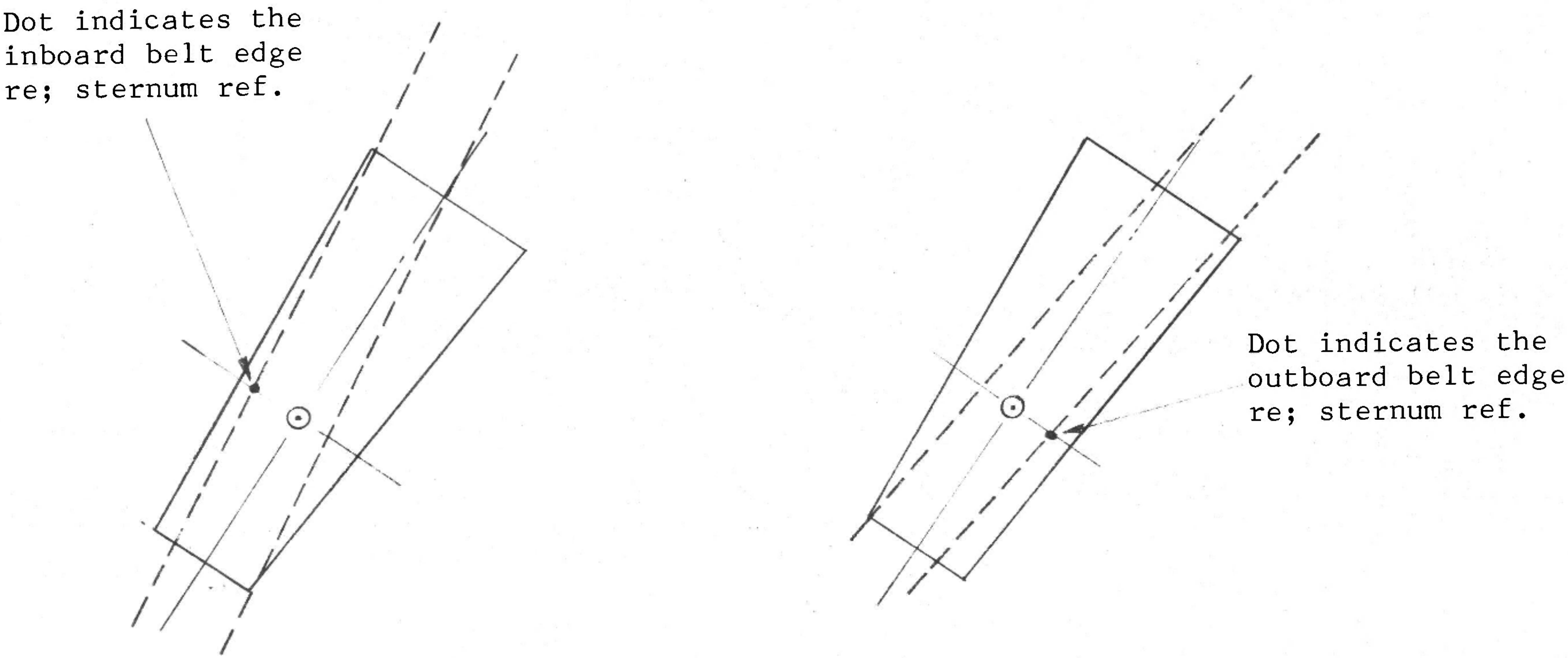


Figure 12 - 10th Percentile Female-90th Percentile Male
Acceptance Envelope



2-inch belt inclined toward the neck

belt inclined toward the shoulder

Figure 13 - Leeway for Belt Shifts Within the 10th-90th Acceptance Envelope

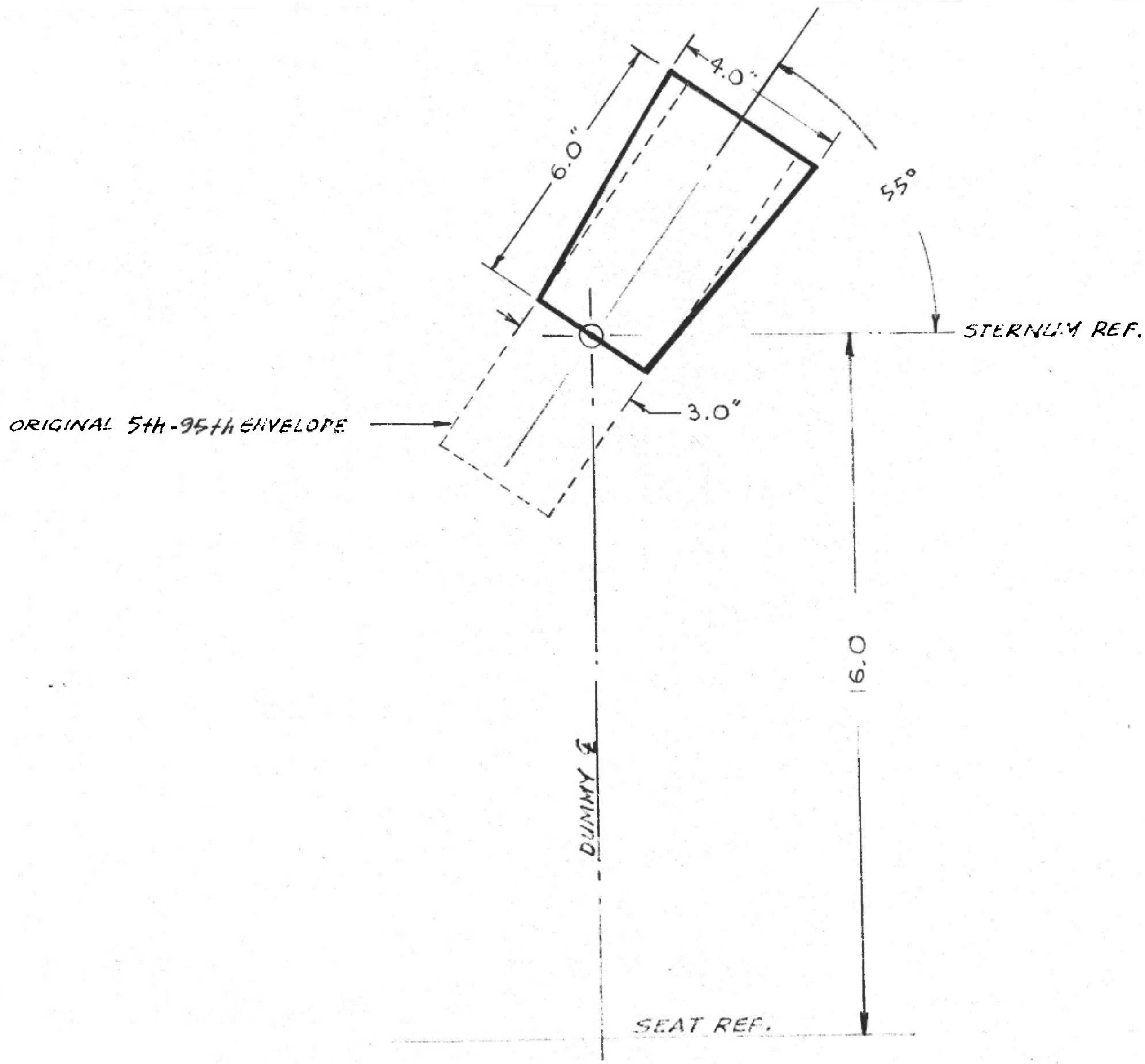


Figure 14 - Modified, Wedge-Shaped Envelope to Accommodate 10th-95th Percentiles

that wrap around the subject). Although there undoubtedly is some distortion in transferring these curvilinear patterns to a plane, we believe the interpretations noted above still are reasonably accurate and useful. At least they probably are as accurate as one might expect considering the fact that repeated fitting of any given subject creates variations comparable to the variations that exist between curvilinear and planar projections.

3.0 Experiment 2: Shoulder Belt Contact Force

3.1 Test Procedure

a. Mockup Preparation - The mockup used for the belt fit experiment also was used in this experiment. As shown in Figure 15, the only difference was to add various combinations of weights to the portion of the shoulder belt extending below the upper anchor D-ring in order to exert force (or resulting pressure) on the subject's chest and shoulder comparable to that of a retractor.

A baseline belt system was installed according to the requirements of the original compliance envelope (see Appendix A). Female subjects were tested with the seat in the forward position, male subjects with the seat in the aft position.

b. Subject Measurement - Since the results of this experiment were intended to consist of the reactions and evaluations of the test subjects, a method-of-limits technique (discussed in Section 1.1.b.) was used to establish the force levels acceptable to each subject.

As part of each subject's indoctrination s/he was allowed to experience high and low force conditions before the actual test sequence was begun. (For review of instructions to subjects see Appendix B.)

Following preparation of each force condition, subjects were allowed to move about in the seat, leaning forward and from side to side, to get the feel of the belt on their body. As soon as a subject considered that he could make a confident judgment about how the belt felt, he was instructed to indicate whether the force seemed "too heavy," "okay," or "too light."

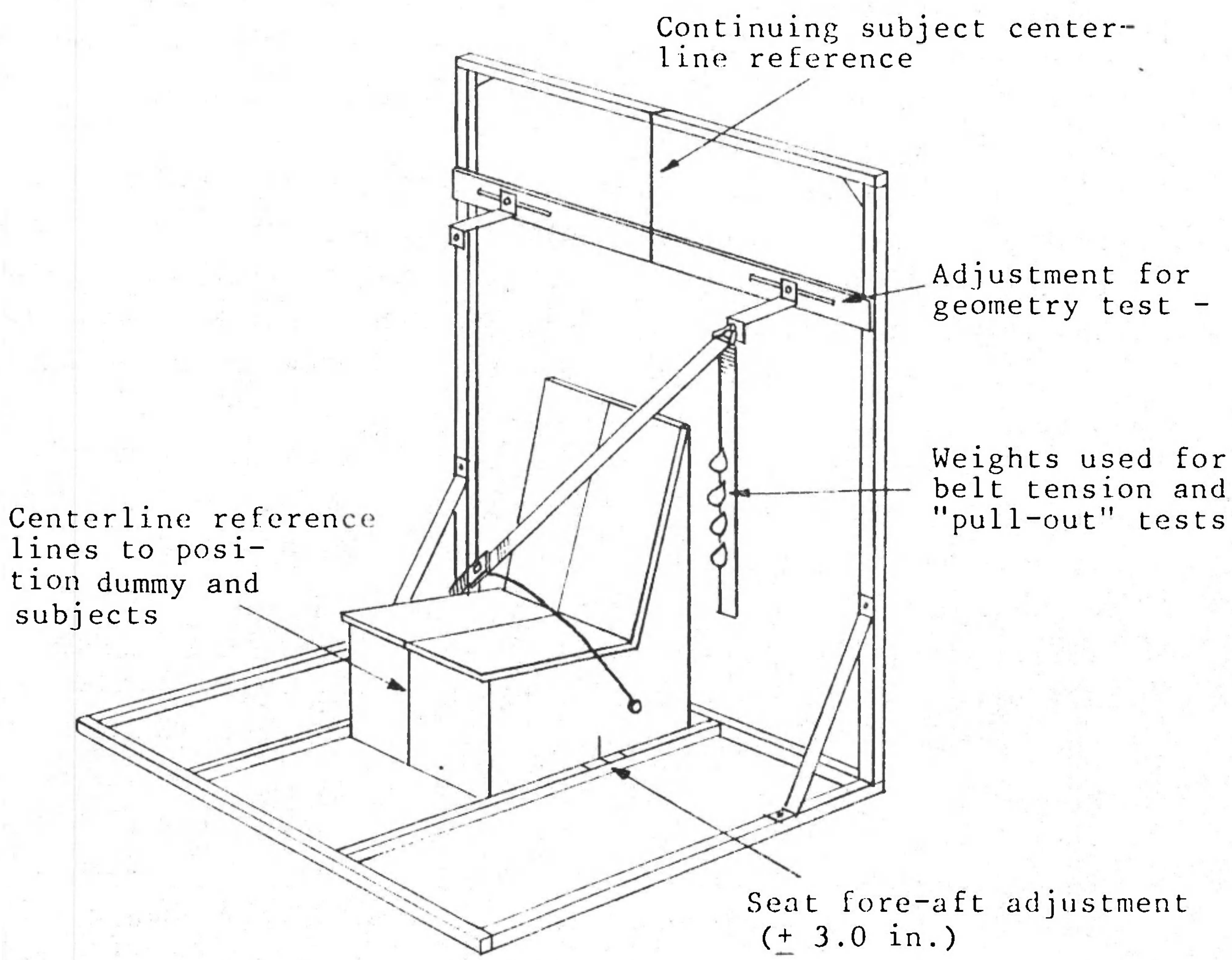


Figure 15 - General Apparatus Used for Tests

subjects were encouraged to verbalize their impressions as they sought to make a judgment about a particular force level. When the subject indicated the force level seemed acceptable (okay), that force level was recorded. Force levels in this experiment ranged from zero to five pounds, the upper limit having been determined in our previous studies.[1,2]

3.2 Test Results

Subject data (i.e., acceptance levels) are plotted in Figure 16 by stature percentiles and male vs. female. Note that this figure shows actual weights as the left hand ordinate and resultant contact force values as the right hand ordinate. These two metrics are provided merely to show the relationship between weight values and contact force values.

Of perhaps primary interest is an analysis of the Figure 16 results shown in Table 5 in terms of percent acceptance at various force (body contact) levels. As an example of how the values in Table 5 are derived from Figure 16, to find the number of subjects for whom a particular contact force greater than, say, 0.7 lbs (> 0.7) would be unacceptable, the reader would count the number of triangular data points in Figure 16 that lie on or under the 0.7 lb. reference line. In this particular example, they total 36, meaning that any force greater than 0.7 lbs would be unacceptable to these 36 but acceptable to the remaining 24 subjects, all of whom chose force values greater than 0.7 lbs. In this case the 36 subjects represent 60 percent of the sample (of 60 subjects), and the 24 represent 40 percent, as shown in the percentage columns opposite the $>$0.7 lbs line.

3.3 Discussion

One can conclude the following from the above:

- A shoulder belt contact force greater than 1.0 lb. probably will be unacceptable to most users (85%).
- Properly-fitted shoulder belts with a contact force of 0.6 lbs. or less probably will be acceptable to approximately 63% of belt users. This generally confirms results found in an earlier study (i.e., 0.57 lbs.).[1] Although 63% may not appear to be

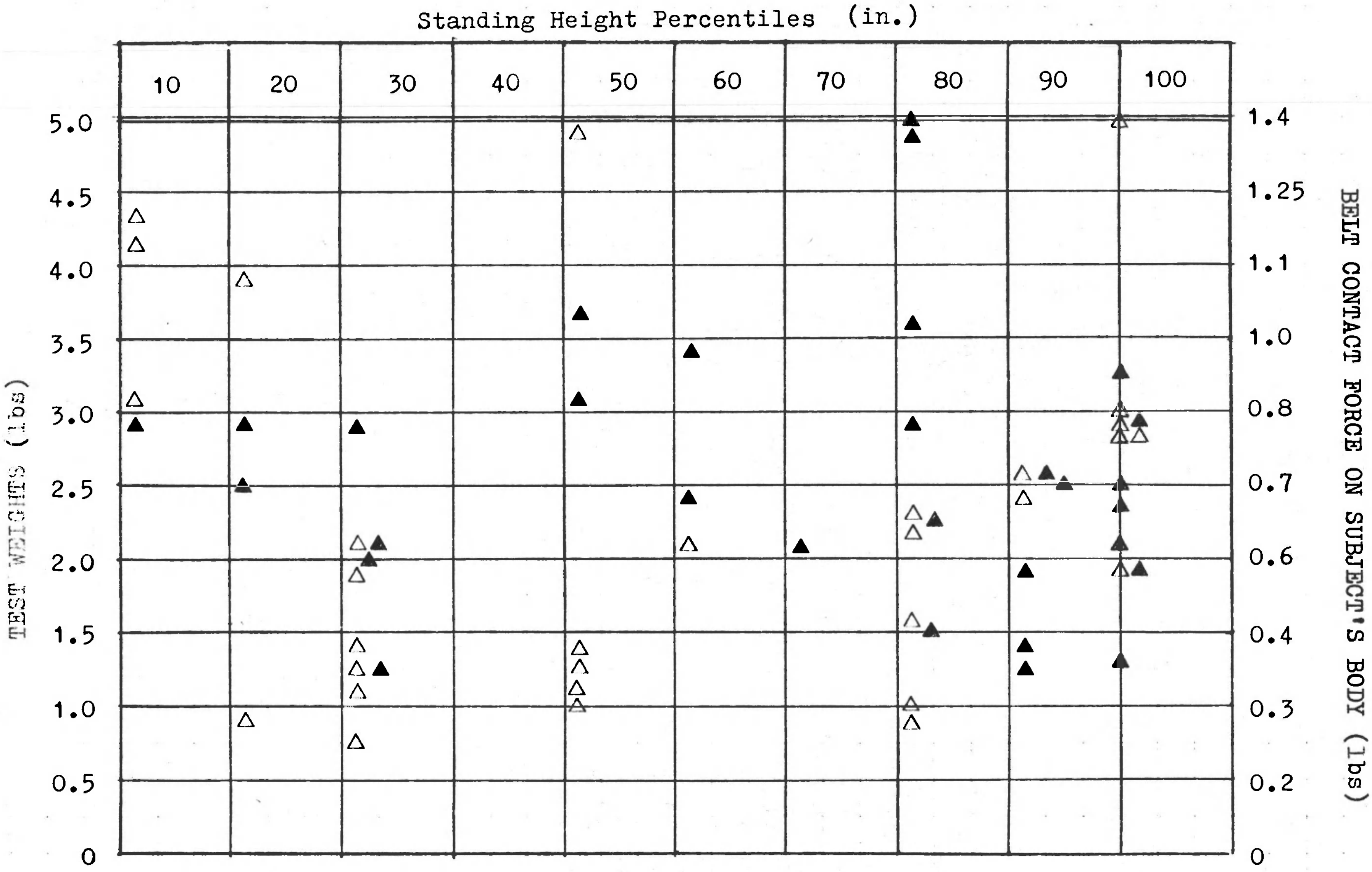


Figure 16 - Distribution of Belt Contact Force Acceptability Threshold By Sex and Stature; Composite of Left and Right Crossing Values. (60 subjects: 30M/30F)

△ Females
▲ Males

Table 5 - Seat Belt Contact Force Acceptability
(60 subjects: 30M/30F)

Force	Unacceptable To		Acceptable To	
	No. Ss	%	No. Ss	%
> 0.2 lbs.	0	0	60	100
> 0.3	5	8	55	92
> 0.4	16	27	44	73
> 0.6	22	37	38	63
> 0.7	36	60	24	40
> 0.8	47	78	13	22
> 1.0	51	85	9	15
> 1.1	54	90	6	10
> 1.25	56	93	4	7
> 1.4	60	100	0	0

an overly large segment of the total user population, it probably represents a practical criterion, considering the subjective nature of belt pressure perception and the potential problems designers have in producing systems that do not impose oppressive pressures on belt wearers yet provide sufficient webbing force to ensure full retraction of the belt system after it is unbuckled.

4.0 Experiment 3: Shoulder Belt Pull-Out Force

4.1 Test Procedure

a. Mockup Preparation - The same mockup used in the previous two experiments again was used. The belt system was arranged in such a way that test subjects could reach for the shoulder belt latchplate from a stowed position above both right and left shoulders.

As before, the belt system represented the baseline geometry (i.e., so that the shoulder belt webbing would pass precisely through the center of the 5th-95th percentile compliance envelope). This was done for both the left and right configurations. Weights were used to simulate the various force levels in the same manner as in Experiment 2. Prior to commencing the tests a force/weight calibration test was run and a graph prepared so that weight values could be translated directly into pull-out forces (see Figure 17). Pre-test indoctrination of subjects was similar to that provided in Experiment 2 (see Appendix B).

b. Subject Measurement - After being briefed on the purpose of the experiment, seated, and properly aligned in the mockup, subjects were given a demonstration of the range of pullout forces over which they would be tested. Following this indoctrination each was asked to interpret the acceptability of various force levels, using the method-of-limits approach (i.e., approaching an acceptable level from the high and low force ends of the scale). They were instructed to pull out the latchplate several times, to a point that approximated the buckling-up position, until they were

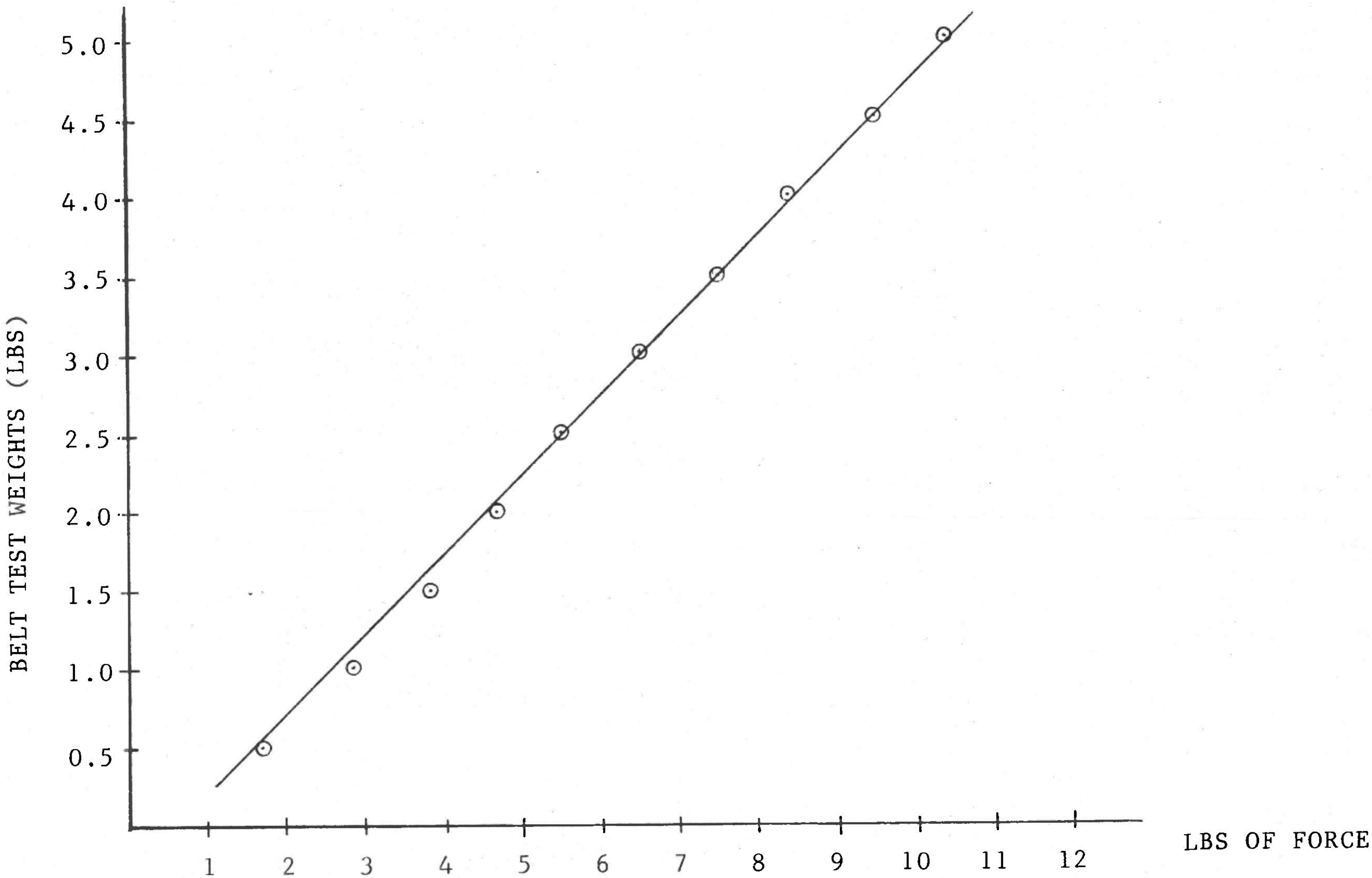


Figure 17 - Shoulder Belt Dynamic Pullout Force vs. Test Weights (in lbs)

satisfied that they could make a confident judgment as to whether the force seemed "too high," "okay" or "too light." Subjects started with the latchplate over either the right or left shoulder, depending on the position it was in for the previous subject. Thus, part of the subjects started with a right shoulder configuration, others with a left shoulder configuration.

Evaluations were made for each force level using the "near hand" and the "far hand" (crossover vs. non-crossover approach). The near hand for the driver configuration was, of course, the left hand, referred to as a "non-crossover operation." The opposite (right) hand was referred to as a "crossover operation" (see Figure 18). The purpose of examining the forces for both of these procedures was to determine if reach awkwardness was a factor in the subjects' acceptance judgments. This could be important in a practical sense since in some vehicle configurations a belt user may be encouraged to use the near hand to reach for the latchplate, while in others this procedure would be extremely awkward or even impossible to do.

4.2 Test Results

The results of this experiment are shown in Figure 19. Subject data were averaged for left and right belt configurations and left- and right-hand pull. As noted in the above figure, the data have been plotted in terms of stature percentiles. Both actual weight values (the left ordinate) and pull-out forces measured at the latchplate (the right ordinate) are shown.

Again (as in the previous experiment) percent-acceptance values at various force levels were of particular interest and are shown in Table 6. This table therefore presents user acceptability or unacceptability in percentage values for the various force levels. For example, 84% of the user population probably will consider forces greater than 4.5 pounds unacceptable, whereas 80% of the population probably will consider a force of 2.7 lbs or less, acceptable.

The above results represent the combined means for non-crossover/crossover and left vs. right shoulder belt configurations.

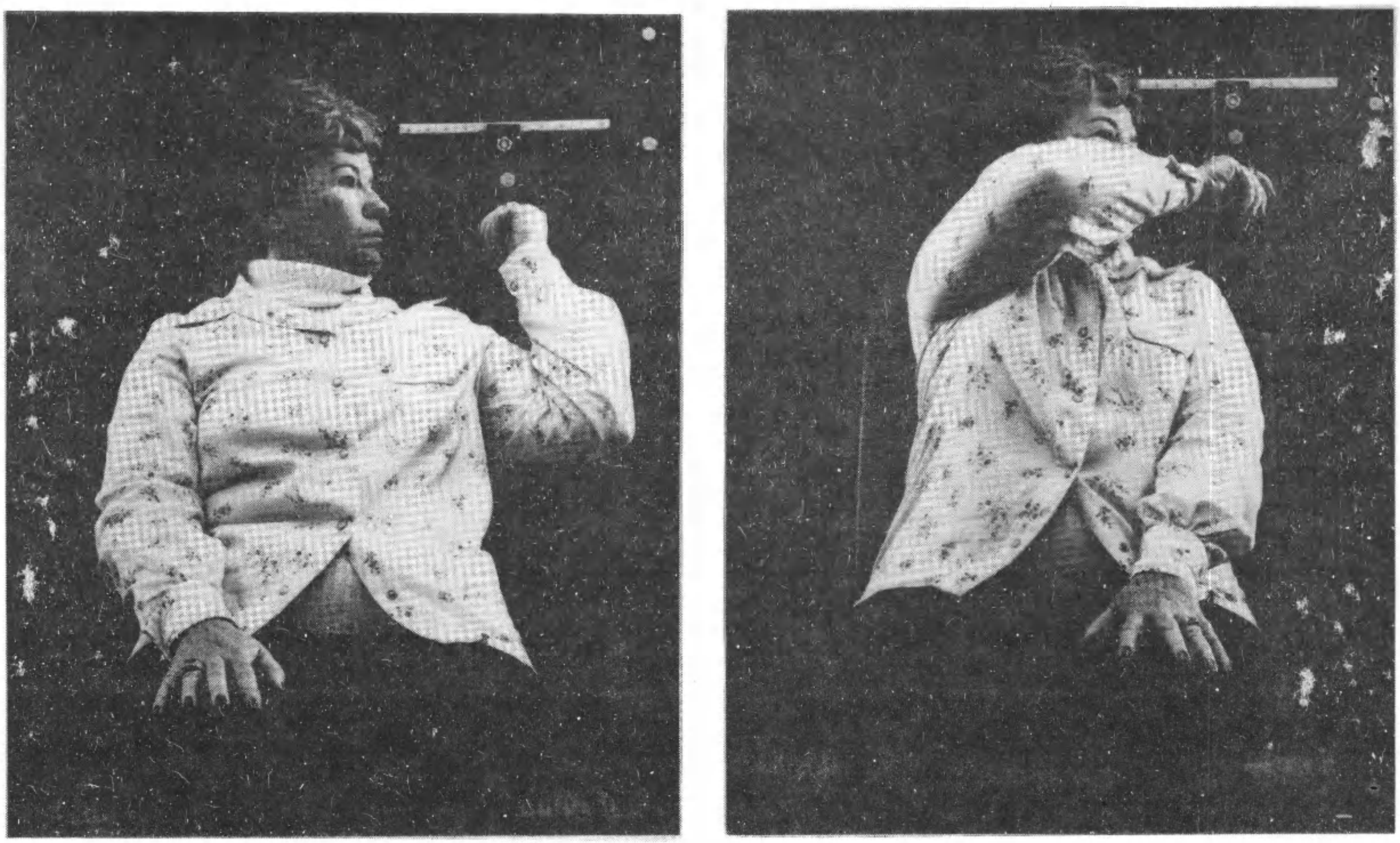


Figure 18 - Seat Belt Extension Mode, Crossover vs. Non-Crossover

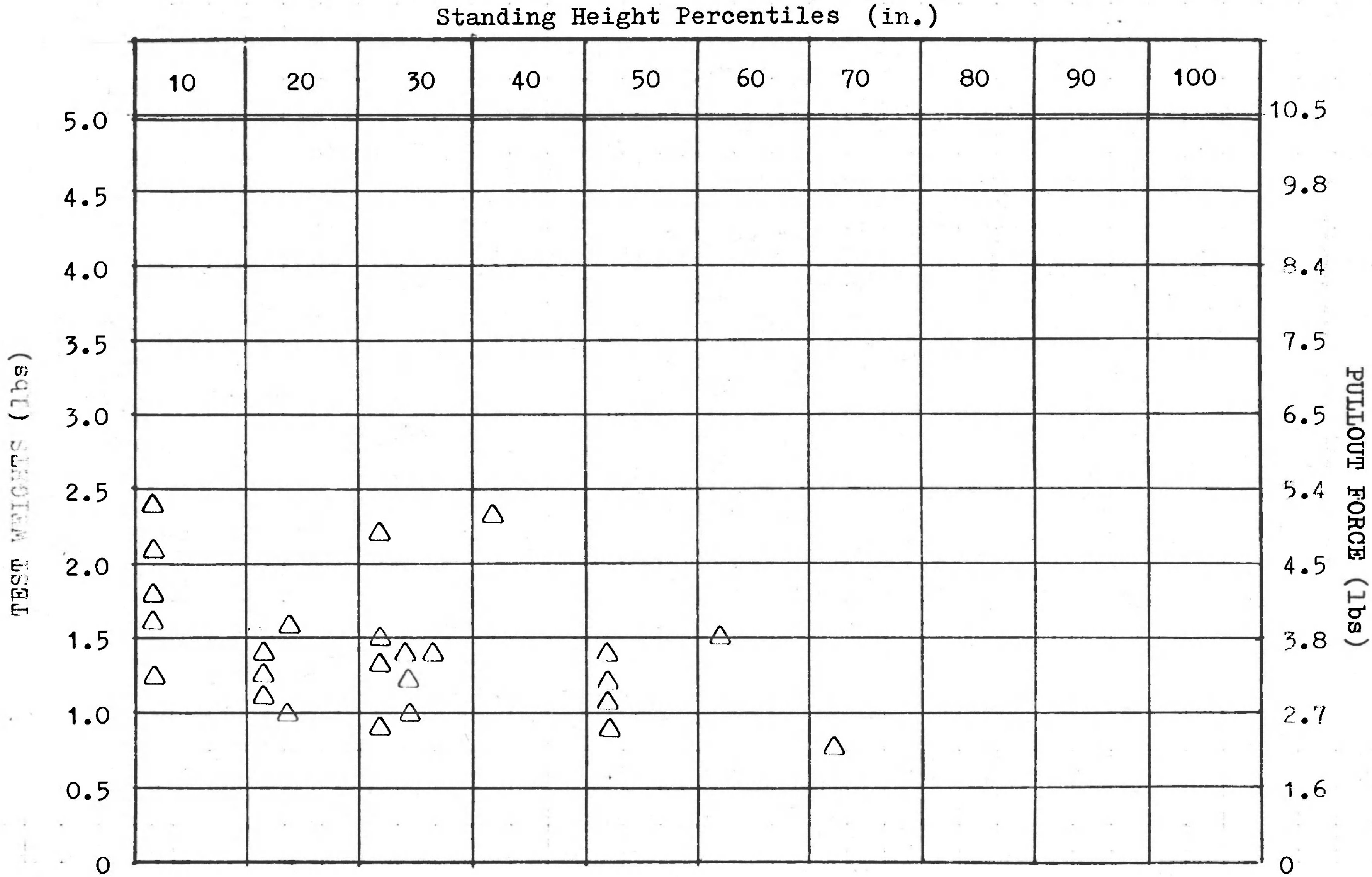


Figure 19- Distribution of acceptable Seat Belt Pullout Forces by Subject Standing Height (Females)

Table 6 - Seat Belt Pullout Force Acceptability
(25 S's - Small Females)

Force	Unacceptable To		Acceptable To	
	No. Ss	%	No. Ss	%
> 1.6	0	0	25	100
> 2.7	5	20	20	80
> 3.8	18	72	7	28
> 4.5	21	84	4	16
> 5.4	25	100	0	0

Separate results for each of these conditions have not been included here since no significant differences were found.

4.3 Discussion

Analysis of the above results suggests the following conclusions:

- As the shoulder belt pullout force approaches 4.0 lbs, a great share of users will complain that the force is too high.
- If pullout forces are kept below about 3.0 lbs, most users will find the force level acceptable. However, this acceptance level assumes the latchplate is reasonably accessible. If a particular latchplate's stowage position is such that it requires the user to reach so far aft of his/her shoulder that s/he has difficulty grasping it, complaints probably will occur regardless of the actual pullout force involved.

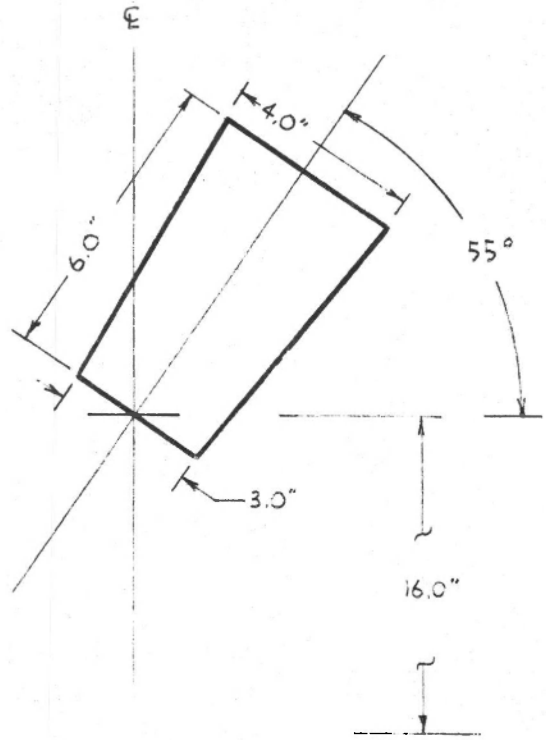
5.0 Summary Conclusions and Recommendations

5.1 Shoulder Belt Fit Specifications

Based on the results of this study it is concluded that if one is willing to accept a fit criterion of 80 rather than 90 percent of the user population, the originally proposed compliance envelope specifications can be altered as shown in Figure 20. This should have the effect of reducing some of the problems designers may have in fitting a greater range of vehicle body styles.

We believe this compromise is both warranted and desirable since, although the data developed in this study indicate that a somewhat smaller portion (80%) of the user population will be ideally fit, variability in the way people sit in any given seat, at any particular time, may well introduce an equal amount of degradation in belt fit even if the more stringent geometric specification is imposed. Therefore the feasibility of a "fit rule" becomes more practicable in terms of meeting the intent of the requirements.

Belt should remain within the envelope shown



Location of envelope on chest of 50th percentile dummy

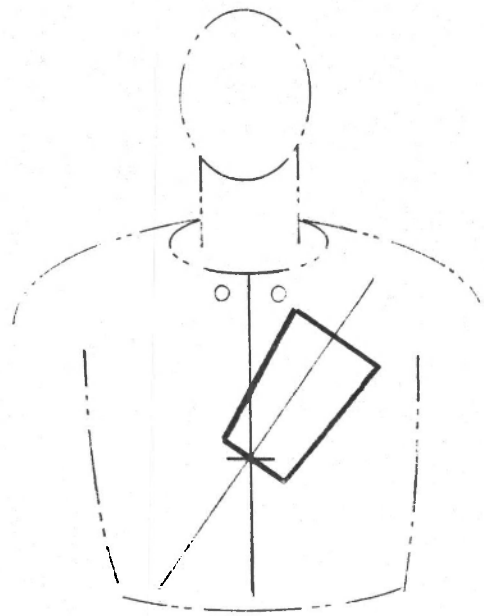


Figure 20 - Specification for Shoulder Belt Chest-Crossing Compliance (for 10th %-ile female-90th %-ile male occupants)

It is therefore recommended that the herein-proposed compliance envelope be used for new belt systems design and testing. Suggestions for marking a Part 527 anthropomorphic test dummy are provided in Figures 21 and 22.

5.2 Shoulder Belt Contact Force Specifications

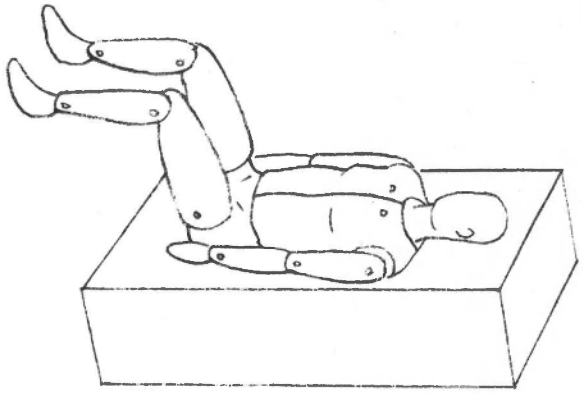
Results of this study essentially confirm recommendations made in the previous passive seat belt study, namely, that shoulder belt pressure on an occupant's body should not exceed 0.6 lbs. This value includes a reasonable tolerance. That is, in the previous study an actual value of 0.57 lbs or less was found to be acceptable to a majority of test subjects. In this study, a majority of subjects found the acceptable level to be somewhere between 0.4 and 0.6 lbs. It is therefore concluded that an upper contact force level of 0.6 lbs is a reasonable criterion for shoulder belt wearing. (Note: "Wearing" assumes the occupant is sitting in a normal position, with his or her body against the seat backrest, and not leaning forward into the belt). The criterion value also represents one that should be measured on the chest of the Part 527 test dummy, properly seated in a front seat of the test vehicle, with the seat in its mid-adjustment position. However, because of practical aspects of manufacturing tolerance and compliance measuring problems, it is recommended that a value of 0.7 lbs would provide a practical upper limit.

5.3 Shoulder Belt Pullout Force Specifications

Based on the results of the pullout force experiment performed in this study it is concluded that an upper force limit criterion of 3.5 lbs would be desirable and probably practical in terms of difficulties for the designer (i.e., webbing must fully retract for stowage). However, this is based on the unique subject sample used and thus suggests that the 3.5 lbs may be too stringent. In a previous study of active seat belt pullout force acceptance limits(1), an upper force limit of 4.0 lbs was recommended. A more broadly representative subject sample used in that study makes the 4.0 lbs less biased, and

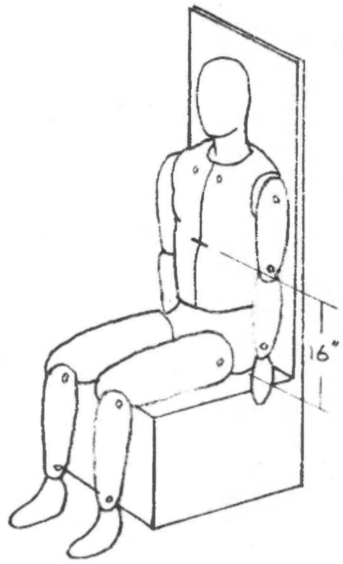
Step 1: Mark Mid-Saggital Plane

Lay dummy on its back and mark a centerline on the front of the torso sheath



Step 2: Mark Sternum Reference

Seat dummy in erect position and place a horizontal line across mid-saggital plane centerline. Sternum line should be 16" above seat reference. The line should be about 3" long.



Step 3: Mark Belt Centerline

Place a belt-angle line at 55^{o} to the sternum reference, crossing the point at which the sternum reference line crosses the mid-saggital centerline.

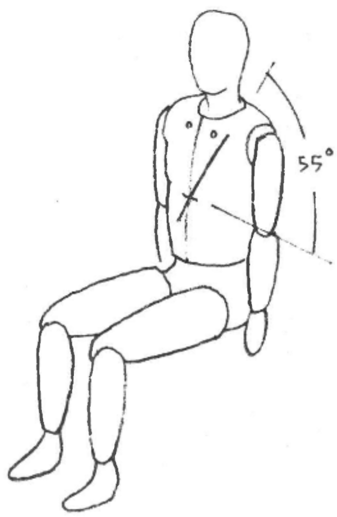
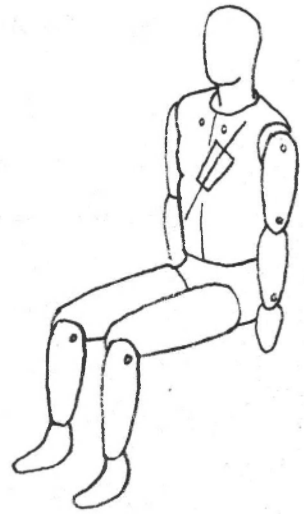


Figure 21 - Test Dummy Marking Procedure

Step 4: Mark Compliance Envelope

Superimpose the proposed compliance envelope on the dummy's chest as shown in the illustration and as specified in Figure 14.

The dummy is now ready to use as a compliance tool for evaluating any new seat belt configuration.



Notes: It will help if the compliance envelope is marked in RED as opposed to other markings in BLACK.

It is also suggested that markings be made with felt tip pens or other suitable marking devices rather than using tape (which tends to pull off as the dummy is used for actual belt system evaluation.

Before marking the dummy, make sure that the head, torso sheath and hip segments are properly aligned with each other. And as the dummy is used for compliance evaluations, recheck this alignment each time in order to insure that marking references are correct before the evaluation is begun.

Figure 22 - Test Dummy Marking Procedure (continued)

since there is actually only a 0.5-lb. difference, it is recommended that a value of 4.0 lbs be used as the upper limit criterion.

To measure compliance the following steps are recommended:

a. Place the 50th percentile dummy in the vehicle seat (seat in its mid-adjustment position).

b. Attach a strain gauge to the latchplate and use it to pull the webbing outward and downward, generally toward the system buckle (making sure it does not contact the dummy and thus add surface drag) to a point approximately at sternum height above the seat (see Figure 23). It is recommended that this procedure be repeated at least five times, taking the average of five pulls to define the pull force requirements of the belt being tested. If this value does not exceed 4.0 lbs, the pull force can be considered compliant.

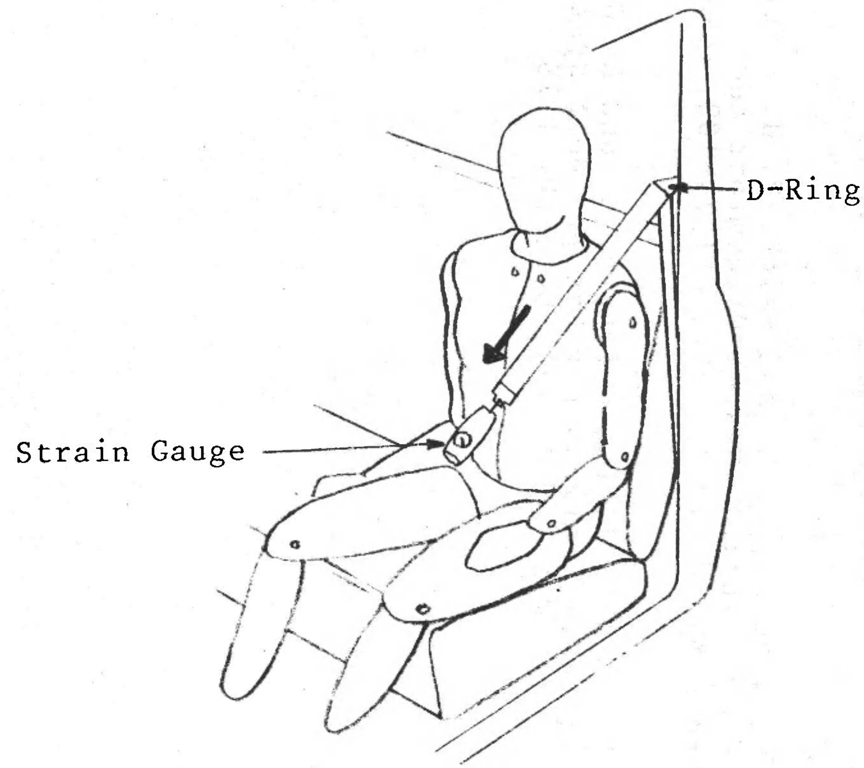


Figure 23 - General Procedure to Test Pull-out Force

REFERENCES

1 - Pierce, B. F., Woodson, W. E. and Selby, P. H. - Sources and Remedies For Restraint System Discomfort and Inconveniences. Man Factors, Inc., MFI 74-108, October 1974.

2 - Woodson, W. E., Black, T. L., Selby, P. H. and R. Coburn - Development of Specifications For Passive Belt Systems. Man Factors, Inc., MFI 78-109 (R), December 1978.

APPENDIX A

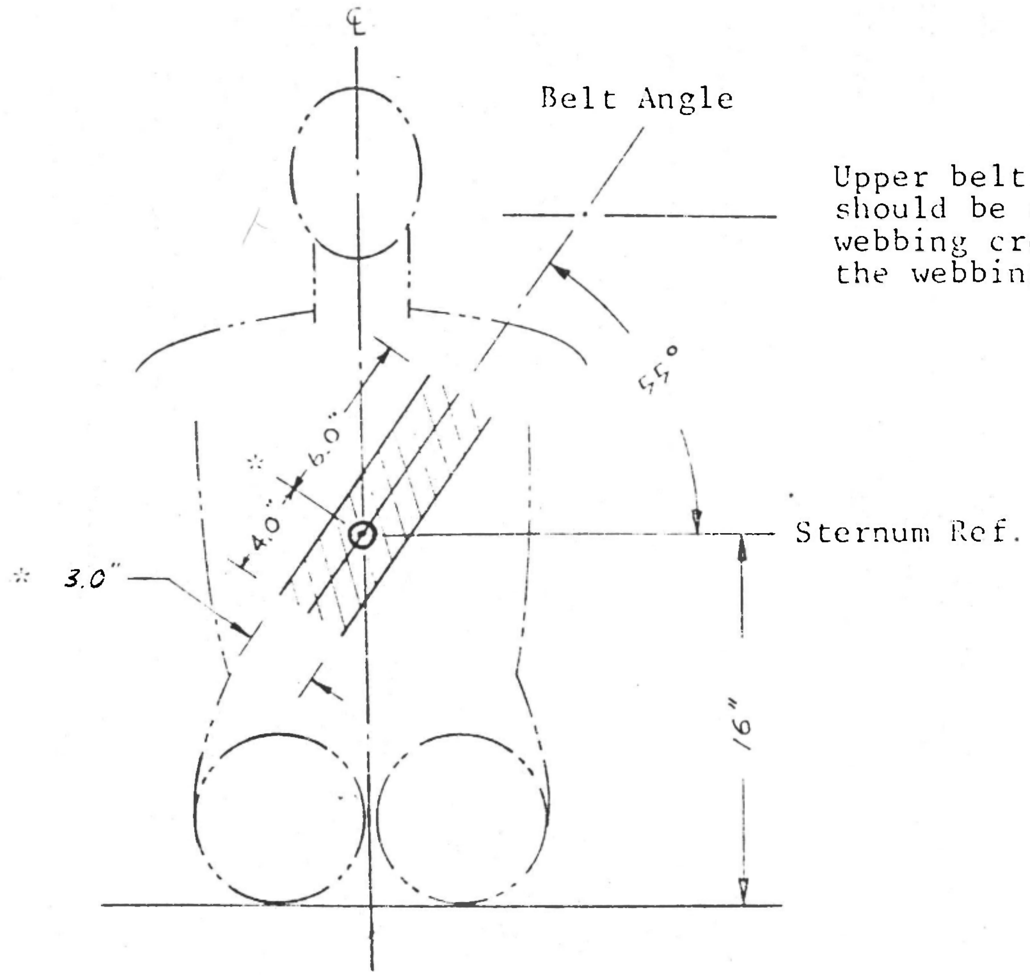
Baseline Belt Geometry

During a recent study entitled, "Development of Specifications for Passive Belt Systems" (Contract DOT-HS-7-01617), specification for a proper shoulder belt fit was proposed.

This specification was developed in the form of a compliance envelope to be marked on the chest of a 50th percentile anthropomorphic dummy (Part 527), making it possible to place the dummy in the seat of a new vehicle and evaluate the geometric characteristics of the seat belt (specifically, the crossing pattern of the shoulder portion to determine if it is anchored in such a way as to ensure that the webbing will cross an occupant's chest and shoulder without creating discomfort by rubbing against the wearer's neck, riding across his/her breast in an irritating fashion, or resting so close to the edge of the occupant's shoulder it is likely to fall off).

The proposed compliance envelope and evaluation procedure were designed to test the compliance of a seat belt system for suitable fit of a range of expected users whose stature fell within the limits of the 5th percentile female through the 95th percentile male. This proposed compliance envelope is illustrated in Figure A-1.

The procedure for evaluating any new seat belt include: (1) proper seating of the test dummy with the compliance envelope marked on its chest as shown in Figure A-2; (2) buckling up the seat belt around the dummy; (3) placing the shoulder belt to be evaluated within the limits of the envelope; (4) rocking the



Upper belt anchor or D-ring departure points should be above dummy's shoulder whenever the webbing crosses the shoulder (i.e., so that the webbing departs aft at a positive angle.

*Compliance envelope, i.e., torso belt (standard 2") falls within this area when deployed.

Figure A-1 - Belt-Crossing Geometric Criteria Using 50th %ile Dummy

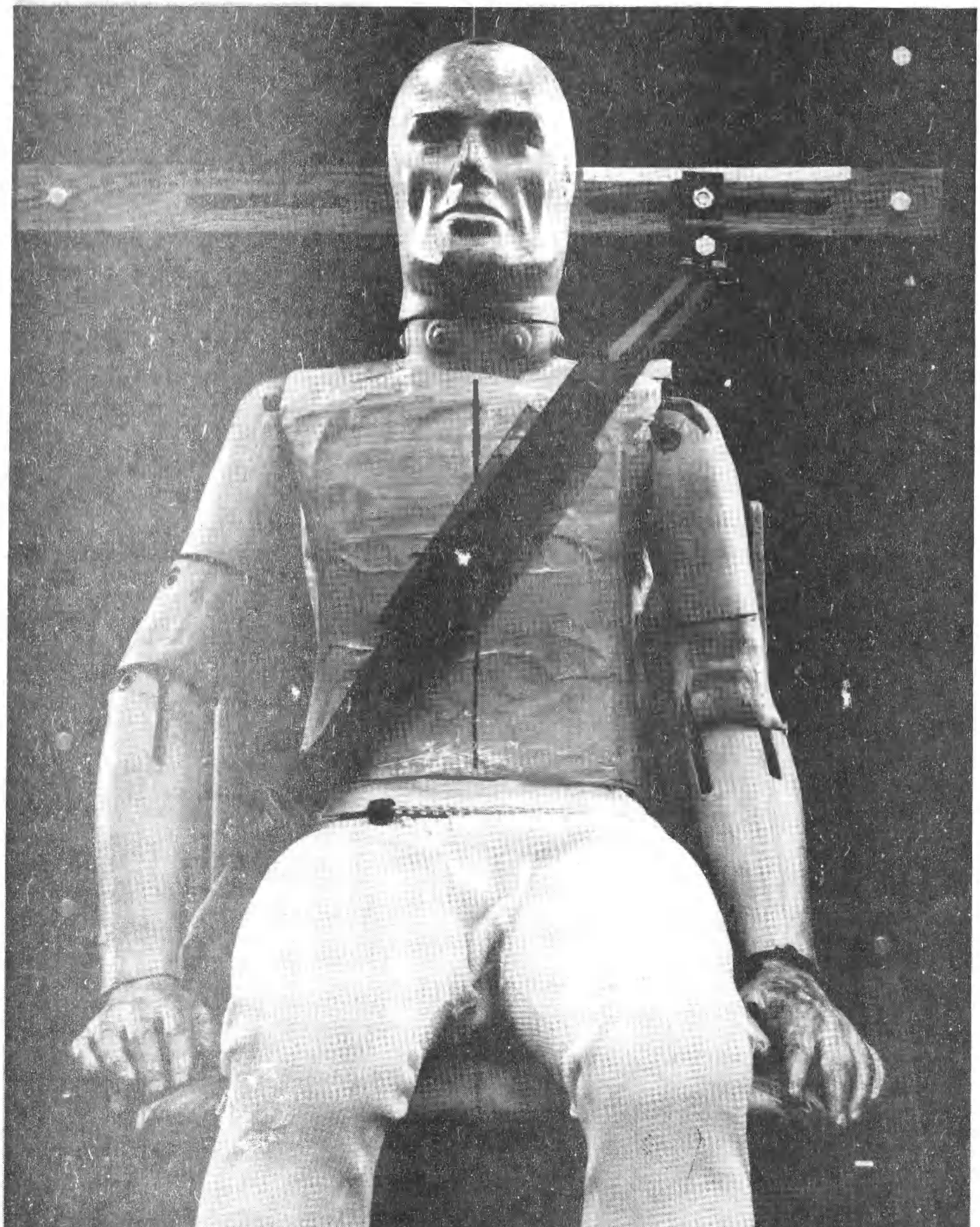


Figure A-2 -Torso Belt in Compliance Envelope on 50th %-ile Male Dummy

dummy from side to side and fore and aft a few inches; and (5) re-establishing the dummy in its initial, erect position. If the shoulder belt continues to fall inside the compliance envelope the belt is considered to meet the fit specifications. If, on the other hand, oscillation of the dummy causes the webbing to fall outside the compliance envelope (since improper positioning of the belt anchors will cause the webbing to seek the shortest distance between two points), the belt is considered non-compliant.

When the dummy is properly positioned in the test vehicle (which includes placing the seat in its mid-position), the compliance marking actually represents the fit requirements of a 5th percentile female who normally would be seated in the most forward seat position, and of a 95th percentile male, who normally would be seated in the most aft seat position.

The purpose of this brief discussion of the compliance specification is to explain the baseline belt geometry used during the present study. That is, during Experiment 1, it was necessary to provide a baseline geometry for setting the initial test belt and identifying a zero reference from which successive shoulder belt fit limits were measured. The same baseline set-up was also used for experiments 2 and 3 since the force measurements were related to a so-called optimum shoulder belt crossing configuration.

Figure A-3 illustrates how a baseline configuration fits a 5th percentile female and a 95th percentile male. As

Figure A-3

Photos of a 5th Percentile Female and 95th Percentile Male With the Torso Belt Positioned on the Centerline of the Proposed 3-inch Compliance Envelope.

Female is seated at the foremost seat adjustment; male at aftmost adjustment. These photos are included for reference in reviewing the previous percentile set.

can be seen, the shoulder belt generally bisects the chest and shoulder areas. Figure A-4 illustrates how the baseline configuration fits the alternate percentile subjects used in this study.

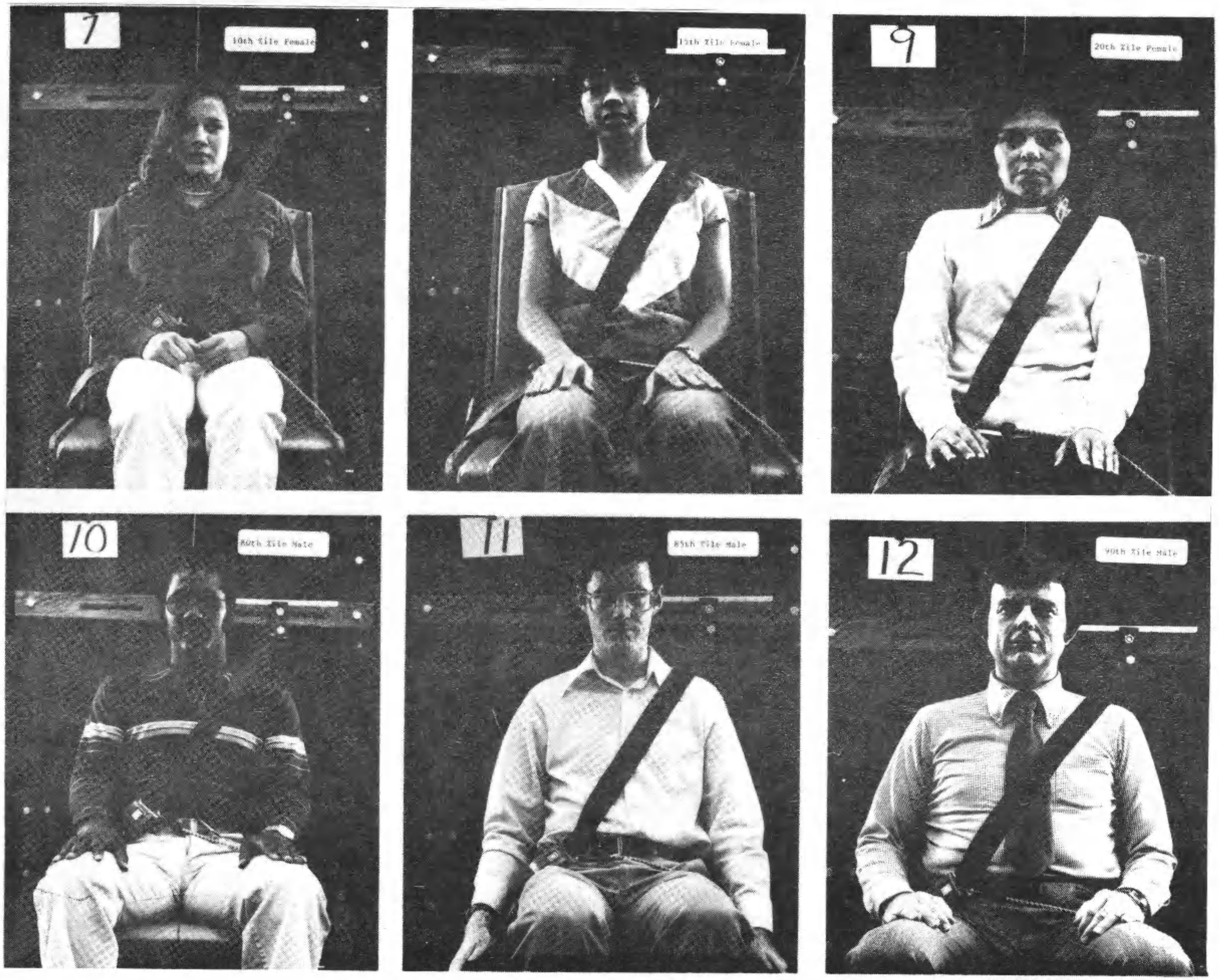


Figure A-4
Photographs Showing Troso Belt in Compliance Position on 10th, 15th and 20th (Female) and 80th, 85th and 90th (Male) Percentile Subjects

APPENDIX B

Instructions to Subjects: Contact Pressure Test

1. The purpose of this test is to get the reactions of a large number of people to shoulder belt contact pressure. The results of these tests will help the Department of Transportation establish standards for seat belt design so that future belt systems will be more comfortable.
2. I will conduct the test in the following way: First I will ask you to sit in this simulated automobile seat which is equipped in such a way that I can vary the contact pressure of the shoulder belt. After you are seated I will ask you to put on the seat belt. When the belt is on, I will ask you to move around (in the belt) in a way similar to what you might do while riding in a car. This will give you a chance to see how the belt might feel after you have been riding for some time. If you feel that the belt force as now set is acceptable, I will record that force value and then we will go on to the second series of trials. But if this force level seems too high, I will reduce the pressure in small amounts until you say the force is acceptable. Once we have found an acceptable force level, we will go on to the second series of trials. In this series I will start with a low force and then increase the force in steps until you say the force is becoming too great. I will then reduce the force one unit and record that as the acceptable force level.
3. Before we start the actual test trials I will demonstrate

the range of contact pressures we will be using. Please take your seat and put on the belt. Are there any questions before we start?

Instructions to Subjects: Pull-Out Force Test

1. The purpose of this test is to get reactions of a large number of people regarding the comfort or discomfort of various shoulder-belt pull-out forces. The results of these tests will help the Department of Transportation establish standards for seat belt design that will make future belt systems easier to use.

2. I will conduct the test in the following way: First I will ask you to sit in this simulated automobile seat which has been equipped with a seat belt in which I can vary the force required to pull out the webbing to buckle up. I will then ask you to reach up and grasp the latchplate (demonstrate), and pull the webbing down to a point about opposite the middle of your stomach (as though you were getting ready to buckle up). Next I will ask you to repeat this several times and to be thinking about whether the force required to pull the latchplate down is too high, okay or too light (i.e., it seems too loose). If you feel the force is okay, we will go to the next trial series. If the force seems too high, I will reduce the force in small amounts until you indicate we have reached a force level that seems okay. I will record that force value. Then we will start with a second series of trials starting with a very low force, and increase the force in steps until we reach a level that you think is too high. At that point I will record the last lower force value.

3. Once we have completed the trials using one hand to pull out the latchplate, we will repeat the tests using the other hand. In that way I will have your force judgments for both hands.

4. Before we start the actual test trials, I will demonstrate the range of contact pressures we will be using. Please take your seat. Are there any questions before we start?