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TWO-DIMENSIONAL KINETIC MODELING
OF HUMAN POSTURE IN AUTOMOTIVE SEATS

presented by

David Fletcher Ekern

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of the requirements for

M.S. degree in Mechanics

Major professor

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TWO-DIMENSIONAL KINETIC MODELING OF HUMAN POSTURE IN AUTOMOTIVE SEATS

By

David Fletcher Ekern

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ABSTRACT

TWO-DIMENSIONAL KINETIC MODELING OF HUMAN POSTURE
IN AUTOMOTIVE SEATS

By

David Fletcher Ekern

To assist automotive seat development, methods for predicting the posture of seated occupants have been developed which utilize two-dimensional computer models constructed using commercial kinetic modeling software. The first model is a two-dimensional representation of the Society of Automotive Engineers (SAE) three-dimensional testing manikin. This model was used to simulate experimental data collected with the SAE three-dimensional testing manikin regarding the stiffness and support force distribution of an automotive seat cushion.

The second model developed was the torso geometry and articulation of a mid-size male model known as JOHN. The kinetic two-dimensional JOHN model was used in a comparative seat study to determine the effect of different seat geometries on the final posture of the model.

This thesis describes the development, use and application of these models for improving automotive seat development.

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DEDICATION

I would like to dedicate this work to my wife, Christie, who has given me undying love and support through this whole process; thank you and I love you.

To my mom, who has encouraged me to learn and discover and who has given me the support to do so, and to my dad, who was not able to help in body and mind, but instead has given me encouragement in spirit.

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ACKNOWLEDGMENTS

This work would not have been possible without the support and assistance of many people:

The crew in the Biomechanical Design Laboratory; Melissa Sloan, Akram Ali, Richard Setyabudhy, Barry Frost, Bruce Liu, Cliff Beckett, and Frank Mills.

A big thanks goes Chris Gedraitis, for letting me bounce ideas off him and making sure I did things right.

Thank you to Tammy and Neil Bush, for supporting and encouraging me and for helping me keep focused.

To my graduate committee, Dr. Averill and Dr. Cloud, thank you for your guidance and for taking the time to review my work.

To my graduate advisor, Dr. Robert P. Hubbard, thank you for the opportunity to work with you over the past two years. You gave a young graduate student the chance to learn and explore in your lab, and I want to tell you how thankful I am for that chance. Working with you has shaped my thinking and given me the tools to continue on in life, much better for the experience of working with you. Thank you.

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INTRODUCTION

1.1 BACKGROUND

Locating the position of seated occupants within the automotive interior space has been an important design goal in the automotive industry for over 40 years. Automobile and seat manufacturers rely on occupant positioning data for a number of reasons; among them are vision, controls reach, and restraint position. One of the most important issues is comfort. Comfort design for seating relies very heavily on accurate knowledge of the location of the occupants in an auto seat. This information is used to determine seat back contour, lumbar support location and many other factors that affect the posture and comfort of the occupant.

Since the early 1960's, the Society of Automotive Engineers (SAE) two-dimensional (2-D) drafting template and three-dimensional (3-D) testing manikin specified in SAE standard J826 [1] have been the main tools used in the design and development of interior packaging and automotive seating (Figures 1 and 2). Though originally designed only for placing an occupant within an automotive interior, the SAE 2-D drafting template and 3-D manikin have been extensively used to design seat shapes and thereby affect the posture and comfort of seated occupants for the past three decades [2].

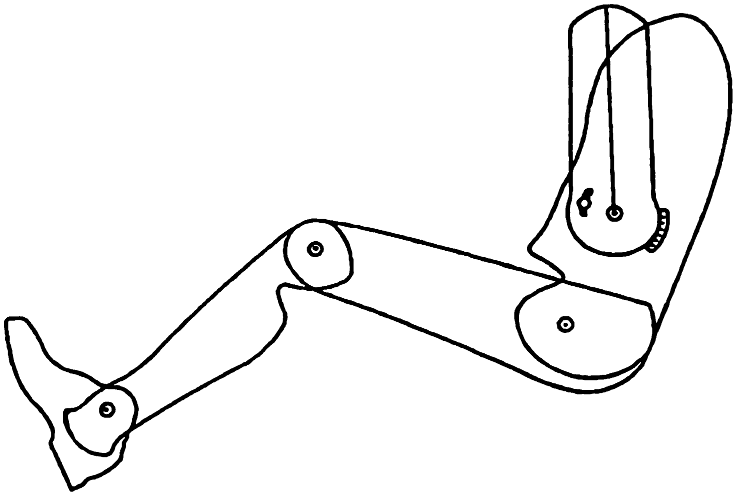

Figure 1: SAE 2-D drafting template

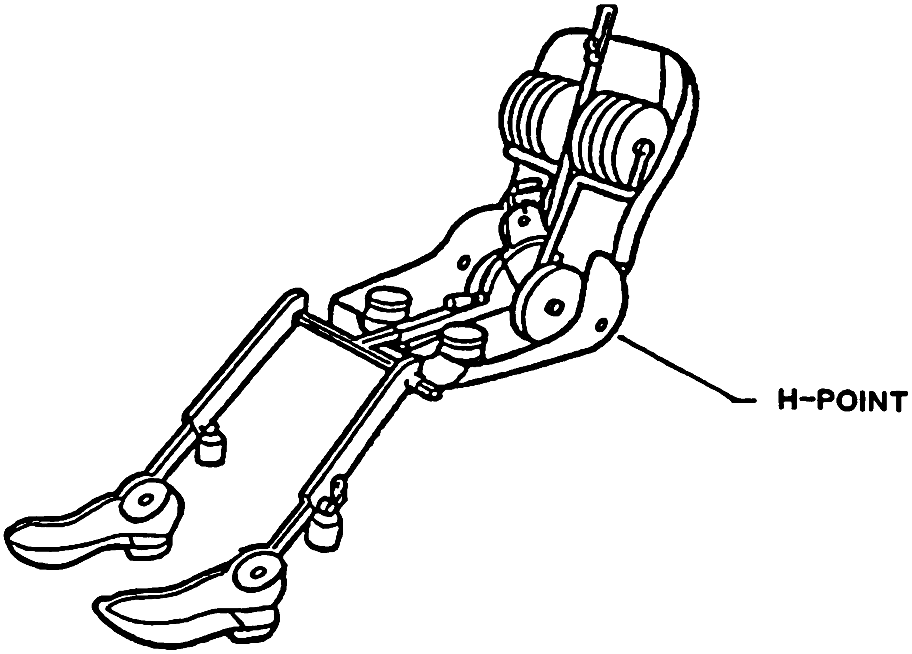

Figure 2: SAE 3-D testing manikin

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The SAE drafting template and testing manikin are comprised of the same body segments. They have a foot, a shank or lower leg segment, a combined thigh-pelvis segment, and a combined lumbar-thorax or torso segment; the manikin has two feet and two shanks These segments can rotate about the hip joint, which is referred to as the H-point, the knee joint and ankle joint. However, the major drawback of the SAE J826 tools are that the torso and thigh-pelvis sections only articulate at the H-point so that, unlike human motion, the SAE tools do not have the capability to represent a change in lumbar curvature. In addition, the posture that the torso segment represents is a slumped posture, with a flat back in the lumbar region. Due to these limitations, the manikin is unable to fit in many automotive seats with large amounts lumbar prominence. If the 3-D testing manikin is placed in an automotive seat and the thigh-pelvis segment placed firmly against the seat back, the torso is unable to move from a fully forward position to rotate about the H-point and come into contact with the seat back without contacting the lumbar area. If the top of the manikin torso is then forced back against the seat, the torso segment pivots about the lumbar area and the thigh-pelvis segment shifts forward in the seat. In sum, the posture and articulations of the SAE tools are not representative of how the torsos of people actually move with variations in lumbar curvature

In recent years, biomechanical research at Michigan State University (MSU) has been directed at developing better human body models for automotive seat design and evaluation [3]. The main thrust of the work at MSU

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has been to provide greater comfort for the seated occupant by improving the representation of human torso shape and posture with the introduction of lumbar curvature as a movement factor. With this representation of lumbar curvature, the human body models developed at MSU also represent more body segments than the SAE tools. Unlike the combined thigh-pelvis segment and torso segment of the SAE tools, the MSU models separately represent the thigh, pelvic, lumbar and thoracic segments. The movement and posture representation of the MSU models are more accurately representative of the human body.

Haas [4] developed a model of human torso motion for an average size male based on the relative movement between the thorax and pelvis (Figure 3). This model was named JOHN to recognize the support of the Automotive Systems Group of Johnson Controls, Inc. Haas selected a one-to-one relationship of motion between the pelvis and thorax to represent human torso articulation from a slumped to erect postures. For example, a pelvis rotation of 5° corresponds to a thorax counter-rotation of 5°, for a total change in posture of 10°. This rotation of the thorax relative to the pelvis was defined as Total Lumbar Curvature (TLC). The zero reference (0°) for TLC is a straight lumbar spine, with the angular orientation of the pelvis and thorax based on the seated occupant posture defined in a study by the University of Michigan Transportation Research Institute (UMTRI) [5,6]. Figure 4 shows the JOHN model moving from a TLC of 0° to 40°. The other measures defining the position of JOHN are Torso

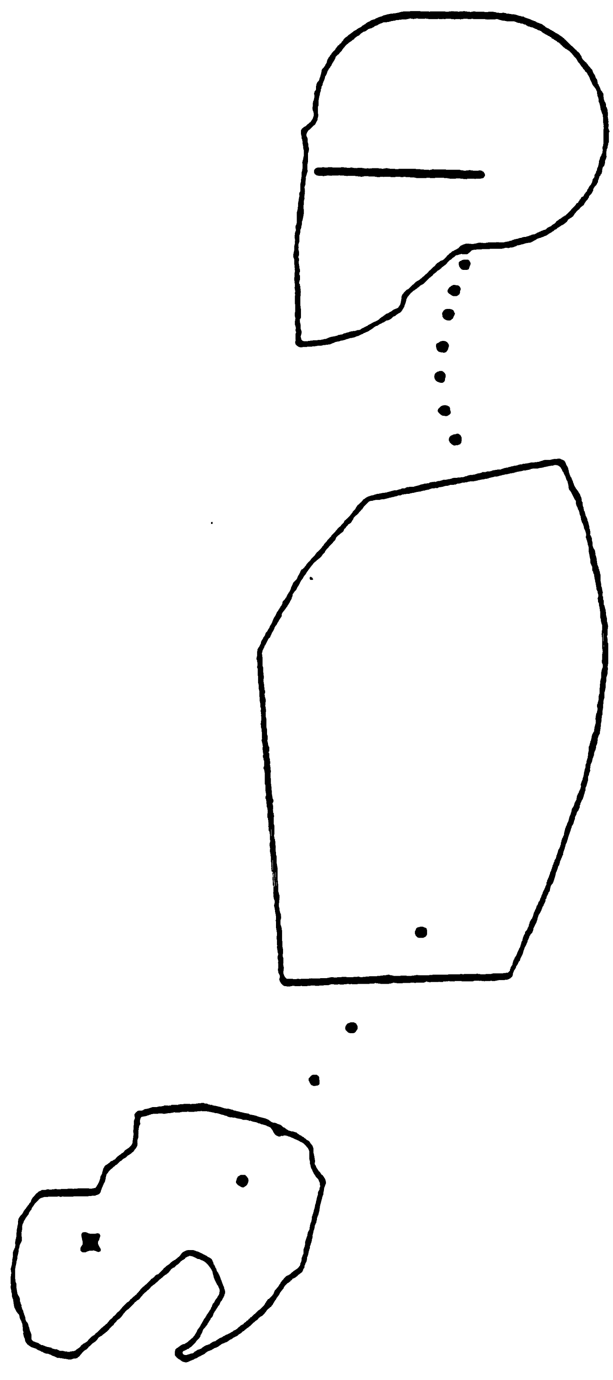

Figure 3: 2-D JOHN model

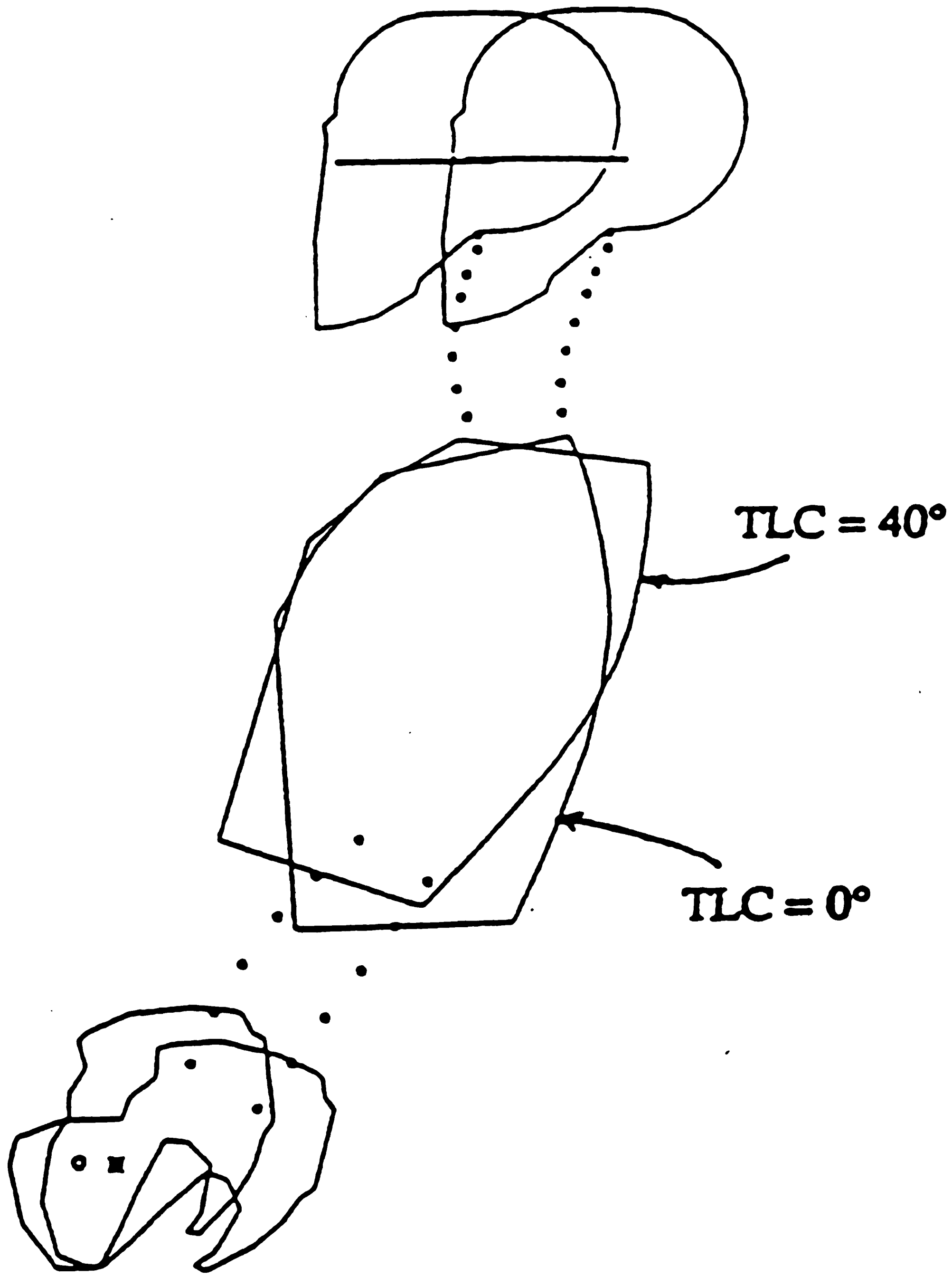

Figure 4: 2-D JOHN model at 0° TLC and 40° TLC

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Recline Angle (TRA) and the Hip Joint Center (HJC). Torso Recline Angle is defined as the angle between vertical and a line passing through the top and bottom lumbar joint centers. These two lumbar joint centers are the twelfth thoracic/first lumbar vertebrae joint (T12/L1) and fifth lumbar/first sacral joint (L5/S1), respectively. The HJC is the location of the femur insertion into the pelvis.

Boughner [7] expanded on the work of Haas and developed a three-dimensional solid model of the human skeletal and muscle geometry for the averaged sized male (JOHN), seen in Figure 5. In addition, 3-D models were created to represent a small female, called JANE, and a large male, named JERRY [3]. From Boughner's work, Bush [8] developed a 2-D articulating template which simplified the JOHN model lumbar motion. By placing gears of equal size at the top and bottom lumbar joints and connecting them by a chain loop with a twist, the relative motion between the pelvis and thorax was physically represented in template form (Figure 6). Bush also developed back contours for the average man by adding flesh thickness to Boughner's 3-D JOHN model of the skeletal and muscle geometry.

The previous work at MSU concentrated on modeling just the shape and kinematics, or geometry and motion, of the human body in seated postures. For this thesis, two computer models were developed that were kinetic, predicting both the motion and forces acting on the body, while continuing to represent the posture descriptors developed for JOHN.

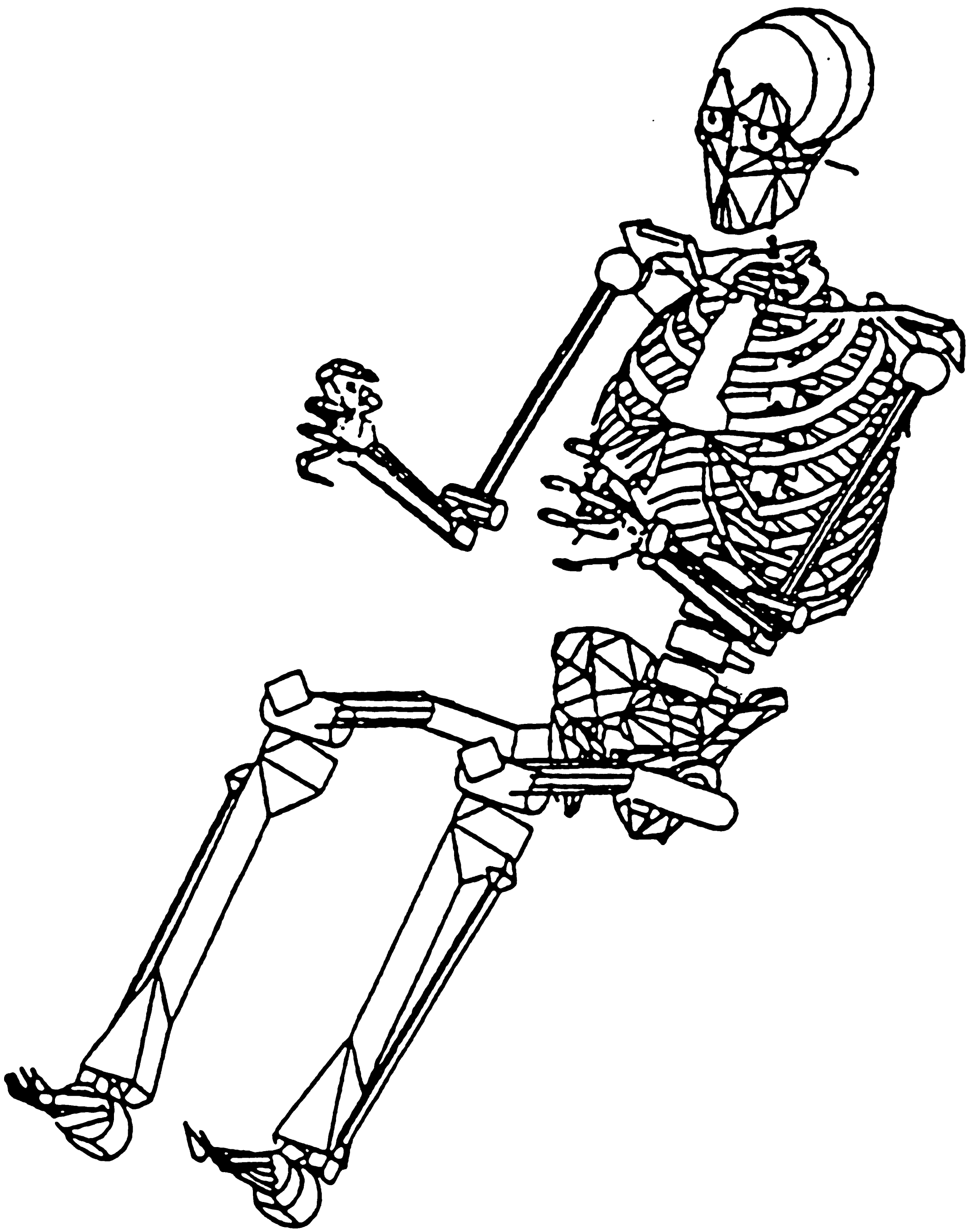

Figure 5: 3-D JOHN model in oblique view

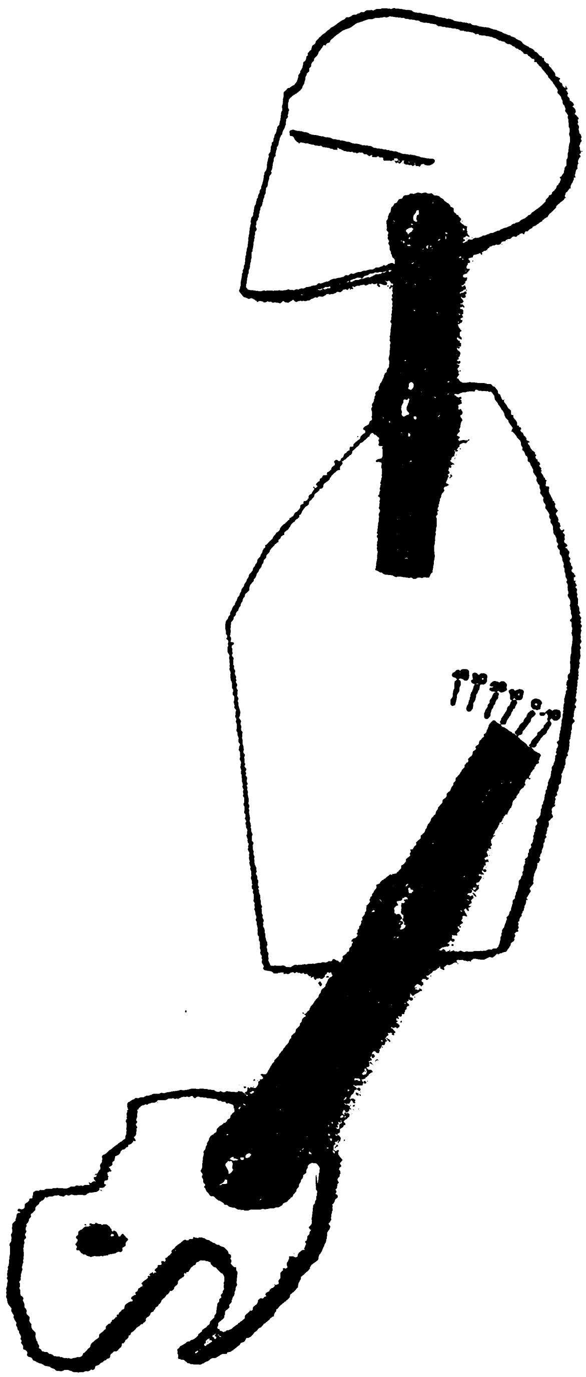

Figure 6: 2-D JOHN physical articulating template

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The first model, a 2-D representation of the SAE 3-D testing manikin (Figure 7), simulates the forces and displacements of the SAE 3-D testing manikin in an automotive seat; the second, a 2-D version of the 3-D JOHN human body model (Figure 8), is used to simulate the possible postures of an occupant interacting with a seat. The 2-D SAE and 2-D JOHN computer models were developed with the aid of Working Model™, a commercial software product, that allows rapid prototyping and design of mechanical systems. It is possible to constrain the model bodies with elements such as pin and rigid joints, gears, and springs, to help simulate mechanisms.

The development of these models represents a step forward in understanding and modeling the force-posture relationship of seated humans in automotive seats. A major design and development goal of seat manufacturers has been to position the seated occupant in the seat and vehicle according to the vehicle manufacturer specifications. This positioning has been done since the 1960's through the use of the SAE J826 tools and will be done in the future with the next generation manikin, currently being developed by MSU and UMTRI in a project titled Automobile Seat Package Evaluation and Comparison Tool (ASPECT). The manufacturers position the occupants and design the seat using the SAE 2-D drafting template. After design, they build a prototype and test the seat using the SAE 3-D testing manikin to determine if the prototype places the manikin in the design position. Other tests are performed with human subjects for subjective response to the comfort of the seat. This begins an

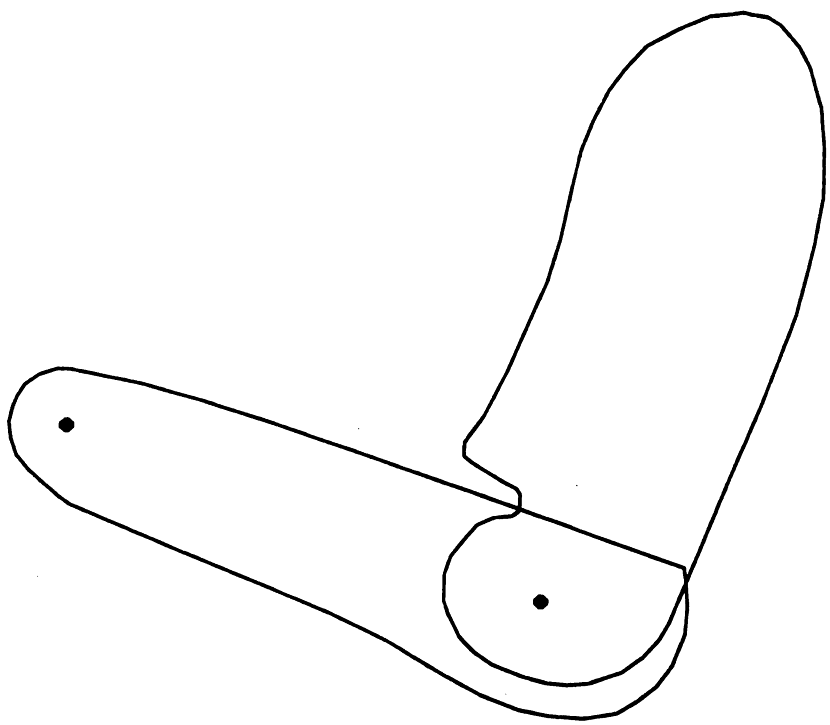

Figure 7: 2-D SAE kinetic computer model

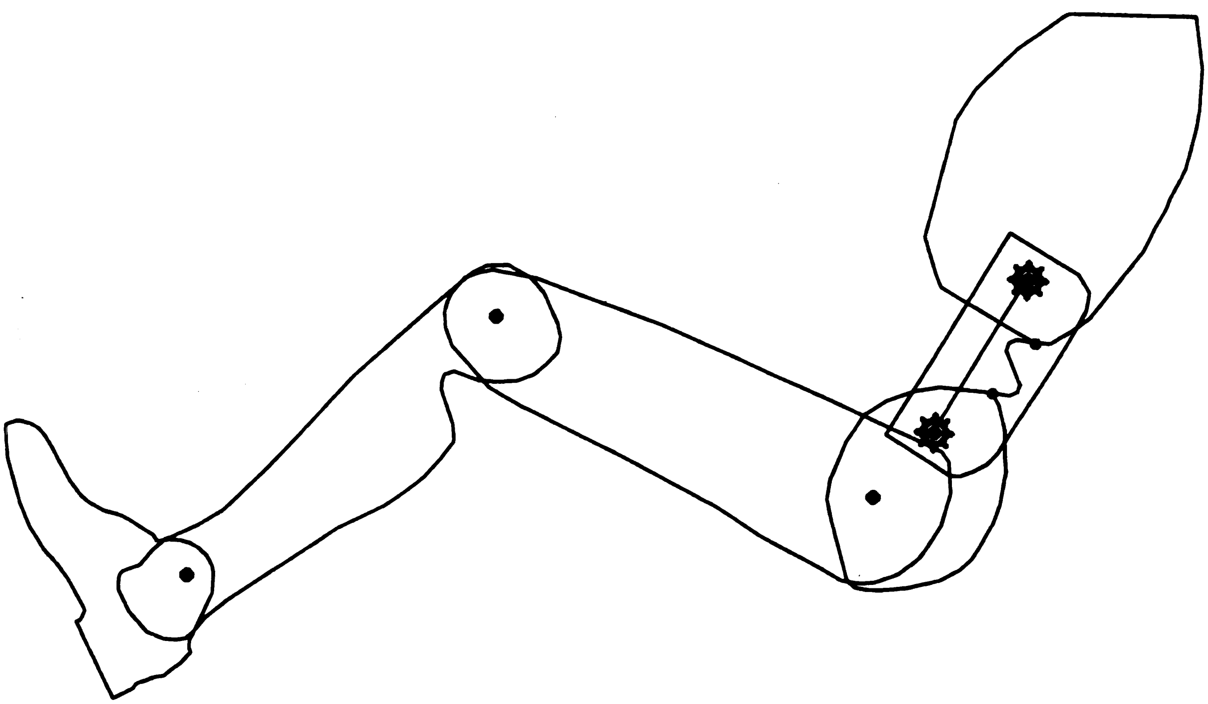

Figure 8: 2-D JOHN kinetic computer model

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iterative cycle of re-design and further testing until the seat is declared ready for production, as much as two years and numerous prototypes later. The development of the kinetic 2-D SAE and JOHN computer models provide a way to relate the measurable data, obtained with the manikin and people through product evaluation, to the design tools. These models will allow the designers to predict the interaction between the person and manikin and the seat in the design stage, before prototyping, saving both time and money.

1.2 OBJECTIVES

The two objectives of this study were to:

1) Develop the 2-D SAE kinetic computer model and simulate experimental data collected using the SAE 3-D testing manikin to further understand the effect of the seat cushion system on the distribution of forces supporting the manikin.

2) Develop the 2-D JOHN kinetic computer model and undertake a comparative study between a standard automotive seat and an articulating prototype seat using the 2-D JOHN model in order to study the effect of different seat designs on the final posture of the model.

This thesis is organized to describe the methods, results and discussion for these two objectives. The final section is a conclusion that summarizes the findings and presents recommendations for future work.

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2-D SAE KINETIC COMPUTER MODEL DEVELOPMENT

2.1 METHODS AND MATERIALS

2.1.1 2-D SAE computer model construction

The 2-D SAE computer model was developed and used to simulate experimental data collected by Hubbard et. al. [9] on automotive seat cushions using the SAE 3-D testing manikin torso and thigh-pelvis segments.

To construct the 2-D SAE computer model, existing CAD computer files of the 2-D drafting template were obtained from the Automotive Systems Group of Johnson Controls, Inc. The main body segments, the torso and thigh-pelvis segments, were imported into the Working Model™ software (Figure 9). Because the Hubbard experiment did not utilize the legs, they were not imported into the software.

After importing the SAE body segments into the simulation, the next step was to assemble the model. The body segment joint locations were found with the aid of measurements taken from an SAE 3-D testing manikin, a 2-D drafting template, and the CAD computer files of the 2-D drafting template. In Working Model™, points were placed on the torso segment at the H-point and on the thigh-pelvis segment at the H-point and knee joint (see Figure 10). Once the points had been located on the segments, the two segments were then

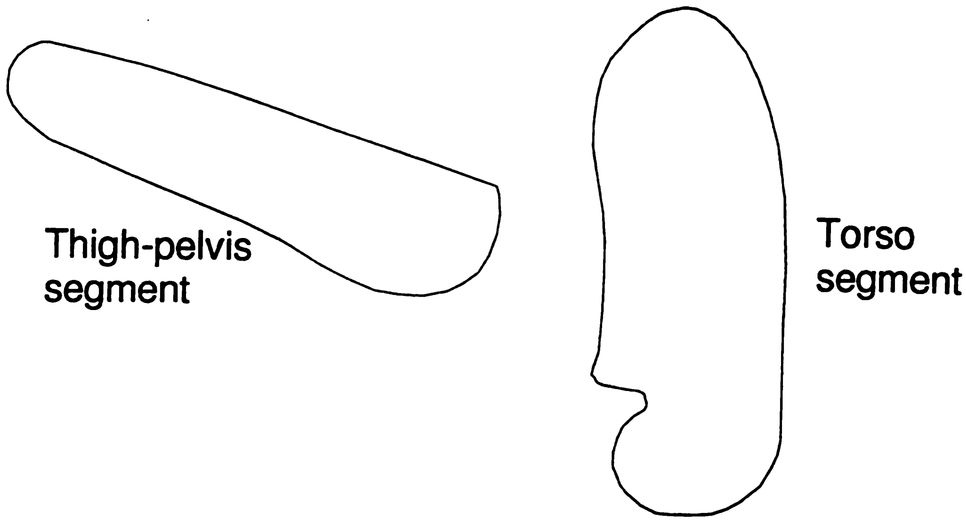

Figure 9: 2-D SAE model torso and thigh-pelvis segments

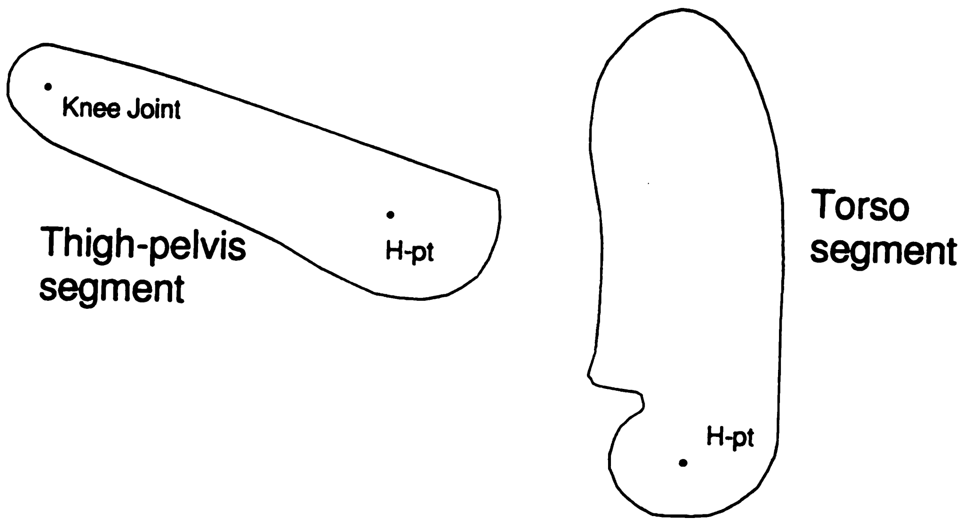

Figure 10: 2-D SAE model segments with joint centers

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assembled to form the 2-D SAE computer model (Figure 11).

2.1.2 Locating the centers of mass for the thorax and thigh-pelvis segments

The next step in developing the 2-D SAE computer model was to assign the mass and center of mass (COM) locations to the torso and thigh-pelvis segments. The SAE 3-D testing manikin was used to determine the location of the COM for each segment.

The torso segment of the SAE 3-D testing manikin was separated from the thigh-pelvis segment at the H-pt axis. Each segment was then attached to a calibrated load cell and hung from the ceiling. The mass of each segment was calculated from the load cell readings and assigned to the appropriate segment in the model. The mass of the thigh-pelvis segment was 10.07 kg and the mass of the torso segment was 9.09 kg.

To find the COM of the torso and thigh-pelvis segments, it was necessary to locate the intersection of two lines extended from balancing points of the segments. To determine the first line, a thin rod was attached to the floor and then each segment was placed on top of the rod and balanced. A vertical line was marked upward on each segment from the balance rod. To find an intersecting line, each segment was suspended from the ceiling by a strap. The thigh-pelvis segment hung from the ceiling by a strap that was attached to the knee joint bar. Two pieces of string were tied to the outer ends of a thin metal rod and then onto the knee joint bar (Figure 12). The strings and rod

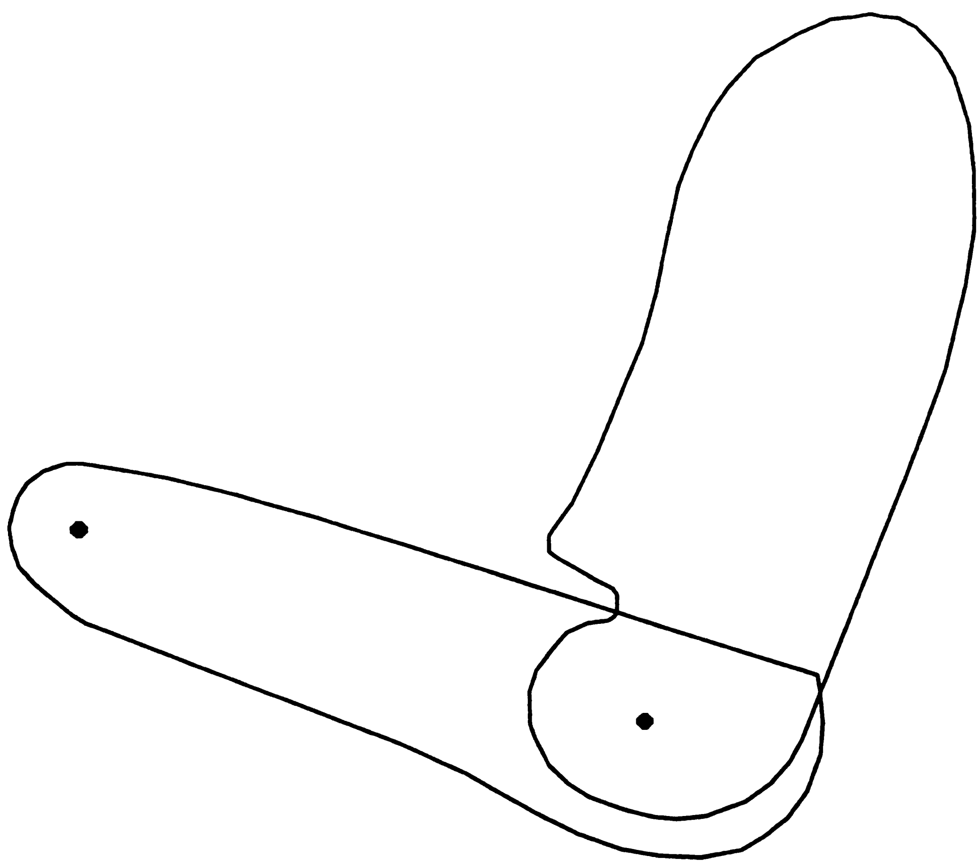

Figure 11: Assembled 2-D SAE kinetic computer model

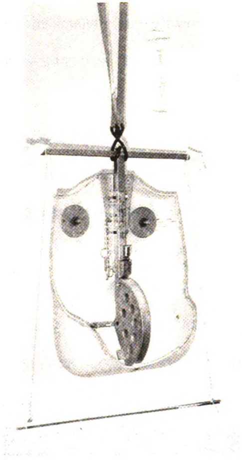

Figure 12: Picture of thigh-pelvis segment COM calculation

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combination acted as a plumb bob, and the intersection point of the string with the line previously marked on the segment defined the COM for the thigh-pelvis segment. The COM location was measured from the H-pt along an axis system defined by the thigh line (a line from the H-pt to the knee joint) and a line in the mid-sagittal plane perpendicular to the thigh line. The COM of the thigh and buttocks segment was 152 millimeters (mm) forward of the H-pt (toward the knee) and 10 mm above the thigh line. It was assumed that the COM was in the mid-line plane of symmetry.

To determine the COM of the torso segment, a strap was attached to the H-point axis and the segment was suspended from the ceiling by the strap. A piece of string was tied to each end of the H-point axis and then to a thin metal rod. This string and rod system acted as a plumb bob (Figure 13) and the intersection of the plumb bob string line with the line previously marked on the torso was defined as the COM. To measure the location of the COM, an axes system for the torso segment was defined as the torso line, (a line through H-pt that is parallel to the straight lumbar region) and a line in the mid-sagittal plane perpendicular to the torso line. Using the H-pt as the origin, the distance to the COM along those axes was 235 mm above the H-pt and 29 mm toward the back of the thorax. Once again, mid-line plane symmetry was assumed for the COM.

The axes described above for the torso and thigh-pelvis segments were then re-created on the 2-D SAE computer model. In Working Model™, a point was placed as a marker on the torso and thigh-pelvis body segments where the

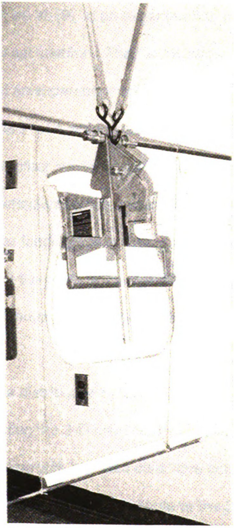

Figure 13: Picture of torso segment COM calculation

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positions of the physical COM were located. The COM of each segment was then modified until it was positioned at the physical COM (Figure 14).

2.1.3 Experimental data collection

The 2-D SAE computer model was developed to simulate the test methods used by Hubbard, et. al. [9], in an experiment to characterize the stiffness of an automotive seat cushion. Their work involved developing a seat cushion support model and an experiment which used the SAE 3-D testing manikin to collect data. The seat cushion was modeled as two springs, one supporting the H-pt and the other supporting the knee joint. The data collection procedure determined the effective forces under the knee and H-pt of the SAE 3-D testing manikin for various loading conditions, and then used the SAE 3-D testing manikin to determine the deflections at the knee and H-pt for the same loading conditions. The methods and results of the experiment are described in detail below.

In the experiment, the distribution of weight at the knee axis and H-pt axis was determined by suspending the 3-D manikin shell (torso and thigh-pelvis segments only) from the ceiling with two load cells, one connected to the knee axis and the other to the H-pt axis. The torso angle of the 3-D manikin was set and kept at 0°, relative to vertical, while the manikin was loaded. The distribution of the weight between the two load cells was recorded. Then two torso masses (circular masses with holes in the center of 3.92 kg each) were set

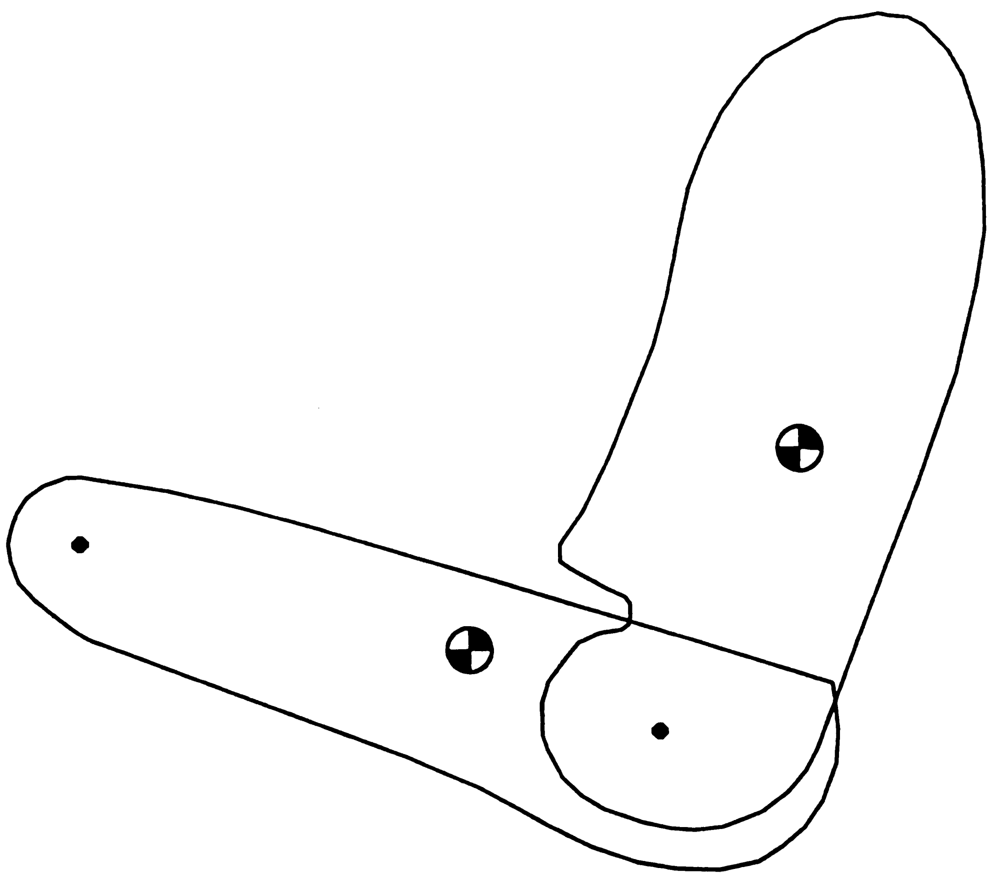

Figure 14: 2-D SAE computer model with COM positions

in the manikin shell on the H-pt (the masses for the 3-D testing manikin are shown in the torso and thigh-pelvis segments in Figure 2). The measurements from the load cells were recorded. Three more sets of torso masses were placed into the torso shell and the data recorded after each set until four (4) pairs of torso masses were placed in the manikin, eight (8) weights total. Next, the thigh masses (metal cylinders with holes at one end of the cylinder of 3.42 kg each) were placed in the manikin on the thigh pins. These thigh pins are small pins set inside the thigh-pelvis segment about halfway between the knee and H-pt. The load cell measurements were recorded again. Then another pair of torso masses were placed directly in front of the thigh masses between the end of the shell and the thigh weights, and the load cell readings recorded. Finally, the two torso masses placed on the thigh were removed and placed over the ends of the knee joint bar, and the load cell readings recorded. The loading conditions and support forces at the knee and H-pt, in Newtons, are listed in Table 1.

Table 1 - Experimental Force Results

Loading Condition	Force at H-pt (N)	Force at knee (N)
2-D template	0	0
3-D manikin shell	154	32
1 set of masses at H-pt	229	34
2 sets of masses at H-pt	305	35
3 sets of masses at H-pt	381	37
4 sets of masses at H-pt	458	36
1 set of masses on thigh	485	78
2 sets of masses on thigh	505	125
1 set of masses at knee	485	158

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These loading conditions were intended to impose loads between the SAE 3-D testing manikin and the seat which ranged from less to more than the typical loading that occurs in manikin use. These conditions provide results for understanding seat response to variations in loading.

The 3-D testing manikin was then placed in a 1996 Chrysler Neon seat and loaded, using the same test protocol described above and shown in Table 1. Retro-reflective targets were attached to the manikin at the knee and H-pt joints so that the positions of those joints could be recorded by a Qualisys™ video-based motion measurement system as the manikin was loaded. The raw position data was tracked in the Qualisys™ motion measurement software and then transferred to a spreadsheet to be analyzed. To obtain an undeflected reference position, the torso and thigh-pelvis segments of the SAE 2-D drafting template were placed in the seat with the torso angle set at 0°. Retro-reflective targets were placed on the 2-D drafting template at the knee and H-pt and the locations of the targets recorded with the motion measurement system. These position data were also analyzed and transferred to a spreadsheet.

The deflection and force values at each loading condition are listed in Table 1. The results obtained by Hubbard, et. al. [9], show that the seat system responded nearly linearly at the H-pt (Figure 15) but that the seat did become incrementally softer as more load was placed on it. At the knee (Figure 16), the seat system responded nearly linearly after the thigh was loaded. Previous to that, the knee joint moved vertically upward as the H-pt was loaded. As the H-pt

Force at H-pt vs. Deflection at H-pt

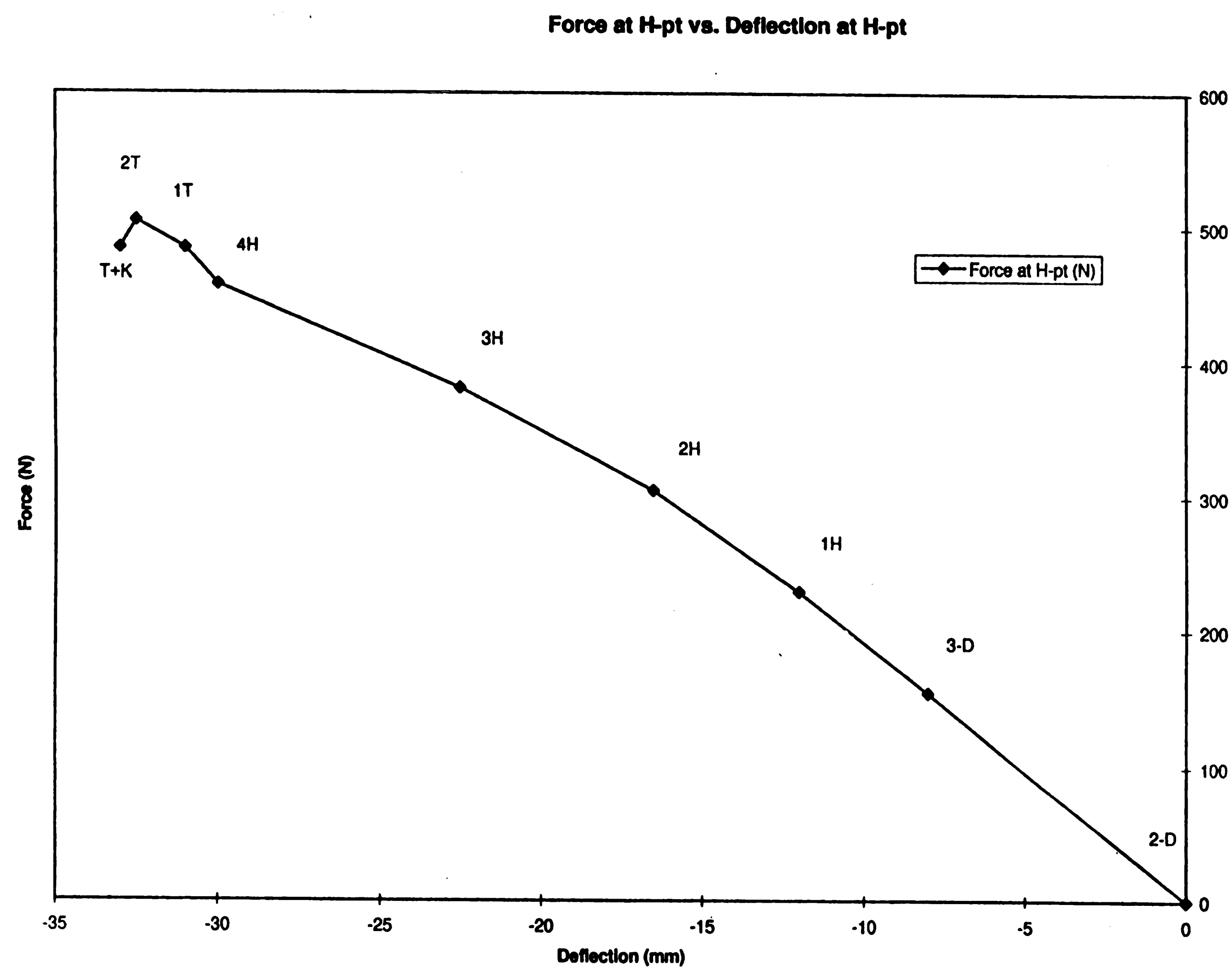

Figure 15: Force vs. deflection graph for seat pan response under H-pt

Force at knee vs. Deflection at knee

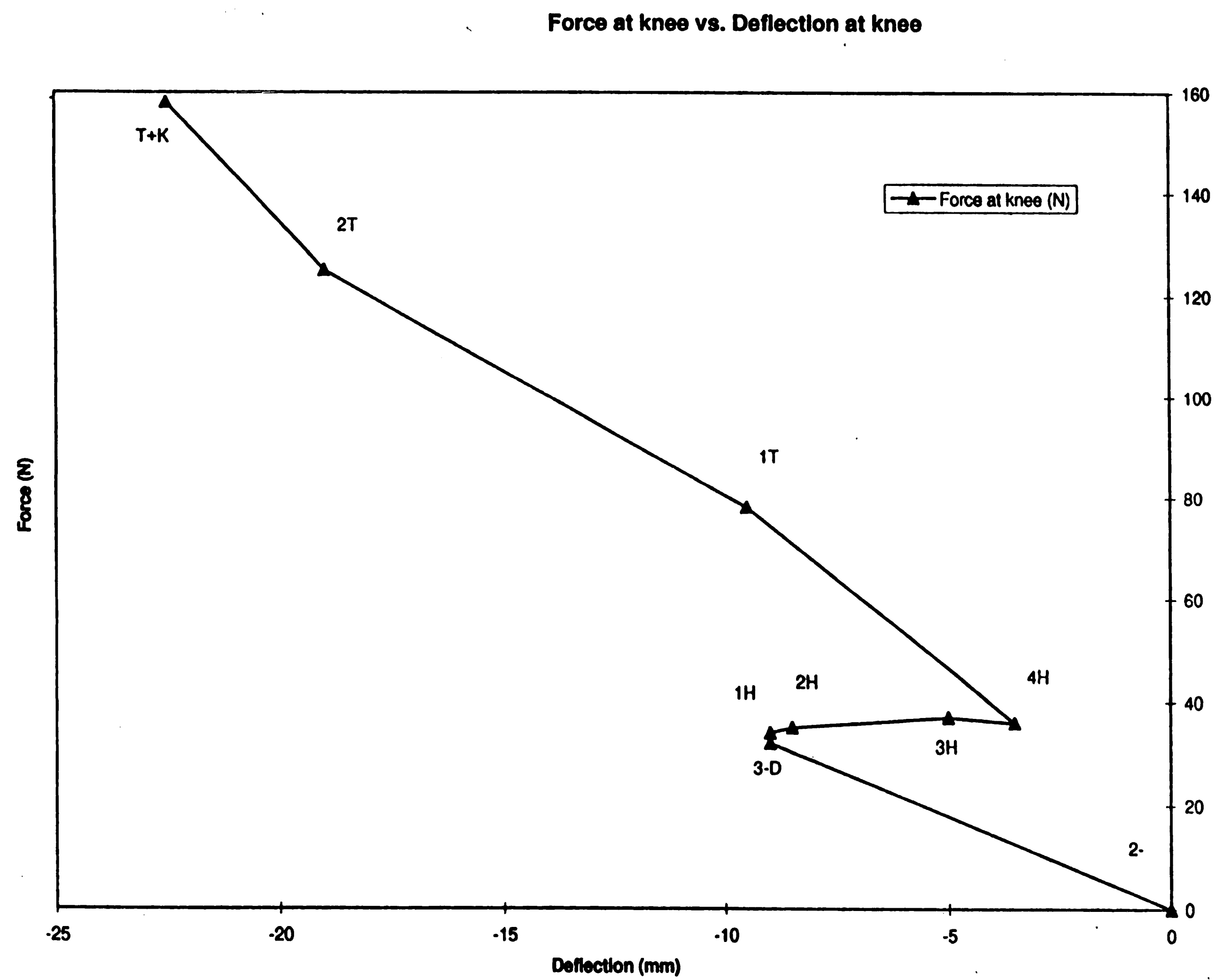

Figure 16: Force vs. deflection graph for seat pan response under knee

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sunk into the seat cushion due to the load, the thigh pelvis section pivoted about a point between the H-pt and knee joint. This point worked as a lever and as a result the knee joint moved upward as the H-pt moved downward.

Table 2 - Experimental force and deflection results from Hubbard, et. al. [9]

Loading Condition	Force at H-pt (N)	Force at knee (N)	Deflection at H-pt (mm)	Deflection at knee (mm)
2-D template	0	0	0	0
3-D manikin	154	32	-8	-9
1 set @ H-pt	229	34	-12	-9
2 sets @ H-pt	305	35	-16.5	-8.5
3 sets @ H-pt	381	37	-22.5	-5
4 sets @ H-pt	458	36	-30	-3.5
1 set @ thigh	485	78	-31	-9.5
2 sets @ thigh	505	125	-32.5	-19
1 set @ knee	485	158	-33	-22.5

2.1.4 Modeling of experimental data

The 2-D SAE computer model was used to simulate the experimental results obtained by Hubbard, et. al. To replicate the static support system, one end of a spring was placed on the H-pt of the model and the other end anchored to the background of the modeling space. A second spring was used to support the knee. One end of the knee support spring was attached to the knee joint and the other end attached to the background of the modeling space (Figure 17). To assist in keeping the torso angle at 0°, the torso and thigh-pelvis segment were pinned to vertical sliders (Figure 18). This system allowed frictionless vertical motion but no horizontal motion. To correctly model the experiment, circular geometric bodies were pinned to the 2-D SAE computer

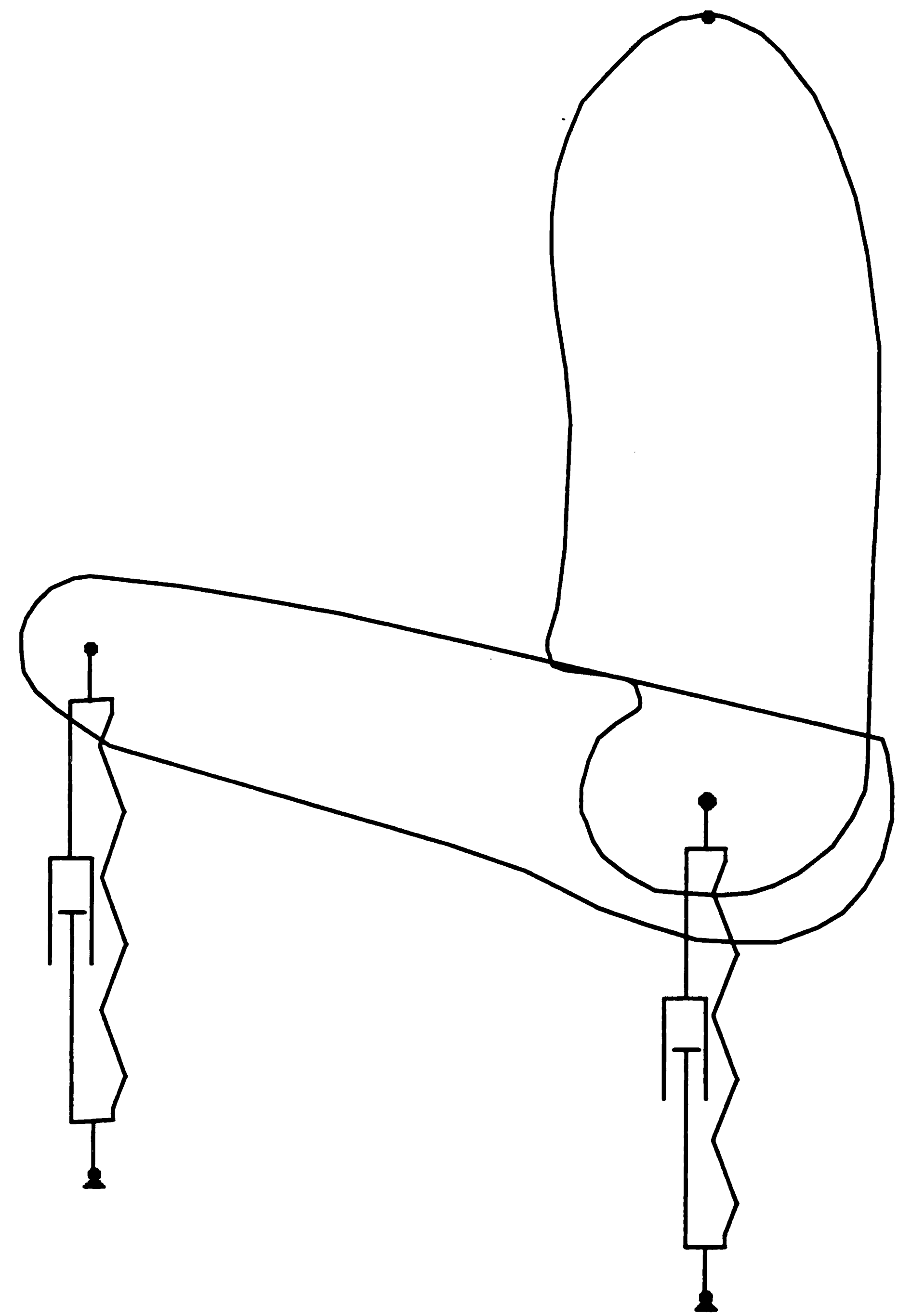

Figure 17: 2-D SAE model with spring supports at knee and H-pt

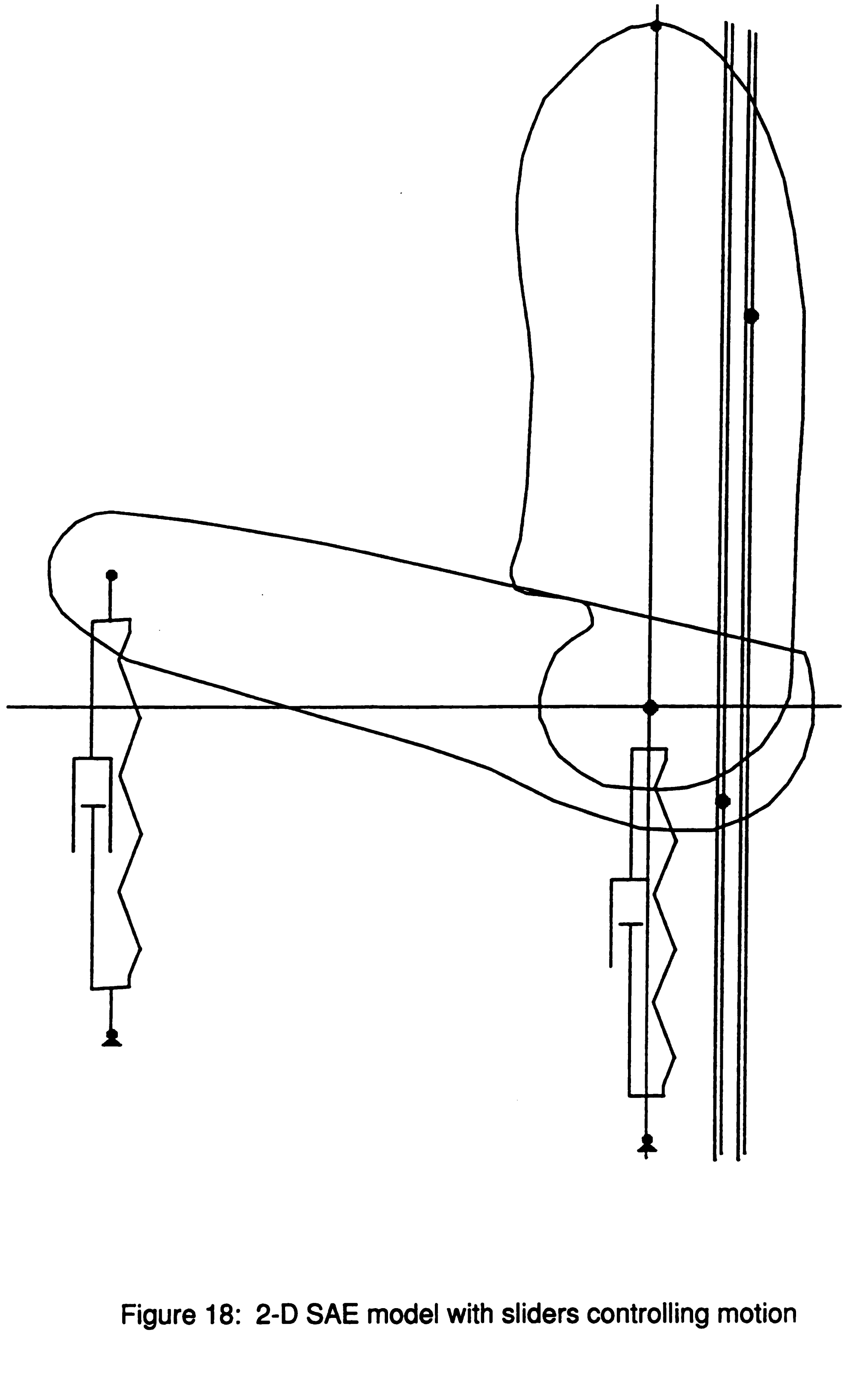

Figure 18: 2-D SAE model with sliders controlling motion

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model to represent the placement of the masses on the SAE 3-D testing manikin. These circular bodies were placed at the H-pt, mid-thigh at the thigh pins, just in front of the thigh pin, and at the knee joint (Figure 19). The masses of these circular bodies were changed during the simulations to represent the different loading conditions shown in Table 1. To aid with the simulations, adjustable slider boxes were created in Working Model™ to allow the user to easily make changes of the mass values. The slider boxes allow the user adjust the mass of an object by sliding a marker up and down a scale in the Working Model™ software. In addition, the H-pt mass slider was broken into increments to allow easy modification of the number of mass pairs positioned at the H-pt. Input value boxes were created to allow the user to easily change the spring constants of the supporting springs. On-screen output boxes were also created to show the deflections at the knee joint and H-pt, and to display the force acting on each spring support (Figure 20).

The 2-D SAE computer model was adjusted in Working Model™ until the thigh angle of the model matched the thigh angle of the physical 2-D drafting template when it was placed in the Chrysler Neon seat. Gravity was applied to the simulation and then the simulations were started, in effect "dropping" the 2-D SAE model onto the spring supports. The loading conditions performed in the experimental testing and described in Table 1 were repeated for the simulations. From the results of Hubbard, et. al. [9], piecewise spring constants were computed for each loading step and are given in Table 3. These were used for

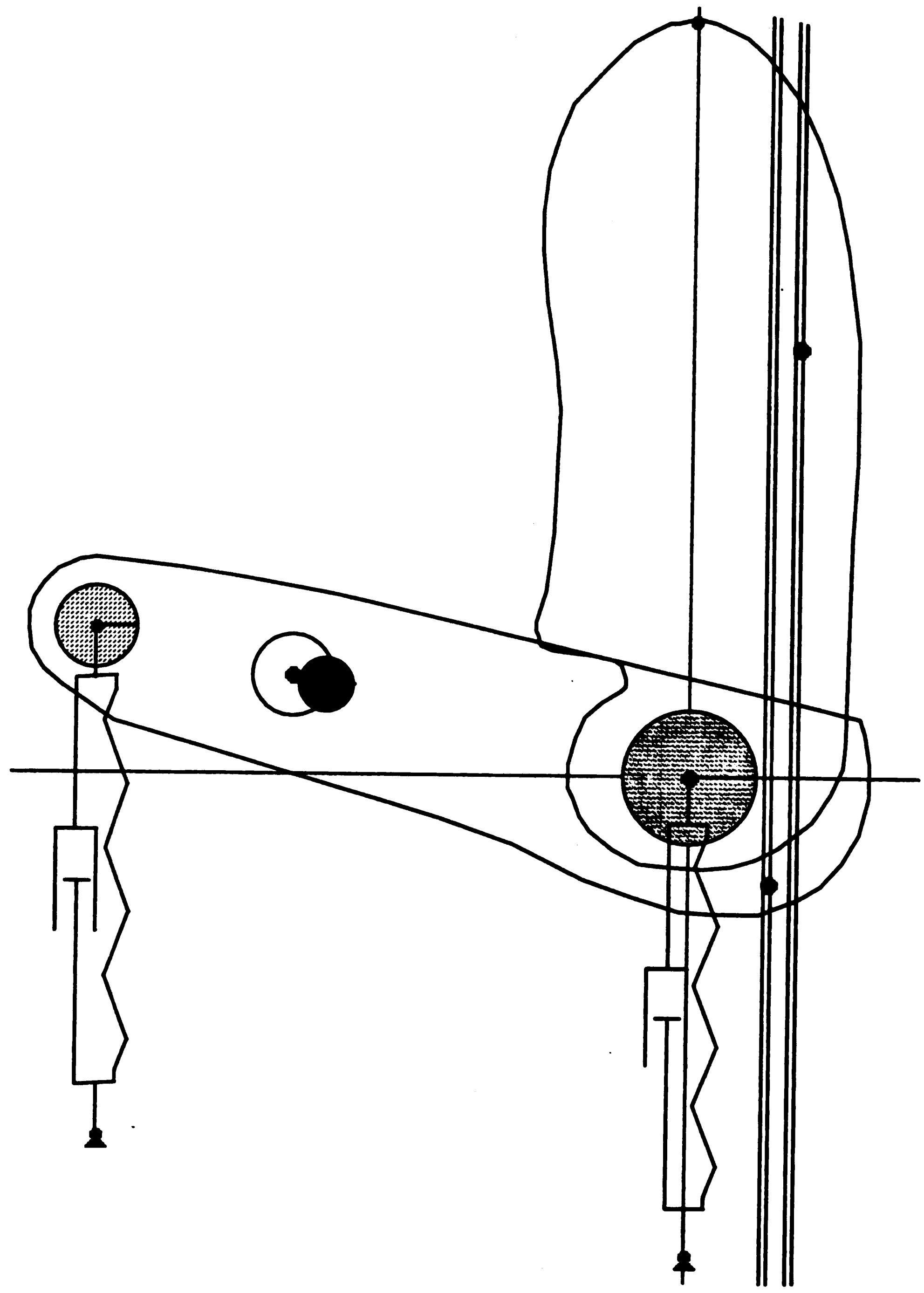

Figure 19: 2-D SAE model with mass circles on body segments

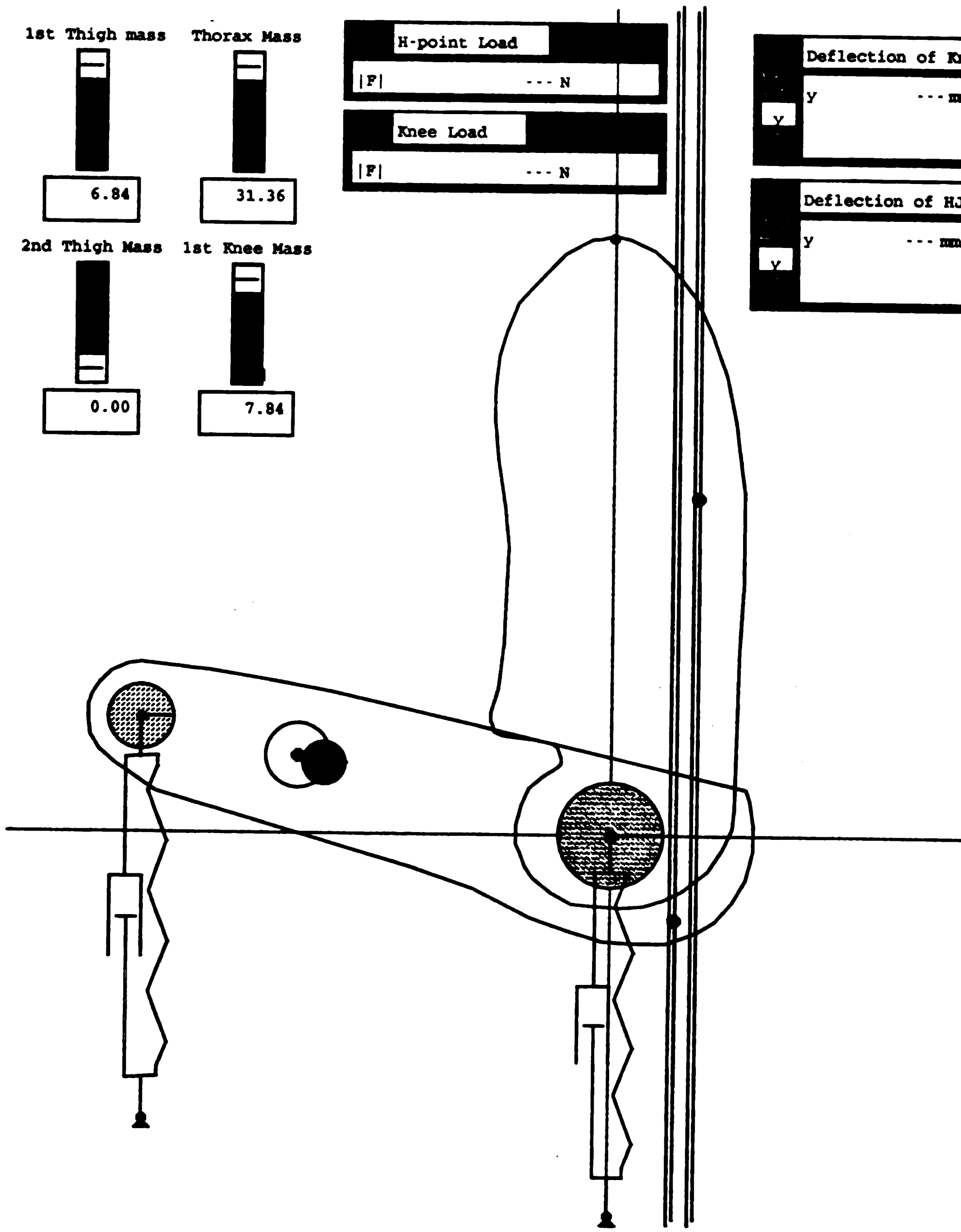

Figure 20: 2-D SAE model with input and output boxes

the H-pt and knee joint springs at each separate loading condition. The deflections and forces under the H-pt and knee were recorded after each simulation had stabilized.

After performing the simulations described above, the spring at the knees was moved to a point on the thigh. This repositioning of the support was performed to more closely simulate the loading of an automotive seat by the manikin and to see if the same deflection results from the experiment could be simulated with a different support system.

A geometric calculation was used to find an appropriate location for the thigh support. From the experimental data collected with the SAE 3-D manikin, it can be seen that the H-pt settled into the seat cushion due to the loading at the H-pt, and as this occurred the knee rose vertically upward relative to its initial deflected position. By plotting this data, a thigh support location was determined. Figure 21 shows the thigh orientations for the first five loading cases (shown in Table 1) superimposed over each other. The thigh support was placed at the point on the thigh about which the thigh rotated as the H-pt was loaded. A thigh support spring would behave in this way, with no deflection, if no load were added to the thighs while load was only added to the H-pt. The location of the rotation point was visually measured from Figure 21 and the spring support relocated to this position on the 2-D SAE model (Figure 22).

The purpose of relocating the spring support to the thigh was to provide a more realistic seat support system for the 2-D SAE model and determine the

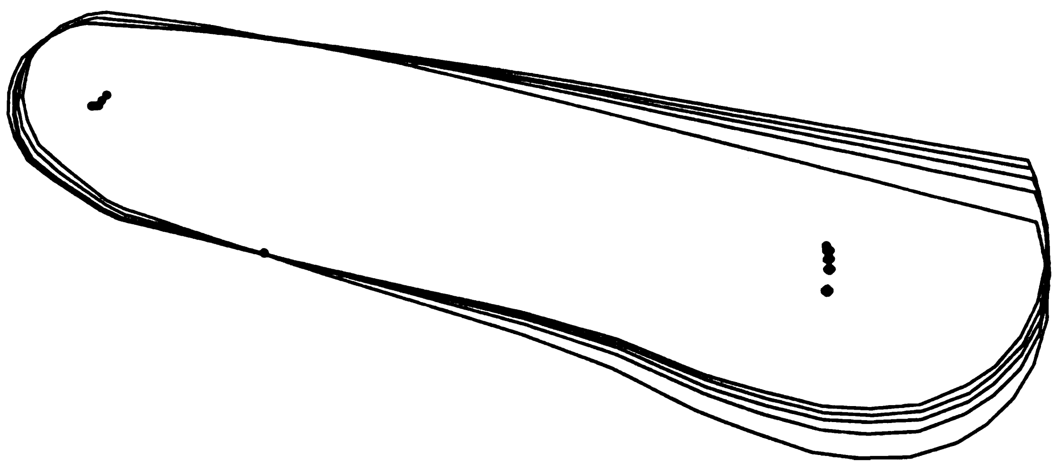

Figure 21: Superimposed thigh orientations for first five cases

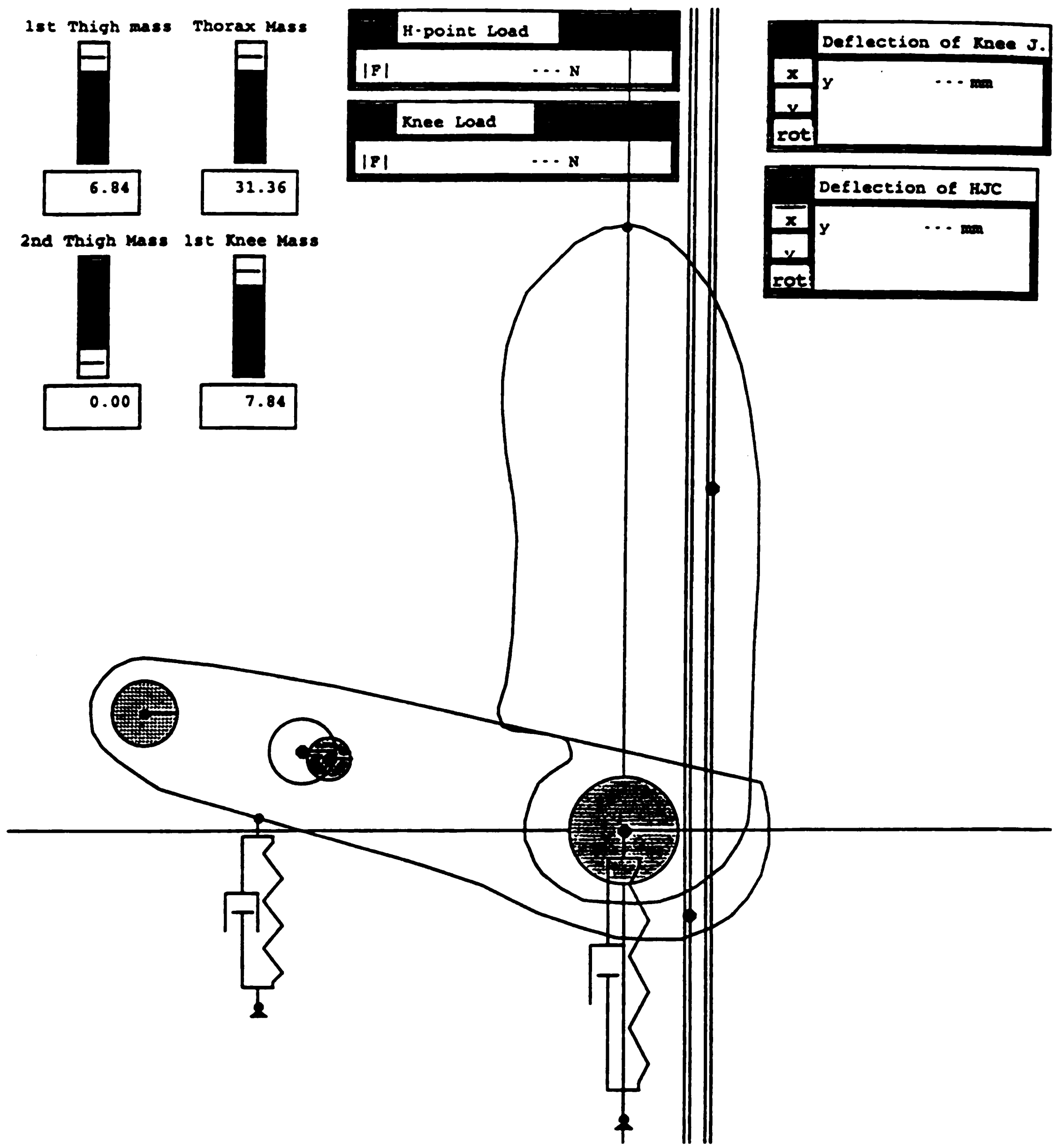

Figure 22: 2-D SAE model with spring supports at thigh and H-pt

support spring constants. To accomplish this, the deflections at the H-pt and knee obtained in the experiment performed by Hubbard, et. al. [9], were reproduced with the 2-D SAE computer model. To do so, the 2-D SAE model was reloaded in the manner described in Table 1 after relocating the knee spring support to the thigh in the model simulation. The support forces at the thigh and H-pt spring supports were recorded. These support forces were different from the previous simulation due to the different support locations. Using the new support force data from the H-pt support and the original experimental deflection data at the H-pt, from Hubbard, et. al. [9], the new piecewise spring constants were calculated for the H-pt. Next, the piecewise spring constants for the thigh were calculated. To accomplish this, the simulation was run again, this time using the new H-pt spring constants. At each loading condition, the spring constants for the thigh support were modified until the deflections at the knee joint matched those from the experimental data obtained by Hubbard, et. al. [9]. The spring constant values for the thigh support were recorded for each loading condition in the simulation.

2.2 RESULTS AND DISCUSSION

The 2-D drafting template model results, with the spring supports located under the knee and H-pt, were similar to the experimental results obtained by Hubbard et. al. [9]. Using this deflection and force data, the piecewise spring constants for both the knee and H-pt were computed for each increase in loading using a linear spring assumption (F=kx). The spring constant results are listed in Table 3. These spring constants are the slope of the line between each loading condition in the graphs shown in Figures 15 and 16.

Table 3 - Piecewise spring constants calculated from experimental data

Loading Condition	Spring constant @ H-pt (N/m)	Spring constant @ knee (N/m)
2-D template	-----	-----
3-D manikin shell	19.25	3.55
1 set of masses at H-pt	19.08	3.78
2 sets of masses at H-pt	18.48	4.12
3 sets of masses at H-pt	16.93	7.40
4 sets of masses at H-pt	15.26	10.28
1 set of masses on thigh	15.64	8.21
2 sets of masses at thigh	15.54	6.58
1 set of masses at knee	14.70	6.20

As it can be seen in Table 4, the measured and modeled results for the forces at the H-pt were within 2% or less for each loading condition. Table 5 displays the results obtained for the knee supports and shows that the modeled and measured results were within 7% or less at every loading condition. The values of the simulated support force under the H-pt compared more closely with the experimental data than the simulated support force values under the knee, but the modeled and experimental results for both supports are very close. The modeled values for the force supporting the H-pt were higher than those in the experiment. The opposite held true for the modeled force under the knee, where the modeled values were less than the experimental values. However, the ΔF

columns in Table 5 and Table 6 show that the magnitude of the change between the experimental and modeled force values is approximately the same. This indicates that there is need for refining the mass placements on the 2-D SAE model by moving a mass toward the knee to correct the discrepancy with the experimental results. The results from the 2-D SAE computer model do show that the model can be used to simulate experimental data collected on an automotive seat cushion by the SAE 3-D testing manikin with a high degree of repeatability.

Table 4 - 2-D SAE model force and deflection results

Loading Condition	Force at H-pt (N)	Force at knee (N)	Deflection at H-pt (mm)	Deflection at Knee (mm)
2-D template	0	0	0	0
3-D manikin	153	33	-7.9	-9.3
1 set @ H-pt	231	33	-12.1	-8.7
2 sets @ H-pt	308	34	-16.7	-8.3
3 sets @ H-pt	385	35	-22.7	-4.7
4 sets @ H-pt	463	35	-30.3	-3.4
1 set @ thigh	489	75	-31.3	-9.1
2 sets @ thigh	514	126	-33.1	-19.1
1 set @ knee	486	150	-33.1	-24.2

Table 5 - Experimental vs. model results for force at H-pt

Loading Condition	Force at H-pt - experimental (N)	Force at H-pt - model (N)	Percent difference	ΔF (N)
2-D template	0	0	-----	0
3-D manikin	154	153	0.6	-1
1 set @ H-pt	229	231	0.9	+2
2 sets @ H-pt	305	308	1.0	+3
3 sets @ H-pt	381	385	1.0	+4
4 sets @ H-pt	458	463	1.0	+5
1 set @ thigh	485	489	0.8	+4
2 sets @ thigh	505	514	1.7	+9
1 set @ knee	485	486	0.2	+1

Table 6 - Experimental vs. model results for force at knee

Loading Condition	Force at knee - experimental (N)	Force at knee - model (N)	Percent difference	ΔF (N)
2-D template	0	0	------	0
3-D manikin	32	33	3.0	+1
1 set @ H-pt	34	33	3.0	-1
2 sets @ H-pt	35	34	2.8	-1
3 sets @ H-pt	37	35	5.4	-2
4 sets @ H-pt	36	35	2.8	-1
1 set @ thigh	78	75	3.8	-3
2 sets @ thigh	135	126	6.6	-9
1 set @ knee	158	150	5.0	-8

The simulated support force results for the H-pt and thigh support system are shown in Table 7. Recall that the deflections are the same as those obtained in the experiment by Hubbard, et. al [9]. As can be expected, when the leg support is moved in from the knee to the thigh, forces acting on the H-pt and thigh supports become more evenly distributed than with the supports at the H-pt

(Table 5) and knee (Table 6). With the support moved from the knee to the thigh, the support force at the H-pt decreased accordingly, and, to achieve the same deflections in the model as those predicted by the experiment the piecewise spring constants under the H-pt (Table 3) decreased, or became softer. The piecewise spring constants for the H-pt and thigh support system are shown in Table 8. As it can be seen, the seat was substansially stiffer under the H-pt than under the thighs. Table 9 shows a comparison between the H-pt spring constants when modeling the seat systems with a H-pt and thigh support as compared to a H-pt and knee support. The support system using springs at the thigh and H-pt is a more realistic system for simulating the response of the manikin placed in an automotive seat, and, as Table 9 shows, after the support system had been changed, the spring constants under the H-pt decreased a substantial amount at the very light and very heavy loading conditions.

Table 7 - Model force results for supports at H-pt and thigh

Loading Condition	**Force at H-pt (N)**	**Force at thigh (N)**
2-D template	0	0
3-D manikin shell	143	44
1 set of masses at H-pt	220	44
2 sets of masses at H-pt	298	45
3 sets of masses at H-pt	376	43
4 sets of masses at H-pt	454	40
1 set of masses at thigh	467	94
2 sets of masses at thigh	476	163
1 set of masses at knee	442	197

Table 8 - Model piecewise spring constants for supports at H-pt and thigh

Loading Condition	Spring constant @ H-pt (kg/s^2)	Spring constant @ thigh (kg/s^2)
2-D template	-----	-----
3-D manikin shell	17.9	5.1
1 set of masses at H-pt	18.3	4.5
2 sets of masses at H-pt	18.1	4.2
3 sets of masses at H-pt	16.7	4.3
4 sets of masses at H-pt	15.1	4.6
1 set masses at thigh	15.1	6.5
2 sets of masses at thigh	14.6	7.3
1 set of masses at knee	13.3	7.2

Table 9 - Comparison of H-pt piecewise spring constants for support at knee vs. support at thigh

Loading Condition	H-pt spring constant with thigh support (N/m)	H-pt spring constant with knee support (N/m)	Δk (N/m)
2-D template	-----	-----	-----
3-D manikin shell	17.9	19.25	-1.35
1 set of masses at H-pt	18.3	19.08	-1.22
2 sets of masses at H-pt	18.1	18.48	-0.38
3 sets of masses at H-pt	16.7	16.93	-0.23
4 sets of masses at H-pt	15.1	15.26	-0.16
1 set masses at thigh	15.1	15.64	-0.54
2 sets of masses at thigh	14.6	15.54	-0.96
1 set of masses at knee	13.3	14.70	-1.40

Using the 2-D SAE computer model to repeat experimental results obtained with the SAE 3-D testing manikin is of great importance to a seat designer. Currently, the seat manufacturers are able to design and construct an automotive seat with the SAE J826 tools. The development of the experimental seat testing protocol by Hubbard, et. al. [9], now enables the manufacturers to measure the response of an automotive seat cushion with the SAE 3-D testing manikin. With the development of the 2-D SAE computer model, the seat manufactures are able to simulate the response of the 3-D testing manikin in an automotive seat cushion with the 2-D SAE computer model. This allows the designers to modify the variables of the seat cushion, such as stiffness, and study the effect of a change with the 2-D SAE computer model. In addition, because the SAE 3-D testing manikin simulates human hip and knee locations and torso angle, and the 2-D SAE computer model simulates the response of the 3-D manikin in a seat, designers can now use the 2-D SAE computer model to model human hip and knee locations for this particular automotive seat. In the future, with further seat testing, it will be possible to model the force/displacement response of the SAE 3-D testing manikin on the computer for different seats. This modeling ability will save the seat manufacturers time and money by allowing them to simulate different seat stiffness characteristics without having to build as many expensive prototypes.

2-D JOHN COMPUTER MODEL DEVELOPMENT

3.1 METHODS AND MATERIALS

3.1.1 2-D JOHN kinetic computer model construction

Once the 2-D SAE computer model had been developed and shown to accurately simulate a physical experiment in an automotive seat, the next step was to develop a representation of JOHN in Working Model™. The goal of the 2-D kinetic JOHN model development was to provide a representation of human torso motion which could be used to predict seated human position and the forces between the model and seat.

To construct the 2-D JOHN model torso, numerous contour points were selected from pre-existing 2-D CAD drawings of the pelvic, lumbar, and thoracic body segments of JOHN [8], and the coordinates of these points were entered into the Working Model™ software as the vertices of polygons (Figure 23). The body segment contours represented the skeletal geometry of the three segments surrounded by soft tissue. The body segment contours were adapted by Hubbard et. al. [3] based on data obtained from the University of Michigan Transportation Research Institute (UMTRI) study on seated occupant anthropometry [5,6] and a corrected pelvis location that had been used in developing the JOHN model in which the lumbar spine was lengthened by 30 mm. In addition, this anthropometric data was used to locate the joint centers on the thorax, lumbar and pelvis body segments in Working Model™. Points were placed on the pelvis body segment at the HJC and L5/S1 joint center, and on the thorax segment at the T12/L1 joint center. Two corresponding points for the T12/L1 and L5/S1 joint centers were placed on the lumbar segment (Figure 24).

After the torso had been completed, the legs for the 2-D JOHN model were constructed. The average male legs of the SAE 2-D drafting template (composed of the thigh-pelvis, shank and foot segments) [1] were imported into Working Model™ from a CAD computer file obtained from the Automotive Systems Group of Johnson Controls, Inc. Unlike the typical SAE practice of using the 95th percentile male leg lengths with the 50th percentile body, the SAE average male legs were used for the development of the 2-D JOHN model because the model was to be used only with seat related issues, and not packaging issues; therefore a model with consistent anthropometry was preferred. Because the 2-D JOHN model included a pelvis segment, the thigh-pelvis segment from the SAE 2-D drafting template was reshaped to represent only a thigh (Figure 25). The CAD file of the SAE 2-D drafting template contained the placement of the hip joint center and knee joint on the thigh, the knee joint on the shank, and the ankle joint on shank and foot. The location of these joint centers were confirmed with measurements from the SAE 2-D drafting template and the physical SAE 3-D testing manikin. In Working Model™, points were placed on the thigh, shank and foot segments to represent the location

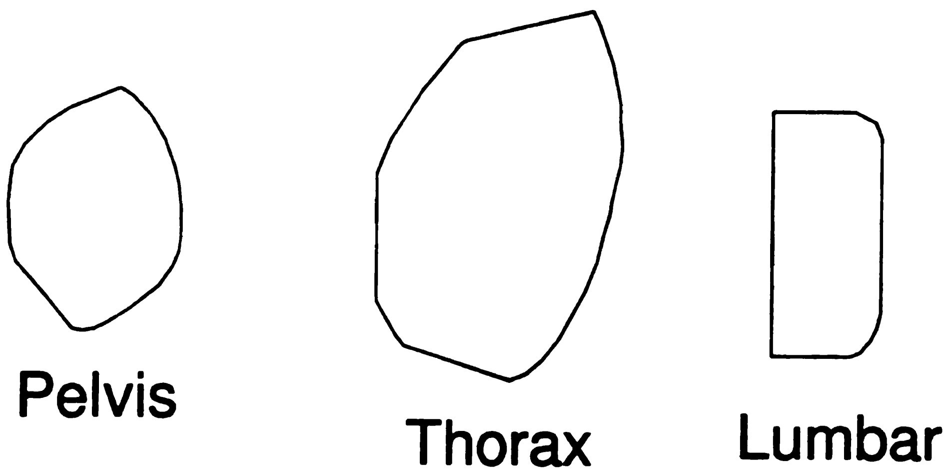

Figure 23: 2-D JOHN thorax, lumbar and pelvis segments

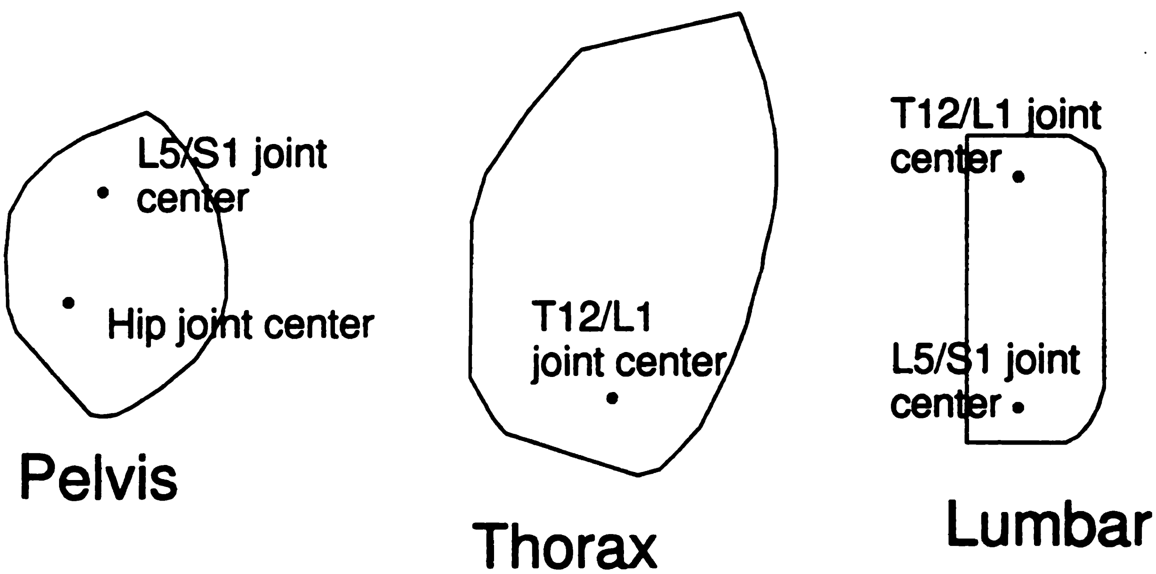

Figure 24: 2-D JOHN torso segments with points at joint centers

of the joint centers.

With all the body segments sized appropriately and the joint center locations correct, the JOHN model segments were assembled. To simulate the one-to-one thorax to pelvis motion of JOHN, a linkage using gears was developed. Two gear circles, with diameters of 75 mm, were created. Points were placed at the centers of the two gear circles (Figure 26). The gear circles were adjusted until points at the centers were aligned over the lumbar joint center points on the pelvis segment at the T12/L1 joint and on the thorax segment at the L5/S1 joint center. The two gear circles were rigidly pinned to the thorax and pelvis segments (Figure 27). The lumbar segment was then joined to the two gear circles at the gear circle points, creating the L5/S1 and T12/L1 joints and a completed torso (Figure 28). Although in the 2-D forms the thorax, lumbar, and pelvis segments and gear circle bodies overlap, they do not collide with each other because they are layered. Any two segments that are pinned together are assumed to not collide in the Working Model™ software. Finally, a gear linkage was placed between the two circles, changing the circle bodies into gears (Figure 29). Because the gear circles were of the same diameter, they had a 1:1 gear ratio, thereby establishing the one-to-one counter-rotation of the thorax and pelvis. In effect, the mechanism consisted of one gear resting upon the other with the teeth of the two gears intermeshed, and with the gears each pinned to a body and held a fixed distance apart.

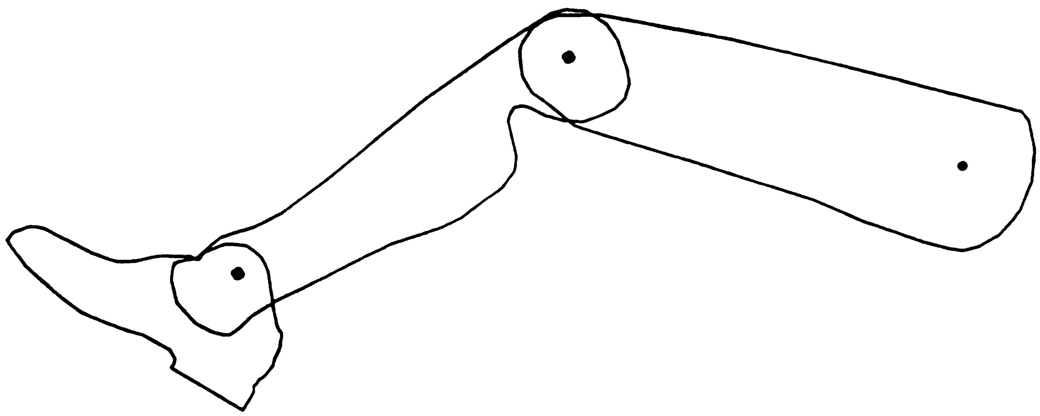

Figure 25: 2-D JOHN legs with redesigned thigh

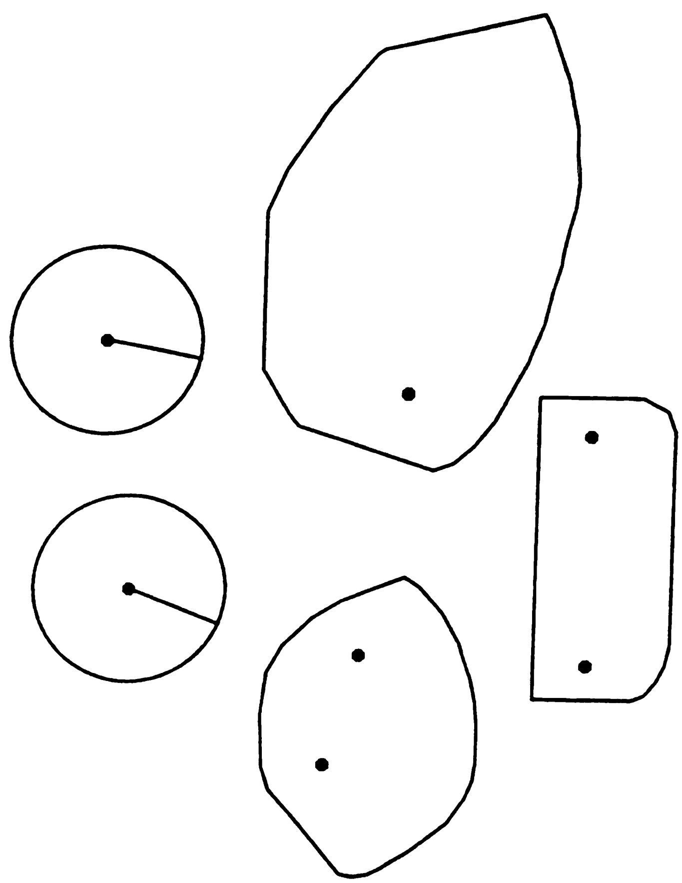

Figure 26: 2-D JOHN torso segments with gear circles and joint centers

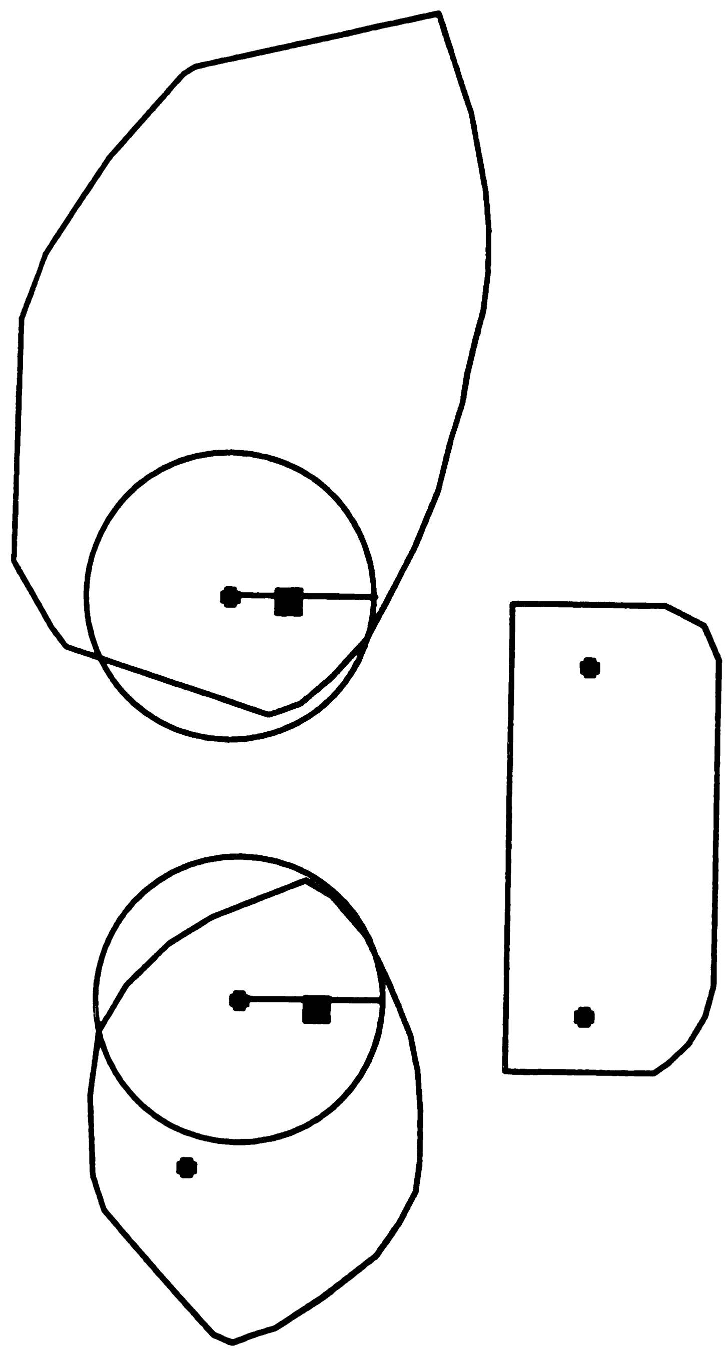

Figure 27: Gear circles pinned to thorax and pelvis segments

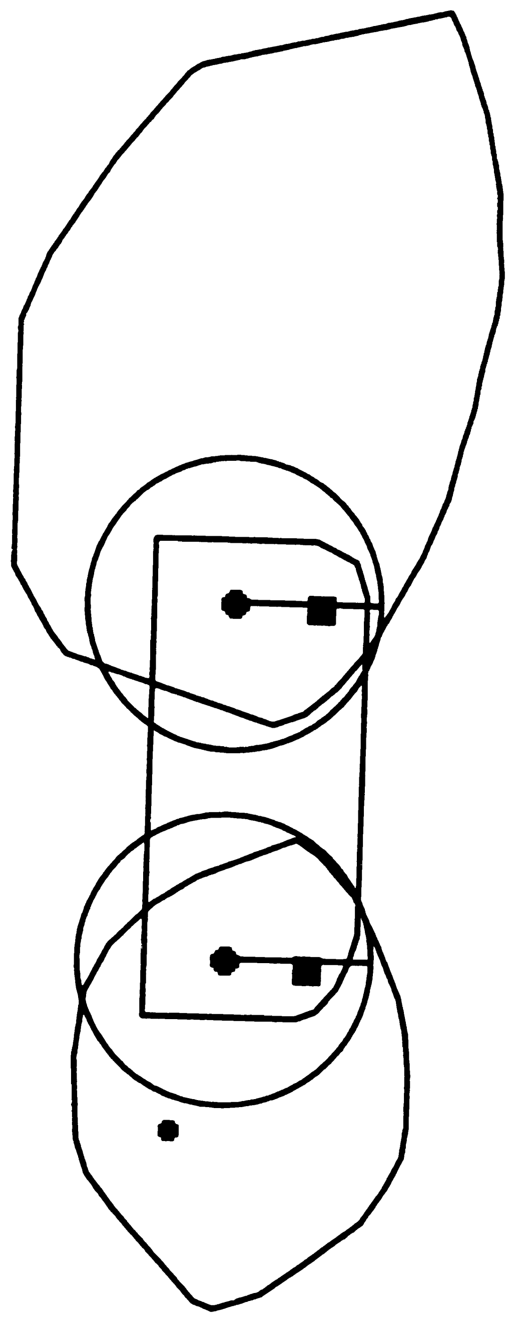

Figure 28: Lumbar segment joined to thorax and pelvis segments

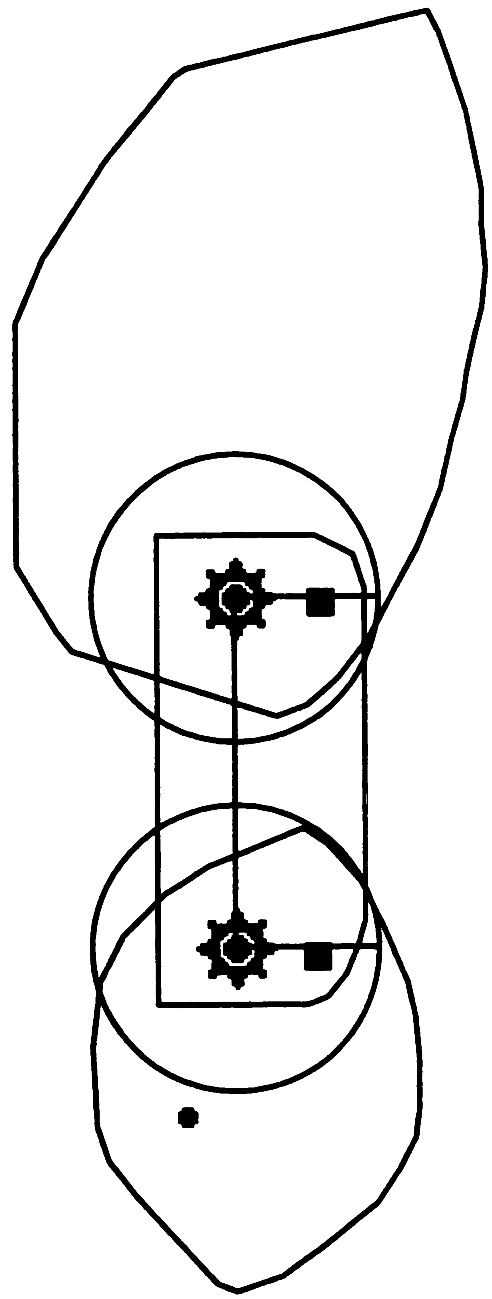

Figure 29: Gear linkage added to 2-D JOHN model

Once the 2-D JOHN model was fully assembled, a nominal posture for the model was defined in Working Model™, using previous data on the orientation of JOHN [4,7,8]. The positioning of JOHN was described in joint center orientations because JOHN had been constructed as an accurate skeletal model of the human body. In order to orient the thorax, lumbar and pelvis body segments of the 2-D JOHN model in Working Model™ the same as the 2-D JOHN model described in Hubbard et. al. [3], the model was placed in a 30° TRA (Torso Recline Angle) posture, which corresponded to a line between the T12/L1 and L5/S1 joint centers being 30° right of vertical. To achieve a 0° TLC posture at 30° TRA, the thorax segment was oriented so that a line from the T12/L1 joint center to the C7/T1 joint center was at 0° or vertical. This measure was determined from the 2-D articulating JOHN template developed by Bush [8]. The pelvis segment was oriented so that a line from the HJC to the L5/S1 joint center was 64° right of vertical (Figure 30).

After the 2-D JOHN model body segments had been aligned, output boxes were created to continuously update the values of TLC and TRA on-screen during a simulation. As described previously, the measure of TRA was the angle, from vertical, of a line between the L5/S1 and T12/L1 joint centers. This measure corresponded to the rotational orientation of the lumbar segment in Working Model™, so that when the lumbar segment was at 45° right of vertical, the TRA of the JOHN model was also 45° right of vertical. The TLC was measured by determining the relative rotation of the thorax and pelvis to each

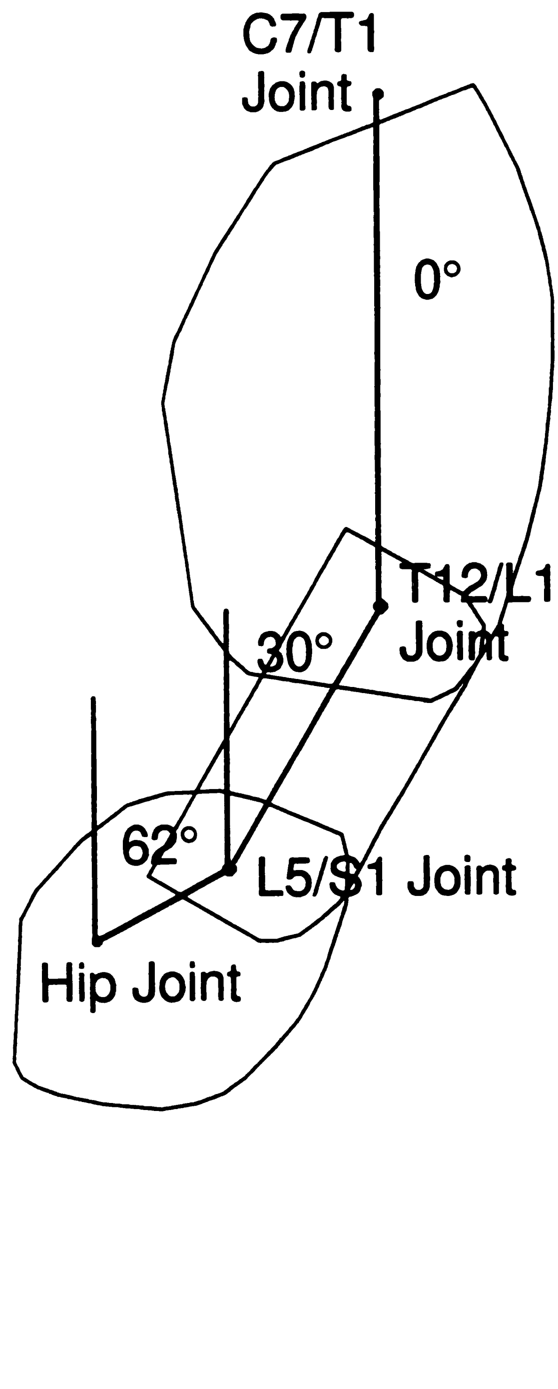

Figure 30: 2-D JOHN torso showing segments with joint center orientations

other, starting with the 0° TLC value described above. The values displayed were the state of each variable at each time step in the simulation run (Figure 31).

After initial trial simulations had been run with the 2-D JOHN model it became apparent that another constraint was needed because the model would occasionally slump so much that it would achieve a posture beyond the range of human movement. To alleviate this problem, a rope was added between the lower rear of the thorax and upper rear of the pelvis to act as a constraint (Figure 32). This rope restricts the model from movement to a TLC less than -10°, the assumption being that people will not slump past that point due to passive muscle and ligament constraints.

3.1.2 Locating the COM's for the 2-D JOHN model body segments

When the 2-D JOHN model had been fully constructed, the mass and center of mass (COM) were assigned to each body segment. For ease in modeling a symmetrical posture was assumed in the sagittal plane, so the masses of the 2-D JOHN model thigh, shank and foot are the combined mass of the right and left body segments. In addition, because this study was focused on the effects of seat geometry, not the vehicle interior, it was decided to eliminate the steering wheel and its possible effect on the posture of the model due to the moment placed about the back when the arms were held out to grasp the wheel. An equivalent COM was calculated for the thorax, combining the masses of both

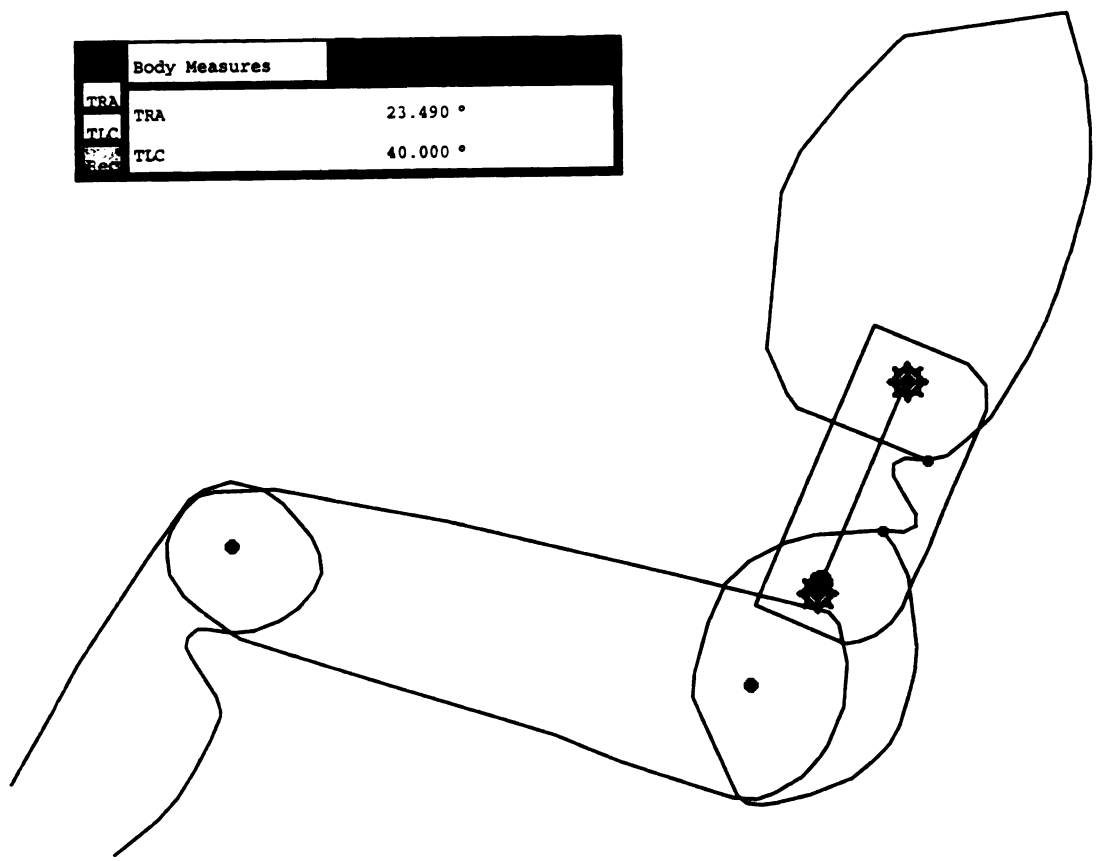

Figure 31: Output box showing TLC and TRA

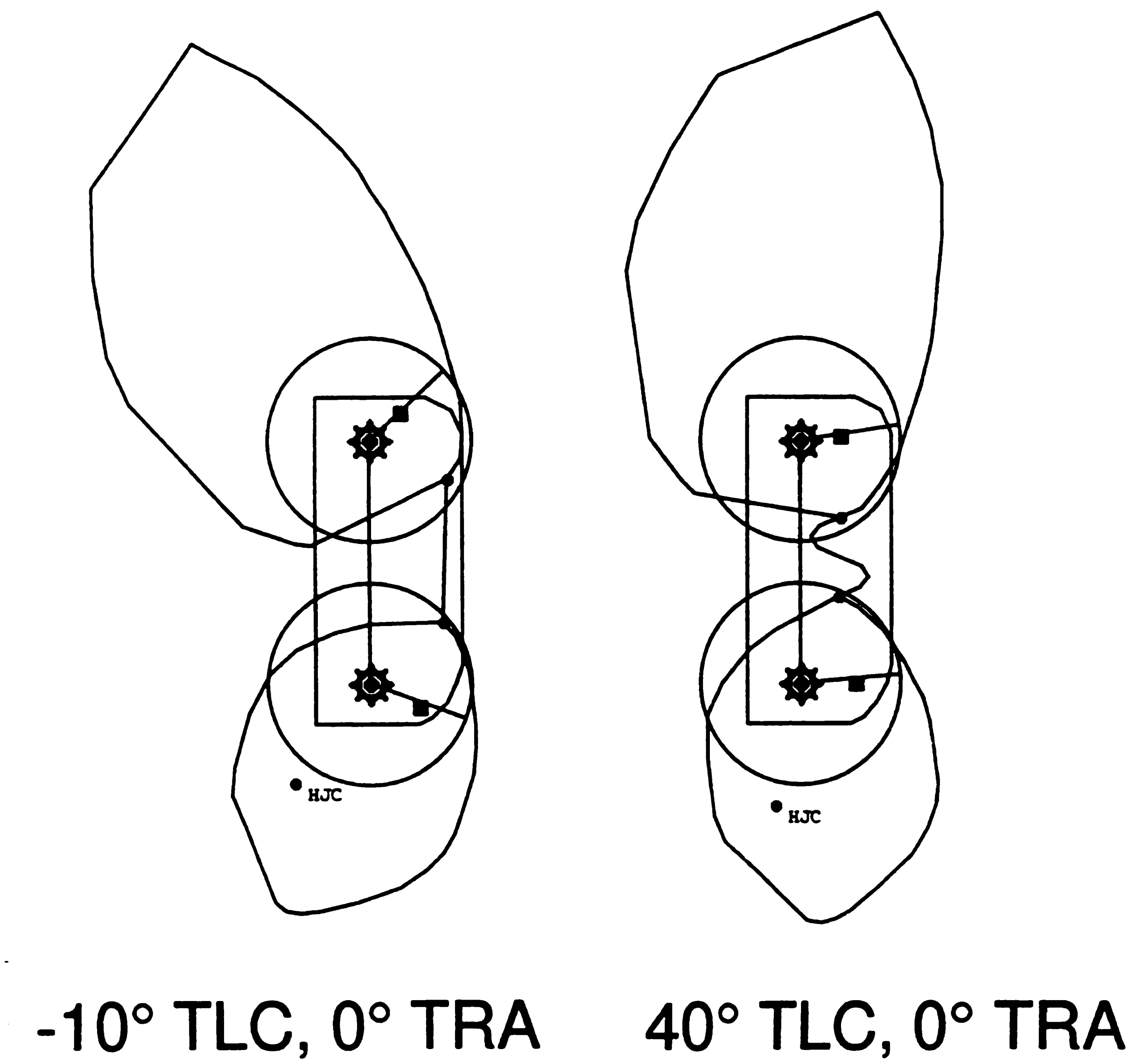

Figure 32: Rope added to 2-D JOHN torso

arms, thorax, head, and neck and orienting the arms straight down by the sides of the body.

The COM's for the foot, shank, thigh, pelvis and lumbar segments were found utilizing a full size drawing of the average sized male developed in the seated UMTRI study [5,6]. In order to locate the COM's, a coordinate system was established by placing a line between the known joint locations for the foot, shank, thigh, pelvis and lumbar body segments on the drawing. Each line formed one axis and a line perpendicular to it formed the other axis. For each body segment, the distance to the center of mass was measured along those axes from one joint center, which was the origin. The same axes were duplicated on the respective body segments of the 2-D JOHN model and a point was placed on each body segment at its COM. The COM for each 2-D JOHN model body segment was then positioned according to the location defined by the UMTRI data [5,6] (Figure 33). Table 10, below, is listing of the body segment masses.

Table 10 - 2-D JOHN body segment masses

Body Segment	Mass (kg)
Thorax (combined thorax, head, neck and both arms (including hands))	36.447
Lumbar	2.365
Pelvis	11.414
Thigh	17.228
Shank	7.174
Foot	1.962

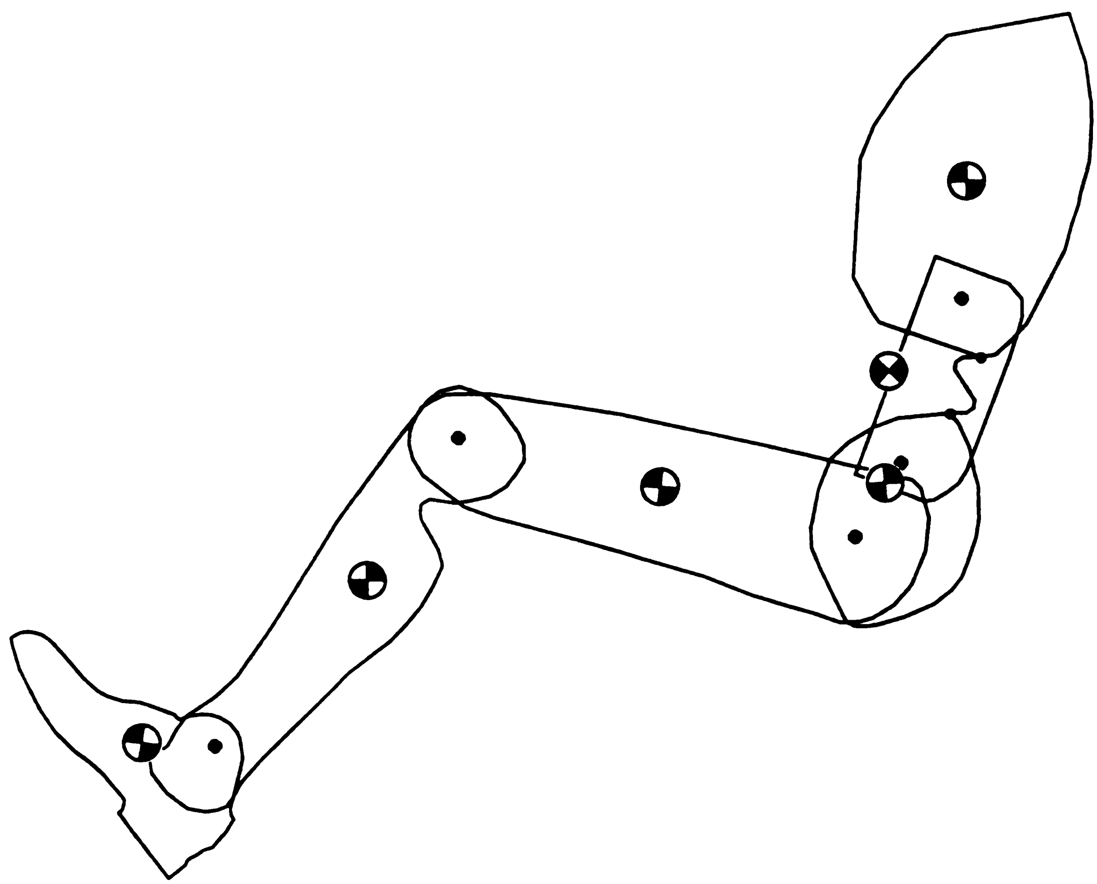

Figure 33: COM positions on all segments except thorax

The equivalent COM for the 2-D JOHN thorax was determined by utilizing the UMTRI drawing of the average male seated occupant with the arms straight down from the shoulders (vertical) along the sides of the body (Figure 34). The head and neck were oriented as described in the UMTRI data [5,6] on seated anthropometry. The UMTRI data was used because this was the only reference available showing the human body with the centers of mass for the body segments in a typical automotive seated position.

To calculate this equivalent COM, a coordinate system was set up on an full size drawing of the average male developed by UMTRI. A coordinate system was established which placed the origin at the glenohumeral joint of the shoulder. The x and y axes of the coordinate system corresponded to the x and y axes of the UMTRI drawing. The length of the upper arm, from the shoulder joint to the elbow joint, and the length of the lower arm, were determined from the UMTRI drawing. The upper arm and lower arm (which included the hand) were redrawn in a new orientation, with the arm joint centers in a line straight down from the glenohumeral joint, oriented parallel to the y axis.

The COM for the upper arm and lower arm body segments were measured using a segmental coordinate system. The upper arm COM was measured from the shoulder joint using a line between the shoulder joint and elbow joint as one axis, and a line perpendicular to that as the second axis. The same method was applied to the lower arm, using instead the elbow joint and wrist joint as one axis, a line perpendicular to that as the second axis and the

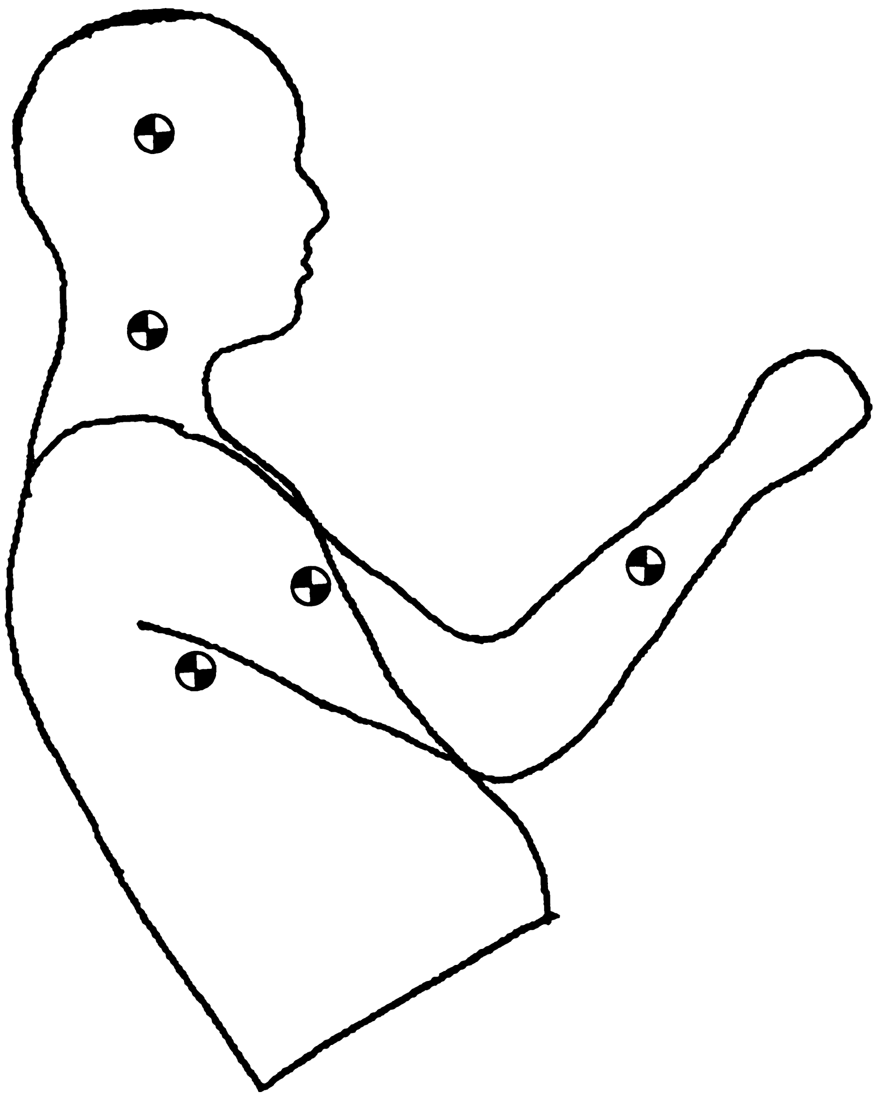

Figure 34: Original orientation of head, neck, arms and thorax showing COM's

elbow joint as the origin. The upper and lower arm COM's were relocated on the full sized UMTRI drawing using the new upper and lower arm segment orientations (see Figure 35).

With all the segment centers of mass in place and the segments oriented correctly, the equivalent COM for the vertical arm placement was calculated. The x-direction distance of the equivalent COM from the origin, $\bar{x}$, equals the sum of all the body segment moments in the x-direction, divided by the total mass. The sum of the moments in the x-direction is the mass of each segment multiplied by the distance from the origin, positive or negative, in the x-direction. The same approach was used for calculating the y-direction location of the equivalent COM, $\bar{y}$ [10]. To calculate the moments for $\bar{y}$, the masses of the head, neck, thorax, upper arm and lower arm segments were all multiplied by the distance, in the y-direction, each segment was from the shoulder joint. The moments of all the segments were summed and divided by the total mass of all the segments in order to find the location of the equivalent COM in the y-direction. When the calculations had been completed, the equivalent COM for the thorax, which included the masses of the arms, neck, head and thorax, was found to be 8.4 mm forward (x-direction) and 111.3 mm below (y-direction) the shoulder joint. The equivalent thorax COM was 2.6 mm rearward (x-direction) and 14.7 mm above (y-direction) the normal COM of the thorax. This point was located and marked on the thorax segment of the average male UMTRI drawing.

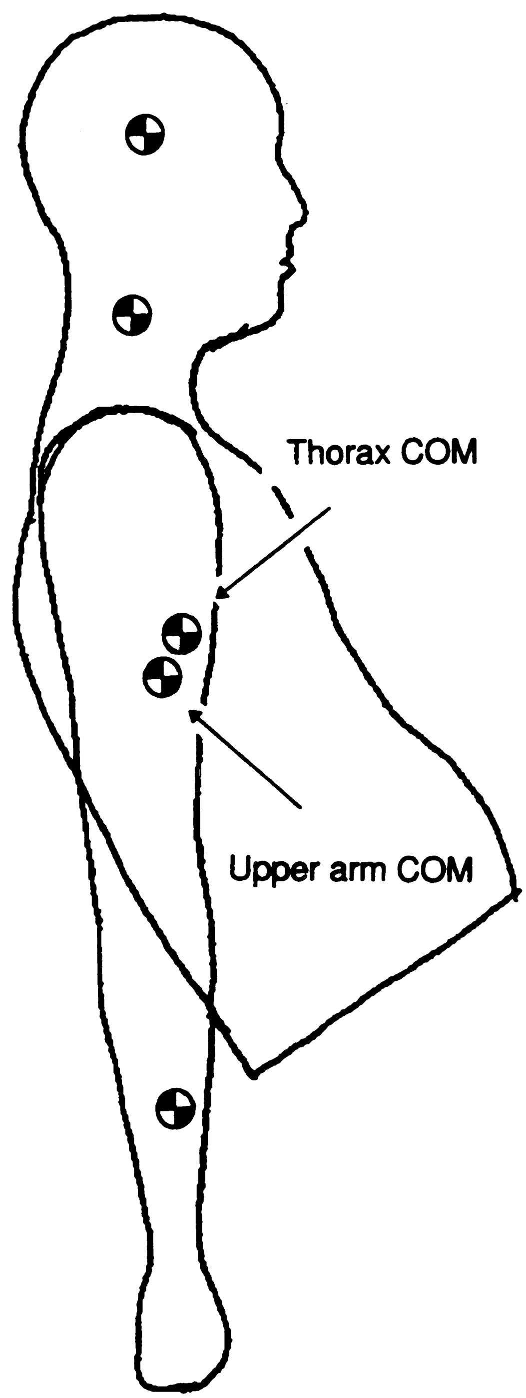

Figure 35: New orientation of head, neck, arms and thorax for
2-D JOHN thorax equivalent COM calculation

In order to apply the equivalent center of mass to the thorax segment of the 2-D JOHN model, the location of the equivalent center of mass was measured from the UMTRI drawing relative to the C7/T1 (seventh cervical/first thoracic vertebrae) joint center along a body segment axis system that consisted of a line from the C7/T1 joint center to the T12/L1 joint center and another line perpendicular to it. When the location had been determined, the body segment axes were duplicated on the thorax of the 2-D JOHN model, a point was placed at the location of the equivalent COM of the thorax, and the model COM positioned to coincide with the calculated COM (Figure 36).

Combining the masses and locations of the arms, head, and neck, with the thorax mass and COM effectively fixes the orientation of those body segments with respect to the thorax. This may have an effect on the final position of the 2-D JOHN model. However, since the distance between the equivalent COM and the normal thorax COM is only 2.6 mm in the x-direction and 14.7 mm in the y-direction, fixing the orientation of the head, neck and arms segments with respect to the thorax will likely have only a minimal effect of the final posture of the 2-D JOHN model.

3.1.3 Seat model construction

After the 2-D JOHN model had been completed, it was used in a seat geometry comparison. The purpose of this study was to determine if the model could be used to differentiate between seat designs based on the postural

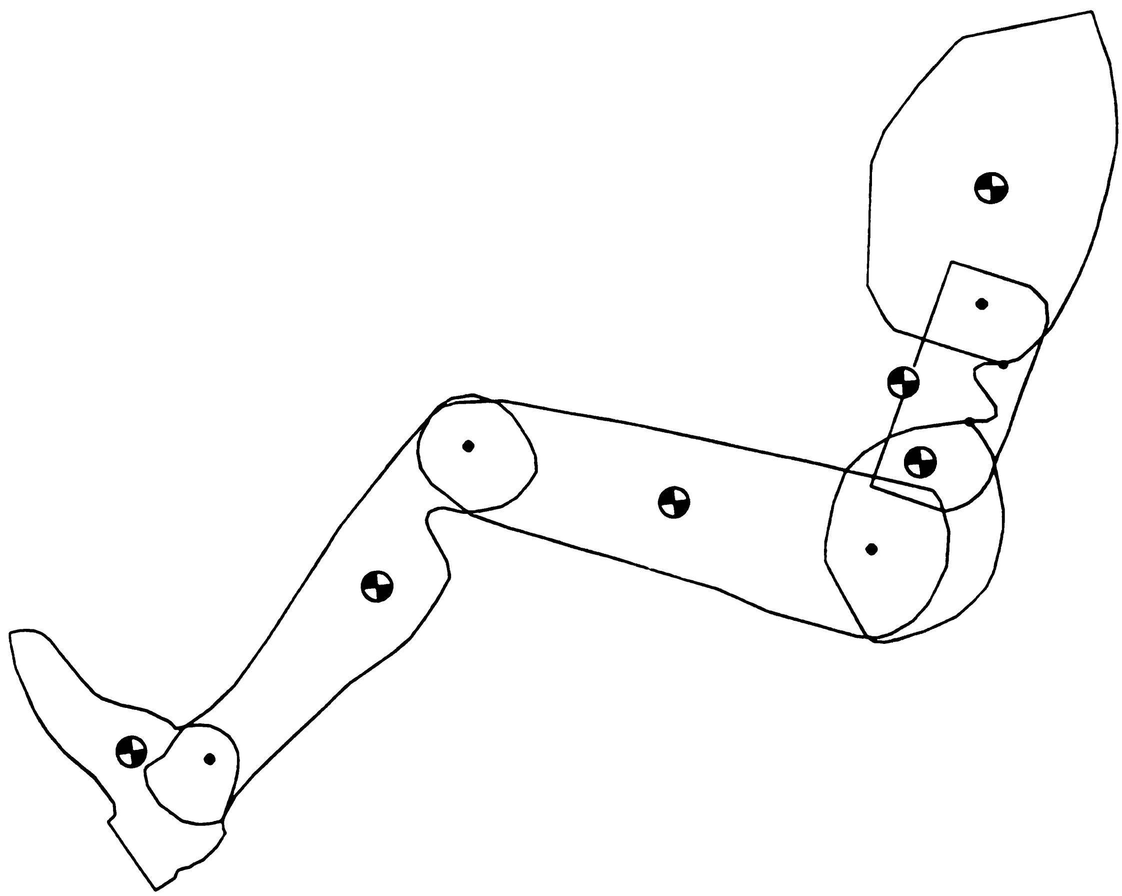

Figure 36: 2-D JOHN model with COM positions for all body segments

response of the model to different seat geometries. The two seats compared in this study were an automotive seat, a Chrysler LH, and a prototype articulating seat called the Biomechanically Articulating Chair (BAC) [11].

3.1.3.1 BAC model development and construction

The BAC was designed to support the body in a wide variety of postures by matching the chair motions to the motions of the human body segments, defined through the JOHN model. There are four major parts of the BAC; 1. a pelvis support that cradles the back and bottom of the pelvis and rotates under the pelvis near the ischial tuberosities, 2. a thorax support that pivots in the mid-back and allows rotation of the thorax with spinal flexion and extension, 3. a recline bar that connects the pivots of the pelvis and thoracic supports, and 4. a thigh support that pivots on the front of the pelvis support (Figure 37). Like the JOHN model, the thorax and pelvis supports move together in a one-to-one motion where a rotation of the pelvis support results in an equivalent counter rotation of the thorax support. Because the chair moves like the JOHN model, the position of the BAC can be described in terms of TLC and TRA. The coupled rotation of the thorax and pelvis supports result in a change of TLC. A seated person's TRA can be changed by adjusting the angle of the recline bar.

To develop the BAC in the Working Model™ simulation, dimensions of the pelvis support, thorax support and recline bar were measured from a full size working prototype. The dimensions were entered into the simulation to construct

Figure 37: Picture of the BAC prototype

four rectangles and the seat assembled with pin and rigid joints. The thigh support was not simulated because the focus of this study was on torso posture.

To determine the starting relationship between the pelvis and thorax supports of the BAC, as well as the initial recline bar angle, the full size physical JOHN 2-D articulating template, developed by Bush [8], was set into the BAC prototype. The TLC of the template was set to 40° and the pelvis and thorax supports were adjusted to fit the shape of the template and support it at 40° TLC. The angle of the recline bar was then adjusted until the TRA of the JOHN template was 28°. The angles of the pelvis support, thorax support and recline bar on the BAC prototype were measured relative to the vertical. The reasoning behind the 40° TLC and 28° TRA is described later in Section 2.4. The BAC seat computer model was adjusted to fit the support structure angles measured from the BAC prototype (Figure 38).

3.1.3.2 Chrysler LH seat model development and construction

To develop the model of a Chrysler LH automobile seat, a design drawing for the seat was obtained from the manufacturer, Johnson Controls, Inc. This full sized drawing was used to determine the seat geometry. First, the coordinates of the seat frame were measured from the design drawing. Fifteen points on the seat frame were measured, using the design drawing H-pt position as the origin of a coordinate system, and the x and y axis of the drawing as horizontal (forward) and vertical (upward), respectively. The measured points

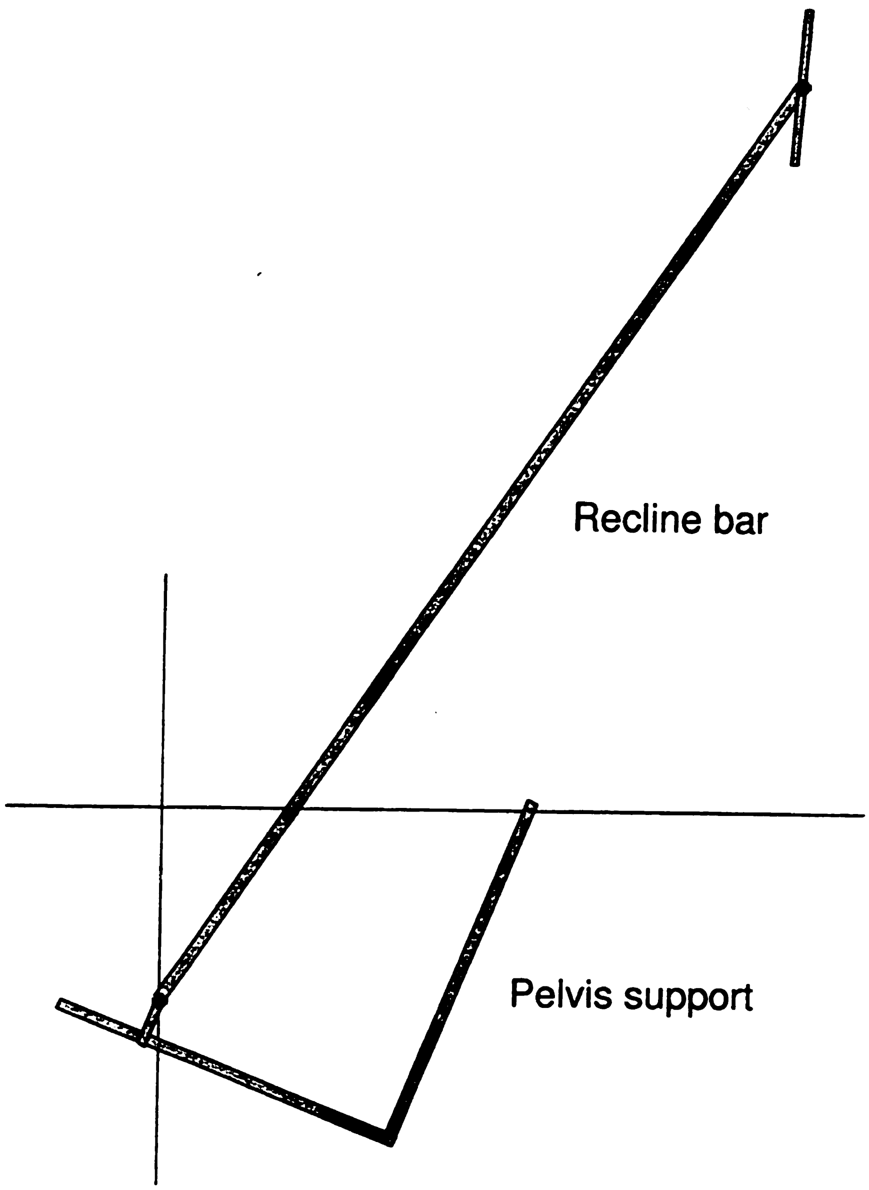

Figure 38: BAC computer model

were entered into the program as vertices of a polygon body that represented the seat frame. The seat frame body was then anchored at the seat frame recliner location with a pin joint (Figure 39).

The second step involved importing the undeflected seat contours to act as a visual reference. Eighteen points were measured along the undeflected centerline contour of the seat cushion. The point coordinates were used as the vertices on one side of a long, thin polygon. By doubling back over the same x-coordinate points, but with a 1 mm offset in the negative y-direction, the other side of the seat cushion polygon was created (Figure 40). The one mm thickness was chosen so that the contour was thick enough to be seen on the computer screen as a reference, but thin enough to not distract from the simulations. The seat back cushion was constructed in the same manner; sixteen points along the undeflected seat back contour line were measured from the design drawing and the point coordinates were used to create the vertices of a 1 mm thick polygon (Figure 41). Because they were made only for visual reference, both the seat cushion and seat back objects were designated to not collide with the rest of the model.

The third step involved representing the deflected contour surface of the seat cushion. The contour shape used for the deflected seat cushion was a reference line from the seat design drawing that represented the interface between the deflected seat cushion and a fully loaded SAE 3-D testing manikin. The construction of the deflected contour body in Working Model™ followed the

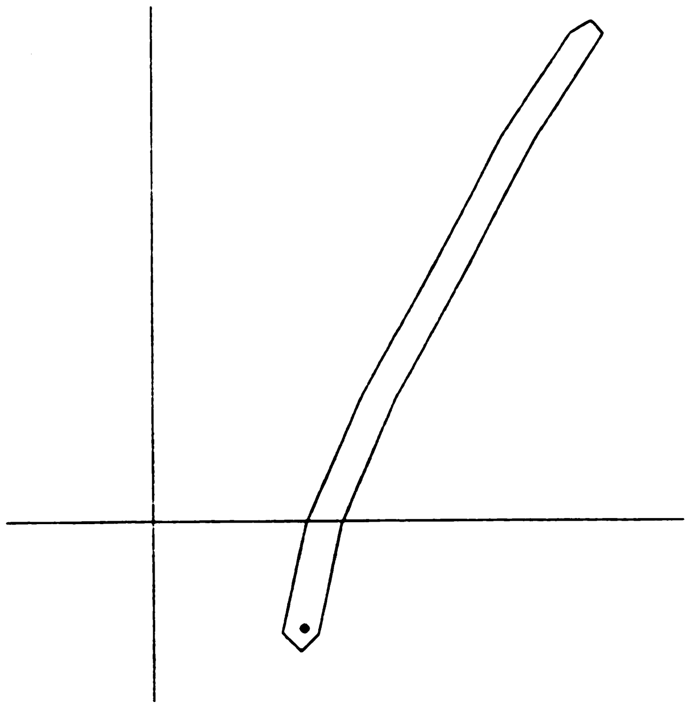

Figure 39: LH model seat frame

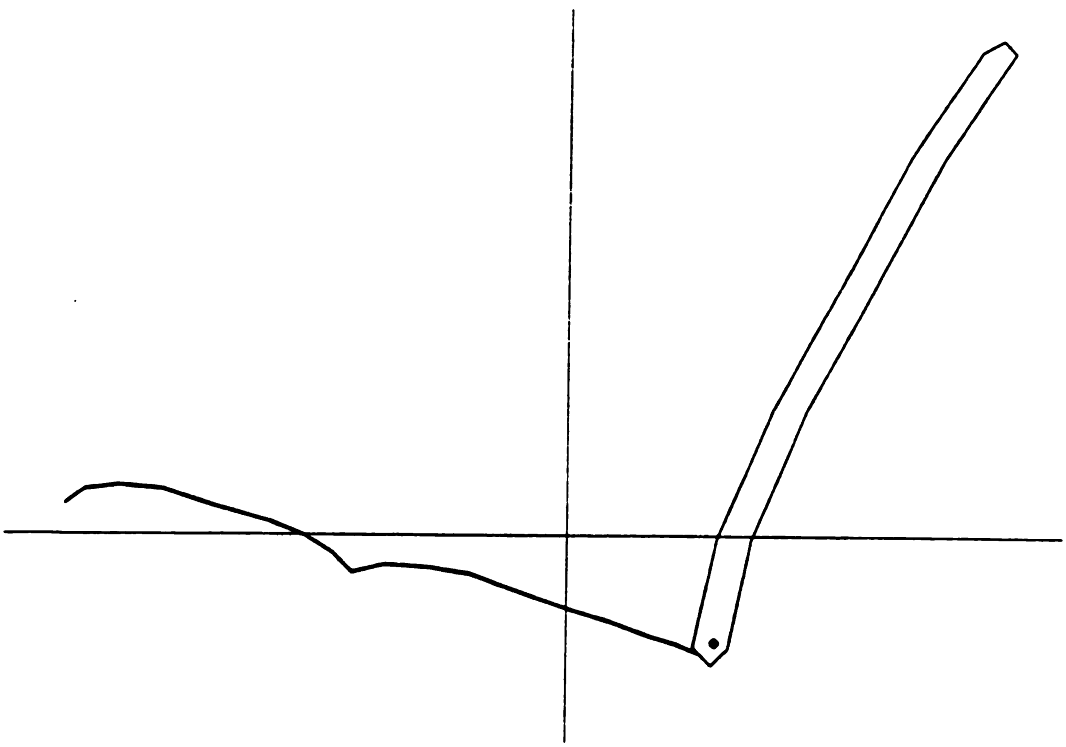

Figure 40: LH model with undeflected seat cushion

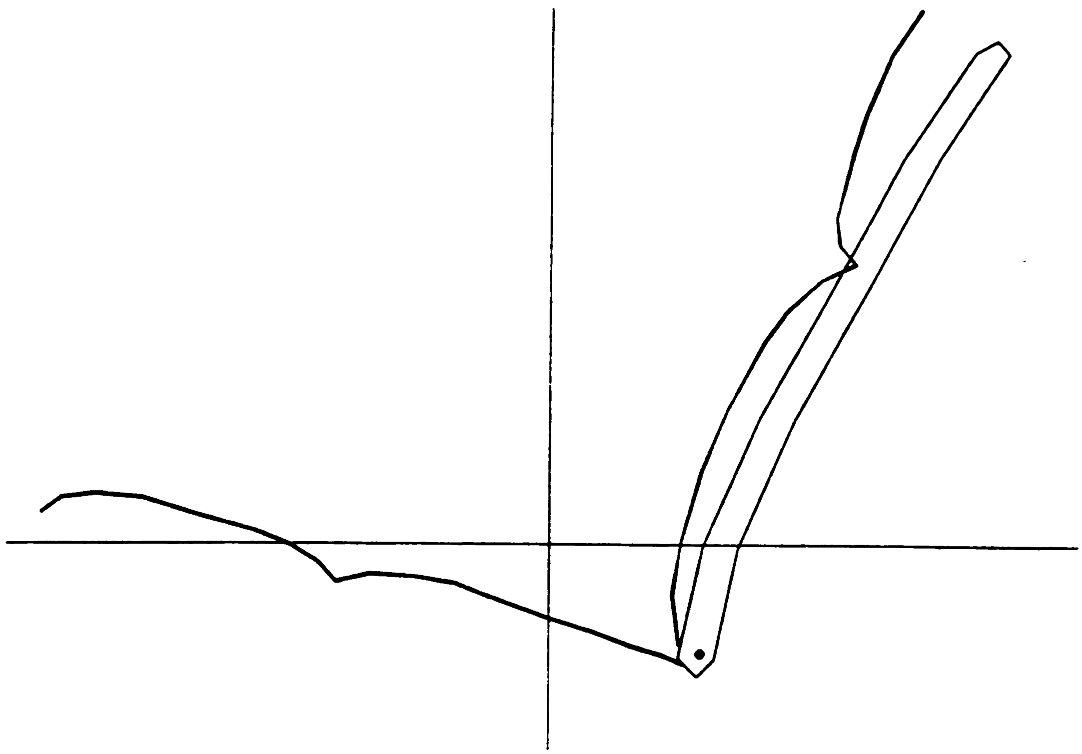

Figure 41: LH model with undeflected seat back

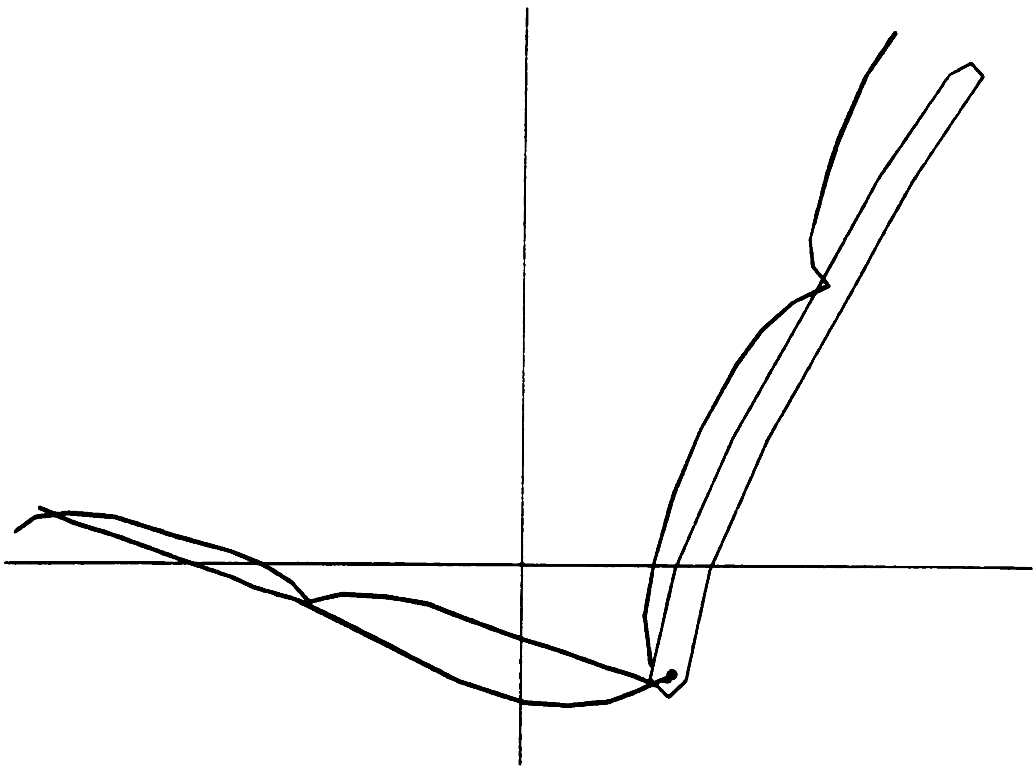

Figure 42: LH model with deflected seat cushion

same approach as the undeflected contours. Seventeen points were taken from the design drawing and these points were used to create a 1 mm thick polygon to represent the deflected contour (Figure 42). During the initial simulation runs, this contour interacted with the 2-D JOHN model. However, during the first few simulations, the running speed of the simulation was very slow. The main reason for the slow simulation speed was that the collision between the pelvis body and the deflected seat cushion body was very complex. The computer spent an excessive amount of time calculating the position of the pelvis as it collided with the deflected seat cushion body. This situation was resolved when the deflected seat cushion body was replaced by a several rectangular objects that were smaller than the deflected contour (Figure 43). To develop the multiple piece contour from the one piece contour, the one piece contour was set in place, and seven small, thin rectangles were oriented on top of it, following the contour as smoothly as possible. These rectangles were then anchored to the background and were assigned to be the surfaces with which the 2-D JOHN model collided.

When the simulations were run with the multiple piece contour, the amount of time to run a simulation decreased noticeably. By replacing the one piece seat cushion body with several rectangles, the computer was able to run each simulation more quickly because it was easier for the program to predict a collision between the pelvis body segment and a smaller body with simpler geometry than a large body with very complex geometry.

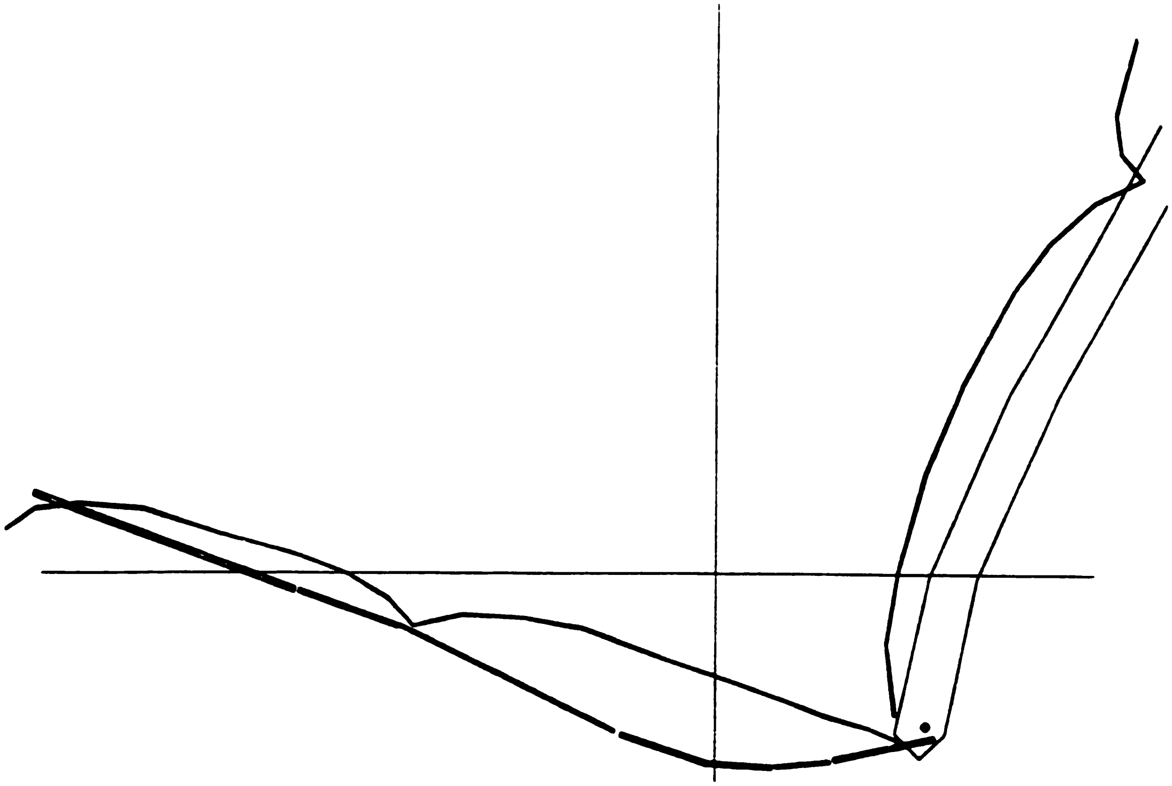

Figure 43: LH model with segmented seat cushion

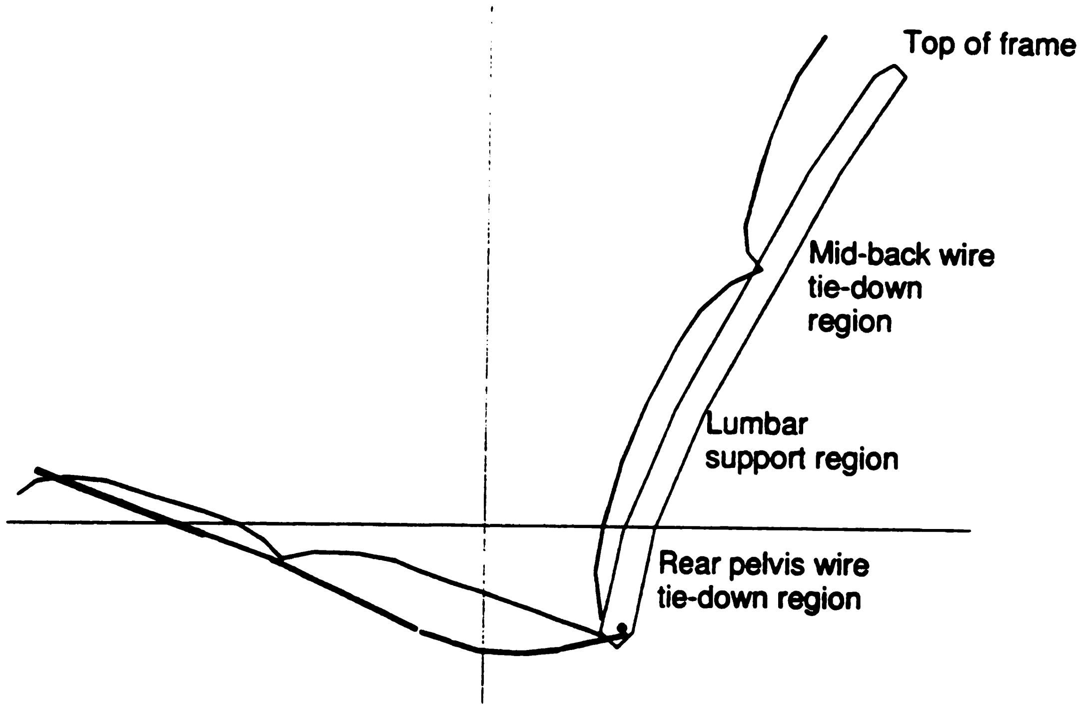

Figure 44: LH model with four seat back contact regions displayed

Representing the seat back contour was the fourth and final step in the development of the automobile seat model. Based on recommendations from the seat manufacturer, it was decided to represent the seat back contour as the maximum deflection of the foam at four regions of known foam thickness. To develop the contour, the four regions of known foam thickness, the top of the seat frame, lumbar paddle, mid back wire tie down, and rear pelvis wire tie down, were located on the design drawing (Figure 44). The distance between the undeflected seat back contour and the back of the foam was measured from the seat drawing at these regions The maximum deflection into the seat was estimated as 65% of the foam thickness at these four regions. This estimation was based on the experience of Johnson Controls Inc., Automotive Systems Group. The deflections at the four regions were calculated and the new deflected points placed on the design drawing. Four rectangle bodies were created in Working Model™ to represent the deflected cushion surface at each of the regions. These rectangle bodies were then placed appropriately in the simulation (Figure 45).

After the model geometry had been completed, the material properties for all contact surfaces were specified. There was very little data on the coefficient of friction between a clothed human and a car seat. A series of simulations were run in Working Model™ using the 2-D JOHN model and the automotive seat to determine a coefficient of friction values for static and kinetic friction ($\mu_{s,k}$) that would resemble a real world situation. For all Working Model™ simulations, μ_s=

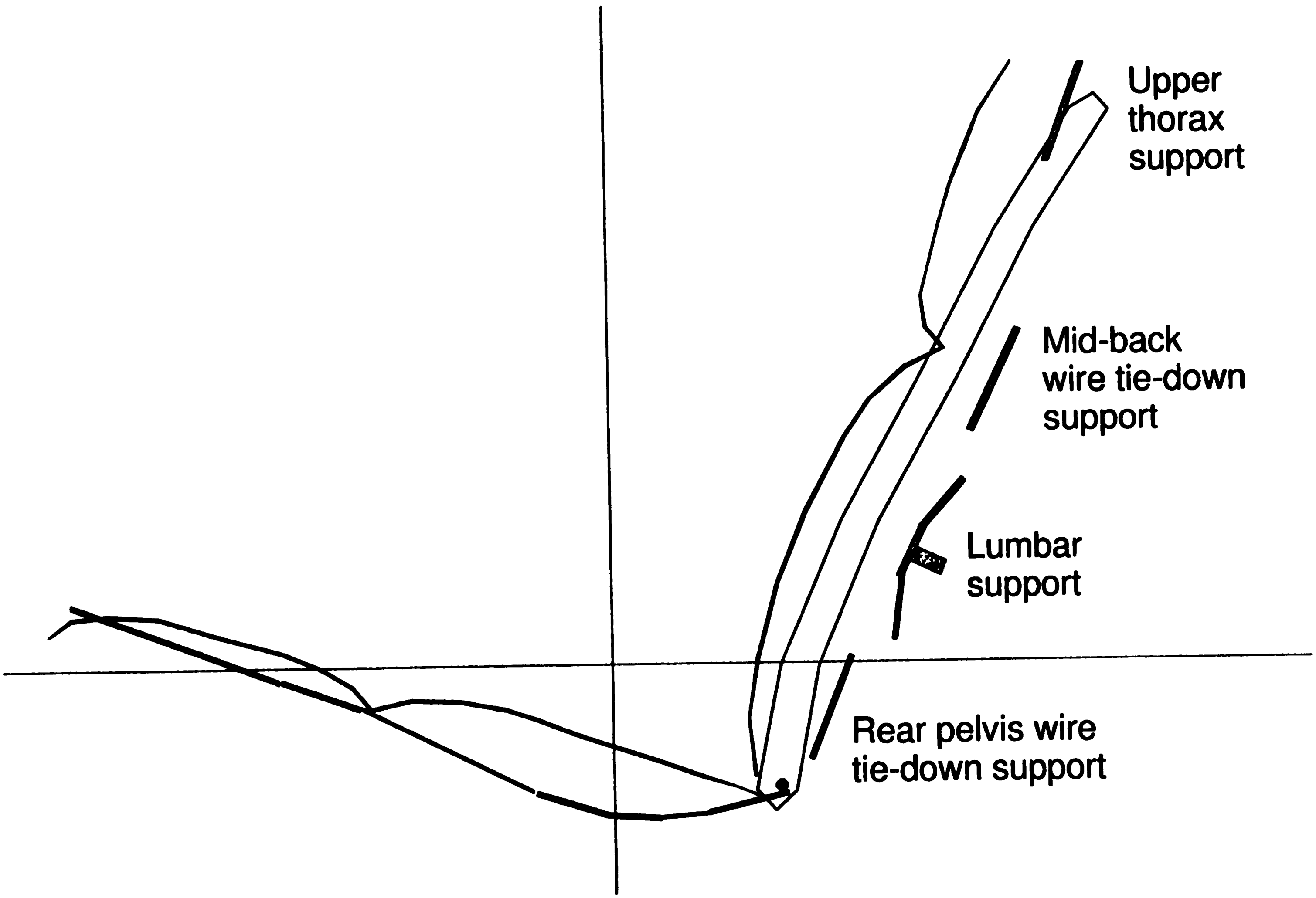

Figure 45: Completed LH seat model

$\mu_k=\mu$. Three simulations were run with different values of μ. These values were 0.3, 0.5, and 0.7. When μ was set at 0.3 and 0.5, the 2-D JOHN model would occasionally slip when in contact with the seat surfaces. At 0.7, this did not happen, and as a result, 0.7 was chosen at the coefficient of friction for all contact surfaces. It was reasoned that the model should represent a person clothed in cotton pants sitting on a cloth trimmed seat rather than a person wearing silk sitting on a leather covered seat, since the cotton/cloth combination is more likely to occur in a normal driving scenario.

The other material property which had an effect on the simulations was the coefficient of restitution, or coefficient of elasticity. It was reasoned that human sitting into an automotive seat would have a very low coefficient of restitution because of the nature of the two materials which come in contact. Both human flesh and foam absorb much of the energy in a collision, therefore the contact between those two surfaces would result in an inelastic collision. In addition, a goal of the simulations was to approach a static position as soon a possible in order to simulate static equilibrium. For these reasons, the coefficient of restitution was set at a value of 0.02.

3.1.4 Seat evaluation protocol

With the 2-D JOHN model and the seat models completed, a simulation protocol and study conditions were developed. In order to compare the two seats, a matrix of seating possibilities was defined. To study the ability of the seat models to support different postures, the effects of two seat factors on the posture of the 2-D JOHN model were simulated. The seat factors chosen were; 1. amount of lumbar curvature promoted, defined for the 2-D JOHN model as TLC, and 2. angle of the torso support, relative to vertical, defined for the 2-D JOHN model as TRA. The two variables of the Chrysler LH automotive seat that produced such posture changes were seat back recline angle and amount of lumbar prominence. The seat back recline angle was the angle between the seat frame and vertical, and the amount of lumbar prominence was defined as the distance the lumbar support was forward of its fully retracted design position. The corresponding variables for the BAC were the recline bar angle and the Total Lumbar Curvature (TLC). The recline bar angle was the angle of the recline bar with respect to vertical, and the TLC was defined as the relative position of the thorax support to the pelvis support, as measured with the JOHN articulating template. In order to study whether the Chrysler LH and BAC could support a wide range of postures, LH seat frame angles and BAC recline bar angles were chosen to support upright, reclined, and intermediate angles of torso recline. In addition, values of LH lumbar support prominence and angular orientation of the thorax support relative to the pelvis support of the BAC were selected that would support slumped, erect and intermediate postures. The variables affecting torso recline and lumbar curvature for each seat were placed on different axes of a matrix and when the possibilities were combined, the 3x3 grid resulted in nine potential seating conditions.

The baseline measure for developing the matrix of seating possibilities was obtained from the design drawing of the Chrysler LH seat. In design position, the seat frame angle was at 28°, which corresponded to a torso angle of 24°, and there was zero lumbar prominence. The torso angle is determined with the SAE 3-D testing manikin The seat frame angle of 28° was included in the matrix as an intermediate value, and an upright seat frame angle of 23° and reclined seat frame angle of 33° were also added. The level of lumbar prominence shown in the design drawing of the Chrysler LH seat was defined as 0 mm, corresponding to a slumped posture, and was included in the matrix. The two other values used for the matrix were a maximum value of 25 mm, for an erect posture, and an mid-range value of 12.5 mm for an intermediate posture. The amount of lumbar prominence is defined as the distance the lumbar paddle was forward of the zero position, along a line perpendicular to the seat frame. The pre-simulation matrix for the automotive seat is shown in
Table 11.

Table 11 - Simulation matrix for automotive seat study

Lumbar Prominence / Seat frame recline angle	0 mm	12.5 mm	25 mm
23°			
28°			
33°			

In order to compare the seating conditions of the Chrysler LH to the BAC seat model, the measures of seat recline angle and amount of lumbar curvature supported were re-defined for the BAC. The seat recline angle for the BAC was the recline bar angle and the amount of lumbar curvature supported by the BAC was defined as the TLC promoted by the chair. Values for these variables were assigned which corresponded to upright, intermediate and reclined torso angles, and erect, intermediate and slumped torso postures. As mentioned earlier, the positions of these supports corresponding to values of TLC and TRA were selected using the BAC prototype and the 2-D articulating template. To model erect and reclined torso angles, the recline bar was set to produce 23° and 33° TRA's, as well as an intermediate TRA of 28°. To model from a slumped to an erect posture, TLC's of 0°, 20° and 40° were added to the matrix as seat conditions. Table 12 shows the empty matrix for the BAC.

Table 12 - Simulation matrix for BAC study

TLC / TRA	0°	20°	40°
23°			
28°			
33°			

Once the matrix of study conditions had been completed, a simulation protocol was developed. In order to compare the LH simulation results to the BAC results, the study conditions for the BAC and LH seat simulations had to be as similar as possible. To help accomplish this, the 2-D JOHN model was started in a 40° TLC posture for all simulations in the LH seat and BAC. This was done to allow the seat geometry the opportunity to support a very erect posture. Because of the forces acting on the 2-D JOHN model and because of the nature of the mechanism controlling its movement, the model moved from an erect to a slumped posture after it came into contact with the seat surfaces. If the model was placed, for example, in a 20° TLC posture and placed into a seat where the geometry of the seat would support a 30° TLC posture, the 2-D JOHN model would not be able to conform and obtain the 30° TLC posture due to gravity and the gear linkage controlling torso articulation. Therefore, the 2-D JOHN model was started at an erect, 40° TLC posture in order to allow the largest range of postural support by the seat model.

In addition, for all LH seat and BAC simulations, the starting TRA of the 2-D JOHN model was modified to be the same as the torso angle promoted by the seat. This was done for the same reason stated above. By starting the model with the same recline angle as the seat frame and in an erect posture, the seat model had the opportunity to support a very erect posture, not limited by the starting condition of the 2-D JOHN model.

For the LH seat simulations, initial position of the 2-D JOHN model was such that its HJC was 33 mm forward of and 6 mm above of the design H-pt position. The 2-D JOHN model was placed there to simulate the actions of a person sitting in the seat. The LH seat was designed with the SAE J826 tools, and as discussed before, the SAE 3-D testing manikin represents a flat back, or rather slumped posture. It is with this posture that the design H-pt location is determined. In order to start the 2-D JOHN model in a 40° TLC, or erect, posture it was reasoned that the initial position HJC of the 2-D JOHN model would have to be farther ahead of the design H-pt. This was because when the 2-D JOHN model came into contact with the seat surface, the pelvis rolled rearward on the ischial tuberosities and the model moved from an erect to a slumped posture. As the model slumped, the HJC position moved rearward. If the model had been started in an erect posture with the HJC at the design H-pt, the response of the model would not have been realistic of a seated person.

This starting position of JOHN was determined by first placing the model at a 0° TLC with the HJC centered over the design H-pt location described on the design drawing. The bottom of the pelvis was pinned to background at the location of the ischial tuberosities. The pelvis was then rotated forward 20° until its position corresponded to a 40° TLC alignment. The location of the HJC was recorded and the model started that horizontal (x) and vertical (y) distance away, 33 mm (x), 6 mm (y), from the design H-pt for every automotive model simulation (Figure 46).

For the BAC simulations, the HJC of the 2-D JOHN model was positioned with the ischial tuberosities of the pelvis 5 mm above the pivot on the pelvis support (Figure 47). The design of the BAC is such that the pivot for the pelvis support is approximately in the location of the ischial tuberosities of a seated person.

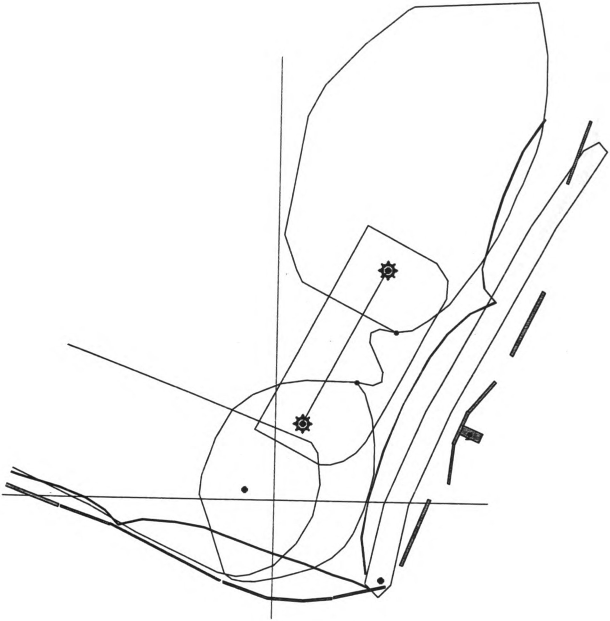

Figure 46: 2-D JOHN set in place over LH seat

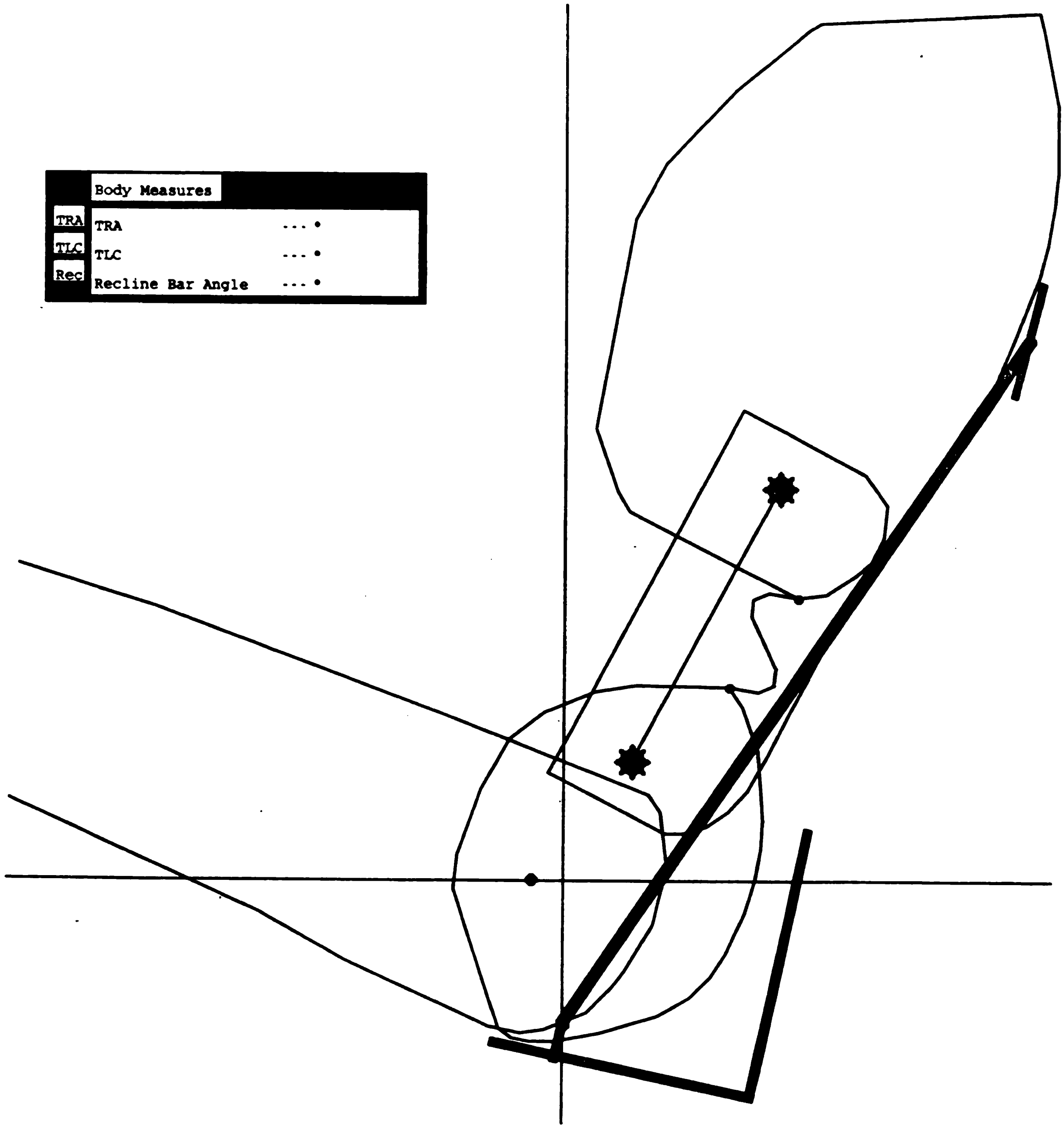

Figure 47: 2-D JOHN set in place over BAC

Before the HJC of the 2-D JOHN model was positioned, the TRA of the model was adjusted to match the torso angle promoted by the seat for that simulation. Then the simulation was started. Due to the effects of gravity and the mass of the 2-D JOHN model, the 2-D JOHN model dropped into the seat, and its final posture was determined by the location of the seat supports The simulation was stopped when the 2-D JOHN model did not have a change in TLC or TRA for 20 consecutive time-steps. When the simulation was stable, the program was stopped and the posture recorded. For the Chrysler LH seat simulations, the lumbar support and seat frame recline angle were adjusted to another case in to matrix study conditions and the simulations run until all nine cases described in the matrix had been modeled. In the BAC cases, the seat support structures were modified and the simulation run again until all nine BAC cases had be completed.

After the 18 simulations described above had been completed and the data analyzed, another five simulations were run in the automotive seat model. These simulations were run to study the effect of the upper thorax support on the final posture of the model. The seat configuration used for these simulations was the one that produced the greatest amount of lumbar curvature in the automotive seat The postural effect of the proximity of the upper thorax support on the 2-D JOHN model was studied by moving the upper thorax support rearward, perpendicular to the seat frame, in 10 mm intervals, until the 2-D JOHN model was no longer in contact with the upper thorax support. The thorax support was moved, the simulation was run, and the TLC and TRA of the 2-D JOHN model were recorded when the model had stabilized. Then the upper thorax support was moved and the cycle repeated.

3.2 RESULTS AND DISCUSSION

3.2.1 Chrysler LH results

The results for the Chrysler LH automotive seat simulations can be seen in Table 13. Figures 48 - 56 show the final posture of the 2-D JOHN model for each simulation.

Table 13 - Simulation results for automotive seat study

Lumbar Prominence / Seat frame recline angle	0 mm	12.5 mm	25 mm
23°	TLC = -10° TRA = 25°	TLC = -10° TRA = 24°	TLC = -10° TRA = 21°
28°	TLC = -2° TRA = 30°	TLC = -8° TRA = 29°	TLC = 3° TRA = 29°
33°	TLC = -1° TRA = 35°	TLC = 5° TRA = 38°	TLC = 14° TRA = 38°

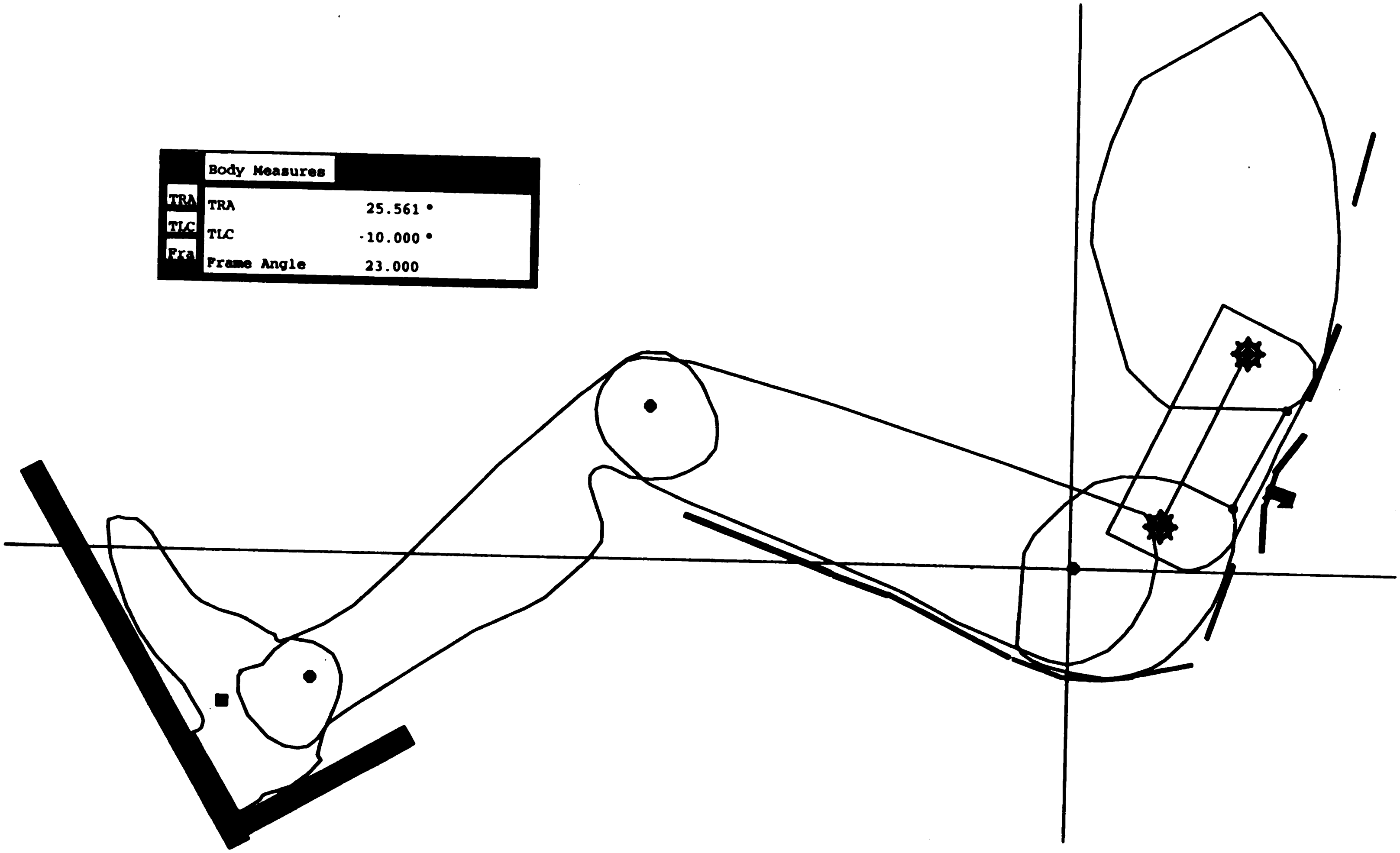

Figure 48: LH seat with 23° frame angle, 0 mm lumbar prominence

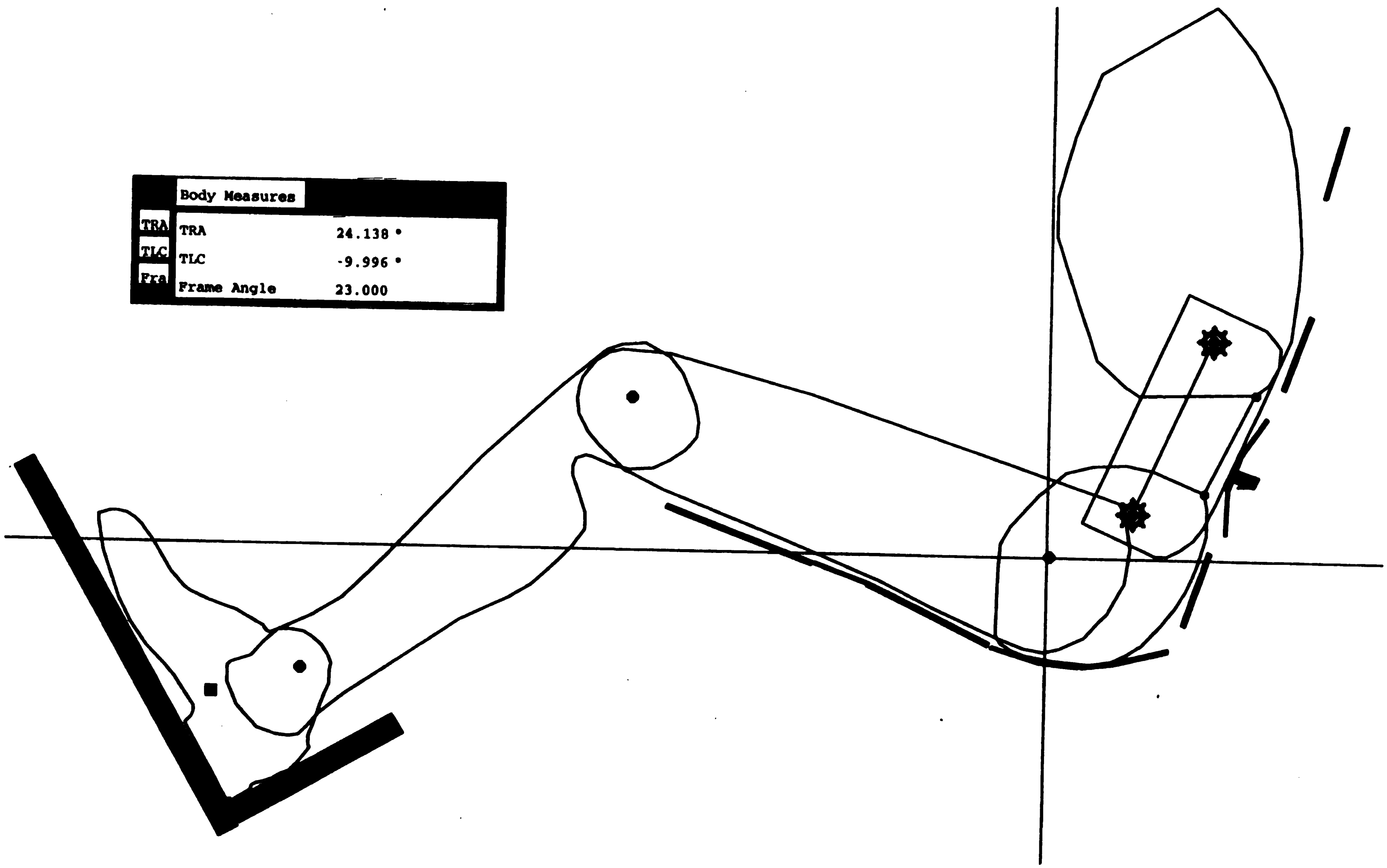

Figure 49: LH seat with 23° frame angle, 12.5 mm lumbar prominence

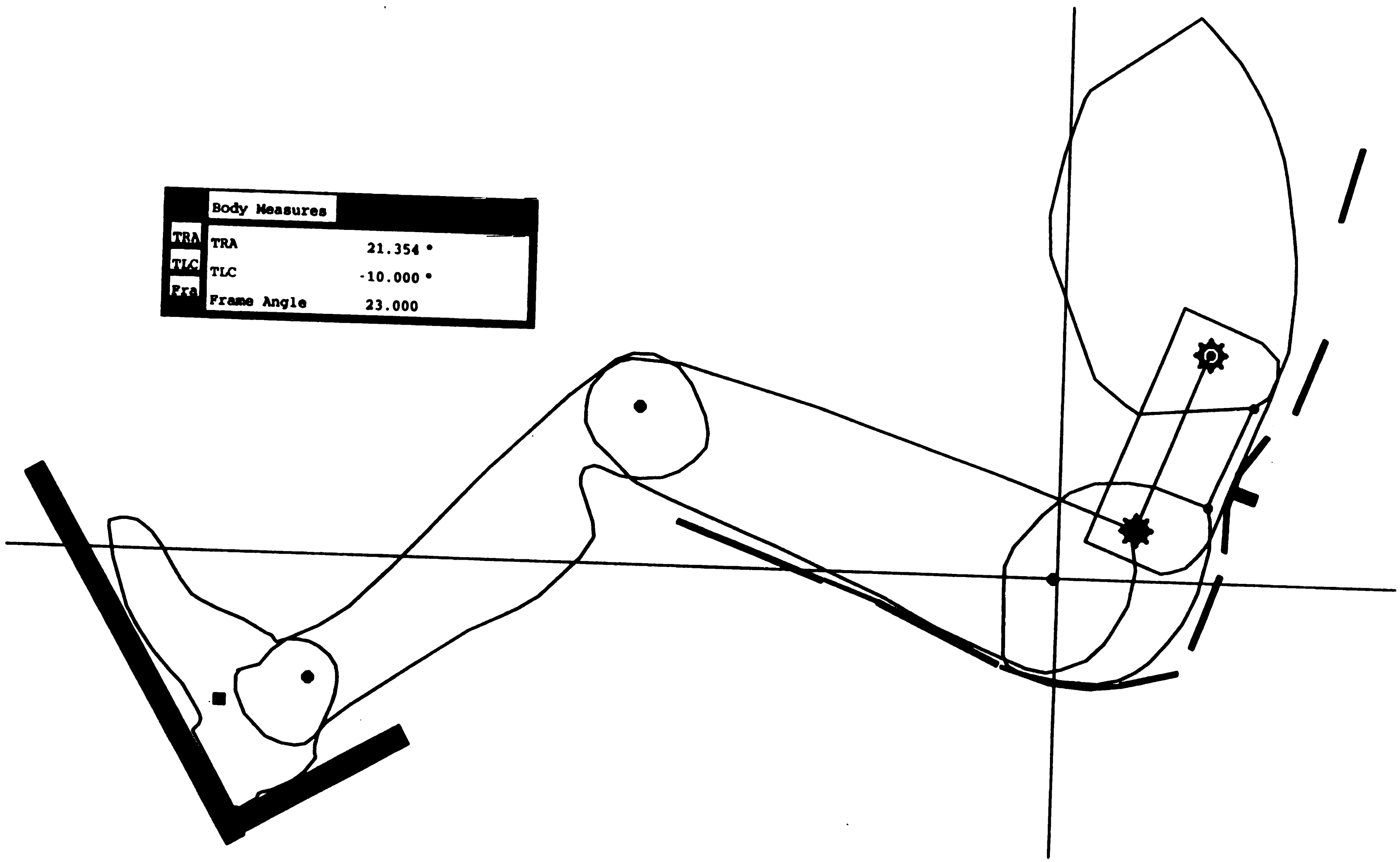

Figure 50: LH seat with 23° frame angle, 25 mm lumbar prominence

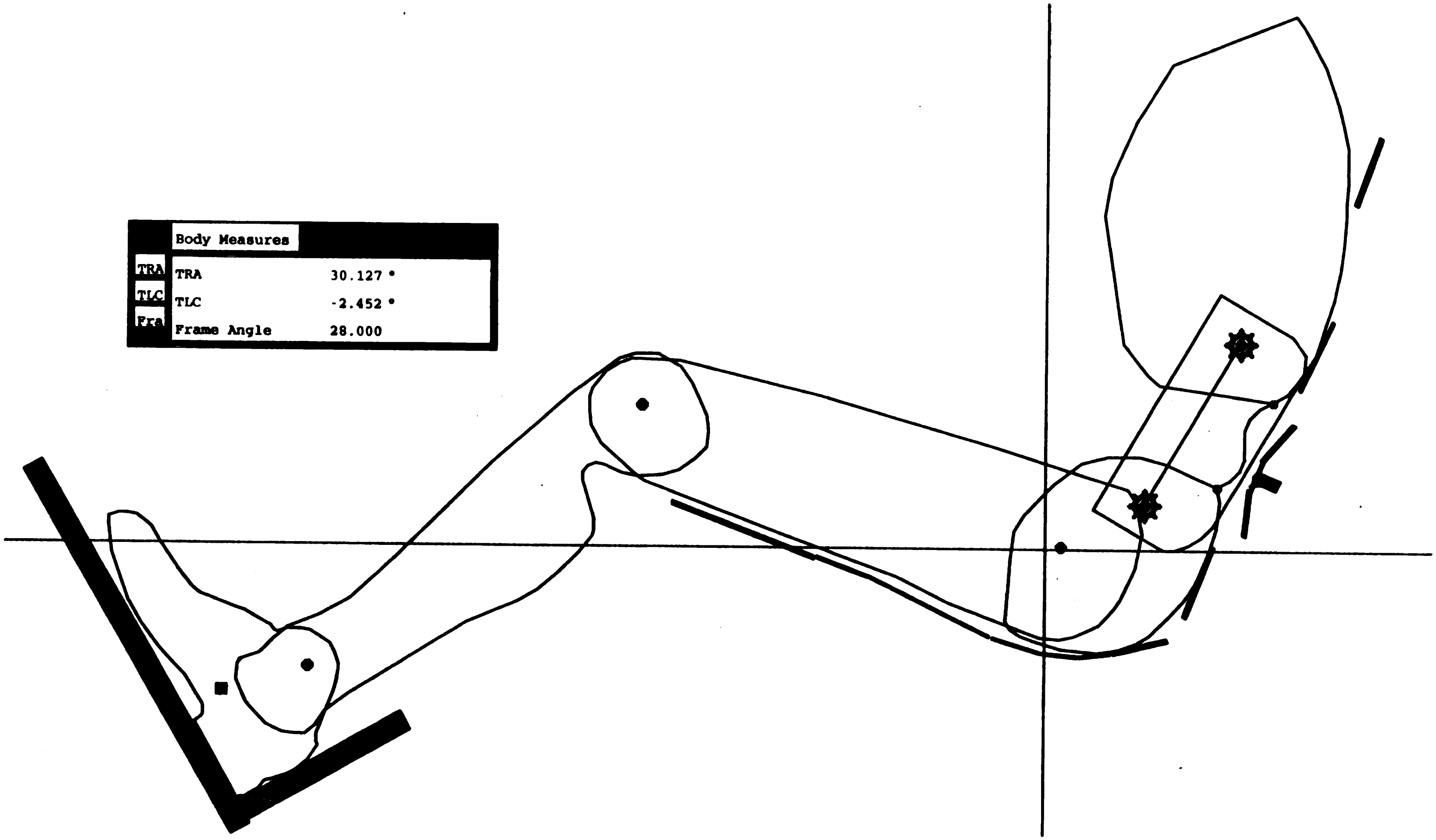

Figure 51: LH seat with 28° frame angle, 0 mm lumbar prominence

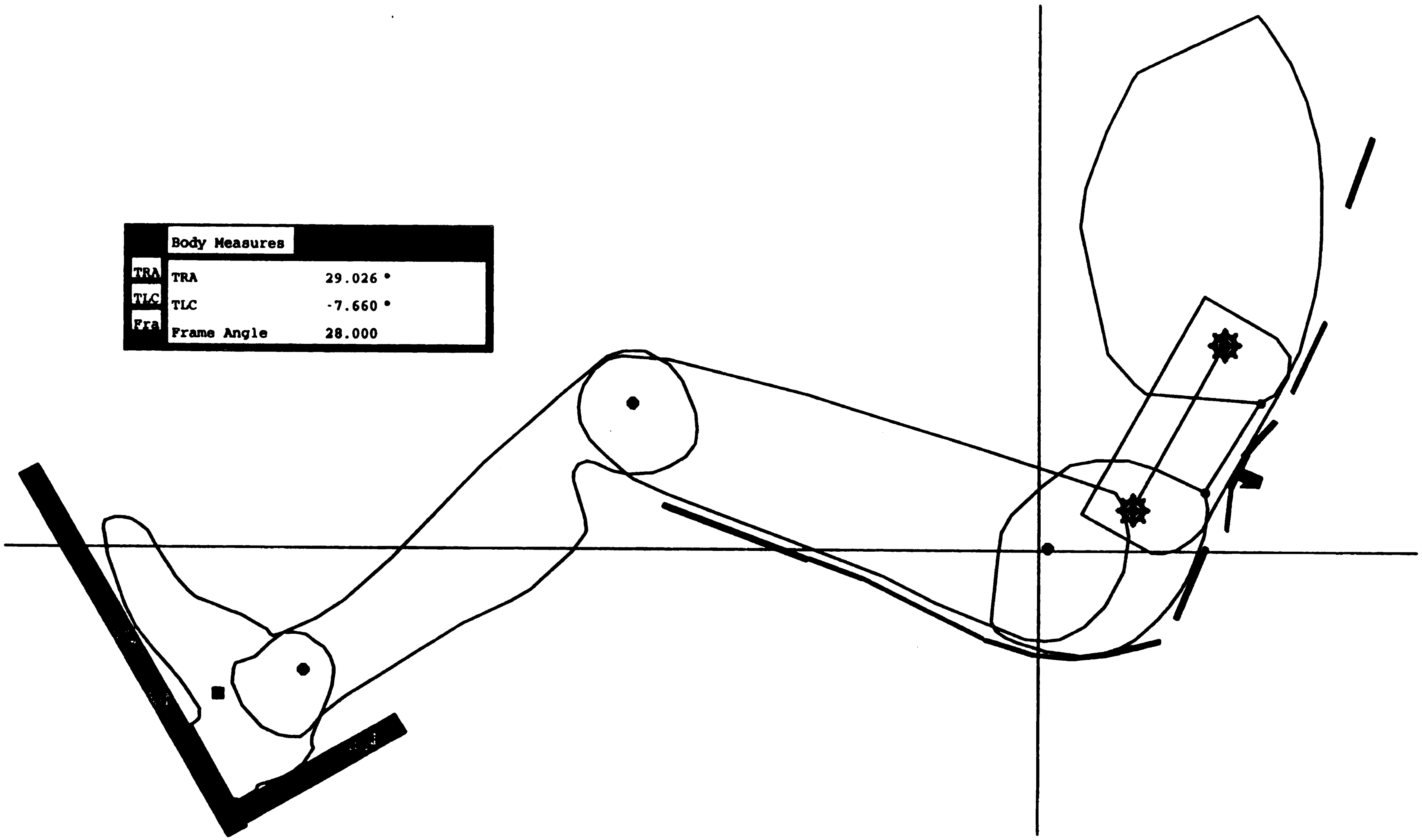

Figure 52: LH seat with 28° frame angle, 12.5 mm lumbar prominence

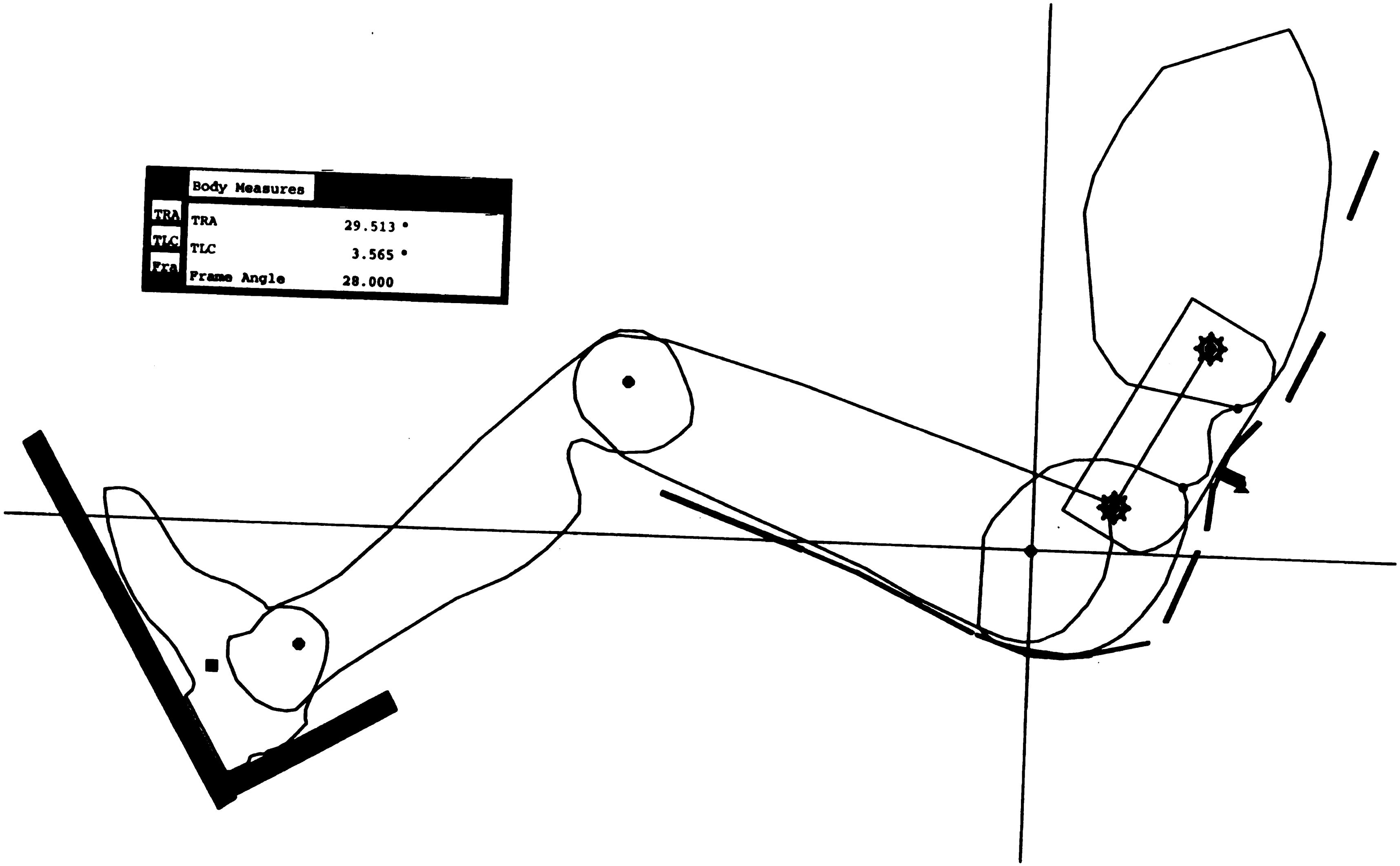

Figure 53: LH seat with 28° frame angle, 25 mm lumbar prominence

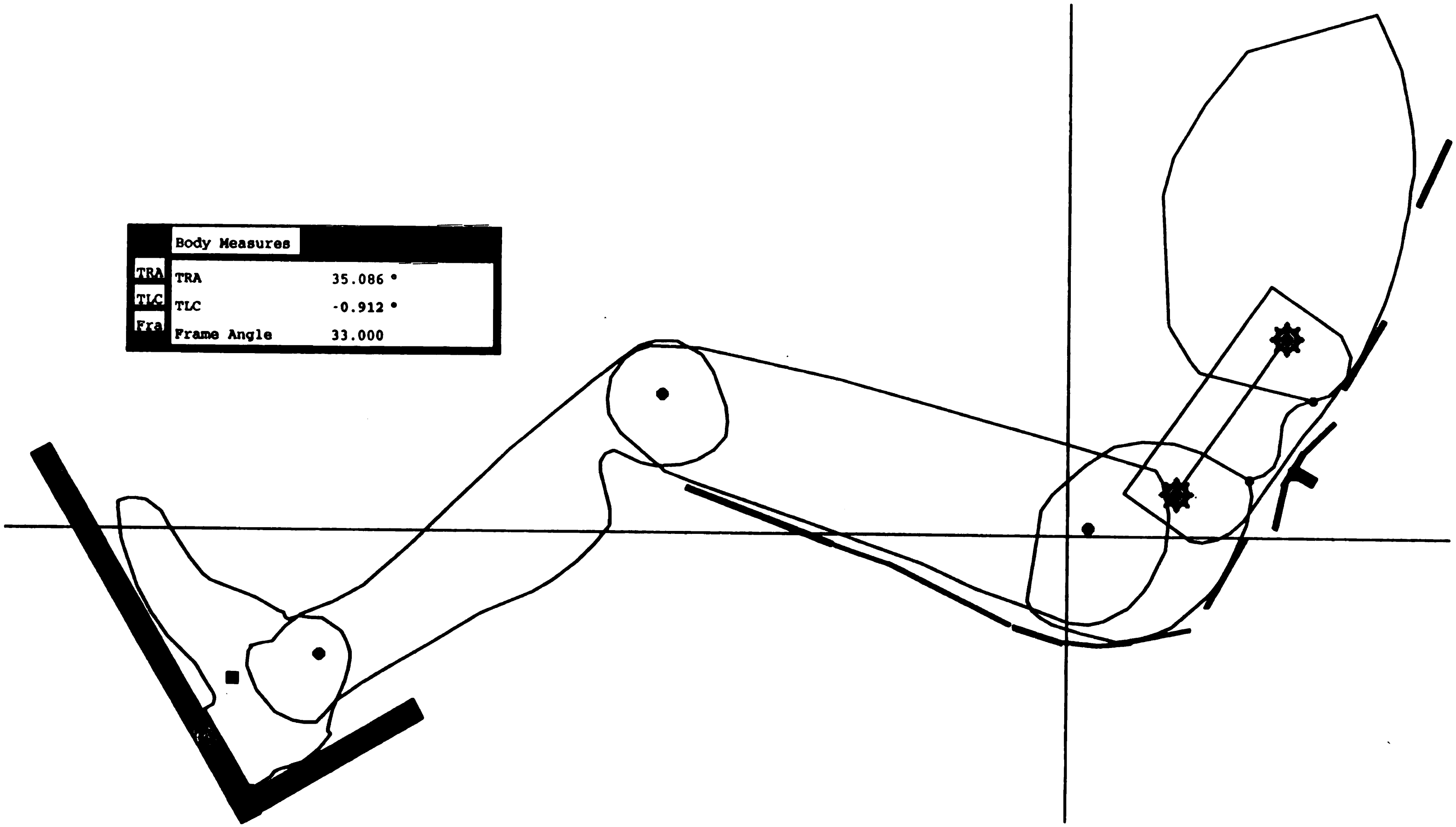

Figure 54: LH seat with 33° frame angle, 0 mm lumbar prominence

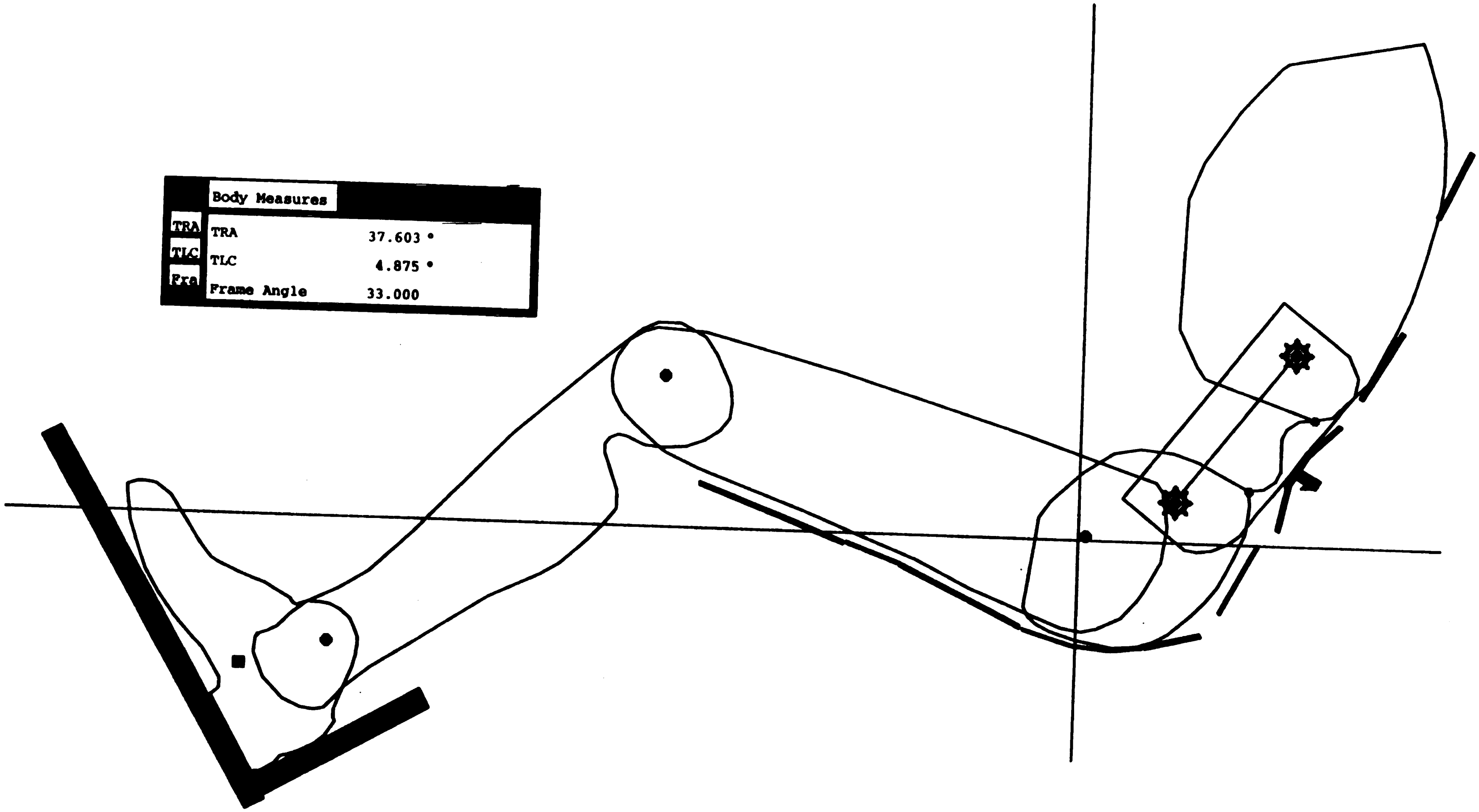

Figure 55: LH seat with 33° frame angle, 12.5 mm lumbar prominence

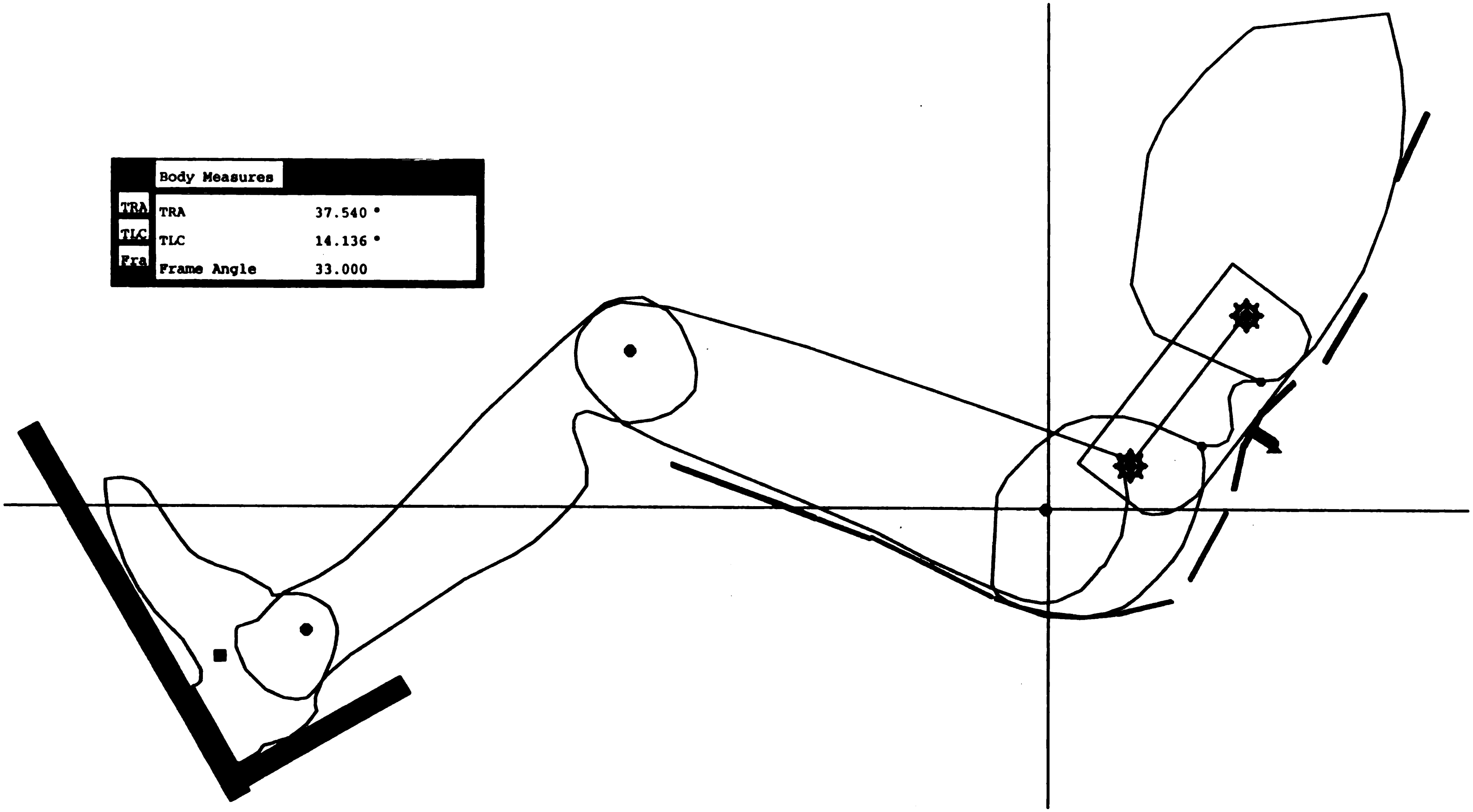

Figure 56: LH seat with 33° frame angle, 25 mm lumbar prominence

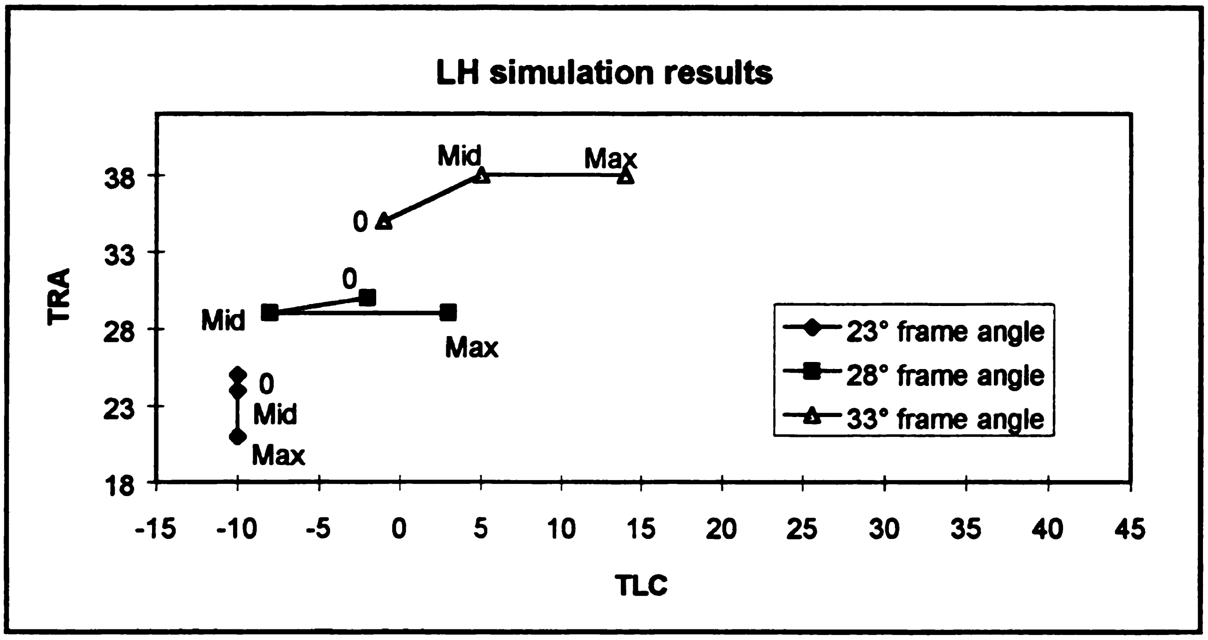

Figure 57: Graph plotting TRA vs. TLC at constant frame angle for LH simulations

The results from the automotive seat study, shown in Table 13, are plotted in Figure 57. The graph plots TRA vs. TLC for the different levels of lumbar prominence at constant frame angles. For viewing purposes, 0 mm of lumbar prominence is represented on the graph as 0, 12.5 mm is shown as Mid, and 25 mm of prominence is represented by Max. The results show that for the seat frame angles of 28° and 33°, the TLC of the 2-D JOHN model increased as the amount of lumbar prominence increased. At each of those seat frame angles, the 2-D JOHN model TLC was the greatest when the seat had the maximum amount of lumbar prominence. In addition, as the seat frame angle increased from 28° to 33°, the TLC also increased, represented by the rightward shift in the 33° frame angle line versus the 28° frame angle line in Figure 57.

The increase in TLC occurs because the center of mass of the thorax is allowed to move rearward due to the interaction with the increased lumbar prominence and more reclined seat. The TLC was greatest in the simulations with the maximum amount of lumbar prominence because the rearward shift of the thorax COM, due to the increased recline angle, was enhanced because of the early contact between lumbar segment and the lumbar support. This contact created an arching effect over the lumbar support and allowed the thorax to continue to rotate rearward, enabling the 2-D JOHN model to be supported with a higher TLC.

However, in the three simulations with 23° seat frame recline angle (Figures 48-50), the geometry of the model and seat were such that the equivalent COM of the thorax was forward of the intersection point of the two gears controlling the lumbar motion. As the 2-D JOHN model comes into contact with the seat cushion surface, the pelvis begins to rotate rearward about the ischial tuberosities, and the thorax rotates forward due to the coupled motion of the two segments. Because there were no supports immediately behind the pelvis or bottom of the thorax to stop the rotation of those segments relative to each other, it was impossible for the model to maintain an erect posture. At a seat frame recline angle of 23° and with only a lumbar support and not pelvic and thoracic supports, the geometry on the seat and model are such that the thorax COM cannot remain rearward far enough to maintain an erect posture at all. The 23° seat frame angle plot in Figure 57 shows that the seat set up was unable to support any change in the TLC of the 2-D JOHN model, represented by the vertical line, and that the TLC supported was the most slumped posture possible, -10° TLC.

On further observation, the amount of TLC the 2-D JOHN model exhibits in the Chrysler LH model seems to be dependent on the lumbar prominence and seat frame recline angle. As can be seen in Figure 57, changing the lumbar prominence does not produce a very large change in TLC at a specific recline angle. A long line would indicate a wide range of TLC values supported at a constant seat frame angle, but the constant seat frame angle lines are not very long. Overall, however, by adjusting the seat frame recline angle, in addition to varying the lumbar prominence, the seat does support a range of TLC values, though none of these values supported by the Chrysler LH seat model are above 15° TLC, leaving quite a range of more erect TLC values unsupported.

3.2.2 BAC results

The simulation matrix results for the BAC simulations are listed in Table 14. Figures 61-69 describe the final posture of the 2-D JOHN model for each simulation.

Table 14 - Simulation results for BAC study

TRA \ TLC	0°	20°	40°
23°	TLC = -1° TRA = 22°	TLC = 20° TRA = 23°	TLC = 39° TRA = 23°
28°	TLC = -2° TRA = 27°	TLC = 21° TRA = 28°	TLC = 40° TRA = 28°
33°	TLC = -2° TRA = 32°	TLC = 21° TRA = 33°	TLC = 39° TRA = 33°

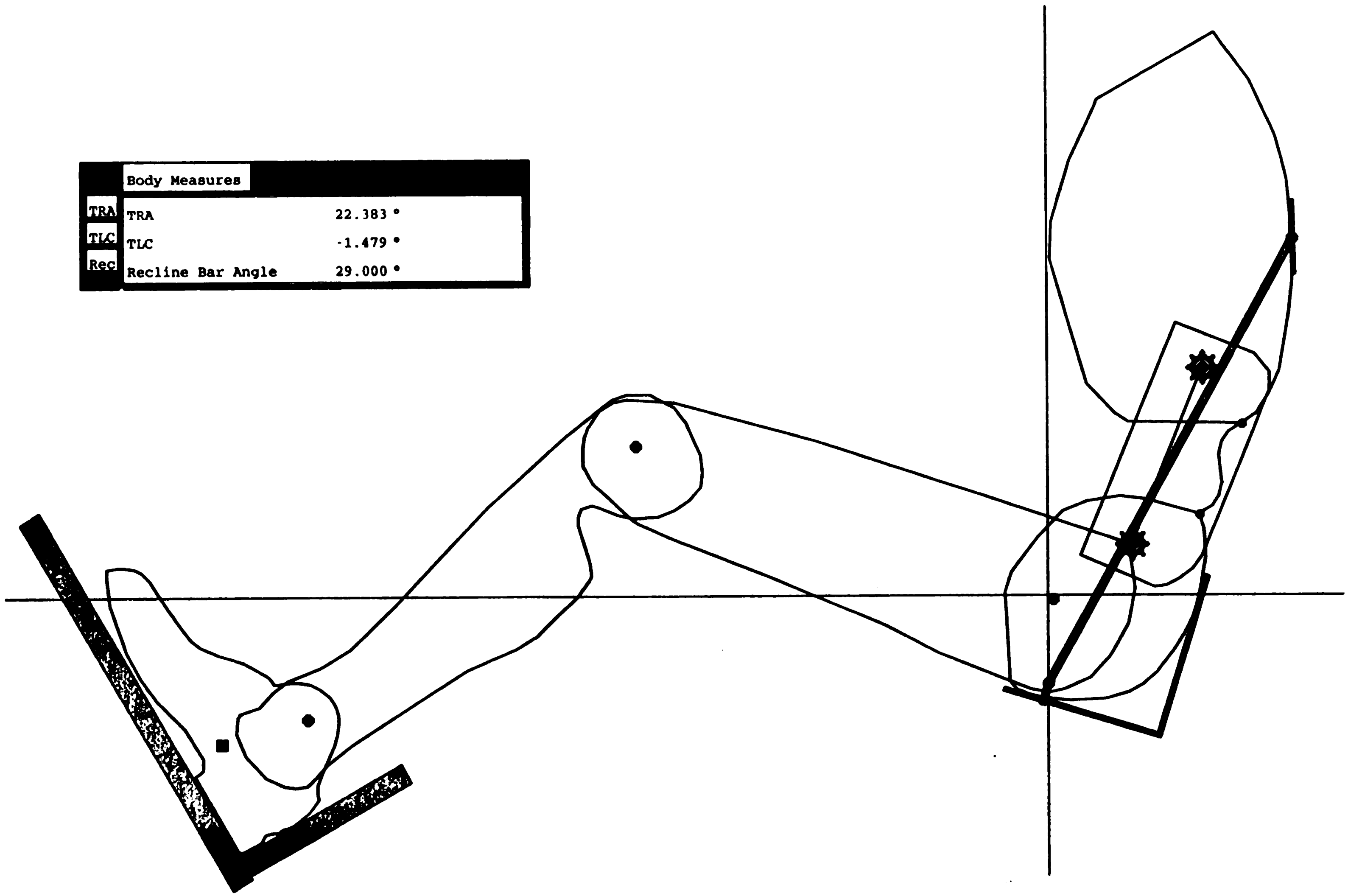

Figure 58: BAC set for 23° TRA, 0° TLC

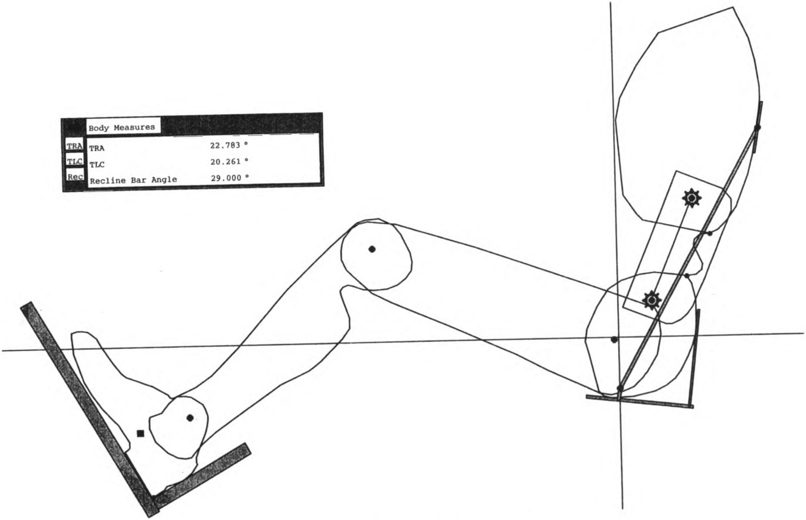

Figure 59: BAC set for 23° TRA, 20° TLC

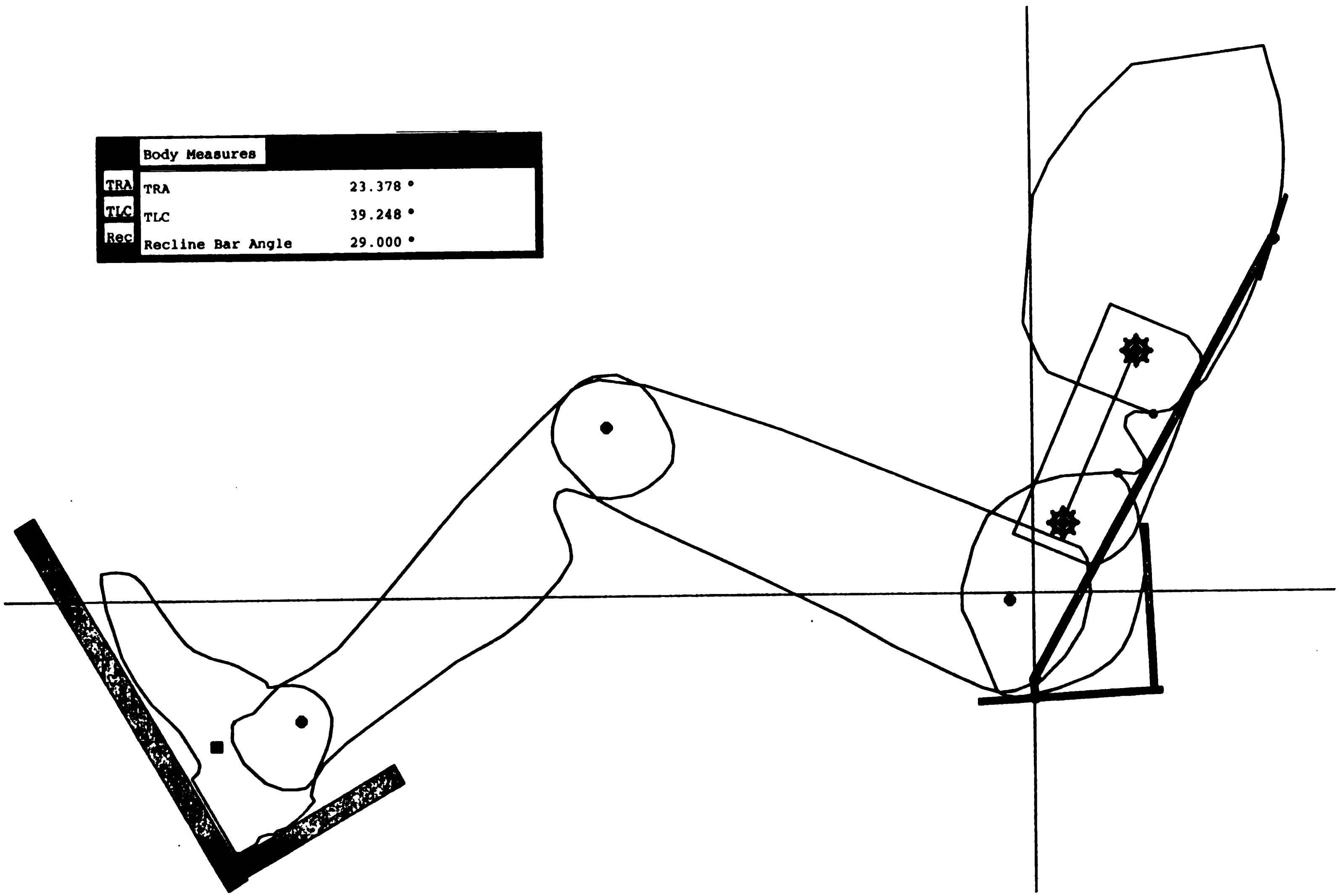

Figure 60: BAC set for 23° TRA, 40° TLC

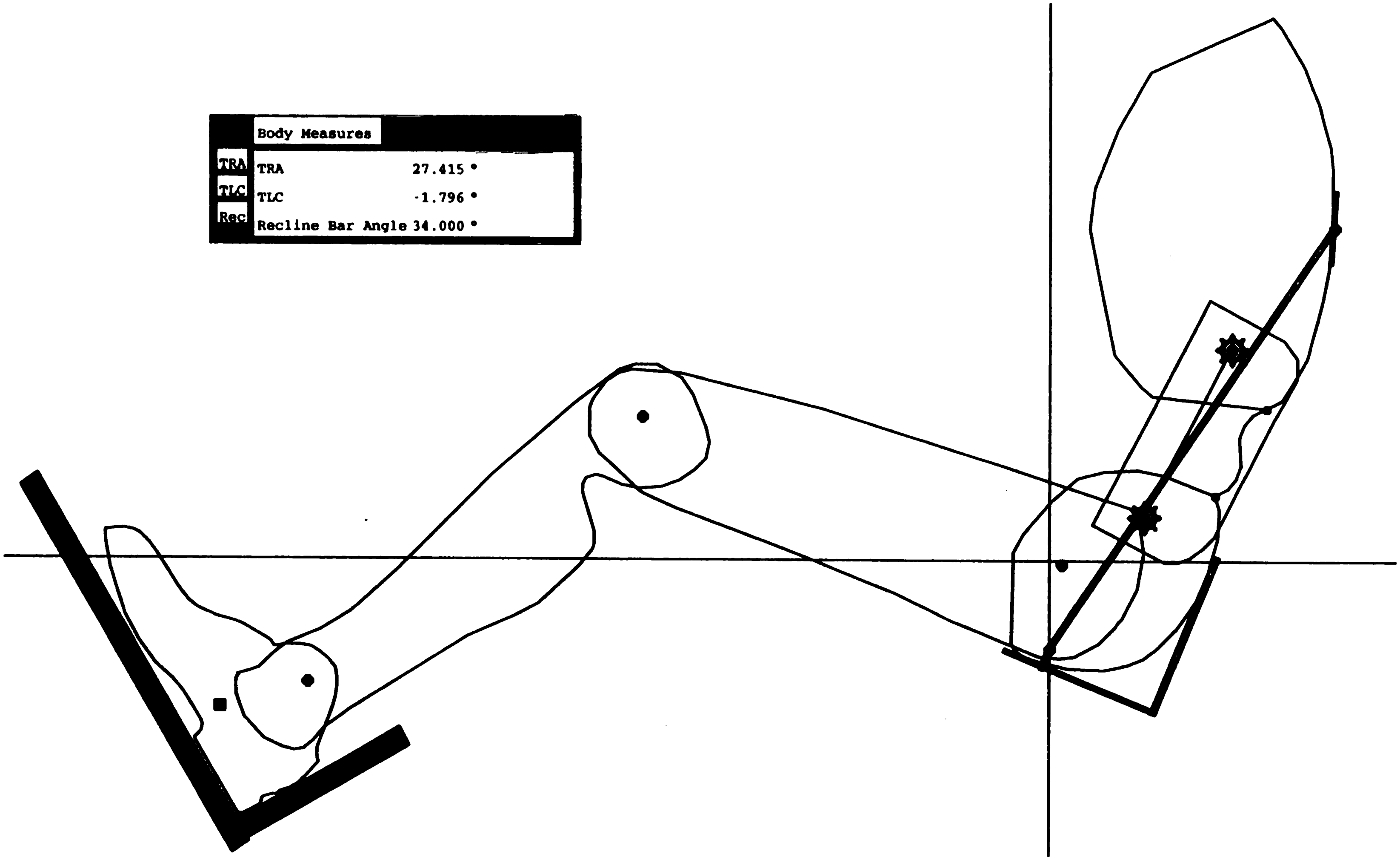

Figure 61: BAC set for 28° TRA, 0° TLC

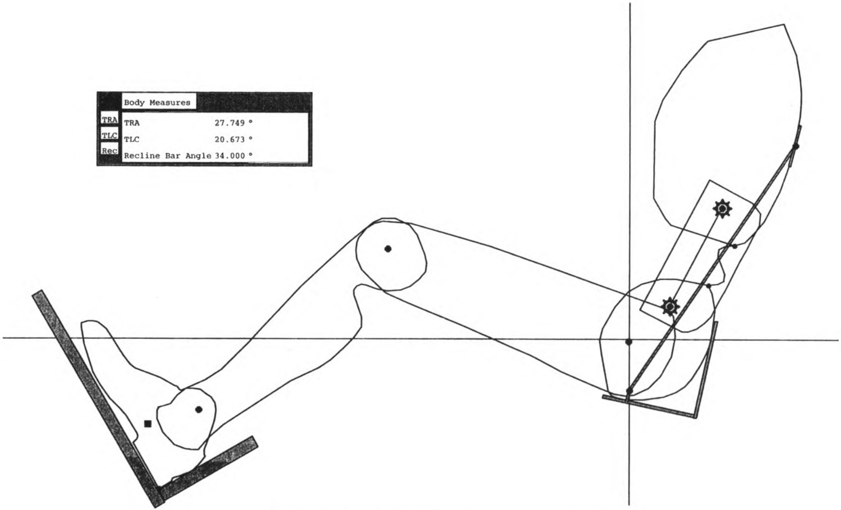

Figure 62: BAC set for 28° TRA, 20° TLC

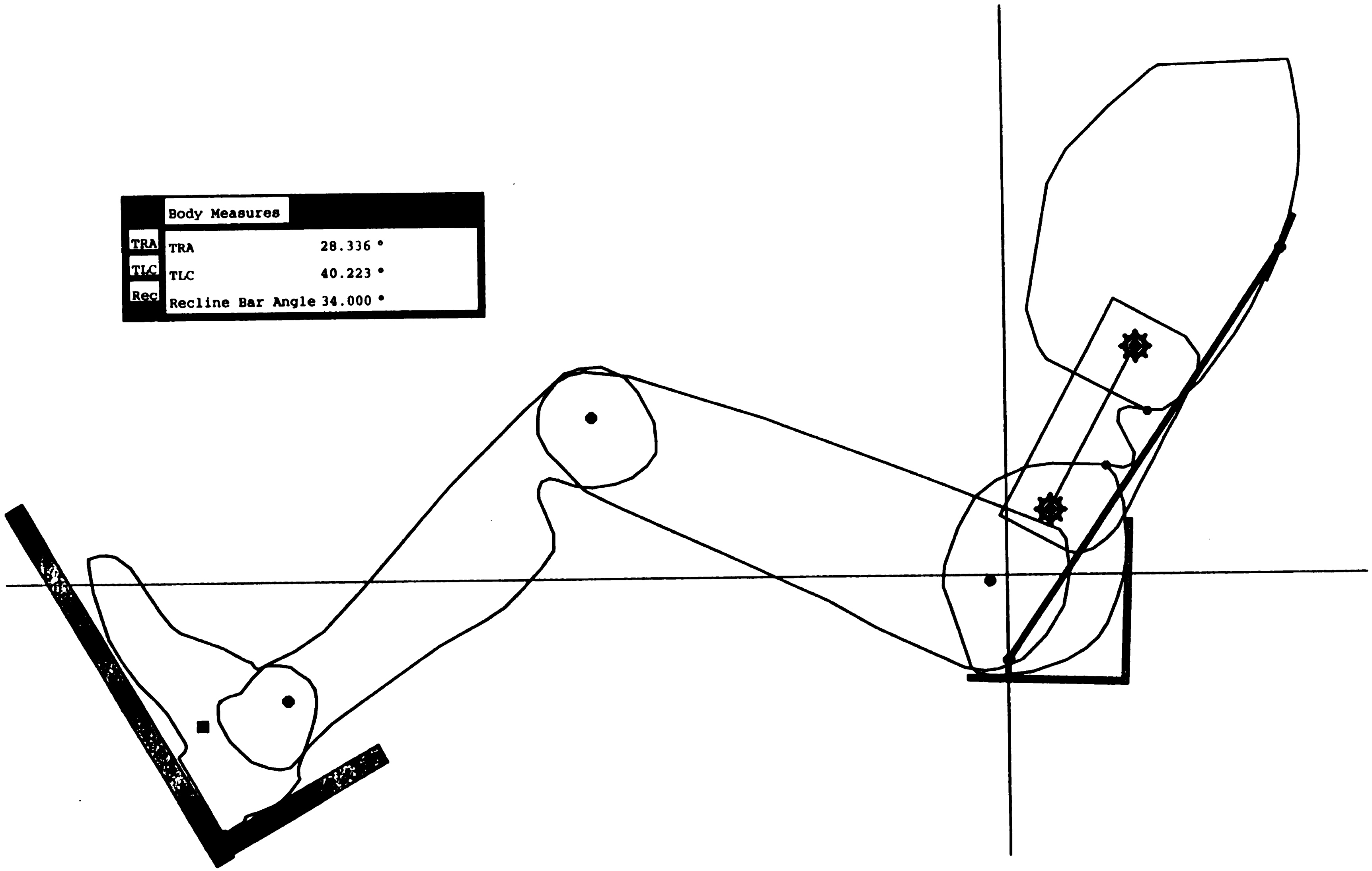

Figure 63: BAC set for 28° TRA, 40° TLC

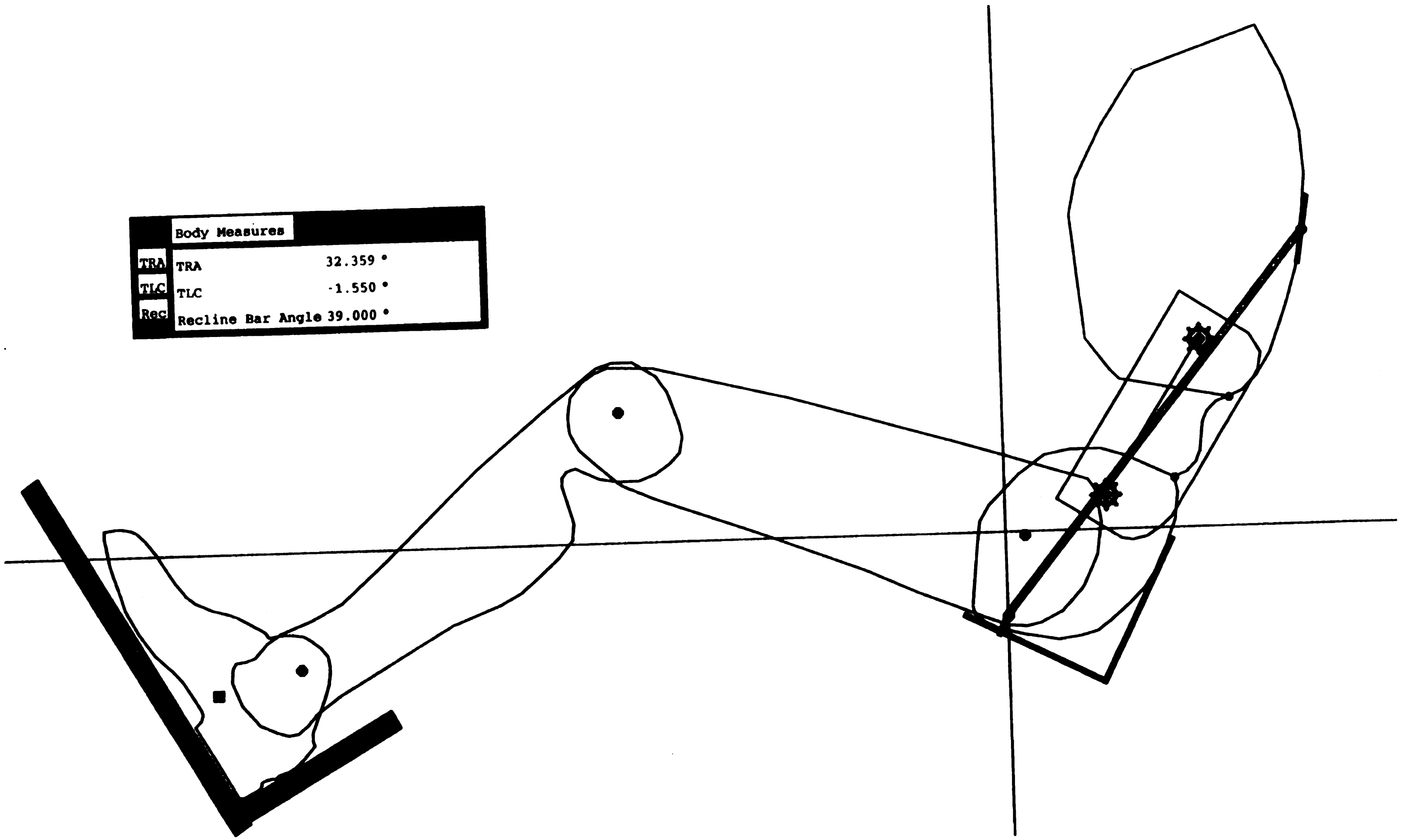

Figure 64: BAC set for 33° TRA, 0° TLC

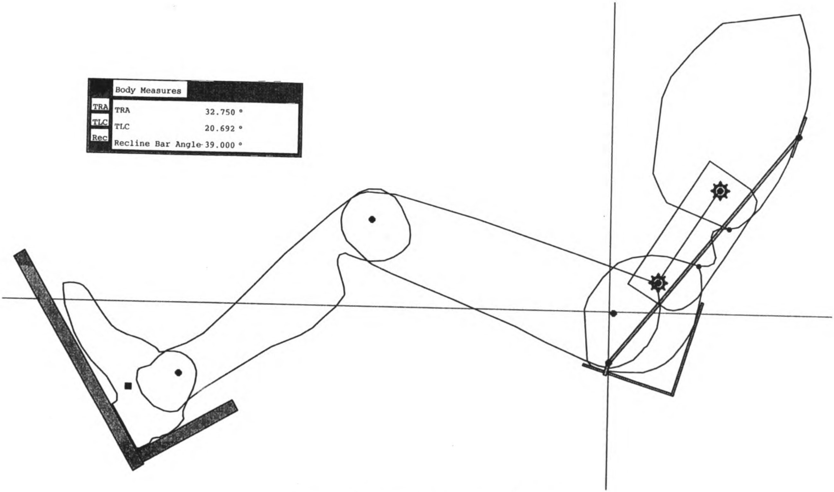

Figure 65: BAC set for 33° TRA, 20° TLC

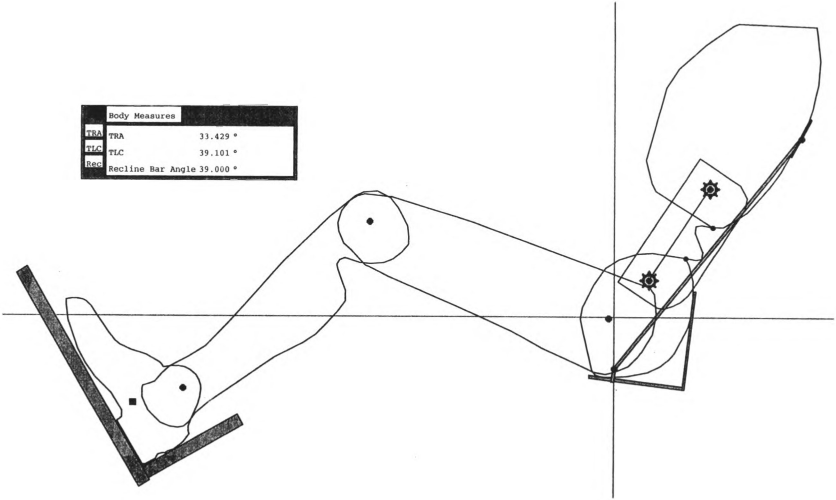

Figure 66: BAC set for 33° TRA, 40° TLC

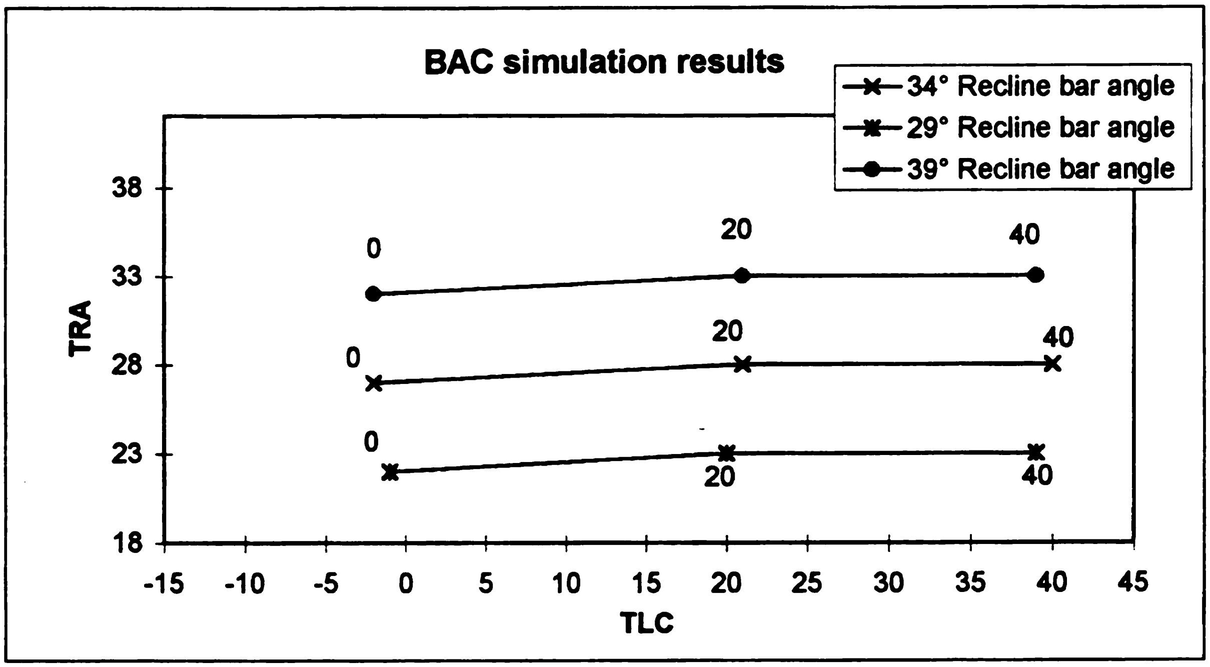

Figure 67: Graph plotting TRA vs. TLC at constant recline bar angle for BAC simulations

The TLC values of the 2-D JOHN model in the BAC match those corresponding to the placement of the seating supports within 2° or less for every simulation. As can be seen by the length of the graph lines in Figure 67, which plots the TRA values versus the TLC values for each level of constant recline bar angle, the BAC can support a wide range of lumbar curvature (TLC), from 0° to 40°. In addition, the TLC change is not a function of the recline angle (TRA) of the BAC, meaning that the model can move the full range of TLC for any constant TRA value, unlike in the Chrysler LH seat model. This is shown in Figure 67 by the fact that the plotted line have very little slope, if any. To contrast the BAC results to the Chrysler LH results, recall that the TRA vs. TLC plot for a constant seat frame angle of 23° in the Chrysler LH seat model was vertical, indicating no change of TLC possible at that seat frame angle, whereas for all three values of recline bar in the BAC simulations the TRA vs. TLC plotted lines are flat, showing that the BAC was able to support the 2-D JOHN model in a wide range of postures at any Torso Recline Angle.

The most striking result from the BAC simulations is the control that the pelvis support has over the TLC of the 2-D JOHN model. In all nine simulations the pelvis comes to an immediate stop when it contacts the pelvis support. The TRA and thorax position continue to adjust slightly, but TLC change stops soon after the pelvis stops. The different amounts of TLC possible in the BAC are directly dependent on the starting distance between the back of the 2-D JOHN model pelvis, in an erect 40° TLC posture, and the pelvis support. When this distance is very small, as in the case of all three simulations to support 40° TLC, the pelvic support constrains any rotation of the pelvis, thereby keeping TLC at 40°. When the distance is the largest, as with the cases for 0° TLC, the pelvis will rotate rearward, resulting in a decrease in TLC, until it comes into contact with the pelvis support. At that time the rotation of the pelvis support stops, and the TLC does not change any further.

2.3 Upper thorax support location results

The results of the simulations run to study the effect of the upper thorax support in the automotive seat on the final posture of the 2-D JOHN model are shown in Table 15 and can be seen in Figures 66-69.

Table 15 - Simulation results for upper thorax support location study

Distance of shoulder support	0 mm	10 mm	20 mm	30 mm
TLC	14°	18°	22°	25°

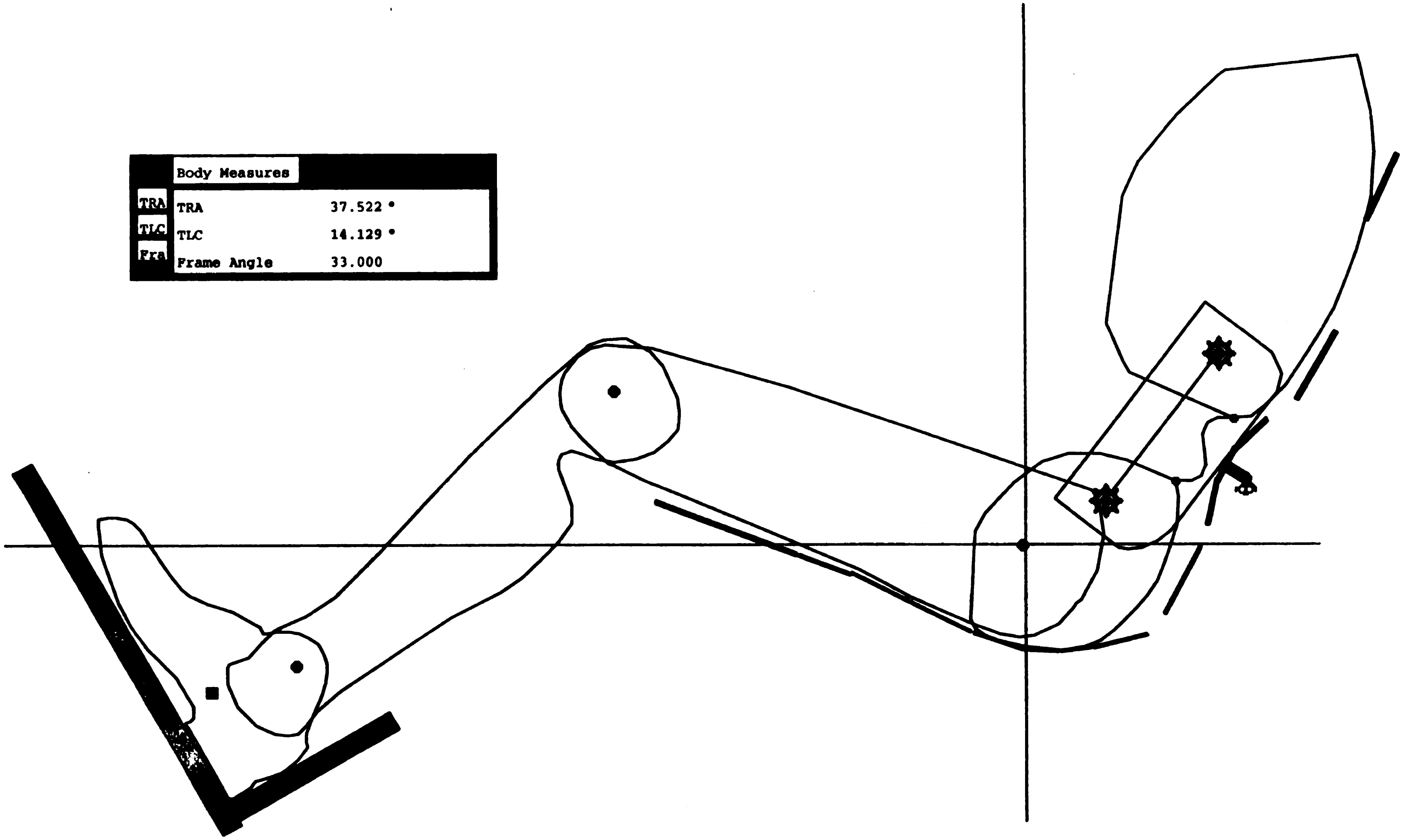

Figure 68: LH seat with upper thorax support at 0 mm displacement

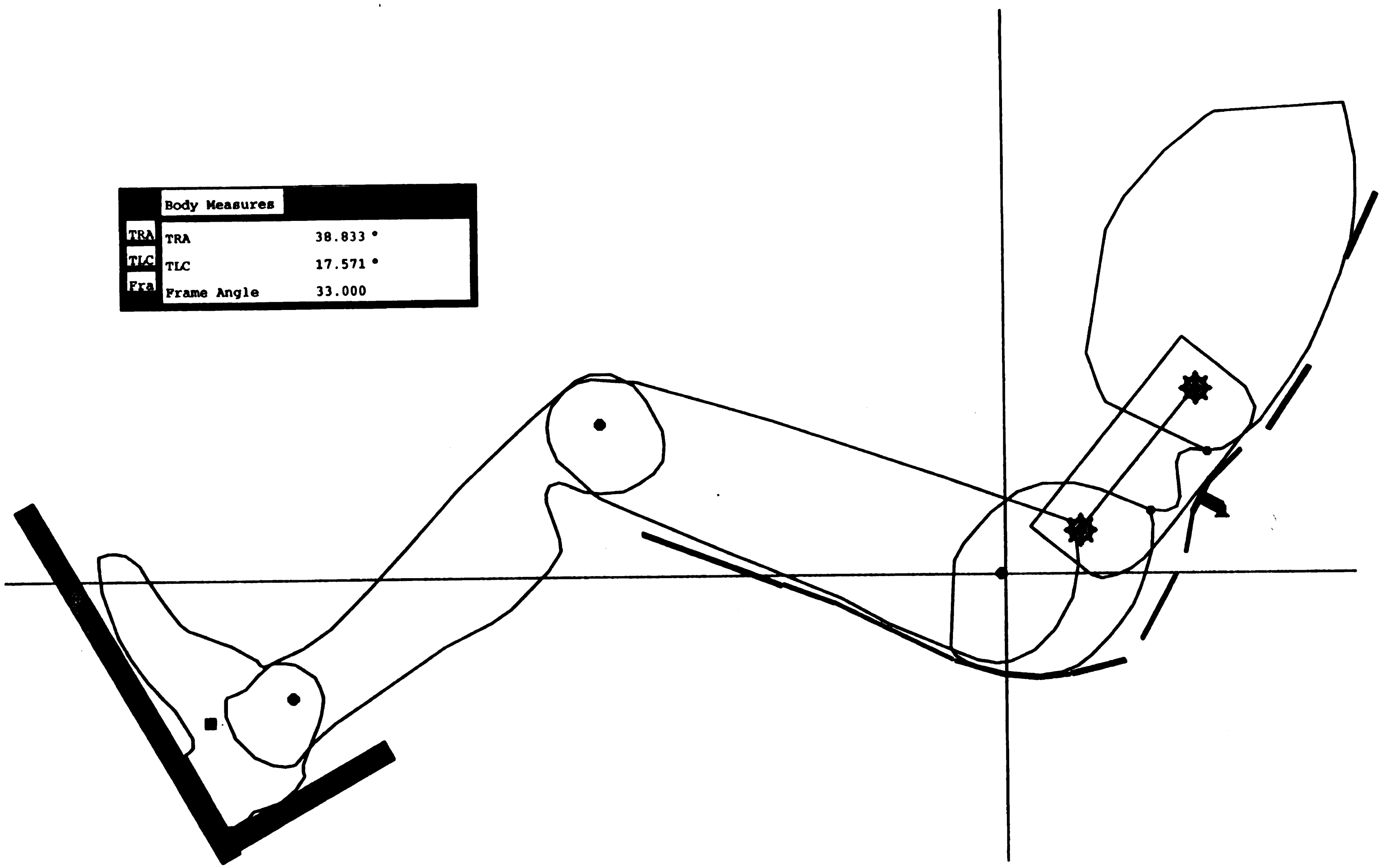

Figure 69: LH seat with upper thorax support at 10 mm displacement

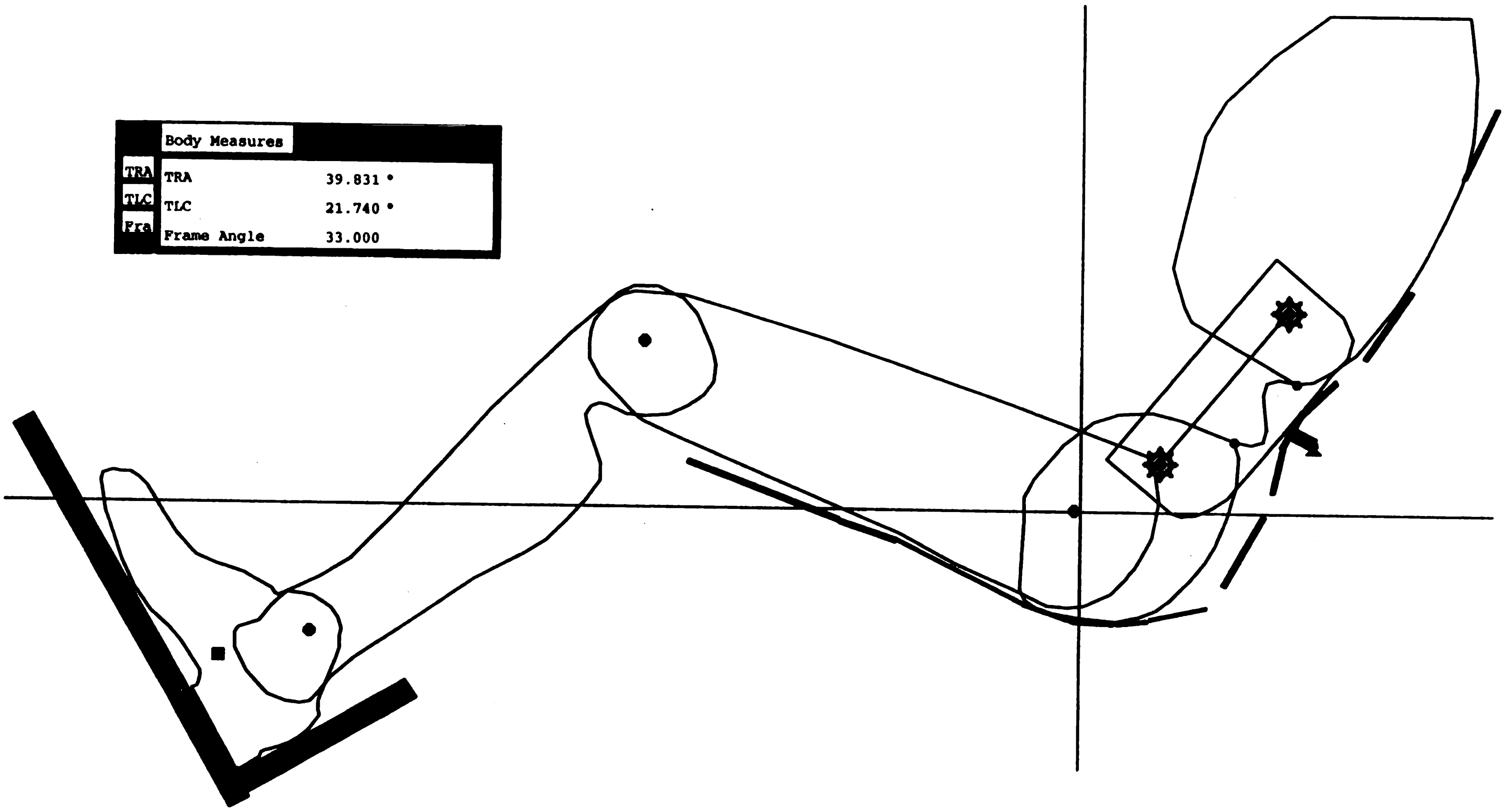

Figure 70: LH seat with upper thorax support at 20 mm displacement

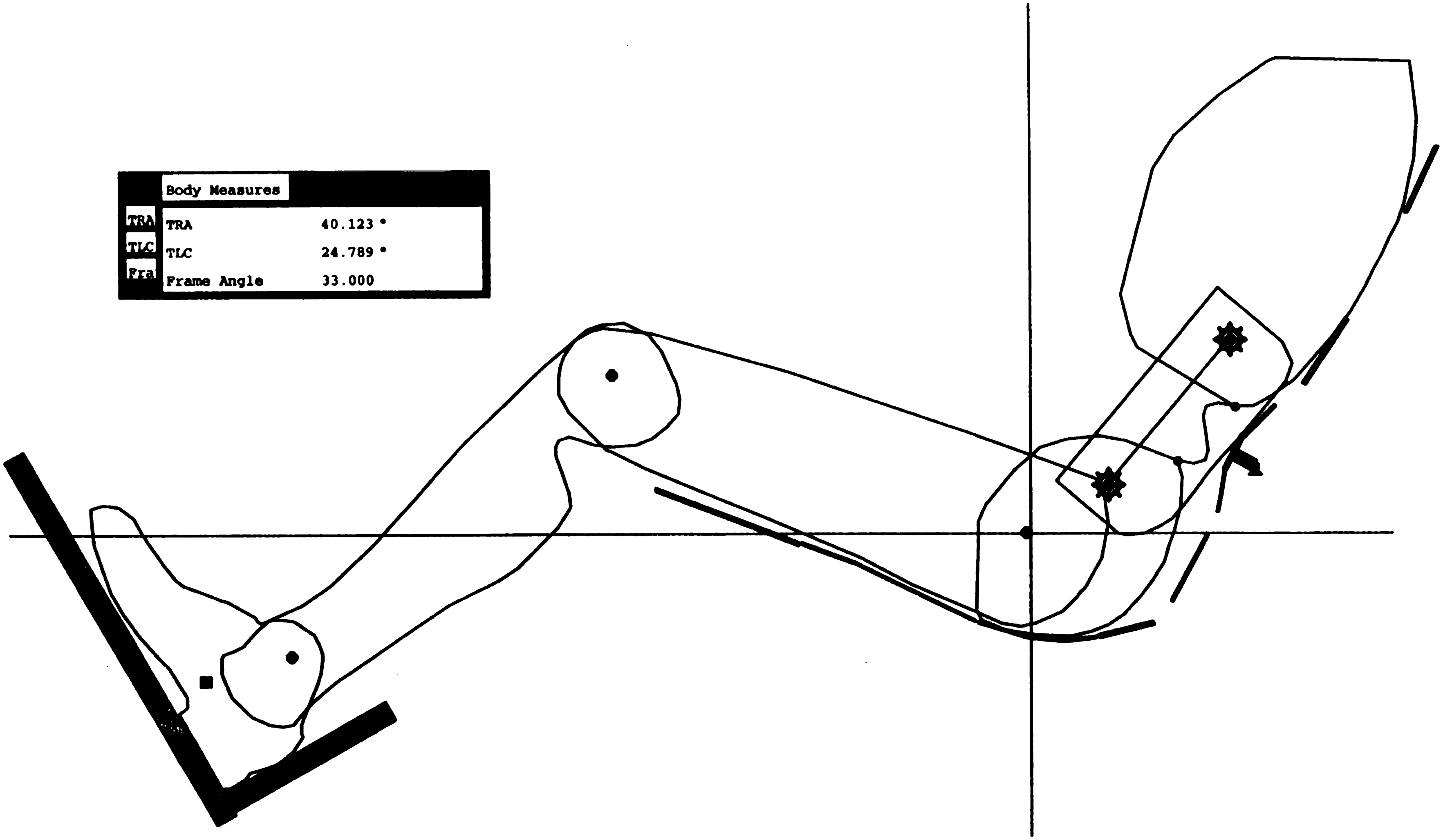

Figure 71: LH seat with upper thorax support at 30 mm displacement

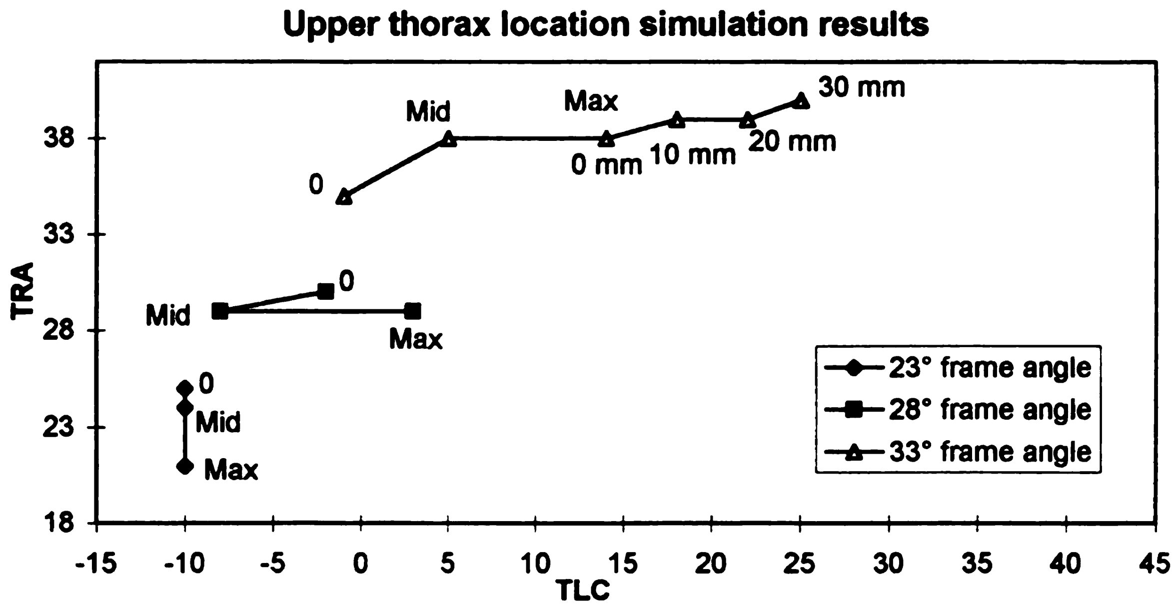

Figure 72: Upper thorax location results with LH seat results

The results from the upper thorax simulations are plotted as an addition to the LH results and are show in Figure 72. As mentioned previously, the simulations for this study were run with the Chrysler LH seat geometry generating the largest TLC value, a 33° seat frame recline angle and with maximum lumbar prominence. Moving the thorax support rearward 30 mm, just over 1 inch, allowed the final posture of the model to be 11° greater. This can be seen in Figure 72 by observing the extra length added to the constant 33° frame angle line. Each 10 mm increment resulted in about a 4° change in lumbar curvature. As can also be seen in Figure 72, the TRA of the 2-D JOHN model changed only 2° as the upper thorax support was moved rearward. In this case, allowing the upper thorax of the 2-D JOHN model to rotate rearward provided a large increase in TLC with minimal change in TRA, which is like the results from the BAC simulations. This shows that if the final posture of the model is supported, or restricted, by the upper thorax support, then allowing the upper thorax support to move rearward can have a dramatic effect on the final posture of the model.

3.3 OBSERVATIONS

From the 2-D JOHN model simulation results, it can be seen that the rear pelvis support has the greatest influence on the final posture of the model. This can be seen most clearly in the BAC simulations, where as the distance between the rear pelvis support and the starting position of the pelvis decreases, there is a dramatic increase in the TLC supported. When the back of the pelvis comes into contact with the rear pelvis support in either the automotive or BAC simulations, there is an immediate constraint of the thorax to pelvis rotation, or change in TLC. The closer this support is to the back of the pelvis when the 2-D JOHN model is in a 40° TLC posture, the greater the final TLC will be.

Of second most importance to the final position of the 2-D JOHN model is the proximity of the upper thorax support. If the upper thorax support is positioned too far forward, the 2-D JOHN model will come in contact with the upper thorax support before the rear pelvis support and an erect posture is not possible. Due to the nature of the mechanism controlling the coupled movement of the thorax, lumbar and pelvic segments, the contact with the upper thorax support stops the rearward translation of the torso of the model, the TRA, and forces any motion to occur to be rotation of the thorax. Because the thorax is coupled to the pelvis this causes a rapid decrease in TLC, resulting in a more slumped posture. One of the reasons the 2-D JOHN model could not obtain a very erect posture in the LH seat model was due to the interference with the close upper thorax support.

From the simulation results, it was observed that the human torso can be thought of as two structures and a linkage, the structures being the thorax and pelvis, and the linkage the lumbar segment. Controlling the posture of the torso by influencing the position of the structures, like the BAC, is much more effective than trying to control the posture of the torso by pushing on the lumbar linkage, as is the case in many current automotive seats. It seems clear from the simulation results that in order to control the posture of seated occupants it is necessary to replace the current method of a single lumbar support with a more influential support structure. This new structure would involve a rear pelvis support, lower thorax support and ability to let the upper part of the shoulders move rearward. If a seat model can support a simplified mechanistic model of the human body that has no muscle forces acting on it in an erect posture, then it can surely support a relaxed human body in a real seat.

CONCLUSION

The objectives of this thesis were to develop two kinetic computer models that simulate the human body for automotive seating design. The first computer model represented the current SAE 3-D testing manikin, defined in the SAE J826 Standard. The second model was a representation of the human body model developed at Michigan State University called JOHN. The JOHN model is an improvement over the SAE J826 models because JOHN has the ability to represent a change of lumbar curvature. The 2-D SAE computer model was used to simulate experimental data collected with the SAE 3-D testing manikin. The 2-D JOHN model was used in a seat study comparing a current production automotive seat designed with the SAE tools and an articulating prototype seat.

The results from the 2-D SAE computer model show that it is possible to reproduce data collected with the SAE 3-D testing manikin with good accuracy. This method of predicting the penetration of the SAE 3-D testing manikin into an automotive seat cushion may prove valuable to automotive seat designers.

The results from the 2-D JOHN model show that a prototype articulating seat called the Biomechanically Articulating Chair (BAC) can support the 2-D JOHN model in a greater variety of postures than a current automotive seat. These results show that the current method of supporting the human torso with a lumbar support may not be a effective as supporting the torso with a combination of pelvic and thoracic support.

Kinetic modeling of both the 2-D JOHN model and the SAE J826 tools will be very useful for designers and manufacturers of seating products. There are no current computer models that show lumbar articulation and none that allow kinetic evaluation. Allowing the seat designers to see the results of their work quickly will be of great benefit to them because it will help to lower prototyping costs and shorten design time. The 2-D JOHN model can be used to better understand the interaction between the body and the seat by observing the influence of different supporting conditions on the posture of the model.

From the results and conclusions of this research the following future work is recommended;

1. A study to compare the 2-D JOHN model results obtained from the simulations in the automotive seat model to postural data collected from human subjects seated in the same automotive seat. This study would not only compare the model results to individual data but to the average posture of the seated subjects. It would be useful for determining the reliability of the 2-D JOHN model to predict general human seated posture.
2. Research that would combine the spring-damper support modeling of the SAE 2-D drafting template with the more advanced 2-D JOHN model postural measures. This research would also investigate modeling of the seat back cushion as a spring-damper support system.

3. Develop and construct models representing the 5% female and 95% male and perform simulations to study the effect of body size on the deflection into the seat and final posture of the model.

BIBLIOGRAPHY

1. SAE Standard J826, "Devices for the Use in Defining and Measuring Vehicle Seating Accommodation", Body Engin. Comm., Soc. Auto Eng., Approv. Nov. 1962.

2. Roe, R.W. "Occupant Packaging", Automotive Ergonomics, eds., B. Peacock, W. Karwowski, Taylor and Francis Ltd., 1993.

3. Hubbard, R.P., W.A. Haas, R.L. Boughner, R.A. Canole, N.J. Bush, "New Biomechanical Models for Automobile Seat Design", paper no. 930110, Internat. Cong., Soc. Auto. Eng., 1993.

4. Haas, W.A., "Geometric Model and Spinal Motions of the Average Male in Seated Postures", Thesis of the Master of Science Deg., Dept. Of Metal., Mechanics, and Mat. Sci., Michigan State Univ., 1989.

5. Schneider, L.W., D.H. Robbins, M.A. Pflug, and R.G. Snyder, "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropometrically Family" Vol. 1, Fin. Rep. No. DOT-HS-806-715, U.S. Dept. of Trans., NHTSA, 1985.

6. Robbins, D.H., "Anthropometric Specifications for Mid-sized Male Dummy", Vol. 2, Fin. Rep. No. DOT-HS-806-716, U.S. Dept. of Trans. NHTSA, 1985.

7. Boughner, R.L., "A Model of Average Adult Male Human Skeletal and Leg Muscle Geometry and Hamstring Length for Automotive Seat Designers", Thesis for Master of Science Deg., Dept. of Metal., Mechanics and Mat. Sci., Michigan State Univ., 1991.

8. Bush, N.J., "Two-dimensional Drafting Template and Three dimensional Computer Model Representing the Average Adult Male in Automotive Seated Postures", Thesis for Master of Science Deg., Dept of Metal., Mechanics and Mat. Sci., Michigan State Univ., 1992.

9. Hubbard, R.P., C. Beckett, C. Gedraitis, "Method for Determining the Stiffness of an Automotive Seat Cushion", Internal Document for SAE sponsored ASPECT program, 1996.

10. Beer, FP, E.R. Johnston Jr., "Vector Mechanics for Engineers: Statics and Dynamics", 5th ed., McGraw-Hill Pub. Co., pp. 176-77, 1988.

11. Hubbard R.P., "Seat with Biomechanical Articulation" U.S. Patent Appl. # 08/259,662, filed June 14, 1994.