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**THE STANDARD AUTOMATED MASS PROPERTIES
(STAMP) TESTING AND CALIBRATION PROCEDURES**

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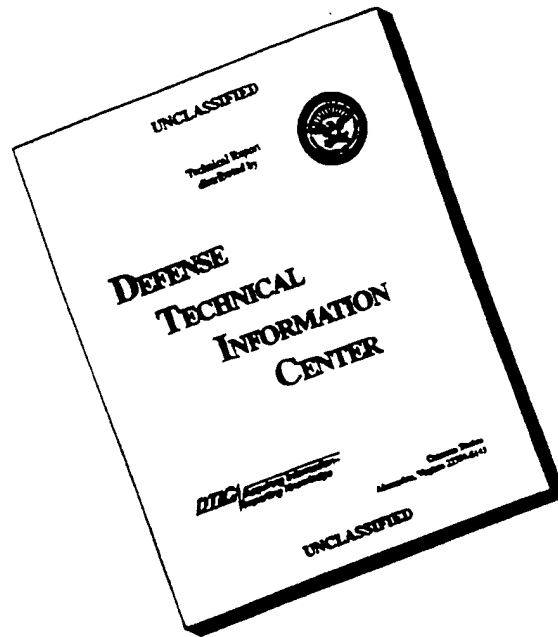
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13. ABSTRACT (Maximum 200 words) This document describes an automated procedure to measure the mass, center of gravity, and principal moments of inertia of objects weighing up to 100 pounds. The procedure uses three-sided, orthogonal support boxes - to secure the test objects during testing and to provide a method for relating test object features to a known coordinate system, a digital balance and moment table - to determine the mass and center of gravity, a torsional pendulum - to determine the moments of inertia, a three-dimensional digitizer - to specify various axes systems and location of discrete landmarks, and a computer - for data acquisition and analysis. The procedure consists of measuring the mass properties of the test object secured within a support fixture and then subtracting the contribution of the support fixture, resulting in the mass properties of the test object alone. The inertial properties of the test object are then referenced to the center of mass of the test object through the location of reference points on the test object which form a test object based coordinate axis system.				
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PREFACE

This procedure was developed by the Vulnerability Assessment Branch, Biodynamics and Biocommunications Division, Crew Systems Directorate, Armstrong Laboratory (AL/CFBV) and supported by Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Road, Dayton, Ohio. The procedure is conducted in the Manikin Testing Laboratory (MTL), Building 824, Area B, Wright-Patterson Air Force Base, Ohio.

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BACKGROUND

The mass, center of gravity, and mass moments of inertia of the body and any encumbering equipment are important factors in assessing injury potential for individuals subjected to impact. Once the mass properties of a system are determined, various types of analysis may be performed. The mass properties of prototype equipment may be compared with other equipment to identify potential problems such as excessive weight or misplaced center of gravity which may result in injury to the user. The knowledge of the mass properties of head and helmet mounted equipment provides a means for estimating net head inertial properties changes with the addition of head mounted equipment. These data can be used to define the combined head and helmet properties for determining the human dynamic response to impact environments and to predict the head/neck injury potential from the use of such equipment. Precisely defined mass properties data can be used to create computer databases to be used in predictive simulations for automobile occupant and air crew member safety studies. These models provide an economical and time efficient means to identify and quantify potential system hazards and subsequently provide direction for system improvement. In addition, the mass properties of automotive testing dummies, made by different manufactureres, may be compared to ensure that the properties of all of the manufacturer's dummies are within the acceptable limits for use in automotive safety compliance testing.

The Automated Mass Properties Measurement System, developed at the Armstrong Laboratory, provides an accurate and time efficient means of measuring mass, center of gravity location, and mass moments of inertia. This procedure has been used to test complete manikins, segment by segment, including the Advanced Dynamic Anthropomorphic Manikin (ADAM), Sea Water Instrumented Manikin (SWIM), Hybrid III 5th, 50th, and 95th percentile male and 5th percentile female dummies, Side Impact Dummy (SID), and a nine-month-old infant dummy as well as the following helmet systems and Night Vision Goggles (NVG): HGU -5/P, -26/P, -55/P, Combat Edge, Eagle Eyes, Cats Eyes, Anvis, Merlin, and I-Nights systems. The results of these studies have been compiled into databases which have been used in computer models to assess the effectiveness of vehicle safety design and to study the human response to various head encumbering equipment. These data have also been used by review boards for the assessment of flight safety and for establishing criteria for allowable added head mass.

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INTRODUCTION

This document is intended for use by persons interested in the design and operation of the Automated Mass Properties Measurement System. The testing procedures described herein have previously been described in "The Automated Mass Properties Measurement System Testing Procedure" (AAMRL-TP-89-300). This document was prepared as an update to those procedures.

Included in this report are theoretical calculations, a description of materials required, step-by-step procedures for determining mass, center of mass location, and magnitude and orientation of the principal moments of inertia and equipment calibration methods. Appendices describing potential problems and suggested solutions, proper manipulation of data files, and data entry logs are also included.

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MATERIALS AND THEORETICAL CALCULATIONS

The equipment used for determining the mass properties of a test object include a moment table, electronic balance, level, adjustable stand, holding box, Space Electronics Mass Properties Instrument, Metrecom (an electronic position coordinate digitizer), computer and associated software.

Construction and Purpose of Holding Boxes

The three-sided boxes, illustrated in Figure 1, are designed to hold the object during testing and to provide a cartesian coordinate system which allows transformation of properties measured with respect to the box axis system to a predetermined object coordinate system. The boxes are constructed of welded sheets of thin perforated aluminum, providing a rigid but very light-weight structure. Velcro straps secure the test object within the box. There are a number of boxes to accommodate various sized objects.

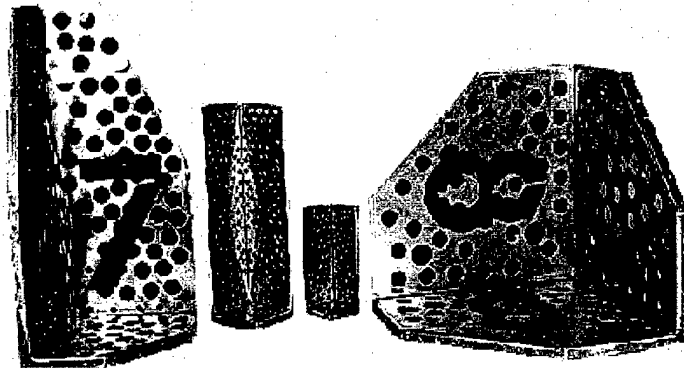


Figure 1 Typical Holding Boxes

Center of Gravity Determination

The center of mass location is determined with the use of a balance and moment table assembly. Figure 2 shows the electronic balance and moment table assembly loaded with the composite (test object and box together) in the CG_x measurement configuration.

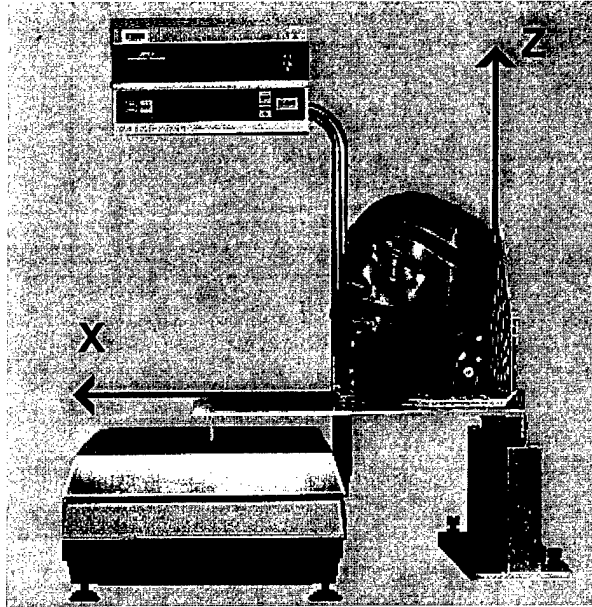


Figure 2 "Loaded" Moment Table - Balance Assembly in CG_x Configuration

The free body diagram of this assembly is shown in Figure 3.

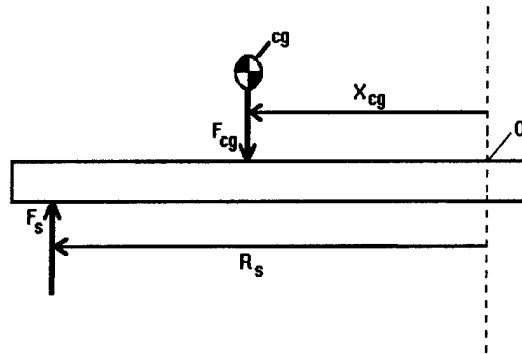


Figure 3 Free Body Diagram of "Loaded" Moment Table

The following computations show that after taring off the weight of the moment table, summing the moments due to the weight of the composite and balance reaction force allows the CG_x coordinate of the composite to be calculated. The same procedure is used in calculating CG_y and CG_z . For static equilibrium

$$\sum M_o = F_s R_s - F_{CG} X_{CG} = 0 \quad (1)$$

or

$$F_S R_S = F_{CG} X_{CG} \quad (2)$$

where,

$$F_{CG} = M g \quad (3)$$

and M is the mass of the composite. Solving for X_{CG} we get

$$X_{CG} = \frac{F_S R_S}{F_{CG}} \quad (4)$$

To determine the center of gravity of the test object alone, the box contribution must be subtracted from the measured composite CG. The total moment due to the test object and box is

$$F_{CG} X_{CG} = F_B X_B + F_T X_T \quad (5)$$

and solving for X_T we get

$$X_T = \frac{F_{CG} X_{CG} - F_B X_B}{F_T} \quad (6)$$

where, F_B = Weight of Box
 F_T = Weight of Test Object
 F_{CG} = Weight of Composite
 X_B = CG location of Box
 X_T = CG location of Test Object
 X_{CG} = CG location of Composite.

This provides the CG of the test object with respect to the axis system of the box. The same procedure is used to determine Y_T and Z_T .

Measurement of Moments of Inertia

Measurement of the moments of inertia of a test object secured within a holding box requires the use of the Space Electronics Mass Properties Instrument, which is based on a torsional pendulum technique. A torsional pendulum, illustrated in Figure 4, consists of a disk that is attached to a vertical shaft that is fixed at the other end and that can be induced to oscillate about the shaft.

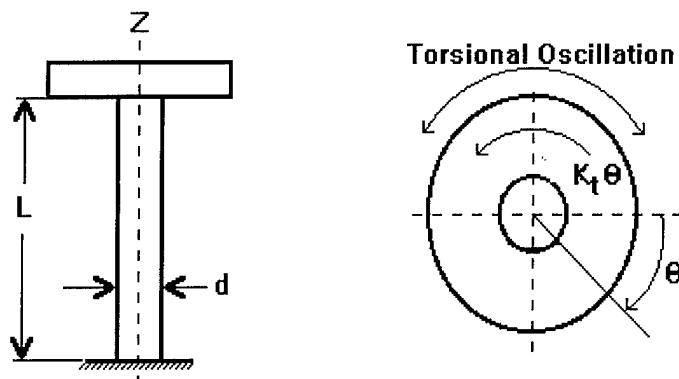


Figure 4 Torsional Pendulum

If the disk is given an angular displacement, θ , from its equilibrium position and released, it will oscillate due to the restoring torque, T , exerted by the shaft. The magnitude of T is given by

$$T = \frac{GJ}{L} \theta = K_t \theta \quad (7)$$

where K_t is the torsional spring constant for the shaft and is a function of the shear modulus, G , the length of the shaft, L , and the polar moment of inertia, J , of the cross section of the shaft.

If the torsional moment of inertia is I and the torsional force acts to bring the system back to equilibrium, then we can write

$$-K_t \theta = I \frac{d^2 \theta}{dt^2} \quad (8)$$

Equation 8 can also be written as

$$\frac{d^2\theta}{dt^2} + \frac{K_t}{I} \theta = 0 \quad (9)$$

which is a homogenous differential equation for which the solution is

$$\theta = C_1 \cos\sqrt{\frac{K_t}{I}} t + C_2 \sin\sqrt{\frac{K_t}{I}} t \quad (10)$$

where C_1 and C_2 are constants which can be determined from the initial conditions. If the boundary conditions are

$$\theta(t=0) = \theta_0 \quad , \quad \theta\left(\sqrt{\frac{K_t}{I}} t = \frac{\Pi}{2}\right) = A \quad (11)$$

then

$$C_1 = 0 \quad , \quad C_2 = A \quad (12)$$

and equation 10 becomes

$$\theta = A \sin\sqrt{\frac{K_t}{I}} t \quad (13)$$

Equation 13 is the equation for simple harmonic motion in which

$\sqrt{\frac{K_t}{I}}$ is the circular frequency, ω_n , at which the disk and shaft oscillate in radians per second. The period of oscillation, τ_n , is given by

$$\tau_n = \frac{1}{\omega_n} = \sqrt{\frac{I}{K_t}} \quad (14)$$

Solving equation 14 for the moment of inertia gives

$$I = K_t \tau_n^2 \quad (15)$$

Equation 15 shows that the moment of inertia is directly proportional to the square of the period of the rotational oscillation, with the proportionality constant being the torsional spring constant.

The Space Electronic instruments utilize an inverted torsional pendulum composed of a gridded test platter mounted on top of a torsion rod housed within the instrument. The period of the oscillations is measured by using a photocell device. To ensure that only rotational motion of the pendulum occurs about the fixed pendulum axis (through the centroid of the platter), the model KGR 8945 instrument, Figure 5, rides on a spherical gas bearing while the model XR-50, Figure 6, utilizes a low friction carbide bearing.

The proportionality constant, K_t , of the pendulum is a function of the torsional stiffness and length of the torsion rod. The instruments measure moments of inertia about the torsional pendulum axis. The moment measured is that of the pendulum itself plus any object rigidly attached to the pendulum platform.

Although the KGR 8945 instrument has the capability to measure the CG position of items on the platform, it functions most accurately when the CG position of the object being tested is closely aligned with the fixed pendulum axis. The standard procedure then is to mount the composite on the gridded test platter so that the horizontal CG position of the composite is within +/- .1 inches of the pendulum vertical axis.

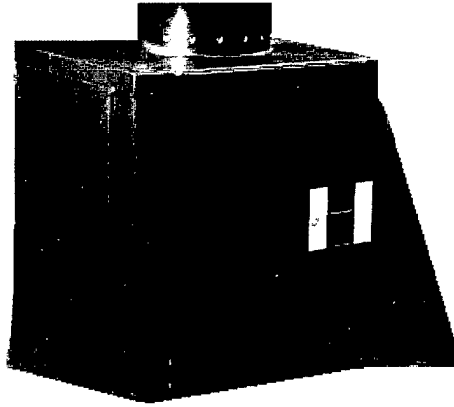


Figure 5 Model KGR 8945
Space Electronics Mass
Properties Instrument

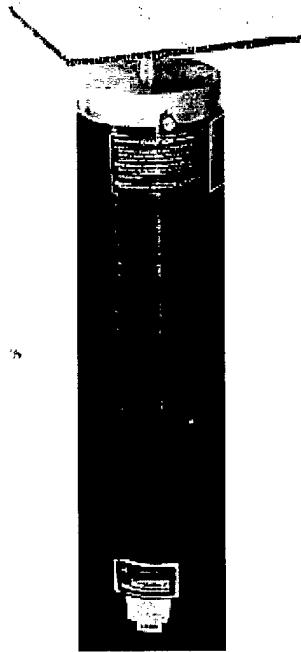


Figure 6 Model XR-50
Space Electronics Mass
Properties Instrument

The rotational inertial properties of a rigid body can be expressed by an inertia tensor. The tensor values depend on the coordinate system origin and orientation with respect to which the tensor is calculated. Six moment of inertia measurements must be taken about six different axes to generate an inertia tensor from which the orientation of the principal axes and the magnitudes of the principal moments of inertia can be determined. For simplicity, three of the axes chosen are the cardinal axes (box edges) of the holding box. The remaining three axes are axes in the planes of the three walls of the holding box at 45-degree angles to the cardinal axes. All six axes intersect at the origin of the coordinate system of the box.

In order to measure a moment about any given axis, that axis must be normal to the pendulum test platter. With the cardinal axes (x , y , z) this presents no problem since placing the box on any one of its three sides causes one axis to be normal to the platter (Figure 7).

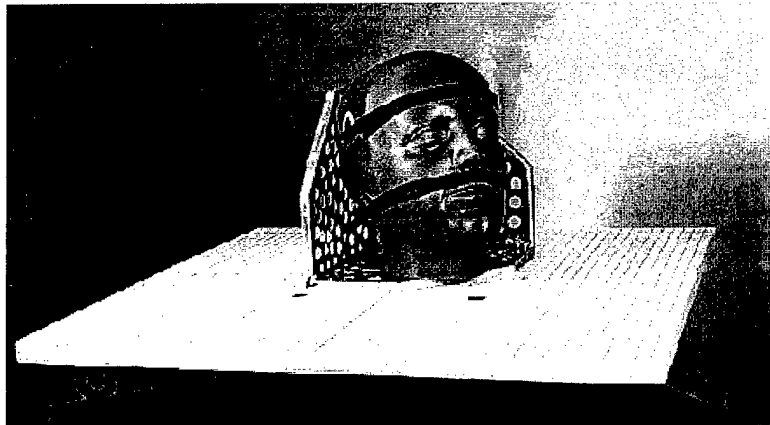


Figure 7 Moment of Inertia Measurement about a Cardinal Axis

With the noncardinal axes, however, it is necessary to utilize a jig which, when placed on the pendulum surface, places two of the cardinal planes at an angle of 45-degrees to the horizontal platter. In this way, the other axis which is at 45-degrees to the cardinal axes is aligned normal to the platter surface as shown in Figure 8.

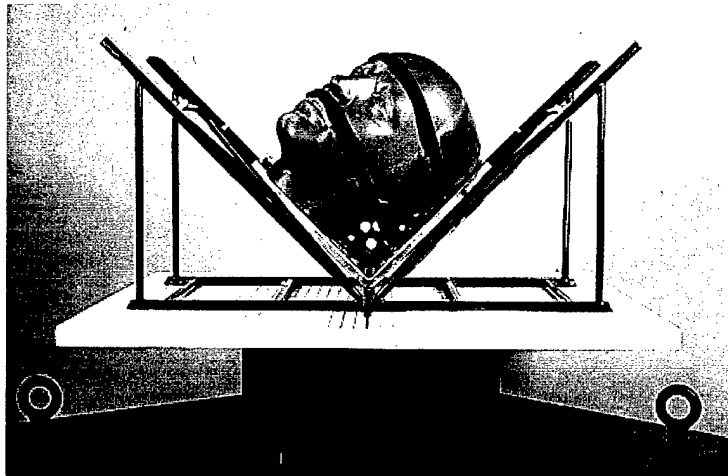


Figure 8 Moment of Inertia
Measurement about a Noncardinal Axis

From these six moment of inertia measurements, the products of inertia can be determined from the equation

$$P_{ab} = \frac{I_a + I_b \tan^2\theta - (1 + \tan^2\theta) I_{ab}}{2\tan\theta} \quad (16)$$

where, P_{ab} = the product of inertia in the ab plane

I_a = the moment of inertia about the cardinal axis a

I_b = the moment of inertia about the cardinal axis b

I_{ab} = the moment of inertia about the noncardinal axis in the ab plane

θ = the angle between axis a and axis ab.

Because the angle between axes is 45 degrees, equation 16 simplifies to

$$P_{ab} = \frac{(I_a + I_b - 2I_{ab})}{2} \quad (17)$$

The box plus jig inertial properties are subtracted from the measured composite properties using the parallel axis theorem.

The resulting inertia tensor, which is with respect to the center of mass of the test object, may be written as

$$T_i = \begin{bmatrix} I_X & -P_{XY} & -P_{XZ} \\ -P_{XY} & I_Y & -P_{YZ} \\ -P_{XZ} & -P_{YZ} & I_Z \end{bmatrix} \quad (18)$$

This inertia tensor is reduced to diagonal form in which the inertia products equal zero and the diagonal elements are the principal moments. This is accomplished by determining the values of λ which satisfy the equation

$$(T_i - I\lambda)\omega = 0. \quad (19)$$

These values are the principal moments of inertia. The vectors associated with these values are the directions of the principal axes associated with the principal moments of inertia. These vectors, expressed as a matrix of cosines, define the direction of the principal axes with respect to the axis parallel to the box axis system, but are centered at the test object's center of mass.

Coordinate System Transformation

To this point, all measurements have been located with respect to the support fixture coordinate axes. To reference the properties of the test object to a test object based coordinate system, the test object landmarks must be digitized with respect to the support fixture axis system using the electronic position coordinate digitizer shown in Figure 9.

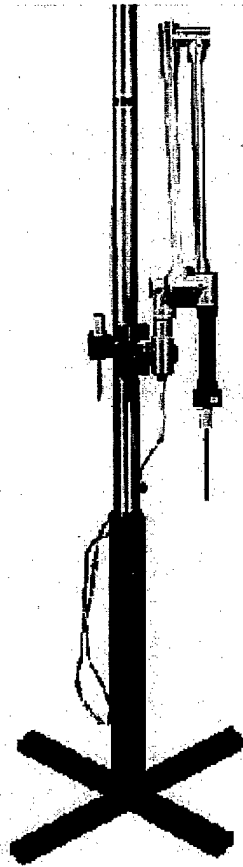


Figure 9 Electronic
Position Coordinate
Digitizer

The support fixture origin and points representing the X, Y, and Z axes of the support fixture are digitized along with three landmarks located on the test object. These three landmarks define the axis system of the test object with respect to the support fixture axes. This specifies a transformation matrix which is multiplied by the principal axis cosine matrix to produce a transformation matrix from the principal axes to the test object axis system.

This transformation process is performed according to

$$[A_{tp}] = [A_{tb}] [A_{pb}^T] \quad (20)$$

where, A_{tp} = Transformation cosine matrix from principal to test object axis system

A_{tb} = Transformation cosine matrix from support fixture to test object axis system

A_{pb}^T = Transpose of transformation matrix from support fixture to principal axis system.

The inertia tensor is then transformed to the test object coordinate system by performing a similarity transformation according to

$$[I^{(t)}] = [A_{tp}] [I^{(p)}] [A_{tp}^T] \quad (21)$$

where, $I^{(t)}$ = Inertia tensor in the test object axis system

$I^{(p)}$ = Principal moments of inertia

A_{tp} = Transformation matrix from the principal to test object axis system

A_{tp}^T = Transpose of transformation matrix A_{tp} .

The origin of the test object axis system may be chosen to remain at the test object center of mass or it may be located at some arbitrary point and the center of mass of the object given in terms of this new origin by simple vector operations. By convention, the principal moment values are defined with respect to the object center of mass.

MEASUREMENT PROCEDURES

Measuring Properties of the Box

To subtract the contribution of the box properties from the composite (test object plus box) properties, the box properties must first be measured. The procedure to determine box data is different from that of a test object in that the box properties must be stored for later use since the boxes are standard fixtures for various test objects. If a box is altered in such a way as to change its mass or mass distribution, new box data should be taken. Also, if one of the jigs is altered, all of the boxes tested with this jig should be retested.

Optional Procedure: Before beginning testing, an inertial entry log (as shown in Appendix C) may be obtained. Measured weight and CG_x , CG_y , and CG_z data may be recorded on this before entering it into the computer. Measured offsets and MOI data may also be recorded here.

NOTE: The procedures differ slightly between the two torsional pendulums. Follow the procedures listed below the appropriate heading for the instrument that will be used. The Model KGR 8945 torsional pendulum procedures are listed below. Procedures for using the Model XR-50 torsional pendulum begin on page 20.

Model KGR 8945

1. Insert the STAMP tape into the HP 85B.
2. Turn on the HP 85B. (If already on, turn off, then on)
3. Wait for the STAMP main menu display.
4. At the prompt, enter 1 to load and run the box placement program.
5. Turn on the electronic balance and zero it by pressing the ZERO button on its front panel. Measure the box mass, in pounds, and enter it at the computer prompt.
6. Position the moment table with its chock side in the groove on the adjustable stand and the other side on the electronic balance. If necessary, level the table by adjusting the stand screws.
7. Zero the balance again with the moment table in place.

8. Enter balance readings for the CG_x , CG_y , and CG_z positions of the box on the moment table at the computer prompt. Proper box placement configurations are shown in Figure 10. The electronic balance reading should return to 0.00 between test positions with the moment table in place. If not, zero the balance again and retest.

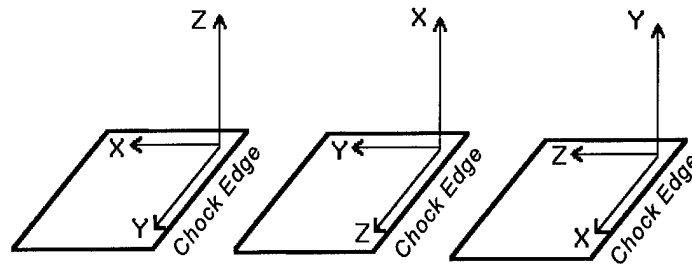


Figure 10 Proper Positions of the Box on the Moment Table to Measure CG_x , CG_y , and CG_z

9. The box placement program prints out the x and y offsets that will be used to place the test object on the platter of the torsional pendulum so that the pendulum axis passes through the object's CG. This printout should be saved.
10. When the STAMP menu is displayed, enter 5 to load and run the Space Electronics (SE) measurement program. For the first test, enter D at the SE measurement menu to take the moment of inertia tare. This is done so that the SE measurement program can subtract the properties of the test platter to yield only the inertial properties of the test object.

Proceed with the following steps:

At the prompt **READ TARE FROM TAPE?**, enter **N**.

Open the gas valve leading from the air source to the base of the instrument and turn on the air dryer.

Turn on the switch controlling the gas flow to the bearing.

Press the **CONT** button on the HP 85B. This causes the platter to rotate to zero degrees and then oscillate until a tare is measured. Do not touch the platter while it is oscillating.

11. Place the box on the Mass Properties Instrument (MPI) platter at the x and y offsets found by the box placement program. For the I_x measurement, the x-axis of the box should be perpendicular to the platter with the y and z axes parallel to the platter axes.
12. Using the double sided tape on the outer walls of the box make sure that the box is mounted securely onto the platter and cannot move with respect to the platter. If the box is poorly attached, errors can be introduced into the measurement and the measurement will have to be repeated.
13. Choose **F** to determine the average time period of oscillation.
14. Choose **G** to calculate the moment of inertia using the average time period of oscillation from step 13.
15. When asked to **Save this moment to tape?** enter **Y** or **N**. Typically, the moment should be saved unless a mistake has been made.
16. Repeat steps 11 through 15 for the I_y and I_z measurements making appropriate box placement and axis configuration changes.
17. For the noncardinal moments, I_{xy} , I_{yz} , and I_{xz} , the jig corresponding to the box size must be used. Appendix H contains a list of which box should be tested with which jig.
18. Place the box securely in the jig. The box should be positioned so that the box origin is in the corner of the "V" of the jig and the corresponding axes of the moment being measured are parallel to the sides of the "V" as shown in Figure 8.
19. At the lowest point of the "V" of the jig, there is a mark used for proper placement. Place this mark at the offsets corresponding to the moment being measured.

20. Perform steps 13 through 15 for each of the noncardinal measurements with the box properly placed within the jig.
21. Choose H to quit and return to the STAMP menu. The computer will print out the moments that will be stored to tape. Save this printout. If there is anything wrong with these moments, choose Y when asked to **Alter data? (Y/N)** and make the appropriate changes. Otherwise, enter N.
22. Choose 2 at the STAMP menu to load and run the box calculation program. Enter the appropriate data at the computer prompts.
23. Save the printout from this program by filing it according to the box number in the box data binder.

Model XR-50

1. Screw the aluminum stem onto the desired test platter (6 X 6 inch or 12 X 12 inch platter). Insert the stem into the mass properties instrument and tighten the chock about the stem by holding the platter firmly and rotating the chock clockwise until the stem cannot rotate with respect to the chock.
2. Turn on the 286 computer.
3. At the C:\ prompt type **Menu**. This will display the menu shown in Figure 11.

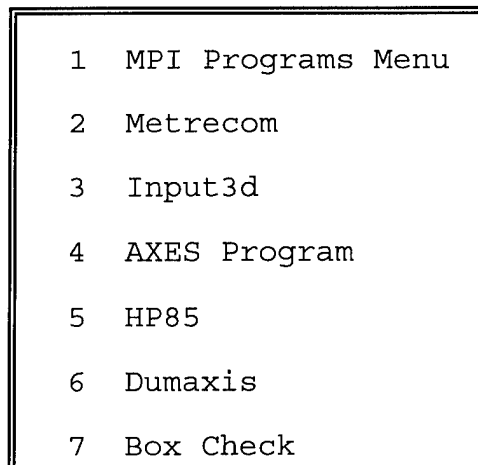


Figure 11 Main Menu

4. Select option 1 by pressing the arrow keys until the **MPI Programs Menu** option is highlighted and then press the return key. This will display the menu shown in Figure 12.

1	Box Placement
2	Box Calculation
3	Composite Placement
4	Segment Calculation
5	S.E. Meas. - Small

Figure 12 MPI Programs Menu

5. Select option 1 by pressing the arrow keys until the **Box Placement** option is highlighted and then press the return key.
6. Turn on the electronic balance and zero it by pressing the ZERO button on its front panel. Measure the box mass, in pounds, and enter it at the computer prompt.
7. Position the moment table with its chock side in the groove on the adjustable stand and the other side on the electronic balance. If necessary, level the table by adjusting the stand screws.
8. Zero the balance again with the moment table in place.
9. Enter balance readings for the CG_x , CG_y , and CG_z positions of the box on the moment table at the computer prompt. Proper box placement configurations are shown in Figure 10. The balance reading should return to 0.00 between test positions with the moment table in place. If not, zero the balance again and retest.
10. The box placement program prints out the x and y offsets from the center of the test platter for each moment measurement. This printout should be saved. These offsets are the coordinates at which the box origin is placed so that the pendulum axis passes through the object's CG.

11. The main menu, Figure 11, will be displayed. Select option 1 again to display the MPI Programs Menu, Figure 12.
12. Select option 5 by pressing the arrow keys until the **S.E. Meas. - Small** option is highlighted and then press return.
13. When asked **Do you wish to calibrate?** enter **Y** or **N**. Typically, calibration is not required. However, calibration should be performed monthly. Calibration procedures are discussed in the section entitled Equipment Calibration.
14. An MOI tare measurement must be performed so that the program can subtract the properties of the test platter to yield only the inertial properties of the test object.
15. Manually rotate the test platter clockwise a very small amount until it can no longer rotate and hold the platter in place.
16. While holding the platter with one hand, press and hold the silver and black hold button at the top of the instrument with the other hand to lock the platter in place.
17. While continuing to depress the hold button, remove the hand from the platter and press the green **Reset** button located on the front panel of the counter.
18. Release the hold button and allow the platter to freely oscillate.
19. At the prompt **Test 1:**, input the number displayed in the counter window. Repeat steps 15 through 18 twice more and input the counter readings at the **Test 2:** and **Test 3:** prompts.
20. When asked **Do you wish to make a measurement (y or n)?**, enter **Y**.
21. Place the box on the MPI platter at the x and y offsets found by the box placement program. For the I_x measurement the x-axis of the box should be perpendicular to the platter with the y and z axes parallel to the platter axes.

22. Using the double sided tape on the outer walls of the box make sure that the box is mounted securely onto the platter and cannot move with respect to the platter. If the box is not securely attached, errors can be introduced into the measurement and the measurement will have to be repeated.
23. With the box mounted securely onto the platter perform steps 15 through 19 for the I_x , I_y and I_z measurements making appropriate box placement and axis configuration changes.
24. For the noncardinal moments, I_{xy} , I_{yz} , and I_{xz} , the jig corresponding to the box must be used. Appendix H contains a list of which box should be tested with which jig.
25. Place the box securely in the jig. The box should be positioned so that the box origin is in the corner of the "V" of the jig and the corresponding axes of the moment being measured are parallel to the sides of the "V" as shown in Figure 8.
26. At the lowest point of the "V" of the jig, there is a mark used for proper placement. Place this mark at the offsets corresponding to the moment being measured.
27. Perform steps 15 through 19 for each of the noncardinal measurements with the box properly placed within the jig.
28. When asked Do you wish to make a measurement (y or n)?, enter N.
29. The main menu, Figure 11, will be displayed. Select option 1 again to display the MPI Programs Menu, Figure 12.
30. Select option 2 by pressing the arrow keys until the **Box Calculation** option is highlighted and then press return. Enter the appropriate data at the computer prompts.
31. Save the printout from this program by filing it according to the box number in the box data binder.
32. The new box data will be appended to the file called **Boxdat**. This file will need to be edited so that the box data is positioned correctly in the file according to the number of the box that was tested.

Proceed with the following steps:

The main menu in Figure 11 should be displayed. Exit this menu by pressing the **Esc** key and return to Dos.

Type **lb boxdat** at the C:\ prompt. This will display the box data in the Lahey editor.

Pressing the **Esc** key while in the editor mode will display the editor functions menu. Use these editor commands to replace the old box data with the data just collected.

Measuring Test Object Properties

Optional Procedure: Before beginning testing, an inertial entry log (as shown in Appendix C) may be obtained. Measured weight and CG_x , CG_y , and CG_z data may be recorded on it before entering it into the computer. Measured offsets and MOI data may also be recorded here.

NOTE: The procedures differ slightly between the two torsional pendulums. Follow the procedures listed below the appropriate heading for the instrument that will be used. The Model KGR 8945 torsional pendulum procedures are listed below. Procedures for using the Model XR-50 torsional pendulum begin on page 28.

Model KGR 8945

1. Select the smallest box that will adequately hold the test object. Appendix H contains a list of suggested boxes for each segment.
2. Determine the points on the object to be used as reference landmarks. Mark these points with ink that can be removed after testing.
3. Position the object in the box so that at least three of these landmarks are easily accessible for digitizing.
4. Secure the object in the box using the velcro straps to hold the object firmly against the sides of the fixture. In addition, masking tape may be used to hold the object more securely. The test object must be rigidly fixed in the box without distorting the box or object in any way since distortion will affect the

mass distribution and the mass properties.

5. Insert the STAMP tape into the HP 85B.
6. Turn on the HP 85B. (If already on, turn off, then on)
7. Wait for the STAMP main menu display.
8. At the prompt, enter 3 to load and run the composite placement program.
9. Turn on the electronic balance and zero it by pressing the ZERO button on its front panel. Measure the composite mass, in pounds, and enter it at the computer prompt.
10. Position the moment table with its chock side in the groove on the adjustable stand and the other side on the electronic balance. If necessary, level the table by adjusting the stand screws.
11. Zero the balance again with the moment table in place.
12. Enter balance readings for the CG_x , CG_y , and CG_z positions of the composite on the moment table at the computer prompt. Proper placement configurations are shown in Figure 10. The balance reading should return to 0.00 between test positions with the moment table in place. If not, zero the balance again and retest.
13. The composite placement program prints out the x and y offsets from the center of the test platter for each moment measurement. This printout should be saved. These offsets are the coordinates at which the box origin is placed so that the pendulum axis passes through the object's CG.
14. When the STAMP menu is displayed, enter 5 to load and run the SE measurement program. For the first test, enter D at the SE measurement menu to take the moment of inertia tare. This is done so that the SE measurement program can subtract the properties of the test platter, to yield only the inertial properties of the test object.

Proceed with the following steps:

At the prompt READ TARE FROM TAPE?, enter N.

Open the gas valve leading from the air source to

the base of the instrument and turn on the air dryer.

Turn on the switch controlling the gas flow to the bearing.

Press the **CONT** button on the HP 85B. This causes the platter to rotate to zero degrees and then oscillate until a tare is measured. Do not touch the platter while it is oscillating.

15. Place the composite on the MPI platter at the x and y offsets found by the composite placement program. For the I_x measurement the x-axis of the box should be perpendicular to the platter with the y and z axes parallel to the platter axes.
16. Using the double sided tape on the outer walls of the box make sure that the composite is mounted securely onto the platter and cannot move with respect to the platter. If the composite is poorly attached, errors can be introduced into the measurement and the measurement would have to be repeated.
17. Choose **F** to determine the average time period of oscillation.
18. Choose **G** to calculate the moment of inertia using the average time period of oscillation from step 17.
19. When asked to **Save this moment to tape?** enter **Y** or **N**. Typically, the moment should be saved unless a mistake has been made.
20. Repeat steps 16 through 20 for the I_y and I_z measurements making appropriate composite placement and axis configuration changes.
21. For the noncardinal moments, I_{xy} , I_{yz} , and I_{xz} , the jig corresponding to the box must be used. Appendix H contains a list of which box corresponds to which jig.
22. Place the composite securely in the jig. The composite should be positioned so that the box origin is in the corner of the "V" of the jig and the corresponding axes of the moment being measured are parallel to the sides of the "V" as shown in Figure 8.
23. At the lowest point of the "V" of the jig, there is a mark used for proper placement. Place this mark at the

offsets corresponding to the moment being measured.

24. Perform steps 21 through 23 for each of the noncardinal measurements with the composite properly placed within the jig.
25. Choose H to quit and return to the STAMP menu. The computer will print the moments that will be stored to tape. Save this printout. If there is anything wrong with these moments choose Y when asked to **Alter data?** (Y/N) and make the appropriate changes. Otherwise, enter N.
26. Choose 4 at the STAMP menu to load and run the segment calculation program. Enter the appropriate data at the computer prompts.
27. At the prompt **Hardcopy?** (Y/N), enter Y.
28. At the prompt **Filename?**, type INERT.
29. Save the printout from this program.

Model XR-50

1. Select the smallest box that will adequately hold the test object. Appendix H contains a list of suggested boxes for each segment.
2. Determine the points on the object to be used as reference landmarks. Mark these points with ink that can be removed after testing.
3. Position the object in the box so that at least three of these landmarks are easily accessible for digitizing.
4. Secure the object in the box using the velcro straps to hold the object firmly against the sides of the fixture. In addition, masking tape may be used to hold the object more securely. The test object must be rigidly fixed in the box without distorting the box or object in any way since distortion will affect the mass distribution and the mass properties.
5. Screw the aluminum stem onto the desired test platter (6 X 6 inch or 12 X 12 inch platter). Insert the stem into the mass properties instrument and tighten the chock about the stem by holding the platter firmly and

rotating the chock clockwise until the stem cannot rotate with respect to the chock.

6. Turn on the 286 computer.
7. At the C:\ prompt type **Menu**. This will display the menu shown in Figure 11.
8. Select option 1 by pressing the arrow keys until the **MPI Programs Menu** option is highlighted and then press the return key. This will display the menu shown in Figure 12.
9. Select option 3 by pressing the arrow keys until the **Composite Placement** option is highlighted and then press the return key.
10. Turn on the electronic balance and zero it by pressing the ZERO button on its front panel. Measure the box mass, in pounds, and enter it at the computer prompt.
11. Position the moment table with its chock side in the groove on the adjustable stand and the other side on the electronic balance. If necessary, level the table by adjusting the stand screws.
12. Zero the balance again with the moment table in place.
13. Enter balance readings for the CG_x , CG_y , and CG_z positions of the box on the moment table at the computer prompt. Proper box placement configurations are shown in Figure 10. The balance reading should return to 0.00 between test positions with the moment table in place. If not, zero the balance again and retest.
14. The box placement program prints the x and y offsets from the center of the test platter for each moment measurement. This printout should be saved. These offsets are the coordinates at which the box origin is placed so that the pendulum axis passes through the object's CG.
15. The main menu, Figure 11, will be displayed. Select option 1 again to display the MPI Programs Menu, Figure 12.
16. Select option 5 by pressing the arrow keys until the **S.E. Meas. - Small** option is highlighted and then press return.

17. When asked **Do you wish to calibrate?** enter **Y** or **N**. Typically, calibration is not required. However, calibration should be performed monthly. Calibration procedures are discussed in the section entitled Equipment Calibration.
18. An MOI tare measurement must be performed so that the program can subtract the properties of the test platter, to yield only the inertial properties of the test object.
19. Manually rotate the test platter clockwise a very small amount until it can no longer rotate and hold the platter in place.
20. While holding the platter with one hand, press and hold the silver and black hold button at the top of the instrument with the other hand to lock the platter in place.
21. While continuing to depress the hold button, remove the hand from the platter and press the green **Reset** button located on the front panel of the counter. Release the hold button and allow the platter to freely oscillate.
22. At the prompt **Test 1:**, input the number displayed in the counter window. Repeat steps 19 through 22 twice more and input the counter readings at the **Test 2:** and **Test 3:** prompts.
23. When asked **Do you wish to make a measurement (y or n)?**, enter **Y**.
24. Place the box on the MPI platter at the x and y offsets found by the box placement program. For the I_x measurement, the x-axis of the box should be perpendicular to the platter with the y and z axes parallel to the platter axes.
25. Using the double sided tape on the outer walls of the box make sure that the box is mounted securely onto the platter and cannot move with respect to the platter. If the box is attached poorly, errors can be introduced into the measurement and the measurement will have to be repeated.
26. With the box mounted securely onto the platter perform steps 19 through 21 for the I_x , I_y and I_z measurements making appropriate box placement and axis configuration changes.

27. For the noncardinal moments, I_{xy} , I_{yz} , and I_{xz} , the jig corresponding to the box must be used. Appendix H contains a list of which boxes correspond to which jigs.
28. Place the box securely in the jig. The box should be positioned so that the box origin is in the corner of the "V" of the jig and the corresponding axes of the moment being measured are parallel to the sides of the "V" as shown in Figure 8.
29. At the lowest point of the "V" of the jig, there is a mark used for proper placement. Place this mark at the offsets corresponding to the moment being measured.
30. Perform steps 19 through 21 for each of the noncardinal measurements with the box properly placed within the jig.
31. When asked Do you wish to make a measurement (y or n)?, enter N.
32. The main menu, Figure 11, will be displayed. Select option 1 again to display the MPI Programs Menu, Figure 12.
33. Select option 4 by pressing the arrow keys until the Segment Calculation option is highlighted and then press return. Enter the appropriate data at the computer prompts. Save the printout from this program.

DATA TRANSFER FROM THE HP 85B TO THE 286 COMPUTER

Setup and Procedures

These procedures are necessary only if the model KGR 8945 was used to collect the inertial property data. If the model XR-50 was used then the inertial data file already resides on the 286 computer hard disk.

Make sure that the HP 85B and the 286 computer (AT class microcomputer with 80286,16 bit CPU chip) are set up properly. The 82939A Serial Interface which allows the HP 85B to transfer data to the 286 computer should be connected from the HP 85B to the COM port on the 286 computer.

HP 85B setup

1. Make sure that the HP 85B is displaying the STAMP menu. If it is not, insert the STAMP tape into the HP 85B and turn the computer off then on.
2. At the STAMP menu, select 7 to load and run the program called `termem`.
3. When the screen displays `DATA-COMM READY FOR USE` and the control menu for the function keys is displayed, select function key K-4 to go on to the next menu.
4. Select function key K-2 to read or create a file.
5. At the prompt `CREATE A FILE: Y\N?`, enter N.
6. At the prompt `FILENAME?`, enter `INERT`. The screen will display `FILE OPEN`.

286 Computer setup

1. Turn on the 286 computer.
2. At the `C:\` prompt type `Dir inert.dat`. This will ascertain whether the `inert.dat` file already exists. If it does exist, type `Del inert.dat`. At the `C:\` prompt type `Menu`. This will display the menu shown in Figure 10.
3. Select option 5 by pressing the arrow keys until the `HP 85B` option is highlighted and then press return.

4. Type `inert.dat` when the prompt `ENTER FILE NAME TO STORE DATA IN:` is displayed. If a file called `inert.dat` already exists an error message will appear. Step 2 of these procedures will eliminate this error.
5. The display will read `READY TO RECEIVE HP 85B DATA.`

Transfer of data

1. Select function key `K-6` on the HP 85B to upload the data to the 286 computer.
2. At the HP 85B prompt `DOES YOUR HOST PROMPT: Y\N?`, enter `N`.
3. Enter `0` at the HP 85B prompt `ENTER DELAY (MILLISECONDS) BETWEEN SENDING LINES.`
4. It will be apparent that the transfer is in process. The HP 85B will display: `UPLOAD IN PROGRESS`, and the 286 computer will display: `RECEIVING.....`
5. When the transfer has been completed the HP 85B will display: `FILE TRANSFER COMPLETE` and the 286 computer will display: `RECEIVE COMPLETE! GOING TO SEND ANOTHER? (Y/N):` At this prompt, enter `N` and the main menu shown in Figure 10 will be displayed.

NOTE: If there is any doubt of a successful transfer, the inertial data can be recalled on the 286 computer by exiting the menu program by pressing the `Esc` key and at the `C:\` prompt typing `lb inert.dat`. The data should be aligned vertically along the left side of the screen and can be checked against the data on the inertial properties printouts. To exit the editor, press `Ctrl-Z`. At the `C:\` prompt type `MENU` to display the menu shown in Figure 10. If the data in the `inert.dat` file is incorrect, repeat the transfer process.

DIGITIZING PROCEDURES

To this point, all measurements have been located with respect to the support fixture coordinate axes. To reference the properties of the test object to a test object based coordinate system, the test object landmarks must be located with respect to the support fixture axis system using the Metrecom, an electronic position coordinate digitizer.

Metrecom set up procedure

1. The RS-232 cable should link the 286 computer to the Metrecom. Ensure that this is connected properly. The cable connector marked 3 should be inserted into the connector numbered 3 on the back of the 286 computer. The other end of this cable, numbered 4, should be connected to the connector marked 4 on the Metrecom stand.
2. The cable that extends from the electro-goniometer arm should be inserted into the connector numbered 7 on the Metrecom stand.
3. The cable connector marked 11 should be connected to the connector designated 11 on the printer. The other end of this cable, numbered 1, should be connected to the connector numbered 1 on the back of the 286 computer.

Digitizing the landmarks

1. Turn on the 286 computer.
2. At the C:\ prompt type **Menu**. This will display the menu shown in Figure 11.
3. Select option 2 by pressing the arrow keys until the **Metrecom** option is highlighted and then press the return key.
4. Press **Enter** at the prompts **Enter New Time:** and **Enter New Date (mm-dd-yy):**.
5. Insert a disk into drive A and press any key to continue.
6. The master menu shown in Figure 13 will be displayed.

Select option 6 for the advanced applications menu shown in Figure 14. Select option 1 for the 3-D digitizer.

- 1- SKELETAL ANALYSIS
- 2- QUAD BALANCE SCAN
- 3- X-RAY ANALYZER
- 4- AXIS MUSCLE TESTER
- 5- RANGE OF MOTION
- 6- ADVANCED APPLICATIONS
- 7- SYSTEM SELF DIAGNOSTICS
- 8- DISK OPERATION AND SOFTWARE UPDATE
- 9- GROUP SPECIFIC PROTOCOLS

Figure 13 Metrecom Master Menu

- 1- 3-D DIGITIZER
- 2- LEG LENGTH ANALYSIS
- 3- RETURN TO MASTER MENU

Figure 14 Metrecom
Advanced Applications Menu

7. The 3-D digitizer screen will be displayed. Press **Enter** for the **COMMAND>** prompt. Appendix G contains a listing of all Metrecom commands.
8. Press **R** to set up the object orientation. At the prompt, digitize the origin of the box by placing the probe at the origin of the box and pressing the red button on the handle of the probe. At the next prompt, digitize any point along the x-axis of the box in the same manner and then digitize a point along the y-axis at the last prompt. These points are used to set up an orientation for the Metrecom only, they will not be displayed as part of the data collected.

9. The orientation of the test object within the box is established by first digitizing the support fixture origin and points along the Z, Y, and X axes, respectively. The farther these points are from the origin, the more accurate the calculation of the axis system. All test object landmarks that can be digitized without removing the test object from the support fixture or moving the composite in any way are digitized next. At least three test object landmarks must be digitized while the object is in the support fixture. The digitization entry log shown in Appendix D may be used to record the order of digitization of the landmarks.
10. This set of data should be saved to disk at this time. This is accomplished by pressing **Enter** for the **COMMAND>** prompt and P to print data to disk. A directory of files on drive A will be displayed on the screen. At the prompt, **Enter Object Name:**, enter the filename with no extension. Two files will be saved to the disk. A file with an extension of .txt will contain all digitized points in an ASCII format as shown in Table 1. The other file contains graphics information and will not be used.

Table 1 : DIGITIZER OUTPUT FILE

4			
1	-2	9	9
2	18	-2	4014
3	40	5026	23
4	4005	-16	-2

11. Remove the test object from the support fixture and place it on the table in a configuration convenient for reaching as many of the points that have not been digitized as possible while being able to digitize the first three test object landmarks digitized in the first set of data collected. Secure the object in this configuration so that it will not move or be deformed in any way during testing.
12. Repeat step 8 to set up the object orientation using a 90 degree angle for the origin and points along the x and y axes. The x and y axes should be aligned such that the z axis will result in a positive value.
13. First digitize the first three test object landmarks digitized in the first set of data collected. Digitize all other landmarks that can be reached in this

13. First digitize the first three test object landmarks digitized in the first set of data collected. Digitize all other landmarks that can be reached in this configuration. Save this set of data using the procedure described in step 10.
14. Additional data sets can be acquired using the above procedures until all test object landmarks have been digitized, being careful not to move the test object for a given set of points and making certain that the first three points of every set corresponds to three points in a previous set.
15. When digitizing has been completed press **Enter** for the **COMMAND>** prompt. Press **E** for exit. Answer **Y** at the prompt **Have you saved digitized object? (y/n):.**
16. The master menu shown in Figure 13 will be displayed. Exiting the Metrecom program can be accomplished in two ways. If the Metrecom will be used again the same day without turning the computer off, then exiting the program should be performed by rebooting the computer. This is done by removing the disk from drive A and pressing **Ctrl-Alt-Del**. If the Metrecom software will not be used before turning the computer off then pressing **Ctrl-C** will exit the program and the main menu shown in Figure 11 will be displayed.

TRANSFORMATION OF DATA

Input3d

The text file created by the Metrecom contains the coordinate values of landmarks in tenths of millimeters. The program input3d converts the units to centimeters, merges the sets of data by transforming the data to the box axis system and allows the landmarks to be labeled. Three data files will be produced. One file will contain the transformed data, one will contain untransformed data, and the third will contain both transformed and untransformed data.

1. Copy the .txt file from the floppy disk in drive A to the computer hard disk. Type **menu** at the C:\ prompt to display the main menu shown in Figure 11. Select option 2 by pressing the arrow keys until the **Input3d** option is highlighted and then press return.
2. Enter a filename with a .dat extension at the prompt **Type the name of the file to be read by TNO (will contain transformed data only):**
3. Enter a filename with a .dat extension at the prompt **Type the name of the file to be read by Dumaxis (will contain untransformed data only):**
4. Enter a filename with a .dat extension at the prompt **Print the name of the file that will contain transformed and untransformed data:**

NOTE: The filenames entered in steps 2 through 4 must differ from one another in some way.

5. List all pertinent information about the segment being tested at the prompt **Enter File Header:.** This will be displayed at the top of the created data files.
6. Enter the number of sets of digitized points collected at the prompt **How many sets of points will be entered?.**
7. Enter the name of the .txt file that contains the first set of points collected at the prompt **The name of set 1 is:.**
8. The first four points of data in set 1 are box data. Enter a landmark description for the fifth through last data point at the appropriate prompt.

9. If more than one set of data were collected the computer will prompt for the name of the second set of data. Type the name of the .txt file that contains the second set of points collected and type the landmark descriptions for each landmark in the second set of data. Repeat the procedure for each additional set of data collected.
10. The program will next prompt **Is inertial data available (Y/N)?**. Answer appropriately. Either response will cause the prompt **Choose the number corresponding to the type of segment**. The list is shown in Table 2.
11. Type the name of the segment at the prompt **Type segment name**.
12. If inertial data is available the prompt **Is the source of the data the file inert.dat which was uploaded from the HP 85B? (Y/N)** will be displayed. Answer appropriately. If the answer is **Y** then the program will automatically use the data in the **inert.dat** file. If the response is **N** then proceed with the following steps:

Type the center of gravity coordinates in centimeters at the prompt **Enter the center of gravity coordinates**. Enter the data as real numbers, including the decimal, in the order CG_x , CG_y and CG_z and press the enter key after each entry.

Type the direction cosines at the prompt **Enter the direction cosines**. Type the data as real numbers, including the decimal, and press the enter key after each entry. These should be entered in order by row.

Type the principal moments in Kg-Cm at the prompt **Enter principal moments**. Enter the data as real numbers, including the decimal, in the order I_x , I_y and I_z and press the enter key after each entry.

Type the mass in Kg at the prompt **Enter the segment mass**. Enter the mass as a real number value, including the decimal point.

Table 2: NUMBERS CORRESPONDING TO MANIKIN SEGMENTS

<u>Manikin Segment</u>	<u>Segment Number</u>
Head	1
Neck	2
Thorax	3
Pelvis	4
Right Upper Arm	5
Left Upper Arm	6
Right Forearm	7
Left Forearm	8
Right Upper Leg	9
Left Upper Leg	10
Right Lower Leg	11
Left Lower Leg	12
Right Hand	13
Left Hand	13
Right Foot	14
Left Foot	15
Lumbar Spine	16
Right Clavicle	17
Left Clavicle	18
Helmet	19
Spine Box	20

13. The reference landmarks in the box axis system of set number one and the message **Note the 3 reference set numbers and landmark numbers which will coincide with the next set** will be displayed. Press the enter key to continue.
14. The second set of untransformed landmarks will appear. Press the enter key to continue.
15. Type the pairs of numbers that will assign the first 3 landmarks of set number one to three landmarks in set number 2. Separate the numbers with a comma and press the enter key after each pair. For example:

1,5
1,6
1,7

The first digit represents the set number and the second digit represents the number of the landmark within that set. These landmarks must be the same as and in the exact order of the first three landmarks in

the next set.

16. The next set of untransformed landmarks will be displayed. Repeat step 15 at the prompt for each additional set of data. After the final pair of numbers have been entered, press enter to return to the main menu displayed in Figure 11.
17. The data are now contained in the three files named at the beginning of the input3d program.

Dumaxis

The program Dumaxis is a Fortran program that is used to transform a second set of points into the coordinate system of a first set of points by using three points that are common between the two data sets. This program is used when additional sets of points are needed to be brought into an existing data file.

Editing the input file

1. There should be two files containing the necessary data. One file can be either the original transformed or untransformed file of data produced by Input3d. The second file of data is the untransformed data file created by running input3d after digitizing three points that were digitized in the original data set and any additional points.
2. The two data files must be merged into one file to be read by Dumaxis. This is done by typing **lb "original data filename"**. The original set of either transformed or untransformed data will be displayed in the Lahey editor. If transformed data were chosen to be used then the inertial properties information should be deleted from this file. All of the landmarks or only the box points and three points in common with the second data set may be chosen to remain in this file. If only three landmarks are to remain in the file then the original file should be saved under a different file name. The second set of untransformed data is brought into this file by going to the end of the file and pressing **Alt-I** and typing the filename of the second data set at the filename prompt. An example of a correctly edited file is shown in Appendix F.
3. The data file format should be as follows:

- * The first line of the file, in (I3) format, indicates the total number of sets of points in this file.
 - * The second line of the file, in (I3) format, indicates the total number of points, n, in the first set of data.
 - * The third line is blank.
 - * The fourth through n+3 lines contain the label and x, y, and z coordinates of the points in centimeters in the first set of data. The format for these lines is (A41,3F8.2). The first four points of data should be the box origin, a point on the box z axis, a point on the box y axis, and a point on the box x axis, respectively.
 - * The n+4 line of the file, in (I3) format, indicates the total number of points in the second set of data.
 - * The remaining lines contain the label and x, y, and z coordinates of the points in centimeters in the second set of data. The format for these lines is (A41, 3F8.2). The first three points must be three points that are also in the first set of data.
4. Press Ctrl-Z to exit the Lahey editor and to save the new file of data.

Running the program

1. At the C:\ prompt type **Dumaxis** to run the program.
2. Enter an appropriate filename with a .dat extension at each of the three prompts.
3. The program will next prompt **Is inertial data available (Y/N)?**. Answer appropriately. Either response will cause the prompt **Choose the number corresponding to the type of segment**. The list is shown in Table 2.
4. Type the name of the segment at the prompt **Type segment name**.
5. If inertial data is available the prompt **Is the source of the data the file inert.dat which was uploaded from the HP 85B? (Y/N)** will be displayed. Answer

appropriately. If the answer is **Y** then the program will automatically use the data in the **Inert.dat** file. If the response is **N** then proceed with the following steps:

Type the center of gravity coordinates in centimeters at the prompt **Enter the center of gravity coordinates**. Enter the data as real numbers, including the decimal, in the order CG_x , CG_y and CG_z and press the enter key after each entry.

Type the direction cosines at the prompt **Enter the direction cosines**. Type the data as real numbers, including the decimal, and press the enter key after each entry. These should be entered in order by row.

Type the principal moments in Kg-Cm at the prompt **Enter principal moments**. Enter the data as real numbers, including the decimal, in the order I_x , I_y and I_z and press the enter key after each entry.

Type the mass in Kg at the prompt **Enter the segment mass**. Enter the mass as a real number value, including the decimal point.

6. The reference landmarks in the box axis system of set number one and the message **Note the 3 reference set numbers and landmark numbers which will coincide with the next set** will be displayed. Press the enter key to continue.
7. The second set of untransformed landmarks will appear. Press the enter key to continue.
8. Type the numbers of the 3 landmarks in set number one that correspond to the first three landmarks in the second set.
9. The data are now contained in the three files named at the beginning of the Dumaxis program. The computer C:\ prompt should be displayed.

Editing the output file

If only three points were chosen to remain in the first set of data then the file of transformed data just created will need to

be brought into the original set of transformed data by the following steps.

1. Type lb "original transformed data filename" to display the file in the Lahey editor.
2. Go to the end of the file and press **Alt-I**. Type the name of the file containing the transformed data that was just created by Dumaxis at the filename prompt. This file will be displayed at the end of the first file.
3. Data that are in the file that was just created but not in the original file need to be moved to the original file. The editor commands are used to move these data. Pressing the esc key while using the Lahey editor will display the functions menu.
4. When editing has been completed, exit the editor and save the changes by pressing **Ctrl-Z**. The computer C:\ prompt will be displayed.

AXES

The data file created by Input3d or Dumaxis which contains transformed data also includes a description of the test object, the test object's cg coordinates in the box axis system, the principal moments of inertia, the direction cosines, and the mass of the test object. This file, after editing, will be the input file for the Fortran program AXES. This program is used to transform the data from the box axis system to anatomical and mechanical axes.

Editing the input file

1. If the main menu shown in Figure 11 is displayed on the computer screen. Press the **Esc** key and exit to DOS for the C:\ prompt. Type lb "filename" to display the file in the Lahey Fortran editor. An example of a correctly edited file is shown in Appendix F.
2. The data file format should be as follows:
 - * The first line of the file should contain the header information typed at the prompt described in step 5 of the section entitled Input3d.
 - * The second line of the file, in (I3) format,

indicates the total number of points in this file, n.

- * The third line should contain the center of gravity coordinates of the test object in (1x,3F7.2) format in the box axis system.
 - * Lines 4 through n+3 contain the label and x, y, and z coordinates of the points in centimeters referenced in the box axis system. The format for these lines is (A41,3F8.2). The order of the points is very important as the first three to five points determine the anatomical axis system and the next four to 15 points generate the mechanical axis system. The correct order of landmarks for each segment is found in Appendix A.
 - * The n+3 line should contain the center of gravity coordinates of the test object in the box axis system in (A41,3F8.2) format.
 - * The n+4 line should contain the number corresponding to the desired manikin segment in (I3) format. A listing of the segments and corresponding numbers is found in Table 2 in the section entitled Input3d.
 - * The n+5 line contains the direction cosines of the principal axes with respect to the box axes. These data should be in (1X,9F8.4) format.
 - * The n+6 line contains the magnitudes of the principal moments of inertia in kg-cm². These data should be in (1X,3F10.4) format.
 - * The last line contains the mass in kg of the test object in (1X,F8.2) format.
3. The editor commands should be used to move appropriate lines of data to the correct order and to delete extraneous data. Pressing the esc key while using the Lahey editor will display the functions menu.
 4. When editing has been completed, exit the editor and save the changes by pressing Ctrl-Z. The computer C:\ prompt will be displayed.

Running the Program

1. Run the program by typing **AXES**.

2. Type the name of the input file when prompted.
3. Type the desired name for the output file when prompted. This file should be descriptive of the segment being tested.

Analysis of AXES output data

The output file from AXES, as seen in Appendix F, contains the resulting mass properties data from testing an object. All data are in both English and metric units, and displayed in the box, anatomical and mechanical coordinate axis systems.

1. The output data file may be viewed by typing `lb "filename"` at the `C:\` prompt. The data file format should be as follows:
 - * The landmarks in the box axis system.
 - * The transformation matrix from the box axis system to the unassigned principal axes.
 - * The landmarks in the segment anatomical axis system.
 - * The transformation matrix from the anatomical axis system to the unassigned principal axes.
 - * The transformation matrix from the anatomical axis system to the assigned principal axes.
 - * The yaw, pitch, and roll angle from the anatomical axis system to the assigned principal axes.
 - * The mechanical joint centers in inches in the anatomical axis system.
 - * The landmarks in the segment mechanical axis system.
 - * The transformation matrix from the assigned principal axes to the mechanical axis system.
 - * The transformation matrix from the anatomical axis system to the mechanical axis system.
 - * The yaw, pitch, and roll angles from the anatomical axis system to the assigned principal axes.
 - * The mechanical joint centers in inches in the mechanical axis system.

- * The principal moments in $\text{kg}\cdot\text{cm}^2$.
 - * The principal moments in $\text{lbs}(\text{force})\cdot\text{sec}^2\cdot\text{in}$.
 - * The principal moments in $\text{lbs}(\text{mass})\cdot\text{in}^2$.
 - * The segment mass in kg.
 - * The segment weight in $\text{lbs}(\text{force})$.
2. Refer to the landmarks in the anatomical and mechanical axis systems. Make certain that the coordinate systems were generated properly. Appendix A contains tables describing the anatomical and mechanical axes for each segment and also illustrates approximately where the principal axes, anatomical axes, and mechanical axes should be. If either coordinate system looks incorrect then the wrong subroutine number was probably used in Input3d or the order of the anatomical or mechanical landmarks in the AXES input files was incorrect. If unsure about the data, measure distances from landmark to landmark on the segment and check these distances with the coordinates in the file.
 3. Ensure that the joint centers in the anatomical axis system seem reasonable. If necessary, measure apparent distances from the joint centers to the landmarks and check these distances to make certain these are oriented properly. The joint centers in the mechanical axis system should represent the origin or be found along an axis.
 4. If there are no errors then print the data by typing `print "filename"` at the `C:\` prompt and save the output file onto a 3 1/2 inch floppy disk by typing `copy "filename" a:.`

EQUIPMENT CALIBRATION PROCEDURES

Calibrating the Electronic Balance

The EP-40KA industrial balance is a high precision balance with a weighing capacity of 40 Kg. It consists of a balance, weighing pan and pan support, digital display, power cable, and .3 A (100/115V) anti-surge fuse. Calibration of the balance is required when it is initially installed and when changing installation sites. Additionally, calibration is recommended every 90 days.

1. With a stable display reading and nothing on the weighing pan, remove the plastic calibration plug on the right side of the display pod. Slide the calibration switch ON (downwards). Do not switch on the calibration switch when the display is off, or "Err C" will be displayed.
2. The display will show "CAL 0" which means that the zero weight point should be entered by pressing the Re-Zero key. After this the display will blank for a few seconds. The "CAL 0" display then returns while the zero weight point is automatically entered by the FDC function.
3. The display will change to "CAL F". Place a 40Kg weight on the balance and press Re-Zero. The display will blank for a few seconds. The "CAL F" display then returns while the maximum capacity weight point is entered.
4. The display will show "CAL End" to show that the calibration has ended. Switch the calibration switch off and replace the plastic plug, the display will blank and then revert to normal weighing mode.

Calibrating the Mass Properties Instruments

Model KGR 8945

The calibration procedure for the Model KGR 8945 mass properties instrument uses two steel weights placed in two specific locations on the instrument. The moments of inertia of the weight configurations are analytically determined and compared to the moments of inertia, calculated from the measured time periods of the two steel weights. The instrument is adjusted to reflect the

analytically determined moments of inertia. This procedure should be performed monthly.

1. Insert the Space Electronics tape cartridge into the HP-85B. Turn on the HP-85B, mass properties instrument, air flow, air dryer and console.
2. At the computer prompt, **Which program do you want to run**, enter **M** for the measurement program.
3. Mount the black metal Universal Fixture plate onto the platter and fasten it with a "T" handle hex key. If looking at the front of the mass properties instrument the positive x direction should point directly at the front left eye bolt, while the positive y direction should point directly at the front right eye bolt. The hole marked A must align with the +X direction and the hole marked E must align with the +Y direction.
4. Mount the two cylindrical weights marked s7091 and s7092 into the appropriate holes. S7091 will mount into the hole marked A and s7092 will mount into the hole marked E. Make sure that the air has been turned on and press **CONT** when ready. The instrument will measure the moment of inertia of the table plus the weights.
5. The average measured time period will be recorded. Place both weights in hole C at the center of the instrument when prompted to do so and press **CONT** when ready. The instrument will measure the moment of inertia of the table plus the weights.
6. The calibration inertia and the moment of inertia calibration constant will be printed.
7. Remove the Universal Fixture so that nothing is on the pendulum except the bare circular test platter and perform a moment of inertia tare.
8. From the average measured time period printed at the end of the tare, compute the tare moment of inertia which is equal to the calibration constant times the square of the measured time period. Check the tare inertia against the manufacturer's standard by ensuring that this moment is within the manufacturer's tolerance of 302.97 -306.01 Lb-in². If it is not, repeat the calibration procedures. If it is still out of tolerance after repeating the procedure then the

manufacturer should be contacted.

Model XR-50

The calibration constant for the Model XR-50 mass properties instrument is determined by using a calibration weight of known moment of inertia. Time period readings are taken with and without the calibration weight, permitting calculation of the calibration constant. This procedure should be performed monthly.

1. Mount the calibration weight on the instrument. Make certain that the collet is properly tightened.
2. Turn on the 286 computer.
3. At the C:\ prompt type **Menu**. This will display the menu shown in Figure 11.
4. Select option 1 by pressing the arrow keys until the **MPI Programs Menu** option is highlighted and then press the return key. This will display the menu shown in Figure 12.
5. Select option 5 by pressing the arrow keys until the **S.E. Meas. - Small** option is highlighted and then press return.
6. When asked **Do you wish to calibrate?** enter **Y**.
7. Obtain 5 time period readings. These readings should not vary more than .1%. The computer program will compute the average of these readings.
8. Remove the calibration weight. Obtain 5 tare period readings. The computer program will compute the average of these readings.
9. The value of the calibration constant will be calculated by the computer using the time period readings with and without the calibration weight. The calibration constant will be stored in the computer. This constant should not vary more than .5% between calibrations. Using this value for the calibration constant gives measured values of moment of inertia expressed in lb-in² units.

Calibrating the Metrecom

The Metrecom system prompts the user to perform a system self-diagnosis each month. This procedure consists of digitizing prespecified points on the base of the metrecom unit. The computer then performs a self-diagnostic evaluation of the transducers for basic function and accuracy. This is not a means of calibrating the electrogoniometer but a means of ensuring that the calibration is within the acceptable range of accuracy throughout its entire reach.

Calibration Procedures

1. Turn on the 286 computer.
2. At the C:\ prompt type **Menu**. This will display the menu shown in Figure 11.
3. Select option 2 by pressing the arrow keys until the **Metrecom** option is highlighted and then press the return key. If this is the first time that the computer has been turned on since the first of the month a system self diagnosis prompt will be displayed. The Metrecom must be calibrated each month.
4. Press **Enter** at the prompts **Enter New Time:** and **Enter New Date (mm-dd-yy):**.
5. Insert a disk into drive A and press any key to continue.
6. The master menu shown in Figure 13 will be displayed. Select option 7 for the System Self Diagnosis menu shown in Figure 15. Select option 1 for the 3-D digitizer.

1- 3-D Digitizer Diagnosis
2- Hand/Foot Switch
3- X-ray Numeric Keypad Diagnosis
4- Quad Balance Scan Diagnosis
5- Axis Muscle Tester Diagnosis
6- Return To Master Menu

Figure 15 System Self Diagnosis Menu

7. The drill holes located on each of the four feet should be digitized as prompted by the computer screen. The corresponding indices will be displayed on the screen.
8. If, for any reason, the calibration is no longer within its proper range, the computer will display a "CALIBRATION ERROR, CONTACT FARO" prompt. If this should happen, call the Faro Customer Service department with the values obtained from this diagnosis.

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APPENDIX A

Axes & Landmark Definitions
and
Order of Landmarks for AXES Input File

HEAD

Anatomical Axes

Y-axis - vector from right trigion to left trigion.

X-axis - normal from Y-axis to right infraorbitale.

Z-axis - $X \times Y$.

Origin - intersection of Y-axis and a normal passing through sellion.

Mechanical Axes

Z-axis - vector from lower midpoint to upper bolt hole midpoint on mounting interface between back cap and head.

Y-axis - vector parallel to the head/neck joint axis (i.e., vector from the upper bolt hole midpoint to the right upper bolt hole on mounting interface between back cap and head, positive to the left).

X-axis - $Y \times Z$.

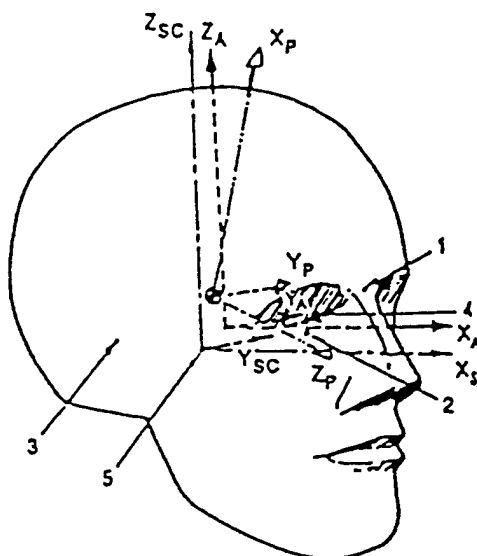
Origin - head/neck joint center.

Segment Landmarks

1. Sellion - on the bridge of the nose between the eyes.
2. Right Infraorbitale - center of the lower edge of the right eye.
3. Right Trigion - on the right side of the head, a point on a line extending vertically 1 inch above the posterior edge of the lower jaw.
4. Left Trigion - on the left side of the head, a point on a line extending vertically 1 inch above the posterior edge of the lower jaw.
5. Head/Neck Joint Center - determined by the midpoint, right and left ends of the head/neck joint.

Order of Landmarks for AXES Input File

1. Right Trigion
2. Left Trigion
3. Right Infraorbitale
4. Sellion
5. Midpoint of the Upper Two Skull Cap Bolt Holes
6. Midpoint of the Lower Two Skull Cap Bolt Holes
7. Upper Right Skull Cap Bolt Hole
8. Lower Right Skull Cap Bolt Hole
9. Right End of Head/Neck Axis
10. Left End of Head/Neck Axis
11. Midpoint of Head/Neck Axis



NECK

Anatomical Axes

Y-axis - normal vector to the left from the plane formed by cricoid cartilage (adam's apple), cervicale, and suprasternale.

X-axis - normal from Y-axis through the midpoint of a line between left and right clavicles.

Z-axis - $X \times Y$.

Origin - at cervicale.

Mechanical Axes

Z-axis - vector from the neck/thorax attachment center to the head/neck joint center.

X-axis - vector from the posterior neck point, perpendicular to the Z-axis.

Y-axis - $Z \times X$.

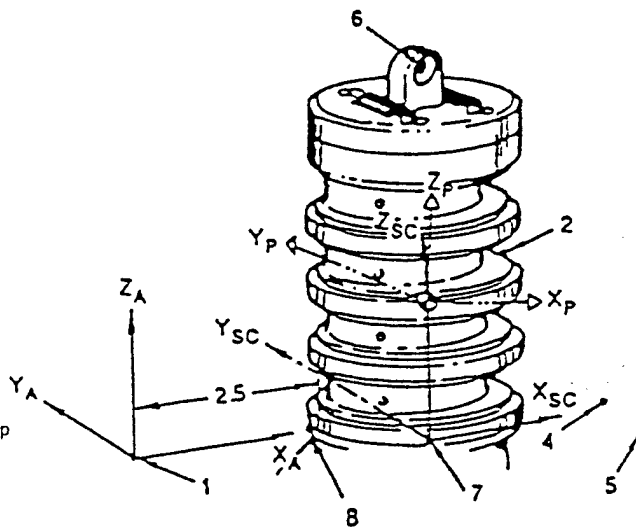
Origin - neck/thorax attachment center.

Segment Landmarks

1. Cervicale - a point on the thorax jacket posterior to the posterior midline of the lowest neck ring.
2. "Adam's Apple" - anterior midpoint on the third neck ring.
3. Suprasternale - a point on the thorax jacket in between the two clavicle torque bolt holes.
4. Left Clavicle - the anterior projection on the surface of the elevation/depression axis of the left clavicle.
5. Right Clavicle - the anterior projection on the surface of the elevation/depression axis of the right clavicle.
6. Head/Neck Joint Center - determined by the midpoint, right and left ends of the head/neck joint.
7. Neck/Thorax Attachment Center - center of bottom plate of neck.
8. Posterior Neck Point - the rear most point on the bottom plane of the neck.

Order of Landmarks for AXES Input File

1. Cervicale
2. Suprasternale
3. Adams Apple
4. Right Clavicle
5. Left Clavicle
6. Right End of Head/Neck Axis
7. Left End of Head/Neck Axis
8. Midpoint of Head/Neck Axis
9. Center of Bottom of Neck
10. Posterior Neck Point (Rearmost Point on Bottom of Neck)
11. Third Point on Bottom of Neck (i.e. Leftmost Point on Bottom of Neck)
- 12-14. Three Points on Top of Neck (i.e. Front Right and Left Bolt Holes on Top of Neck and Rear Right Bolt of Neck)



THORAX

Anatomical Axes

Z-axis - vector from the tenth rib midspine to cervicale.

X-axis - normal from Z-axis to suprasternale.

Y-axis - $Z \times X$.

Origin - at tenth rib midspine.

Mechanical Axes

Z-axis - vector from thorax/lumbar spine to neck/thorax attachment center.

X-axis - vector normal to the Z-axis to the midpoint between right and left front lumbar spine mounting bolt holes.

Y-axis - $Z \times X$.

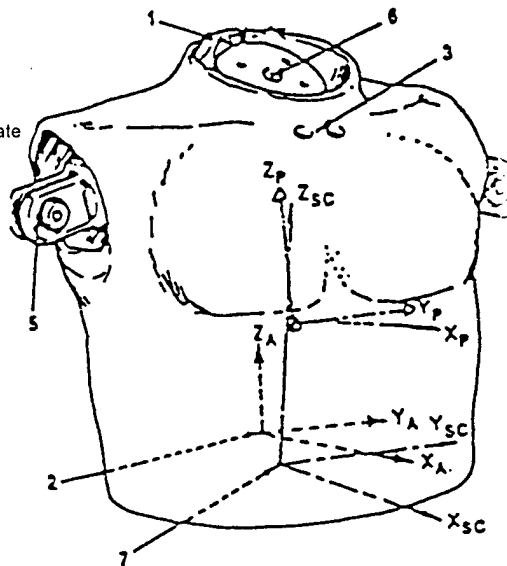
Origin - thorax/lumbar spine attachment center.

Segment Landmarks

1. Cervicale - a point on the thorax jacket posterior to the posterior midline of the lowest neck ring.
2. Tenth Rib Midspine - at the level of the lowest rib's inferior edge, a point on the posterior midline of the thorax jacket.
3. Suprasternale - a point in between the two clavicle torque bolt holes.
4. Left Shoulder Joint Center - the midpoint on the abduction/adduction axis of the left shoulder determined by the midpoint, anterior and posterior ends of the left shoulder joint.
5. Right Shoulder Joint Center - the midpoint of the abduction/adduction axis of the right shoulder determined by the midpoint, anterior and posterior ends of the right shoulder joint.
6. Neck/Thorax Attachment Center - center of bottom plate of neck.
7. Thorax/Lumbar Spine Attachment Center - the center of the mounting plate between the thorax and lumbar spine.

Order of Landmarks for AXES Input File

1. Cervicale
2. 10th Rib Midspine
3. Suprasternale
4. Center of Four Bolt Holes on Lumbar Interface Plate
5. Center of Neck Mounting Bracket
6. Midpoint of Front Two Bolt Holes on Lumbar Interface Plate
7. Front Right Bolt Hole on Lumbar Interface Plate
8. Front Left Bolt Hole on Lumbar Interface Plate
9. Rear Right Bolt Hole on Lumbar Interface Plate
10. Right Front of Shoulder Joint Center
11. Right Rear of Shoulder Joint Center
12. Right Midpoint of Shoulder Joint Center
13. Left Front of Shoulder Joint Center
14. Left Rear of Shoulder Joint Center
15. Left Midpoint of Shoulder Joint Center
16. Right Front of Elevation/Depression Axis
17. Right Rear of Elevation/Depression Axis
18. Right Midpoint of Elevation/Depression Axis
19. Left Front of Elevation/Depression Axis
20. Left Rear of Elevation/Depression Axis
21. Left Midpoint of Elevation/Depression Axis
- 22-23. Two Points on Neck Mounting Bracket
(i.e. Frontmost and Rightmost Points on Neck Mounting Bracket)



THORAX WITHOUT RIGHT AND LEFT CLAVICLES

Anatomical Axes

Z-axis - vector from the tenth rib midspine to cervicale.

X-axis - normal from Z-axis to suprasternale.

Y-axis - $Z \times X$.

Origin - at tenth rib midspine.

Mechanical Axes

Z-axis - vector from thorax/lumar spine to neck/thorax attachment center.

X-axis - vector normal to the Z-axis to the midpoint between right and left front lumbar spine mounting bolt holes.

Y-axis - $Z \times X$.

Origin - thorax/lumbar spine attachment center.

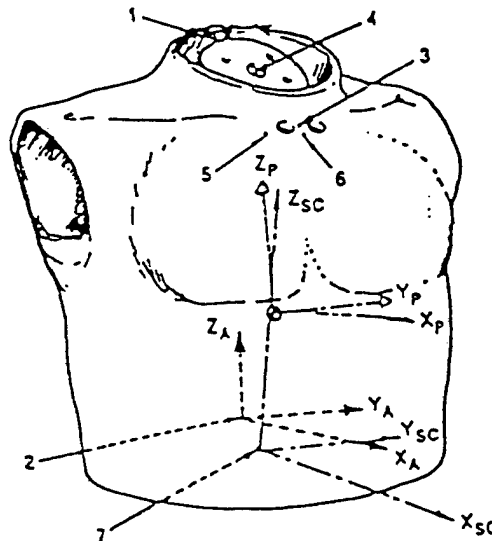
Segment Landmarks

1. Cervicale - a point on the thorax jacket posterior to the posterior midline of the lowest neck ring.
2. Tenth Rib Midspine - at the level of the lowest rib's inferior edge, a point on the posterior midline of the thorax jacket.
3. Suprasternale - a point in between the two clavicle torque bolt holes.
4. Neck/Thorax Attachment Center - center of bottom plate of neck.
5. Thorax/Right Clavicle Joint Center - the center of rotation of the right clavicle elevation/depression axis determined by the anterior, posterior and midpoint of the right clavicle elevation/depression axis.
6. Thorax/Left Clavicle Joint Center - the center of rotation of the left clavicle elevation/depression axis determined by the anterior, posterior and midpoint of the left clavicle elevation/depression axis.
7. Thorax/Lumbar Spine Attachment Center - the center of the mounting plate between the thorax and lumbar spine.

Order of Landmarks for AXES Input File

Order is the same as that with clavicles

* Should be measured after the configuration with the clavicles so that points between this set and the "with clavicles" set can be related. Simply digitize three common points and use all the landmarks of the "with clavicles" set.



RIGHT CLAVICLE

Anatomical Axes (same as used with the torso)

Z-axis - vector from the tenth rib midspine to the cervicale.
 X-axis - normal from Z-axis to suprasternale.
 Y-axis - $Z \times X$.
 Origin - at tenth rib midspine.

Mechanical Axis

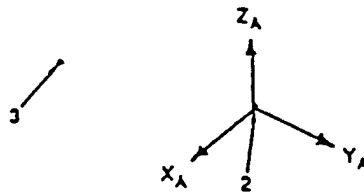
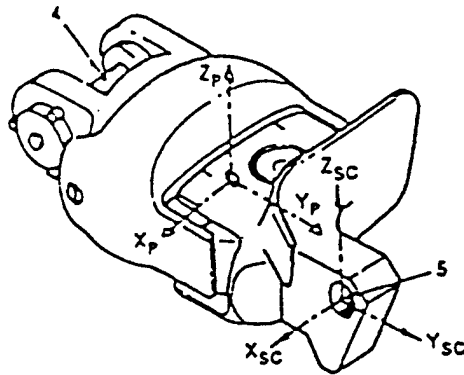
X-axis - vector along elevation/depression axis of rotation, positive to the front determined by the front and rear ends of the right clavicle elevation/depression axis.
 Z-axis - parallel to vector along pronation/retraction axis of rotation determined by the top and bottom ends of the right clavicle pronation/retraction axis.
 X-axis - $Z \times X$.
 Origin - thorax/clavicle joint center.

Segment Landmarks

1. Cervicale - a point on the thorax jacket posterior to the posterior midline of the lowest neck ring.
2. Tenth Rib Midspine - at the level of the lowest rib's inferior edge, a point on the posterior midline of the thorax jacket.
3. Suprasternale - a point in between the two clavicle torque bolt holes.
4. Right Shoulder Joint Center - the midpoint of the abduction/adduction axis of the right shoulder determined by the front, rear, and midpoint of the right shoulder axis.
5. Thorax/Clavicle Joint Center - the center of rotation of the elevation/depression axis determined by the front, rear, and midpoint of the right clavicle elevation/depression axis.
6. Right Clavicle Pronation/Retraction Joint Center - the center of rotation of the pronation/retraction axis determined by the top, bottom and midpoint of the right clavicle pronation/retraction axis.

Order of Landmarks for AXES Input File

1. Cervicale
2. 10th Rib Midspine
3. Suprasternale
4. Front of Elevation/Depression Axis
5. Rear of Elevation/Depression Axis
6. Midpoint of Elevation/Depression Axis
7. Bottom of Pronation/Retraction Axis
8. Top of Pronation/Retraction Axis
9. Midpoint of Pronation/Retraction Axis
10. Front of Shoulder Joint Center
11. Rear of Shoulder Joint Center
12. Midpoint of Shoulder Joint Center



LEFT CLAVICLE

Anatomical Axes (same as used with the torso)

Z-axis - vector from the tenth rib midspine to the cervicale.
 X-axis - normal from Z-axis to suprasternale.
 Y-axis - $Z \times X$.
 Origin - at tenth rib midspine.

Mechanical Axis

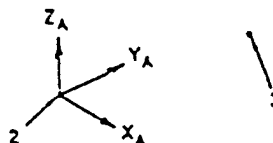
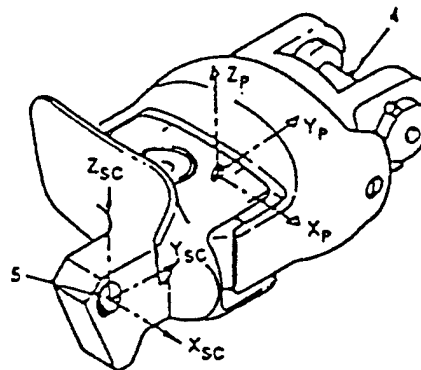
X-axis - vector along elevation/depression axis of rotation,
 positive to the front determined by the front and rear
 ends of the right clavicle elevation/depression axis.
 Z-axis - parallel to vector along pronation/retraction axis of
 rotation determined by the top and bottom ends of the
 right clavicle pronation/retraction axis.
 X-axis - $Z \times X$.
 Origin - thorax/clavicle joint center.

Segment Landmarks

1. Cervicale - a point on the thorax jacket posterior to the posterior midline of the lowest neck ring.
2. Tenth Rib Midspine - at the level of the lowest rib's inferior edge, a point on the posterior midline of the thorax jacket.
3. Suprasternale - a point in between the two clavicle torque bolt holes.
4. Left Shoulder Joint Center - the midpoint of the abduction/adduction axis of the left shoulder determined by the front, rear, and midpoint of the left shoulder axis.
5. Thorax/Clavicle Joint Center - the center of rotation of the elevation/depression axis determined by the front, rear, and midpoint of the left clavicle elevation/depression axis.
6. Left Clavicle Pronation/Retraction Joint Center - the center of rotation of the pronation/retraction axis determined by the top, bottom and midpoint if the left clavicle pronation/retraction axis.

Order of Landmarks for AXES Input File

1. Cervicale
2. 10th Rib Midspine
3. Suprasternale
4. Front of Elevation/Depression Axis
5. Rear of Elevation/Depression Axis
6. Midpoint of Elevation/Depression Axis
7. Bottom of Pronation/Retraction Axis
8. Top of Pronation/Retraction Axis
9. Midpoint of Pronation/Retraction Axis
10. Front of Shoulder Joint Center
11. Rear of Shoulder Joint Center
12. Midpoint of Shoulder Joint Center



RIGHT UPPER ARM

Anatomical Axes

Z-axis - vector from lateral humeral epicondyle to acromiale.
Y-axis - vector normal from Z-axis to medial humeral epicondyle.
X-axis - $Y \times Z$.
Origin - at acromiale.

Mechanical Axes

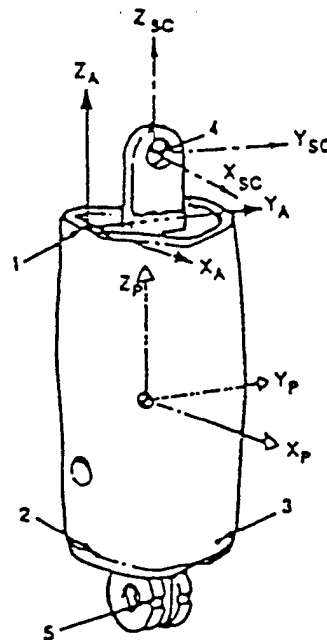
Z-axis - vector from elbow joint center to shoulder joint center.
Y-axis - vector normal to the Z-axis from the lateral end of the shoulder abduction/adduction axis.
X-axis - $Y \times Z$.
Origin - shoulder joint center.

Segment Landmarks

1. Acromiale on Arm Sleeve - lateral superior edge of arm covering.
2. Lateral Humeral Epicondyle on Arm Sleeve - lateral inferior edge of the arm covering.
3. Medial Humeral Epicondyle on Arm Sleeve - medial inferior edge of the arm covering.
4. Shoulder Joint Center - the midpoint on the abduction/adduction axis of the right shoulder determined by the midpoint, lateral and medial ends of the abduction/adduction axis.
5. Elbow Joint Center - determined by the midpoint, lateral and medial ends of the elbow axis.

Order of Landmarks for AXES Input File

1. Lateral Epicondyle
2. Acromiale
3. Medial Epicondyle
4. Lateral End of Shoulder Abduction/Adduction Axis
5. Medial End of Shoulder Abduction/Adduction Axis
6. Midpoint of Shoulder Abduction/Adduction Axis
7. Lateral End of Elbow Axis
8. Medial End Elbow Axis
9. Midpoint of Elbow Axis
10. Lateral End of Shoulder Abduction/Adduction Axis (AGAIN)



RIGHT FOREARM

Anatomical Axes

Z-axis - vector from ulnar styloid to the radiale.
Y-axis - vector normal from radial styloid to Z-axis.
X-axis - $Y \times Z$.
Origin - at radiale.

Mechanical Axes

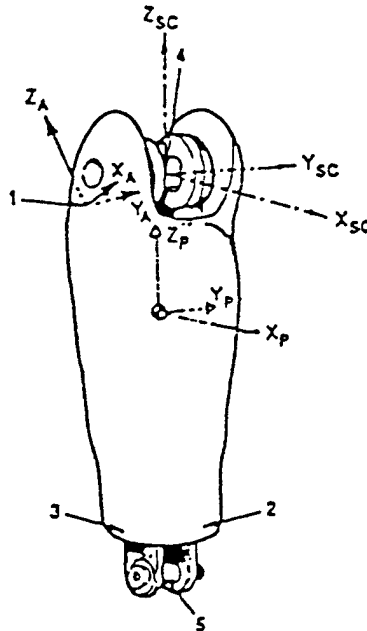
Z-axis - vector from wrist joint center to elbow joint center.
Y-axis - vector normal to the Z-axis from the lateral (right) end of the elbow flexion/extension axis.
X-axis - $Y \times Z$.
Origin - elbow joint center.

Segment Landmarks

1. Radiale - at the level of the distal edge of the elbow hardware, approximately two-thirds of the distance from the anterior to the posterior midlines.
2. Ulnar Styloid Process on arm sleeve - distal medial edge of the arm covering.
3. Radial Styloid Process on arm sleeve - distal lateral edge of the arm covering.
4. Elbow Joint Center - determined by the midpoint, lateral and medial end of the elbow axis.
5. Wrist Joint Center - determined by the midpoint, lateral and medial ends of the wrist axis.

Order of Landmarks for AXES Input File

1. Ulnar Styloid Process
2. Radiale
3. Radial Styloid Process
4. Lateral End of Elbow Axis
5. Medial End of Elbow Axis
6. Midpoint of Elbow Axis
7. Lateral End of Wrist Axis
8. Medial End of Wrist Axis
9. Midpoint of Wrist Axis



LEFT FOREARM

Anatomical Axes

Z-axis - vector from ulnar styloid to the radiale.

Y-axis - vector normal from Z-axis through radial styloid.

X-axis - $Y \times Z$.

Origin - at radiale.

Mechanical Axes

Z-axis - vector from wrist joint center to elbow joint center.

Y-axis - vector normal to the Z-axis from the lateral (right) end of the elbow flexion/extension axis.

X-axis - $Y \times Z$.

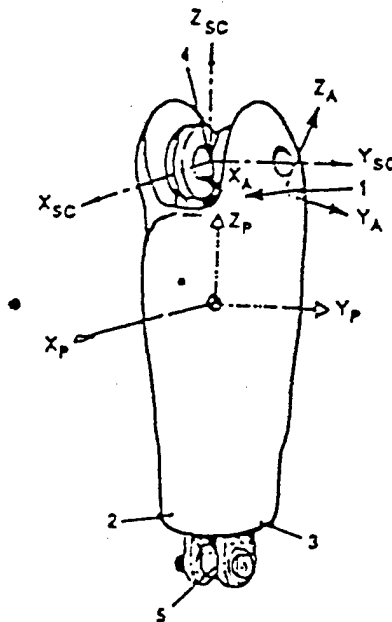
Origin - elbow joint center.

Segment Landmarks

1. Radiale - at the level of the distal edge of the elbow hardware, approximately two-thirds of the distance from the anterior to the posterior midlines.
2. Ulnar Styloid Process on arm sleeve - distal medial edge of the arm covering.
3. Radial Styloid Process on arm sleeve - distal lateral edge of the arm covering.
4. Elbow Joint Center - determined by the midpoint, lateral and medial end of the elbow axis.
5. Wrist Joint Center - determined by the midpoint, lateral and medial ends of the wrist axis.

Order of Landmarks for AXES Input File

1. Ulnar Styloid Process
2. Radiale
3. Radial Styloid Process
4. Medial End of Elbow Axis
5. Lateral End of Elbow Axis
6. Midpoint of Elbow Axis
7. Lateral End of Wrist Axis
8. Medial End of Wrist Axis
9. Midpoint of Wrist Axis



RIGHT HAND

Anatomical Axes

Y-axis - vector from metacarpale II to metacarpale V.

Z-axis - vector normal from dactylion to Y-axis.

X-axis - $Y \times Z$.

Origin - at intersection of Y-axis and the normal passing through metacarpale III.

Mechanical Axes

X-axis - vector from pinky side of wrist joint axis to thumb side of wrist joint axis.

Z-axis - vector normal to X-axis from dorsal edge of wrist joint flexion stop.

Y-axis - $Z \times X$.

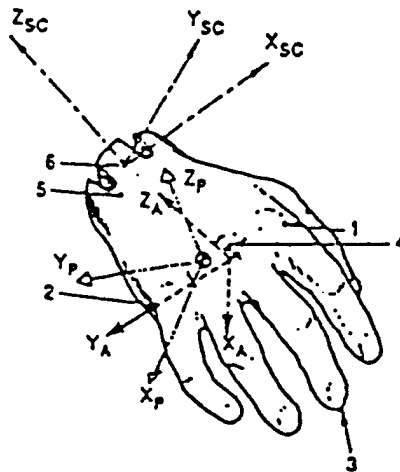
Origin - wrist joint center.

Segment Landmarks

1. Lateral Aspect of Metacarpal-Phalangeal Joint II (metacarpale II) - lateral side of the location.
2. Medial Aspect of Metacarpal-Phalangeal Joint V (metacarpale V) - medial side of the location.
3. Dactylion - tip of digit III.
4. Metacarpale III - top of the bump on the back of the hand representing the Knuckle of digit III.
5. Palmar Edge of Wrist Joint Flexion Stop.
6. Wrist Joint Center - determined by the midpoint, lateral, and medial ends of the wrist axis.

Order of Landmarks for AXES Input File

1. Metacarpale-II
2. Metacarpale-V
3. Dactylion
4. Metacarpale-III
5. Lateral End of Wrist Axis
6. Medial End of Wrist Axis
7. Midpoint of Wrist Axis
8. Distal Edge of Flexion Stop



LEFT HAND

Anatomical Axes

Y-axis - vector from metacarpale V to metacarpale II.

Z-axis - vector normal from dactyion to Y-axis.

X-axis - $Y \times Z$.

Origin - at intersection of Y-axis and the normal passing through metacarpale III.

Mechanical Axes

X-axis - vector from pinky side of wrist joint axis to thumb side of wrist joint axis.

Z-axis - vector normal to X-axis from dorsal edge of wrist joint flexion stop.

Y-axis - $Z \times X$.

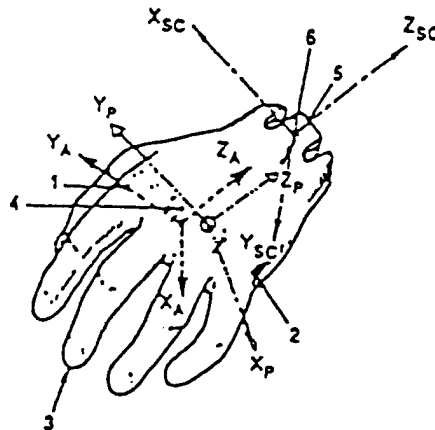
Origin - wrist joint center.

Segment Landmarks

1. Lateral Aspect of Metacarpal-Phalangeal Joint II (metacarpale II) - lateral side of the location.
2. Medial Aspect of Metacarpal-Phalangeal Joint V (metacarpale V) - medial side of the location.
3. Dactyion - tip of digit III.
4. Metacarpale III - top of the bump on the back of the hand representing the Knuckle of digit III.
5. Palmar Edge of Wrist Joint Flexion Stop.
6. Wrist Joint Center - determined by the midpoint, lateral, and medial ends of the wrist axis.

Order of Landmarks for AXES Input File

1. Metacarpale-V
2. Metacarpale-II
3. Dactyion
4. Metacarpale-III
5. Lateral End of Wrist Axis
6. Medial End of Wrist Axis
7. Midpoint of Wrist Axis
8. Distal Edge of Flexion Stop



SPINE BOX

Anatomical Axes

Z-axis - vector from the tenth rib midspine to the cervicale.

X-axis - normal from Z-axis to suprasternale.

Y-axis - $Z \times X$.

Origin - at tenth rib midspine.

Mechanical Axes

Z-axis - vector from thorax/lumbar spine to neck/thorax attachment center.

X-axis - vector normal to the Z-axis to the midpoint between right and left front lumbar spine mounting bolt holes.

Y-axis - $Z \times X$.

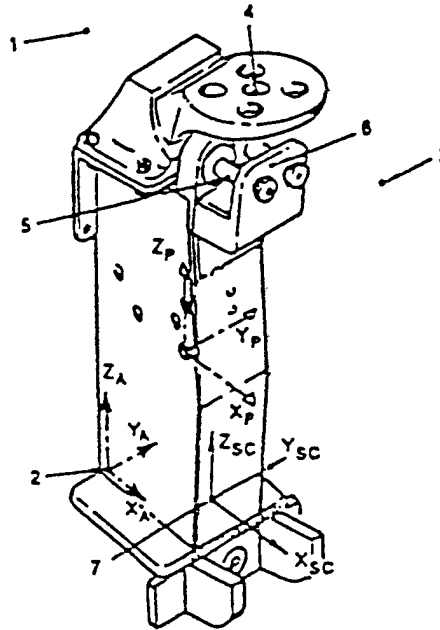
Origin - thorax/lumbar spine attachment center.

Segment Landmarks

1. Cervicale - a point on the thorax jacket posterior to the posterior midline of the lowest neck ring.
2. Tenth Rib Midspine - at the level of the lowest rib's inferior edge, a point on the posterior midline of the thorax jacket.
3. Suprasternale - a point in between the two clavicle torque bolt holes.
4. Neck/Thorax Attachment Center - center of bottom plate of neck.
5. Thorax/Right Clavicle Joint Center - the center of rotation of the right clavicle elevation/depression axis determined by the front, rear, and midpoint of the right clavicle elevation/depression axis.
6. Thorax/Left Clavicle Joint Center - the center of rotation of the left clavicle elevation/depression axis determined by the front, rear, and midpoint of the left clavicle elevation/depression axis.
7. Thorax/Lumbar Spine Attachment Center - the center of the mounting plate between the thorax and the lumbar spine.

Order of Landmarks for AXES Input File

1. Cervicale
2. 10th Rib Midspine
3. Suprasternale
4. Center of Four Bolt Holes on Lumbar Interface Plate
5. Center of Neck Bracket
6. Midpoint of Front Two Bolt Holes on Lumbar Interface Plate
7. Front Right Bolt Hole on Lumbar Interface Plate
8. Front Left Bolt Hole on Lumbar Interface Plate
9. Rear Right Bolt Hole on Lumbar Interface Plate
10. Right Front of Elevation/Depression Axis
11. Right Rear of Elevation/Depression Axis
12. Right Midpoint of Elevation/Depression Axis
13. Left Front of Elevation/Depression Axis
14. Left Rear of Elevation/Depression Axis
15. Left Midpoint of Elevation/Depression Axis
- 16-17. Two Points on Neck Bracket (i.e. Frontmost and Rightmost Points on Neck Bracket)



LUMBAR SPINE

Anatomical Axes (same as used with the pelvis)

Y-axis - vector from right anterior superior iliac midspine (ASIS) to left ASIS.

Z-axis - normal from symphision to Y-axis.

X-axis - $Y \times Z$.

Origin - at intersection of Y-axis and the normal to it passing through the posterior superior iliac midspine.

Mechanical Axes

Z-axis - vector from origin to center of torso/lumbar spine mounting interface.

X-axis - vector normal to the Z-axis to an anterior point on the bottom surface of the spine.

Y-axis - $Z \times X$.

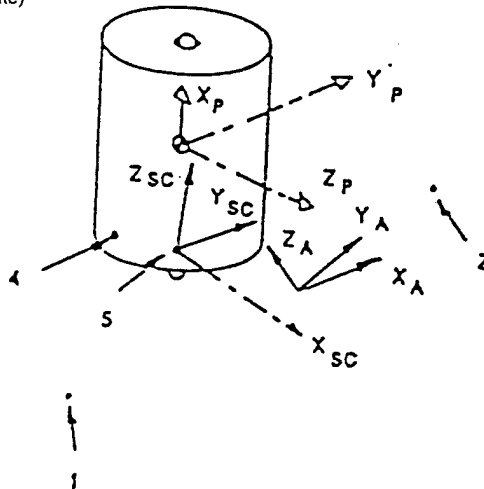
Origin - spine/spine adapter attachment center.

Segment Landmarks

1. Right ASIS - a palpable protrusion at the right anterior superior corner of the internal framework.
2. Left ASIS - a palpable protrusion at the left anterior superior corner of the internal framework.
3. Symphision - on the front of the pelvis, a point just above the junction of the thighs.
4. Posterior Superior Iliac Midspine - in the posterior midline, a point at the level of the floor of the pelvis.
5. Spine/Spine Adapter Attachment Center - center of the interface between lumbar spine and lumbar spine adapter.

Order of Landmarks for AXES Input File

1. Right ASIS
2. Left ASIS
3. Symphision
4. Posterior Superior Iliac Midspine
5. Center of Bottom of Spine
6. Center of Top of Spine
7. Frontmost Point on Bottom of Spine
- 8-9. Two Points on Bottom of Spine (i.e. Right and Rear Bolt Holes on Bottom of Spine)
- 10-11. Two Points on Top of Spine Interface Plate (i.e. Frontmost and Rightmost Points on Top of Spine Interface Plate)



PELVIS

Anatomical Axes

Y-axis - vector from right anterior superior iliac midspine (ASIS) to left ASIS.

Z-axis - normal from symphision to Y-axis.

X-axis - $Y \times Z$.

Origin - at intersection of Y-axis and the normal to it passing through the posterior superior iliac midspine.

Mechanical Axes

Y-axis - vector from right top to left top accelerometer mounting holes.

Z-axis - vector normal to the Y-axis from the left bottom accelerometer mounting hole.

X-axis - $Y \times Z$.

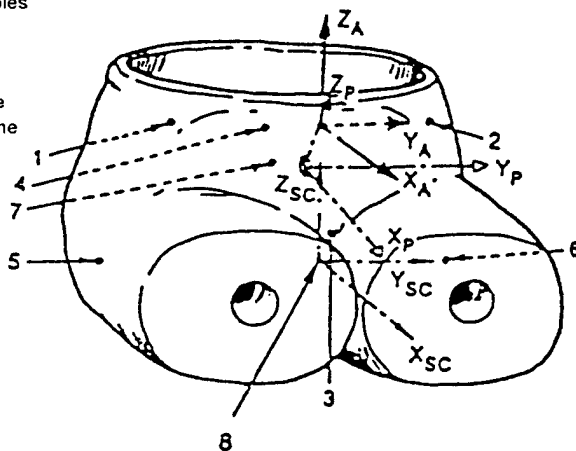
Origin - midpoint between right and left hip joint centers.

Segment Landmarks

1. Right ASIS - a palpable protrusion at the right anterior superior corner of the internal framework.
2. Left ASIS - a palpable protrusion at the left anterior superior corner of the internal framework.
3. Symphision - on the front of the pelvis, a point just above the junction of the thighs.
4. Posterior Superior Iliac Midspine - in the posterior midline, a point at the level of the floor of the pelvis.
5. Right Trochanterion - a point on the pelvis surface lateral to the right hip joint center.
6. Left Trochanterion - a point on the pelvis surface lateral to the left hip joint center.

Order of Landmarks for AXES Input File

1. Right ASIS
2. Left ASIS
3. Symphision
4. Posterior Superior Iliac Midspine
5. Top Left Accelerometer Bolt Hole
6. Top Right Accelerometer Bolt Hole
7. Bottom Left Accelerometer Bolt Hole
8. Midpoint of the Top Two Accelerometer Bolt Holes
9. Right Hip Joint Center
10. Left Hip Joint Center
11. Center of Lumbar Spine Adapter Plate
- 12-13. Two Points on Lumbar Spine Adapter Plate (i.e. Front and Right Bolt Holes on Lumbar Spine Adapter Plate)



RIGHT UPPER LEG

Anatomical Axes

Z-axis - vector from lateral femoral condyle to trochanterion.

Y-axis - normal from Z-axis to medial femoral condyle.

X-axis - $Y \times Z$.

Origin - at right trochanterion.

Mechanical Axes

Y-axis - vector from the lateral (right) end of the knee axis to the medial end of the knee axis.

X-axis - vector normal to the Y-axis from the hip joint center.

Z-axis - $X \times Y$.

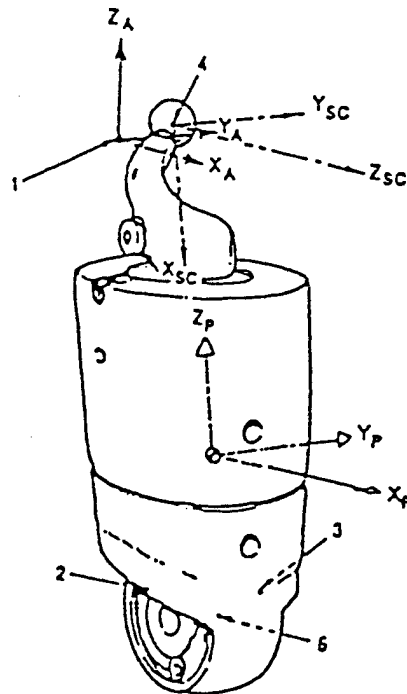
Origin - hip joint center.

Segment Landmarks

1. Right Trochanterion - on the seated pelvis, a point on the surface lateral to the right hip joint center.
2. Lateral Femoral Condyle on thigh - a point on the inferior lateral edge of the thigh covering superior to the knee axis.
3. Medial Femoral Condyle on thigh - a point on the inferior medial edge of the thigh covering superior to the knee axis.
4. Hip Joint Center - center of the hip ball joint which is determined by the front, rear, and midpoint of the hip ball joint.
5. Knee Joint Center - determined by midpoint, lateral, and medial ends of the knee axis.

Order of Landmarks for AXES Input File

1. Lateral Femoral Condyle
2. Trochanterion
3. Medial Femoral Condyle
4. Medial End of Knee Axis
5. Lateral End of Knee Axis
6. Midpoint of Knee Axis
7. Top of Hip Ball
8. Bottom of Hip Ball
9. Midpoint of Hip Ball



LEFT UPPER LEG

Anatomical Axes

Z-axis - vector from lateral femoral condyle to trochanterion.

Y-axis - normal from medial femoral condyle to the Z-axis.

X-axis - $Y \times Z$.

Origin - at right trochanterion.

Mechanical Axes

Y-axis - vector from the medial (right) end of the knee axis to the medial end of the knee axis.

X-axis - vector normal to the Y-axis from the hip joint center.

Z-axis - $X \times Y$.

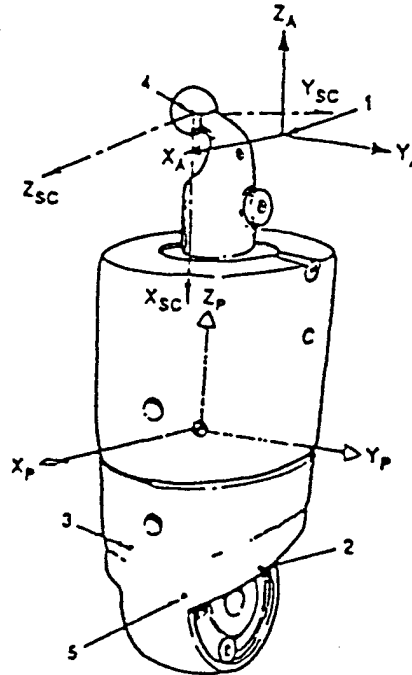
Origin - hip joint center.

Segment Landmarks

1. Right Trochanterion - on the seated pelvis, a point on the surface lateral to the right hip joint center.
2. Lateral Femoral Condyle on thigh - a point on the inferior lateral edge of the thigh covering superior to the knee axis.
3. Medial Femoral Condyle on thigh - a point on the inferior medial edge of the thigh covering superior to the knee axis.
4. Hip Joint Center - center of the hip ball joint which is determined by the front, rear, and midpoint of the hip ball joint.
5. Knee Joint Center - determined by midpoint, lateral, and medial ends of the knee axis.

Order of Landmarks for AXES Input File

1. Lateral Femoral Condyle
2. Trochanterion
3. Medial Femoral Condyle
4. Lateral End Knee Axis
5. Medial End Knee Axis
6. Midpoint End Knee Axis
7. Top of Hip Ball
8. Bottom of Hip Ball
9. Midpoint of Hip Ball



RIGHT LOWER LEG

Anatomical Axes

Z-axis - vector from sphyrion to tibiale.

Y-axis - normal from Z-axis to lateral malleolus.

X-axis - $Y \times Z$.

Origin - at tibiale.

Mechanical Axes

Z-axis - vector from ankle joint center to knee joint center.

Y-axis - vector normal to the Z-axis from the lateral (right) end of the knee axis.

X-axis - $Y \times Z$

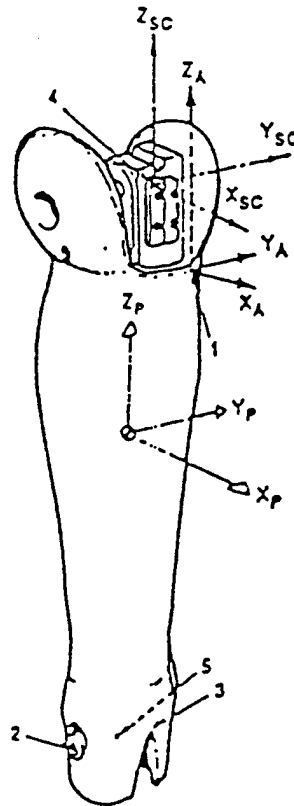
Origin - knee joint center.

Segment Landmarks

1. Tibiale - at the level of the inferior edge of the knee axis hardware, a point on the antero-medial surface of the lower leg.
2. Lateral Malleolus - the lateral projection of the covering surface on the ankle flexion axis.
3. Sphyrion - the medial projection to the covering surface of the ankle flexion axis.
4. Knee Joint Center - determined by the midpoint, lateral, and medial ends of the knee axis.
5. Ankle Joint Center - center of the ankle pivot ball which is determined by the midpoint, lateral, and medial ends of the ankle pivot ball,

Order of Landmarks for AXES Input File

1. Sphyrion
2. Tibiale
3. Lateral Malleolus
4. Lateral End of Knee Axis
5. Medial End of Knee Axis
6. Midpoint of Knee Axis
7. Lateral End of Ankle Axis
8. Medial End of Ankle Axis
9. Midpoint of Ankle Axis



LEFT LOWER LEG

Anatomical Axes

Z-axis - vector from sphyrion to tibiale.
Y-axis - normal from Z-axis to lateral malleolus.
X-axis - $Y \times Z$.
Origin - at tibiale.

Mechanical Axes

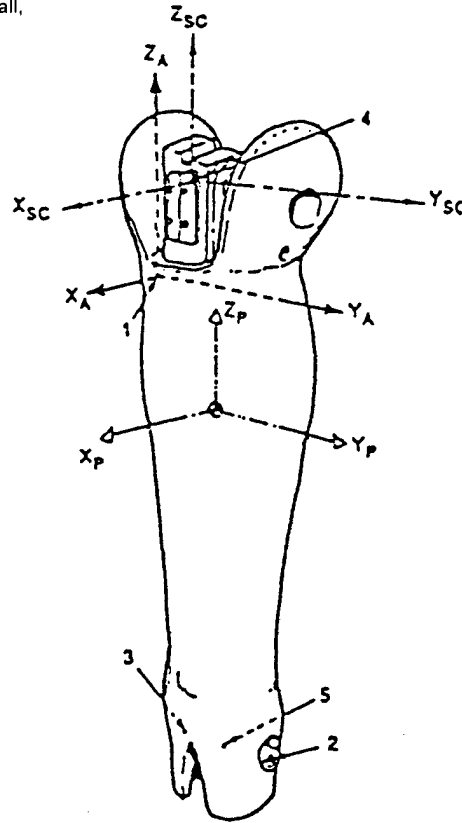
Z-axis - vector from ankle joint center to knee joint center.
Y-axis - vector normal to the Z-axis from the medial (right) end of the knee axis.
X-axis - $Y \times Z$
Origin - knee joint center.

Segment Landmarks

1. Tibiale - at the level of the inferior edge of the knee axis hardware, a point on the antero-medial surface of the lower leg.
2. Lateral Malleolus - the lateral projection of the covering surface on the ankle flexion axis.
3. Sphyrion - the medial projection to the covering surface of the ankle flexion axis.
4. Knee Joint Center - determined by the midpoint, lateral, and medial ends of the knee axis.
5. Ankle Joint Center - center of the ankle pivot ball which is determined by the midpoint, lateral, and medial ends of the ankle pivot ball,

Order of Landmarks for AXES Input File

1. Sphyrion
2. Tibiale
3. Lateral Malleolus
4. Medial End of Knee Axis
5. Lateral End of Knee Axis
6. Midpoint of Knee Axis
7. Lateral End of Ankle Axis
8. Medial End of Ankle Axis
9. Midpoint of Ankle Axis



LEFT FOOT

Anatomical Axes

Z-axis - superiorly directed vector normal to the X-Y plane formed by metatarsal I, metatarsal V, and posterior calcaneous.

X-axis - vector from posterior calcaneous to normally projected position of toe II on X-Y plane.

Y-axis - $Z \times X$.

Origin - at the intersection of the X-axis and the normal passing through metatarsal-phalange I.

Mechanical Axes

Z-axis - vector from center of ball shaft mount to ankle joint center.

Y-axis - vector normal to the Z-axis from the bolt on the lateral (left) side for securing shaft.

X-axis - $Y \times Z$.

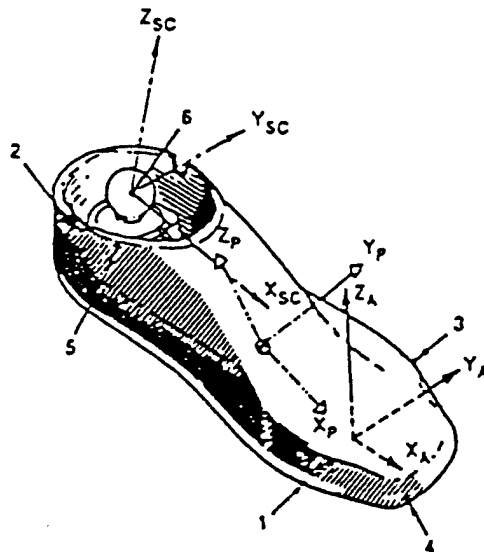
Origin - ankle joint center.

Segment Landmarks

1. Metatarsal-Phalangeal Joint I - a bulge on the medial side of the foot, approximately 2 inches from the front.
2. Posterior Calcaneous - the posterior-most point on the foot, approximately 1 inch above the sole.
3. Metatarsal-Phalangeal Joint V - a bulge on the lateral side of the foot, approximately 2 1/2 inches from the front.
4. Toe II - the anterior-most point on the foot.
5. Center of Ball Mount - center of shaft clearance hole.
6. Ankle Joint Center - ankle ball center which is determined by midpoint, lateral, and medial ends of the ankle ball.

Order of Landmarks for AXES Input File

1. Metatarsal-Phalangeal Joint I
2. Posterior Calcaneous
3. Metatarsal-Phalangeal Joint V
4. Toe II
5. Lateral End of Ankle Ball Axis
6. Medial End of Ankle Ball Axis
7. Midpoint of Ankle Ball Axis
8. Center of Ankle Ball Shaft Hole
9. Lateral Side of Ankle Ball Shaft Hole
10. Medial Side of Ankle Ball Shaft Hole
11. Center of Bolt for Securing Shaft (on Lateral Side of Foot)



HELMET

Anatomical Axes

Y-axis - vector from right tragion to left tragion.

X-axis - normal from Y-axis to right infraorbitale.

Z-axis - $X \times Y$.

Origin - intersection of Y-axis and a normal passing through sellion.

Mechanical Axes

Z-axis - vector from lower midpoint to upper bolt hole midpoint on mounting interface between back cap and head.

Y-axis - vector parallel to the head/neck joint axis (i.e., vector from the upper bolt hole midpoint to the right upper bolt hole on mounting interface between back cap and head, positive to the left).

X-axis - $Y \times Z$.

Origin - head/neck joint center.

Helmet Axes

Y-axis - vector from point on lower front right side to point on lower front left side of helmet.

X-axis - vector perpendicular to the y-axis and directed through the center of front edge of the helmet shell.

Z-axis - $Y \times X$

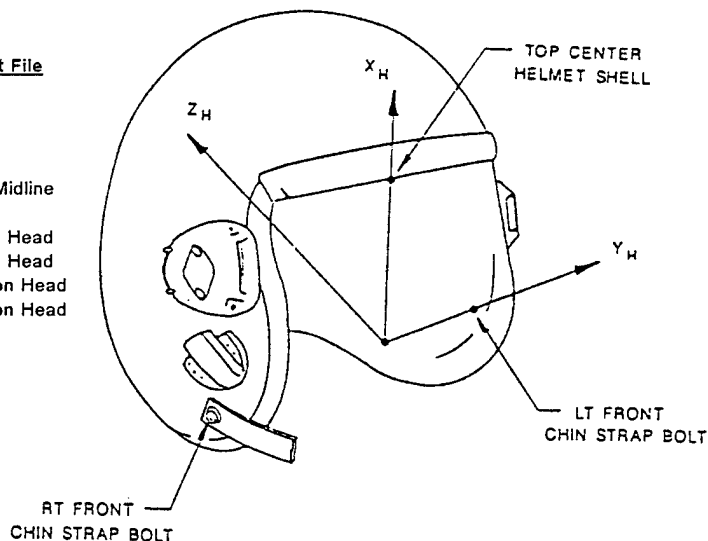
Origin - Intersection of the x and y axes.

Segment Landmarks

1. Sellion - on the bridge of the nose between the eyes.
2. Right Infraorbitale - center of the lower edge of the right eye.
3. Right Tragion - on the right side of the head, a point on a line extending vertically 1 inch above the posterior edge of the lower jaw.
4. Left Tragion - on the left side of the head, a point on a line extending vertically 1 inch above the posterior edge of the lower jaw.
5. Head/Neck Joint Center - determined by the midpoint, right and left ends of the head/neck joint.

Order of Landmarks for AXES Input File

1. Right Dimple on Helmet
2. Left Dimple on Helmet
3. Center of Brow of Helmet
4. A Point Approximately Along the Midline of Helmet on Top of Helmet
5. Upper Left Skull Cap Bolt Hole on Head
6. Lower Left Skull Cap Bolt Hole on Head
7. Upper Right Skull Cap Bolt Hole on Head
8. Lower Right Skull Cap Bolt Hole on Head
9. Right End of Head/Neck Axis
10. Left End of Head/Neck Axis
11. Midpoint of Head/Neck Axis
12. Right Tragion
13. LEFT TRAGION
14. Right Infraorbitale
15. Sellion



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APPENDIX B

Problem/Solution Index

Problem/Solution Index

- Problem Uncertain if new box data should be taken
- Solution.... New box data should be taken any time a box is altered in any way. If a jig has been altered then all boxes tested with that jig must be retested.
-
- Problem More support is needed or the velcro straps do not suffice
- Solution.... Masking tape may be used to hold the object more securely but it must be applied as not to deform the object in any way.
-
- Problem An object is too large for any of the current boxes
- Solution.... A new box should be made in order to assure that none of the current boxes are damaged.
-
- Problem An object or composite is too heavy for the electronic balance
- Solution.... If the composite weighs more than 40 killograms then use the balance located near the drop tower or another balance of known dependability.
-
- Problem The mass seems too awkward or bulky for the balance or moment table
- Solution.... Center the object or composite over the balance or moment table. This usually requires two people: one to center the mass and one to secure the moment table.

Problem Incorrect data was typed in while running the box placement or composite placement program

Solution.... Enter yes when prompted to alter data.
Make any necessary corrections.

Problem Nothing happens when the tape is inserted into the HP 85B

Solution.... Reinsert the tape. Turn the power off and back on again. This should be performed every time the tape is inserted.

Problem Uncertain whether or not to read the TARE from the tape

Solution.... The only time the TARE moment should be read from the tape is if a series of tests are being performed and the TARE moment has already been measured, as it should before any test or series of tests.

Problem During step F of the SE Measurement Program, the instrument appears to be oscillating as it should, but does not record an average time of oscillation

Solution.... Check the screen of the HP 85B. In nearly all cases, the screen will appear blank, or show only one or two period measurements. This indicates that an average time was not found. This is due to a command in the program which requires that the computer read three consecutive measurements that do not differ by more than .01%. If the measurements do not meet this requirement, then the computer stops taking data. At this point, the object must be removed from the platter and the platter must be oscillated manually. This is done by slightly pulling back on one of the corners of the platter and then releasing it. The platter will oscillate, stop, and rotate back to zero degrees. Before

attempting to test the object again, the object should be secured to prevent the object from moving with respect to the box. The box should also be resecured to the platter with double sided tape to assure that there is no movement between the two.

Problem The object seems to move with respect to the box at any time during the procedure

Solution.... The object should be resecured and the entire procedure should be started over at the beginning.

Problem The object appears to have moved during digitizing

Solution.... An additional set of data should be digitized.

APPENDIX C

Inertial Entry Log

Name _____

Date _____

Digitization Data

Set 1: _____

Set 2: _____

Set 3: _____

1. _____

1. _____

1. _____

2. _____

2. _____

2. _____

3. _____

3. _____

3. _____

4. _____

4. _____

4. _____

5. _____

5. _____

5. _____

6. _____

6. _____

6. _____

7. _____

7. _____

7. _____

8. _____

8. _____

8. _____

9. _____

9. _____

9. _____

10. _____

10. _____

10. _____

11. _____

11. _____

11. _____

12. _____

12. _____

12. _____

13. _____

13. _____

13. _____

14. _____

14. _____

14. _____

15. _____

15. _____

15. _____

16. _____

16. _____

16. _____

17. _____

17. _____

17. _____

18. _____

18. _____

18. _____

19. _____

19. _____

19. _____

20. _____

20. _____

20. _____

APPENDIX D

Digitization Entry Log

Data Sheet For Small Mass Properties Instrument

Name _____
Date _____

Object: _____

Box Coordinates

Ix _____

Ixy _____

Iy _____

Iyz _____

Iz _____

Ixz _____

Tare Moments

1 _____

2 _____

3 _____

Composite Moments

Ix

Ixy

1 _____

1 _____

2 _____

2 _____

3 _____

3 _____

Iy

Iyz

1 _____

1 _____

2 _____

2 _____

3 _____

3 _____

Iz

Ixz

1 _____

1 _____

2 _____

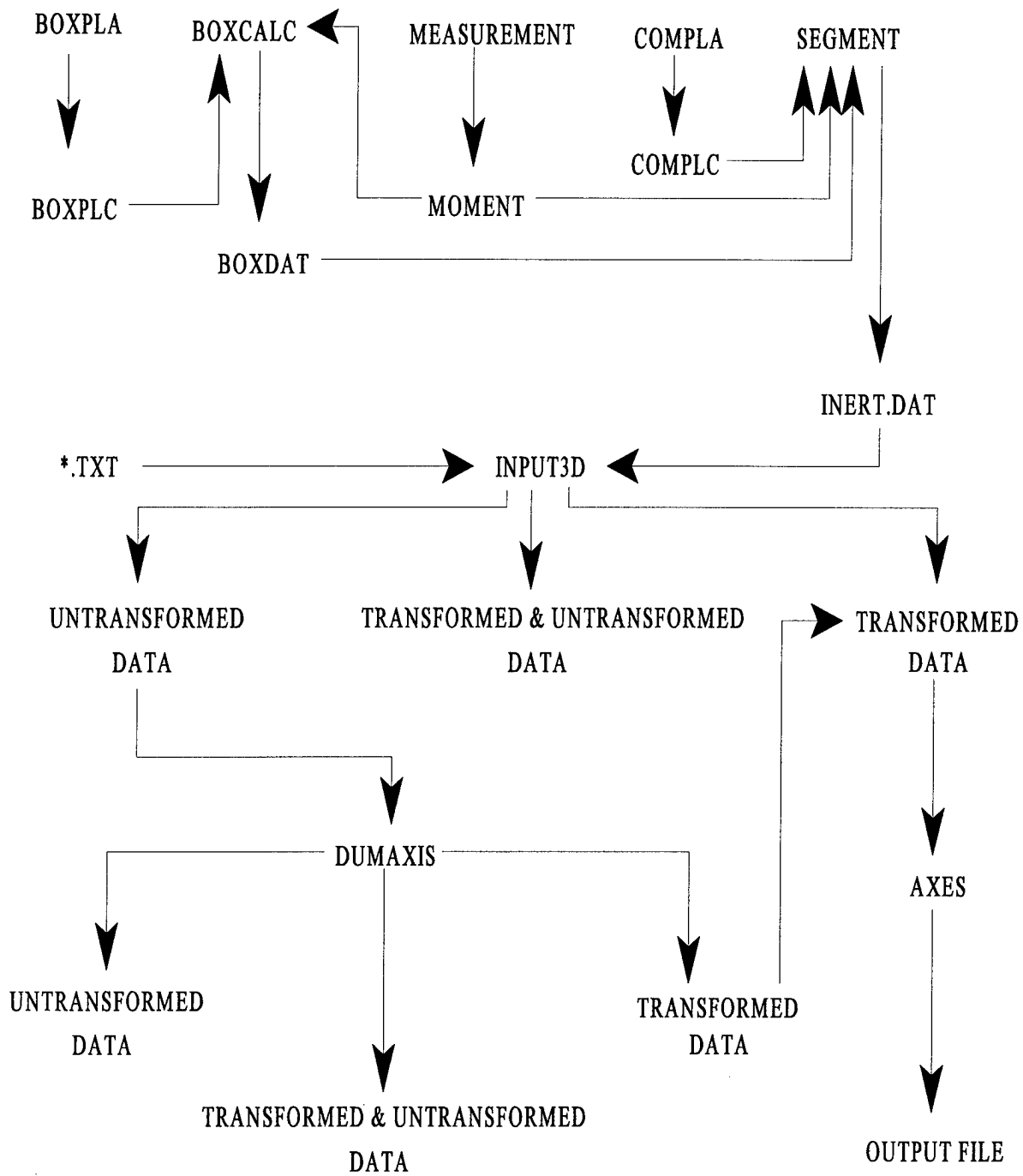
2 _____

3 _____

3 _____

APPENDIX E

Software Flow Chart



APPENDIX F

Input and Output Files

DATA FILE CONTAINING TRANSFORMED DATA

LG ADAM HEAD, DUMMY LOAD CELL 11-22-91

23

	13.96	11.25	11.89			
RT-TRAGION				12.25	18.20	8.56
LT-TRAGION				11.81	6.67	18.16
RT-INFRAORBITALE				15.41	18.90	15.93
SELLION				18.53	16.48	18.41
CENTER-OF-UPPER-BOLT-HOLES				18.65	6.71	6.16
CENTER-OF-LOWER-BOLT-HOLES				9.48	8.31	8.35
RT-UP-BOLT-HOLE				18.64	9.22	4.27
RT-LOW-BOLT-HOLE				9.46	10.78	6.39
RT-END-HEAD-NECK-AXIS				8.69	13.41	10.37
LT-END-HEAD-NECK-AXIS				8.70	9.77	13.40
MIDPOINT-HEAD-NECK-AX				8.05	11.76	11.90
O				0.00	0.00	0.00
Z				0.00	0.00	17.25
Y				0.00	17.02	-0.06
X				19.86	-0.03	-0.16
A				7.80	19.38	21.39
B				7.13	10.31	19.70
C				6.57	20.05	13.96
M				3.61	17.98	11.57
G				14.23	11.22	20.92
Lt-UP-BOLT-HOLE				18.68	4.17	8.25
LT-LOW-BOLT-HOLE				9.50	5.75	10.35
HEAD				13.96	11.25	11.89

1

	0.8593	0.2790	0.4287	0.0245	0.8147	-0.5793	-0.5109
0.5083	0.6932						
	227.8030	252.4160	150.7820				
	4.14						

DATA FILE CONTAINING UNTRANSFORMED DATA

LG ADAM HEAD, DUMMY LOAD CELL 11-22-91

3			
7			
O	0.03	0.00	0.05
Z	-0.05	-0.01	17.30
Y	-0.01	17.02	0.00
X	19.89	0.02	-0.02
A	7.68	19.39	21.49
B	7.04	10.32	19.79
C	6.49	20.06	14.05
16			
A	7.90	27.25	6.16
B	3.25	19.20	5.86
C	13.83	23.08	5.27
M	14.48	19.57	2.45
G	2.86	21.10	12.87
SELLION	8.15	23.68	17.10
RT-INFRAORBITALE	11.64	23.73	14.01
LT-TRAGION	2.02	15.73	10.72
RT-TRAGION	16.81	18.24	11.20
LT-UP-BOLT-HOLE	7.82	7.75	18.09
RT-UP-BOLT-HOLE	14.13	8.96	18.06
RT-UP-BOLT-HOLE	14.13	8.98	18.06
CENTER-OF-UPPER-BOLT-HOLES	11.06	8.31	18.07
LT-LOW-BOLT-HOLE	7.36	9.83	8.78
RT-LOW-BOLT-HOLE	13.64	11.06	8.75
CENTER-OF-LOWER-BOLT-HOLES	10.55	10.46	8.77
6			
A	14.79	28.81	15.06
B	18.26	20.61	16.61
C	8.32	25.80	17.45
RT-END-HEAD-NECK-AXIS	8.71	17.90	16.48
LT-END-HEAD-NECK-AXIS	13.20	16.43	16.21
MIDPOINT-HEAD-NECK-AXIS	10.95	17.41	16.97

DATA FILE CONTAINING TRANSFORMED AND UNTRANSFORMED DATA

LG ADAM HEAD, DUMMY LOAD CELL 11-22-91

POINTS BEFORE TRANSFORMATION		SET 1		CENTIMETERS
LANDMARKS		X	Y	Z
7				
O		0.03	0.00	0.05
Z		-0.05	-0.01	17.30
Y		-0.01	17.02	0.00
X		19.89	0.02	-0.02
A		7.68	19.39	21.49
B		7.04	10.32	19.79
C		6.49	20.06	14.05
POINTS AFTER TRANSFORMATION		SET 1		CENTIMETERS
LANDMARKS		X	Y	Z
7				
O		0.00	0.00	0.00
Z		0.00	0.00	17.25
Y		0.00	17.02	-0.06
X		19.86	-0.03	-0.16
A		7.80	19.38	21.39
B		7.13	10.31	19.70
C		6.57	20.05	13.96
POINTS BEFORE TRANSFORMATION		SET 2		CENTIMETERS
LANDMARKS		X	Y	Z
16				
POINTS BEFORE TRANSFORMATION		SET 3		CENTIMETERS
LANDMARKS		X	Y	Z
6				
POINTS AFTER TRANSFORMATION		SET 2		CENTIMETERS
16				
A		7.80	19.38	21.39
B		7.12	10.26	19.69
C		6.62	20.12	14.22
M		3.61	17.98	11.57
G		14.23	11.22	20.92
SELLION		18.53	16.48	18.41
RT-INFRAORBITALE		15.41	18.90	15.93
LT-TRAGION		11.81	6.67	18.16
RT-TRAGION		12.25	18.20	8.56
LT-UP-BOLT-HOLE		18.68	4.17	8.25
RT-UP-BOLT-HOLE		18.64	9.20	4.26
RT-UP-BOLT-HOLE		18.64	9.22	4.27
CENTER-OF-UPPER-BOLT-HOLES		18.65	6.71	6.16
LT-LOW-BOLT-HOLE		9.50	5.75	10.35
RT-LOW-BOLT-HOLE		9.46	10.78	6.39
CENTER-OF-LOWER-BOLT-HOLES		9.48	8.31	8.35

POINTS AFTER TRANSFORMATION	SET 3	CENTIMETERS	
6			
A	7.80	19.38	21.39
B	7.14	10.52	19.74
C	6.59	20.18	14.01
RT-END-HEAD-NECK-AXIS	8.69	13.41	10.37
LT-END-HEAD-NECK-AXIS	8.70	9.77	13.40
MIDPOINT-HEAD-NECK-AXIS	8.05	11.76	11.90

AXES Output File

LG ADAM HEAD, DUMMY LOAD CELL 11-22-91

BOX AXIS SYSTEM

LANDMARKS IN BOX AXIS SYSTEM

	CENTIMETERS			INCHES		
23						
RT-TRAGION	12.25	18.20	8.56	4.82	7.17	3.37
LT-TRAGION	11.81	6.67	18.16	4.65	2.63	7.15
RT-INFRAORBITALE	15.41	18.90	15.93	6.07	7.44	6.27
SELLION	18.53	16.48	18.41	7.30	6.49	7.25
CNTR-UP-BOLT-HOLES	18.65	6.71	6.16	7.34	2.64	2.43
CNTR-LOW-BOLT-HOLES	9.48	8.31	8.35	3.73	3.27	3.29
RT-UP-BOLT-HOLE	18.64	9.22	4.27	7.34	3.63	1.68
RT-LOW-BOLT-HOLE	9.46	10.78	6.39	3.72	4.24	2.52
RT-END-HEAD-NECK	8.69	13.41	10.37	3.42	5.28	4.08
LT-END-HEAD-NECK	8.70	9.77	13.40	3.43	3.85	5.28
MIDPNT-HEAD-NECK	8.05	11.76	11.90	3.17	4.63	4.69
O	0.00	0.00	0.00	0.00	0.00	0.00
Z	0.00	0.00	17.25	0.00	0.00	6.79
Y	0.00	17.02	-0.06	0.00	6.70	-0.02
X	19.86	-0.03	-0.16	7.82	-0.01	-0.06
A	7.80	19.38	21.39	3.07	7.63	8.42
B	7.13	10.31	19.70	2.81	4.06	7.76
C	6.57	20.05	13.96	2.59	7.89	5.50
M	3.61	17.98	11.57	1.42	7.08	4.56
G	14.23	11.22	20.92	5.60	4.42	8.24
LT-UP-BOLT-HOLE	18.68	4.17	8.25	7.35	1.64	3.25
LT-LOW-BOLT-HOLE	9.50	5.75	10.35	3.74	2.26	4.07
CENTER OF MASS	13.96	11.25	11.89	5.50	4.43	4.68
TRANSFORMATION FROM THE BOX AXIS SYSTEM TO THE UNASSIGNED						
PRINCIPAL AXES (APB)						

COSINES			DEGREES		
0.85930	0.27900	0.42870	30.76	73.80	64.61
0.02450	0.81470	-0.57930	88.60	35.44	125.40
-0.51090	0.50830	0.69320	120.72	59.45	46.12

ANATOMICAL AXIS SYSTEM

LANDMARKS IN SEGMENT ANATOMICAL AXIS SYSTEM

	CENTIMETERS				INCHES	
23						
RT-TRAGION	0.00	-7.44	0.00	0.00	-2.93	0.00
LT-TRAGION	0.00	7.57	0.00	0.00	2.98	0.00
RT-INFRAORBITALE	6.94	-3.35	0.00	2.73	-1.32	0.00
SELLION	8.77	0.00	2.67	3.45	0.00	1.05
CNTR-UP-BOLT-HOLES	-4.98	-0.33	10.17	-1.96	-0.13	4.01
CNTR-LOW-BOLT-HOLES	-6.92	0.11	0.82	-2.73	0.04	0.32
RT-UP-BOLT-HOLE	-4.89	-3.47	10.01	-1.92	-1.37	3.94
RT-LOW-BOLT-HOLE	-6.91	-3.04	0.69	-2.72	-1.20	0.27
RT-END-HEAD-NECK	-3.09	-2.50	-2.22	-1.22	-0.98	-0.87
LT-END-HEAD-NECK	-3.02	2.24	-2.09	-1.19	0.88	-0.82
MIDPNT-HEAD-NECK	-3.26	-0.23	-2.78	-1.28	-0.09	-1.09
O	-21.73	1.43	-1.95	-8.56	0.56	-0.77
Z	-9.90	12.46	-7.93	-3.90	4.91	-3.12
Y	-12.36	-11.68	-7.42	-4.87	-4.60	-2.92
X	-12.47	0.77	15.61	-4.91	0.30	6.14
A	7.35	-0.01	-8.75	2.89	0.00	-3.45
B	0.86	5.90	-5.83	0.34	2.32	-2.30
C	2.04	-5.24	-7.47	0.80	-2.06	-2.94
M	-2.14	-5.09	-8.58	-0.84	-2.00	-3.38
G	5.55	5.77	-0.29	2.19	2.27	-0.12
LT-UP-BOLT-HOLE	-4.93	2.95	10.30	-1.94	1.16	4.05
LT-LOW-BOLT-HOLE	-6.96	3.35	0.97	-2.74	1.32	0.38
HEAD CENTER OF MASS	-0.75	-0.02	2.59	-0.30	-0.01	1.02

TRANSFORMATION FROM THE ANATOMICAL AXIS SYSTEM TO THE UNASSIGNED PRINCIPAL AXES (APA)

	COSINES			DEGREES		
0.85466	0.03468	0.51804	31.28	88.01	58.80	
0.06481	-0.99705	-0.04016	86.28	175.60	92.30	0.51509
0.06788	-0.85439	59.00	86.11	148.69		

TRANSFORMATION FROM THE ANATOMICAL AXIS SYSTEM TO THE ASSIGNED PRINCIPAL AXES (APAA)

	COSINES			DEGREES		
0.85466	0.03468	0.51804	31.28	88.01	58.80	
-0.06481	0.99705	0.04016	93.72	4.40	87.70	
-0.51509	-0.06788	0.85439	121.00	93.89	31.31	

YAW= 2.32 PITCH= -31.20 ROLL= 2.69

JOINT CENTERS IN THE ANATOMICAL SYSTEM
(CM) (IN)

HEAD/NECK	-3.0577	-0.2510	-2.1561	-1.2038	-0.0988	-0.8488
ANAT. ORIGIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	2.5400	2.5400	2.5400	1.0000	1.0000	1.0000
	2.5400	2.5400	2.5400	1.0000	1.0000	1.0000
	2.5400	2.5400	2.5400	1.0000	1.0000	1.0000

SEGMENT COORDINATE AXIS SYSTEM

LANDMARKS IN SEGMENT COORDINATE AXIS SYSTEM

	CENTIMETERS			INCHES		
23						
RT-TRAGION	2.29	-7.15	3.06	0.90	-2.81	1.20
LT-TRAGION	2.85	7.84	2.38	1.12	3.09	0.94
RT-INFRAORBITALE	9.23	-3.26	4.28	3.63	-1.28	1.69
SELLION	10.61	0.17	7.12	4.18	0.07	2.80
CNTR-UP-BOLT-HOLES	-4.37	0.61	11.67	-1.72	0.24	4.60
CNTR-LOW-BOLT-HOLE	-4.37	0.62	2.11	-1.72	0.24	0.83
RT-UP-BOLT-HOLE	-4.37	-2.53	11.67	-1.72	-1.00	4.60
RT-LOW-BOLT-HOLE	-4.45	-2.53	2.12	-1.75	-1.00	0.84
RT-END-HEAD-NECK	-0.10	-2.24	0.03	-0.04	-0.88	0.01
LT-END-HEAD-NECK	0.12	2.49	-0.04	0.05	0.98	-0.01
MIDPNT-HEAD-NECK	-0.07	-0.01	-0.65	-0.03	0.00	-0.26
O	-18.25	2.20	-3.68	-7.19	0.87	-1.45
Z	-5.05	12.58	-7.62	-1.99	4.95	-3.00
Y	-8.47	-11.43	-6.52	-3.33	-4.50	-2.57
X	-12.76	2.20	15.41	-5.02	0.86	6.07
A	11.53	-0.39	-4.34	4.54	-0.15	-1.71
B	4.81	5.84	-3.07	1.89	2.30	-1.21
C	5.88	-5.39	-3.94	2.31	-2.12	-1.55
M	2.01	-5.19	-5.88	0.79	-2.04	-2.32
G	8.28	5.87	3.30	3.26	2.31	1.30
LT-UP-BOLT-HOLE	-4.23	3.89	11.65	-1.67	1.53	4.59
LT-LOW-BOLT-HOLE	-4.31	3.87	2.10	-1.70	1.52	0.83
CENTER OF MASS	1.31	0.41	5.10	0.51	0.16	2.01

TRANSFORMATION FROM THE ASSIGNED PRINCIPAL AXES TO THE SEGMENT COORDINATE AXIS SYSTEM (AMP)

	COSINES			DEGREES		
0.73300	-0.03402	-0.67933	42.86	91.95	132.79	
0.03773	0.99921	-0.00930	87.84	2.28	90.53	
0.67919	-0.01881	0.73371	47.22	91.08	42.80	

YAW= 2.95 PITCH= -42.78 ROLL= -1.47

TRANSFORMATION FROM THE ANATOMICAL TO THE SEGMENT COORDINATE AXIS SYSTEM (AMA)

COSINES			DEGREES			
0.97864	0.03764	-0.20212	11.86	87.84	101.66	
-0.02771	0.99828	0.05172	91.59	3.36	87.04	
0.20372	-0.04501	0.97799	78.25	92.58	12.04	
YAW=		-1.62	PITCH=	-11.75	ROLL=	-2.64

	JOINT CENTERS IN SEGMENT COORDINATE SYSTEM					
	(CM)			(IN)		
HEAD/NECK	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ANAT. ORIGIN	2.5660	0.2773	2.7203	1.0102	0.1091	1.0710
	2.5660	0.2773	2.7203	1.0102	0.1091	1.0710
	4.6340	2.8739	5.6075	1.8244	1.1314	2.2077
	4.6340	2.8739	5.6075	1.8244	1.1314	2.2077
	4.6340	2.8739	5.6075	1.8244	1.1314	2.2077

MOMENT MAGNITUDES AND SEGMENT WEIGHT (MASS)

PRINCIPAL MOMENTS (KG-CM**2) X= 227.803 Y= 252.416 Z= 150.782
 PRINCIPAL MOMENTS (LBS-SEC**2-IN) X= 0.202 Y= 0.223 Z= 0.133
 PRINCIPAL MOMENTS (LBS-IN**2) X= 77.845 Y= 86.256 Z= 51.526

SEGMENT MASS (KG) = 4.14
 SEGMENT WEIGHT (LBS) = 9.13

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APPENDIX G

Metrecom Advanced Applications
(Section 12 of User's Manual)

12.1. 3-D DIGITIZATION

12.1. INTRODUCTION

The six degrees of freedom electrogoniometer used in the METRECOM Skeletal Analysis System is capable of providing not only three dimensional (3-D) total motion description but also the 3-D position of points. This has been demonstrated when the digitizer is used during the standard Metrecom tests. For use simply as a 3-D digitizer the digitizer tip is mounted on the last link of the electrogoniometer and can be used to locate points in space, connect them with lines, and present them in 3-D perspective views which can be rotated, enlarged, reduced and translated. This facility is primarily oriented towards research applications, but can be considered for potential use in intra surgical applications where tendon and ligament placement, as well as bone removal and joint surface replacement require a detailed knowledge of the 3-D structure of the joint. The points digitized in any particular series are all numbered and can be located on the screen. A tabular list of the digitized points, including their number and their 3-D coordinates, can be provided on the printer through the appropriate command.

The ability to translate, rotate, and change the perspective view of the object on the screen provides a convenient way of establishing surgical protocol, and attachment points etc, which can then be printed on the METRECOM for final record keeping. The object and the list of points can also be stored on diskette. Note however, that the diskette is not in the form of a patient diskette, but rather a newly formatted 3 1/2 inch diskette used specifically for digitization data storage.

The following section describes the numerous commands which can be entered through the keyboard and through the hand/foot switch for the purpose of carrying out a 3-D digitization.

12.2 DIGITIZATION COMMANDS

Selecting Advanced Applications from the Metrecom Master Menu, and selecting item #1- 3-D DIGITIZATION, will result in the presentation of the digitized screen with a X, Y, Z coordinate system and a block of commands

The default coordinate system has its center at the base of the electrogoniometer where it attaches to the Metrecom mounting block. The center is at the center of the pivoting shaft where the second link attaches to the first link of the electrogoniometer. The position of this coordinate system can be checked at this point by attaching the digitizer tip to the last link of the electrogoniometer and attempting to touch the center. Although you will not be able to touch the center, because of the geometry of the electrogoniometer you will be able to see on the screen the proximity of the tip to the center. If desired, you may attach the thumb switch which is normally located on the standard digitizer probe to the 3-D digitizer probe (Figure)

The orientation of the default coordinate system is as follows:

X-Axis - The X-axis passes through the center in a direction perpendicular to the sliding mounting block on the Metrecom and is positive in the leftward direction.

Y-Axis - The Y-axis passes through the center in a direction perpendicular to the plane of the sliding mounting block and is positive in the upward direction.

Z-Axis - The Z-axis passes through the center, is perpendicular to the X and Y-axis and is positive in the direction inward towards the support pole.

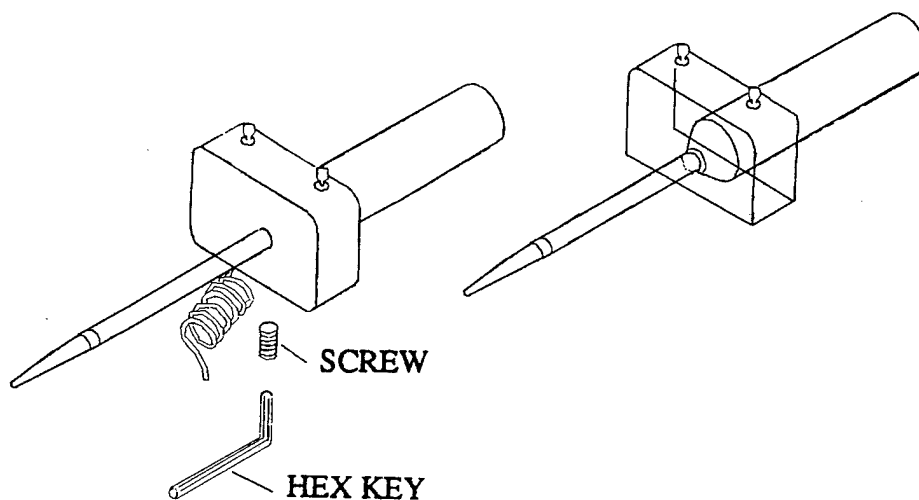


Figure 12.1.1. Switch Installation on 3-D Probe

To set up your own coordinate system, you will use the <R> command to establish a new reference coordinate system. This is accomplished by digitizing

- (1) a point to be considered the origin of the coordinate system
- (2) a point on the X-axis and
- (3) a point on the X-Y plane.

Digitization is performed by pressing the right hand/foot switch. Continuous digitization can be performed by pressing the left hand footswitch. In the continuous digitization mode the points are digitized at approximately 15 per second.

To enter any of the following commands, first press <enter> which will then prompt with the COMMAND sign (>). You are then required to enter first a letter corresponding to the desired command followed by a number corresponding to the degree to which this command should be carried out. Table of this section summarizes the keyboard codes used for the creation and manipulation of the images produced using the 3- dimensional digitizer. In the order that they are presented in the table the following is an explanation of each keyboard command.

<A> Rotate about positive X-axis. This command permits the user to rotate the image about the image's X-axis from +/-1 to +/- 360 degrees. Upon striking the key the image will be erased and re-drawn with the desired rotation about the X-axis.

 Rotate about positive Y-axis. This command permits the user to rotate the image about the image's Y-axis. Upon striking the key the image will be erased and re-drawn with the desired rotation about the Y-axis.

<C> Rotate about positive Z-axis. This command permits the user to rotate the image about the image's Z-axis. Upon striking the key the image will be erased and re-drawn with the desired rotation about the Z-axis.

<D> Dump the screen on the printer. This command provides the facility for hardcopy reproduction of the screen's 3-dimensional image on the printer. A

precise representation of the screen will be produced on the printer with a slight reduction in the scale from the full size represented on the screen.

<E> Exit to master menu. The completion of the digitization procedures can be followed by returning to the master menu for selection of other operations.

NOTE: the image must be saved or it will be lost, once the user exits. The routine will verify by asking "HAVE YOU SAVED DIGITIZED OBJECT? (Y/N)". Responding to this command will permit the entry of the following instructions.

<G> Retrieves an object from the disk and displays it on the screen. This command permits the re-drawing of a prestored 3-dimensional image by simply entering in the name of the file used for its storage. The prompt requesting the proper file name is preceded by a disk directory and appears on the lower portion of the screen before drawing.

<H> Help. The help command results in presentation on the screen of the full command menu.

<J> Start/Stop Joining. This command permits the joining of digitized points during the digitization procedure. The J command is basically a toggle and will change alternately from true to false each time the J command is entered. Successive points will be connected by line segments if the J command is true.

<M> Enter desired current point. This command allows you to define for the purposes of point joining or printing. When you digitize an object the current point is always the last point unless you override using this command.

<N> Enter desired starting point. Again, this is a command used for setting a string of points to be joined or printed.

<P> Save object on disk. This command saves the 3-dimensional object just digitized on a disk file. The P command presents the current disk directory and then prompts for the data file name, which the user should choose in order to specify the screen image on the disk by name.

<Q> Print Coordinates. This command leads to a tabular print out of the points digitized in their three X, Y and Z coordinates. The table contains all points from the starting point to current point, listing both the point number and its coordinates

<R> Set New Reference. This command permits the user to re-reference the digitizer sequence and restart digitization. Since this instruction will destroy the previously digitized object be sure to save the object on disk.

<S> Enter New scale. This command will increase or decrease the scale of the object on the screen by the amount entered (1-500%). A decrease in scale would result from entry of a negative number.

<T> Join starting to current point. This command will provide a line segment joining the starting point and the current point indicated on the point counter.

<U> Join series of points. This command will provide line segments joining all points starting from the starting point up to the current point. Note: The current point must have a greater X, Y, and Z coordinate than the starting point.

<V> Viewing distance. This command provides an increase or decrease of the viewing distance from the object by the entered number (in centimeters).

<X> Move object along X-axis. These commands move the object along the positive or negative X-axis respectively by 1 centimeter each time the command is entered.

<Y> Move object along Y-axis. This command moves the object along the positive Y-axis or negative Y-axis respectively by 1 centimeter each time the command is entered.

<Z> Move object along Z-axis. This command will move the object either along the positive or negative Z axis respectively by 1 centimeter each time the command is entered.

<+> Remove/Re-draw Coordinate Axes. The coordinate axes may be removed from or replaced on the display by entering this command.

12.1.3. 3-D SCREEN MENU

Figure is a screen representation of an object which has been digitized using the 3-dimensional digitizer. On the right portion of the screen a menu of labels and their corresponding current values is presented as they existed at the time of digitization.

The items described in this menu include the current point number, the last point number, the starting point, the rotation about the X-axis in degrees, the rotation about the Y-axis in degrees, the rotation about the Z-axis in degrees, the scale in percent, the translation of the object along the X-axis, the translation along the Y-axis and the translation along the X-axis in millimeters and finally the viewing distance in millimeters.

The summary of screen commands can be presented on the screen simply by pressing H whereupon the full command listing will be presented on the screen, pressing the return key will return the user to the digitization screen.

Press right foot or hand switch and release to digitize a point.

Press left foot or hand switch to digitize continuously.

When in the insert mode using the command I, move from one enter window to the next by pressing the space bar until the desired position is reached for insertion.

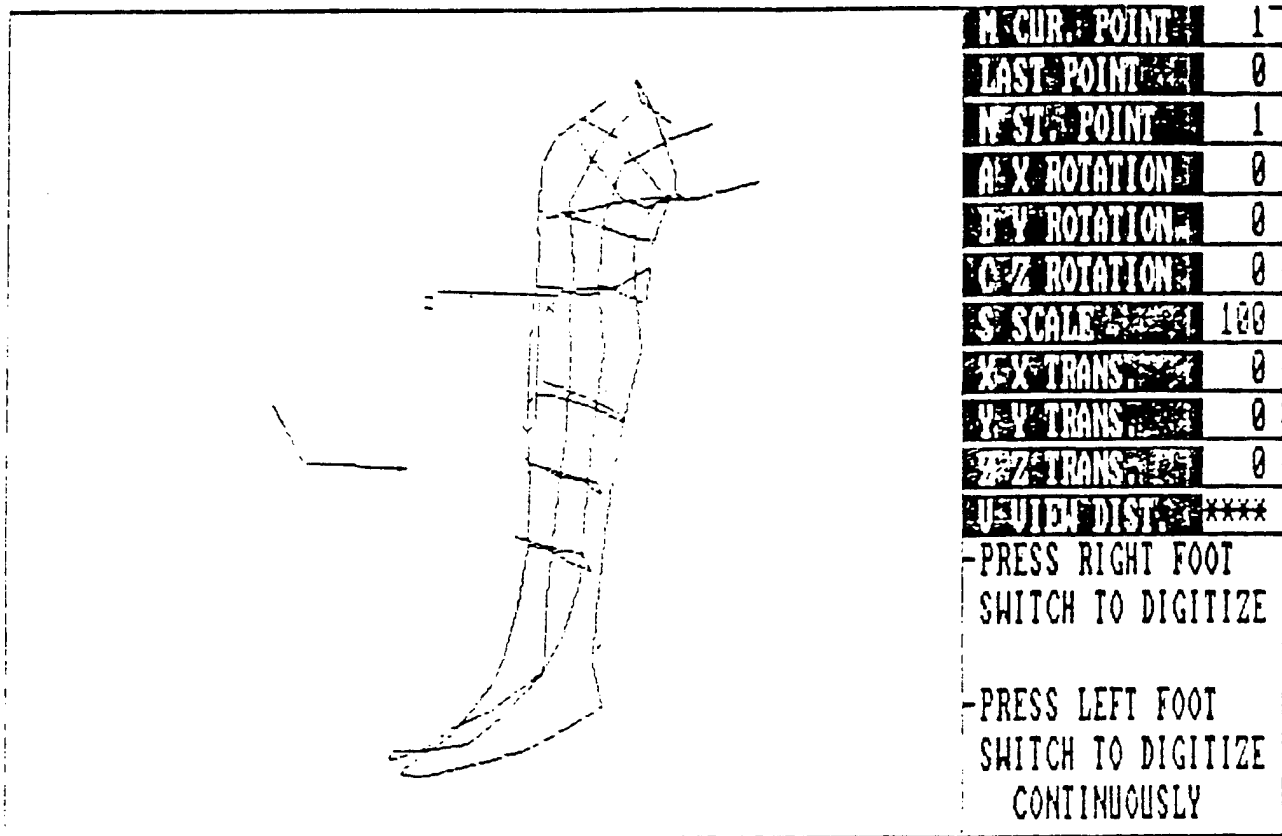


Figure 3-D Digitized Object and Digitization Menu

<A> Rotate about positive X axis 1 degree
 <a> Rotate about positive X axis -1 degree
 Rotate about positive Y axis 1 degree
 Rotate about positive Y axis -1 degree
 <C> Rotate about positive Z axis 1 degree
 <c> Rotate about positive Z axis -1 degree
 <D> Dump the screen on the printer
 <E> Exit to master menu
 <F> Sets the starting point to current point
 <G> Gets an object from disk and displays on the screen
 <H> Help
 <I> Puts you in insert mode for rotation angle as well as displacement and scale
 <J> Join the points as they are digitized or stop joining (changes join from true to false and vice versa)
 <P> Put the object on the screen on the disk
 <Q> Print coordinates of the points starting from starting point up to current points
 <R> Set a new reference (make sure your previous object is saved on the disk)
 <S> Increase the scale by 25%
 <s> Decrease the scale by 25%
 <T> Join a line from starting point to current point
 <U> Join line between points starting from starting point up to the current point (current should be bigger than starting point)
 <V> Increase the viewing distance by 1cm
 <v> Decrease the viewing distance by 1cm
 <W> Double the viewing distance
 <w> Halve the viewing distance
 <X> Move the object along X-axis by 1cm
 <x> Move the object along X-axis by -1cm
 <Y> Move the object along Y-axis by 1cm
 <y> Move the object along Y-axis by -1cm
 <Z> Move the object along Z-axis by 1cm
 <z> Move the object along Z-axis by -1cm
 <>> Advance the current point by one
 <<> Back up the current point by one

For commands such as <Q>, <U> the following procedure should be used: set the starting point using <M> then enter the current point and then use <N> to set the starting point to the current point.

APPENDIX H

List of Boxes and Jigs

<u>Box Number</u>	<u>Dimensions(in)</u>	<u>Suggested Segments</u>	<u>Jig Number</u>
1	2 x 2 x 5	Night Vision Goggles	3
2	3 x 7 x 4	Hands and Feet	3
3	3 x 3 x 10	Forearms	3
4	4 x 4 x 12	Forearms	2
5	4 x 4 x 19	Lower Legs	1
6	8 x 8 x 8	Head	2
7	7 x 7 x 15	Thighs	1
8	11 x 11 x 11	Helmets	1
9	12 x 12 x 18	Small Torso	1
10	14 x 14 x 20	Large Torso	1
11	16 x 16 x 20		1