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AUTOMATED MASS PROPERTIES MEASUREMENT SYSTEM
CALIBRATION PROCEDURES

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PREFACE

The research work described in this report was performed for the Modeling and Analysis Branch, Biodynamics and Bioengineering Division, of the Harry G. Armstrong Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base under Contract No. F33615-85-C-0530. The research was monitored by Dr. Ints Kaleps, Chief of Modeling and Analysis Branch, and was performed by Systems Research Laboratories, Inc., A division of Arvin/Calspan.
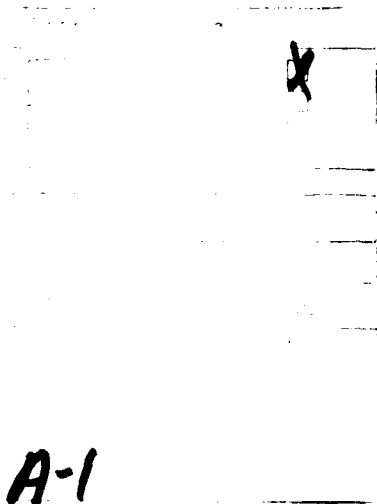
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1.0 INTRODUCTION

This report describes the procedures used to calibrate the automated mass properties measurement system, a system consisting of various components that together measure the mass, center of mass location, magnitudes of the principal mass moments of inertia, and orientation of the principal axes of a given test object. This system, located at the Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, can determine the mass properties of test objects weighing from 0.5 to 450 pounds. It is used for a variety of applications including measuring the properties of manikin segments for modeling purposes or evaluating newly developed helmets and night vision goggles to determine the effects of adding their mass to the head-neck system.

As the system is actually composed of a number of devices that measure different aspects of the mass properties, each of these components must be calibrated separately. A description of the use of each component and the procedure used to calibrate it is presented for all of the devices. After each of these separate elements are calibrated, the accuracy of the entire system is then verified using an aluminum test block. The procedure described herein should be repeated at least once a month and before and after every test series.

2.0 ELECTRONIC SCALE: CALIBRATION PROCEDURE

2.1 THE SCALE

The electronic scale developed by Circuits and Systems, Inc., with a maximum capacity of fifty pounds (50 lbs) or approximately twenty two kilograms (22 kg) is an integral part of the automated mass properties measurement system. The scale consists of the base, which displays the measurement in pounds or kilograms, and the tray, which attaches to the top of the base. Described below is the simple procedure used to calibrate the scale.

- First, the base of the scale should be placed upon a sturdy table or desk with an electrical outlet nearby.

- Next, the tray should be removed from the base. Upon removal, a built-in mercury based level will be found at the center of the base. This should be used to level the base. The legs of the base can be adjusted to achieve the desired position.

- Once this leveling procedure has been performed, the tray must be placed back on the base.

- The scale should be turned on and the desired units (lbs) chosen to measure the calibration weights. The scale is zeroed by pushing the ZERO button.

- Place a two-pound (2 lb) calibration weight on the scale. The scale should read: 002.00 lbs. At this minimal weight, there should be no deviation from the known value.

- Next, two five-pound (5 lb) calibration weights should be placed on the scale. The scale should read 010.00 lbs.

- Repeat the test at 10-pound increments until the maximum capacity of the scale is reached. At the maximum capacity, a 000.01 lb or 00.005 kg deviation is considered acceptable.

- If any of the ranges of measurements differ by more than the acceptable allowance, the project engineer should be notified.

2.2 THE MOMENT TABLE

The moment table assembly consists of the electronic scale, the adjustable stand, and the moment table. This assembly allows the center of mass location of a test object to be determined.

- At this time, the scale base and tray should be assembled and calibrated.

- Both the adjustable stand and moment table must be leveled. This is achieved by using an additional level or inclinometer. The set screws on the adjustable stand must be maneuvered such that the stand and the moment table are both level. Place the level or inclinometer on the moment table while it rests on both the scale's surface and the stand. The level or inclinometer should indicate that the table is level (parallel to the scale's surface). If it is not, adjust the screws on the stand to obtain the desired position.

- Once the scale and moment table are level, a check for accuracy should be performed.

- The accuracy of the moment table assembly is ascertained using the calibration block alone (without a balsa wood box). The block is stamped System Research Labs #43257. The block should be used only for calibrating the automated mass properties measuring system.

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- Placing the X axis parallel to the chock with the y axis should result in a reading of 3.41 lbs ± 0.01 lbs.

- Placing the Z axis parallel to the chock with the X axis vertical should result in a reading of 2.14 lbs ± 0.01 lbs.

- Keeping the Z axis parallel to the chock with the Y axis vertical should result in a reading of 1.27 lbs ± 0.01 lbs.

- If any of the readings are not within these tolerances, then remove the calibration block and check the level of the moment table assembly again. Remember to zero the scale and moment table before placing the calibration block on the table. The complete electronic scale assembly is shown in Figure 1.
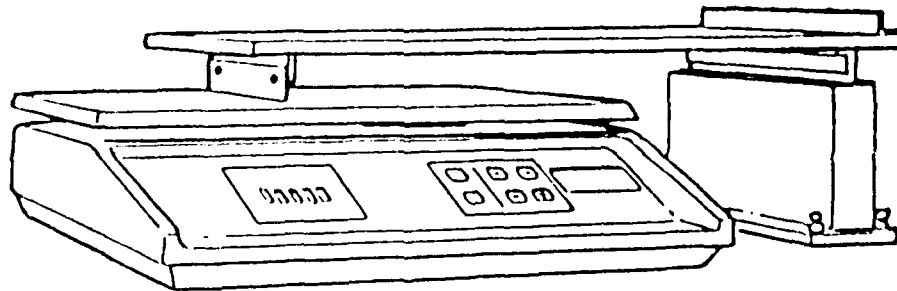

Figure 1. The Electronic Scale, Tray, Moment Table, and Adjustable Stand

3.0 SPACE ELECTRONICS MASS PROPERTIES INSTRUMENT: CALIBRATION PROCEDURE

There are two types of calibrations that must be performed to maintain the mass properties instrument. One is a system calibration using the Space Electronics Universal Test Fixture and two cylindrical steel weights. This calibration determines the exact proportionality constant between the actual moment of inertia and the measured period squared. This system calibration should be performed once every week (usually on Monday), and the results checked against the manufacturer's standard to ensure that the instrument is operating within the specified tolerance.

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The second form of calibration is a moment o. inertia tare that must be performed before any series of tests. The tare moment is measured to allow for the contribution of the test platter that is mounted on the pendulum. In essence, this step redefines the zero mark to the machine as the measured time period of the pendulum plus any equipment that is currently attached to the pendulum (i.e., platter, screws, grid plate, etc.). This should be performed before beginning any test. The measured tare is automatically stored on tape after the tare step is performed. Every time the machine is turned off, or a different tape is loaded into memory the current tare is lost and must be remeasured or read from the tape. Failure to do so results in a measurement of the time period of not only the box (or box plus test object), but a large period which includes the test platter, grid plate, etc. Since this step is very simple to execute and take only about 3 minutes, it is recommended that the tare calibration be performed each time the system is turned on and the tape containing the measurement program is loaded into memory. Mid-day tare calibrations will help reduce zero drift due to changing environmental conditions.

3.1 SYSTEM CALIBRATION

- Insert the Space Electronics tape cartridge into the HP-85B. Turn on the HP-85B, the mass properties instrument, the air, the air dryer, and the console. If the computer (HP-85B) does not return with a prompt within a few moments, turn off the HP-85B and turn it back on, making sure that the tape is inserted correctly.

- Respond to the "WHICH PROGRAM DO YOU WANT TO RUN" prompt with an "M" for the measurement program. (The remaining steps to follow are prompted by the computer but are briefly listed below for clarity).

- Mount the heavy 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 side with gauges, switches, and knobs), the positive X direction should point directly at the front left eye bolt, while the positive Y direction should point directly at the next right eye bolt. Note: The hole marked A must be aligned with the +X direction, while the hole marked E must be aligned with the +Y direction, inscribed on the instrument.

- Mount the two (2) cylindrical weights (S7091 and S7092) into the appropriate holes (S7091 into A and S7092 into E). Make sure that the air is on and then press "continue" when ready. The instrument will now measure the moment of inertia of the table plus the weights.

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- After the average measured time period is recorded by the machine, it will prompt for both weights to be placed at the center of the instrument (hole C) for another measurement. After the weights have been placed in hole C, press "continue" and the machine will proceed with the next measurement.

- At the end of the second measurement, the computer will print out the calibration inertia and the moment of inertia calibration constant. Record both of these values in the Calibration Log, along with the date of calibration.

- Remove the universal test fixture and then perform the moment of inertia tare. Nothing should be on the pendulum except the bare circular test platter. Execute the remainder of the tare step. Note: DO NOT read the tare from the tape - it must be measured!

- From the average measured time period printed out 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. Record the tare moment of inertia on the Calibration Log. Check the tare inertia against the manufacturer's standard and ensure that this moment is within the stated tolerance (it should be between 302.97 306.01 lb in). If it is not, repeat the calibration procedures. If it is still out of tolerance, notify the project engineer.

3.2 TARE CALIBRATION

Note: The following procedure is the same for all of the platters.

- Insert the Space Electronics tape cartridge into the HP-85B computer. Turn on the HP-85B, the mass properties instrument, the air, the air dryer, and the console.

- After the computer prompts you for a "U" or an "M," type "M" for the measurement program, and hit ENDLINE.

- The machine will then prompt you to type the letter of the step that you would like to run. Type "D" for the moment of inertia tare. It will then ask if you would like to read the previous tare from tape (type "Y" or "N"?). It is recommended that you remeasure the tare each time since it only takes a few moments, thus type "N."

- After this is done, hit "continue" and the platter will proceed to rotate 360 degrees and then oscillate until a tare is measured. After the tare is complete, proceed to the next step, which is a moment of inertia measurement. The menu for the selection of the steps will be automatically displayed on the screen of the HP-85B. The Space Electronics automated mass properties measuring system and its components are shown in Figure 2.
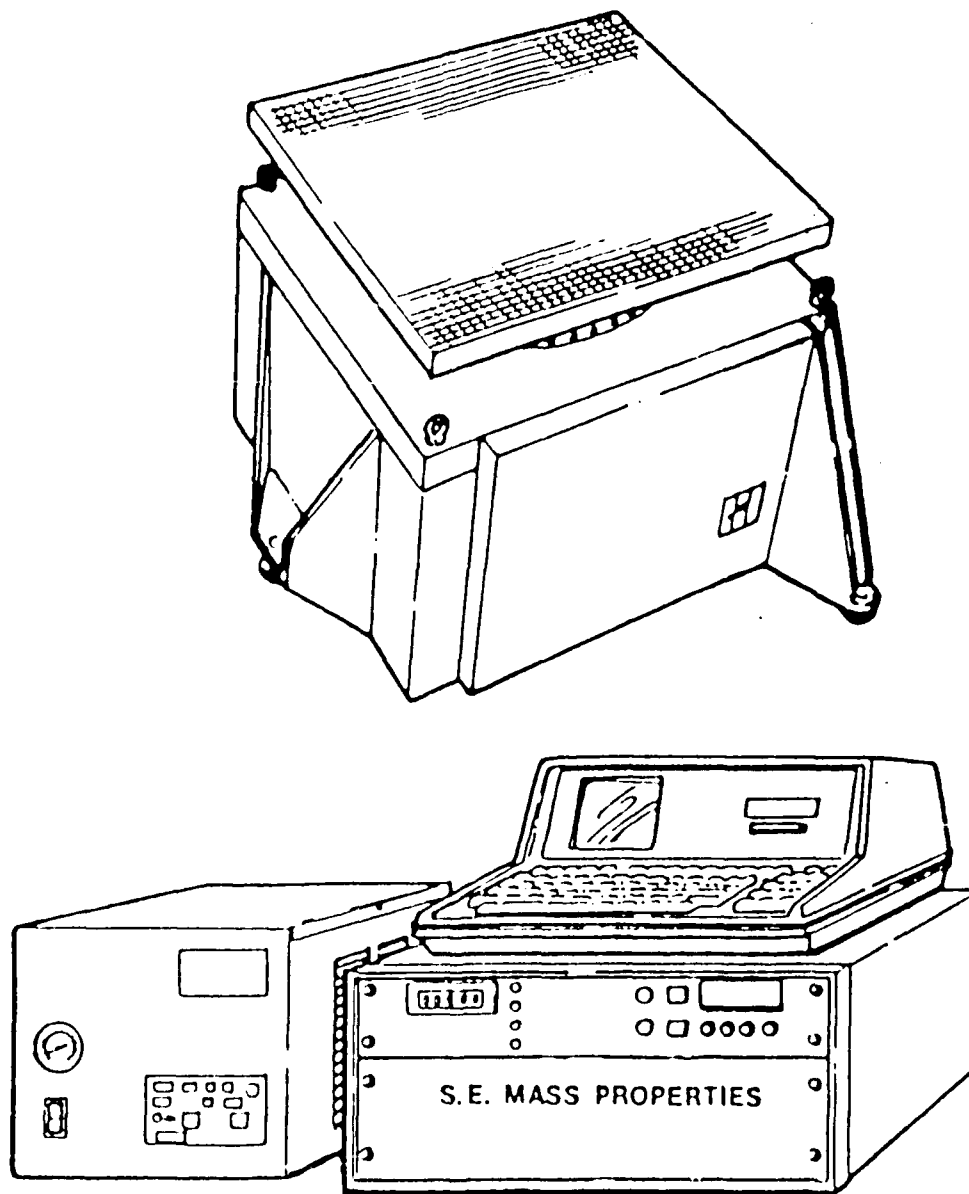
Figure 2. The Mass Properties Instrument, Air Dryer, HP-85B, and the Console

4.0 PERCEPTOR: CALIBRATION PROCEDURE

The Perceptor should be calibrated at the beginning of each month or any time unacceptable results are achieved. Unacceptable results are coordinates or distances which vary from the known values by more than one tenth of a centimeter (0.10 cm). The calibrating procedure can be performed by one person but two are recommended. The proper setup is essential. All of the tools and devices needed to perform this calibration can be found in the drawer under the Perceptor and the Z-100.

4.1 SET UP

* First, connect the cable which will extend from the Perceptor to the Zenith Z-100. The cable is clearly marked. One end indicates the port on the Perceptor (port number J2) to which it should be connected, while the other end should be inserted into the port closest to the center of the back of the Perceptor.

* Next, the Perceptor's power cable and foot pedal cable should be inserted into their appropriate receptacles.

* The power cable to the Z-100 may now be inserted.

4.2 PROCEDURE

* After setting up the Perceptor and the Z-100, remove the rubber bumper guards on the Perceptor's frame.

* Next, the calibration device will be set up. The device, as shown in Figure 3, is a machined tool which is used only for the calibration of the Perceptor.

* Fully extend the arm of the Perceptor to the right of the instrument (as viewed from the front of the instrument) at exactly ninety degrees (90°) with respect to the frame (see Figure 4).

* Place the calibration device above and below the extended armature (see Figure 4). Tighten the screws to secure the arm in this position.
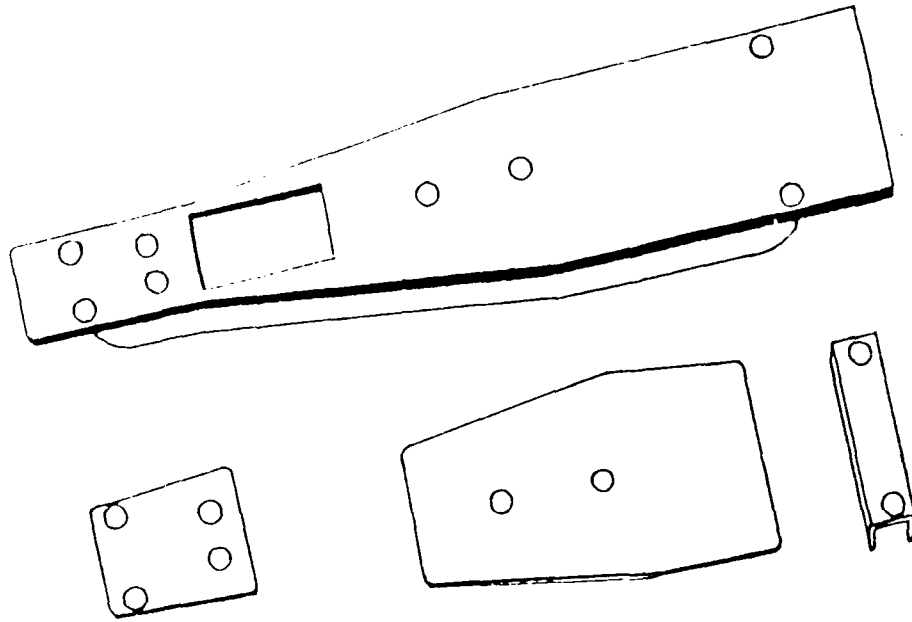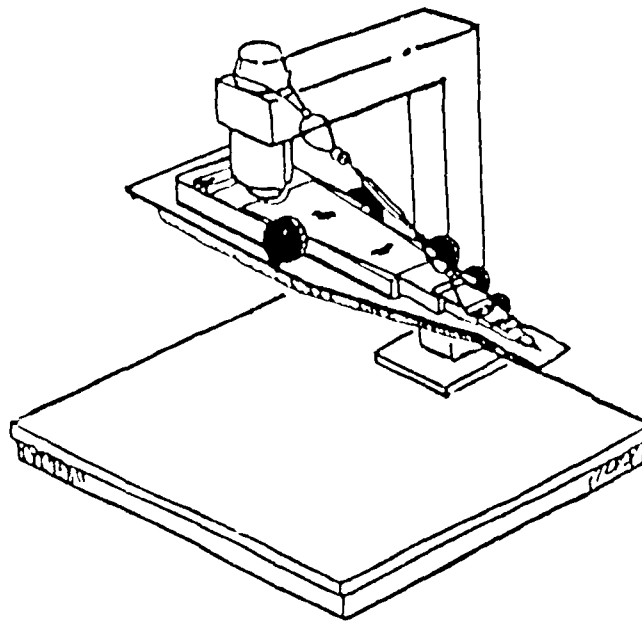
Figure 3. Calibrating Device

Figure 4. The Perceptor with its Armature Extended 90 Degrees and the Calibrating Device

- The most difficult and yet important part is getting the arm extending outward at exactly 90°. This can be achieved by either using a tool (such as a T-square), or by using an aluminum block. Press the block against the front of the frame of the instrument vertically so that it can be used as both a guide and a reference to the armature. Notice the set screw located on the largest joint (directly below the frame). This will be used to secure the armature once the armature is at exactly 90°.

- Once this has been achieved, assemble the lanyard (with turnbuckle) as shown in Figure 4. Place the bubble level on the cap of the first pot and estimate the level of the Perceptor frame. Move the level to the armature and by adjusting the turnbuckle, position the aramature parallel with the Perceptor frame.

- Now, turn on the Z-100 and enter the date and time.

- Once the E prompt appears, access directory H by typing in "H:" and (RET).

- Then, type in: PERCEPTR at the prompt and (RET). Note: There is no "O" in the response "PERCEPTR."

- The computer will then display a choice of eight (8) commands. Notice that number seven (7) is: CALIBRATE. Refer to the separate document titled "The Automated Mass Properties Measuring System Testing Procedure" for an explanation of all the possible options.

- Choose menu item number 7 and return. The instrument will begin sending data instantly. Once the calibration is complete, which is signified by a BEEP sound, the menu will reappear.

- data received by the Z-100 are stored as offsets. To see these offsets, choose number 1 on the menu displayed by the computer. Briefly, these offsets control the potentiometer based joi. in the instrument. The last offset will always be 0000. For further reference, see "The Automated Mass Properties Measuring System Testing Procedure."

4.3 CHECKING THE OFFSETS' ACCURACY

- Once a new set of offsets has been captured, loosen the set screw to allow the arm to rotate freely. Carefully remove the calibration device, making sure the spring-activated pivot does not

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allow the armature to swing up and hit the frame. The rubber guards should also be put back on the frame of the instrument to ensure that no damage is done to the instrument's armature.

- Using the aluminum block, which is stamped 1.75 (its weight in pound units) and is marked with dimensions of the lengths of the sides, the accuracy of this set of offsets can be determined. There should be an origin, a Z-axis point, a Y-axis point, and a X-axis point (see Figure 5). If these marks and measurements are not clear, remark the block. These points will be used to develop an orthogonal, right-handed coordinate system on the block, and the measurements will indicate the accuracy of the offsets.
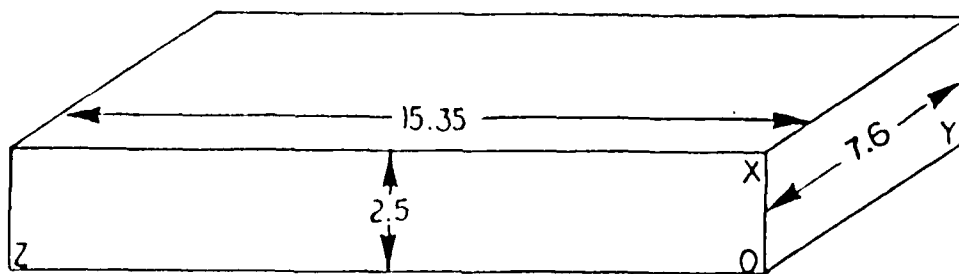

Figure 5. A Calibration Block Used for Evaluation of Accuracy

- Place the block on the platter of the instrument so that the stylus, located at the end of the armature, can easily reach all the desired points.

- Choose number 6 (Capture Data) on the menu and (RET).

- The program will read: ENTER FILE HEADER. Do so and (RET). This file header can be as long as needed. Note: This is not the name of the file in which the data will be stored.

- Next, a note will appear which states:

  If more than one set is to be digitized, the first three landmarks in the second and succeeding sets must correspond to landmarks digitized in a previous set. These will be referred to as reference landmarks, and will establish the relationship between sets.

- The note above does not apply in this case because only one set of points is needed for the accuracy check.

- Next, the following will appear: HOW MANY SETS OF POINTS WILL BE ENTERED? Enter 1 and (RET).

- Now, the program will prompt: TYPE IN THE NUMBER OF POINTS TO BE DIGITIZED IN THIS SET. Do so and (RET). Note: At least four (4) of the possible eight (8) points should be taken. These four (4) points should be the block origin, the Z-axis point, the Y-axis point, and the X-axis point (digitized in that order, always!).

- Next, the program will prompt: ENTER LABEL NOW. Do so and (RET).

- Now, the program prompt: ENTER COORDINATES NOW will appear. Do this by placing the stylus tip at the desired point and depressing the foot pedal. A BEEP will signify the transfer. This process of ENTER LABEL NOW and ENTER COORDINATES NOW will continued until all the points requested have been entered.

- The program will ask: IS INERTIAL DATA AVAILABLE? TYPE YES OR NO. At this point, just (RET). Throughout the rest of the program just hit (RET) any time information is requested. Note: This procedure should only be followed when checking the offsets' accuracy.

- The data just captured can be viewed in three (3) different forms and in three (3) different files. The file, INPUT3D1.DAT contains the points in a transformed axis system as well as any inertial data. The file INPUT3D3.DAT contains the points in "raw" form (points in the laboratory coordinate system). The file that should be examined is INPUT3D5.DAT. This file not only contains the points as "raw" data but also transformed into the necessary axis system. To access this file, choose number 8 (Terminate Program) from the menu.

- Type EDT INPUT3D5.DAT at the H prompt. Using the arrows to move the cursor, the points to examine are the points that are in the form: LANDMARKS AFTER TRANSFORMATION.

- The measured values should be within 0.10 cm (one tenth of a centimeter) from the known values. An example of an acceptable set of points is shown in Figure 6.

```
BLOCK  TEST  FOR  PERCEPTOR  CALIBRATION   6-3-88
```

| POINTS BEFORE TRANSFORMATION   SET 1 | | CENTIMETERS | | |
LANDMARKS		X	Y	Z
4				
ORIGIN		-.79	-12.76	-35.52
Z-AXIS		-12.23	-2.44	-35.54
Y-AXIS		4.30	-7.12	-35.43
X-AXIS		-.77	-12.66	-33.02
POINTS AFTER TRANSFORMATION SET 1		CENTIMETERS		
LANDMARKS		X	Y	Z
4				
ORIGIN		.00	.00	.00
Z-AXIS		.00	.00	15.41
Y-AXIS		.00	7.60	.00
X-AXIS		2.50	.10	.05

Figure 6. A Set of Acceptable Points

5.0 CALIBRATION OF AUTOMATED MASS PROPERTIES MEASURING SYSTEM USING THE 12-POUND RECTANGULAR ALUMINUM BLOCK

A test using the rectangular aluminum block weighing 11.97 lbs with dimensions 3 inches x 5 inches x 8 inches is used to evaluate the accuracy of the entire measurement process. This test is performed using the electronic scale, the Space Electronics mass properties instrument, and the Perceptor. The block is placed in a balsa wood box, and a series of small complete tests are conducted to determine the error associated with the mass properties measurement process. Included in the test results are the object's mass, center of gravity coordinates, magnitudes of the principal moments of inertia, the orientation of the unassigned principal axes with respect to the box axis system, and the orientation of the assigned principal axes with respect to the geometric axis system. Comparing these data to analytical data, the accuracy of the whole system can be evaluated. If any of the data appear to be out of tolerance, then the project engineer should be informed so that the proper measures can be taken.

• The document titled "The Automated Mass Properties Measuring System Testing Procedure" explains the process of measuring the mass properties of a test object or segment secured in a balsa wood box. This procedure should be carefully followed to assure the minimal possibility of error. Although the procedure is briefly stated below, the document should be used as the main source of reference.

• Once th document has been thoroughly reviewed, the block should be in the balsa wood box number 5. Figure 7 shows how the block should be oriented in the box. Not shown in the sketch are two indentations in the box marked with permanent marker which can be used as guides for placement of the block in the box. The velcro straps may not be adequate for securing the object as needed, so strips of duct tape can be used.
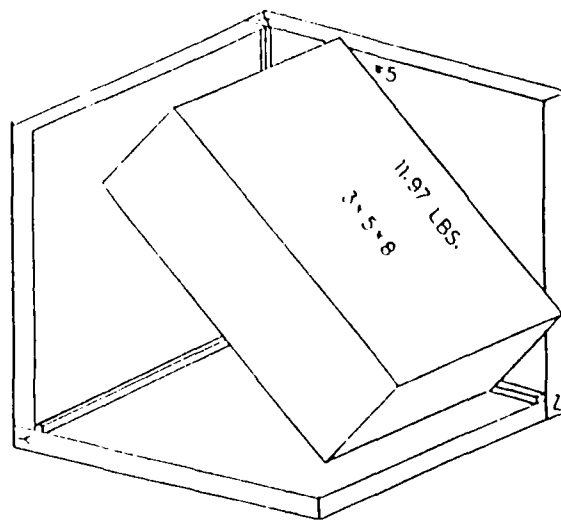

Figure 7. The 11.97-Pound Block Properly Oriented Within Box Number 5

• Next, the composite's (box plus test object) mass and center of gravity coordinates should be found using the scale and moment table.

• The moments about the axes specified in the above mentioned document should be measured using the Space Electronics mass properties instrument.

• Next, the measurements should be transferred from the HP-85B to the Z-100 so that the measured properties of the block can be combined with the digitized data.

• Preceding the data transfer, the block should be digitized with the use of the Perceptor. The box origin and Z, Y, and X points should first be digitized followed by the block origin Z, Y, and X points.

- Next, the appropriate file (INPUT3D1.DAT) should be edited and formatted correctly so that the data can be transformed by the program which computes the final results (MECHAXIS).

- The results of the data output by MECHAXIS are to be used to compare against the analytical values presented below. The measured values should fall within the allowed tolerance for each of the properties.

- The mass of the block should be:

$$.97 \pm .01 \text{ lbs or } 5.43 \pm .005 \text{ kg}$$

- The center of mass should be found at the following coordinates:

$$CM_X: \ 1.51 \text{ in} \pm 0.15 \text{ in} \quad \text{or} \quad 3.84 \pm 0.38 \text{ cm}$$
$$CM_Y: \ 2.53 \text{ in} \pm 0.15 \text{ in} \quad \text{or} \quad 6.43 \pm 0.38 \text{ cm}$$
$$CM_Z: \ 4.03 \text{ in} \pm 0.15 \text{ in} \quad \text{or} \quad 10.24 \pm 0.38 \text{ cm}$$

- The magnitudes of the principal moments of inertia should be:

$$X: \ 73.785 \pm 1.11 \text{ lb in}^2 \quad \text{or} \quad 215.917 \pm 3.24 \text{ kg cm}^2$$
$$Y: \ 90.199 \pm 1.35 \text{ lb in}^2 \quad \text{or} \quad 263.949 \pm 3.96 \text{ kg cm}^2$$
$$Z: \ 34.522 \pm 0.52 \text{ lb in}^2 \quad \text{or} \quad 101.022 \pm 1.52 \text{ kg cm}^2$$

- The direction cosines (in degrees) of the principal axes with respect to the block axis system should be:

$$\begin{bmatrix} 0 & 90 & 90 \\ 90 & 0 & 90 \\ 90 & 90 & 0 \end{bmatrix} \pm 2 \text{ degrees}$$

6.0 REFERENCES

Albery, C., Whitestone, J., and Lephart, Alan, Ph.D. _The Automated Mass Properties Measurement System Testing Procedure_, Unpublished Report.

Bartol, A., Whitestone, J., and Lephart, Alan, Ph.D. _The Automated Mass Properties Measurement System Accuracy Report_, Unpublished Report.