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MASS PROPERTIES TEST PROCEDURE FOR MANIKIN HEADFORMS AND HELMET SYSTEMS

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The mathematical modeling and comparison of manikin headforms and helmet systems requires that the mass properties be accurately determined. The specific properties that must be known are the weight, center of gravity location, magnitudes of the principal moments of inertia and orientation of the principal axes. This data is compared to the specifications of a specific program and also provides insight into issues such as helmet comfort/fit, fatigue and head accelerations/neck forces during ejection or emergency landings. The Mass Properties (M.P.) System and associated software provide a relatively simple method for measuring these mass properties. This document is intended for use by persons responsible for operating the M.P. System. Included in this report are theoretical calculations, a description of materials required, and step-by-step procedures for system set-up, calibration and determination of weight, center of gravity, and magnitude and orientation of the principal mass moments of inertia.

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TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

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1.0 INTRODUCTION

The precise determination of mass properties of a rigid body requires a defined test part coordinate system and an accurate measurement system. This document details the coordinate system to be used for referencing the mass properties of manikin headforms and helmet systems and provides requirements specific to fitting helmet systems to the test headform. The test procedures may also be adapted to measure mass properties of objects other than helmet systems and headforms. Additionally, this document reviews materials required and theoretical calculations for readers with further interests. Sections 4 and 5 provide step-by-step procedures for system set-up, calibration and test part measurement. The document concludes with procedures for analyzing the data and producing documentation including entry into the Helmet Applied Technology (HAT) Team mass properties data base.

2.0 TEST PART DEFINITION

2.1 HEADFORM COORDINATE SYSTEM

A standard mechanical based coordinate system for headforms and helmet systems was adopted for referencing CG location and mass moment of inertia data. This coordinate system allows direct data comparison of headforms and headform/helmet system combinations. Data referenced to this coordinate system may also be translated into other coordinate systems such as the anatomical coordinate system.

The adopted coordinate convention for this test method places the origin of the "headform coordinate system" in the mid-sagittal plane on the line interconnecting the Hybrid III head/neck joint centers. (See General Motors Corporation Drawing No. 78051-61, Head Assembly Complete - Hybrid III). This line is defined as the y-axis. The z-axis is perpendicular to the base plane of the nodding joint, which is the top part of the neck assembly. The x-axis is parallel to the base plane of the nodding joint with the positive direction toward the front of the neck. This joint center origin is intended to represent the midpoint of the occipital condyles of the human head.

This headform coordinate system can be related to the features of the Hybrid headform as follows: +X out toward the nose, +Y out toward the left ear, and +Z normal to the XY plane toward the crown. A side view of the Hybrid III head and neck assembly with the described headform coordinate system is shown in Figure 1. This coordinate system also applies to a Hybrid II headform which has been machined to mount on the Hybrid III neck in the same manner. This type of Hybrid II headform is also known as the ADAM headform.

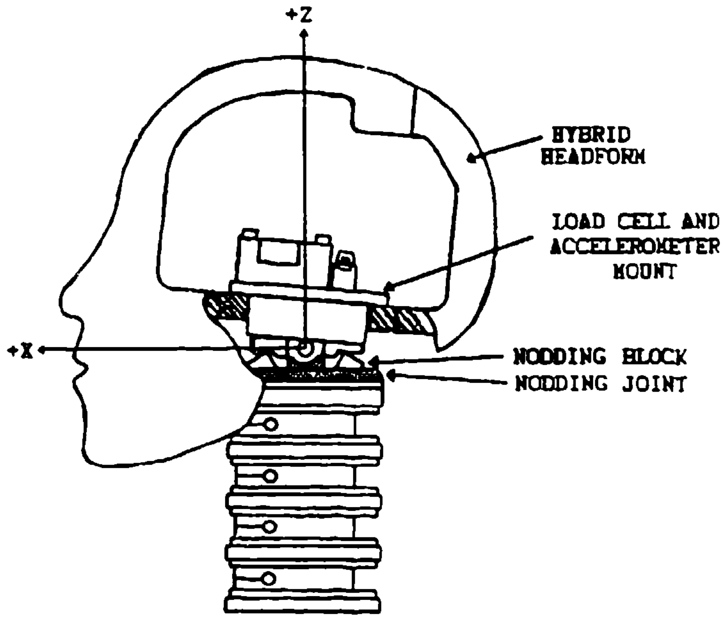


Figure 1
Headform Coordinate System

2.2 HELMET FITTING REQUIREMENTS

Helmet fit to the test headform is a critical factor for mass properties determination. Every attempt to simulate the "as-worn" condition of the helmet system must be made. For example, helmet liner fitting procedures are required to be conducted prior to weight determination since methods used to create some custom fit liners add weight to the helmet system. The same fitting procedures used to fit a helmet to an aircrewman must also be followed when fitting to the test headform. Regardless of the headform type, the following checklist is currently used in preparing and fitting helmet systems for mass properties testing.

* Helmet size shall match that which corresponds to the test headform to be used, in accordance with the NAVAIR 13-1-6.7 manual for aviation helmets currently in USN/USMC fleet use. Prototype helmet size selection, if determined to be subjective, will be on a trial basis, without being excessively loose or tight over the ears, at the forehead, or in the nape area.

* Liners shall be in the as-worn condition, with form-fit procedures performed on the test headform for which tests will be conducted.

* All helmet subcomponents such as communication devices, visor assembly, oxygen mask, etc., shall be in accordance with NAVAIR 13-1-6.7. Prototype helmets shall include all of the equal or proposed replacement parts and be noted as such.

* Cables departing from the helmet shell must be detached approximately 2 inches from the helmet shell to avoid supporting weight which would not be supported by the head and neck when the helmet system is in use.

* Oxygen hose shall be disconnected at the mask.

* Earcups shall be checked for symmetric alignment as neither Hybrid series headform has ears.

* Innermost visor shall be in the down position with the edge interfacing properly with the oxygen mask, minimizing any gap between them.

* Nape and chin straps shall be tightened without causing excessive shell flexation.

3.0 MATERIALS AND THEORETICAL CALCULATIONS

3.1 MEASUREMENT SYSTEM DESCRIPTION

Determining the weight, center of gravity (CG) location and mass moments of inertia (MOI) of headform and helmet systems is accomplished using the Mass Properties System [1]. The components of this system include:

* KGR30 Mass Properties Instrument (Space Electronics Inc.)
* Electronic Scale (Sartorius Inc.)
* NAWCACDIV developed: Test Fixtures, Lab Worksheet and Calculations Software

CG location and mass moments of inertia are determined from the same test platform using the KGR30 mass properties instrument. Weight is determined separately using the electronic scale.

The KGR30 mass properties instrument[2,3], shown in Figure 2, is a general purpose measuring instrument capable of testing parts whose combined weight, including test fixtures, does not exceed 300 lbs. The offset moment limit of 33 in-lb is the true limiting factor of the test platform.

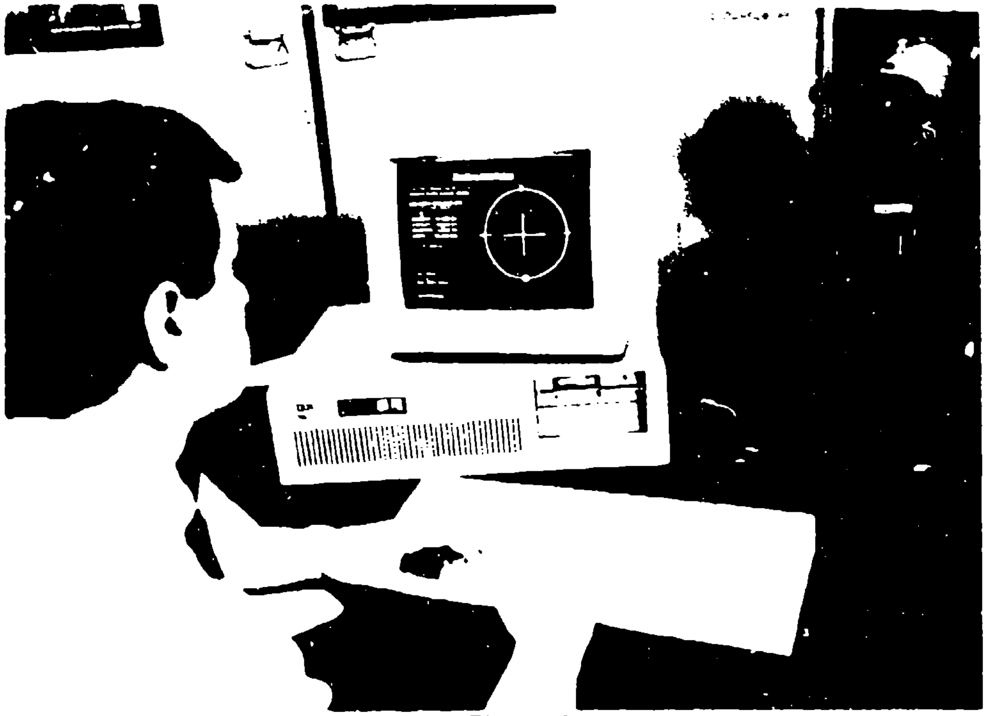


Figure 2
KGR30 Mass Properties Instrument

The KGR30 instrument determines the moment of inertia (I_Z) of the test item about the test platform center of rotation and locates its CG in the X and Y coordinate plane of the test platform surface. The KGR30 test platform, on which the test parts must be securely mounted, is shown in Figure 3.

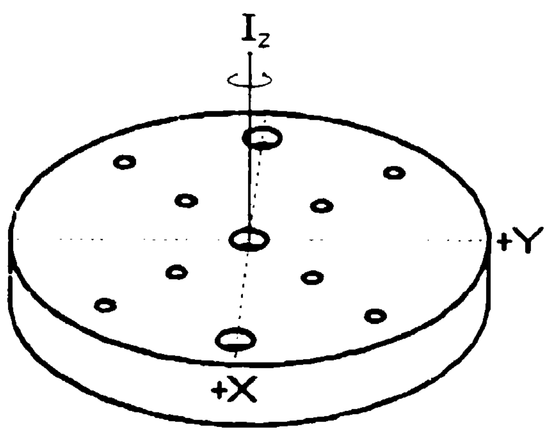


Figure 3
KGR30 Test Platform

The following sections detail the function of the KGR30 for CG and MOI determination. The system design section then discusses the required test positions and calculations necessary to determine complete mass properties of the test part.

3.2 CENTER OF GRAVITY DETERMINATION

The test item CG is located by measuring the offset moment due to the displacement of the test item CG from the measurement axis, or center of rotation, of the instrument. This moment is sensed by a force transducer which is located at a fixed distance from the pivot axis of the test platform. The measured moment is divided by the weight of the test part to determine the location of the CG relative to the pivot axis of the machine. The test platform of the instrument is rotated at 90 degree intervals through 360 degrees, facilitating measurement of CG in the two axis plane of the test platform surface.

To calibrate the instrument for CG, a cylinder with known weight is placed on a calibration beam at a fixed distance from the pivot axis. The weight is then moved to a second location on the beam. The change in offset moment is the product of the weight (W) times the distance moved (D) and results in a change in output (C) of the force transducer. The units of measurement are typically:

transducer output ---------- digital counts (C)
distance ------------------------- inches (in)
weight ------------------------- pounds (lb)

A calibration constant (K) for the machine is calculated by the equation:

$$K = WD/C \text{ (lb-in/count)}$$

When a test item is measured, the offset moment (M) is calculated as:

$$M = CK \text{ (lb-in)}$$

where C is the difference in transducer output (counts) between the test item measurement and tare (zero reference) measurement.

3.3 MOMENT OF INERTIA DETERMINATION

Moment of inertia (MOI) of the test item is measured by the inverted torsional pendulum method. In this method, a low friction gas bearing supports the test part. The upper end of a torsion rod is attached to the underside of the test platform and is fixed at its lower end. The test platform is automatically rotated slightly, and released. The resulting period of oscillation is a function of the stiffness of the torsion rod and the moment of inertia of the oscillating mass. The MOI is equal to:

$$MOI = K\ (T_2^2 - T_1^2)$$

where K is the machine calibration constant, T_1 is the period of oscillation in arbitrary time units of the test platform including fixtures and T_2 is the period of the test part, test platform and fixtures.

To calibrate the instrument for MOI, two cylindrical calibrated weights (W_1 and W_2) are placed at known opposite radial locations (D_1 and D_2) from the center of the test platform and the period of oscillation (T_1) is measured. The weights are then moved to the center of the test platform and the new period of oscillation (T_2) is measured. The change in period is related only to the change in MOI (M_n) of the oscillating mass, which is:

$$M_n = W_1 D_1^2 + W_2 D_2^2$$

For a torsion pendulum, the period of oscillation squared is directly proportional to the MOI of the oscillating mass. Therefore, a calibration constant (K) may be calculated from:

$$K = M_n / (T_2^2 - T_1^2)$$

3.4 SYSTEM DESIGN

Of paramount importance to the accuracy of the mass properties system is alignment of the measurement coordinate system and the test part coordinate system. The alignment is accomplished using test fixtures developed specifically for mounting manikin headforms. Precise alignment simplifies CG and MOI calculations by eliminating offset distances between origins. To improve measurement accuracy, a rigid neck was also designed to replace the flexible Hybrid III neck. This minimizes deflection during testing which can result in erroneous readings. The rigid neck is not representative of the Hybrid III neck with respect to CG and MOI. However, mass properties similarity is not necessary since the neck is part of the fixture assembly and not the test item. The rigid neck, shown in Figure 4, mates with the nodding joint of the Hybrid III neck assembly, enabling attachment of the test headform.

To define the mass properties of our test part the following properties are determined: mass, center of gravity and mass moments about six different axes. These axes include the three previously defined headform coordinate axes (I_x,I_y,I_z) and those at 45 degrees between the positive axes (I_{xy},I_{xz},I_{yz}) as shown in Figure 4.

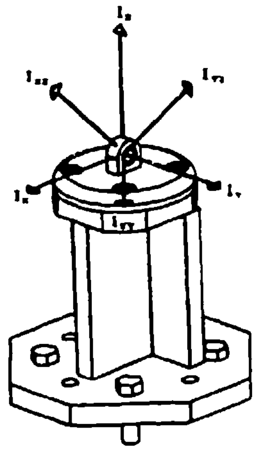


Figure 4
Axes for Mass Moment of Inertia Measurement

Mass moment measurements about each of the six positive headform axes (I_x,I_y,I_z,I_{xy},I_{xz},I_{yz}) enable calculation of the products of inertia (POI) in each plane. POI calculations are simplified and accuracy is maximized by recording moments of inertia about axes precisely 45 degrees between the positive headform coordinate axes (I_x,I_y,I_z). MOI and POI values are then used to calculate Principal Mass Moments of Inertia (PMMI) and principal axes orientations. This is accomplished by inserting MOI and POI values determined at the CG into a symmetric inertia tensor matrix. The matrix is then diagonalized to determine Eigen values and vectors which correspond to the PMMI and the associated principal axes orientations.

The six MOI values and 3-dimensional CG location are determined from a series of six test positions. For each test position, fixtures are mounted and a Tare measurement recorded. This enables the mass properties system to subtract the properties of the test platform and fixtures from the part measurements which follows. Part measurements include the headform and helmet system. This measurement sequence yields mass properties of the headform and helmet system only, through the use of calculation software. The measurement sequence can be described as a three step process:

1) TARE Measurements (Fixture Only)

2) Part Measurements (Fixture and Test Part)

3) Calculations (Determination of Test Part Only Properties)

Each of the six test position aligns one of the headform coordinate system axes (denoted with subscript H) with the KGR30 instrument vertical z-axis (center of rotation). The global coordinate system of the KGR30 instrument is denoted with the subscript G. The KGR30 instrument measures the moment about the aligned axis and outputs this as I_{ZG}. CG data is simultaneously calculated for the two headform coordinate axes which are parallel with the test platform surface. A basic example is Test Position 2 (Figure 5). MOI about the headform coordinate z-axis (I_{ZH}) is measured concurrently with the headform CG coordinates X_H and Y_H. Test Positions 1-6 are presented in Appendix A.

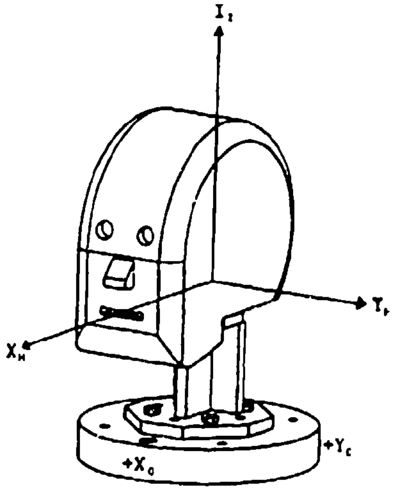


Figure 5
Test Position 2

KGR30 Output			Headform Coordinate
MOI	I_{ZG}	=	I_{ZH}
CG	X_G	=	X_H
	Y_G	=	Y_H

Note that for Test Position 2 only, both CG coordinates of the KGR30 instrument directly correspond to those of the headform coordinate system (i.e., $X_G=X_H$, $Y_G=Y_H$). For the other test positions where CG is determined, only one headform CG coordinate is aligned with the KGR30 coordinate convention. The KGR30 CG coordinates must therefore be matched with the corresponding headform coordinates as detailed in Appendix A (Test Positions).

For Test Position 1, the y-axis of the headform is aligned with the measurement table to measure I_{YH} and headform CG coordinates measured in X_H and Z_H. For Test Position 3, the headform is rotated to align the x-axis of the headform (I_{XH}) with the KGR30 vertical axis while the headform CG is measured in Y_H and Z_H. Test Positions 4, 5 and 6 align the headform coordinate system for MOI measurements at a 45 degree angle between the positive axes of the headform coordinate system, determining I_{xy}, I_{xz}, and I_{yz}, respectively.

4.0 EQUIPMENT SET-UP PROCEDURES

4.1 SET-UP PROCEDURES

Figure 6 is used to locate the parts of the Mass Properties System as referenced in this procedure. For example, (*8) refers to the location of the test platform.

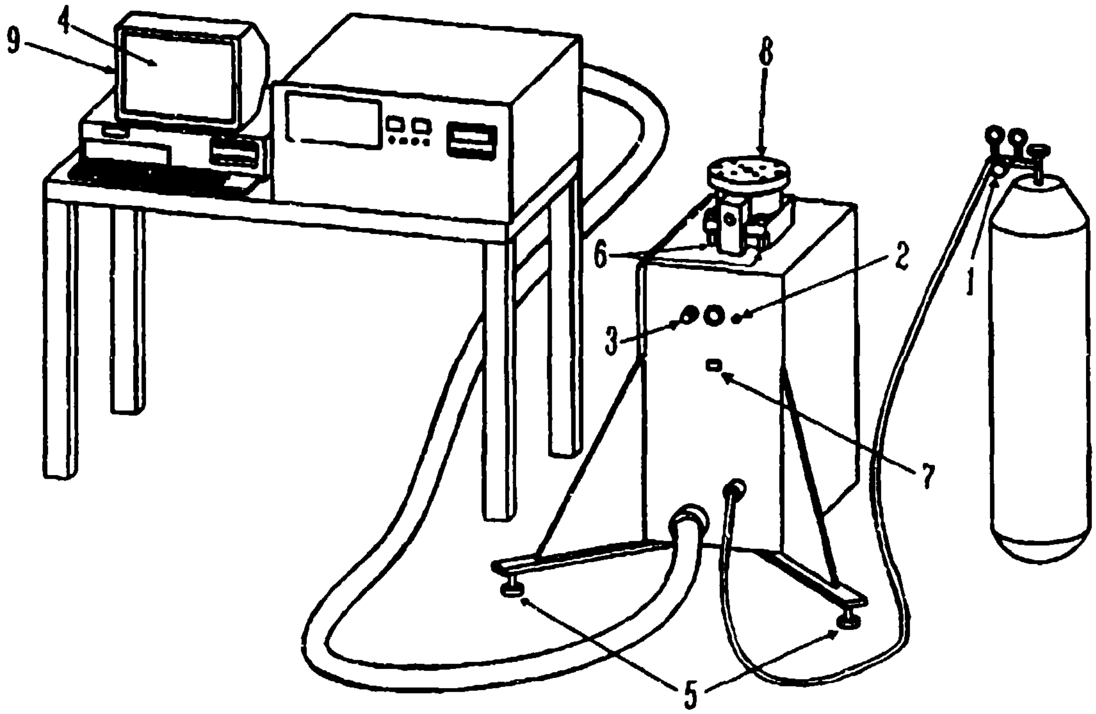


Figure 6: Mass Properties System

1 Regulator Output
2 Purge Switch
3 Bearing Pressure Regulator
4 Computer System
5 Leveling Pads
6 Support Screws
7 Rotation Control Button
8 Test Platform
9 Data Transfer Switch Box

The following list should be used in preparing the KGR30 mass properties instrument for testing.

4.1.1 Initial Preparation

1. The system power switch should be in the **OFF** position.

2. Set the Data Transfer Switch (*9) to **A-KGR30**.

4.1.2 Gas Settings

1. Connect the gas line between the instrument and the source of pressurized nitrogen. Only nitrogen or clean dry air can be used. Normal shop air supplied by standard compressors contains oil and water that will damage the gas bearing used in this instrument.

2. Set the pressure at the regulator output (***1**) on the nitrogen bottle to **75 +/- 5 psi**. Place the purge switch (***2**) in the **OFF** position and set the bearing pressure regulator (***3**) to **45 +/- 3 psi**.

4.1.3 Computer Operation

1. The computer can now be switched **ON** (***4**) and will display a menu system. Select the mass properties option from the menu and sub-menu. The KGR30 main menu will be displayed as shown below. Descriptions of the main menu selections are presented in Appendix B.

>>>>> MAIN MENU <<<<<

OPERATOR: NAME
DATE: MONTH, DAY,YEAR
TIME: HOURS, MINUTES, SECONDS
TEST PART ID: TEST PART NAME, POSITION #, RUN #
TEST SERIAL NUMBER: xxxx

SELECT A FUNCTION KEY OPTION BELOW:
F1: Update Test Information
F2: CG/MOI Part Measurement
F3: CG/MOI Tare Measurement
F4: CG/MOI Calibration
F5: System Utilities
F6: Calculations
F10: Quit

2. Select **F5** (System Utilities) followed by **F2** to Purge Data From Disk. This will prevent using old data as part of any new calculations.

4.1.4 Leveling the Instrument

1. Table support screws (***6**) must be raised and the gas turned **ON** (***2**) during leveling. Place the carpenters level on the KGR30 test platform and if necessary

(it rarely should be) adjust the leveling pads (*5) at floor level until the bubble is centered.

4.1.5 Avoiding Erroneous Data

1. Do not touch the test platform or upper part of the instrument when a measurement sequence is in progress.

2. Avoid drafts during testing. Even an air conditioner operating in the immediate area may affect test results. Excessive vibrations may also affect test results. Subsequently, some other activities may need to be restricted during testing.

3. Read all instructions displayed on the screen following menu selections. It is critical to raise the support screws (*6) for CG measurements and lower them until finger tight for MOI measurements. This is the most common operating error when using the instrument. Screws should only be finger tight for MOI measurements. This corresponds to approximately 1/8 turn after contact with the base. Overtightening of the screws can buckle the flexure pivot, and the lean resulting from uneven tightening can cause a gravity pendulum error.

4.1.6 Avoiding Damage to the Instrument

1. Do not hand rotate the measurement table surface. All turning should be accomplished with bearing pressure ON, using the rotate button (*7) located below the bearing pressure gage.

2. Do not exceed full scale moment (33 in-lb) when loading part. This can occur if the test part is lowered on the instrument improperly or if the part and fixture are not properly balanced.

3. Remove any attachment hardware before lifting part from fixture. Otherwise an upward force will be applied to the test platform of the instrument.

4. Never attempt to lift the machine by its measuring structure. Either use a fork lift under the machine base or insert I-bolts into the threaded holes on the top of the machine base and lift with chains or slings.

4.1.7 Additional Equipment

The following equipment is required to conduct the full set of tests.

Carpenters Level: Required to verify proper leveling of the test platform.

Adjustable Wrenches: Two are required to assemble the test fixtures for each test position.

Allen Wrenches: English and Metric size sets are required for securing fixtures to the test platform, assembly of the headforms and other minor modifications.

Screwdrivers: Phillips head and standard slot head screwdrivers are required for assembly of test fixtures.

Rubber Mallet/ 1/4" dia. shaft: Helpful for inserting and removing the connecting pin used to mount the headform to the neck assembly.

Glue stick / Flashlight: Useful for correcting any problems encountered with the washers when mounting the headform.

Calculator: Helpful for calculation of CG heights, total weights, and mean values of other measured mass properties data.

4.2 CALIBRATION PROCEDURE

The choice must occasionally be made whether or not to calibrate the instrument. If the instrument has been moved, or if it has not been calibrated for one week or more, then it is recommended that the calibration procedure be followed. If the instrument has been calibrated earlier in the day, the same calibration values at that time can be used without the need for repeating the calibration procedure.

1. A system calibration is initiated by selecting **F4** from the main menu. CG and MOI calibrations are separate options but both must be conducted to fully calibrate the KGR30 instrument. Once CG or MOI calibration has been selected, the computer will provide step by step instructions for locating the appropriate calibration weights and I-Beam. The required positions of the weights on the test platform (*8) are referenced with letters A-E for each placement position on the I-Beam. At numerous points in the sequence the operator may select **F9** to abort the sequence and return to the main menu. A typical calibration set-up is shown in Figure 7.

2. Select **F1** for CG calibration. Position I-Beam and calibration weights per screen instruction, select **F10** to initiate CG calibration sequence. Follow screen instructions for movement of weights.

3. Select **F2** for MOI calibration. Position I-Beam and calibration weights per screen instruction, then select **F10** to initiate MOI calibration sequence. Follow screen instructions for repositioning of weights.

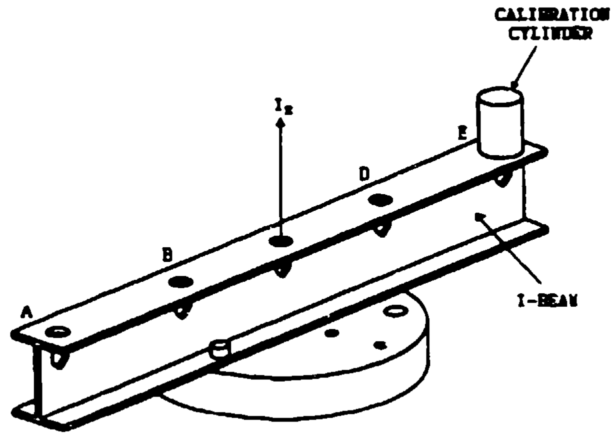


Figure 7
Typical Calibration Set-up

4.3 SYSTEM CHECK PROCEDURE

Following calibration a system check should be performed using a calibrated weight. The following procedure can be used for measurement of any calibrated weight which can be accurately positioned on the test platform. Results for comparison are provided based on using the S7623-A calibrated cylinder.

1. Select **F1** to update test information.

2. A set of Tare measurements for the bare test platform is initiated by selecting **F3**. Select CG Tare and conduct measurements, followed by MOI Tare and measurements. Raise and lower the support screws as prompted on the screen.

3. Place the S7623-A calibrated cylinder in one of the holes on the KGR30 test platform.

4. Select **F2** to record part measurements (CG and MOI). Raise and lower support screws as prompted on the computer screen.

5. Select Calculations **F6**, followed by **F10** for both CG and MOI calculations. Enter the weight as 0.9877 lb. and CG height as 1.0 inch, then select **F10** to continue.

6. Compare resultant data with values in Table 1 to verify proper system function. Record results and file them with all previous system checks. If problems are encountered, consult Appendix D (Problem/Solution Index).

Table 1: Calibrated Cylinder Theoretical Results

HOLE	X (in.)	MOI (lb-in^2)	MOI_{cg} (lb-in^2)
+X	4.00	16.072	0.268
Center	0.00	0.268	0.268
-X	-4.00	16.072	0.268

5.0 MEASUREMENT PROCEDURES

5.1 OVERVIEW

Complete mass properties determinations for a headform and/or helmet system is accomplished using the lab worksheet (Assist.doc) presented in Appendix C. Complete test item descriptions, calibration data, weight and CG/MOI data are all entered on the worksheet.

Six test positions, shown in Appendix A, are required to measure the data necessary to calculate the complete mass properties of the test part. Test positions must be conducted in numerical order since data measured in Position 1 is required to calculate the appropriate CG height for Position 2 and so on. Error is minimized using this technique since CG height must be approximated and typically has the smallest degree of uncertainty for this position. The estimated CG height has only a minor effect on the calculation of the test part CG.

Measurements of helmet/headform mass properties are redundantly determined to evaluate the effects of helmet fit. The helmet system is refitted and measured in combination with the headform three times for each test position. The mean values and standard deviations can then be used to plot a 3-D ellipsoidal CG location for a particular helmet/headform system. The results of this technique are shown in an X/Z plane view in Figure 8.

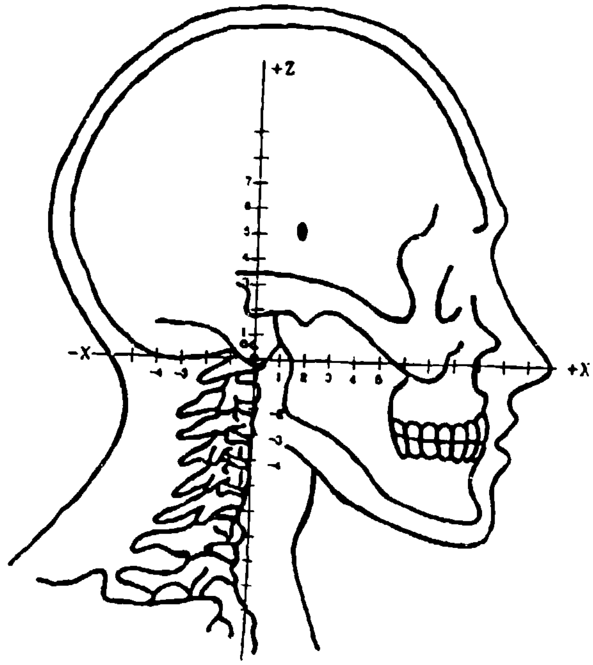


Figure 8: X/Z Plane View of CG Ellipsoid

If any problems arise during this test procedure, refer to Appendix D (Problems/Solutions Index).

5.2 WEIGHT DETERMINATION

1. Obtain a lab worksheet (Assist.doc) and record all pretest information including specifics on the test items.

2. Turn the electronic scale ON, shown in Figure 9, and allow 15 minutes for warm up. Measure the calibrated cylinder (S7623-A) to assure accuracy. The weight of the cylinder is certified at 0.98777 (lb.).

3. Record weights of all components as listed on the lab worksheet. Custom fitting procedures of liner systems must be performed prior to weight determination.

Figure 9: Electronic Scale

5.3 CG/MOI MEASUREMENT SEQUENCE

The following test procedures of Section 5.3 are repeated for each of the six test positions using the appropriate fixture and location on the test platform as specified in Appendix A.

5.3.1 Measuring Fixture Properties

Fixture mass properties are measured using the TARE option, so these properties may be subtracted from the combined fixture and test part measurements. Weight and CG height information are not required for TARE measurements.

1. Select **F1** and update test information with appropriate test position number. For example, "TARE, Test Position #".

2. Position test fixture on test platform (*8) in accordance with Appendix A requirements. As an example, Position 2 Test Fixture is shown mounted to the test platform in Figure 10.

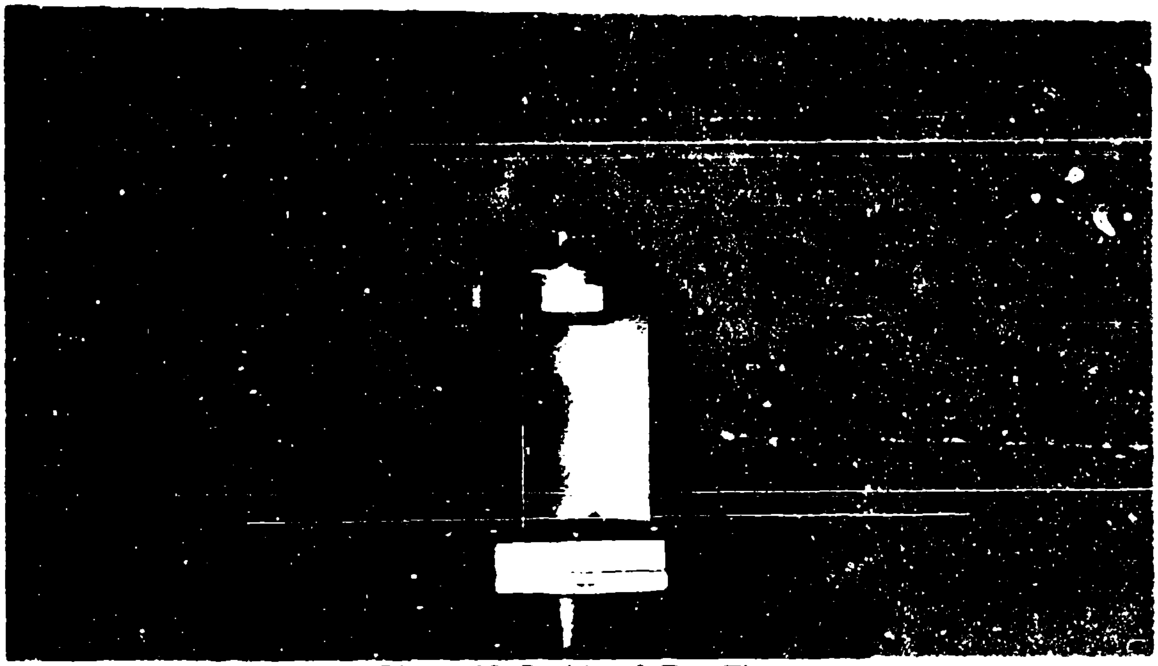


Figure 10: Position 2 Test Fixture

3. Use two 3/8-16 counter-sunk bolts to secure the fixtures to the test platform. Finger tighten each of the bolts, then torque to 5-10 in-lb.

4. As shown in figure 10, insert and center connecting pin into the nodding joint, add washers to both sides and insert rubber nodding blocks.

5. Select TARE measurement F3 from main menu. Perform both CG and MOI Tares separately, raising and lowering support screws as prompted on the computer screen.

5.3.2 Measuring Headform/Helmet Properties

For each test position, headform only mass properties are measured first by following steps 1, 3-9. Headform/Helmet mass properties are then determined by following steps 2-10.

1. Mount the test headform as shown in Appendix A (Test Positions) and record data on the bare headform only by following steps 3 through 9. Make sure the connecting pin is inserted in the same direction and orientation as for the TARE. The typical procedure is to insert the pin in from the direction of the left ear. Figure 11 shows a Test Headform mounted in Test Position 2.

Figure 11
Test Headform Mounted in Test Position 2

2. Mount the helmet system and oxygen mask using proper fit techniques as per Section 2.2 (Helmet Fitting Requirements). Measurements of the helmet/headform system will be repeated three times to obtain redundant data as discussed in the overview. Figure 12 shows a helmet system fit for testing.

Figure 12
Helmet/Headform Mounted in Test Position 2

3. Select **F1** and update test information to include test position number, helmet system, headform type and run number.

4. Select **F2** from the main menu for part measurement.

5. Raise support screws and select CG part measurement.

6. Lower support screws and select MOI part measurement.

7. Select **F6** to perform CG/MOI calculations for this test position. Enter the corresponding weight and calculated CG height for this test position from the lab worksheet.

8. Record resultant CG and MOI values as specified on the lab worksheet.

9. Save all computer printouts of the data by stapling them to the lab worksheet.

10. The helmet system and oxygen mask are now removed and refitted to the test headform for a new set of measurements. The test cycle (steps 2 through 9) are repeated to obtain three sets of measurements for each helmet system type in each test position.

11. Advance to the next test position. Repeat fixture, headform and headform/helmet measurement procedures (5.3.1 and 5.3.2).

6.0 DATA ANALYSIS PROCEDURES

The resultant values from the lab worksheet are entered into a computation program for determination of the magnitudes of the principal mass moments of inertia and orientation of the principal axes. An example of the calculations and program output are found in Appendix C (Sample Data and Calculations). The program is accessible through any computer terminal linked to the HATLAB local area network by using the following procedure.

1. Type **net name *** from the dos prompt.

2. Use the login:**thornton** and the appropriate password.

3. Change your drive to "N" by typing **N:** at the dos prompt.

4. Switch to the mass properties data base directory by typing N:**cd thornton\mpdb**. The program is run by typing N:\thornton\mpdb:**pmcrev2.exe**.

Instructions for entering the appropriate data will be displayed. Output files are named by the date the data was processed and a two digit counter (YYMMDDxx.dat). The results of the program calculations are stored in this file and can be printed by typing Hatt%**lpr YYMMDDxx.dat**. Save this printout by stapling it to the appropriate lab worksheet.

7.0 DOCUMENTATION REQUIREMENTS

Results of all mass properties testing are entered into the Headform/Helmet Mass Properties Data Base in accordance with the document guidelines of Reference 4. This enables the development of a more comprehensive data base to be used in the comparison of various helmet systems and the evaluation of head/neck safety.

8.0 REFERENCES

1. Thornton Jeffrey M., "An Improved Method for Determining the Mass Properties of Helmets and Helmet Mounted Systems", Naval Air Warfare Center - Aircraft Division, Report No. NAWCADWAR-92053-60.

2. Boynton, Richard and Kurt Wiener (1988) Space Electronics, Inc. SAWE paper no.1827, "A New High Accuracy Instrument for Measuring Moment of Inertia and Center of Gravity".

3. Boynton, Richard and Kurt Wiener (1989) Space Electronics, Inc., "Operating and Instruction Manual Mass Properties Instrument Model KGR30".

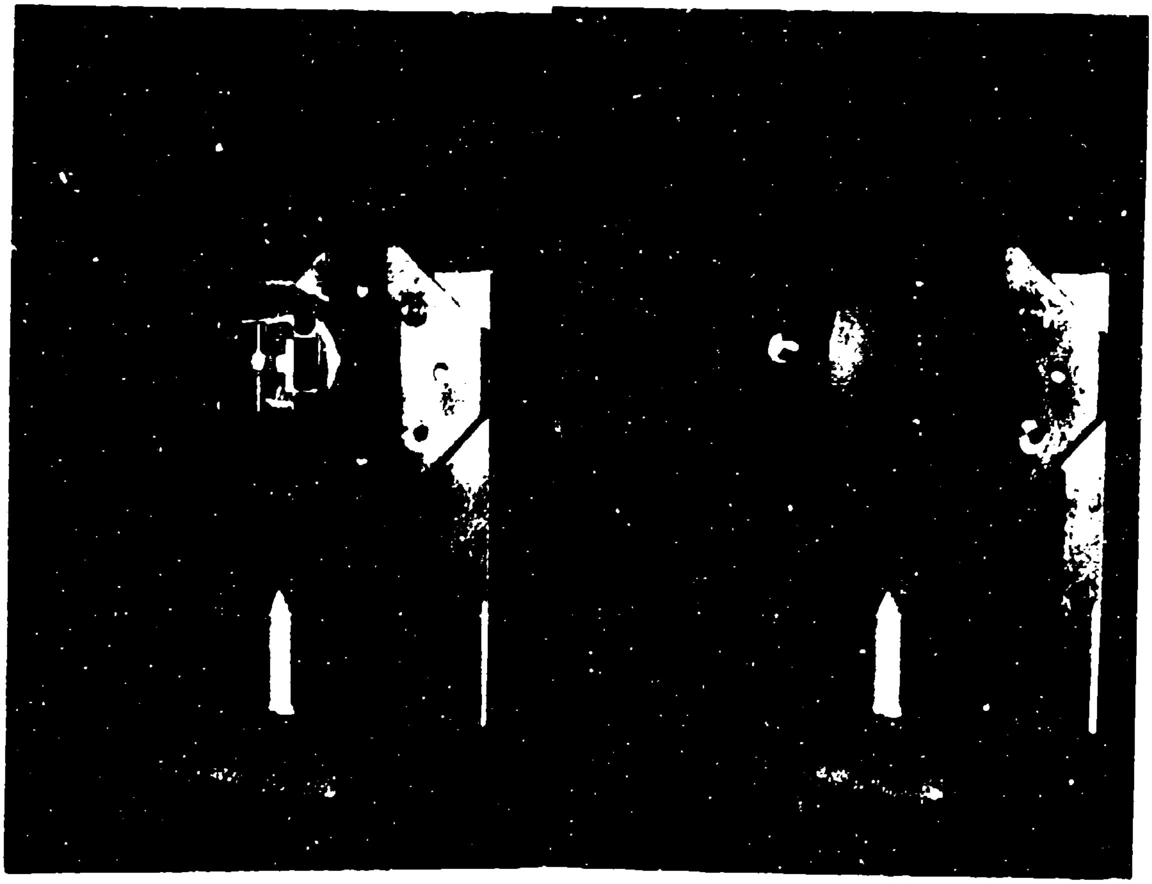
4. Zaborowski, David J. and Jeffrey M. Thornton,"Headform/Helmet Mass Properties Data Base", Naval Air Warfare Center - Aircraft Division, Document Draft 1/13/92.

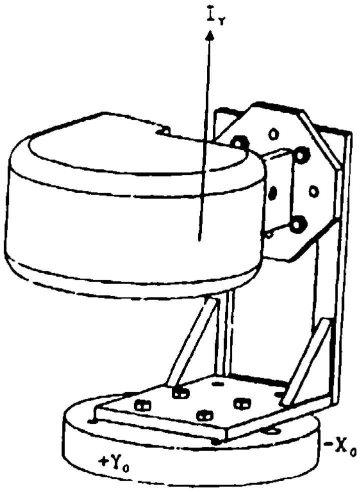
Appendix A

TEST POSITIONS

Appendix A - Test Positions 1-6

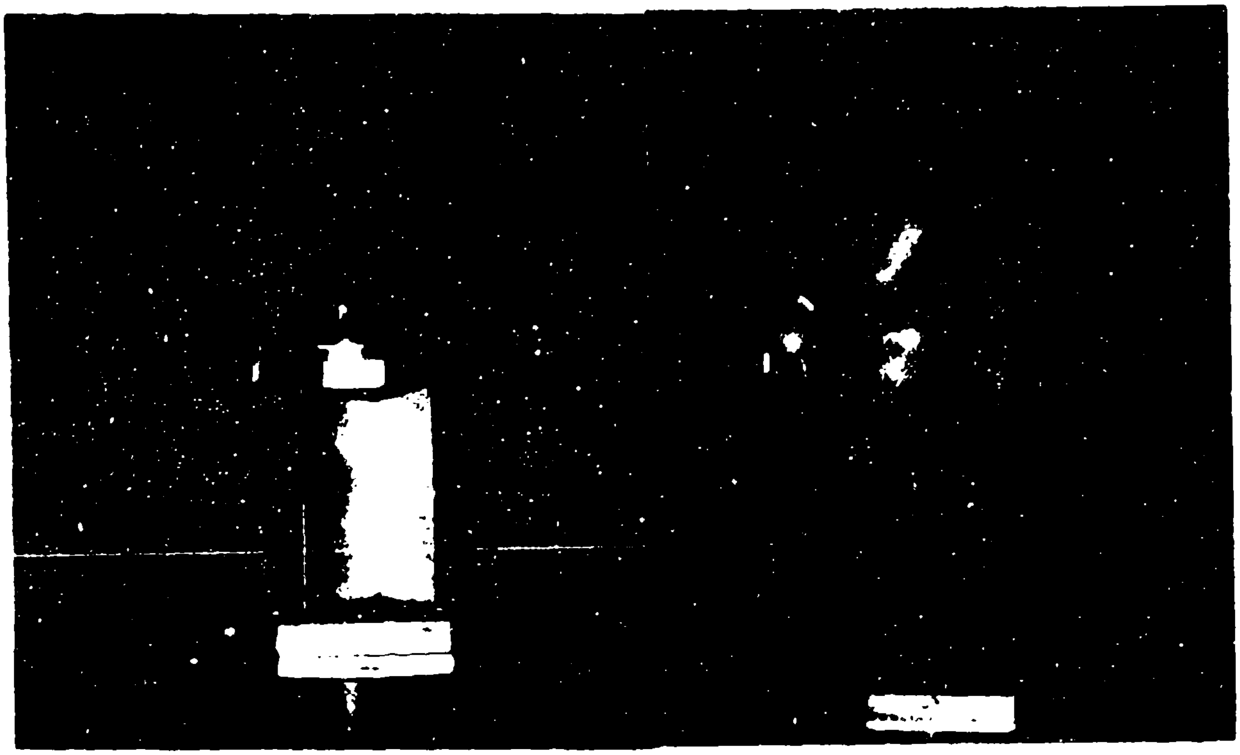
TEST POSITION 1

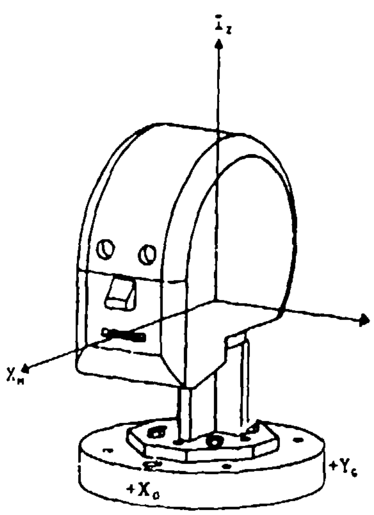




	KGR30 Output		Headform Coord
MOI	I_{ZG}	=	I_{YH}
CG	X_G	=	X_H
	Y_G	=	Z_H

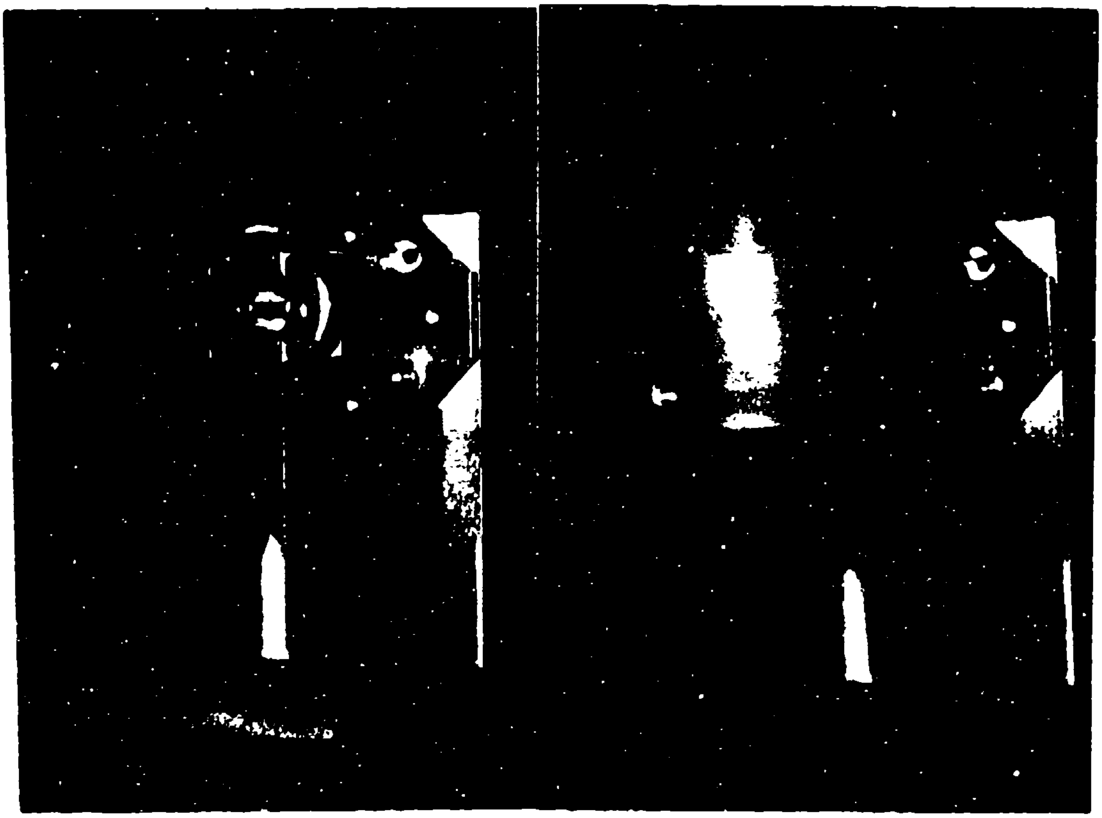
TEST POSITION 2

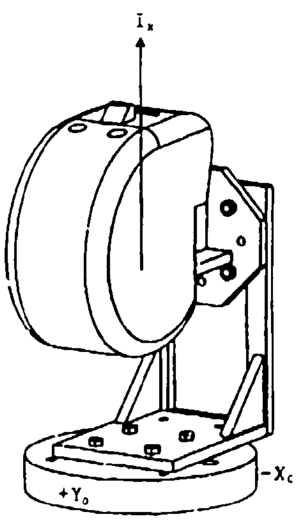




KGR30 Output			Headform Coord
MOI	I_{ZG}	=	I_{ZH}
CG	X_G	=	X_H
	Y_G	=	Y_H

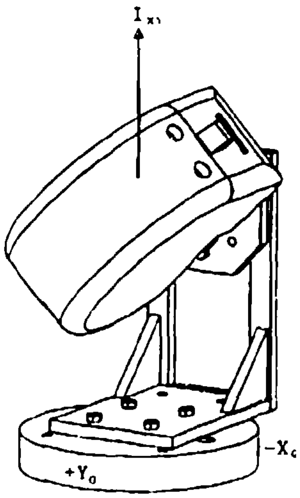
TEST POSITION 3





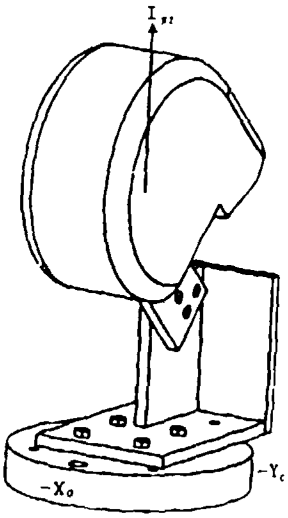
KGR30 Output			Headform Coord
MOI	I_{ZG}	=	I_X
CG	X_G	=	Y_H
	Y_G	=	Z_H

TEST POSITION 4



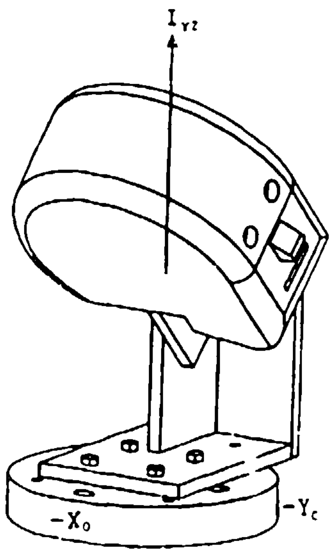
$$\frac{\text{KGR30 Output}}{\textbf{MOI} \quad I_{ZG}} = \frac{\text{Headform Coord}}{I_{XY}}$$

TEST POSITION 5



$$\frac{\text{KGR30 Output}}{\textbf{MOI}\ I_{ZG}} = \frac{\text{Headform Coord}}{I_{XZ}}$$

TEST POSITION 6



$$\frac{\text{KGR30 Output}}{\textbf{MOI } I_{ZG}} = \frac{\text{Headform Coord}}{I_{YZ}}$$

Appendix B

KGR30 MAIN MENU DESCRIPTIONS

MAIN MENU OPERATING DESCRIPTIONS

Selections from the main menu are discussed following each function key listed below:

F1: Update Test Information

Allows the operator to enter a new Operator name and test part information. Test information must be updated previous to every set of measurements (CG and MOI). This information is printed on the data printout and is the only record of the data once new measurements are recorded. Information to be entered should include test part name, test position #, and run #. This will ensure that the data may be properly identified at a later date.

F2: CG/MOI Part Measurement

Allows the operator to select CG or MOI Test Part Measurement function. Support screws are to be raised for CG and lowered for MOI.

F3: CG/MOI Tare Measurements

Allows the operator to select CG or MOI Tare Measurement function. Tare measurements on the fixtures only are subtracted from the part measurements (fixtures and test item) in order to obtain test item only data.

F4: CG/MOI Calibration

Allows the operator to recalibrate the KGR30. Instructions are displayed on the screen for positioning I-Beam and weights.

F5: System Utilities

Allows the operator to select one of the following functions from the utilities menu.

F1: Update Variables
F2: Purge Data From Disk
F3: Diagnostics
F4: Return to Main Menu

Update Utilities (Utilities F1)

This function provides access to system constants through a Password which has been given to an authorized customer representative. Contact manufacturer prior to changing any constants.

Purge Data From Disk (Utilities F2)

This function allows measurement data to be purged. It may be useful, for example, to purge old CG data to prevent calculating old CG results when only MOI measurements through the center of rotation are currently required.

Diagnostics (Utilities F3)

This function provides manual access to options which are useful in debugging system problems:

Read LVDT
Toggle motor ON/OFF
Clamp/unclamp the torsion rod
Enable/disable the Optron monitoring function
Initiate CG sequence
Initiate MOI sequence

F6: Calculations

Allows the operator to perform calculations with existing Calibration, Tare and Part Measurement data. Tare data may be used for successive measurements provided the fixturing has not been changed or moved.

Appendix C

SAMPLE DATA AND CALCULATIONS

Helmet Advanced Technology Laboratory
Mass Properties Data Sheet (ASSIST.DOC)

TESTS CONDUCTED BY: Zaborowski / Thornton DATE: 4/13/92

TEST ITEM (including model # and size): HGU-66/P with Cats-Eyes Size 8 Large with CEECs Assem prototyp

Specify head type and instrumentation included: Hybrid III (50th Percent: Serial #214 with Neck Transducer Structural Replacement (P/N 78051-..

Specify oxygen mask (model # and size): MBU-12/P (Regular)

KGR30 System Calibration

Calibration Date (MM/DD/YY): 4/10/92

MOI Calibration Constant: 94.37452 (lb-in²/sec²)

CG Calibration Constant : 0.00333 (lb-in/ct)

Weight Results

$M_1 = M_{HELMET}$ = 4.3336 (lb.)

$M_2 = M_{OXY\ MASK}$ = 0.6226 (lb.)

$M_3 = M_{HEADFORM}$ = 9.8178 (lb.)

$M_s = M_1 + M_2 + M_3$ = 14.7740 (lb.)

Center-of-Gravity Results

X_R = 1.104 (in.)

Y_R = 0.070 (in.)

Z_R = 2.260 (in.)

Mass Moments of Inertia Results

I_{Xcg} = 123.576 (lb*in²)

I_{Ycg} = 183.676 (lb*in²)

I_{Zcg} = 166.329 (lb*in²)

I_{XYcg} = 152.286 (lb*in²)

I_{XZcg} = 141.376 (lb*in²)

I_{YZcg} = 176.400 (lb*in²)

POSITION 1 (Iy):

1. Align fixture assembly in accordance with Position 1 requirements and TARE the assembly.

2. Mount Headform and Helmet and record part data.

3. For calculations (F6) use Weight=M_s, CG height = 8.625 in. (Fixture design height)

	X (X-output)	Z (Y-output)	I_y (lb*in²)	I_{ycg} (lb*in²)
1.	1.0959	2.2267	273.816	184.129
2.	1.0721	2.2931	279.122	184.911
3.	1.0780	2.2718	275.170	181.987

X_1= 1.0820 (inches) Z_1= 2.2639 (inches) I_y= 276.036 (lb*in²) I_{ycg}= 183.676 (lb*in²)

POSITION 2 (Iz):

1. Align fixture assembly in accordance with Position 2 requirements, then TARE the assembly.

2. Mount Headform and Helemt and record part data.

3. For calculations (F6), Weight=M_s, CG height = 5.375 in. + Z_1 = 7.6389

	X (X-output)	Y (Y-output)	I_z (lb*in²)	I_{zcg} (lb*in²)
1.	1.1187	0.0831	183.806	165.215
2.	1.1331	0.0783	186.450	167.392
3.	1.1271	0.0641	185.211	166.381

X_1= 1.1263 (inches) Y_1= 0.0752 (inches) I_z= 185.155 (lb*in²) I_{zcg}= 166.329 (lb*in²)

POSITION 3 (Ix):

1. Align fixture assembly in accordance with Position 3 requirements, then TARE the assembly.

2. Mount Headform and Helmet and record data.

3. For calculations (F6) use Weight= M_s, CG height = 8.625 in. + $(X_1+X_2)/2$ = 9.72915 (in.)

	Y (X-output)	Z (Y-output)	I_z (lb*in²)	I_{zeq} (lb*in²)
1.	0.0568	2.2784	201.553	124.855
2.	0.0625	2.2379	196.615	122.619
3.	0.0753	2.2535	198.283	123.255

Y_3= 0.0648 (inches) Z_3= 2.2566 (inches) I_x= 198.817 (lb*in²) I_{xeq}= 123.576 (lb*in²)

Center of Gravity (CG) Results

$X_R = (X_1 + X_2)/2$ = 1.104 (in.)

$Y_R = (Y_1 + Y_2)/2$ = 0.070 (in.)

$Z_R = (Z_1 + Z_2)/2$ = 2.260 (in.)

POSITION 4 (Ixy):

1. Align fixture assembly in accordance with Position 4 requirements, then TARE the assembly.
2. Mount Headform and Helmet and record part data.
3. For calculations (F6) use Weight= M_s, CG height = 8.625 in.+ (X_R*sin45 + Y_R*sin45) = 9.4551 (in.)

	Z(Y-output)	I_{XY}(lb*in²)	I_{XYcg}(lb*in²)
1.	2.1837	231.552	151.805
2.	2.2262	235.803	153.204
3.	2.2559	236.081	151.854

Z_3= 2.2219 (inches) I_{XY}= 234.479 (lb*in²) I_{XYcg}= 152.288 (lb*in²)

POSITION 5 (Ixz):

1. Align fixture assembly in accordance with Position 5 requirements, then TARE the assembly.
2. Mount Headform and Hemet and record part data.
3. For calculations (F6) use Weight= M_s, CG height = 8.625in.+(X_R*sin45 + Z_R*sin45) = 11.0037 (in.)

	Y(Y-output)	I_{XZ}(lb*in²)	I_{XZcg}(lb*in²)
1.	0.0525	152.549	140.731
2.	0.0781	152.076	141.840
3.	0.0750	153.194	141.555

Y_3= 0.0685 (inches) I_{XZ}= 152.606 (lb*in²) I_{XZcg}= 141.376 (lb*in²)

POSITION 6 (Iyz):

1. Align fixture assembly in accordance with Position 6 requirements, then TARE the assembly.

2. Mount Headform and Helmet and record part data.

3. For calculations (F6) use Weight= M_s, CG height = 8.625in.+($Y_s$sin45 + Z_s*sin45) = 10.2726 (in.)

	X(- Y-output)	I_{YZ}(lb*in²)	I_{YZcg}(lb*in²)
1.	1.1325	239.263	177.693
2.	1.1451	232.840	176.128
3.	1.1283	233.389	175.378

X_3= 1.1353 (inches) I_{YZ}= 235.164 (lb*in²) I_{YZcg}= 176.400 (lb*in²)

```
Output File Name : 04139204.dat
System description : HGU-66/P (Large) w/CATS-EYES & CEEDS on Hybrid III

Weight of Head/Helmet or Helmet system:     14.77400 lb.
Equivalent mass of system =                  6.70134 kg.

CENTER OF GRAVITY VALUES (in.) w.r.t. pivot pin origin
X   =      1.10400   Y =      0.07000    Z =      2.26000 in.
 or =      2.80416     =      0.17780      =      5.74040 cm.

MASS MOI ENTERED VALUES (About the CG):
  Ixx =    123.57600 lb*in**2
  Iyy =    183.67599 lb*in**2
  Izz =    166.32899 lb*in**2
  Ixy at 45 deg.=    152.28799 lb*in**2
  Ixz at 45 deg.=    141.37601 lb*in**2
  Iyz at 45 deg.=    176.39999 lb*in**2

Inertia Matrix at CG  w.r.t. origin coordinate system:
 Ixx -Pxy -Pxz            123.57600       -1.33800       -3.57649
-Pyx  Iyy -Pyz             -1.33800      183.67599        1.39749
-Pzx -Pzy  Izz             -3.57649        1.39749      166.32899

PRINCIPAL MASS MOMENTS OF INERTIA:
             Ix               Iy              Iz
          123.25433        183.83185       166.49481 (lb(mass)*in**2)
          360.69147        537.96552       487.23041 (kg*cm**2)
            0.31898          0.47576         0.43089 (lbs(force)*in*sec**2)

ROTATION COSINE MATRIX (ORIGIN to PRINCIPAL axes:)
        i                   j                   k
     0.99642            -0.02717            -0.08003
     0.02017             0.99600            -0.08700
     0.08208             0.08508             0.99299

Rotation Matrix in degrees (Row Vectors):
     4.84880            91.56344            94.59754
    88.85100             5.12418            94.99810
    85.29823            85.12589             6.78964

ROTATION ANGLES from ORIGIN to principle axes (deg):
ROLL(x) =    5.007
PITCH(y)=   -4.591
YAW(z)  =    1.562

The Determinant of matrix A =  0.37725E+07
The tolerance is set at :  0.10000E-05

The first check is valid. Product of the eigen values

The second check is valid. Sum of the eigen values
```

Appendix D

PROBLEM/SOLUTION INDEX

PROBLEM/SOLUTION INDEX

PROBLEM		SOLUTION	
1.	If a C prompt (C>) should appear at the system start up.....	1.	Change directories by typing <u>CD\KGR</u>. When the C prompt appears again, type <u>KGR</u>. An introduction menu will be displayed. Press the spacebar, and the main menu will be displayed.
2.	If uncertain which test fixture to use......	2.	See Appendix A which has figures for each test position.
3.	CG variation seems large between test positions....	3.	Repeat one of the sets of measurements and verify correct Tare and Part measurement serial numbers are used in the calculations.
4.	Scale reading of certified weight varies...........	4.	Check leveling of scale and allow proper warm up time...
5.	Incorrect data was typed in for test part I.D..........	5.	Immediately correct the computer printout of the data.
6.	Incorrect Tare or Part measurement data was used for calculations........	6.	Repeat only the incorrect measurement and perform calculations again. Tare and Part measurements are stored until overwritten by the next measurement.
7.	Outside disturbance affects Tare or Part measurements...	7.	Same as 6.
8.	If nothing happens when CG/MOI Tare or Part measurement selected.....	8.	Select **F9** to abort. Check all cable connections. Review diagnostics options discussed in Appendix B.

PROBLEM		SOLUTION	
9.	If test platform oscillates but does not record data..	9.	Check KGR30 processing unit where oscillation period is displayed. Values are recorded until three consecutive measurements do not vary by a specified amount. If the measurements do not meet this requirement, the computer stops taking data. Check for causes of relative oscillation of the fixture, and test part or disturbances such as drafts or vibrations.
10.	Test platform will not rotate...........	10.	Check all pressure gages for proper settings.
11.	Difficultly in mounting headform............	11.	Check that washers are not interfering. Verify that threaded locking studs of the load cell are loosened. These can be accessed through the 2 holes in the rear of the load cell.
12.	Washers won't stay in place when trying to mount headform.........	12.	Use glue stick or rubber cement to hold washers in place.

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