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REPEATABILITY AND REPRODUCIBILITY OF A STANDARD TEST METHOD FOR MEASURING HEAD-SUPPORTED MASS PROPERTIES

by
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14. ABSTRACT U.S. military Service Members are provided protective head gear for use in training and operational environments. This headgear is typically in the form of a helmet, at a minimum consisting of a rigid outer shell and an individual fitting and retention system. Many different helmet configurations are used by the U.S. Soldier, depending on their Military Occupational Series, the anticipated threat, and the operational environment. The helmet shell also provides an ideal mounting surface for ancillary equipment or advanced tactical systems such as night vision systems, weapon targeting displays, and other visual augmentation systems. As technology advances, the use of helmet mounted devices (HMDs) have become increasingly common to enhance capabilities. The cumulative effect of adding components to the helmet is increased mass and a change in weight distribution of the total head-borne system (HBS) being supported by the wearer's neck. These HBSs have the potential to increase the risk of cervical spine injury and to decrease wearer performance through accelerated fatigue rates. During development of military helmets and HMDs, materiel developers need a valid and repeatable test methodology for measuring their mass properties. DEVCOM SC and USAARL reviewed existing mass properties measurement procedures and identified critical items to incorporate into a unified Army methodology. A gage R&R study was performed on this Army method to assess the validity of the system and procedures. This report outlines the joint Army effort undertaken by DEVCOM SC and USAARL to define and validate a method for measuring mass properties of helmets and HMDs																																		
15. SUBJECT TERMS <table border="0"> <tr> <td>HELMETS</td> <td>HELMET SYSTEM</td> <td>COORDINATE SYSTEM</td> <td>COM(CENTER OF MASS)</td> </tr> <tr> <td>FIXTURES</td> <td>HEAD(ANATOMY)</td> <td>MOMENT OF INERTIA</td> <td>TEST AND EVALUATION</td> </tr> <tr> <td>HEADFORMS</td> <td>CENTER OF MASS</td> <td>HEAD-BORNE DEVICES</td> <td>PROTECTIVE EQUIPMENT</td> </tr> <tr> <td>CALIBRATION</td> <td>ARMY PERSONNEL</td> <td>CERVICAL SPINE INJURY</td> <td>CG(CENTER OF GRAVITY)</td> </tr> <tr> <td>NECK INJURIES</td> <td>MASS PROPERTIES</td> <td>WOUNDS AND INJURIES</td> <td>ORIENTATION(DIRECTION)</td> </tr> <tr> <td>MEASUREMENT</td> <td>CENTER OF GRAVITY</td> <td>HEAD SUPPORTED MASS</td> <td>HELMET MOUNTED DEVICE</td> </tr> <tr> <td>MOI(MOMENTS OF INERTIA)</td> <td>MASS PROPERTIES INSTRUMENT</td> <td>ACH(ADVANCED COMBAT HELMET)</td> <td></td> </tr> </table>							HELMETS	HELMET SYSTEM	COORDINATE SYSTEM	COM(CENTER OF MASS)	FIXTURES	HEAD(ANATOMY)	MOMENT OF INERTIA	TEST AND EVALUATION	HEADFORMS	CENTER OF MASS	HEAD-BORNE DEVICES	PROTECTIVE EQUIPMENT	CALIBRATION	ARMY PERSONNEL	CERVICAL SPINE INJURY	CG(CENTER OF GRAVITY)	NECK INJURIES	MASS PROPERTIES	WOUNDS AND INJURIES	ORIENTATION(DIRECTION)	MEASUREMENT	CENTER OF GRAVITY	HEAD SUPPORTED MASS	HELMET MOUNTED DEVICE	MOI(MOMENTS OF INERTIA)	MASS PROPERTIES INSTRUMENT	ACH(ADVANCED COMBAT HELMET)	
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REPEATABILITY AND REPRODUCIBILITY OF A STANDARD TEST METHOD FOR MEASURING HEAD-SUPPORTED MASS PROPERTIES

1 INTRODUCTION

U.S. military Service Members are provided protective head gear for use in training and operational environments. This headgear is typically in the form of a helmet, at a minimum consisting of a rigid outer shell and an individual fitting and retention system, which is an essential personal protective equipment (PPE) item. Many different helmet configurations are used by the U.S. Soldier, depending on their Military Occupational Series, the anticipated threat, and the operational environment. Helmet designs have evolved to provide protection beyond fragmentation, to include head protection from blunt head impact events and maxillofacial protection. Military aviation helmets also include protective visor systems, hearing protection, and integrated communication systems. The helmet shell also provides an ideal mounting surface for ancillary equipment or advanced tactical systems such as night vision systems, weapon targeting displays, and other visual augmentation systems. As technology continues to advance, the use of helmet mounted devices (HMDs) has become increasingly common to enhance capabilities. The cumulative effect of adding components to the helmet is increased mass and a change in weight distribution of the total head-borne system (HBS) being supported by the wearer's neck. These head-borne systems have the potential to increase the risk of cervical spine injury and to decrease wearer performance through accelerated fatigue rates. During development of military helmets and HMDs, materiel developers need a valid and repeatable test methodology for measuring their mass properties.

The U.S. Military has been measuring aviation helmet mass properties since the early 1990s. However, all three Services (Army, Navy, and Air Force) developed unique measurement methodologies and reference coordinate systems which were closely aligned with and supported their respective recommendations or requirement thresholds for mass and center of mass (CM) (Albery 1997, Deavers 1992, Loverro 2012, Thornton 1992). A fundamental difference between the three services lies in the coordinate system definition. Other differences include headforms, test fixtures and procedures for measuring the CM and moment of inertia (MOI) with mass property instruments. As a result of these differences, test results generated by one service are not accurately translatable against the requirements of another service.

Combat Capabilities Development Command Soldier Center (DEVCOM SC) and the U.S. Army Aeromedical Research Laboratory (USAARL) reviewed the Army, Navy and Air Force mass properties measurement procedures and identified critical items to incorporate into a unified Army methodology. This included:

- Utilization of a mass properties instrument (MPI) capable of measuring both CM and MOI
- A coordinate system consistent with the mass properties instrument
- Headforms with defined anatomical markings to allow for consistent monitoring of fixture and test article alignment
- A fixture used to mount the headforms to the MPI, which reduces operator error
- Minimization of headform and fixture weights to improve fidelity of mass property measurements relative to the test article

- Systematically account for the contribution to head-borne mass properties from cables that extend from the helmet system

Once the measurement tools, equipment items and method were finalized, a gage repeatability and reproducibility study was performed to assess the validity of the system and procedures. This report outlines the joint Army effort undertaken by DEVCOM SC and USAARL to define and validate a method for measuring mass properties of helmets and HMDs.

2 METHODS and MATERIALS

The goal of this effort is to develop a standardized methodology for measuring the CM and MOI for the Army using an MPI. To accomplish this, the coordinate system, the MPI, headforms, the fixture that mounts the headforms to the MPI, and measurement procedures needed to be identified. The KSR 330 series MPI (Space Electronics, Inc., Berlin, CT) was the instrument identified to measure the CM and MOI. Three headforms were defined to span the Army male anthropometrics and a gimbal style fixture was designed to consistently align the headforms with the center of the MPI. It was determined to have repeatability and reproducibility testing performed at both DEVCOM SC and USAARL using the same head supported devices. The test equipment, data collection and procedures are outlined in this section.

2.1 Measurement and Test Equipment

2.1.1 Anatomical Coordinate System

The coordinate system recommended and used by the Army for measuring and reporting helmet and HMD mass properties is the head anatomical coordinate system (ACS) whose origin is aligned with the trignon notch, an anatomic landmark feature on the human body. In the head ACS, the X-axis is defined as the intersection of the mid-sagittal and Frankfurt planes, with the positive direction anterior of the trignon notch. The Y-axis is defined by the intersection of the Frankfurt and frontal planes with the positive Y-axis exiting through the left trignon notch. The Z-axis is perpendicular to both, the X- and Y-axes following the right hand rule with the positive direction superior of the trignon notch (Figure 1).

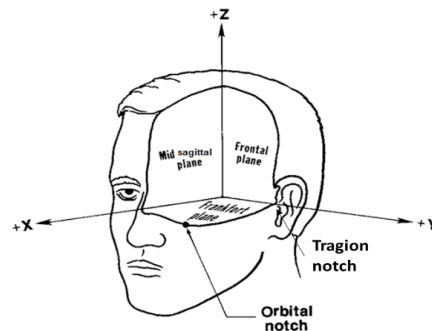


Figure 1. Anatomical Coordinate System (ACS)

2.1.2 Machine Coordinate System, Mass Properties Instrument, and Measurements

The MPI KSR330 series model (Space Electronics, Inc., Berlin, CT; Figure 2) was the system used to determine the CM and MOI of the selected head-borne equipment (Section 2.4). This instrument consolidates the data measurements to a single device, which reduces error due to multiple helmet mounts and repositioning required when measuring CM and MOI on separate instruments. The MPI measures the X-axis and Y-axis CM offset of a test object relative to the rotational centerline of the instrument and the MOI of a test object about a vertical axis perpendicular to the base plate of the MPI located at the rotational centerline of the instrument. A photo of the KSR330 MPI interface plate is in Figure 3. The machine coordinate system (MCS) was based on the coordinate system defined in the Space Electronics KSR software of the MPI. The XY plane was defined as the plane of the interface plate of the MPI machine, where the origin of the MCS was defined as the geometric center of the plate. The +Z axis was defined as the axis perpendicular to the XY plane pointing out of the plate. At the time of this data collection the KSR330 models at DEVCOM SC and USAARL were slightly different. The MPI at DEVCOM SC is the KSR330-20 and the MPI at USAARL is the KSR330-60. The CM specifications for the KSR330-20 and KSR330-60 are outlined in Table 1.

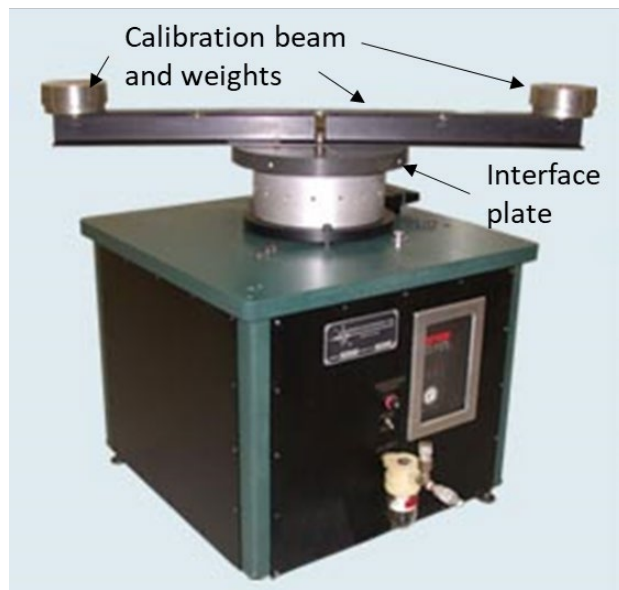


Figure 2. Photo of the KSR 330 series mass properties instrument, which measures both CM and MOI. In this photo, the calibration beam and weights are mounted to the MPI interface plate.

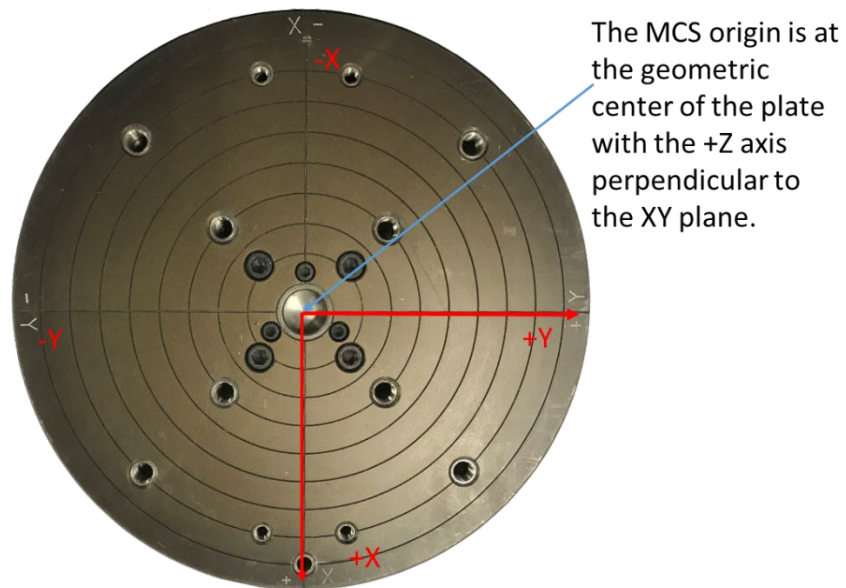


Figure 3. The KSR 330 series mass properties instrument interface plate that the fixture and headform attach to. The X and Y axes are identified as well as the MCS geometric center.

Table 1 KSR 330-20 and 330-60 mass property instrument specifications.

MPI	Specifications
DEVCOM SC KSR 330-20	Full scale moment due to offset CM of part is 23 kg-cm, moment sensitivity is 0.01 kg-mm, moment linearity is 0.1%, cm, maximum CM weight of test object is 18 kg at 600 mm, and rotary table centering error is 0.0254 mm. The MOI accuracy as listed in the manual specifications is $\pm 0.1\%$ of the reading plus 0.09 kg-cm^2 .
USAARL KSR 330-60	Full scale moment due to offset CM of part is 70 kg-cm, moment sensitivity is 0.01 kg-mm, moment linearity is 0.1%, maximum CM weight of test object is 54 kg @ 600 mm, and rotary table centering error is 0.0254 mm. The MOI accuracy as listed in the manual specifications is $\pm 0.1\%$ of the reading plus 0.09 kg-cm^2 .

The KSR 330 instrument measures CM for orthogonal axes along the machine coordinate X- and Y-axes. It achieves this by measuring the overturning moment (torque) created by the test item and uses the test items' mass to calculate the CM location relative to the instrument's central axis. The KSR measures MOI about a vertical axis by utilizing an inverted torsion pendulum to measure the time period of oscillation of the test item and this measurement is used to calculate the items MOI about the measurement's torsional axis (Z-axis). A detailed description of the KSR instrument measurement basics can be found in Boynton 2004 and Deavers 1992.

To define the mass properties of HBS, a total of seven parameters are needed. These include: mass, the CM position along the three cardinal axes (X, Y, and Z), and the mass MOI about the three respective axes (I_{xx} , I_{yy} , and I_{zz}). As mentioned, the KSR 330 is capable of determining the test item's CM position along two axes and the MOI about the remaining orthogonal axis for a given headform orientation. Therefore, in order to define the basic CM and MOI of a test item along the X, Y and Z axes, the headform needs to be oriented in three different positions. Since two CM offsets are measured in each of the three MOI orientations (I_{zz} , I_{xx} and I_{yy}), there are six total CM offsets acquired, two along the X-axis, two along the Y-axis and two along the Z-axis. In this report the six CM offsets measured are designated X_1 , X_2 , Y_1 , Y_2 , Z_1 , and Z_2 . In addition, if it's desired to calculate the principal moments of inertia (PMOI), the products of inertia (POI) are needed. The POI can be calculated if three additional MOI measurements are obtained by orienting the headform along XY, YZ, and XZ planes at a 45 degree angle. Therefore, to obtain the inertia tensor for a test item, the headform and mounted test part must be positioned and tested in six unique orientations (I_{zz} , I_{xx} , I_{yy} , I_{yz} , I_{xz} , I_{xy}) on the KSR 330 MPI for calculation of the test item's CM and PMOI. If only CM and MOI (along I_{zz} , I_{xx} and I_{yy}) are desired, the three additional measurements in the XY, YZ, and XZ planes are not needed.

2.1.3 Fixture

Obtaining the necessary CM and MOI measurements requires a fixture which will align the headform's ACS with the KSR 330 MCS at any orientation. Prior to this effort, DEVCOM SC and USAARL had utilized two different fixtures. Both fixtures required significant manipulation by the operators to achieve the correct orientation. Either the headform had to be fully detached from the fixture, reoriented and re-attached by the operator or the entire fixture had to be rotated and then realigned with the KSR machine coordinate axes. Both approaches introduced a source of measurement error and were time consuming.

In recognizing the limitations of the existing fixtures, a novel fixture was designed as a collaborative effort between USAARL and DEVCOM SC to reduce sources of operator error, optimize testing efficiency and unify the testing methodology within the Army. A primary objective was to ensure the test fixture be designed such that the headform ACS aligned with the KSR 330 MCS in order to take full advantage of the MPI's capabilities and avoid the need for post processing of results. With these two coordinate systems aligned, the test items' mass properties can be interpreted directly from the KSR 330 results without the need to perform subsequent calculations to translate the results to the head ACS. In order to maintain consistent placement of the fixture, the baseplate of the fixture was designed to mount directly to the MPI's interface plate. The second objective was to redesign the method for orienting the headform. The goal was to ensure the headform could be easily rotated about its Y-axis and Z-axis to maintain the headform ACS origin in line with the machine coordinate origin. To achieve this, the concept of a gimbal was utilized in the overall fixture design. Orientation changes are achieved by rotating the headform about its Y-axis on a cradle swing and about its Z-axis on a rotary bearing beneath the headform pedestal (Figure 4) with the point of the cradle rotation occurring at the trignon notch in line with the ACS. To improve efficiency, quick connect pins (QCP) and drill bushings were added to lock the fixture into the desired six orientations while keeping the origin of the ACS static. This simplified method of orientation change allows for consecutive orientation testing without refitting test parts onto the test headform.

Additionally, the pedestal base was designed to provide improved cable and hose management that was not easily repeatable with previous fixtures/methodologies for properly measuring tares. Figure 5 is a picture of the headform and fixture mounted to the KSR in the Izz orientation. Detailed drawings of the fixture are maintained in a Technical Data Package at DEVCOM SC (requests can be made to the author Marina Carboni).

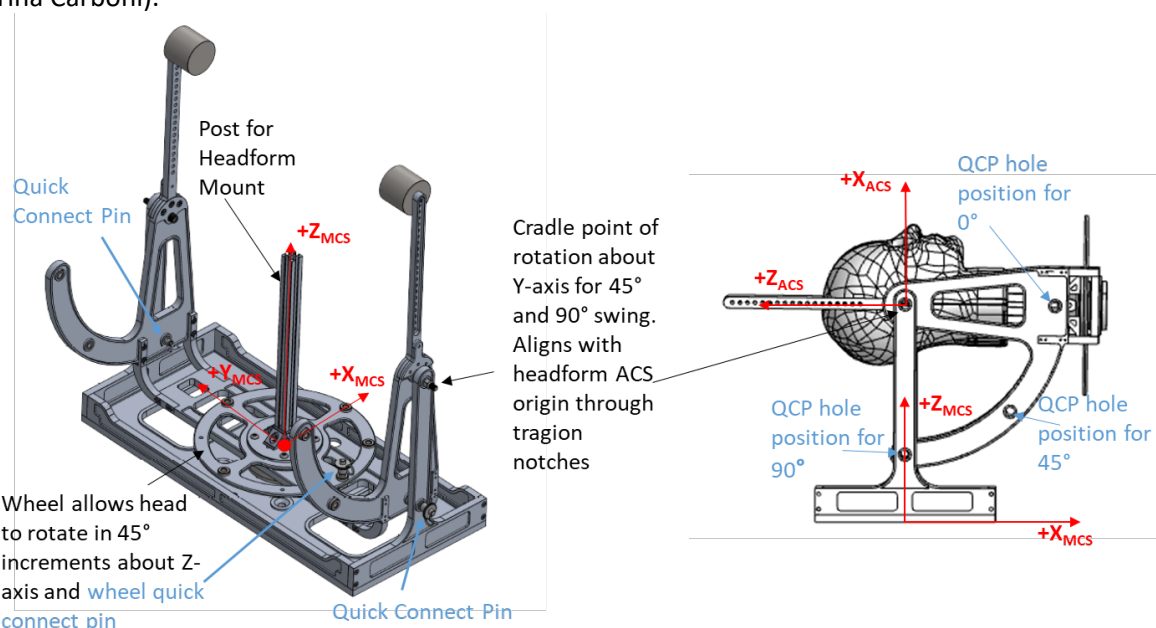


Figure 4. Isometric and right side view of the newly developed gimbal style fixture to mount the headform to the mass properties instrument. The machine coordinate system and anatomical coordinate system on the headform are shown for the headform orientation to measure Ixx (headform X-axis is aligned with MPI Z-axis). With the quick connect pin in the 0° cradle pin hole the headform anatomical and machine coordinate system X, Y and Z axes are aligned with each other.

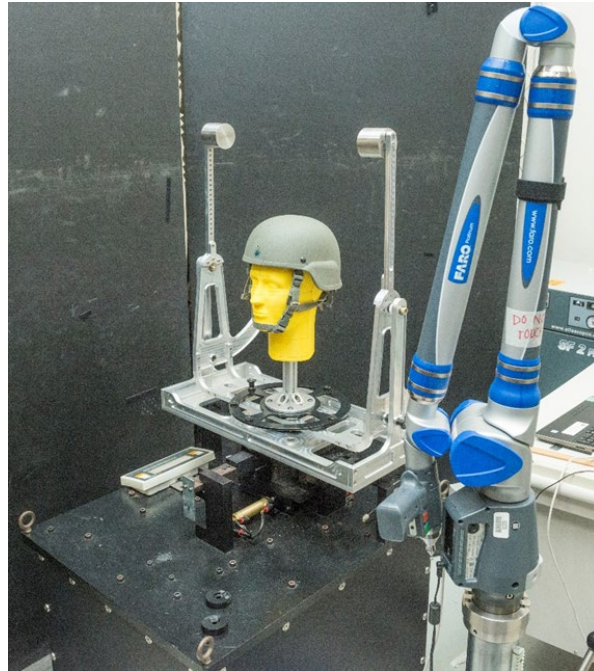


Figure 5. Headform and fixture (Izz orientation) mounted to the KSR 330-20 at DEVCOM SC. The FaroArm (Section 2.1.5) is positioned next to the mass properties instrument for digital measurements.

2.1.4 Mass Scale

The fixture, headform and system masses must be measured for the CM and MOI calculations. To weigh these items, two similar scales were utilized. At DEVCOM SC a Sartorius Combics Platform Scale (Model CAPP1U-50EE-LU, Sartorius North America Edgewood, NY) was used; this scale has a maximum weight capacity of 22.7 kg with a readability of 9 g. At USAARL the Sartorius CUBIS® Precision Balance (Model MSE12201S-000-DO, Sartorius North America Edgewood, NY) was used, which has a maximum weight capacity of 12.2 kg with a readability of 0.1 g.

2.1.5 FARO Arm

A FaroArm (Model Platinum 8ft, FARO Technologies Inc., Lake Mary, FL; Figure 5) and CAM2 software (Version10, FARO Technologies Inc., Lake Mary, FL) were used to digitally locate points in space relative to the MPI machine. The FaroArm is a coordinate measurement machine (CMM) which allowed for the operators to check the alignment of the fixture and headform to the MPI as well as measure the location of helmet systems relative to the headform pre- and post- mass properties measurements. The 6 mm ball point was used on the FaroArm for all measurements. The single point accuracy of the FaroArm is within 0.030 mm.

2.2 Headforms

For this effort, three headforms of varying sizes were utilized. The base geometry of the headforms are from the headforms used by USAARL to measure mass properties. Modifications were made to the existing headforms to improve reference measurements, helmet alignment and fabrication.

The original USAARL headform development began in 1980, when a coordinated Tri-Service effort was initiated to define Air Force, Army, and Navy aviator anthropometry and to standardize on the physical representation of mechanical and analytical human surrogates used in the development and performance assessment of manned systems. This effort relied extensively on available anthropometric

data collected previously from military and non-military sources and culminated in a jointly published report “Anthropometry and Mass Distribution for Human Analogues: Volume I Military Male Aviators” between the U.S. Army, AirForce and Navy (USAARL Report 88-5). This report provided 139 body dimensions of standing and seated males, mass distributions by body segment, and skeletal joint center locations for the small, mid-size, and large male aviators. The stature and weight values for the three sizes represented the 3rd, 50th, and 95th percentiles. Of these 139 body dimensions, 47 were for the head. The anthropometric dimensions provided were not intended to be used for sizing of PPE and clothing, but for use in the design of analytical and physical mechanical surrogates such as anthropomorphic test devices (i.e., crash test dummies). The USAARL subsequently utilized the recommended mid-size male head anthropometry to develop a physical headform, intended to be used for conducting blunt impact testing of protective headgear. This headform was hand sculpted to match the reported head anthropometry with emphasis placed on the key measures of head length, breadth, height, and circumference as well as the facial features and tragion notch location. To facilitate aviator helmet use, which includes communication earcups, the ear structure protrusion on the headform was reduced to better represent the flexible ear cartilage tissue. The resulting headform was a rigid structure with realistic shape and facial features. This mid-size headform was then used as a model and scaled, by head circumference, to produce a smaller and larger headform.

These three headforms were then utilized by USAARL in 1992 as standard headforms for the measurement of CM locations of helmets, helmet mounted devices, and head mounted systems. These headforms were ideally suited for this purpose because of their anthropometric features, possessing realistic chin and nape structures for proper helmet fitting, facial features for adjustment and positioning of display systems, and nasal and mouth structure for the fitting of oxygen and chemical/biological masks. These three headforms were used for the creation of mold castings and copies fabricated for other uses within USAARL and provided to the anthropometry team at DEVCOM SC.

DEVCOM SC assessed each size against the Army’s Anthropometric Survey (ANSUR) 1988 and 2012 data collection for both male and female head circumference, breadth, and length. It was determined that the existing headforms adequately covered a range of anthropometric sizes to allow for measurement of base helmets in a size small, medium and large; therefore, the existing headform shapes and sizes were kept (Table 2). The headforms have been labeled II, III and IV. Giving the headforms this nomenclature allows for the development of a smaller headform (e.g., headform “I”).

Table 2. Headforms II, III and IV head circumference, length and breadth measurements and the associated population percentiles with respect to the Army Anthropometric Surveys (ANSUR) from 1988 and 2012 for both males and females.

Headforms and Corresponding 1988 and 2012 ANSUR Percentile Estimates for MALE Soldiers									
Headforms	Circumference (mm)	1988 ANSUR	2012 ANSUR	Length (mm)	1988 ANSUR	2012 ANSUR	Breadth (mm)	1988 ANSUR	2012 ANSUR
II	553.65	17.7	9.5	192.66	25.3	15.0	149.76	33.9	17.7
III	562.52	36.4	22.8	199.51	62.4	49.3	151.07	49.0	29.8
IV	597.04	96.9	92.3	209.72	96.4	91.8	160.52	94.1	87.6

Headforms and Corresponding 1988 and 2012 ANSUR Percentile Estimates for FEMALE Soldiers									
Headforms	Circumference (mm)	1988 ANSUR	2012 ANSUR	Length (mm)	1988 ANSUR	2012 ANSUR	Breadth (mm)	1988 ANSUR	2012 ANSUR
II	553.65	70.0	35.0	192.66	79	63.2	149.76	85.6	63.2
III	562.52	86.8	56.6	199.51	97.8	91.2	151.07	92.2	76.2
IV	597.04	99.8	95.0	209.72	99.9	99.1	160.52	99.6	99.1

Updates to the headforms were desired to improve overall geometry and measurement feasibility. In addition, it was planned to utilize 3D printing for fabricating the headforms to reduce headform weight and increase reproducibility. The existing headforms were scanned at DEVCOM SC using the Cyberware PX Scanner (Cyberware Inc., Monterey, CA) aligned and processed using Geomagic Design X (3DSystems Inc.) and then exported into Solidworks (Dassault Systemes, Waltham, MA). The headforms were made symmetrical from left to right in order to remove the minor asymmetries from the previous production method. Next, additional anatomical markings were incorporated to allow for higher fidelity in headform and helmet alignment measurements (Figure 6). The new markings included:

- Three anatomical plane lines (sagittal, frontal, Frankfurt) 2 mm wide
- A forehead line (2 mm wide) at the eyebrow line with two indents on either end and the center aligned with the mid-sagittal plane
- Indents for the trignon notch on the right and left side of the head
- Reference lines (.75 mm wide) perpendicular to the frontal plane on the right and left side of the head, which allow for visual alignment of helmets to the headform
- Two horizontal planes (2 mm wide) were added to the neck to allow for headform and MPI alignment while a helmet system is mounted to the headform
- Inscribed +X and +Y for orientation alignment to the MPI

The location of the ears on the original USAARL headforms were positioned where the trignon notch should be anatomically and therefore the ears on the new headform were shifted back to allow for both the ears and trignon notches to have correct anatomical placement on the headform. As mentioned, the ear shape on this headform is intentionally an oval and not representative of a true ear form or size. If a representative ear is needed in the future for equipment mounting requirements, this is something the headforms could be easily adapted to accommodate. The headforms were 3D printed using the Stratasys Fortus450mc and polymer Acrylonitrile Styrene Acrylate (ASA). The build parameters for the headform are provided in Appendix A.

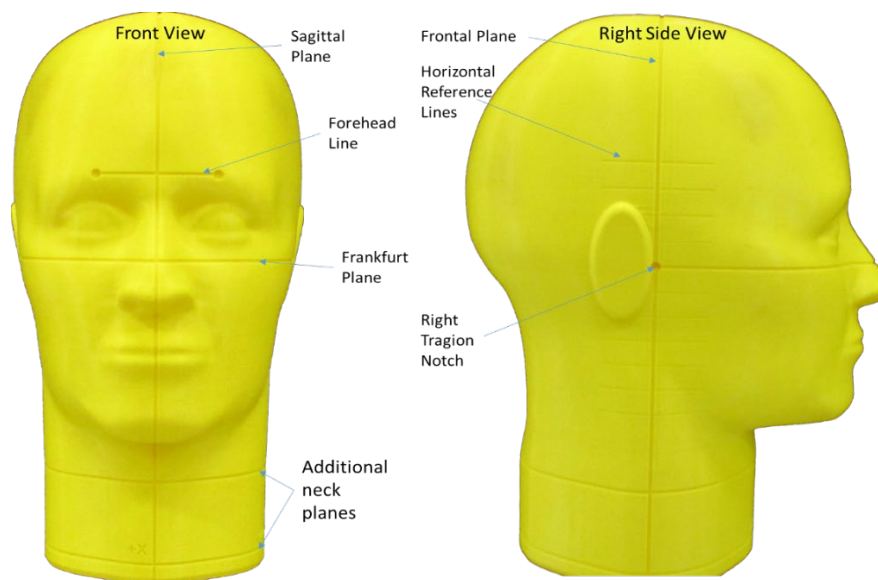


Figure 6. Front and right side view of the headform with key features identified.

Figure 7 provides views of the final headform ACS and with respect to the MCS for the lzz, lyy and lxx orientations. When Headform III is in the lzz position within the fixture, there is 8 inches of space between the right and left side of the headform and the inner sides of the fixture. When the headform is in the lyy position (headform is rotated such that the X-axis of the headform is aligned with the Y-axis of the MCS) there is 7.125 inches of space from the forehead line location to the inner side of the fixture and there is 7.25 inches from the back of the head to the closest inner side of the fixture. These measurements provide an indication for how much space there is to allow for helmet configurations to fit within the fixture.

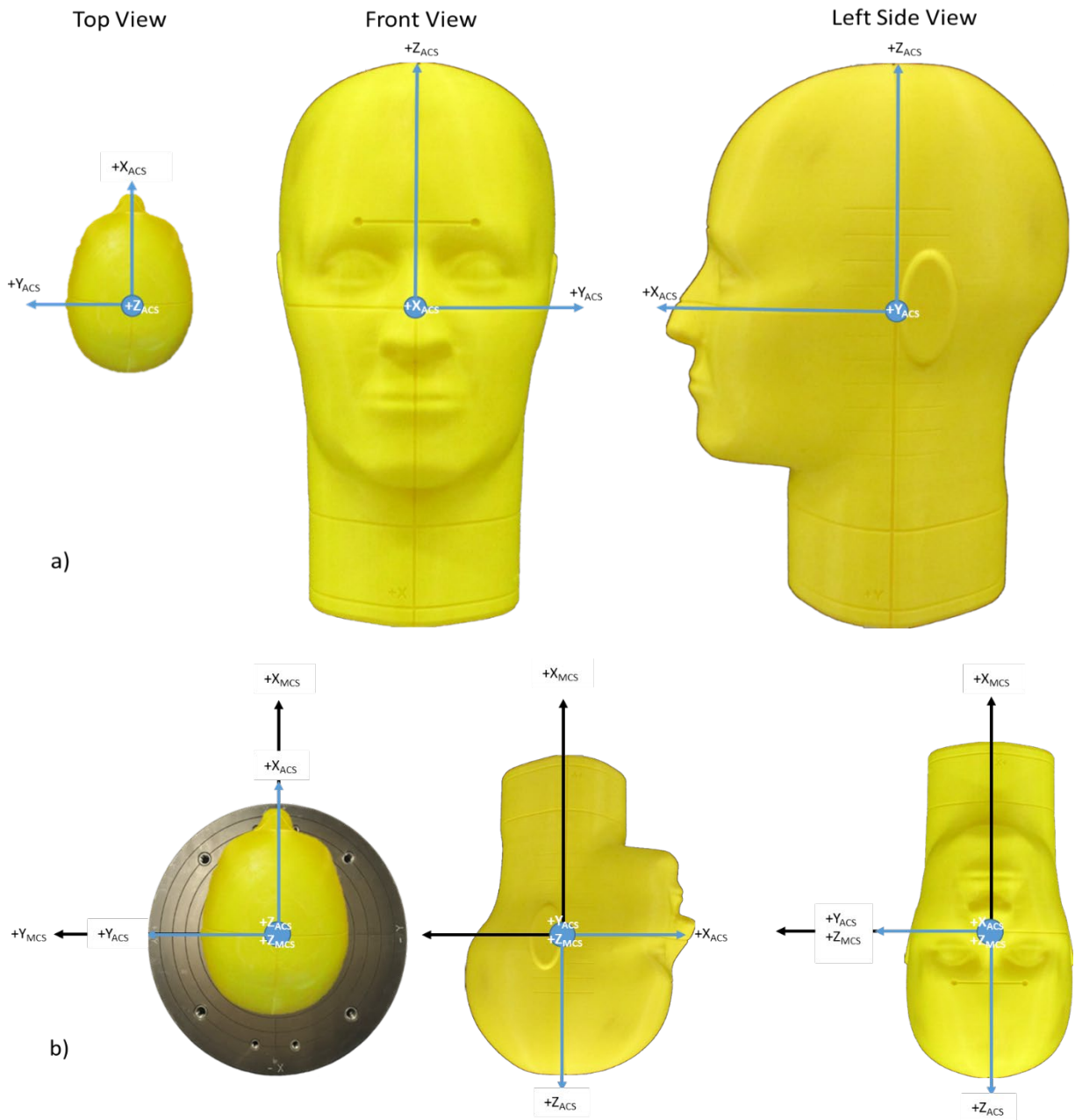


Figure 7. Fabricated headform views a) Top, front, and left view of the headform with the Anatomical Coordinate System and b) Headform views of both the ACS and MCS alignment. From right to left, headform position relative to the MPI interface plate to show the lzz, lyy and lxx headform orientations.

2.3 Head-borne Equipment Test Configurations

For a broad assessment of the measurement procedures, it was desired to have a set of head-borne equipment which would result in a range of CM and MOI measurements. The CM and MOI data from previous data collections were reviewed (Loverro 2020) to identify a set of configurations that would vary the CM and MOI. The Advanced Combat Helmet (ACH), Integrated Head Protection System (IHPS), PVS-14 night vision device (NVD), the M-50 Joint Service General Purpose Mask (JSGPM) and the aviator HGU-56/P helmet were the chosen head-borne equipment items. Photos of each helmet system mounted to the headform are provided in Figure 8. At the time of this data collection the ACH was more readily available than the IHPS (PEO Soldier's helmet on Program of Record at the time) and therefore it was used as the baseline helmet where the PVS-14 and the M-50 JSGPM would attach to. In addition, the ACH size small and size large were included in the test matrix to have a single helmet type measured across three different sizes. All configurations fit well within the dimensions of the fixture for all orientations.

ACH	IHPS
	
ACH with PVS-14 Stowed	ACH with PVS-14 Deployed
	
ACH with M-50 JSGPM	HGU-56/P
	

Figure 8. Photos of the six helmet configurations (ACH, IHPS, ACH with PVS-14 stowed, ACH with PVS-14 Deployed, ACH with M-50 JSGPM and the HGU-56/P) mounted to the headform.

2.4 Repeatability and Reproducibility Statistical Approach

This effort sought to establish the repeatability and reproducibility (R&R) of the determined test method. Repeatability refers to the measurement variation obtained when one operator repeatedly measures the same part using the same gauge, and reproducibility refers to variation due to different operators using the same gauge to measure the same part. In this study, “part” refers to any helmet configuration where the CM and MOI were measured. Additional goals included investigating part-to-part variability and interactions between operator and part. The main R&R testing was performed at DEVCOM Soldier Center with additional testing at USAARL. The additional testing at USAARL aimed to establish any differences in the measurements that can be attributed to a different fixture and MPI. The same headforms and helmets were used in both locations.

The number of operators needed and tests conducted were determined based on targeting a minimum of 34 degrees of freedom for the repeatability estimate, giving consideration to the number of available operators and parts, for achieving a specific margin of error. Having a minimum of 34 degrees of freedom allows for a repeatability estimate within 20% of truth with 90% confidence. For instance, if the standard deviation (SD) due to repeatability was 1, then 34 degrees of freedom provides an estimate within ± 0.2 of the true standard deviation with 90% confidence. A gage R&R study is a methodology used to determine the amount of variation in measurement data due to the measurement system. This type of study can determine the magnitude of the variation in a measurement system and also attribute variability to specific sources (e.g., operator to operator differences). An R&R utilizes a balance of the number of parts and operators to conduct testing. A standard gage R&R study includes two or three operators measuring 10 parts two to three times; however, when a pure assessment of R&R is the goal, it was found that the best designs utilize a single part measured a few times by many operators (Vardeman & Van Valkenburg, 1999).

For the testing at DEVCOM Soldier Center a total of five Operators were selected as testers. Single parts of all helmet configurations would be used except for one part; it was determined that the ACH in a size medium would be used to assess part-to-part variability. At DEVCOM SC, for part-to-part variability, it was determined that seven ACH size medium helmets would be tested five times per operator. All other helmet configurations, where only one part was tested, would be measured eight times by each operator (Table 3).

Table 3. List of helmet systems and test plan for the portion of the gauge Repeatability and Reproducibility testing conducted at DEVCOM SC.

Equipment Item	Size	Number of Operators	Number of Parts	Number of Tests per Part	Total Tests per Operator	Degrees of Freedom
ACH	M	5	7	5	35	140
ACH	S	5	1	8	8	35
ACH	L	5	1	8	8	35
IHPS	L	5	1	8	8	35
ACH w/NVD stowed	M	5	1	8	8	35
ACH w/NVD deployed	M	5	1	8	8	35
ACH w/M-50 JSGPM	M	5	1	8	8	35
HGU-56/P	M	5	1	8	8	35

At USAARL, two operators were available for testing. Therefore, the planned data collection for the seven ACH medium helmets included three tests per operator. For all other testing, where a single part was available, each USAARL operator would test each part 10 times (Table 4).

Table 4. List of helmet systems and test plan for the portion of the gauge Repeatability and Reproducibility testing conducted at USAARL.

Equipment Item	Size	Number of Operators	Number of Parts	Number of Tests per Part	Total Tests per Operator	Degrees of Freedom
ACH	M	2	7	3	21	56
IHPS	L	2	1	10	10	36
ACH w/NVD stowed	M	2	1	10	10	36
ACH w/NVD deployed	M	2	1	10	10	36
ACH w/M-50 JSGPM	M	2	1	10	10	36
HGU-56/P	M	2	1	10	10	36

2.5 Test Methodology and Procedures

The experimental procedure for measuring the mass properties of helmet systems was developed specifically for measuring inertial properties of head mounted equipment and is based on the methods previously used by DEVCOM SC and USAARL (Deavers 1992 and Loverro 2020). The procedure involves measuring the CM and MOI of the helmet system in six orientations, allowing for the calculation of CM in X, Y, and Z coordinates and the PMOI. This section identifies all steps critical to the measurement process. This includes the system calibration, tares, FaroArm measurements, CM and MOI measurements. In addition, a detailed report of the measurement procedures can be found in the technical report by Flath et al., 2020.

2.5.1 Calibrations

Separate calibrations for both the CM and MOI should be performed on a regular basis to ensure the KSR 300 MPI is functioning properly. Performing a calibration ensures the KSR is in working order by measuring the CM and MOI of a calibration mass and comparing the readings to their known values. If conducting mass properties measurements regularly, Space Electronics recommends the system be calibrated daily or weekly, and at a minimum it should be performed one time per month. However, calibration is not required daily or weekly. In some instances, it may not be optimal to calibrate daily because performing a calibration requires removing the fixture from the MPI interface plate. If the system has not been used for an extended period of time, it should be calibrated before measurements are performed.

The KSR software provides step-by-step instructions for completing the CM and MOI calibrations. Both require the use of a calibration beam and weights. The weights are placed in pre-determined locations on the beam and the system compares the measured CM and MOI values against their theoretical values. The KSR software will indicate if the calibration is accepted or rejected. CM and MOI calibration constants are recorded for each calibration.

Frequency of calibrations were performed differently between DEVCOM SC and USAARL. For this testing, DEVCOM SC performed a new calibration prior to each operator beginning their respective test series; this occurred approximately every 3 weeks. USAARL performed calibrations every 1-2 weeks and

their two operators utilized the same calibration to conduct testing. No new calibrations were performed in the middle of testing a head-borne equipment item.

2.5.2 Tares

In order to measure the mass properties of each helmet configuration (without the fixture and headform), tare measurements of the combined fixture and headform (fixture + headform) must be taken for each head orientation (I_{zz} , I_{xx} , I_{yy} , I_{xz} , I_{yz} , I_{xy}). These tare measurements are subsequently subtracted from the respective CM and MOI measurements made with the entire system (fixture + headform + helmet configuration). This process allows for CM and MOI calculations of the helmet configuration only. New tares only need to be performed either when the fixture is moved, a headform is swapped out, or a unique tare is needed to account for excess cables and hoses that are not directly supported by the head. A tare needs to be performed for each configuration a fixture + headform is oriented in. For this data collection it was six orientations. If cables or hoses are part of a helmet configuration, an additional cable or hose is needed to conduct the tare. The duplicate cable for the tare is aligned with the cable on the helmet and cut at the point where the mounted cable meets the rotating wheel. The tare cable is secured to the rotary wheel and a tare is conducted with this remaining portion of the cable. When the CM and MOI of the HSD is measured, the attached cable is secured to the rotary wheel exactly as it was when the tare was performed. The mass of the tare cable is subtracted from the total test item weight when calculating the CM and MOI. Figure 9 is a photo of the cable from the HGU-56/P attached to the fixture “wheel” as it was mounted for a tare measurement in the I_{zz} orientation.

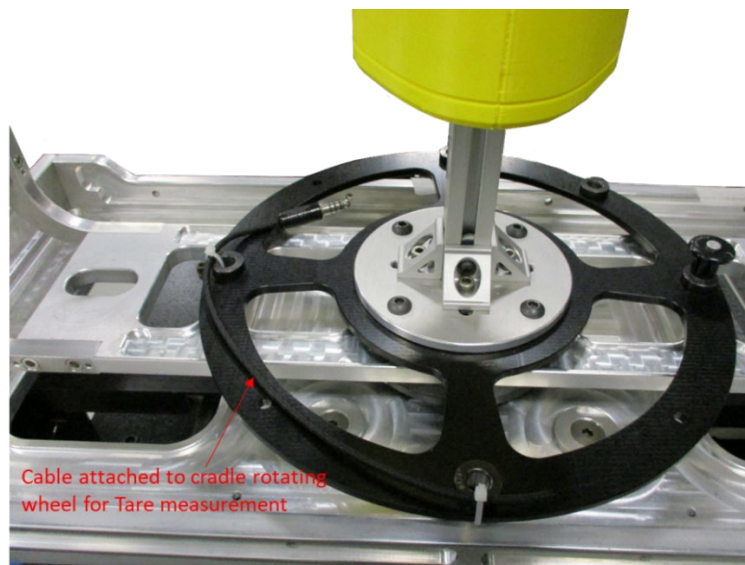


Figure 9. Cable attached to cradle rotating wheel for Tare measurement.

2.5.3 Mass Properties Measurement Process

The steps taken to perform the mass properties measurements and calculations are outlined in this section. A procedural guide for performing the test method can be found in the technical report document USAARL-TECH-TR-2020-052. To begin, the mass of each helmet configuration was measured on the Sartorius scale and a separate measurement was made to determine the mass of the fixture and headform with attached pedestal and hardware (Table 5).

Table 5. List of test equipment and helmet system masses (kg) used in the CM and MOI calculations.

Item	Mass (kg)
Fixture	13.025
Pedestal + Headform II	1.295
Pedestal + Headform III	1.341
Pedestal + Headform IV	1.426
ACH Size Small	1.356
ACH Size Large	1.486
ACH Medium Helmet 1	1.433
ACH Medium Helmet 2	1.342
ACH Medium Helmet 3	1.348
ACH Medium Helmet 4	1.369
ACH Medium Helmet 5	1.352
ACH Medium Helmet 6	1.391
ACH Medium Helmet 7	1.371
IHPS size Medium	1.438
ACH Med w/PVS-14	1.99
ACH Medium with M-50 JSGPM	2.372
HGU-56/P size Large	1.349

The headform mounted to the pedestal was secured to the fixture to ensure that the headform did not move relative to the fixture during the measurements. Alignment measurements (with the headform in the Izz orientation) were taken with the FaroArm to characterize the fixture and headform placement and ensure that the center between the headform +Y and –Y tragion notches was less than 1 mm away from the MPI interface plate center point along the X- and Y-axis. The headform and fixture is then tared in each of the six orientations for both CM and MOI (Figure 10). The helmet configuration to be measured was then fitted and secured to the headform to ensure that it did not move relative to the headform during the measurements. Directions followed by the operator for placement of each helmet configuration are identified in Table 6. With the fixture and helmet configuration in place, additional alignment measurements were taken with the FaroArm of the headform and helmet system. This was done to characterize initial helmet placement and determine if the helmet shifted during the mass properties measurement process. For each helmet system, specific locations on the helmet and equipment were selected for digital measurement; these points were analyzed relative to the forehead line midpoint both pre and post mass properties testing. Measuring each point, to include the forehead line midpoint pre and post mass properties testing, is critical because the KSR 330 baseplate does not return to its exact 0 point after each test. Descriptions with photos of the points measured on each helmet system are provided in Table 7. All measurement points, except the ACH and IHPS +Y and –Y locations, allowed the FaroArm ballpoint to sit in a fixed measurement location. The ACH and IHPS +Y and –Y locations were marked points on the helmets and the FaroArm ballpoint rested against the brim line; therefore, these measurements are subjected to more variability.

Table 6. Each helmet system and associated fit instructions to the headform.

Item	Fit Procedure
ACH size Small, Medium and Large	Align center hole for NVD mount with the mid-sagittal plane. Brim of helmet should be approximately 1 in above forehead line. Visually inspect helmet to ensure there is no tilt from side-to-side or front-to-back.
IHPS	Align center hole for NVD mount with the mid-sagittal plane. Brim of helmet should be approximately 1 in above forehead line. Visually inspect helmet to ensure there is no tilt from side-to-side or front-to-back.
ACH Med with PVS-14 Deployed	Brim of helmet should be approximately 1 in above forehead line. Visually inspect helmet to ensure there is no tilt from side-to-side or front-to-back. Eye-piece aligned with left eye in closest position to the head.
ACH Medium with PVS-14 Stowed	Brim of helmet should be approximately 1 in above forehead line. Visually inspect helmet to ensure there is no tilt from side-to-side or front-to-back. The PVS-14 is placed in a stowed position by directly shifting the NVD from the deployed position. The PVS-14 tilt adjustment is in the furthest clockwise position.
ACH Medium with M-50 JSGPM	M-50 mask is placed on the headform first and centerline is aligned with mid-sagittal plane. Top of goggles is aligned with headform forehead line. Mask is visually inspected to ensure there is no tilt from side-to-side. Helmet is placed on headform and straps are secured under the mask.
HGU-56/P	Align center hole for NVD mount with the mid-sagittal plane. Brim of helmet should be approximately 1 in above forehead line. Visually inspect helmet to ensure there is no tilt from side-to-side or front-to-back. Earcups are placed over headform ears and positioned vertically. Microphone is aligned with the center of the mouth. Cable is tied to the rotary wheel with zip ties through the pre-drilled holes.

Table 7. Photos of each helmet system and measurements taken on the headform and equipment items.

Helmet System	Points	Measurement Notes
ACH size Small, Medium and Large	1. Forehead Line Midpoint 2. Helmet NVD Mount Hole 3. +Y Helmet Brim 4. -Y Helmet Brim	1. The +Y and -Y locations are on either side of the helmet along the indentation and stops where the FaroArm ballpoint rests against lip of helmet brim. 2. The lengths from the forehead line midpoint to each helmet point were calculated.
Helmet System	Points	Measurement Notes
IHPS	1. Forehead Line Midpoint 2. Helmet NVD Mount Hole	1. The length from the forehead line midpoint to the NVD mount hole was calculated.
Helmet System	Points	Measurement Notes
ACH Med with PVS-14 Deployed	1. Forehead Line Midpoint 2. +Y screw point on PVS-14, visible in stowed position 3. -Y screw point on PVS-14, visible in stowed position 4. +Y Helmet Brim 5. -Y Helmet Brim	1. The +Y and -Y locations are on either side of the helmet along the indentation and stops where the FaroArm ballpoint rests against lip of helmet brim. 2. The lengths from the forehead line midpoint to each helmet point were calculated.
Helmet System	Points	Measurement Notes
ACH Medium with PVS-14 Stowed	1. Forehead Line Midpoint 2. +Y screw point on PVS-14, visible in stowed position 3. -Y screw point on PVS-14, visible in stowed position 4. +Y Helmet Brim 5. -Y Helmet Brim	1. The +Y and -Y locations are on either side of the helmet along the indentation and stops where the FaroArm ballpoint rests against lip of helmet brim. 2. The lengths from for the forehead line midpoint to each helmet point were calculated.

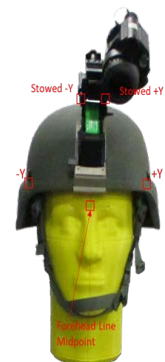


Table 7. Photos of each helmet system and measurements taken on the headform and equipment items (continued).

Helmet System	Points	Measurement Notes
ACH Medium with M-50 JSGPM	1. Forehead Line Midpoint 2. +Y slot on M-50, closest to the midsagittal plane 3. -Y slot on M-50, closest to the midsagittal plane	1. The +Y and -Y locations are on either side of the helmet along the indentation and stops where the FaroArm ballpoint rests against lip of helmet brim. 2. There are two slots at the top of the M-50 mask, the ballpoint was placed in the slot at the point closest to the midsagittal plane 3. The lengths from for the forehead line midpoint to each helmet point were calculated
Helmet System	Points	Measurement Notes
HGU-56/P	1. Forehead Line Midpoint 2. Top Right NVD Mount Hole 3. +Y screw point on helmet 4. -Y screw point on helmet	1. The +Y and -Y locations are on screw tops that are on either side of the helmet 2. This helmet has four mounts holes for an NVD bracket mount, the top right hole was used. 3. The lengths from for the forehead line midpoint to each helmet point were calculated



With the helmet fitted and alignment measurements taken, the CM and MOI of the helmet system can then be measured in each of the six orientations (Figure 10). Upon completion of the six CM and MOI measurements, the same headform and helmet system alignment measurements were taken with the FaroArm. Figure 10, on the left, illustrates the orientations of the fixture to obtain CM and basic MOI along the X-axis, Y-axis and Z-axis and on the right, the XZ, XY and YZ planes which were normal to the rotating plate of the MPI and were offset by 45°. From the three headform orientations along X, Y, and Z, two CM measurements are obtained for each axis. Therefore, there are six CM total with two CM measurements obtained along the X-axis, Y-axis and Z-axis. For the purpose of this study, these measurements were labeled X_1 , X_2 , Y_1 , Y_2 , Z_1 and Z_2 and were evaluated separately. In the figure, “C” is the angle of the cradle in degrees with respect to the XY plane and “H” is the angle of the headform in degrees with respect to the XZ plane. The following is a breakdown of the measurements obtained from each orientation:

- **Figure 10a: lzz orientation** - the X and Y CM coordinates and the MOI about the Z axis (lzz) for the helmet configuration were obtained. These CM measurements were annotated X_1 and Y_1
- **Figure 10b: lxx orientation** - the Z and Y CM coordinates and the MOI about the X axis (lxx) for the helmet configuration were obtained. These CM measurements were annotated Z_1 and Y_2 , as this orientation was the second Y-axis CM measurement
- **Figure 10c: lyy orientation** - the Z and X CM coordinates and the MOI about the Y axis (lyy) for the helmet configuration were obtained. These CM measurements were annotated Z_2 and X_2 as they were both the second Z-axis and X-axis CM measurements.
- **Figure 10d: lxx orientation** - the MOI about the XZ axis (lxx) for the helmet configuration was obtained.
- **Figure 10e: lxy orientation** - the MOI about the XY axis (lxy) for the helmet configuration was obtained.
- **Figure 10f: lyz orientation** - the MOI about the YZ axis (lyz) for the helmet configuration was obtained.

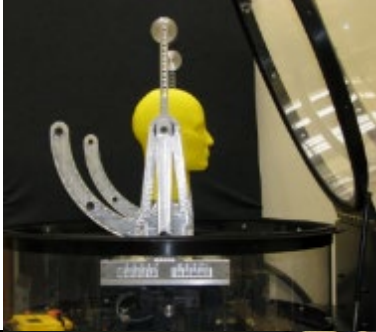
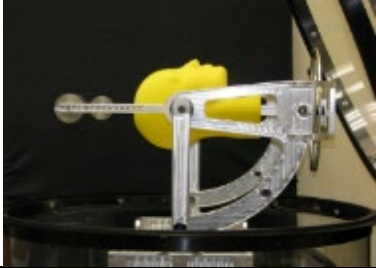
CM and Basic MOI Orientations		PMOI Orientations	
a) Izz $C=0^\circ, H=0^\circ$ $+X_m=+X_h,$ $+Y_m=+Y_h$		d) Ixz $C=45^\circ, H=0^\circ$	
b) Ixx $C=90^\circ, H=0^\circ$ $+X_m=-Z_h,$ $+Y_m=+Y_h$		e) Ixy $C=90^\circ, H=45^\circ$	
c) Iyy $C=90^\circ, H=90^\circ$ $+X_m=-Z_h,$ $+Y_m=+X_h$		f) Iyz $C=45^\circ, H=90^\circ$	

Figure 10. Testing six orientations for measuring CM, Basic MOI and PMOI. In the figure, “C” identifies the cradle angle with respect to the XY plane and “H” identifies the head rotation with respect to the XZ plane. The subscript “m” refers to the machine coordinate system and the subscript “h” refers to the headform anatomical coordinate system.

Once the six CM (X_1, X_2, Y_1, Y_2, Z_1 and Z_2) and MOI ($I_{zz}, I_{xx}, I_{yy}, I_{xz}, I_{yz}$, and I_{xy}) and pre- and post-alignment measurements with the FaroArm were completed, the operator fully removed the helmet system and refit it to the headform for the next test.

2.6 Additional Data Collection

DEVCOM SC conducted the CM and MOI data collection first and then the helmet systems and headforms were shipped to USAARL for testing. During the data collection at DEVCOM SC, after four operators had conducted testing, it was observed that the fixture cradle was shifting along the Y-axis when the operators rotated the cradle. The bolt at the cradle point of rotation on the –Y side of the fixture was loosening (Figure 4). The problem was resolved by changing the locknut and by adding spacers near the quick connect pins, which physically stopped the cradle from translating along the Y-axis. The fifth operator completed the test matrix with this fix in place and then two DEVCOM SC operators performed additional testing. Table 8 identifies the re-tests, which occurred at DEVCOM SC. Testing had not yet occurred at USAARL and therefore no additional tests were performed by the two USAARL operators. The total number of tests for each helmet configuration is reported for each of the six CM and MOI measurements in Chapter 3 Results and Discussion.

Table 8. List of equipment items on which additional testing was performed by Operators 2 and 4 from DEVCOM SC.

Equipment	Number of Operators	Number of Parts	Total Tests Per Operator
ACH Medium	2	7	35
IHPS	2	1	8
ACH Med w/PVS-14 Stowed	2	1	8
ACH Med w/PVS-14 Deployed	2	1	8

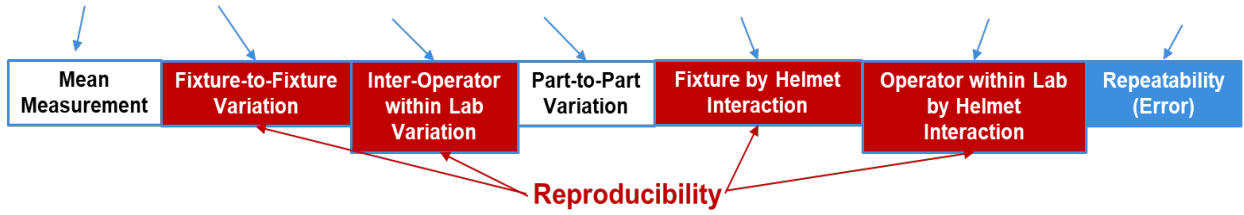
2.7 Data Analysis

The measurements outlined in this report include the alignment of the headform and fixture midpoints to the MPI, the alignment of the HBS to the headform, and CM and MOI measurements. For the headform ACS origin and fixture baseplate midpoint to MPI alignment data, the means, standard deviations and variance were analyzed. For the alignment of the HBS to the headform, pre-test data were analyzed to determine the degree of consistency among operators for helmet placement. The difference in pre- and post-test measurements were also reviewed to evaluate if the helmet systems moved significantly during the orientation of the headform in multiple positions to obtain the six MOI measurements. Descriptive statistics of the length between the forehead midpoint and the helmet system point, pre and post mass properties measurements, are presented for each helmet configuration. The analysis includes minimum and maximum values, means, standard deviations (SD), variances and coefficients of variation (CV). For the CM and MOI data, each measured component is presented separately. As noted in Section 2.5.3, for each helmet system and every test, six CM (X_1 , X_2 , Y_1 , Y_2 , Z_1 and Z_2) and six MOI (I_{zz} , I_{xx} , I_{yy} , I_{xz} , I_{xy} , I_{yz}) measurements were calculated. Descriptive statistics (min and max values, means, SDs, variance and CVs) are provided for each of the six CM and six MOI measurements.

For the R&R analysis, the proportions of variance from the factors defined in the statistical models, applicable to each helmet system, were calculated. The R&R models created were dependent on the helmet system being analyzed. For instance, the model for the ACH medium (Equation 1) had six factors total with crossed and nested effects. A crossed effect occurred since the helmets were shared across DEVCOM SC and USAARL and a nested effect occurred as operators were specific to each site (where the operators only made measurements on one fixture at either DEVCOM SC or USAARL). In addition, the ACH medium was the only helmet system where part-to-part variation was assessed, as there were seven ACH medium helmets measured. The notation $j(i)$ indicates that Operators were nested within Fixture. For the statistical assessment, "Fixture" is the MPI and the gimbal style fixture that mounts to the MPI combined together. The six factors contributing to the total variance are for the ACH medium measurements are: Fixture (MPI and gimbal style fixture), Operator, Helmet (part-to-part), Fixture by Helmet interaction, Operator within lab helmet interaction, and Repeatability (error).

Equation 1

$$Y_{ijkl} = \mu + \text{Fixture}_i + \text{Operator}_{j(i)} + \text{Helmet}_k + (\text{Fixture} * \text{Helmet})_{ik} + (\text{Operator} * \text{Helmet})_{j(i)k} + \varepsilon_{ijkl}$$



For the ACH large and ACH small, only a single part was measured by the DEVCOM SC; therefore, the R&R model was simpler (Equation 2) and only included effects from Operators and Repeatability (error).

$$Y_{ij} = \mu + \text{Operator}_i + \varepsilon_{ij} \text{ Equation 2}$$

The remaining helmet systems—IHPS, HGU-56/P, ACH medium with PVS-14 stowed and deployed, and the ACH medium with M-50 JSGPM—were tested at both DEVCOM SC and USAARL and therefore the R&R model for these conditions included fixture-to-fixture variation in addition to effects from Operator and Repeatability (Equation 3).

$$Y_{ijk} = \mu + \text{Fixture}_i + \text{Operator}_{j(i)} + \varepsilon_{ijk} \text{ Equation 3}$$

For each CM and MOI measurement the proportion of variability was analyzed with its respective model. Calculations of the PMOI are not presented in this report as the goal was to understand the R&R from the CM and MOI measurements collected from the MPI.

3 Results and Discussion

The results of the six CM (X_1 , X_2 , Y_1 , Y_2 , Z_1 and Z_2) and six MOI (I_{zz} , I_{xx} , I_{yy} , I_{xz} , I_{xy} , I_{yz}) measurements from the DEVCOM SC and USAARL data collection are presented in this section. All mass properties measurements included in the analysis are provided in Appendix B. A review of the effect from the loose bolt on the gimbal fixture and resulting y-translation is provided first. Then the FaroArm alignment measurements of the headform and helmet systems along with the CM and MOI results for each helmet system are reported. Operators 1-5 are from DEVCOM SC and Operators 6 and 7 are from USAARL.

3.1 Effect of Fixture Y-Translation

For investigating the influence of the loose bolt and resulting y-translation of the fixture cradle, the six CM measurements were analyzed, as these would show the most apparent effect from a physical displacement of the cradle. Figure 11 to Figure 14 are plots of the X_1 vs X_2 , Y_1 vs Y_2 and Z_1 vs Z_2 CM data for the helmet systems and depict the CM measurements influenced by the loose bolt and resulting y-translation. For the X and Y CM plots, the data in gray are pre-modification to the fixture and the data in black are post-modification to the fixture for all seven operators from DEVCOM SC and USAARL. Ideally, all of the data would have a 1:1 ratio and fall along a line at a 45-degree angle. This was expected as both Z_1 and Z_2 measurements are collected along the machines X-axis and should not have been influenced by an isolated shift along the y-axis. It was observed that three of the CM measurements, Y_1 , Y_2 and X_2 , were the most influenced by the cradle shifting. This was expected as these three variables are the only CM measurements derived from the alignment along the Y-axis (Figure 10). The variability introduced by the loose bolt for Y_1 , Y_2 and X_2 CM measurements is significant, ranging up to 1 cm in some cases. The Z CM measurements were not affected by the cradle movement, all of the Z_1 vs Z_2 data plotted fall along a line with a 1:1 ratio. In the figures, since no Z-axis CM data were excluded, the Z_1 and Z_2 measurements are also identified by Operator. These plots depict the variability in the Y_1 , Y_2 and X_2 CM measurements of the pre- versus post-modification to the fixture and the need to exclude the pre-fixture modification Y_1 , Y_2 and X_2 CM measurements from the analysis. The excluded Y_1 , Y_2 and X_2 CM data are from Operators 1, 5 and the first test series for Operators 2 and 4. The included Y_1 , Y_2 and X_2 CM data are from Operators 3, 6, 7 and the second test series performed by Operators 2 and 4.

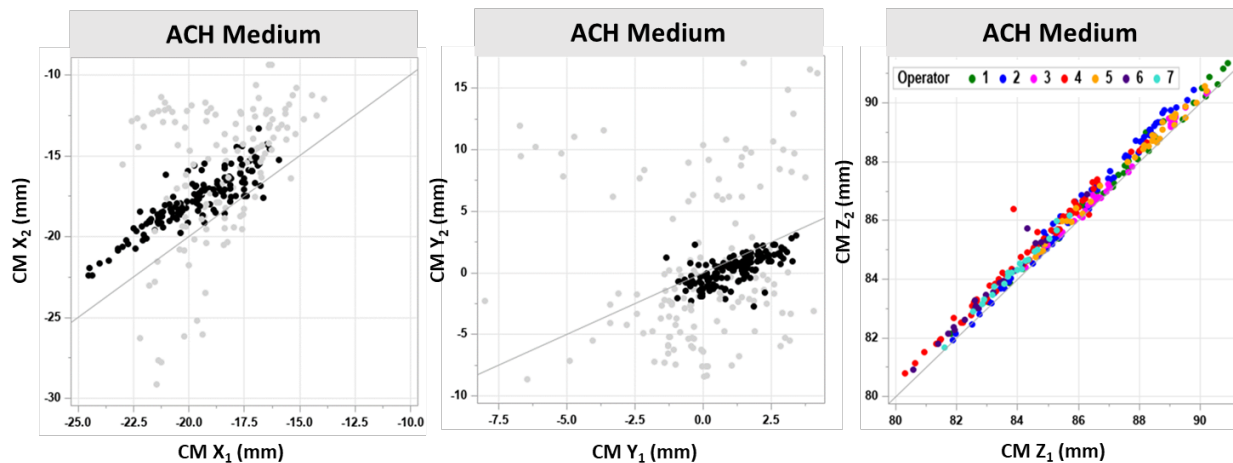


Figure 11. ACH medium CM plots for all measured data of X_1 vs X_2 , Y_1 vs Y_2 and Z_1 vs Z_2 . For X and Y, the gray dots are measurements that were excluded due to y-translation occurring from a loose bolt in the fixture.

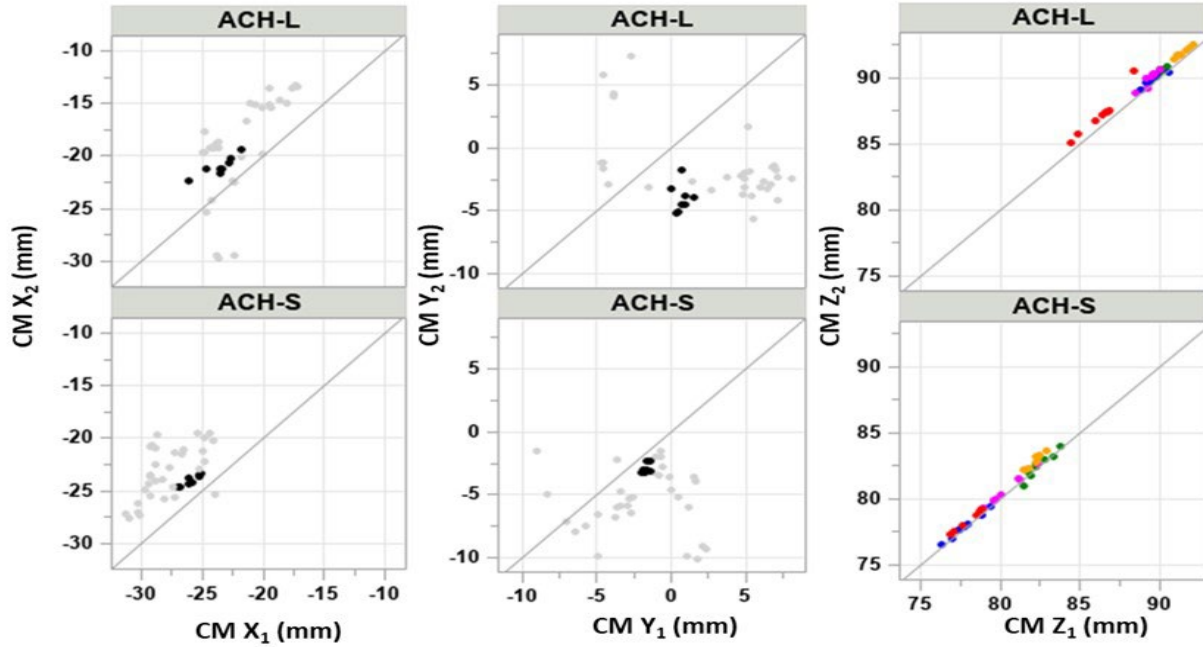


Figure 12. ACH Large and Small CM plots for all measured data of X_1 vs X_2 , Y_1 vs Y_2 and Z_1 vs Z_2 . For X and Y, the gray dots are measurements that were excluded due to y-translation occurring from a loose bolt in the fixture.

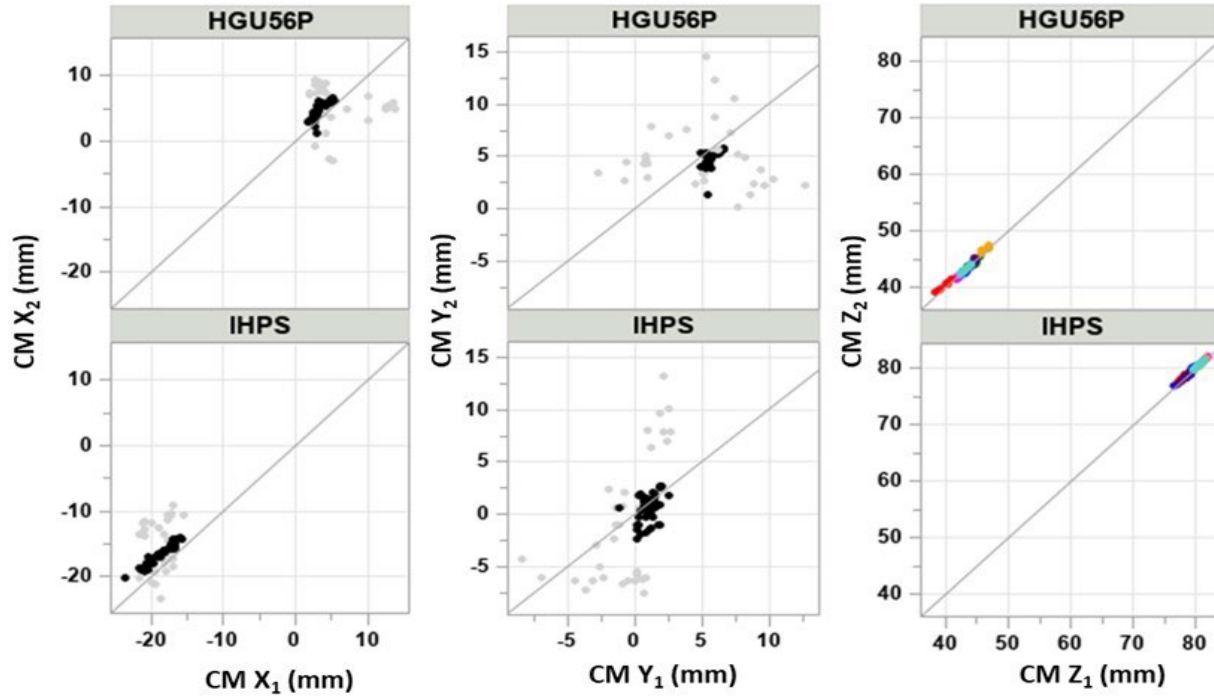


Figure 13. HGU56P and IHPS CM plots for all measured data of X_1 vs X_2 , Y_1 vs Y_2 and Z_1 vs Z_2 . For X and Y, the gray dots are measurements that were excluded due to y-translation occurring from a loose bolt in the fixture.

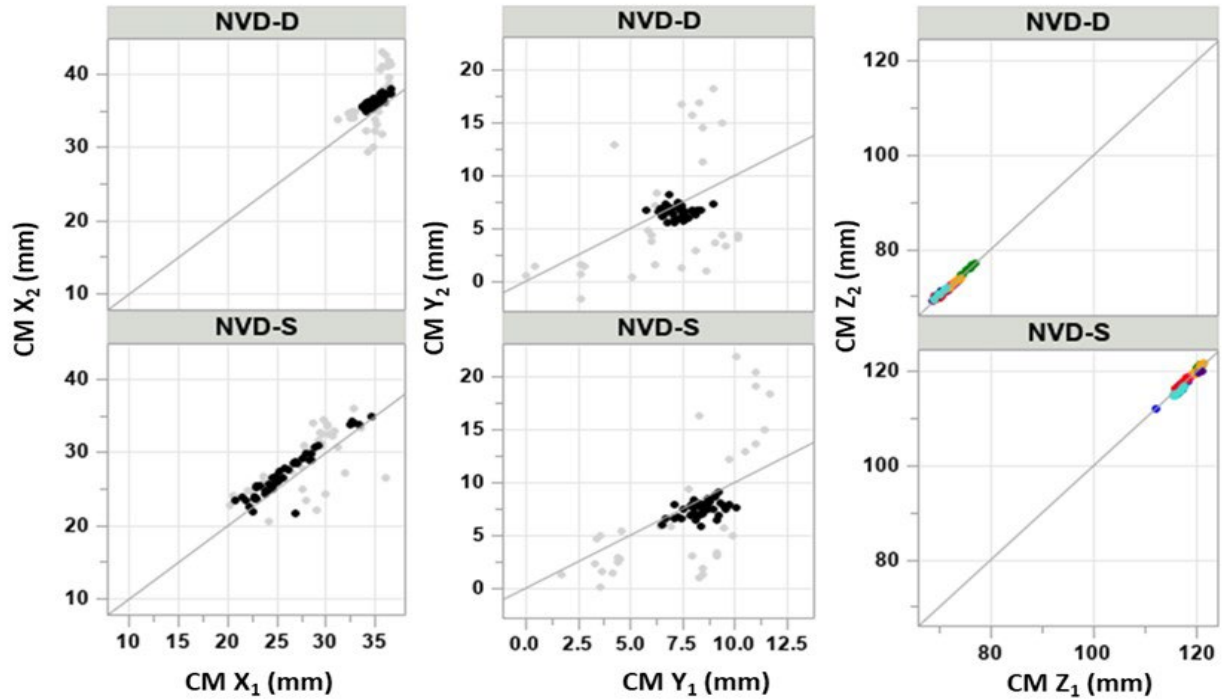


Figure 14. NVD-Deployed and NVD-Stowed CM plots for all measured data of X_1 vs X_2 , Y_1 vs Y_2 and Z_1 vs Z_2 . For X and Y , the gray dots are measurements that were excluded due to y -translation occurring from a loose bolt in the fixture.

3.2 Fixture and Headform Alignment

In this section, alignment measurements of the fixture and headform to the center of the MPI baseplate (Figure 3) are provided. Table 9 provides the X and Y midpoint of the fixture baseplate relative to the origin of the MCS for each DEVCOM SC operator and each headform. In Table 9, there are no Operator 6 or 7 data as USAARL did not collect measurements of the fixture base plate center point. The fixture was centered on the KSR interface plate along the X and Y axes to within less than .1 mm for all mounts except Headform II, where for Operator 2, the X measurement was -.357 mm from the machine centerline.

Table 9. Headform fixture baseplate center point relative to the mass properties instrument center point.

Headform	Operator ID	X (mm)	Y (mm)
II	1	-0.055	-0.021
II	2	-0.357	-0.022
II	3	-0.087	0.016
II	4	-0.017	-0.036
II	5	-0.034	-0.022
III	1	0.096	-0.008
III	2	-0.08	-0.022
III	3	-0.061	0.037
III	4	-0.078	-0.054
III	5	-0.034	-0.022
IV	1	-0.034	-0.022
IV	2	-0.034	-0.022
IV	3	0.041	0.022
IV	4	-0.09	-0.018
IV	5	-0.034	-0.022

The measurements for the head ACS origin (midpoint between the right and left trigion notch), when Headform III is mounted on the fixture and MPI in the lzz, lxz and lxx positions, are provided in Table 10 for all Operators. These positions represent a shift of the cradle from the 0 to 45 to 90 degree position but no rotation of the headform. In Figure 15 and Figure 16, scatterplots of the X, Y and Z positions are provided with respect to the position of the cradle in the 0, 45 and 90 degree positions. Operator “2.5 and 4.5” is meant to represent the second series of tests when Operators 2 and 4 conducted re-tests due to the loose bolt in the cradle allowing it to shift along the Y-axis. The Y-point data for lxx and lxx have the largest variance, which is likely because of the cradle shifting when moved to 45 and 90 degree positions. In Figure 15, the most notable result is the consistent increase in both the X and Z measurements as the cradle is moved from the 0 to the 45 and 90 degree positions. The average difference in the trigion notch midpoint for X is 2.56 mm and the average difference for Z is 1.7 mm. This identifies that the headform trigion notch midpoint is located below the point of rotation on the fixture. The height of the cradle should be at 367 mm. This problem should be addressed for future implementation of this fixture and test method. This can be done by better controlling the mounting of the headform on the pedestal with a reference gauge block or using the known variation in the midpoint position to properly calculate the CM and MOI. Additional sources of error to these trigion notch measurements could be from the following:

1. Ensuring the headform pedestal post mount is to within ± 0.1 degree of 90 degrees. If the pedestal is not perpendicular, the headform lean will result in additional error in positioning the trigion notch midpoint with the MPI baseplate center. In this data collection, the pedestal angle was checked for all headform mounts to be within ± 0.1 of 90 degrees.
2. If the Operators apply too much pressure on the headform with the FaroArm ballpoint, it will move the head and result in varying position measurements. Great care must be taken by the Operators to not physically shift the headform during position measurements.

Table 10. Headform III tragon notch midpoint relative to the mass properties instrument center point at each cradle position of 0, 45 and 90 degrees. Operators 2 and 4 are also Operators 2.5 and 4.5 respectively to separate the data for the cradle positions when they conducted re-tests.

Location	Headform	Operator	Izz- Cradle at 0 Degrees (mm)			Ixz- Cradle at 45 Degrees (mm)			Ixx- Cradle at 90 Degrees (mm)		
			X	Y	Z	X	Y	Z	X	Y	Z
DEVCOM-SC	III	1	-0.02	0.29	365.0	2.22	-0.67	366.1	2.58	-1.05	367.2
DEVCOM-SC	III	2	-0.56	-0.08	365.1	1.18	-0.78	365.6	2.31	-1.01	367.1
DEVCOM-SC	III	3	-0.64	0.55	365.2	1.23	-0.03	365.9	2.22	-0.55	367.4
DEVCOM-SC	III	4	-0.55	0.21	365.1	1.37	0.25	365.5	2.31	-2.03	367.4
DEVCOM-SC	III	5	-1.05	-0.38	367.1	1.35	-1.48	365.7	2.57	-1.23	367.2
DEVCOM-SC	III	2.5	-0.23	0.40	365.2	1.11	0.14	365.9	2.02	-0.43	367.1
DEVCOM-SC	III	4.5	-0.23	0.40	365.2	1.11	0.14	365.9	2.02	-0.43	367.1
USAARL	III	6 and 7	-0.85	-0.15	365.3	1.08	-0.43	365.6	2.51	-0.09	366.6
Mean (mm)			-0.52	0.16	365.4	1.33	-0.36	365.8	2.31	-0.85	367.1
SD (mm)			0.34	0.32	0.72	0.37	0.60	0.23	0.23	0.61	0.25
Variance (mm) ²			0.12	0.10	0.51	0.14	0.36	0.05	0.05	0.38	0.06

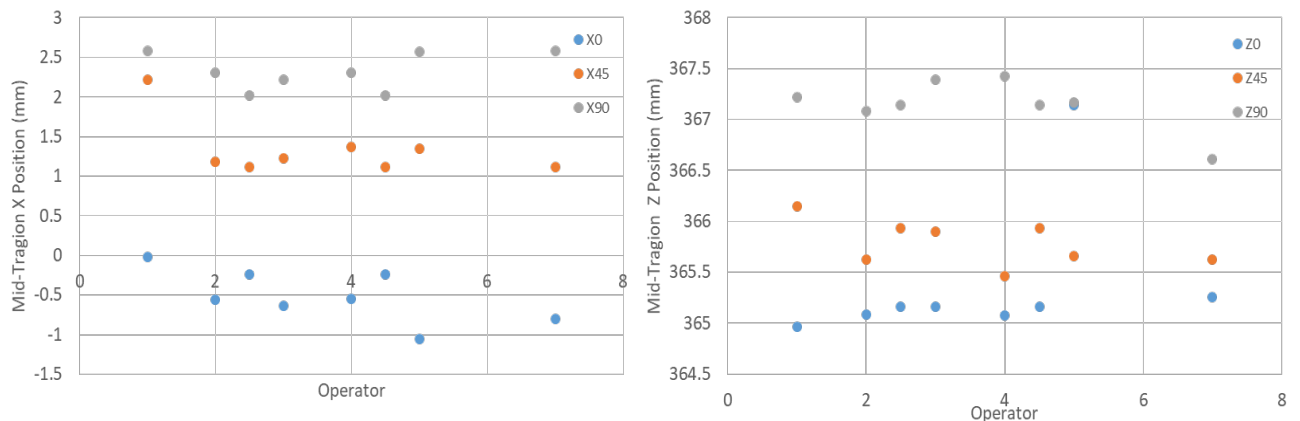


Figure 15. Scatterplot of each Operators tragon notch X and Z midpoint of Headform III for 0, 45 and 90 degree positions.

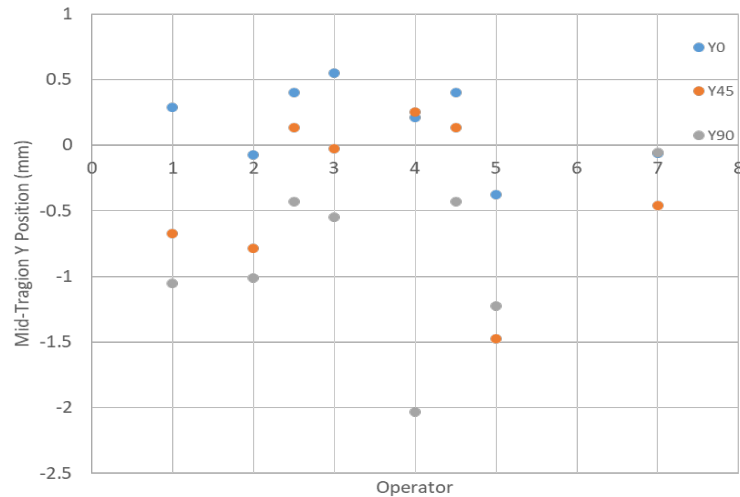


Figure 16. Scatterplot of each Operators average trignon notch Y midpoint of Headform III for 0, 45 and 90 degree positions.

Trignon notch midpoint measurements when the headform was positioned for the lyy measurement (cradle at 90 degrees and headform rotated 90 degrees, Figure 10c) were not collected during the R&R study. Post data collection, additional measurements looking at the position of the trignon notch midpoint for the cradle wheel rotation were conducted (Table 11) by taking measurements in the lzz, lxx and lyy headform orientations. The average shift in the Y-position for DEVCOM SC was about 0.5 mm between the lxx and lyy positions; this is within the error to be expected from Operator measurement. However, the average difference in Y between the lxx and lyy positions for USAARL was 1.5 mm. It is not clear what contributed to this variation, as these measurements were conducted on different fixtures. Further investigation is needed to understand why this shift along the Y-axis is occurring. The average headform trignon notch midpoint shifts between the lzz and lxx cradle positions, for DEVCOM SC and USAARL respectively, are 2.77 and 2.59 mm along the X-axis and 1.52 and 1.93 mm along the Z-axis. These are similar to the average differences between lzz and lxx measured during the R&R data collection of 2.56 mm along X-axis and 1.7 mm along the Z-axis.

Table 11 Post R&R data collection measurements of the trignon notch midpoint relative to the mass properties instrument center point for Headform III in the lzz, lxx and lyy positions. Five additional measurements were conducted at DEVCOM SC and two were conducted at USAARL; the average values are provided.

Location	Headform Orientation	X (mm)	Y (mm)	Z (mm)	lzz to lxx Average Positions (mm)			lzz to lyy Average Positions (mm)		
					Delta X	Delta Y	Delta Z	Delta X	Delta Y	Delta Z
DEVCOM SC	lzz	-1.00	-0.12	365.14						
	lxx	1.77	-1.04	366.67	2.77	-0.91	1.52	2.78	-0.41	1.41
	lyy	1.78	-0.54	366.55						
USAARL	lzz	-0.25	-0.40	365.52						
	lxx	2.34	-0.20	367.44	2.59	0.20	1.93	2.60	1.67	1.77
	lyy	2.36	1.27	367.28						

3.3 ACH Medium

3.3.1 ACH Medium Headform Alignment

Figure 17 is the Army Combat Helmet (ACH) medium mounted to the headform and depicts the four points: +Y and -Y ACH points, NVD mount hole (NVD_{MH}) on the ACH and the forehead line midpoint (FLM) used in evaluating the alignment of the ACH to the headform with the FaroArm. The resultant

lengths between the FLM and each of the three helmet points pre-mass properties tests, along with the difference between the +Y and -Y ACH lengths and the difference between the pre- and post-mass properties tests were calculated and are presented in this section. In addition, the pre-mass properties measurement X, Y and Z point differences between the FLM to the NVD_{MH} are provided. Table 12 includes the minimum and maximum, mean, SD, variance and CV for each measurement. The large CV for the Y point measurements is due to the mean of .03 mm. The FLM to +Y and -Y ACH points lengths are plotted in Figure 18. The +Y and -Y ACH measurement locations are subject to more variability from the Operator positioning because these measurement points on the helmet were marked locations and didn't allow for the FaroArm ballpoint to "sit" in a constrained space. Overall, these Operator measurements are self-consistent with the USAARL Operator measurements being smaller than those from DEVCOM SC. The FLM to NVD_{MH} length data range from 57 to 72 mm, which is a span of 1.5 cm, indicating that the Operators did not all mount the helmet similarly. In Figure 19, the average pre-test length of the FLM to NVD_{MH} measurements for each helmet are plotted for each operator. The red box around a subset of Operator 2's measurements is of the second round of mass properties tests conducted by the Operator. In the second test series, Operator 2 mounted the ACH to the headform differently, but consistently, for the two different sessions of 35 mass properties measurements performed. Operator 1 and 2 (second test series only) mounted the ACHs similarly and out of range of the other Operator helmet mounts. In Figure 20 to Figure 22, the individual X, Y and Z point differences between the FLM point and NVD_{MH} are provided to further analyze the ACH positioning. For Operator 2, the X point measures for the second test series are smaller, meaning they are closer to the machine origin and the Z point measures are larger so they are further from the origin. Taken together, this indicates the helmet was shifted up and posterior on the headform. The same pattern occurs with Operator 1. For the Y point measurements, Operators 1 and 5 were skewed towards -Y and Operators 4, 6 and 7 were skewed towards +Y. In Figure 23, the difference between the pre- and post-test lengths of the FLM to the NVD_{MH} are plotted. The majority of differences are small and hover around zero; however, there are average length differences as high as 5 mm for some helmet systems. Eight tests had differences between 1-2 mm and six tests were greater than 2 mm. The majority of differences in the pre- and post-test length differences are positive, indicating that the helmet shifted back and up rather than down and forward during the mass properties measurements.

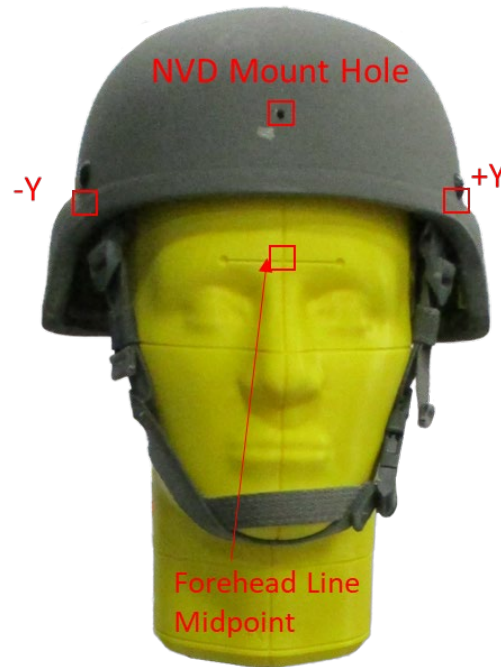


Figure 17. ACH medium helmet with the red squares identifying the NVD mount hole and forehead line midpoint location. The length between the two points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 12. The minimum and maximum, mean, SD, variance and CV for the lengths measured from the FLM to the three ACH medium helmet points and the X, Y and Z point differences of the forehead midpoint to NVD Mount Hole. Data are provided for the lengths and points measured prior to taking the CM and MOI measurements (pre) and then for the length difference of the pre and post CM and MOI measurements for all three lengths.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to NVD _{MH}	Length	Pre	57	72	64	3.4	11.7	5
X: FLM to NVD _{MH}	Point	Pre	0	14	8	2.7	7.1	36
Y: FLM to NVD _{MH}	Point	Pre	-4	4	0.03	1.5	2.2	5000
Z: FLM to NVD _{MH}	Point	Pre	55	72	63	3.7	13.8	6
FLM to ACHM +Y	Length	Pre	107	124	120	3.8	14.3	3
FLM to ACHM -Y	Length	Pre	109	123	119	3.8	14.1	3
FLM to ACHM +Y vs -Y	Length	Pre Difference	-5	6	1	1.5	2.2	
FLM to NVD _{MH}	Length	Pre/Post Difference	-3.4	14.2	0.6	1.6	2.5	
FLM to ACHM +Y	Length	Pre/Post Difference	-2.7	6.0	0.3	1.1	1.2	
FLM to ACHM -Y	Length	Pre/Post Difference	-2.1	3.5	0.2	0.8	0.6	

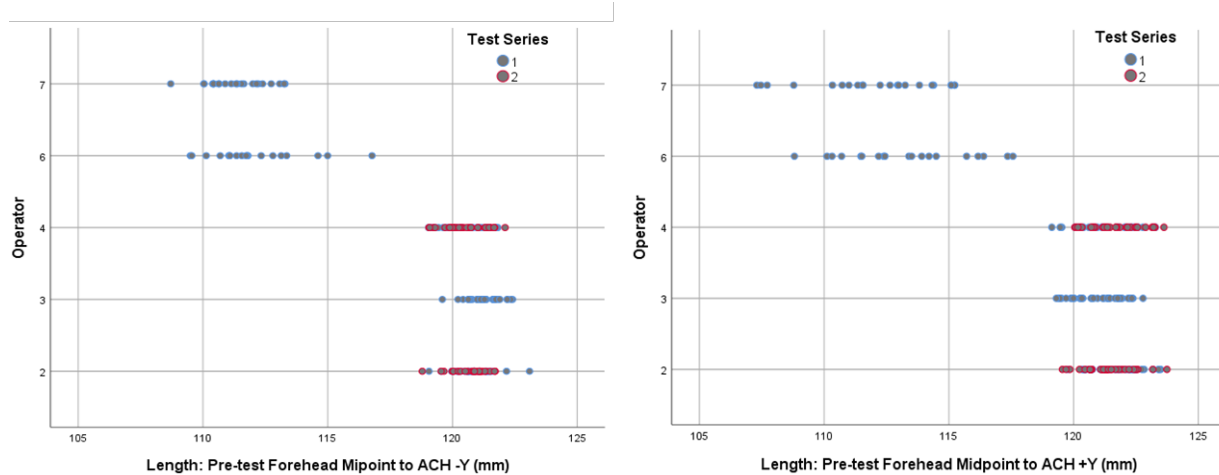


Figure 18. Scatterplot of the differences in lengths between the FLM to ACH -Y and FLM to ACH +Y for the ACH Medium mass properties measurements.

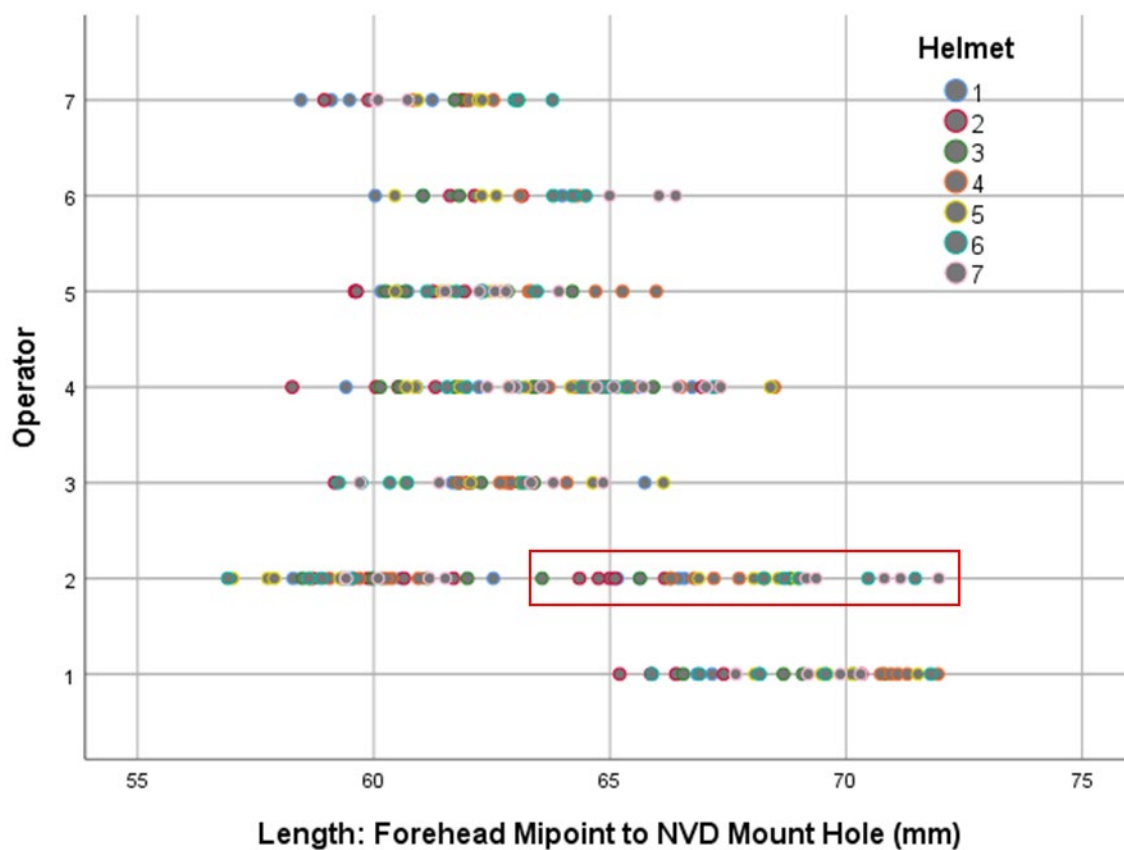


Figure 19. The pre-mass properties test length measurements of the NVD mount hole to the FLM for all seven helmets are plotted for each Operator.

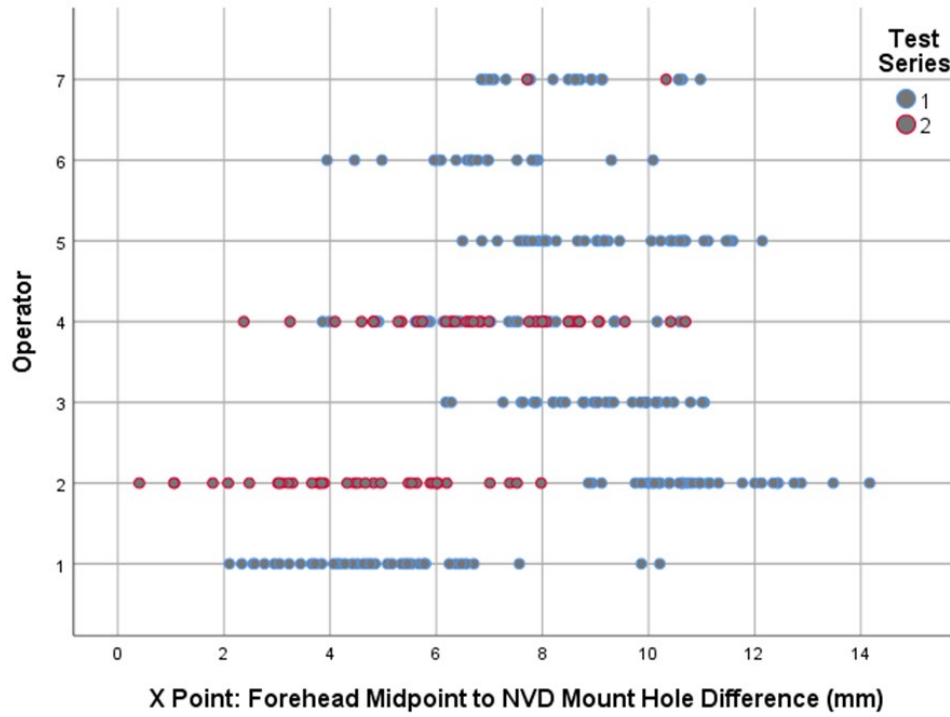


Figure 20. The pre-mass properties test X Point measurements of the NVD mount hole to the FLM organized by test series.

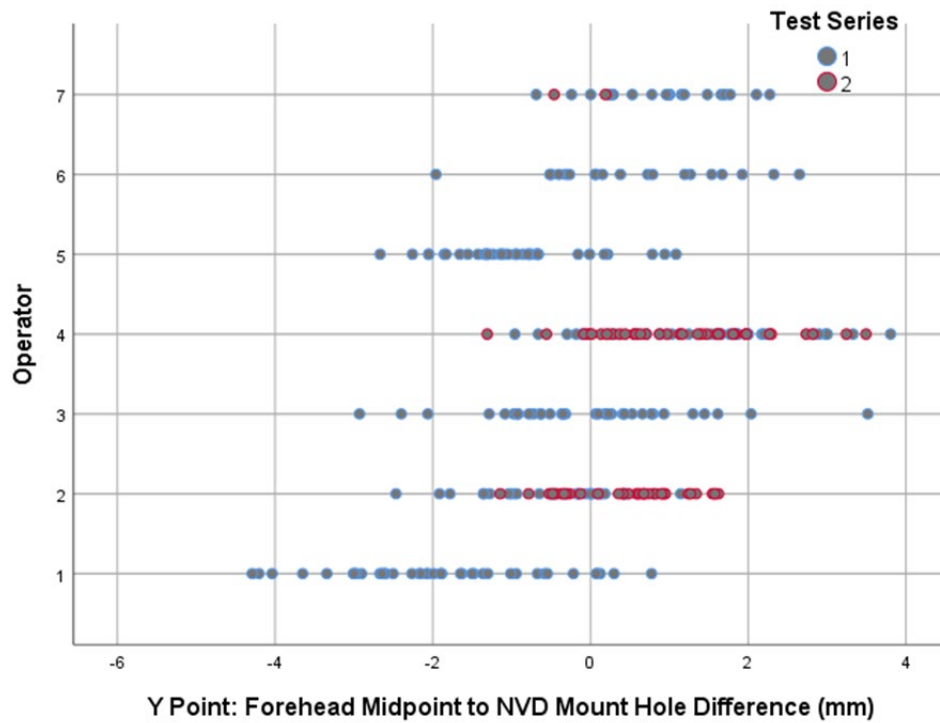


Figure 21. The pre-mass properties test Y Point measurements of the NVD mount hole to the FLM organized by test series.

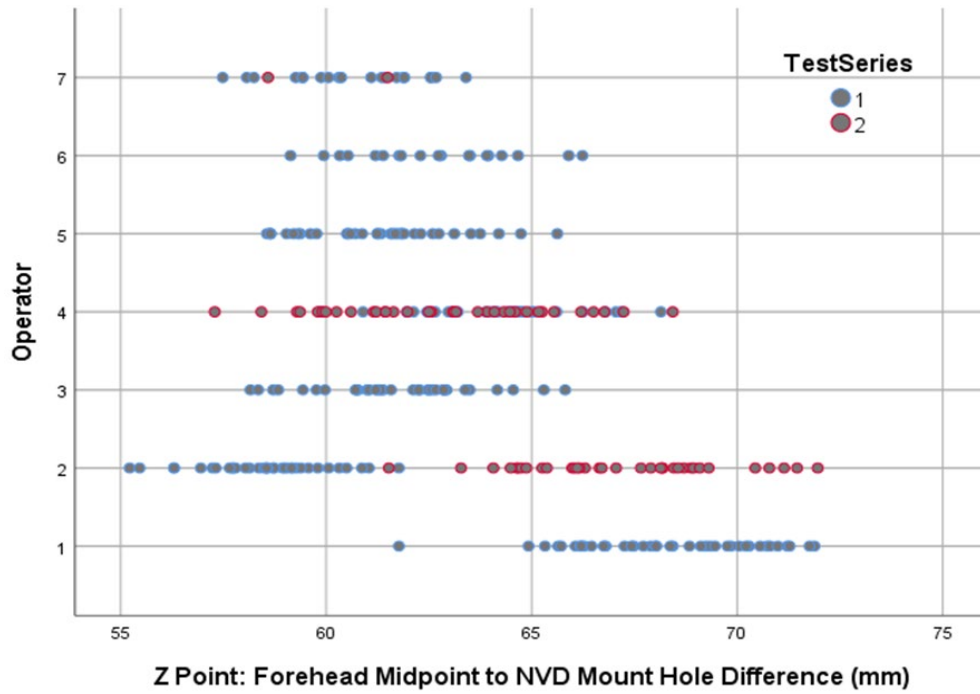


Figure 22. The pre-mass properties test Z Point measurements of the NVD mount hole to the FLM organized by test series.

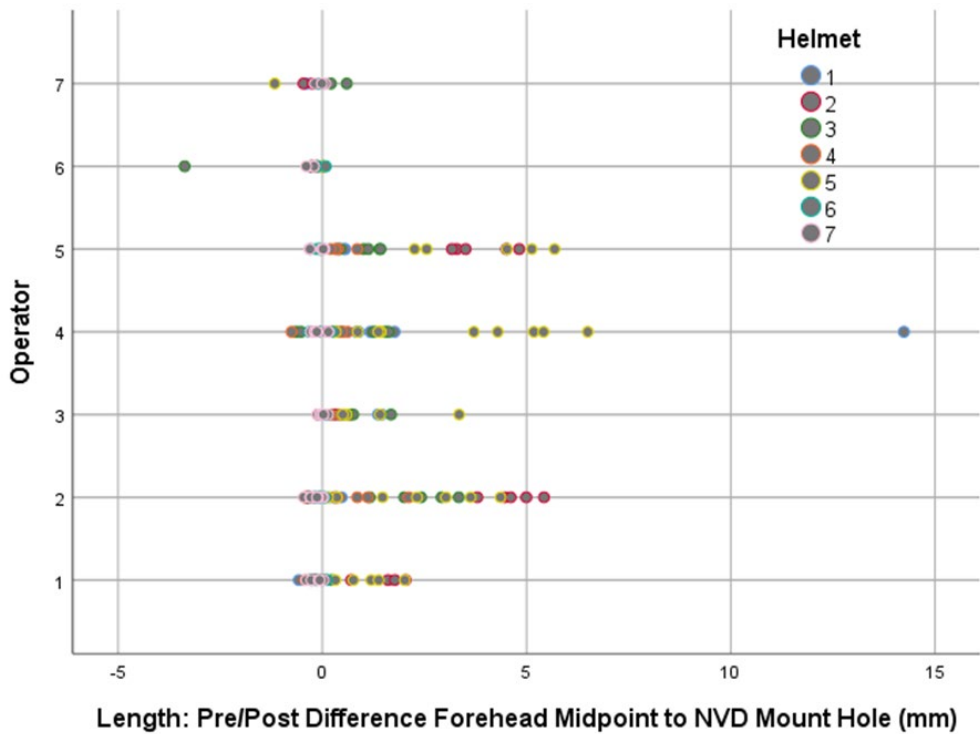


Figure 23. The average difference in pre- and post-mass properties test length measurements of the NVD mount hole to the mid forehead point for all seven helmets are plotted for each Operator.

3.3.2 ACH Medium CM Measurements

The means, SDs, variances and CV from the seven ACH Medium helmets for CM are presented in this section. Table 13 provides the CM mean, SD, variance and CV for all seven operators and helmets combined. Table 14 is a breakdown of the data for each of the seven ACH medium helmets. Variances differed for each CM measurement, where the CM for $X < 4.2 \text{ mm}^2$, $Y < 1.4 \text{ mm}^2$ and $Z < 5.7 \text{ mm}^2$. The SDs are good indicators of precision. For the X, Y and Z measurements, all SDs fall within a range of 1.1 to 2.4 mm; therefore, the coefficient of variation results were driven by the actual CM mean values for X, Y and Z. The Z-axis CM measurements had the largest variance and the lowest coefficient of variation. The CV values for Y are large because the means are close to zero but the SDs are still similar to those observed for X and Z.

Table 13. Overall ACH medium CM measurement means, SD, variance and CV for X, Y and Z-axes. *Some measurements were excluded from the analysis due to the fixture y-translation.

	X_1 (n= 286)	X_2 *(n= 147)	Y_1 *(n= 147)	Y_2 *(n= 147)	Z_1 (n= 286)	Z_2 (n= 286)
Mean (mm)	-19.1	-17.7	1.1	0.2	85.8	86.2
SD (mm)	2.1	1.7	1.1	1.2	2.4	2.4
Variance (mm ²)	4.2	2.9	1.1	1.4	5.6	5.7
CV %	11	10	100	535	3	3

Table 14. CM measurements for all operators for each ACH medium helmet measured.

Helmet	X_1		X_2		Y_1		Y_2		Z_1		Z_2	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
1	-18.3	1.5	-16.9	1.3	1.4	0.4	0.5	1.0	86.6	1.8	87.1	1.7
2	-18.7	1.8	-17.7	1.5	0.2	0.5	-0.3	0.9	86.6	2.2	87.0	2.2
3	-19.2	1.6	-17.6	1.1	-0.1	0.6	-0.9	0.6	86.9	2.1	87.4	2.1
4	-18.6	2.0	-17.3	1.3	1.4	0.5	0.5	0.8	85.0	2.3	85.4	2.3
5	-18.7	2.4	-17.8	1.7	1.8	0.5	0.8	1.0	87.0	2.6	87.4	2.7
6	-20.0	2.1	-17.9	2.2	0.3	0.4	-0.6	0.9	84.7	1.6	85.0	1.6
7	-20.3	2.1	-18.5	2.3	2.4	1.0	1.6	0.6	83.7	1.6	84.1	1.6

The scatterplots in Figure 24 to Figure 26 provide a visual display of the measurement between the operators for each CM variable (X_1 , X_2 , Y_1 , Y_2 , Z_1 , and Z_2). The USAARL data (Operators 6 and 7) are closely aligned in all measurements. A likely contributor to this is from the USAARL data collection process where both operators conducted CM measurements with each helmet system on the same fixture mount and using the same tares. The DEVCOM SC operators performed calibrations of the KSR instrument in between each operator which required the fixture to be removed and remounted; this potentially increases the variation that would occur from fixture placement. None of the DEVCOM SC Operator data are from the same gimbal fixture setup and tares. The X_1 , Z_1 and Z_2 data for Operators 2 and 4 have larger scatter, as these operators were the two individuals from DEVCOM SC who conducted a re-test of some measurements. In Figure 24, the red box around the data set Operator 2 are the 35 CM measurements from the re-tests performed by Operator 2. All other data along the Operator 2 line are from the first 35 ACH medium measurements. There is a clear separation in the CM results for these two data collections, which aligns with the length and X point differences observed in mounting of the helmets between the two series of tests conducted by Operator 2 (Figure 19 to Figure 22). In addition, in Figure 24 it's clear that the CM X_1 measurements for Operator 1 and 2 re-tests overlap as did the length

and X point alignment measurements. Overall, the length and X point position data of the NVD_{MH} relative to the FLM track the CM measurements (Figure 19 and Figure 20 vs Figure 24) for the X-axis. This indicates that even small variations in how the helmet is mounted can have a significant effect on the CM; in this case, that effect is specific to the X-axis

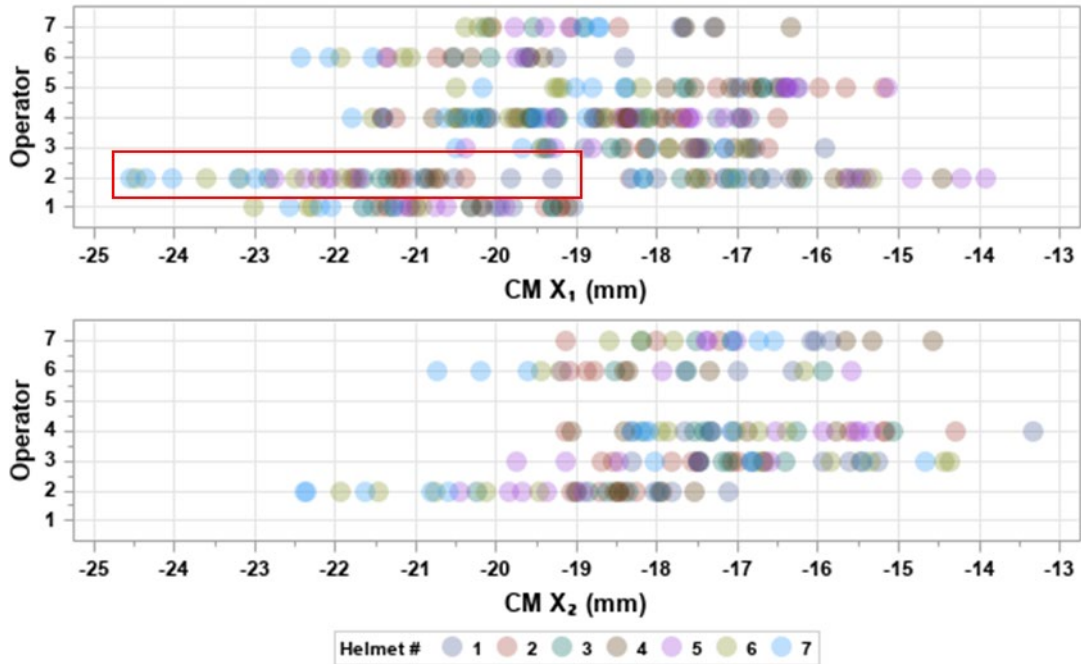


Figure 24. ACH medium X_1 and X_2 center of mass measurements for all tests included in the analysis for each Operator. Operator 2 has a red box around measurements from the second test series to visually distinguish the outcomes from the first test series since they did not overlap.

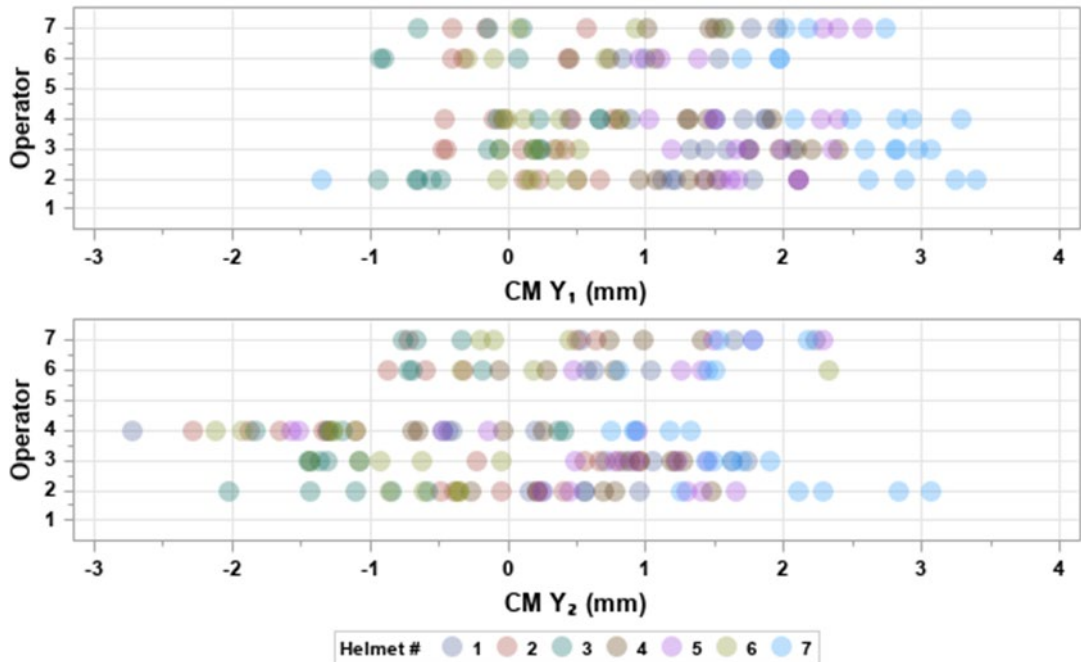


Figure 25. ACH medium Y_1 and Y_2 center of mass measurements for all tests included in the analysis for each Operator.

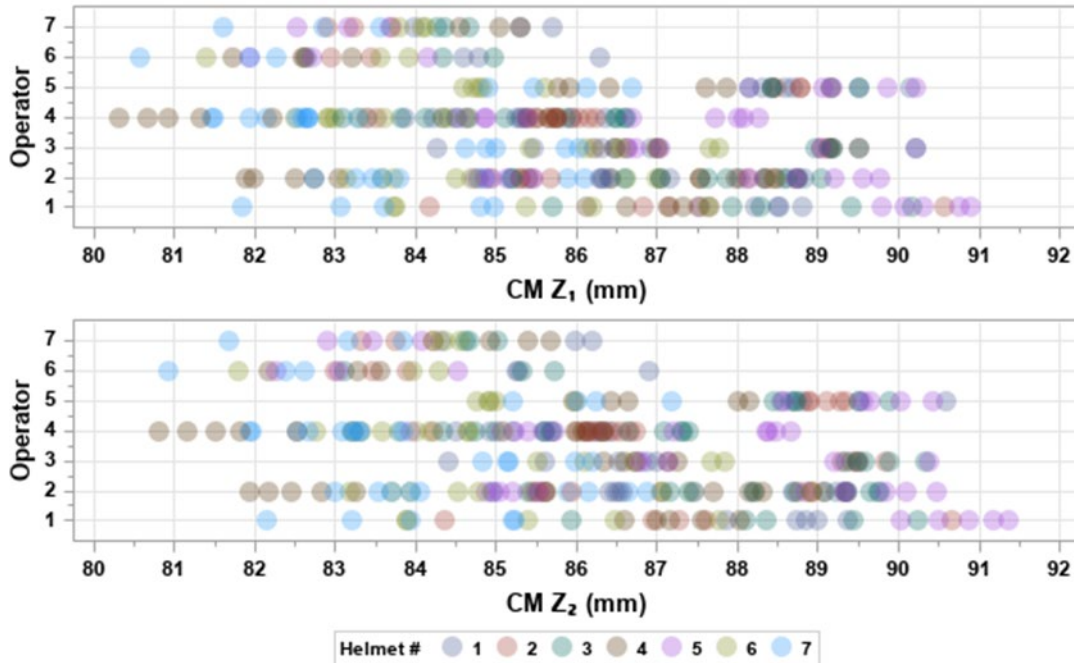


Figure 26. ACH medium Z₁ and Z₂ center of mass measurements for all tests included in the analysis for each Operator.

Table 15 and Figure 27 provide a breakdown of the variance. Table 15 indicates the proportion of variability each factor contributed in the R&R model (Equation 1). For the CM X₁ and X₂ data, only the X₁ data variance is largely due to repeatability with the X₂ variance spread across Operator, the interaction of Operator and Helmet and repeatability. The CM for Y₁ and Y₂ are the only variables where part-to-part variability is a primary factor. For Z₁ and Z₂ the USAARL Operator data were skewed lower than the DEVCOM SC Operators with high consistency for within Operator measurement. This resulted in Fixture being a primary contributor towards the Z CM variance.

Table 15. ACH Medium breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CG Outcomes					
	X ₁ (n=286)	X ₂ * (n= 147)	Y ₁ * (n= 147)	Y ₂ * (n= 147)	Z ₁ (n= 286)	Z ₂ (n= 286)
Fixture	0	0	0	0.0217	0.4451	0.4295
Operator(Fixture)	0.2869	0.3642	0.0365	0.1733	0.15	0.1214
Helmet	0.1032	0.028	0.7011	0.454	0.0793	0.091
Operator(Fixture)*Helmet	0	0.2745	0.0307	0.1141	0.0339	0.035
Fixture*Helmet	0	0	0	0.0146	0.0857	0.0869
Error (Repeatability)	0.6099	0.3333	0.2318	0.2224	0.2059	0.2363

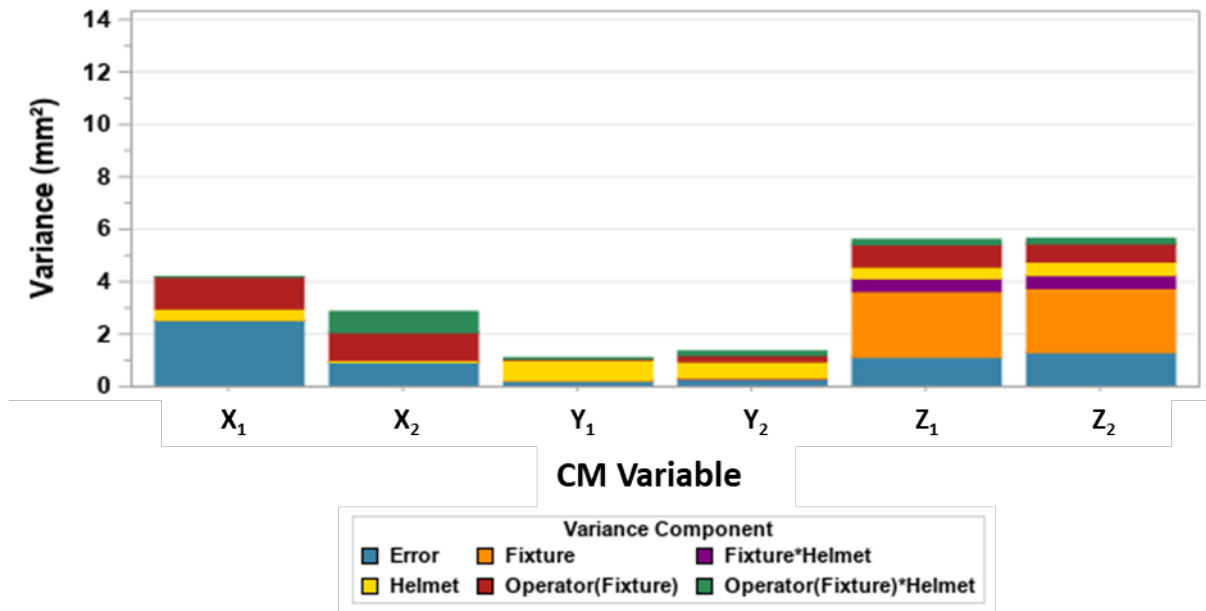


Figure 27. ACH Medium MOI Measurements: Breakdown of each factor indicating the contribution to total variance (mm²) for each CM variable.

3.3.3 ACH Medium MOI Measurements

The MOI measurements from the ACH medium are presented in this section. Table 16 provides the MOI means, SD, variance and CV for all seven DEVCOM SC and USAARL operators. The SDs are consistent across the MOIs and coefficients of variation are also low with the highest value for Izz at 7.6%. This statistical summary of the MOI data relative to the CM data presented in the previous section suggests that the MOI measurements are less sensitive to small shifts in the helmet alignment for this helmet system. Scatterplots of each MOI measurement are provided in Figure 28 and Figure 29. Overlap of Operator data occurs for each MOI measurement. The reason for a single outlier from Operator 2 Izz measurements could not be identified and therefore it was included in the analysis.

Table 16. ACH Medium MOI Mean, SD, Variance and CV for the seven DEVCOMSC and USAARL operators.

	Izz (n= 280)	Ixx (n= 279)	Iyy (n= 280)	Iyz (n= 279)	Ixz (n= 280)	Ixy (n= 278)
Mean (kg-m²)	0.01188	0.00953	0.01013	0.01107	0.00949	0.00980
SD (kg-m2)	0.00090	0.00066	0.00072	0.00066	0.00042	0.00053
Variance (kg-m2)²	8.08E-07	4.36E-07	5.15E-07	4.29E-07	1.80E-07	2.80E-07
CV %	7.6	6.9	7.1	5.9	4.5	5.4

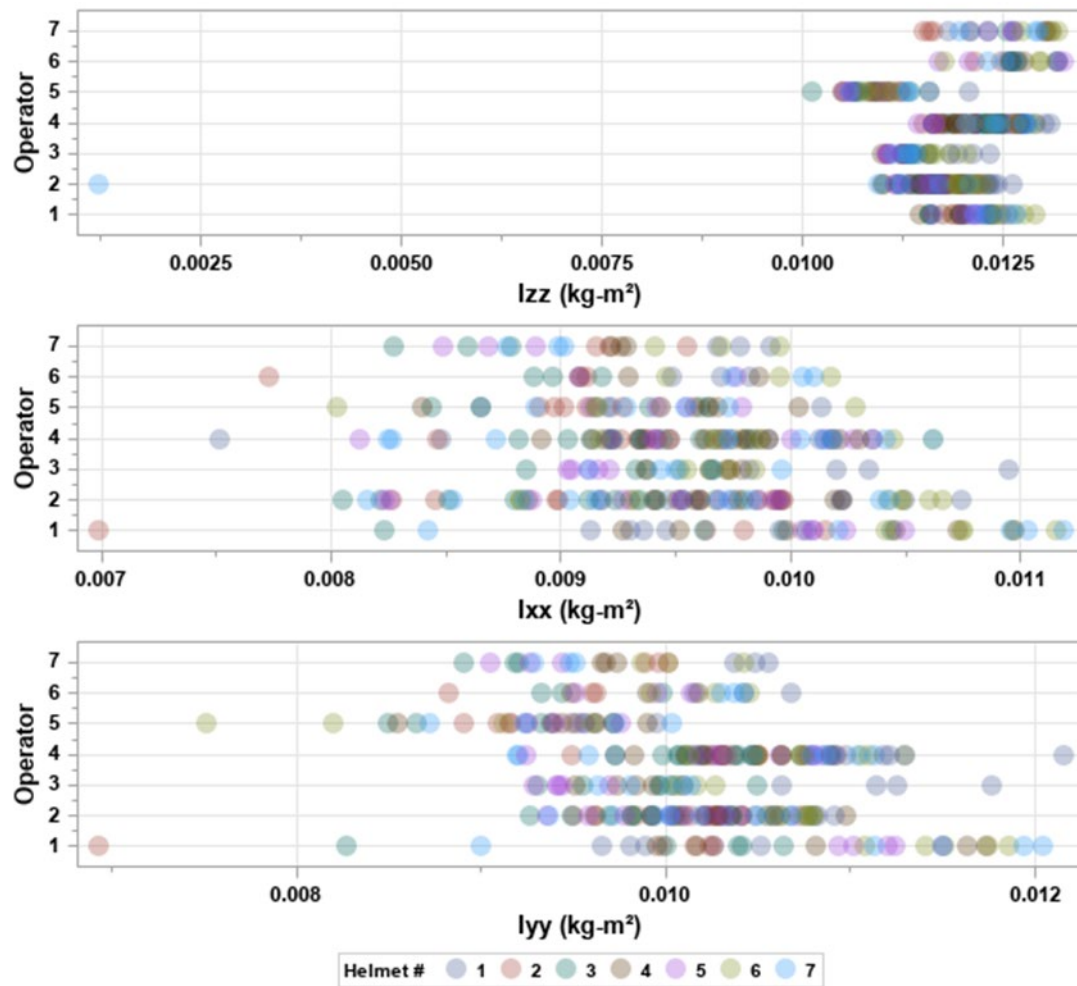


Figure 28. ACH Medium basic MOI Izz, Ixx and Iyy scatter plots of data for all seven Operators.

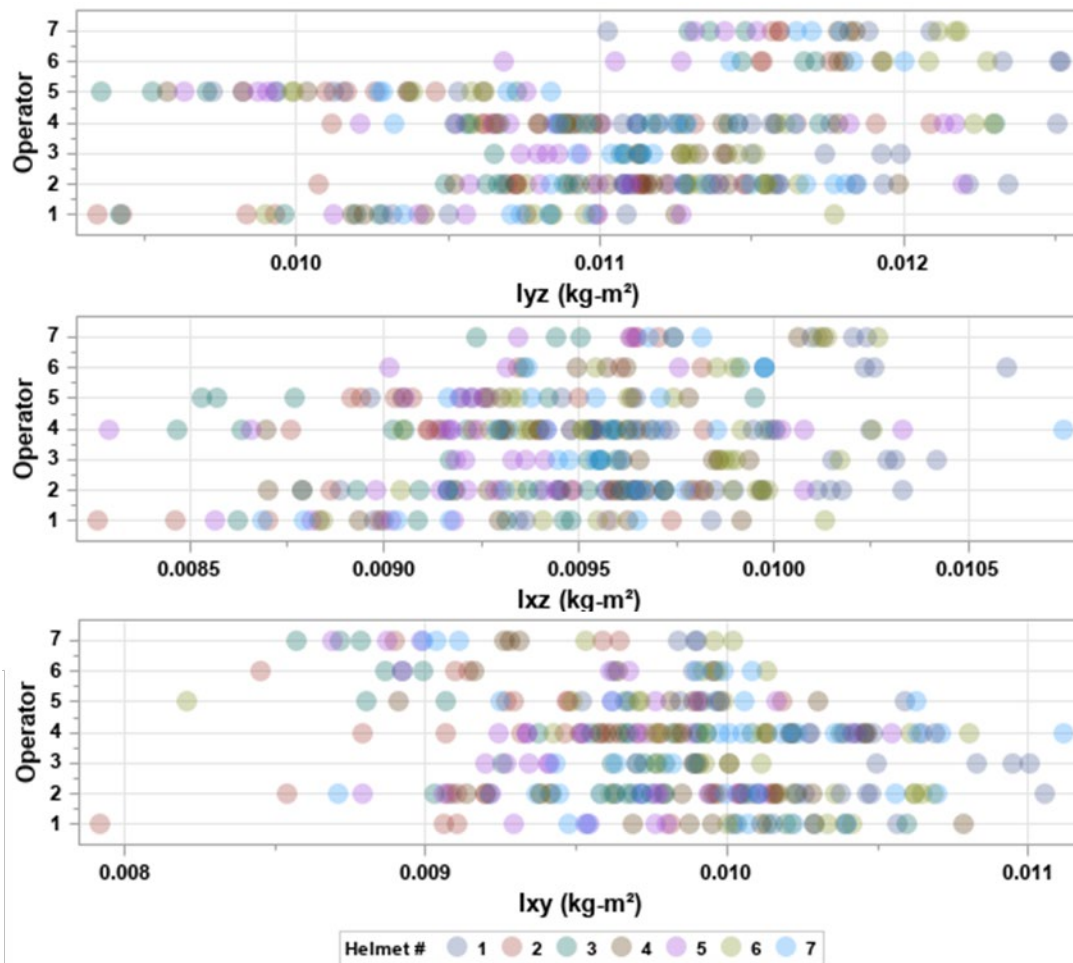


Figure 29. ACH Medium MOI for lyz, lxx, and lxy scatter plots of data for all seven Operators.

In reviewing the proportion of variance (Table 17 and Figure 30), the largest variance for all MOIs except lyz was due to pure repeatability. The largest proportion of variance for lyz was Fixture (.4282), then Operator (.2667) and repeatability (.2393). In looking at the lyz scatterplot in Figure 29, Operators 1 and 5 measurements are skewed towards the lower end of the data range. The USAARL Operators 6 and 7 nearly overlap and their range of data is skewed to the higher end of the data range.

Table 17. ACH Medium breakdown of each MOI measure lzz, lxx, lyy, lyz, lxx, and lxy proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the Mol Outcomes					
	lzz (n= 280)	lxx (n= 279)	lyy (n= 280)	lyz (n= 279)	lxx (n= 280)	lxy (n= 278)
Fixture	0.2596	0.0345	0	0.4282	0.2085	0.2633
Operator (Fixture)	0.2101	0.1026	0.3138	0.2667	0.1285	0.0182
Helmet	0.0286	0.1089	0.0905	0.0529	0.1397	0.2008
Operator (Fixture)*Helmet	0.0297	0.0191	0.1776	0.0128	0	0.077
Fixture*Helmet	0	0	0	0	0	0.0111
Error (Repeatability)	0.4719	0.7349	0.4181	0.2393	0.5233	0.4296

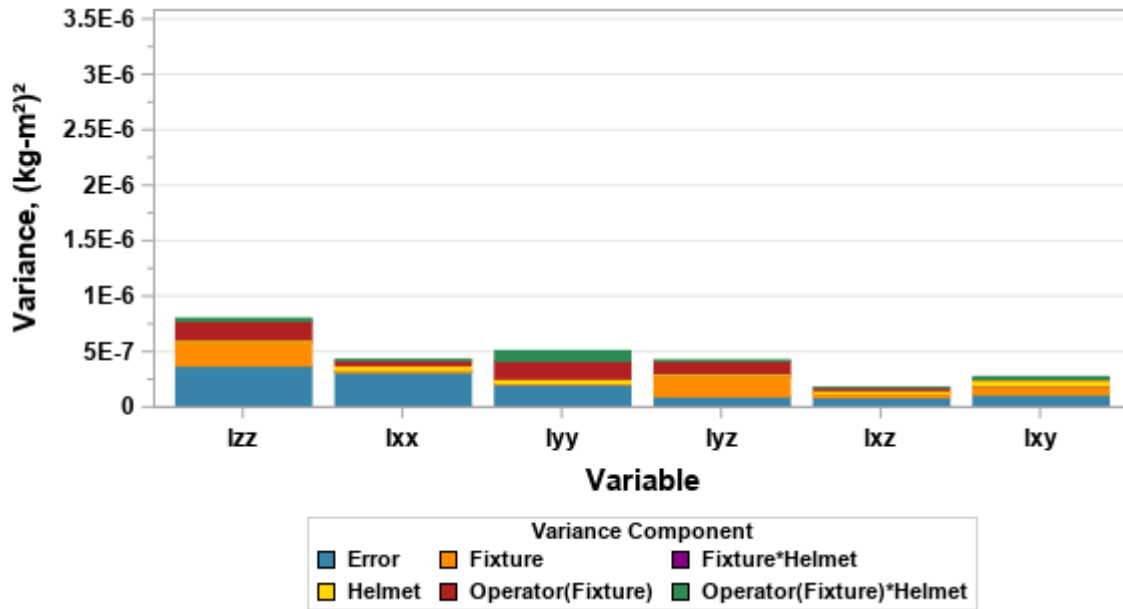


Figure 30. ACH Medium MOI Measurements: Breakdown of each factor indicating the contribution to total variance $(\text{kg}\cdot\text{m}^2)^2$ for each MOI variable.

3.4 ACH Large

3.4.1 ACH Large Headform Alignment

Figure 31 is the ACH mounted to the headform and depicts the four points: +Y and -Y ACH points, NVD_{MH} on the ACH and the FLM used in evaluating the alignment of the ACH large to the headform. The resultant length between the forehead midpoint and each of the three points on the helmet measured pre-mass properties tests and the difference between the pre- and post-mass properties tests were calculated and are presented in this section (Table 18). In addition, the pre-mass properties measurement X, Y and Z point differences between the FLM to the NVD Mount Hole are provided. A scatterplot of the length from the FLM to NVD_{MH} for pre-mass properties tests is in Figure 32. In Figure 33 to Figure 35 the X, Y and Z point data are broken up to better understand the position of the NVD_{MH} relative to the mid-forehead. Data for Operators 2 and 4 were not properly recorded; therefore, they are not included. USAARL did not conduct ACH large testing; therefore, there are no Operator 6 and 7 data. For the pre-test lengths, the Operators 1 and 5 were consistent within 5 mm and Operator 3 data range was less than 7 mm. In Figure 36, the differences in length for the FLM to NVD_{MH} between the pre- and post-mass properties measurements are plotted. For all tests except for three instances the change in length did not exceed .6 mm and in no case did it exceed .9 mm.

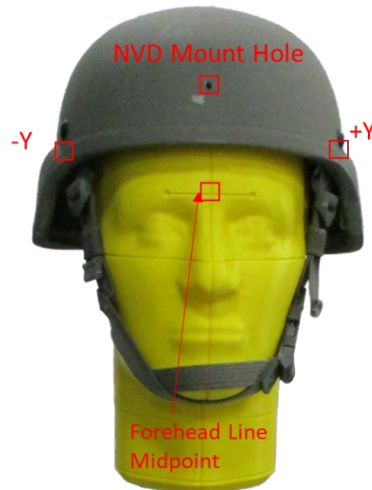


Figure 31. ACH large helmet with the red squares identifying the +Y and -Y points, NVD mount hole and forehead midpoint locations. The length between the forehead midpoint and each of the three helmet points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 18. The minimum and maximum, mean, SD, variance and CV for the lengths measured from the forehead midpoint to the three ACH large helmet points and the X, Y and Z point differences of the forehead midpoint to NVD Mount Hole. Data are provided for the lengths and points measured prior to taking the CM and MOI measurements (pre) and then for the length difference of the pre and post CM and MOI measurements for all three lengths.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to NVD _{MH}	Length	Pre	56	70	65	4.3	18.3	7
X: FLM to NVD _{MH}	Point	Pre	-13	-2	-7	3	10	44
Y: FLM to NVD _{MH}	Point	Pre	0	3	1	1	1	75
Z: FLM to NVD _{MH}	Point	Pre	-70	-55	-63	5	25	8
FLM to ACHL +Y	Length	Pre	118	123	122	1.5	2.3	1
FLM to ACHL -Y	Length	Pre	120	126	122	1.7	2.9	1
FLM to NVD _{MH}	Length	Pre/Post Difference	0.1	0.8	0.4	0.2	0.0	
FLM to ACHL +Y	Length	Pre/Post Difference	-1.5	1.9	0.6	0.9	0.7	
FLM to ACHL -Y	Length	Pre/Post Difference	-0.4	1.1	0.2	0.5	0.2	

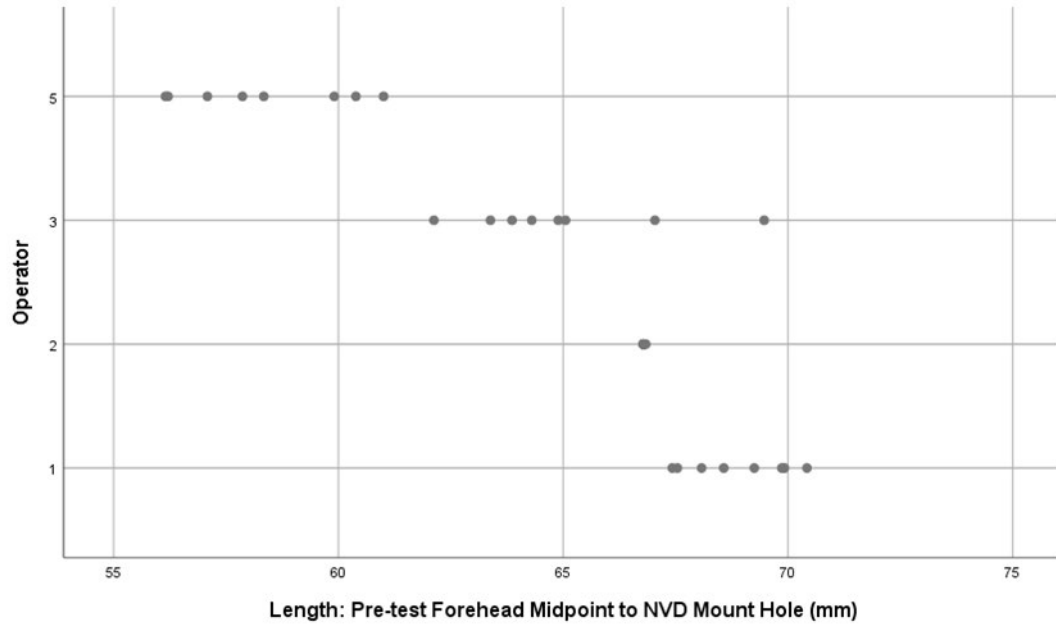


Figure 32. Scatterplot of the ACH large FLM to NVD mount hole lengths measured prior to mass properties measurements.

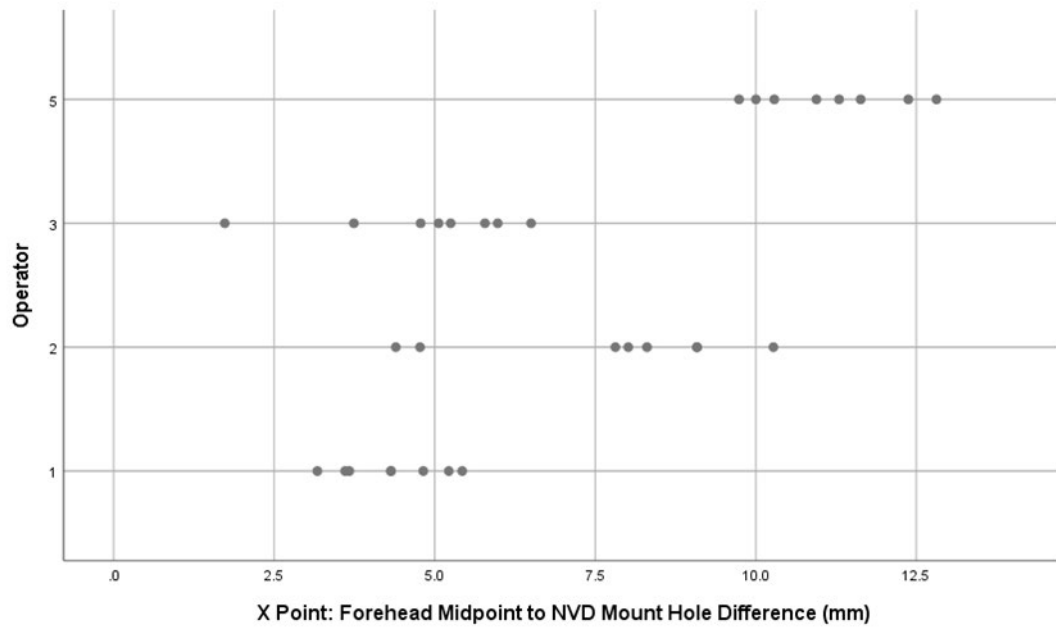


Figure 33. Scatterplot of the difference along the X-axis of the FLM to the ACH large NVD mount hole pre-test.

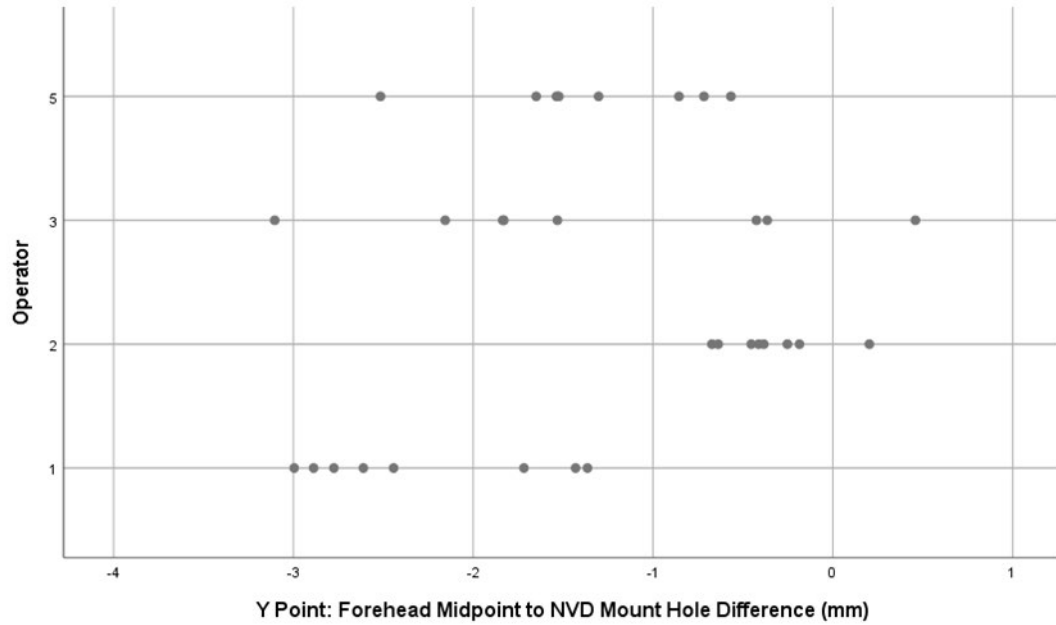


Figure 34. Scatterplot of the difference along the Y-axis of the FLM to the ACH large NVD mount hole pre-test.

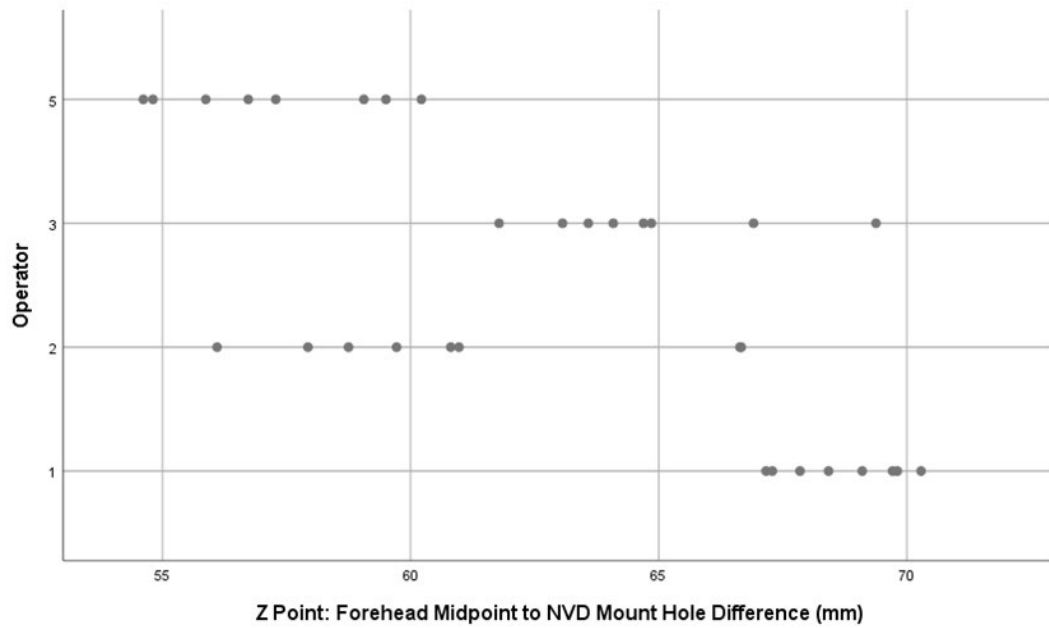


Figure 35. Scatterplot of the difference along the Z-axis of the FLM to the ACH large NVD mount hole pre-test.

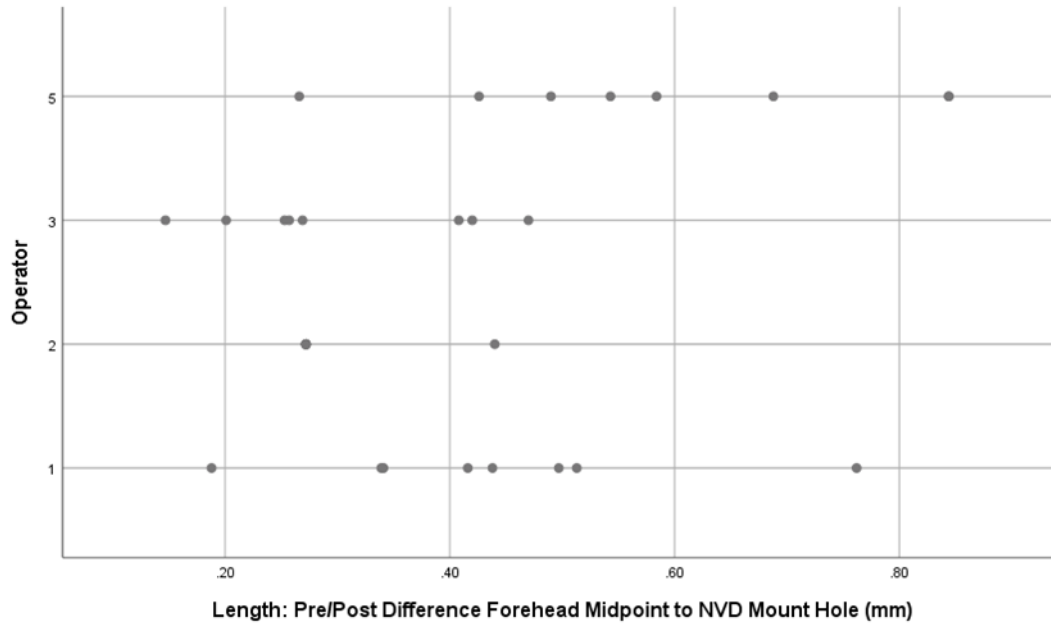


Figure 36. Scatterplot of the difference in length pre vs post mass property measurements for the ACH large FLM to NVD mount hole.

3.4.2 ACH Large CM Measurements

ACH large testing was only conducted at DEVCOM SC. The means, SDs, variances and CV from the ACH large helmet CM tests are presented in this section. Table 19 provides the CM mean, SD, variance and CV for all five Operators for X_1 , Z_1 and Z_2 . The CM results for X_2 , Y_1 and Y_2 are only included from Operator 3 as this is the only Operator whose testing of the ACH large was conducted post-fix of the loose bolt that caused the cradle to translate along the Y-axis. The scatterplots in Figure 37 to Figure 39 provide a visual display of the individual measurements of the Operators for each CM variable (X_1 , X_2 , Y_1 , Y_2 , Z_1 , and Z_2). The X_1 CM measurements have the largest variation. The scatterplot of the X_1 data shows that Operator 5 is outside the range of the other testers except for one of Operator 2's measurements. This is potentially due to Operator 5 having mounted the helmet lower than the other testers (Figure 32 and Figure 35). For the X CM data, the variance for X_1 is larger than X_2 ; however, this is largely due to only one Operator's data set being included for the X_2 statistics. Overall the X CM measurements follow the same pattern of the X point position measurements plotted in Figure 33. The Y_1 and Y_2 means are not similar where the Y_2 mean of -4 mm is inconsistent with the other ACH CM values along the Y-axis. Since the helmet is symmetric from right to left, the Y-axis CM values should be close to zero. The scatterplot of the Z_1 and Z_2 measurements (Figure 39) are consistent with each other for each Operator. However, Operator 4 and 5 data do not overlap with the exception of one test, and are not within range of Operators 1-3 measurements. This range in data is likely due to how tightly the helmet was secured to the headform. The CV values for Y are large because the means are close to zero but the standard deviations are still similar to those observed for X and Z CM measurements.

Table 19. Overall ACH large CM measurement means, SD, variance and CV for X, Y and Z-axes. CM Data Included: X_1 , Z_1 and Z_2 Operators 1-5, X_2 , Y_1 and Y_2 Operator 3. *Some measurements were excluded from the analysis due to the fixture y-translation.

	X_1 (n= 39)	X_2 *(n= 8)	Y_1 *(n= 8)	Y_2 *(n= 8)	Z_1 (n= 39)	Z_2 (n= 39)
Mean (mm)	-22.2	-21.0	0.7	-4.0	89.2	89.7
SD (mm)	2.4	0.9	0.5	1.1	1.8	1.7
Variance (mm ²)	5.9	0.8	0.2	1.2	3.3	2.9
CV (%)	11	4	65	28	2	2

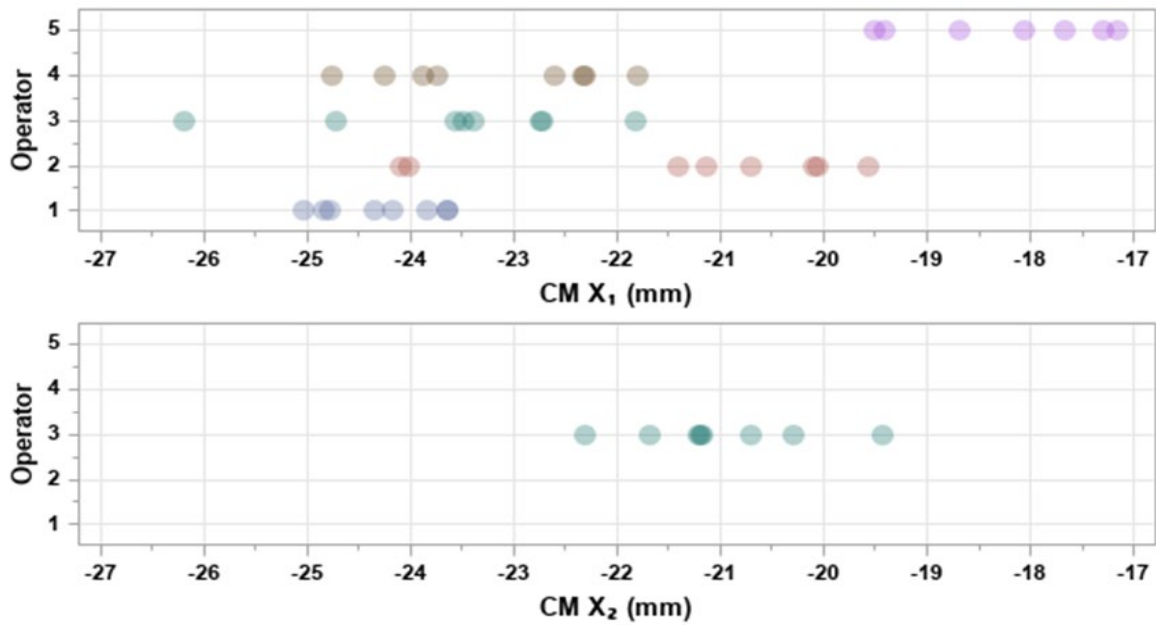


Figure 37. ACH medium X_1 and X_2 center of mass measurements for all tests included in the analysis for each Operator.

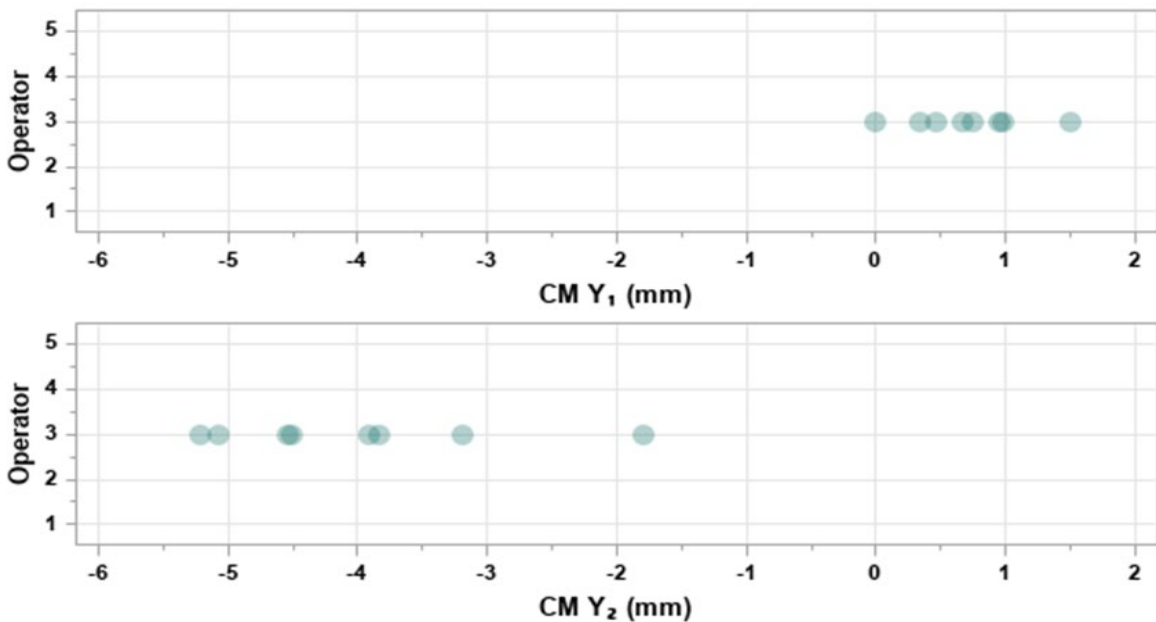


Figure 38. ACH medium Y_1 and Y_2 center of mass measurements for all tests included in the analysis for each Operator.

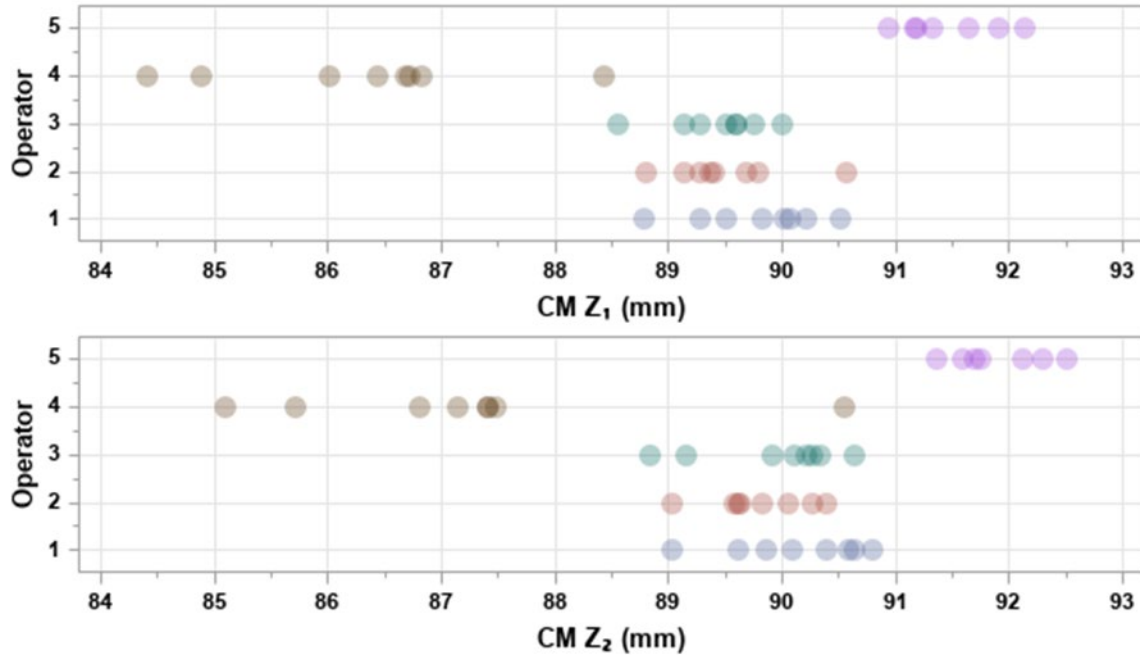


Figure 39. ACH medium Z1 and Z2 center of mass measurements for all tests included in the analysis for each operator.

Table 20 and Figure 40 provide a breakdown of the variance. Table 20 indicates the proportion of variability each factor contributed in the reproducibility and repeatability model (Equation 2). The largest proportion of variance is due to Operator (reproducibility). Since there are only data from Operator 3 for X_2 , Y_1 and Y_2 the R&R assessment could not be performed.

Table 20. ACH large breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CM Outcomes					
	X_1 (n= 39)	X_2^* (n= 8)	Y_1^* (n= 8)	Y_2^* (n= 8)	Z_1 (n= 39)	Z_2 (n= 39)
Operator	0.7938	NA	NA	NA	0.8696	0.7822
Error (Repeatability)	0.2062	NA	NA	NA	0.1304	0.2178

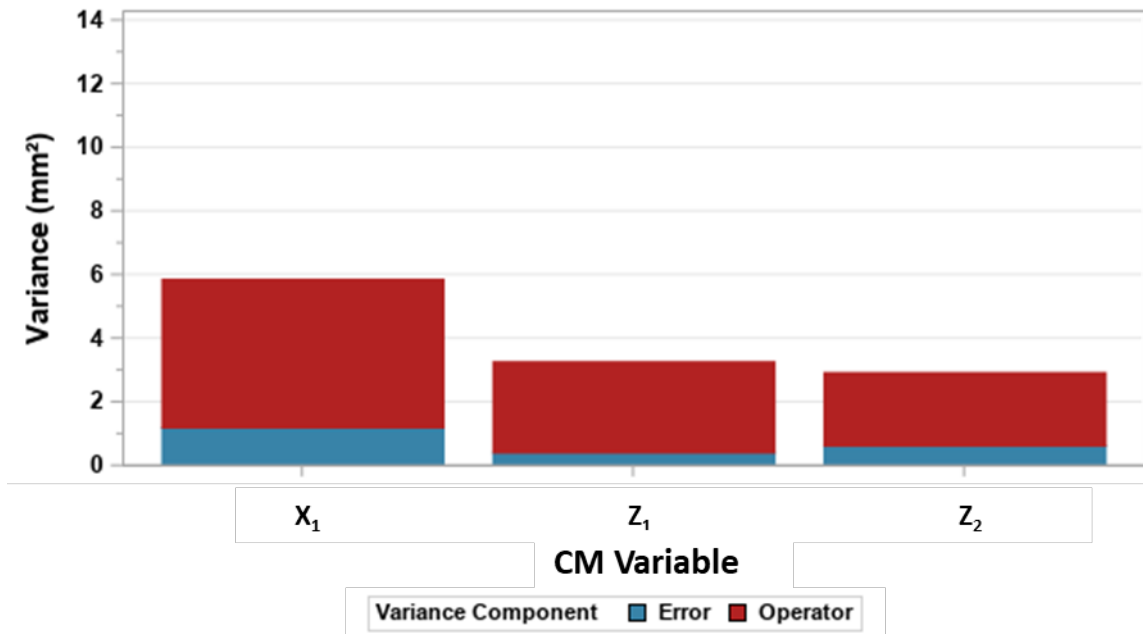


Figure 40. ACH Large CM Measurements: breakdown of each factor indicating the contribution to total variance (mm²) for each CM variable.

3.4.3 ACH Large MOI Measurements

The MOI measurements from the ACH large are presented in this section. All of the MOI data have been included in the analysis. It is not known to what extent the fixture cradle shifting influenced the outcomes. Table 21 provides the MOI means, SD, variance and CV for all five DEVCOM SC Operators. The standard deviations are consistent across the MOIs and coefficients of variation are also low with the highest value for Ixy at 8.8%. The scatterplots of the MOI measures (Figure 41 and Figure 42) show that Operator 4 data have several measurements not within range of the other Operators (Table 22 and Figure 43) causing the largest proportion of variance to be due to reproducibility in most cases.

Table 21. ACH large MOI Mean, SD, Variance and CV for the seven Operators.

	Izz (n= 39)	Ixx (n= 39)	Iyy (n= 39)	Iyz (n= 39)	Ixz (n= 39)	Ixy (n= 39)
Mean (kg-m²)	0.01379	0.01118	0.01205	0.01307	0.01096	0.01161
SD (kg-m²)	0.00059	0.00088	0.00065	0.00060	0.00043	0.00102
Variance (kg-m²)²	3.43E-07	7.67E-07	4.19E-07	3.58E-07	1.88E-07	1.05E-06
CV %	4.3	7.8	5.4	4.6	4.0	8.8

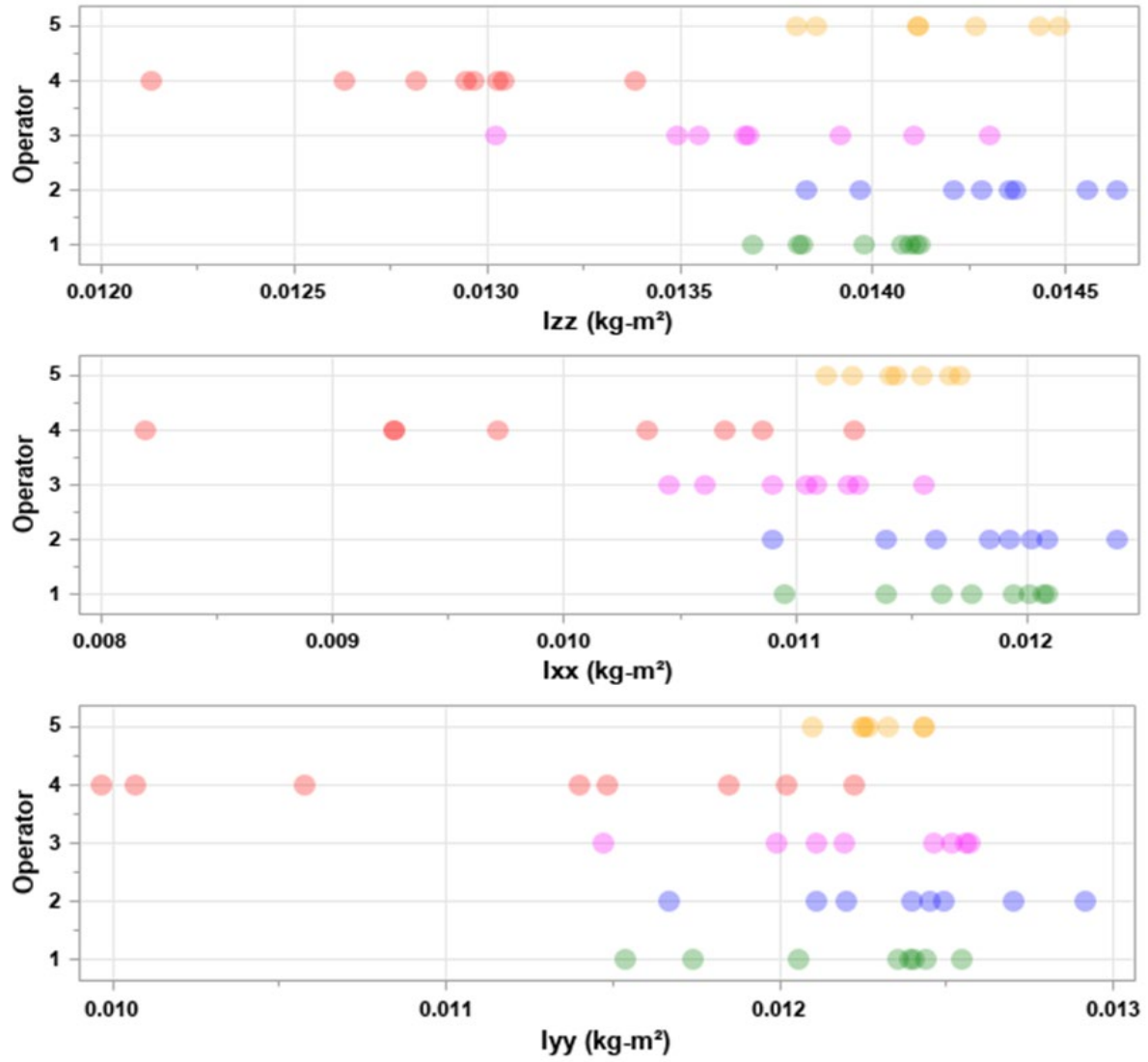


Figure 41. ACH large basic MOI Izz, Ixx and Iyy scatter plots of data for all five DEVCOM SC Operators.

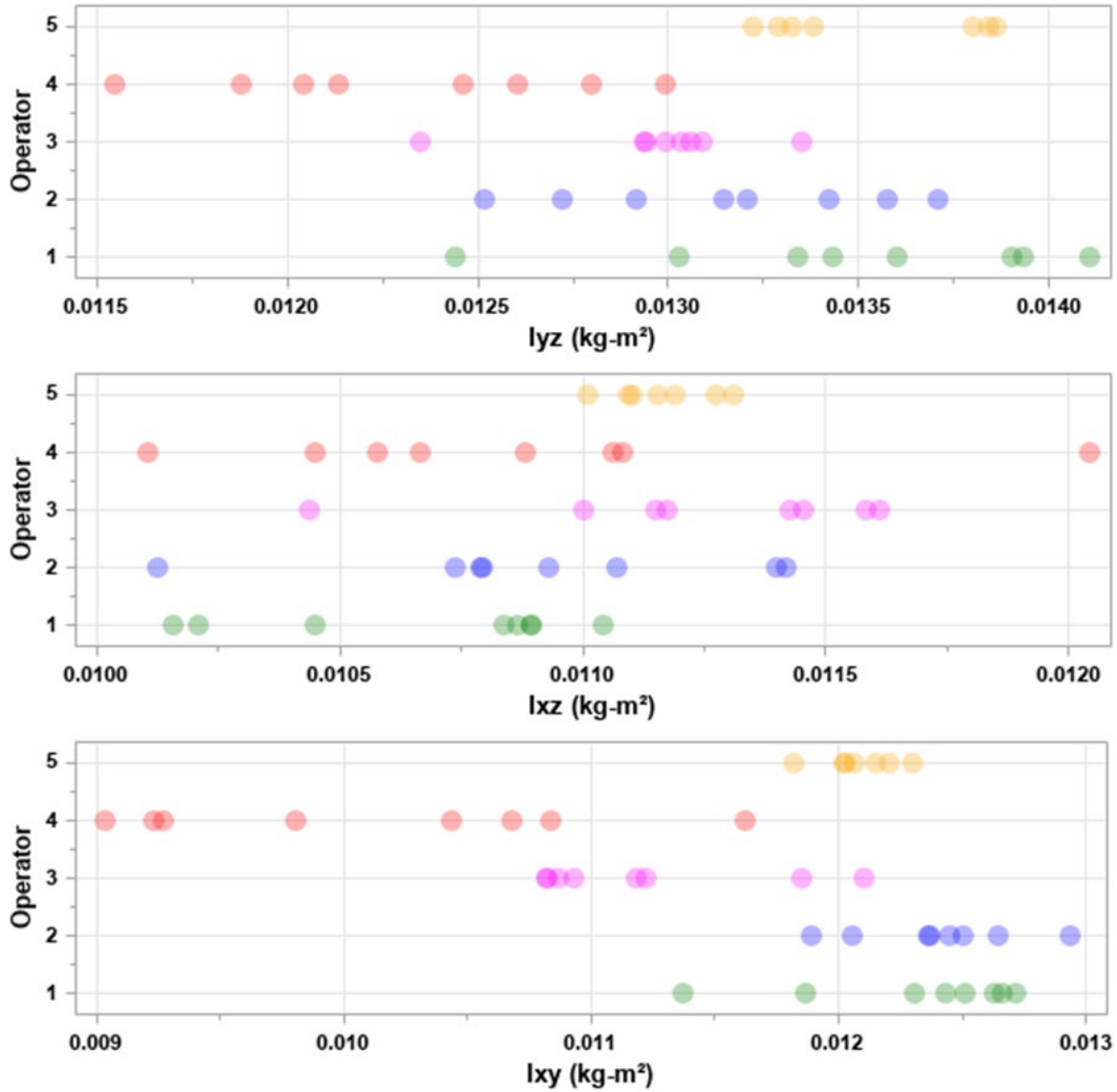


Figure 42. ACH large MOI for lyz, lxz, and lxy scatter plots of data for all five DEVCOM SC Operators.

Table 22. ACH large breakdown of each MOI measure lzz, lxx, lyy, lyz, lxz, and lxy proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the CG Outcomes					
	lzz (n= 39)	lxx (n= 39)	lyy (n= 39)	lyz (n= 39)	lxz (n= 39)	lxy (n= 39)
Operator	0.7631	0.6168	0.4489	0.5532	0.1666	0.7512
Error (Repeatability)	0.2369	0.3832	0.5511	0.4468	0.8333	0.2488

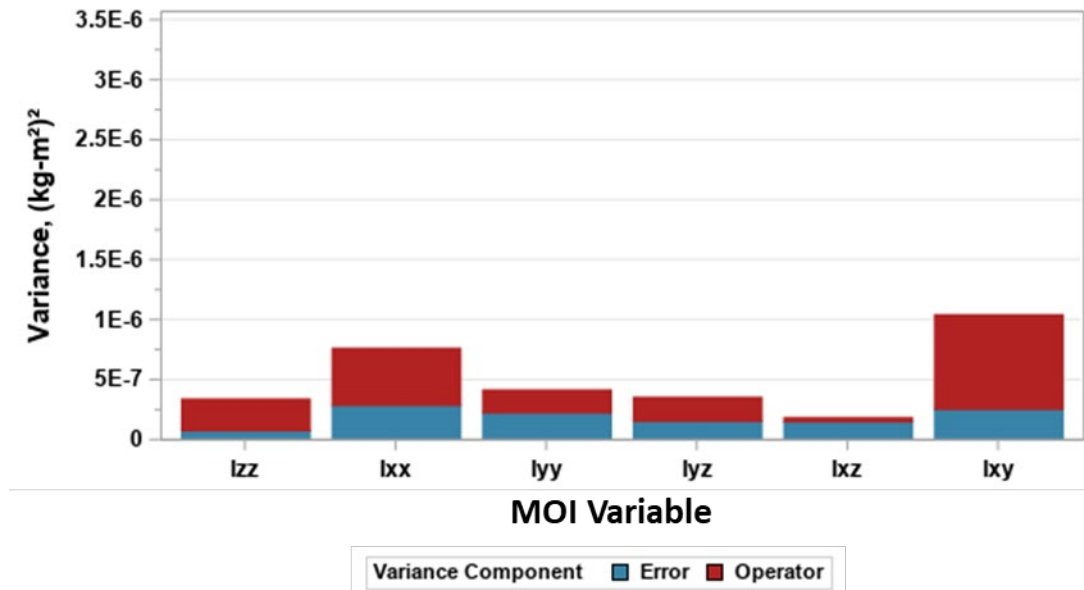


Figure 43. ACH Large MOI Measurements: breakdown of each factor indicating the contribution to total variance for each MOI variable.

3.5 ACH Small

3.5.1 ACH Small Headform Alignment

Figure 44 is the ACH mounted to the headform and depicts the four points: +Y and –Y ACH points, NVD_{MH} on the ACH and the FLM used in evaluating the alignment of the ACH small to the headform. The resultant length between the forehead midpoint and each of the three points on the helmet measured pre-mass properties tests and the difference between the pre- and post-mass properties tests were calculated and are presented in this section (Table 23). In addition, the pre-mass properties measurement X, Y and Z point differences between the FLM to the NVD_{MH} are provided. The lengths between the FLM and the +Y and –Y locations of the ACH small were similar, both averaging 119 mm in length pre-test. A scatterplot of the length from the FLM to NVD_{MH} for pre-mass properties tests is in Figure 45. In Figure 46 to Figure 48 the X, Y and Z point data are broken up to better understand the position of the NVD_{MH} relative to the mid-forehead. Data for Operators 2 and 4 were not properly recorded, and therefore they are not included. USAARL did not conduct ACH small testing; therefore, there are no Operator 6 and 7 data. For the pre-test lengths, Operators 3 and 5 overlapped each other; however, Operator 1 was about 1 cm longer. In Figure 49, the differences in length for the FLM to NVD_{MH} between the pre- and post-mass properties measurements is plotted. For all Operators the changes in length were less than .4 mm, suggesting the helmets did not shift much during the testing.

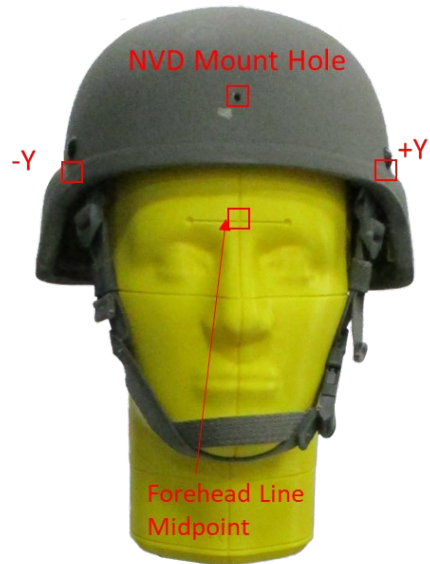


Figure 44. ACH small helmet with the red squares identifying the +Y and -Y points, NVD mount hole and forehead midpoint locations. The length between the forehead midpoint and each of the three helmet points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 23. The minimum and maximum, mean, SD, variance and CV for the lengths measured from the forehead midpoint to the three ACH small helmet points and the X, Y and Z point differences of the forehead midpoint to NVD Mount Hole. Data are provided for the lengths and points measured prior to taking the CM and MOI measurements (pre) and then for the length difference of the pre and post CM and MOI measurements for all three lengths.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to NVD _{MH}	Length	Pre	58	72	63	4.9	23.8	8
X: FLM to NVD _{MH}	Point	Pre	-4	6	3	3.1	9.4	120
Y: FLM to NVD _{MH}	Point	Pre	-3	1	-1	1.1	1.1	168
Z: FLM to NVD _{MH}	Point	Pre	58	72	63	5.0	25.2	8
FLM to ACHS +Y	Length	Pre	117	122	119	1.3	1.8	1
FLM to ACHS -Y	Length	Pre	117	122	119	1.7	2.8	1
FLM to NVD _{MH}	Length	Pre/Post Difference	-0.2	0.3	0.0	0.2	0.0	
FLM to ACHS +Y	Length	Pre/Post Difference	-2.2	1.3	-0.4	1.1	1.1	
FLM to ACHS -Y	Length	Pre/Post Difference	-1.2	2.3	0.6	0.9	0.8	

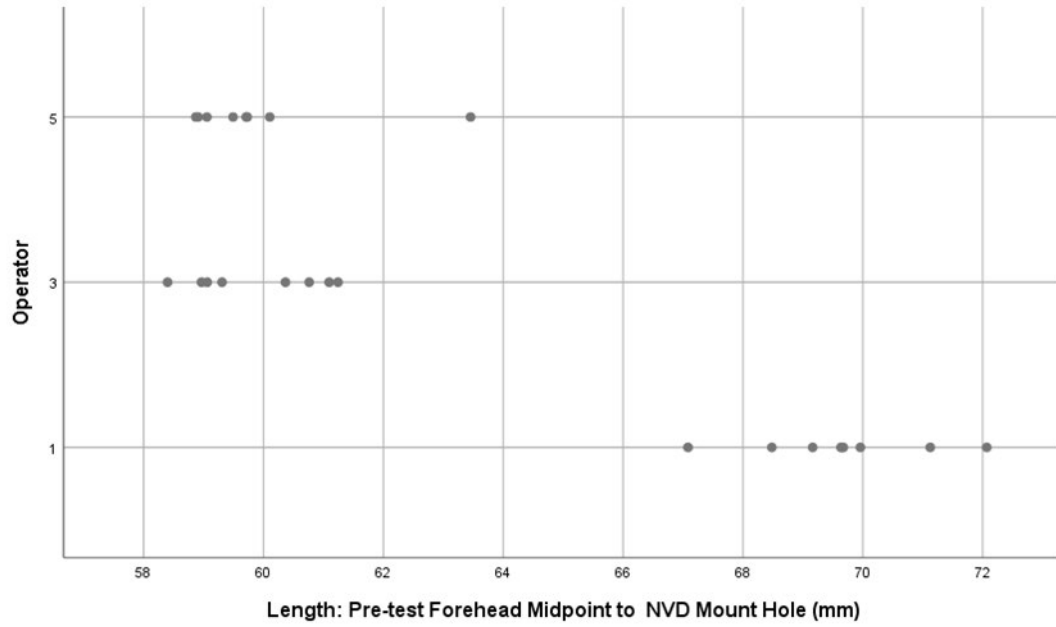


Figure 45. Scatterplot of the ACH small FLM to NVD mount hole lengths measured prior to mass properties measurements.

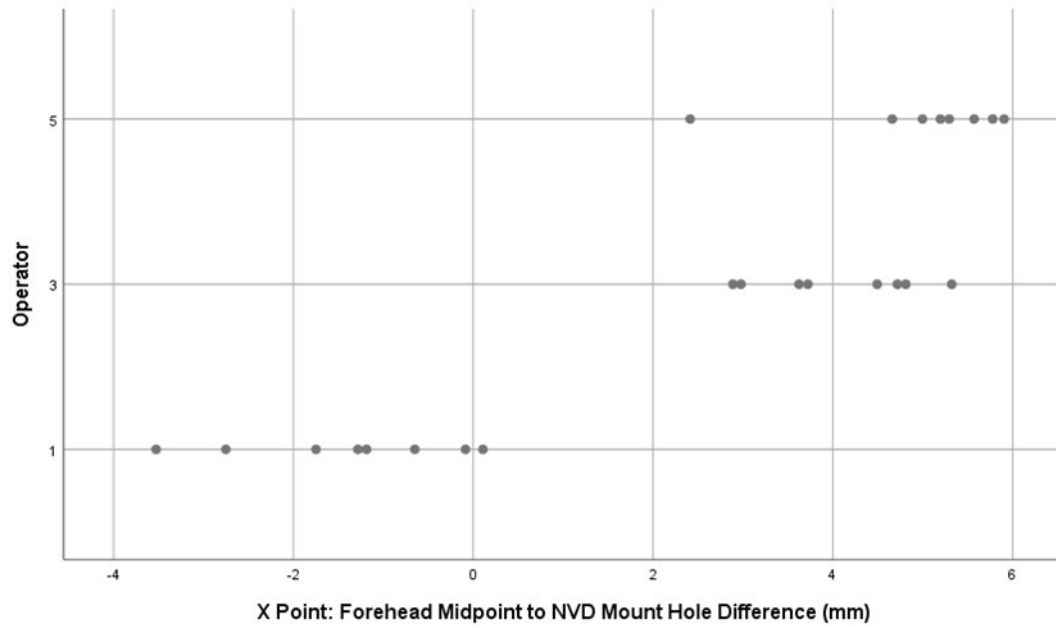


Figure 46. Scatterplot of the difference along the X-axis of the FLM to the ACH small NVD mount hole pre-test.

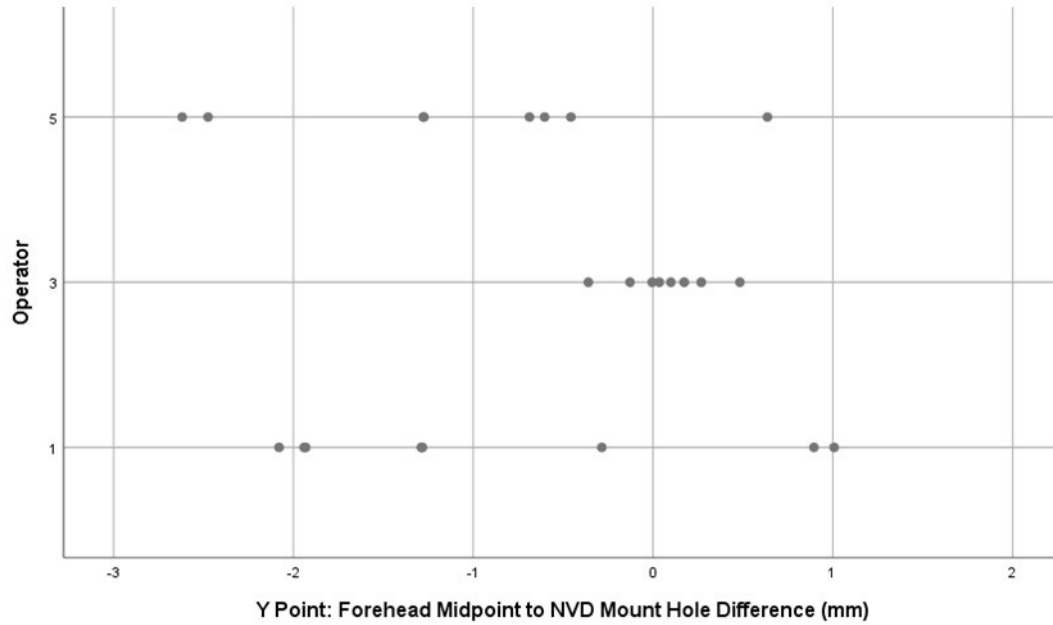


Figure 47. Scatterplot of the difference along the Y-axis of the FLM to the ACH small NVD mount hole pre-test.

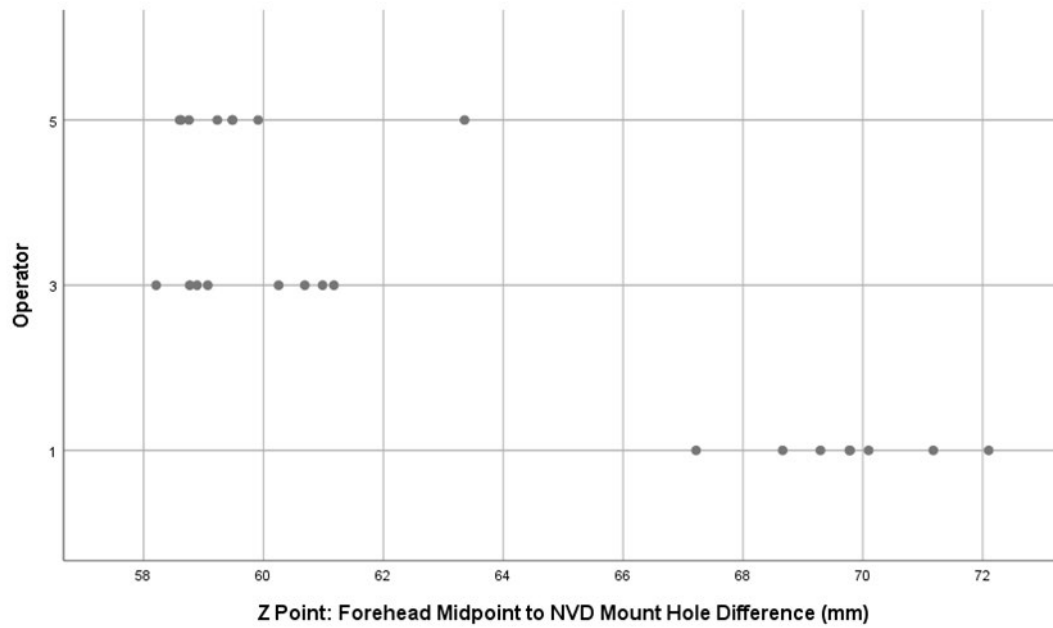


Figure 48. Scatterplot of the difference along the Z-axis of the FLM to the ACH small NVD mount hole pre-test.

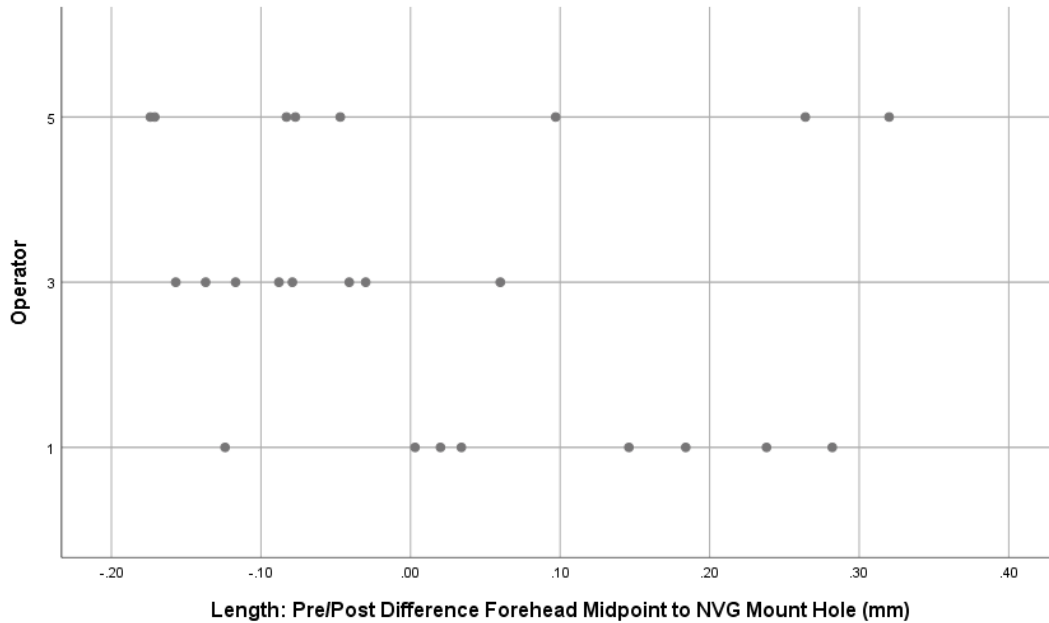


Figure 49. Scatterplot of the difference in length pre vs post mass property measurements for the ACH small FLM to NVD mount hole.

3.5.2 ACH Small CM Measurements

ACH small testing was only conducted at DEVCOM SC, which are Operators 1-5. The means, SDs, variances and coefficient of variation from the ACH small helmet CM tests are presented in this section. Table 24 provides the CM mean, SD, variance and CV for all five Operators for X_1 , Z_1 and Z_2 . The CM results for X_2 , Y_1 and Y_2 are only included from Operator 3, as this is the only Operator whose testing of the ACH small was conducted post-fix of the loose bolt that caused the cradle to translate along the y-axis. The scatterplots in Figure 50 to Figure 52 provide a visual display of the individual measurements of the Operators for each CM variable (X_1 , X_2 , Y_1 , Y_2 , Z_1 , and Z_2). The X_1 , Z_1 and Z_2 have similar standard deviations and variance in CM measurements. Operator 1 has X_1 CM measurements outside the range of Operators 2-5 which is potentially due to how Operator 1 positioned the helmet. For X_1 , Operators 3 and 5 CM measurements aligned, which is consistent with the pre-test helmet alignment measurements (Figure 45 and Figure 46). The scatterplots of the X_1 , Z_1 and Z_2 data show that Operator 2 and 4 consistently overlapped. For the Z-axis CM measurements Operators 1 and 5 were also consistent with each other. A summary of the proportion of variance is provided in Table 25 and Figure 53. Operators were fairly self-consistent and Operator-to-Operator differences contributed the most to variability rather than pure repeatability, indicating that helmet mounting guidelines could be improved.

Table 24. Overall ACH small CM measurement means, SD, variance and CV for X, Y and Z-axes. *Some measurements were excluded from the analysis due to the fixture y-translation.

	X_1 (n= 40)	X_2 *(n= 8)	Y_1 *(n= 8)	Y_2 *(n= 8)	Z_1 (n= 20)	Z_2 (n= 20)
Mean (mm)	-27.5	-24.0	-1.7	-2.8	80.2	80.5
SD (mm)	2.1	0.5	0.2	0.4	2.1	2.2
Variance (mm ²)	4.4	0.2	0.0	0.2	4.6	4.8
CV (%)	8	2	11	16	3	3

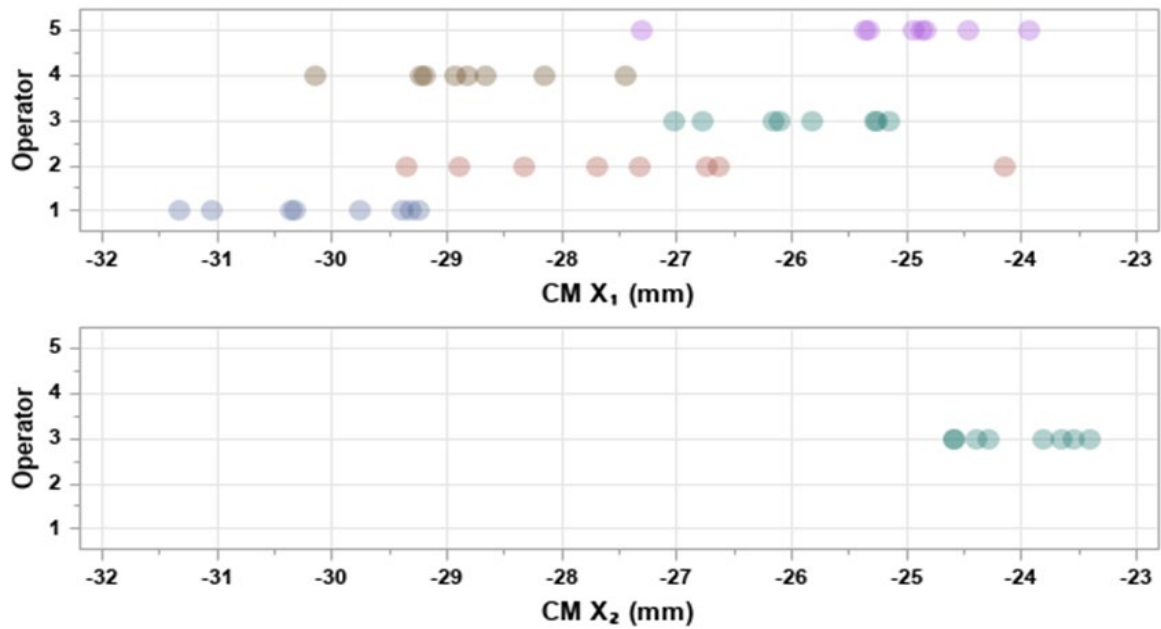


Figure 50. ACH small X_1 and X_2 center of mass measurements for all tests included in the analysis for each operator.

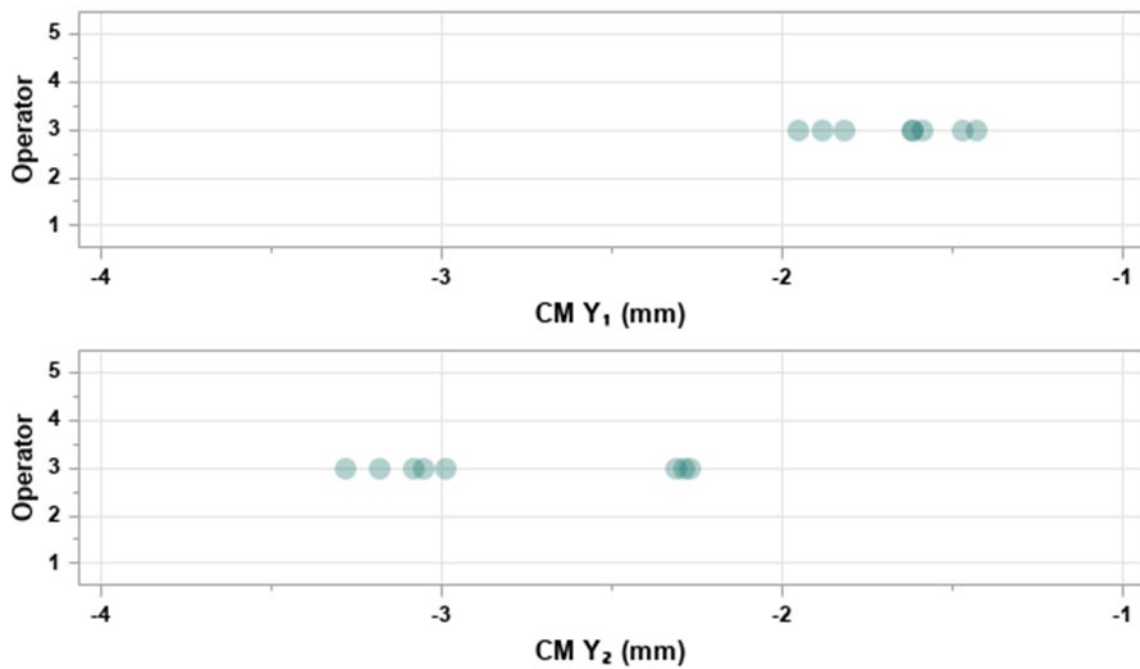


Figure 51. ACH small Y_1 and Y_2 center of mass measurements for all tests included in the analysis for each operator.

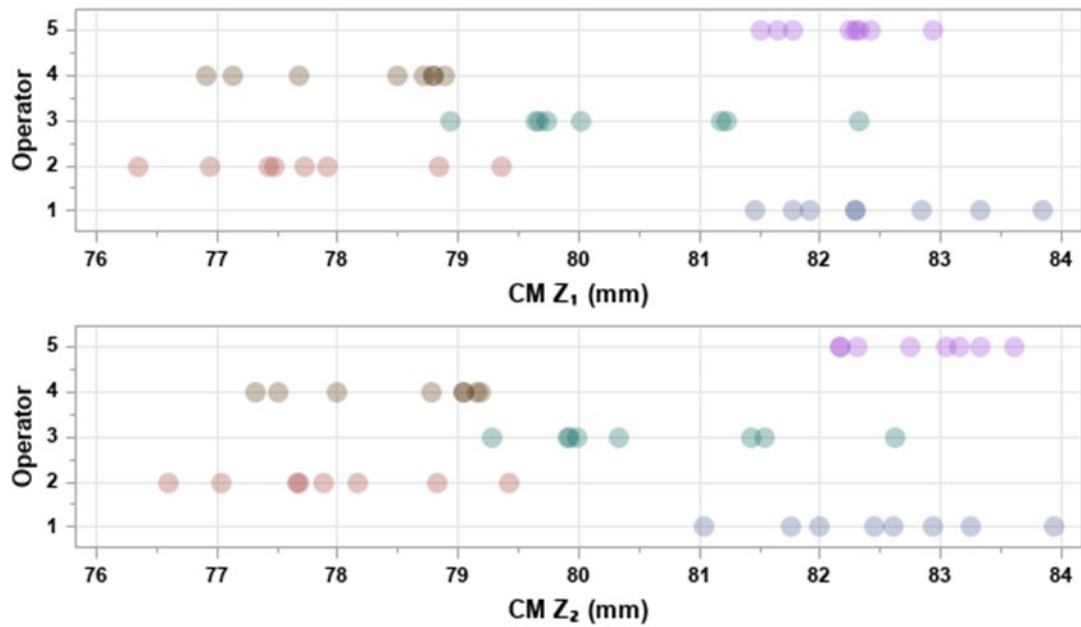


Figure 52. ACH small Z_1 and Z_2 center of mass measurements for all tests included in the analysis for each operator.

Table 25. ACH small breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CM Outcomes					
	X_1 (n= 40)	X_2^* (n= 8)	Y_1^* (n= 8)	Y_2^* (n= 8)	Z_1 (n= 20)	Z_2 (n= 20)
Operator	0.7867	NA	NA	NA	0.8618	0.8654
Error (Repeatability)	0.2133	NA	NA	NA	0.1382	0.1346

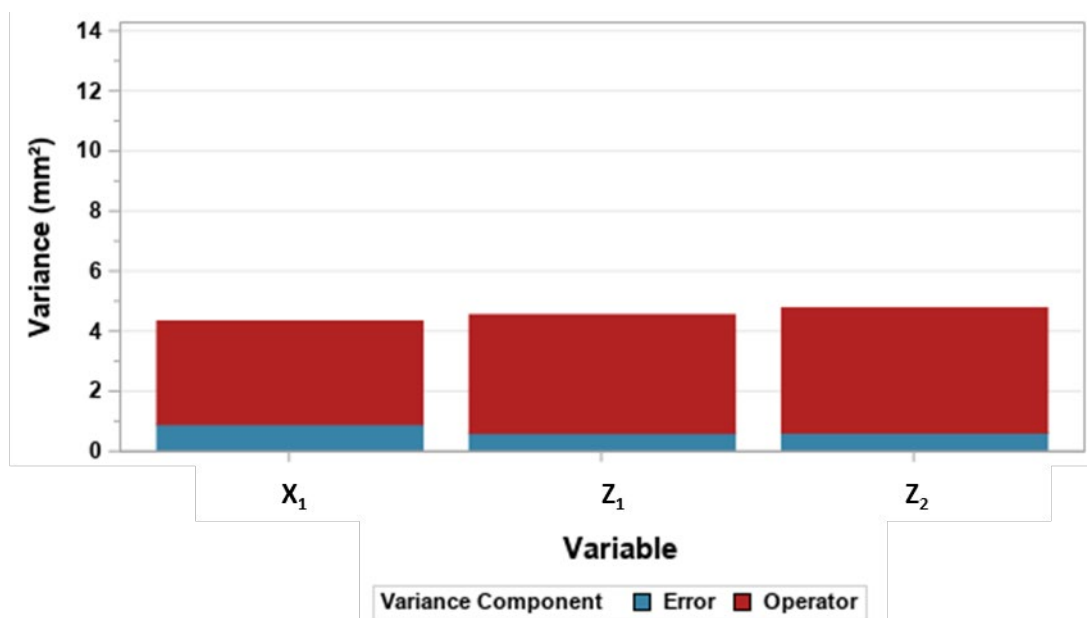


Figure 53. ACH Small CM Measurements: breakdown of each factor indicating the contribution to total variance for each CM variable.

3.5.3 ACH Small MOI Measurements

The MOI measurements from the ACH small are presented in this section. All of the MOI data have been included in the analysis. It is not known to what extent the fixture cradle shifting influenced the outcomes. Table 26 provides the MOI means, SD, variance and CV for the five DEVCOM SC operators; USAARL operators did not conduct testing on the ACH small. The standard deviations are consistent across the MOIs and coefficients of variation are also low with the highest value for Ixy at 10.9%. The scatterplots of the MOI measures (Figure 54 and Figure 55) show that Operator 4 data have several measurements for Izz, Ixx and Iyy not within range of the other Operators, and for Ixz and Ixy Operator 1 does not overlap the other Operators. These measurements are the factors driving the largest proportion of variance (Table 27 and Figure 56) to be due to reproducibility in most cases.

Table 26. ACH small MOI Mean, SD, Variance and CV for the seven Operators.

	Izz (n= 40)	Ixx (n= 40)	Iyy (n= 40)	Iyz (n= 40)	Ixz (n= 40)	Ixy (n= 40)
Mean (kg-m²)	0.01077	0.00948	0.00962	0.00983	0.00875	0.00910
SD (kg-m2)	0.00080	0.00079	0.00066	0.00056	0.00056	0.00100
Variance (kg-m2)²	6.40E-07	6.25E-07	4.29E-07	3.11E-07	3.13E-07	9.90E-07
CV %	7.4	8.3	6.8	5.7	6.4	10.9

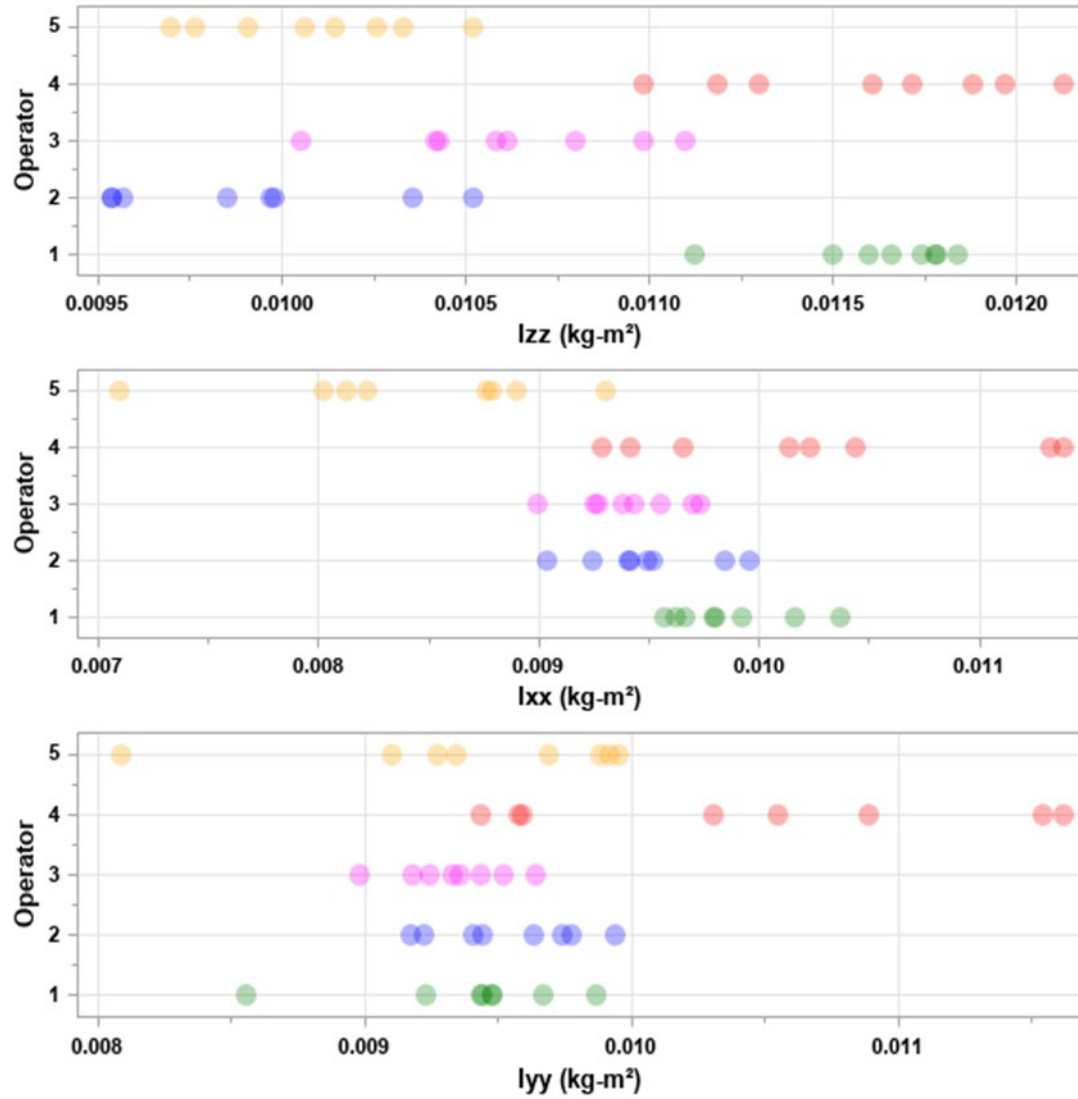


Figure 54. ACH small basic MOI I_{zz} , I_{xx} and I_{yy} scatter plots of data for all five DEVCOM SC operators.

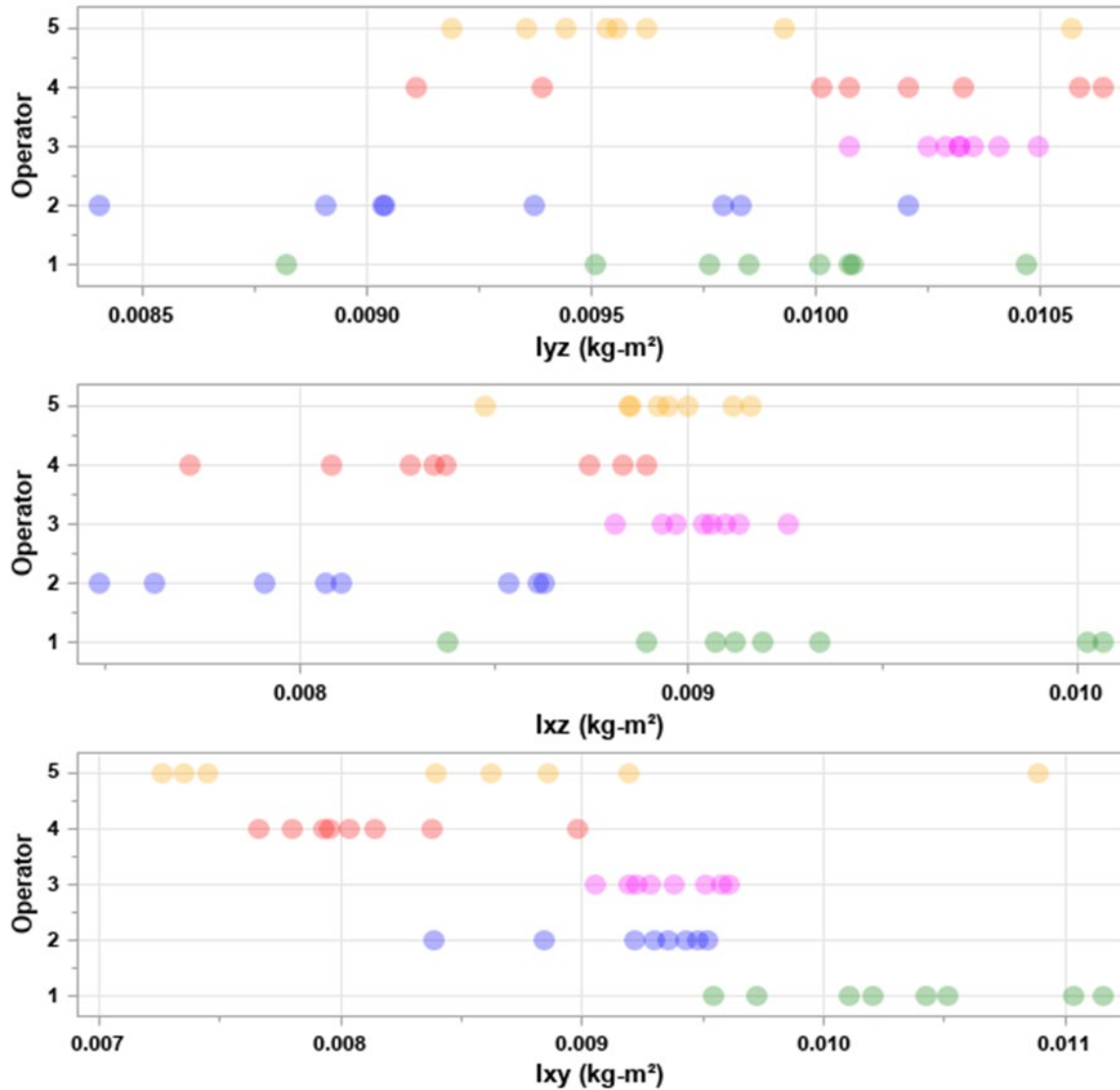


Figure 55. ACH small MOI for lyz, lxz, and lxy scatter plots of data for all five DEVCOM SC Operators.

Table 27. ACH small breakdown of each MOI measure lzz, lxx, lyy, lyz, lxz, and lxy proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the MOI Outcomes					
	lzz (n= 40)	lxx (n= 40)	lyy (n= 40)	lyz (n= 40)	lxz (n= 40)	lxy (n= 40)
Operator	0.8537	0.6206	0.3862	0.3462	0.5778	0.612
Error (Repeatability)	0.1463	0.3794	0.6138	0.6538	0.4222	0.388

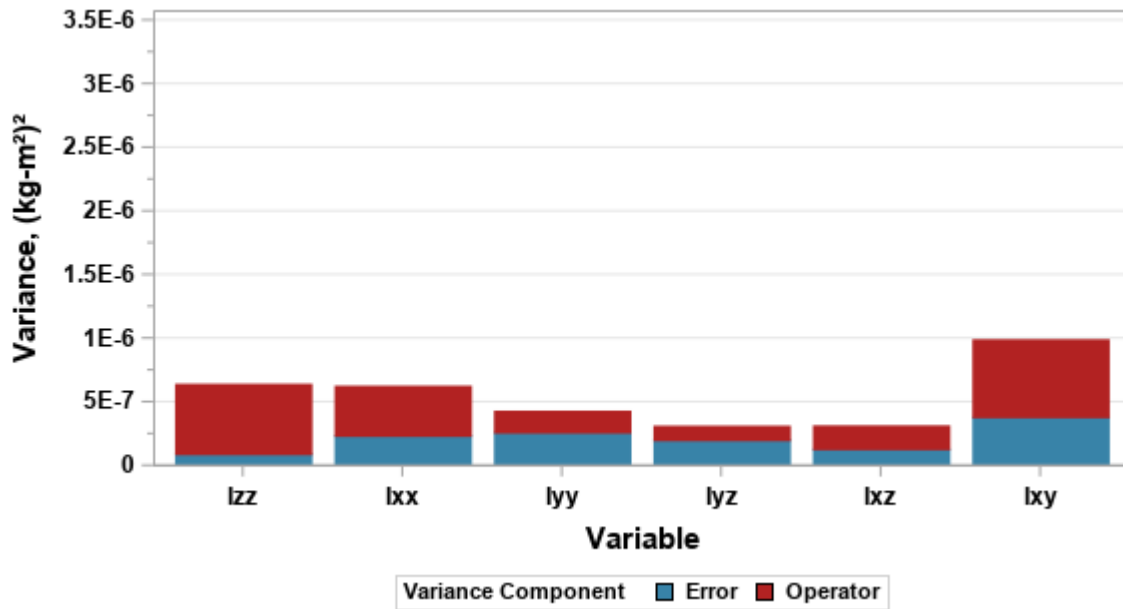


Figure 56. ACH Small MOI measurements: breakdown of each factor indicating the contribution to total variance for each MOI variable.

3.6 IHPS

3.6.1 IHPS Headform Alignment

Figure 57 is a picture of the IHPS size large mounted to the headform and depicts the two points, NVD_{MH} on the IHPS and the FLM, used in evaluating the alignment of the IHPS to the headform. The resultant length between the FLM and IHPS NVD_{MH} measured pre-mass properties tests and the difference between the pre- and post-mass properties tests were calculated and are presented in this section (Table 28). In addition, the pre-mass properties measurement X, Y and Z point differences between the FLM to the NVD_{MH} are provided. A scatterplot of the length from the FLM to NVD_{MH} for pre-mass properties tests is in Figure 58. Data for Operators 2 and 4 show the largest variation at 13 mm and 7 mm respectively. All Operators have some measurement overlap but with a minimum value of 61 mm and a maximum value of 75 mm, there is a large range in lengths measured. The colored arrows (blue, red and green) show general groupings of Operators with similar pre-test helmet mountings based on the lengths measured from the FLM to the NVD_{MH} . In Figure 59 to Figure 61 the pre-test X, Y and Z point data are provided to better understand the position of the NVD_{MH} on the headform. In Figure 62, the differences in length for the FLM to NVD_{MH} between the pre- and post-mass properties measurements are plotted. For all but three measurements, the changes in length were less than .4 mm. Operator 1 had shifts at -.79 and -1.26 mm and Operator 7 had a shift of -1.32 mm. A negative shift indicates the post-test length was shorter than the pre-test length and therefore the helmet shifted lower on the forehead. The CV for the pre/post difference measurements is high because the mean is close to zero, the SD of .3 mm is well within an expected range.



Figure 57. IHPS with the red squares identifying the NVD mount hole and forehead midpoint location. The length between the two points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 28. The minimum and maximum, mean, SD, variance and CV for the length measured from the forehead midpoint to the NVD mount hole and the X, Y and Z point differences of the forehead midpoint to NVD Mount Hole. Data are provided for the length measured prior to taking the CM and MOI measurements (pre) and then for the difference in lengths measured for the pre and post CM and MOI measurements.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to NVD _{MH} IHPS	Length	Pre	61	75	67	2.9	8.7	4
X: FLM to NVD _{MH}	Point	Pre	4	18	13	3.0	9.1	23
Y: FLM to NVD _{MH}	Point	Pre	-3	5	0	1.4	2.1	648
Z: FLM to NVD _{MH}	Point	Pre	59	75	66	3.5	12.4	5
FLM to NVD _{MH} IHPS	Length	Pre/Post Difference	-1.3	0.4	0.0	0.3	0.1	

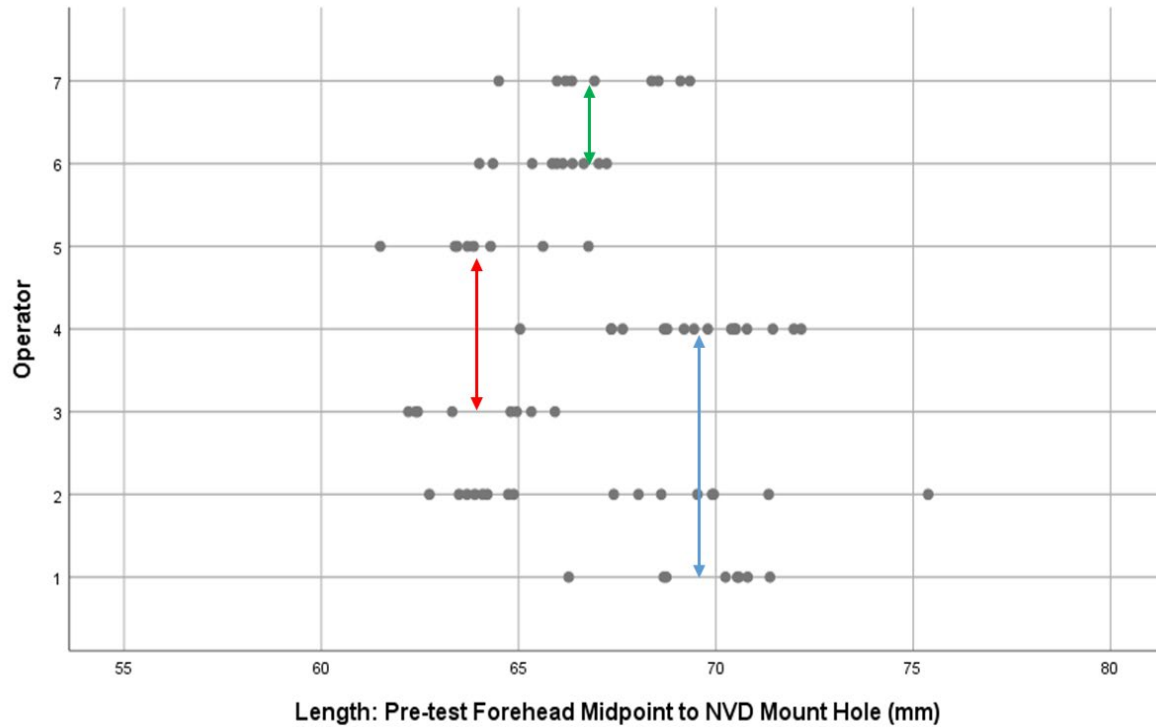


Figure 58. Scatterplot of the IHPS FLM to NVD mount hole lengths measured prior to mass properties measurements for each Operator. The arrows indicate general grouping of similar alignments: Blue arrow = Operators 1, 2 and 4, Red arrow = Operators 3 and 5, Green arrow = Operators 6 and 7.

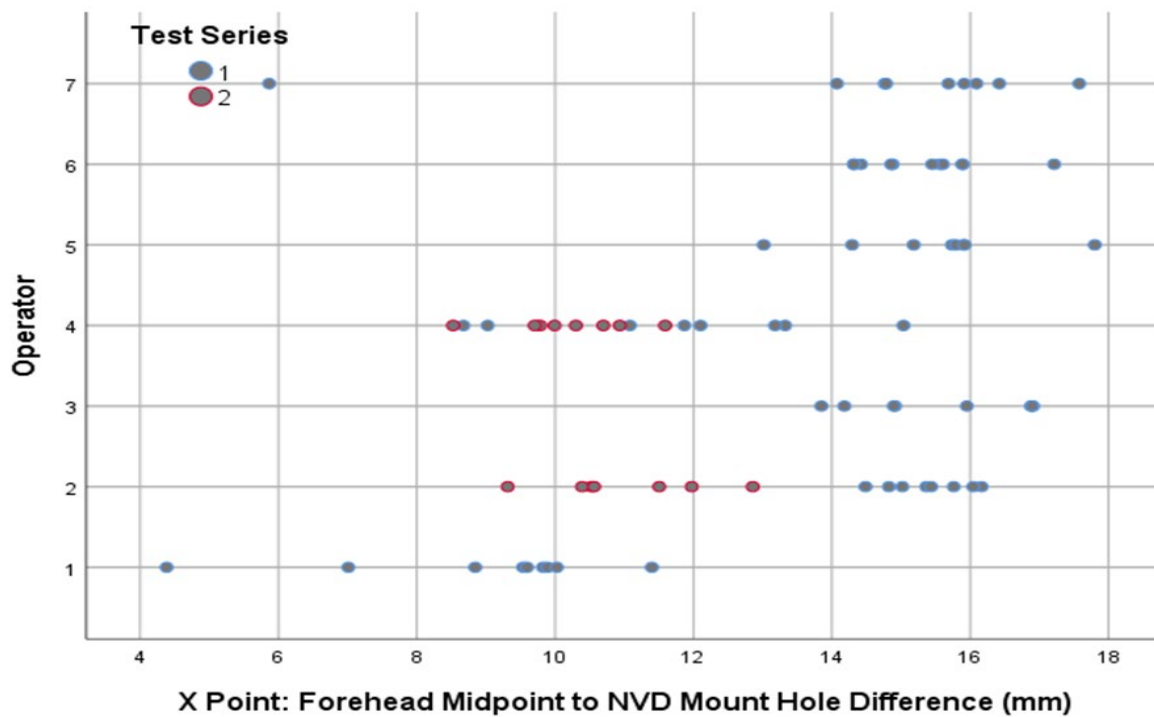


Figure 59. Scatterplot of the difference along the X-axis of the FLM to the IHPS NVD mount hole pre-test.

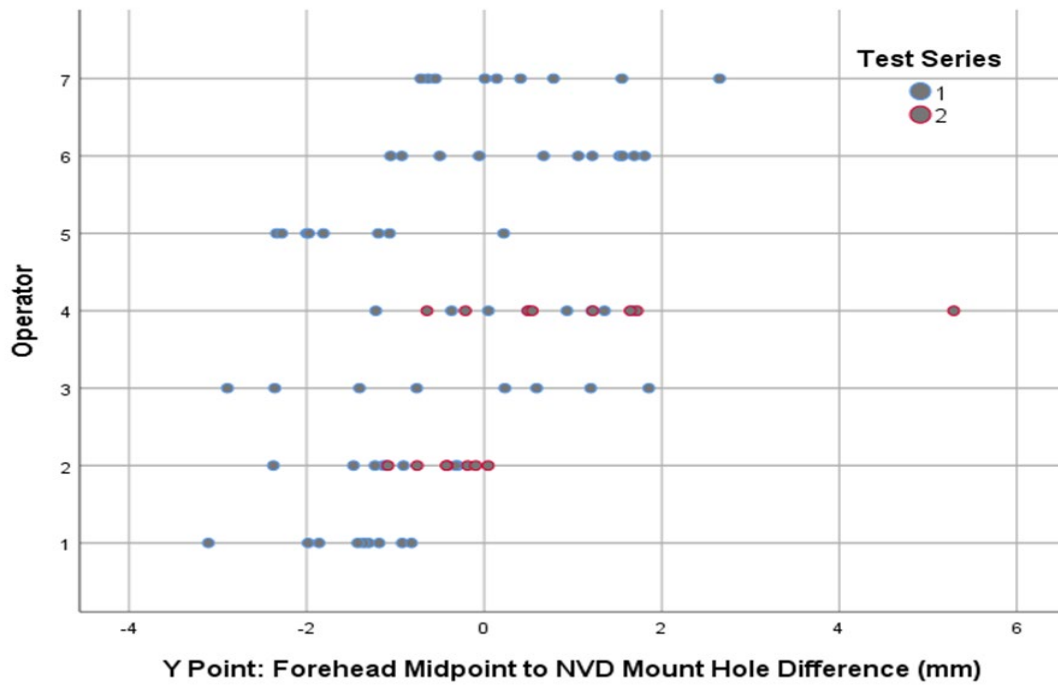


Figure 60. Scatterplot of the difference along the Y-axis of the FLM to the IHPS NVD mount hole pre-test.

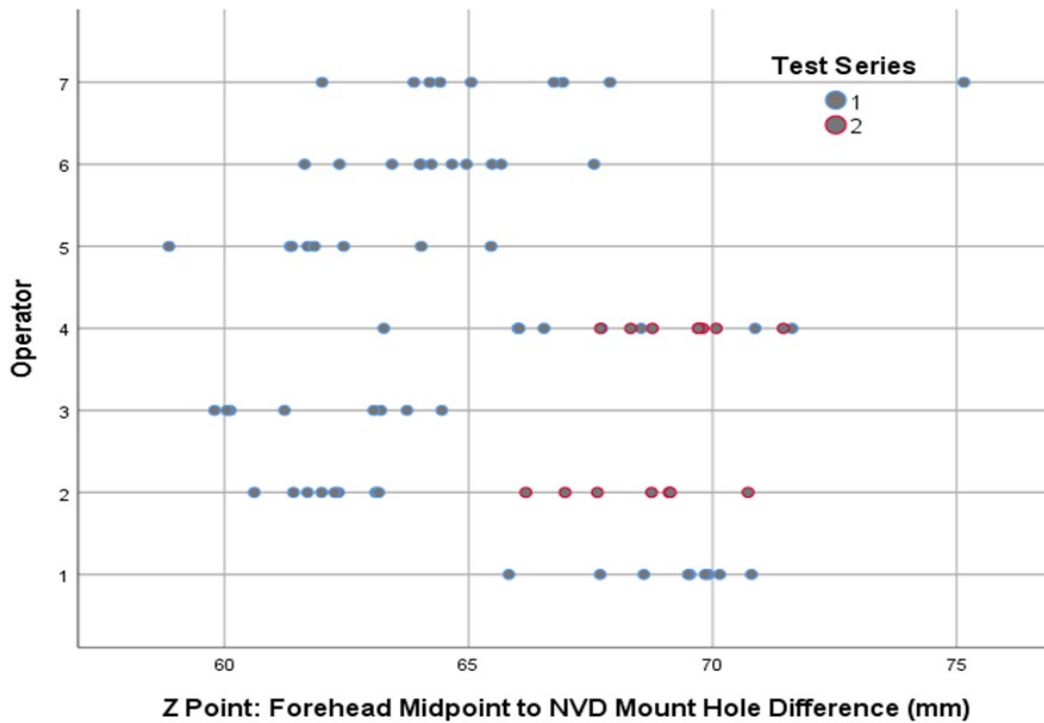


Figure 61. Scatterplot of the difference along the Z-axis of the FLM to the IHPS NVD mount hole pre-test.

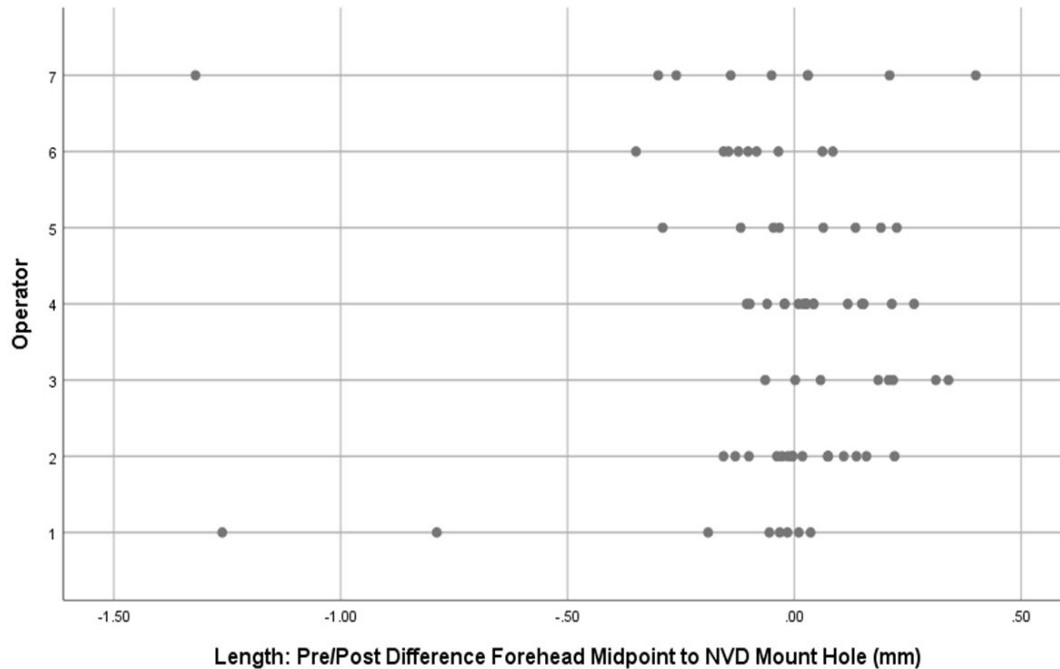


Figure 62. Scatterplot of the difference in length pre vs post mass property measurements for the IHPS FLM to NVD mount hole for each Operator.

3.6.2 IHPS CM Measurements

The means, standard deviations, variances and coefficient of variation from the IHPS large helmet CM tests are presented in this section. Table 29 provides the CM mean, SD, variance and CV for all seven Operators for six CM measurements (X_1 , X_2 , Y_1 , Y_2 , Z_1 and Z_2). The CM results vary the most for the X_1 and X_2 measurements with a max variance of 3.2 mm^2 and both CVs at 10%. The standard deviations for all CM variables are less than 1.8 mm. The scatterplots in Figure 63 to Figure 65 provide a visual display of the individual measurements of the Operators for each CM variable. The X_1 CM measurements follow a similar pattern as the pre-test X point measurements shown in Figure 59. The smaller X point and larger Z point (Figure 61) measurements indicate the helmet is shifted up and back, which is reflected in the CM measurements along the X-axis.

A summary of the proportion of variance for each CM variable is provided in Table 30 and Figure 66. The proportions of variance are largely split between Operator and Fixture. The Z_1 and Z_2 CM data are the only consistent data set in that, for both variables, the proportion of variance is largely due to Operator influence. However, between X_1 and X_2 , while Operator is a main factor, repeatability is an equivalent factor for X_1 and Fixture is an equivalent factor for X_2 . For the CM measurements along the Y-axis, Y_1 is due to pure repeatability and Y_2 is mostly due to Fixture. For the Y_1 measurements the data for each Operator largely overlap, and for Y_2 Operators 6 and 7 from USAARL are clustered together and data for Operators 2-4 from DEVCOM SC are aligned, but Operator 4 does not overlap any CM measurements by USAARL Operators. Again, helmet fitting procedures are a critical factor in the outcomes of the measurements and is an area where improvement to the guidelines should reduce Operator variability.

Table 29. IHPS CM measurement means, SD, variance and CV for X, Y and Z variables for all seven Operators. For X_2 , Y_1 and Y_2 data from Operators 1 and 5 are not included as they did not perform re-tests. *Some measurements were excluded from analysis due to fixture y-translation.

	X_1 (n= 76)	X_2 *(n= 44)	Y_1 *(n= 44)	Y_2 *(n= 44)	Z_1 (n= 76)	Z_2 (n= 76)
Mean (mm)	-18.6	-16.4	1.0	0.5	79.2	79.5
SD (mm)	1.8	1.6	0.6	1.3	1.3	1.2
Variance (mm ²)	3.2	2.5	0.4	1.7	1.6	1.5
CV (%)	10	10	63	254	2	2

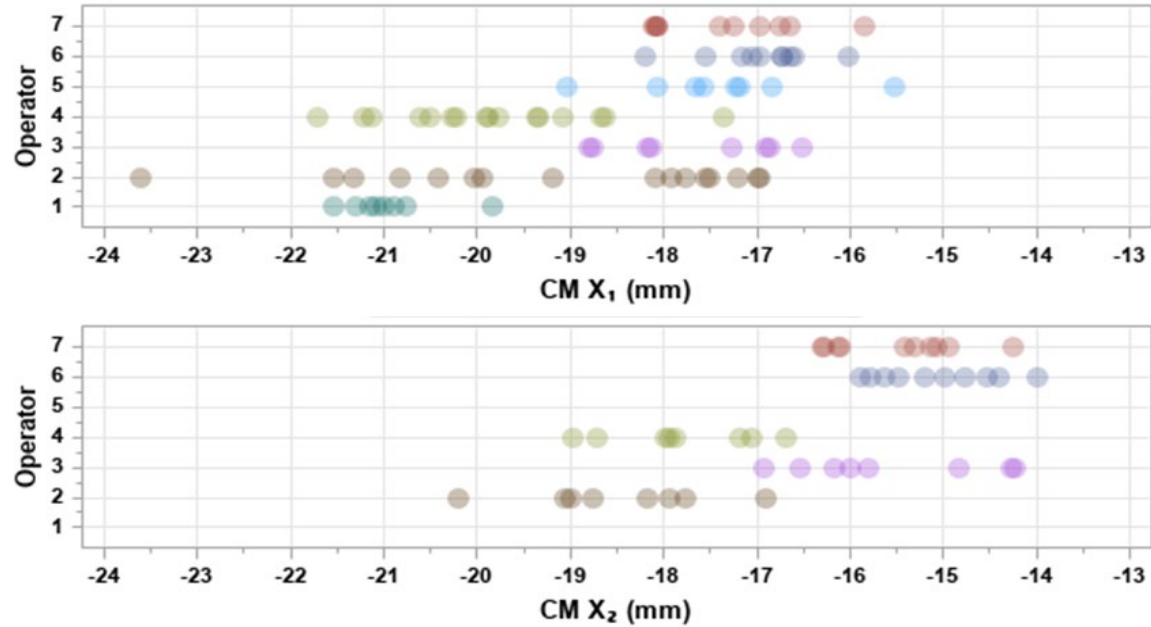


Figure 63. IHPS X_1 and X_2 center of mass measurements for all tests included in the analysis for each operator.

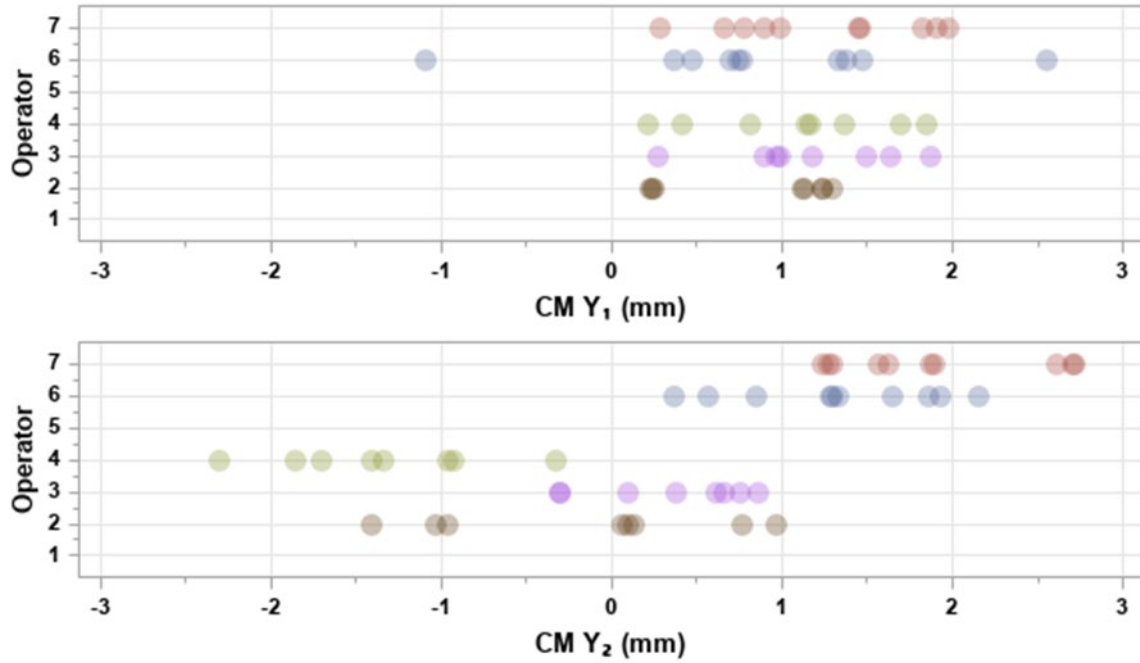


Figure 64. IHPS Y_1 and Y_2 center of mass measurements for all tests included in the analysis for each operator.

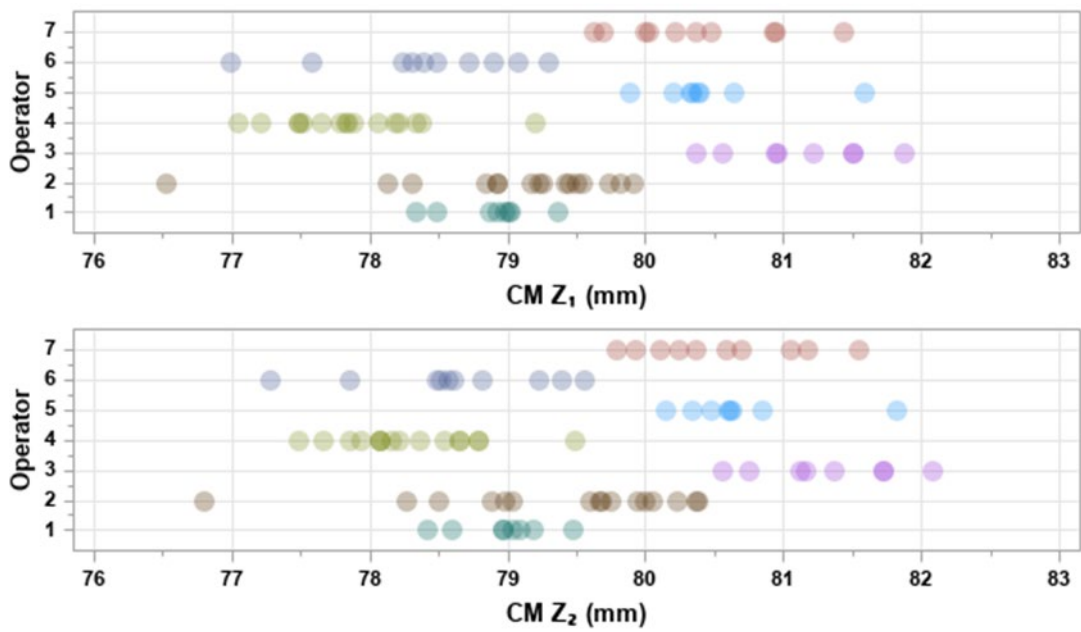


Figure 65. IHPS Z_1 and Z_2 center of mass measurements for all tests included in the analysis for each operator.

Table 30. IHPS breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CM Outcomes					
	X ₁ (n= 76)	X ₂ * (n= 44)	Y ₁ * (n= 44)	Y ₂ * (n= 44)	Z ₁ (n= 76)	Z ₂ (n= 76)
Fixture	0.2742	0.3921	0	0.6604	0	0
Operator(Fixture)	0.3784	0.4131	0	0.1881	0.7876	0.7554
Error (Repeatability)	0.3474	0.1949	1	0.1515	0.2124	0.2446

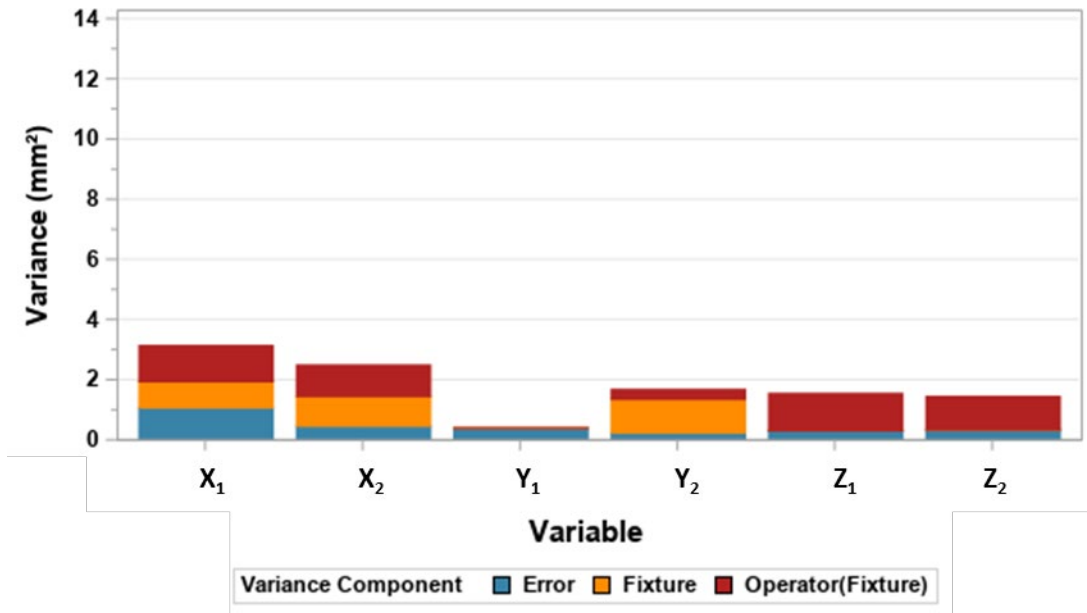


Figure 66. IHPS CM Measurements: Breakdown of each factor indicating the contribution to total variance (mm²) for each CM variable.

3.6.3 IHPS MOI Measurements

The MOI measurements from the IHPS are presented in this section. Table 31 provides the MOI means, SD, variance and CV for all seven DEVCOM SC and USAARL operators. All of the MOI data have been included in the analysis; it is not known to what extent the fixture cradle shifting influenced the outcomes. The standard deviations are consistent across the MOIs and coefficients of variation are also low with the highest value for Iyy at 6.4%. The scatterplots of the MOI measures (Figure 67 and Figure 68) show that Operators 2 and 3 and Operators 6 and 7 have overlapping data for all MOI measurements data. The other Operators have some overlap; however, it varies for each MOI variable, there is no Operator data set that does not overlap with another Operator. The proportion of variance for each MOI measure is provided in Table 32 and plotted in Figure 69. Operator reproducibility is a consistent contributor to variance for all variables except Ixy.

Table 31. IHPS MOI Mean, SD, Variance and CV for the seven Operators.

	lzz (n= 76)	lxx (n= 76)	lyy (n= 76)	lyz (n= 76)	lzx (n= 76)	lxy (n= 76)
Mean (kg-m ²)	0.01397	0.01119	0.01139	0.01244	0.01103	0.01136
SD (kg-m ²)	0.00058	0.00068	0.00073	0.00058	0.00049	0.00054
Variance (kg-m ²) ²	3.39E-07	4.61E-07	5.39E-07	3.33E-07	2.40E-07	2.90E-07
CV %	4.2	6.1	6.4	4.6	4.4	4.7

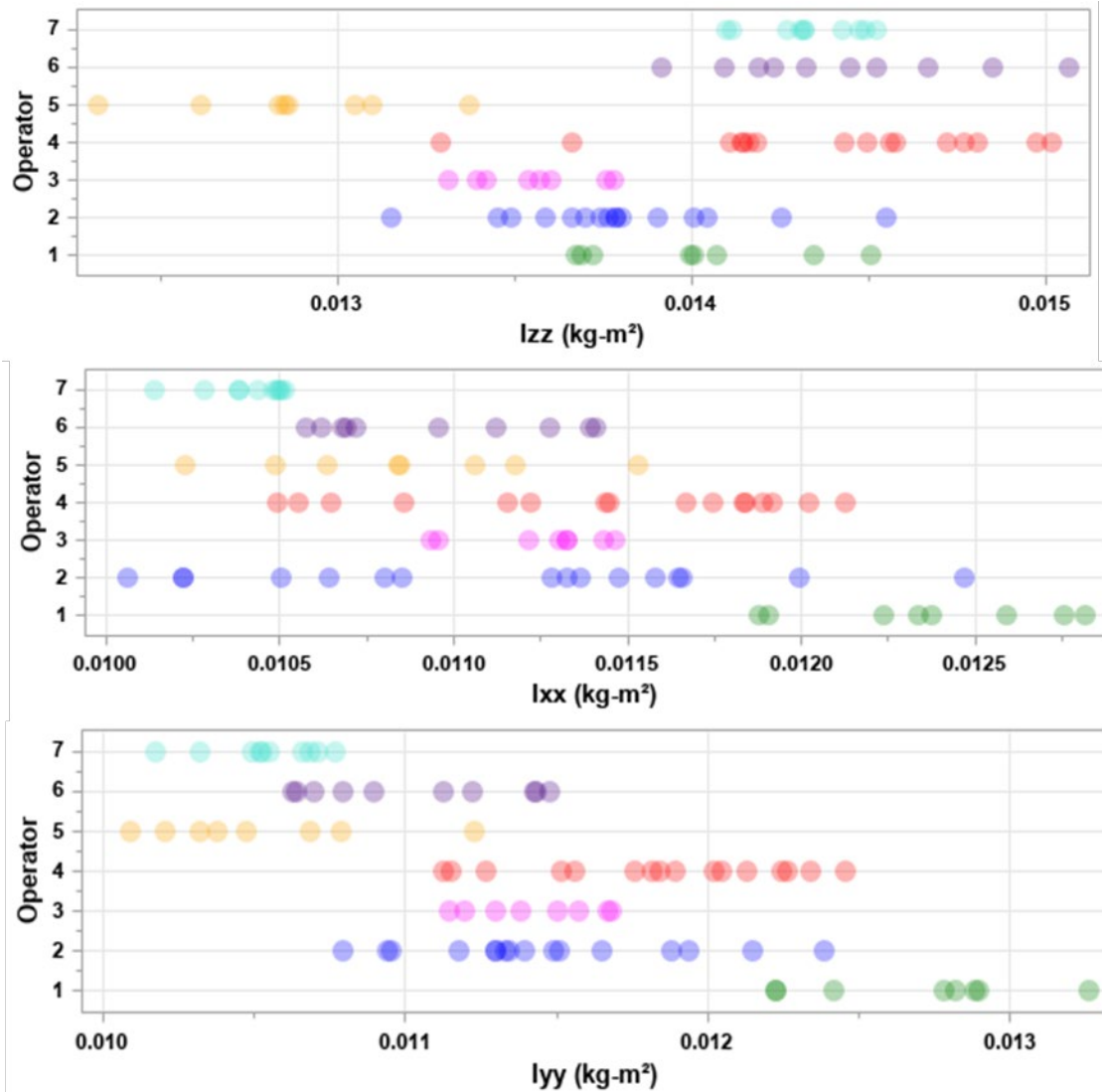


Figure 67. IHPS basic MOI lzz, lxx and lyy scatter plots of data for all seven Operators.

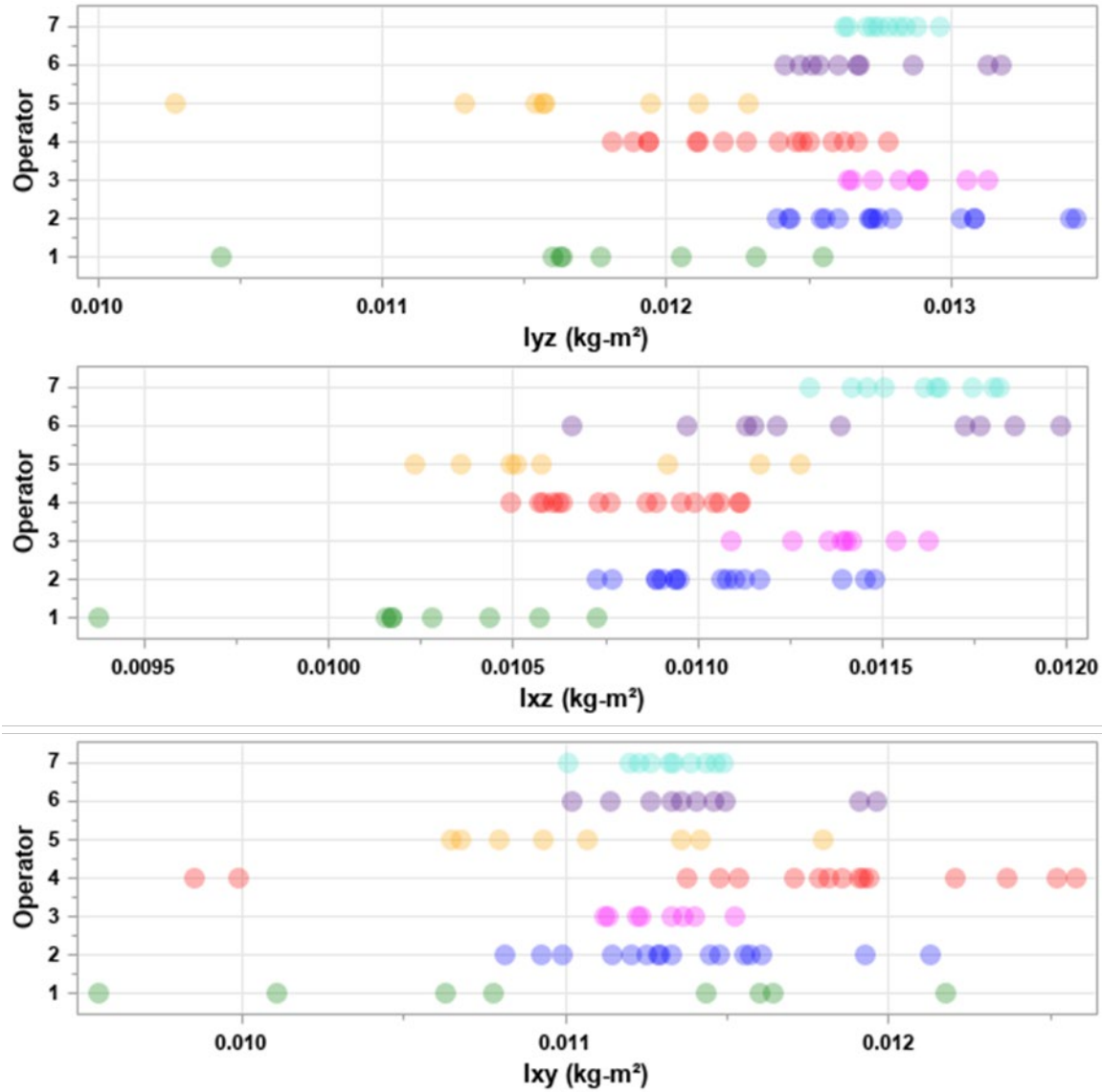


Figure 68. IHPS MOI for lyz, lxz, and lxy scatter plots of data for all seven Operators.

Table 32. IHPS breakdown of each MOI measure lzz, lxx, lyy, lyz, lxz, and lxy proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the MOI Outcomes					
	lzz (n= 76)	lxx (n= 76)	lyy (n= 76)	lyz (n= 76)	lxz (n= 76)	lxy (n= 76)
Fixture	0.268	0.253	0.1871	0.0528	0.4213	0
Operator(Fixture)	0.4992	0.4073	0.6423	0.6143	0.3607	0.0963
Error (Repeatability)	0.2327	0.3397	0.1706	0.3329	0.2181	0.9037

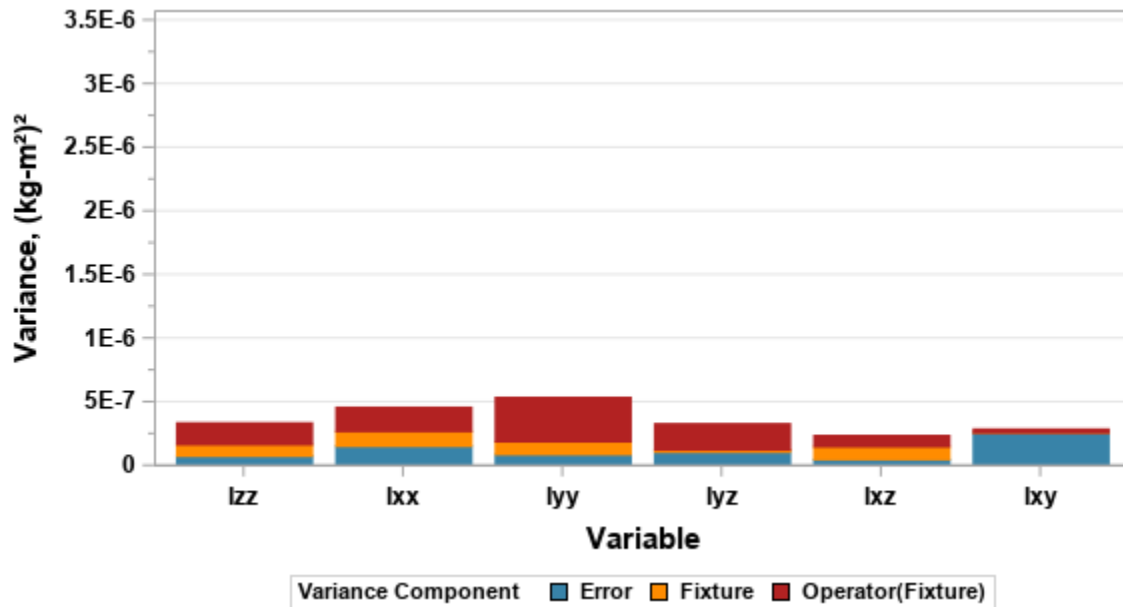


Figure 69. IHPS MOI Measurements: breakdown of each factor indicating the contribution to total variance for each MOI variable.

3.7 ACH Medium with PVS-14 Stowed

3.7.1 ACH Medium with PVS-14 Stowed Headform Alignment

Figure 70 is the ACH with PVS-14 in the stowed position mounted to the headform. In the figure, the four helmet system points: +Y and –Y PVS-14 Stowed and the +Y and –Y ACH helmet along with one headform point at the FLM are identified. These points were used in evaluating the alignment of the ACH and PVS-14 to the headform with the FaroArm. The resultant lengths for each of the four points on the helmet system measured pre-mass properties tests, along with the differences between the +Y and –Y ACH and NVD-Stowed lengths from the pre- and post-mass properties tests, were calculated and are presented in Table 33. In addition, the pre-mass properties measurement X, Y and Z point differences between the FLM to the ACH –Y and PVS-14 Stowed –Y are provided.

For the ACH medium data, the mean FLM to the ACH +Y location is 4 mm larger than the mean length to the ACH –Y location. In Figure 71 to Figure 73, scatterplots of the X, Y and Z point data for the ACH –Y location are plotted. The Y-axis data indicate that the helmet was aligned from right to left similarly for all Operators. However, the X and Z point data show that the helmet alignment of Operator 1 was shifted up and posterior on the headform.

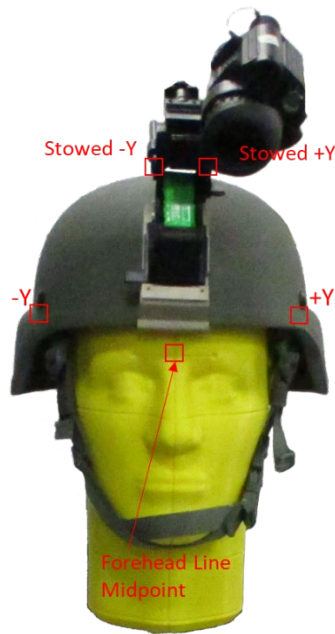


Figure 70. ACH medium with PVS-14 stowed. The red squares identify the ACH +Y and –Y points, the PVS-14 Stowed +Y and –Y points, and the forehead midpoint locations. The length between the forehead midpoint and each of the four helmet points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 33. The minimum and maximum, mean, SD, variance and CV for the lengths measured from the FLM to the four ACH with PVS-14 stowed helmet points. Data are provided for the X, Y and Z points as well as the lengths measured prior to taking the CM and MOI measurements (pre), differences between the pre-test +Y and –Y lengths, and then for the difference of the pre and post CM and MOI measurements for all four lengths.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to ACHM +Y	Length	Pre	114	119	116	1.1	1.2	1
FLM to ACHM -Y	Length	Pre	109	115	111	1.2	1.5	1
FLM to ACHM +Y vs -Y	Length	Pre Difference	2	8	5	1.4	1.9	
X: FLM to ACHM -Y	Point	Pre	-58	-51	-54	1.5	2.2	3
Y: FLM to ACHM -Y	Point	Pre	-97	-93	-95	0.7	0.5	1
Z: FLM to ACHM -Y	Point	Pre	16	29	21	2.3	5.5	11
FLM to ACHM +Y	Length	Pre/Post Difference	-3.5	1.8	-0.4	1.1	1.3	
FLM to ACHM -Y	Length	Pre/Post Difference	-1.9	5.0	0.8	1.3	1.6	
FLM to PVS-14 Stowed +Y	Length	Pre	132	148	140	3.3	11.1	2
Mid-Forehead to PVS-14 Stowed -Y	Length	Pre	133	149	141	3.4	11.5	2
FLM to PVS-14 Stowed +Y vs -Y	Length	Pre Difference	-1	1	-0.3	0.2	0.0	
X: FLM to PVS-14 Stowed -Y	Point	Pre	25	48	36	6	32	16
Y: FLM to PVS-14 Stowed -Y	Point	Pre	-21	-14	-17	2	2	9
Z: FLM to PVS-14 Stowed -Y	Point	Pre	123	146	135	5	26	4
FLM to PVS-14 Stowed +Y	Length	Pre/Post Difference	-2.3	8.8	0.7	1.9	3.8	
FLM to PVS-14 Stowed -Y	Length	Pre/Post Difference	-0.8	9.3	1.0	2.1	4.5	



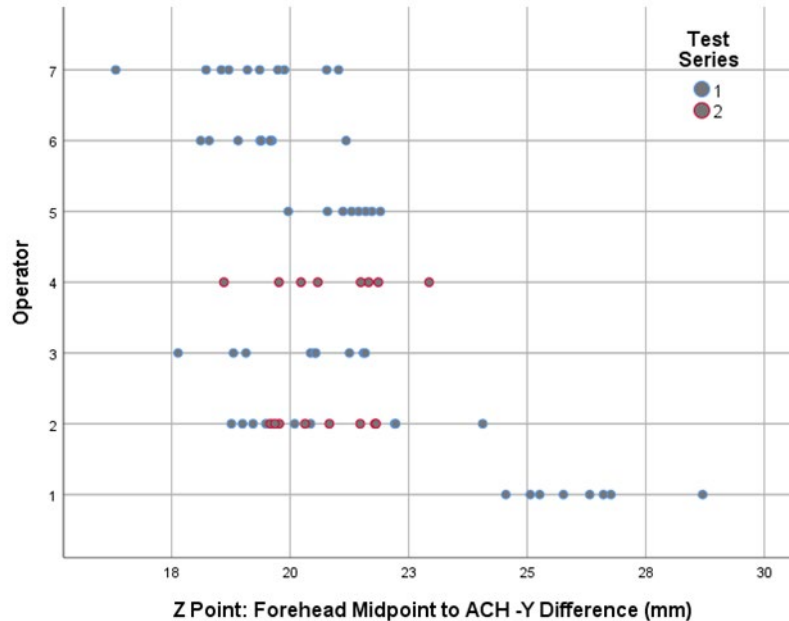


Figure 73. Scatterplot of the difference along the Z-axis of the FLM to the ACH M -Y pre-test.

The resultant length between the FLM and the PVS-14 +Y and -Y stowed is 140 and 141 mm respectively with similar minimum and maximum data ranges. A scatterplot of the length from the FLM to +Y PVS-14 Stowed point pre-mass properties tests is in Figure 74. Data for Operator 1 are slightly larger and Operator 3 is slightly smaller than the other Operators. In Figure 75 to Figure 77, the X, Y and Z position data of the PVS-14 Stowed -Y location are depicted in scatterplots. From the X and Z point data, Operator 1 and Operator 2 (test series 2) mounted the helmet brim slightly higher and posterior than the other Operators. From front to back, Operator 2 mounted the helmet differently for the second versus the first series of testing conducted. Almost all of the Y point data are positioned within 6 mm of each other. Operator 3 measurements are smaller than the other Operators, which indicates the PVS-14 was closer to the midline of the headform than the other Operators. Operator 6 was slightly larger, indicating the PVS-14 was shifted more towards the -Y side of the headform than the other Operators. The pre- vs post-mass properties position of the PVS-14 is plotted in Figure 78. All differences were less than 3 mm except for Operators 2 and 6. Operator 2 had three tests where the difference was 9 mm and one test where the difference was 5.3 mm. Operator 6 had one test where the difference was 7.2 mm.

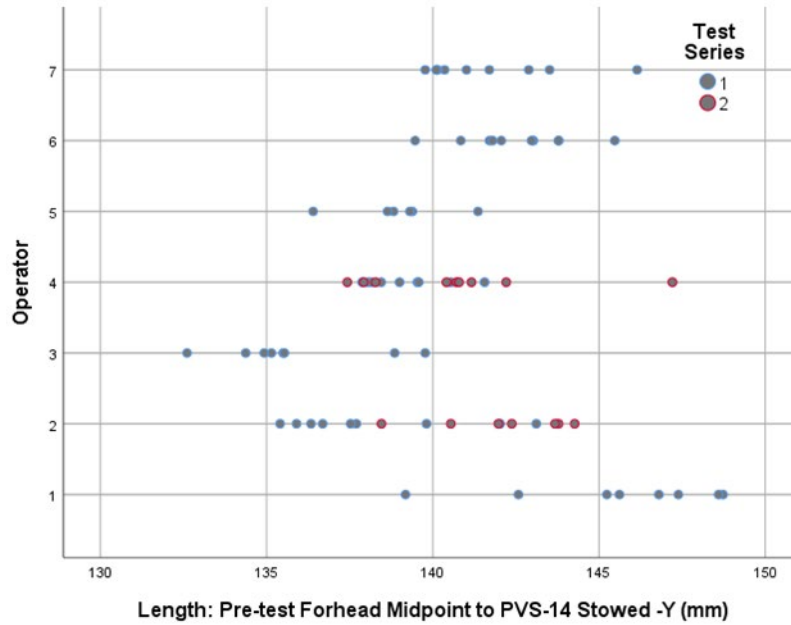


Figure 74. Scatterplot of the length measured between the FLM and the ACH medium PVS-14 Stowed -Y point for the helmet system mount prior to mass properties measurements. The second series of tests conducted by Operators 2 and 4 are distinguished from the first test series by the color red.

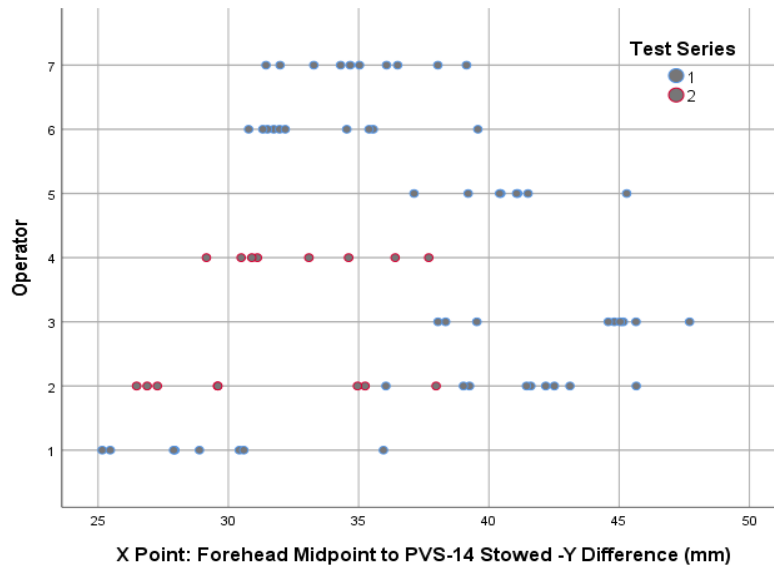


Figure 75. Scatterplot of the difference along the X-axis of the FLM to the PVS-14 Stowed -Y pre-test.

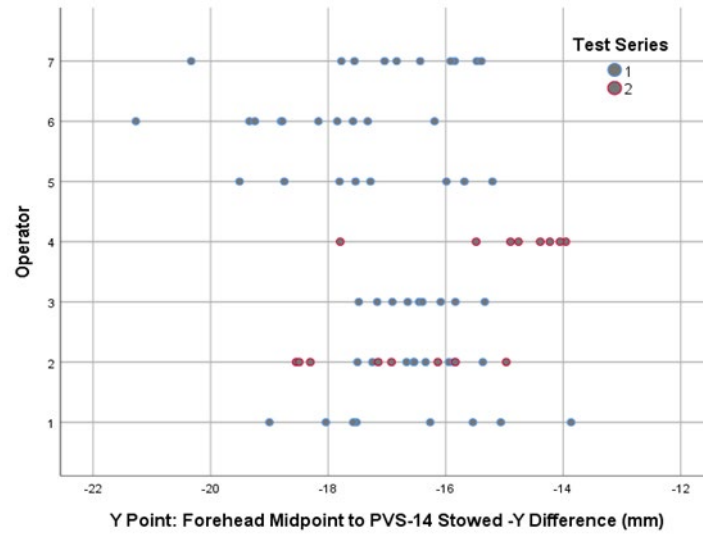


Figure 76. Scatterplot of the difference along the Y-axis of the FLM to the PVS-14 Stowed -Y pre-test.

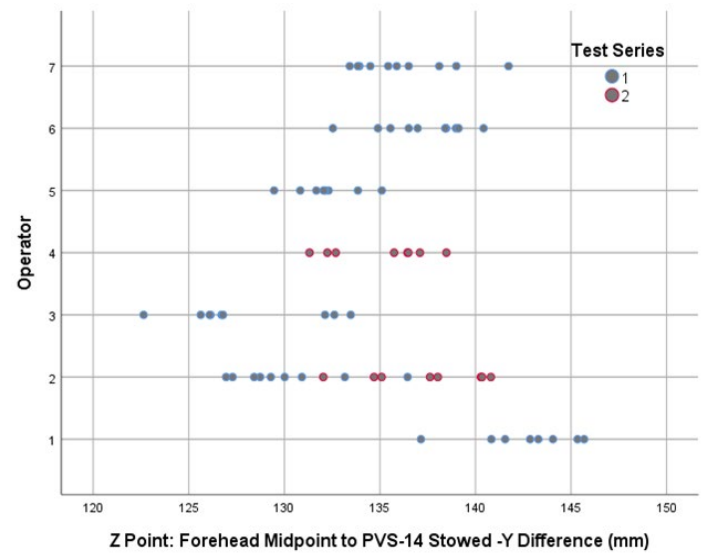


Figure 77. Scatterplot of the difference along the Z-axis of the FLM to the PVS-14 Stowed -Y pre-test.

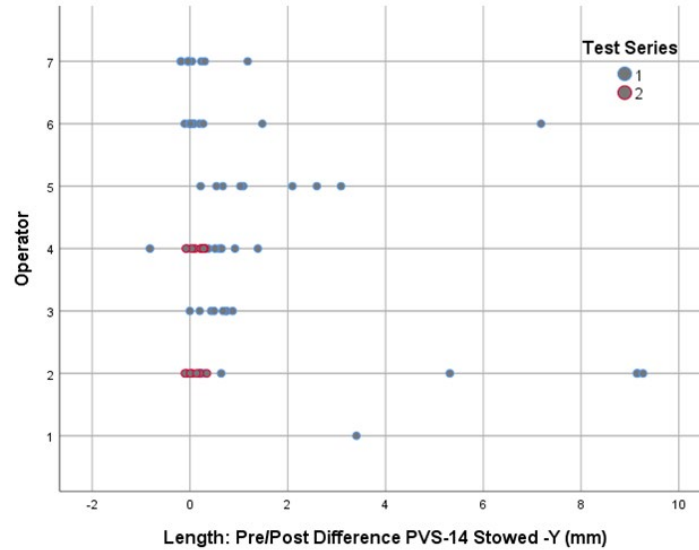


Figure 78. Scatterplot of the difference in length measured between the FLM and the ACH medium PVS-14 Stowed -Y point, pre vs post mass property measurements. The second series of tests conducted by Operators 2 and 4 are distinguished from the first test series by the color red.

3.7.2 ACH Medium with PVS-14 Stowed CM Measurements

The CM measurements from the ACH medium with PVS-14 Stowed are presented in this section. Table 34 provides the CM mean, SD, variance and CV for all seven Operators for X_1 , Z_1 and Z_2 and also include the additional tests performed by Operators 2 and 4. The CM results for X_2 , Y_1 and Y_2 include measurements from Operator 2-4, 6 and 7 as Operators 1 and 5 data were removed because they were performed prior to the modification of the fixture to resolve the Y-axis translation that occurred. The scatterplots in Figure 79 to Figure 81 provide a visual display of the individual measurements of the Operators for each CM variable. For the X_1 CM measurements, Operator 2 has the largest variation, ranging from 21 to 36 mm. The measurements from this Operator's second test series (mean = 24 mm) were much lower than the first test series (mean = 31.7 mm) and is the most significant contributor to the large variation observed for the X_1 CM. The differences between the CM measurements for the two test series conducted by Operator 2 are reflected in the X point measurements of the PVS-14 Stowed -Y scatterplot in Figure 75. A similar correlation occurs for the Y point data of PVS-14 stowed -Y (Figure 76) and the Y_1 CM measurements (Figure 80). In Figure 78, it can also be observed that Operator 2 had four measurements where the PVS-14 to headform length differences, measured pre vs post testing, differed greater than 5 mm. It is not known to what extent this influenced the data because it is not known when during the test measurement process the equipment shifted. Additional factors for the large variation observed are that Operator 1 does not overlap with Operators 3 and 5 for any X_1 measurements and within Operator measurements vary greater than 5 mm. The X_2 CM measurements also have a large variation in measurement. Operator 3 does not overlap with both USAARL Operators and all within Operator measurements vary greater than 5 mm. The CM variables along the Y-axis and Z-axis do not have significant variation and are similar to other helmet systems. For the Y CM measurements, all Operators overlap. For the Z CM measurements, DEVCOM SC Operators 2 and 4 are consistent with USAARL Operators 6 and 7. Operators 1 and 5 are consistent but skewed higher than all other Operators.

Table 34. ACH with PVS-14 Stowed CM measurement means, SD, variance and CV for each X, Y and Z variable for all operators.

*Some measurements were excluded from the analysis due to the fixture y-translation.

	X_1 (n= 77)	X_2 *(n= 44)	Y_1 *(n= 44)	Y_2 *(n= 44)	Z_1 (n= 77)	Z_2 (n= 77)
Mean (mm)	26.8	27.1	8.4	7.5	117.8	117.8
SD (mm)	3.7	3.5	0.8	0.7	1.8	2.1
Variance (mm ²)	13.7	12.0	0.6	0.5	3.3	4.3
CV (%)	14	13	9	10	2	2

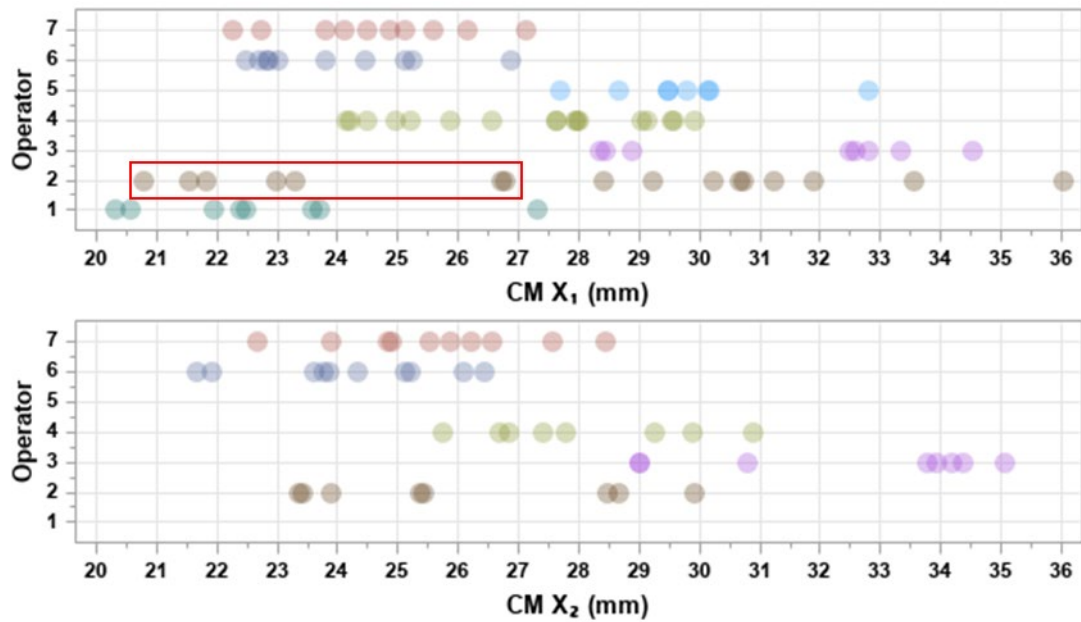


Figure 79. ACH medium with PVS-14 stowed X_1 and X_2 center of mass measurements for all tests included in the analysis for each operator. Operator 2 has a red box around measurements from the second test series to visually distinguish the outcomes from the first test series since they did not overlap.

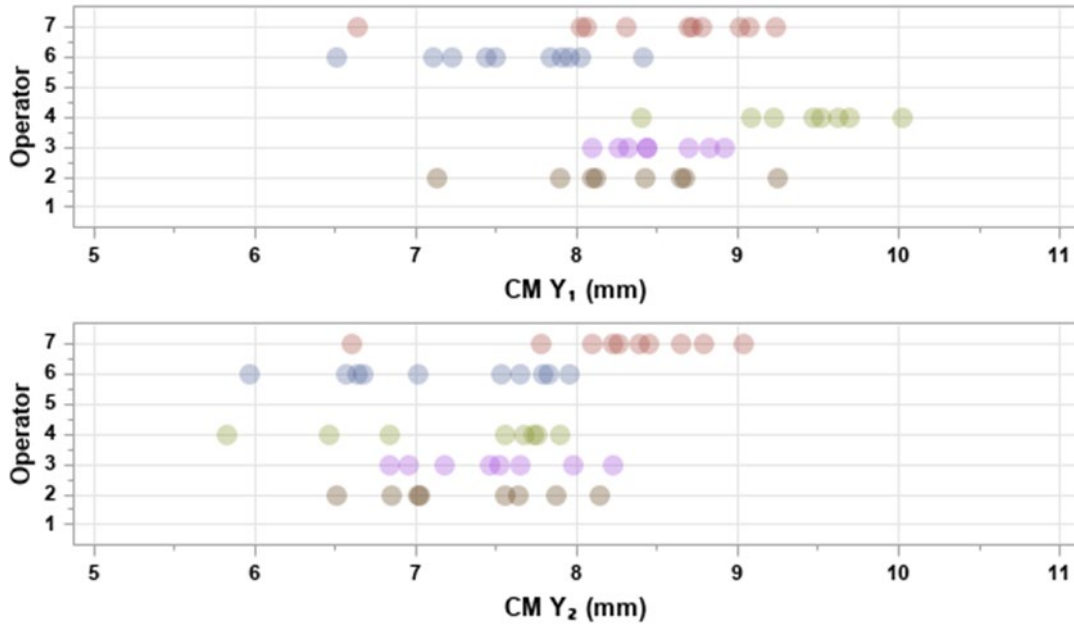


Figure 80. ACH medium with PVS-14 stowed Y_1 and Y_2 center of mass measurements for all tests included in the analysis for each operator.

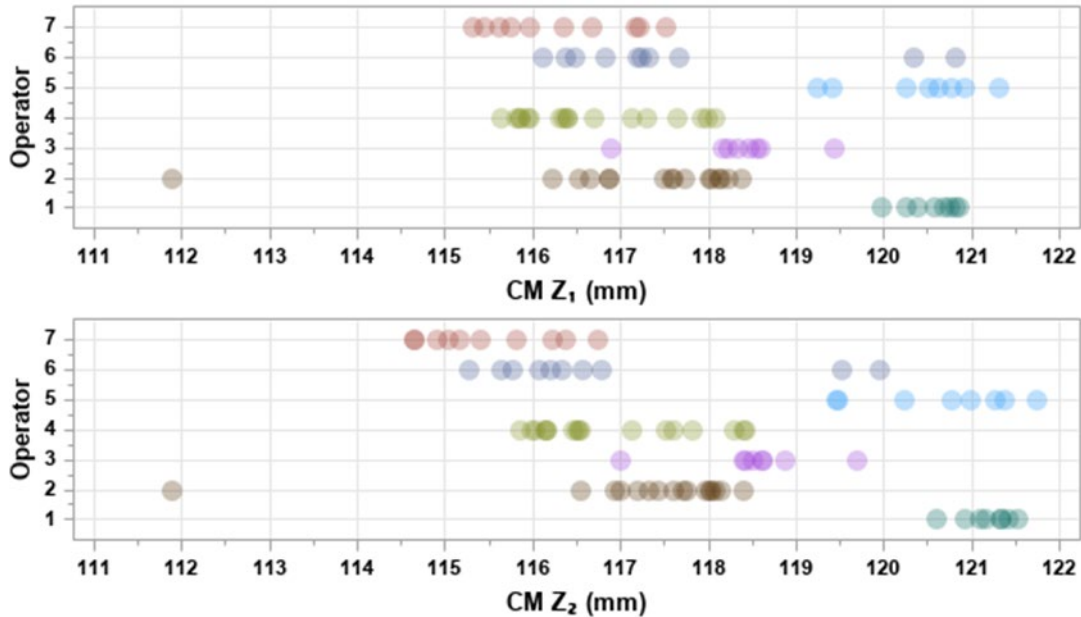


Figure 81. ACH medium with PVS-14 stowed Z_1 and Z_2 center of mass measurements for all tests included in the analysis for each operator.

A summary of the proportion of variance for each CM variable is provided in Table 35 and Figure 82. Operator was a significant contributor to variation for all variables except Y_2 where Operator data largely overlapped. There was a wide range of X_1 and Y_1 measurements both between and within Operators, leading to an even split in the proportions of variation attributed to Operator and Repeatability. The average variation in the X_1 and X_2 CM measurements for the PVS-14 stowed condition is 13.5 mm^2 but for the PVS-14 deployed condition is $.8 \text{ mm}^2$. Additional testing of this helmet system with more controlled helmet fitting guidelines is necessary in order to better understand the true variation.

Table 35. ACH medium with PVS-14 stowed breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. The * indicates that DEVCOM SC pre-fix measurements for this variable have been excluded from the analysis. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CM Outcomes					
	X ₁ (n= 77)	X ₂ * (n= 44)	Y ₁ * (n= 44)	Y ₂ * (n= 44)	Z ₁ (n= 77)	Z ₂ (n= 77)
Fixture	0.1832	0.2951	0.1309	0	0.0846	0.3787
Operator(Fixture)	0.4086	0.444	0.421	0.2702	0.6259	0.4439
Error (Repeatability)	0.4082	0.261	0.4481	0.7298	0.2895	0.1774

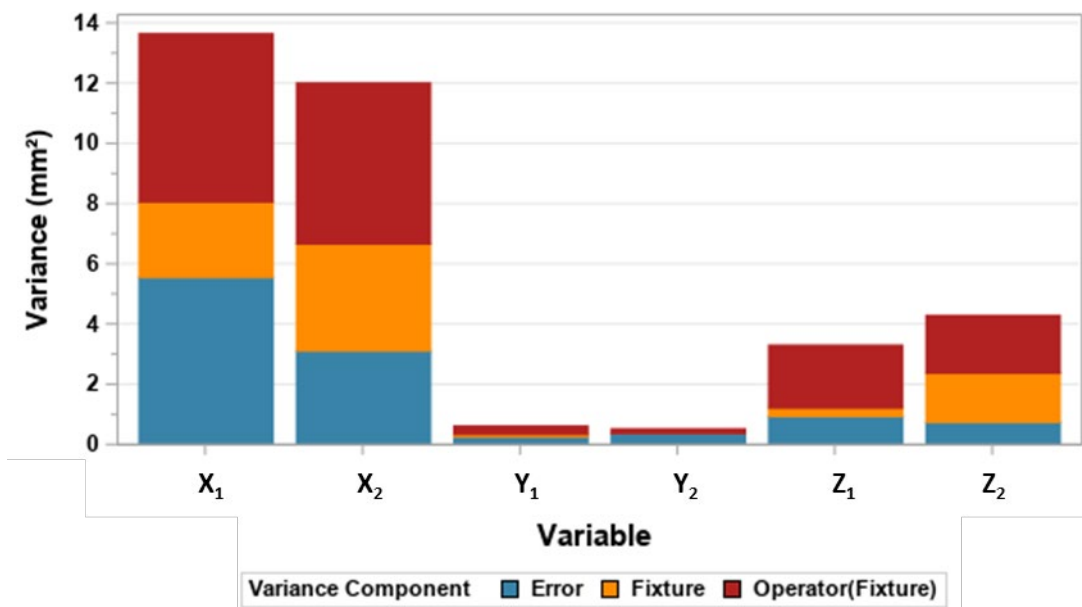


Figure 82. ACH Medium with PVS-14 Stowed: breakdown of each factor indicating the contribution to total variance (mm²) for each CM variable.

3.7.3 ACH Medium with PVS-14 Stowed MOI Measurements

The MOI measurements from the ACH medium with PVS-14 Stowed are presented in this section. Table 36 provides the MOI means, SD, variance and CV for all seven DEVCOM SC and USAARL Operators. The standard deviations are consistent across the MOIs and coefficients of variation range from 3.7 to 7.0%. The scatterplots of the MOI measures (Figure 83 and Figure 84) show that Operators 6 and 7 are consistent with each other for each MOI measurement and for Iyz and Ixy are almost completely out of range of the other Operators. For Iyy, the USAARL Operators only overlap Operator 5 data and no other DEVCOM SC Operators. For Izz, Operator 2 has a measurement that is significantly out of range of all other measurements. When the data were reviewed, an error in the measurement process or calculation could not be identified and therefore the measurement was kept. However, it is likely that there was an error with the actual measurement that has not been identified.

The proportion of variance for each MOI measure is provide in Table 37 and plotted in Figure 85. Fixture seems to play a larger role in variability for PVS-14 Stowed than the other pieces of equipment—a result of the separation of data of the USAARL Operators from the DEVCOM SC Operators for Iyy, Iyz and Ixy. The Operator 2 Izz potential outlier is the driver for Repeatability as the largest contributing factor of

this variable. The MOI measurements for all Operators were included in these results and the degree to which these outcomes were affected by the cradle fixture translation is not known.

Table 36. ACH medium with PVS-14 stowed MOI Mean, SD, Variance and CV for the seven Operators.

	lzz (n= 77)	lxx (n= 77)	lyy (n= 77)	lyz (n= 76)	lxz (n= 77)	lxy (n= 77)
Mean (kg-m ²)	0.02195	0.01770	0.02741	0.02387	0.01098	0.02177
SD (kg-m ²)	0.00154	0.00105	0.00102	0.00109	0.00049	0.00150
Variance (kg-m ²) ²	2.37E-06	1.11E-06	1.03E-06	1.20E-06	2.38E-07	2.25E-06
CV %	7.0	6.0	3.7	4.6	4.4	6.9

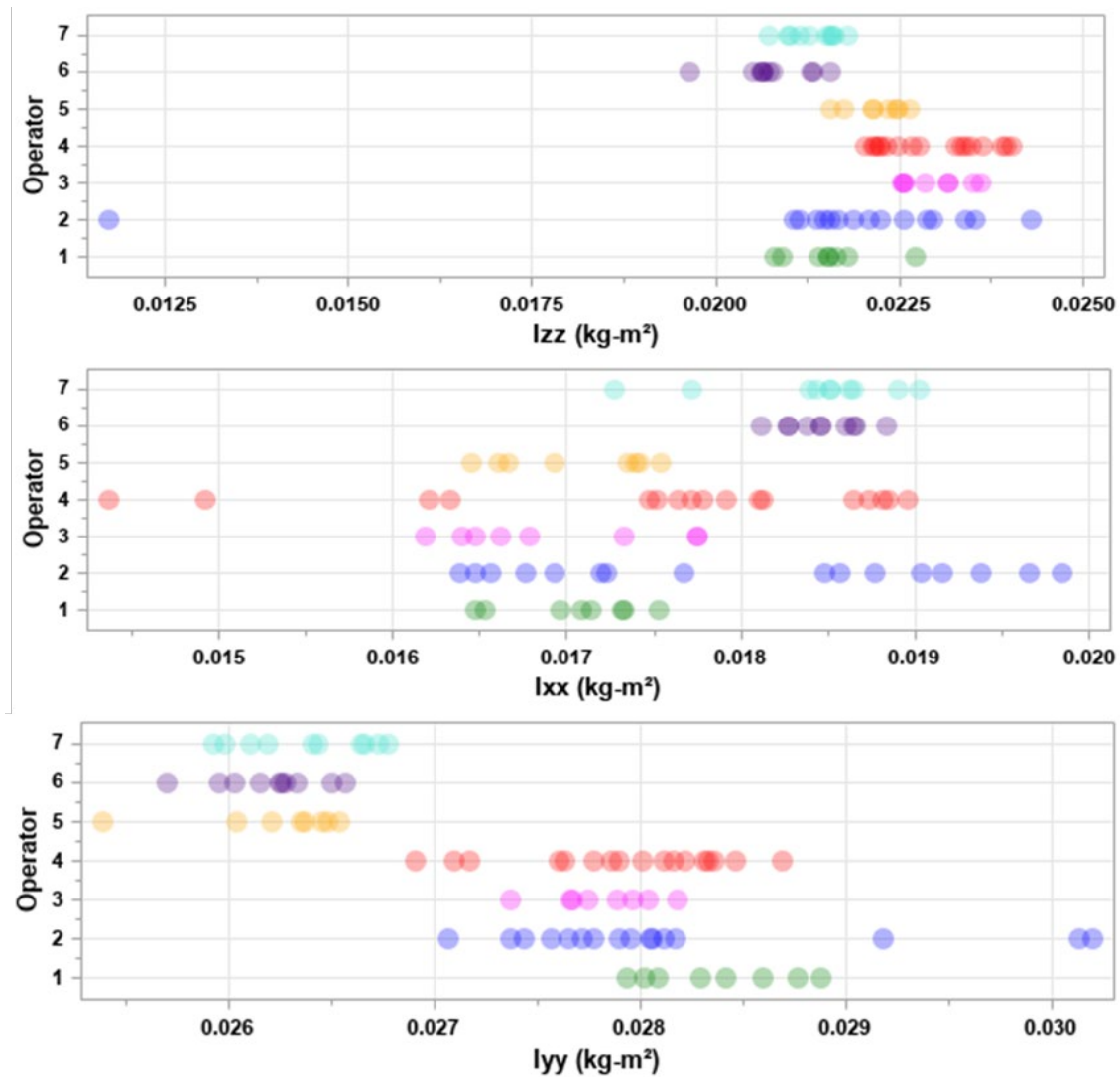


Figure 83. ACH medium with PVS-14 stowed basic MOI lzz, lxx and lyy scatter plots of data for all seven Operators.

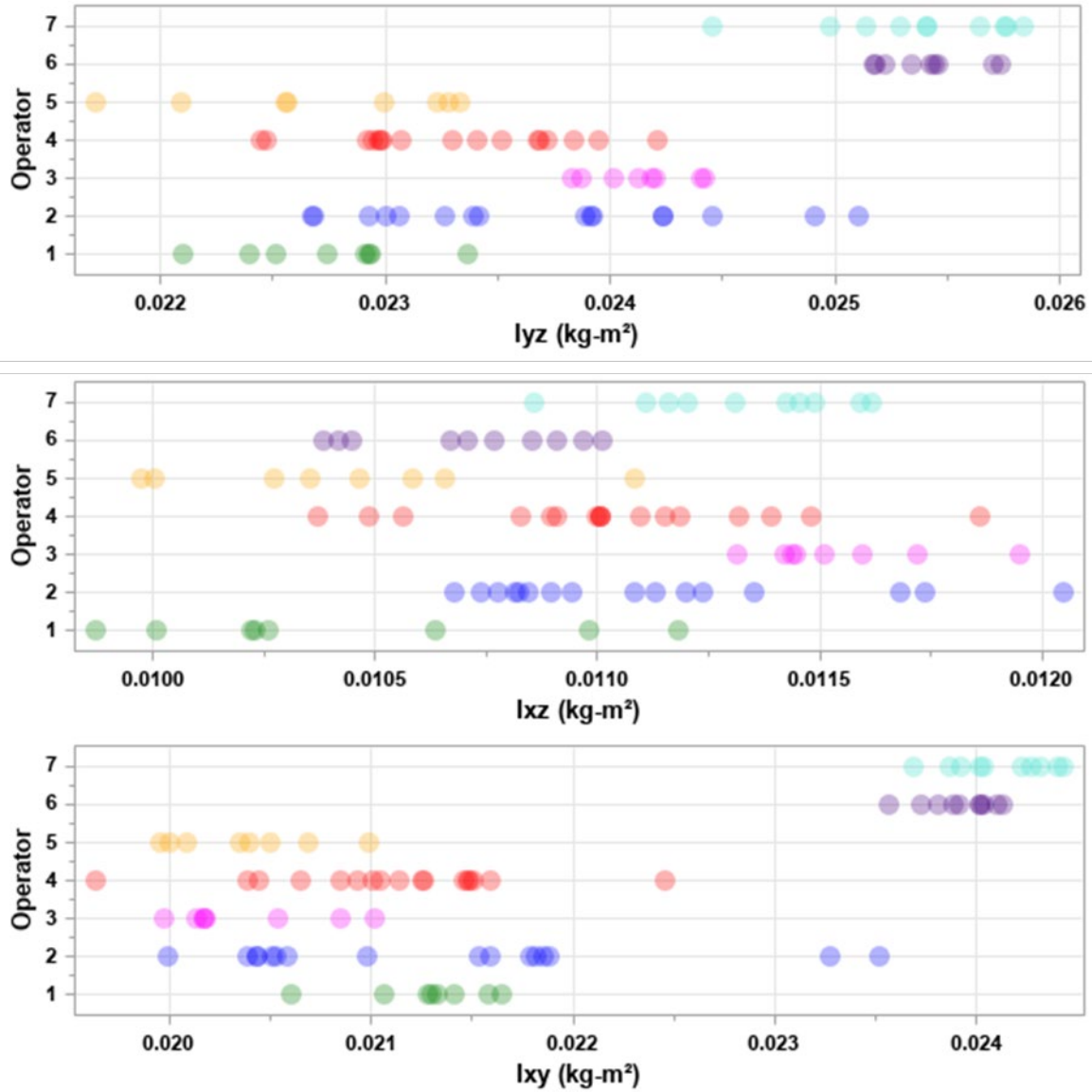


Figure 84. ACH medium with PVS-14 stowed MOI for lyz, lxz, and lxy scatter plots of data for all seven Operators.

Table 37. ACH medium with PVS-14 stowed breakdown of each MOI measure lzz, lxx, lyy, lyz, lxz, and lxy proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the MOI Outcomes					
	lzz (n= 77)	lxx (n= 77)	lyy (n= 77)	lyz (n= 76)	lxz (n= 77)	lxy (n= 77)
Fixture	0.2117	0.3485	0.4879	0.7926	0	0.904
Operator(Fixture)	0.0947	0.0709	0.3323	0.1021	0.5937	0.0268
Error (Repeatability)	0.6935	0.5806	0.1798	0.1053	0.4063	0.0691

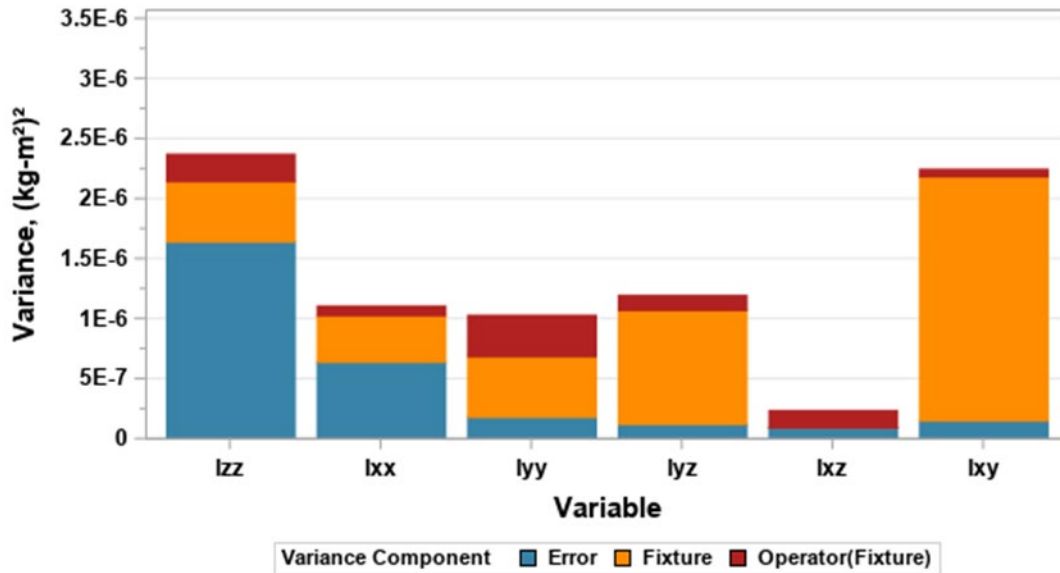


Figure 85. ACH Medium with PVS-14 Stowed MOI Measurement: breakdown of each factor identifying the contribution to total variance for each MOI variable.

3.8 ACH Medium with PVS-14 Deployed

3.8.1 ACH Medium with PVS-14 Deployed Headform Alignment

Figure 86 is the ACH with PVS-14 in the deployed position mounted to the headform. In the figure, the four helmet system points: +Y and –Y PVS-14 Deployed and the +Y and –Y ACH helmet along with one headform point at the FLM are identified. These points were used in evaluating the alignment of the ACH and PVS-14 Deployed to the headform. The resultant lengths for each of the four points on the helmet system measured pre-mass properties tests, along with the differences between the +Y and –Y ACH and NVD-Deployed lengths and the pre- and post-mass properties tests, were calculated and are presented in Table 38. In addition, the pre-mass properties measurement X, Y and Z point differences between the FLM to the ACH –Y and PVS-14 Deployed –Y are provided.

In Figure 87 to Figure 89 the X, Y and Z point positions of the ACH M –Y location are plotted. The X point data show a difference in positioning of the DEVCOM SC Operators versus the USAARL Operators. However, for the Y point data, the Operators overlapped, indicating consistency for the helmet mount from side to side.

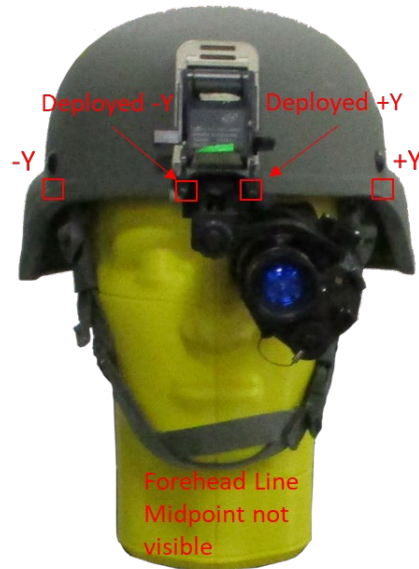


Figure 86. ACH medium with PVS-14 deployed. The red squares identify the ACH +Y and -Y points, the PVS-14 Deployed +Y and -Y points, and the forehead midpoint locations. The length between the forehead midpoint and each of the four helmet points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 38. The minimum and maximum, mean, SD, variance and CV for the lengths measured from the forehead midpoint to the four ACH with PVS-14 deployed helmet points. Data are provided for the X, Y and Z points as well as lengths measured prior to taking the CM and MOI measurements (pre) and then for the difference of the pre and post CM and MOI measurements for all four lengths.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to ACHM +Y	Length	Pre	113	120	116	1.3	1.7	1
FLM to ACHM -Y	Length	Pre	109	115	111	1.3	1.7	1
FLM to ACHM +Y vs -Y	Length	Pre Difference	1	9	5	1.9	3.8	
X: FLM to ACHM -Y	Point	Pre	-57	-52	-54	1.3	1.7	2
Y: FLM to ACHM -Y	Point	Pre	-97	-93	-95	0.7	0.5	1
Z: FLM to ACHM -Y	Point	Pre	15	28	20	2.6	6.7	13
FLM to ACHM +Y	Length	Pre/Post Difference	-4.0	1.1	-1.0	1.2	1.4	
FLM to ACHM -Y	Length	Pre/Post Difference	-1.6	3.4	0.7	1.0	1.0	
FLM to PVS-14 Deployed +Y	Length	Pre	119	129	124	2.7	7.5	2
FLM to PVS-14 Deployed -Y	Length	Pre	118	130	124	2.9	8.2	2
FLM to PVS-14 Deployed +Y vs -Y	Length	Pre Difference	-1	2	0	0.5	0.3	
X: FLM to PVS-14 Deployed -Y	Point	Pre	112	120	116	2.3	5.5	2
Y: FLM to PVS-14 Deployed -Y	Point	Pre	-28	-15	-21	2.1	4.5	10
Z: FLM to PVS-14 Deployed -Y	Point	Pre	27	60	38	6.9	47.7	18
FLM to PVS-14 Deployed +Y	Length	Pre/Post Difference	-1.2	4.8	0.5	1.4	2.1	
FLM to PVS-14 Deployed -Y	Length	Pre/Post Difference	-1.1	6.9	0.8	2.1	4.3	

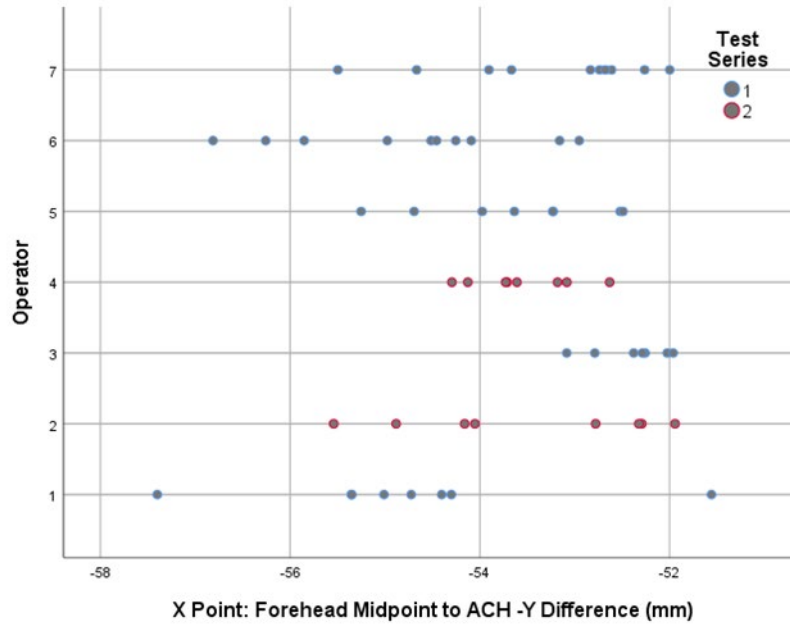


Figure 87. Scatterplot of the difference along the X-axis of the FLM to the ACH M -Y pre-test.

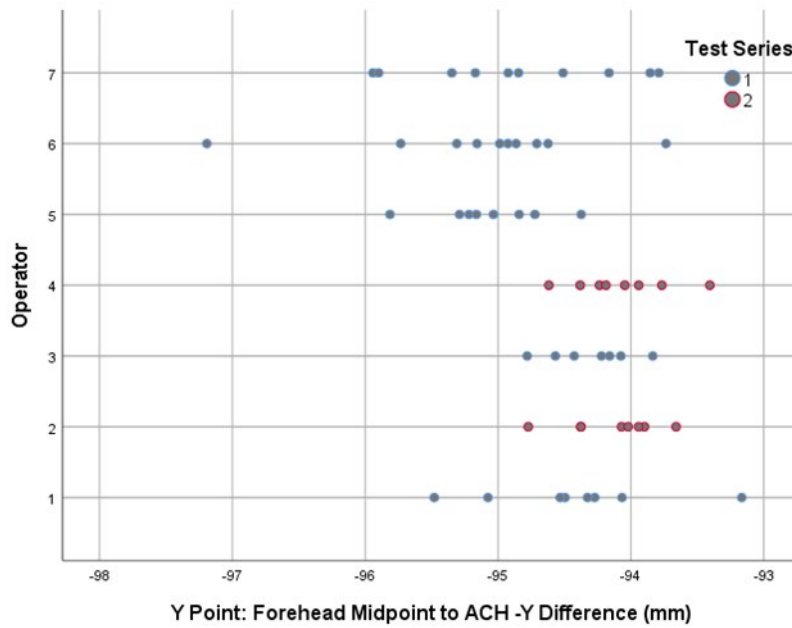


Figure 88. Scatterplot of the difference along the Y-axis of the FLM to the ACH M -Y pre-test.

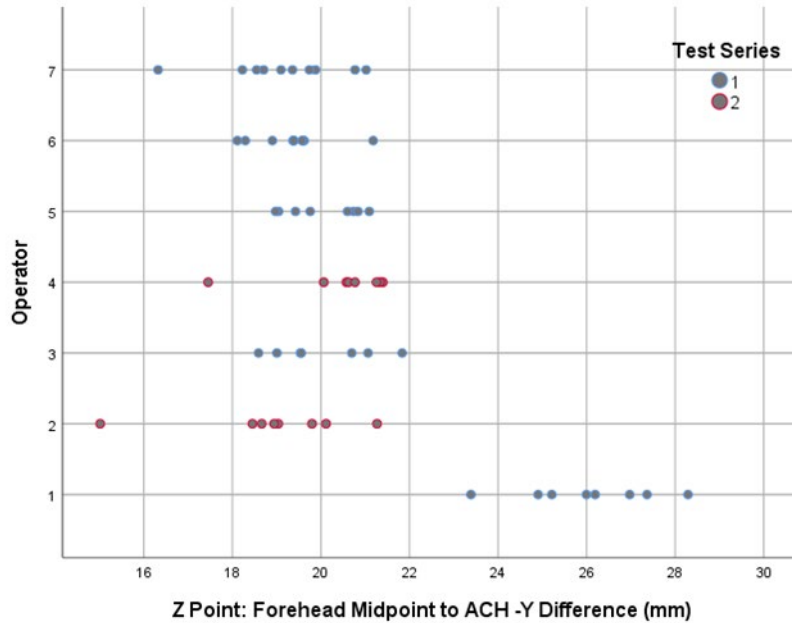


Figure 89. Scatterplot of the difference along the Z-axis of the FLM to the ACH M -Y pre-test.

The resultant mean lengths for the forehead midpoint and the PVS-14 +Y and -Y Deployed are both 124 mm with similar minimum and maximum data ranges. Looking at the difference in length for the PVS-14 +Y and -Y Deployed the differences were small and ranged from -1 to 2 mm. This indicates that the PVS-14 was consistently positioned by each Operator. The consistency of the PVS-14 in the deployed position is also reflected in the point data. The X, Y and Z point data for the PVS-14 -Y location are plotted in Figure 90 to Figure 92. The X and Y data are consistent for all Operators with ranges of 4 mm and 6 mm respectively. The Z point data range of 22 mm is larger, which is mostly driven by Operators 1, 2 and 5 measurements. The pre- vs post-mass properties difference in length of the PVS-14 Deployed +Y is plotted in Figure 89. Except for Operator 5, all differences were centered about 0. Operator 5 had a mean difference of 4.2 mm.



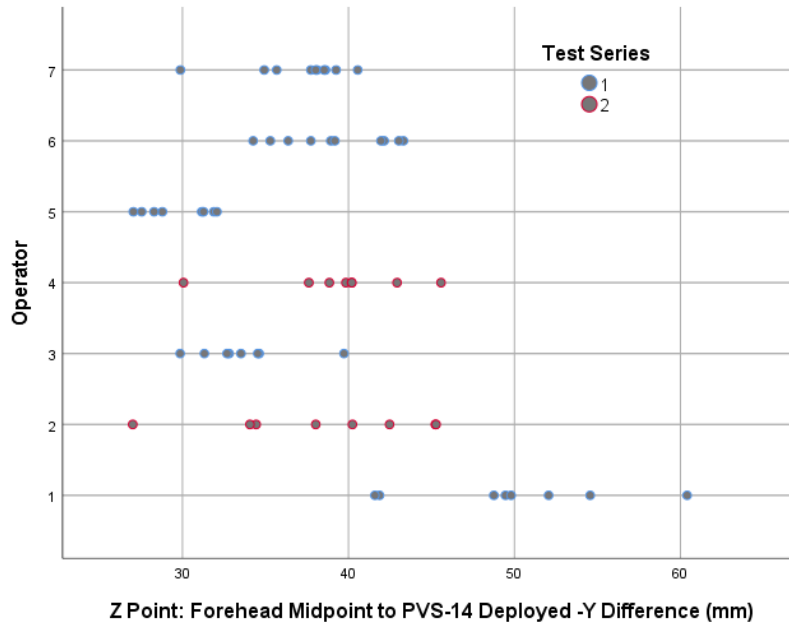


Figure 92. Scatterplot of the difference along the Z-axis of the FLM to the PVS-14 Deployed -Y pre-test.

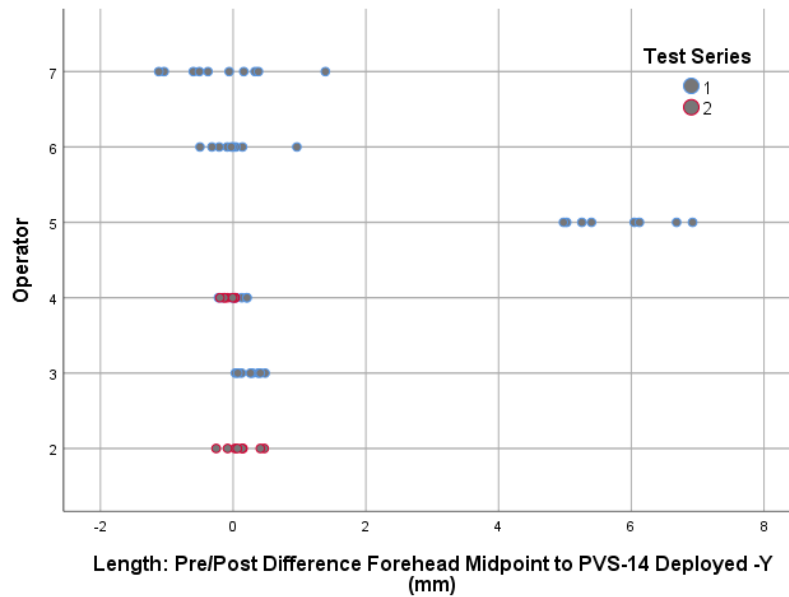


Figure 93. Scatterplot of the difference in length measured between the FLM and the ACH medium PVS-14 Deployed -Y point, pre vs post mass property measurements. The second series of tests conducted by Operators 2 and 4 are outlined in red.

3.8.2 ACH Medium with PVS-14 Deployed CM Measurements

The CM measurements from the ACH medium with PVS-14 Deployed are presented in this section. Table 39 provides the CM mean, SD, variance and CV for all seven Operators for X_1 , Z_1 and Z_2 and also includes the additional tests performed by Operators 2 and 4. The CM results for X_2 , Y_1 and Y_2 include measurements from Operator 2-4, 6 and 7 as data from Operators 1 and 5 were removed because they were performed prior to the modification of the fixture to resolve the Y-axis translation that occurred. The ACH medium with PVS-14 Deployed CM measurements were consistent with small standard deviations, variances and all CVs less than 9%. The scatterplots in Figure 94 to Figure 96 provide a visual

display of the individual measurements of the Operators for each CM variable. For the X_1 and X_2 CM measurements, all Operators align except Operator 1 who is skewed towards lower CM measurements. For Y_1 measurements, Operators 2-4 are slightly skewed towards higher CM values with respect to USAARL Operators 6 and 7, but for Y_2 they are skewed slightly towards lower measurements. Operator 6 has one CM measurement along the Y-axis that is out of range of all data outcomes; it is unknown what caused this, but it is observed in both Y_1 and the Y_2 measurement so it is likely a result of helmet system placement or movement during the test. The Z_1 and Z_2 measurements are consistent among Operators. DEVCOM SC Operators 2 and 4 align with USAARL Operators 6 and 7 while Operators 1, 3 and 5 skew slightly higher. The mean X_1 and X_2 CM measurements for Operator 2 are about 2 mm greater in the second test series. In Figure 96, the data for Operator 2 are outlined with green for the first test series and red for the second test series. The high consistency in these CM measurements within and between Operators versus the outcomes from the PVS-14 Stowed configuration is potentially due to the alignment of the eye piece with the protective fold to the headform.

A summary of the proportion of variance for each CM variable is provided in Table 40 and Figure 97. Either Operator or Repeatability were the most significant contributors to variation for all variables except Y_1 where USAARL Operator data did not overlap with most of the DEVCOM SC measurements increasing the variation due to Fixture.

Table 39. ACH medium with PVS-14 Deployed CM measurement means, SD, variance and CV for each X, Y and Z variable for all operators. *Some measurements were excluded from the analysis due to the fixture y-translation.

	X_1 (n= 76)	X_2 *(n= 44)	Y_1 *(n= 44)	Y_2 *(n= 44)	Z_1 (n= 76)	Z_2 (n= 76)
Mean (mm)	34.9	36.2	7.2	6.6	71.7	71.8
SD (mm)	1.1	0.7	0.6	0.6	1.9	1.9
Variance (mm ²)	1.1	0.5	0.4	0.3	3.7	3.5
CV (%)	3	2	8	9	3	3

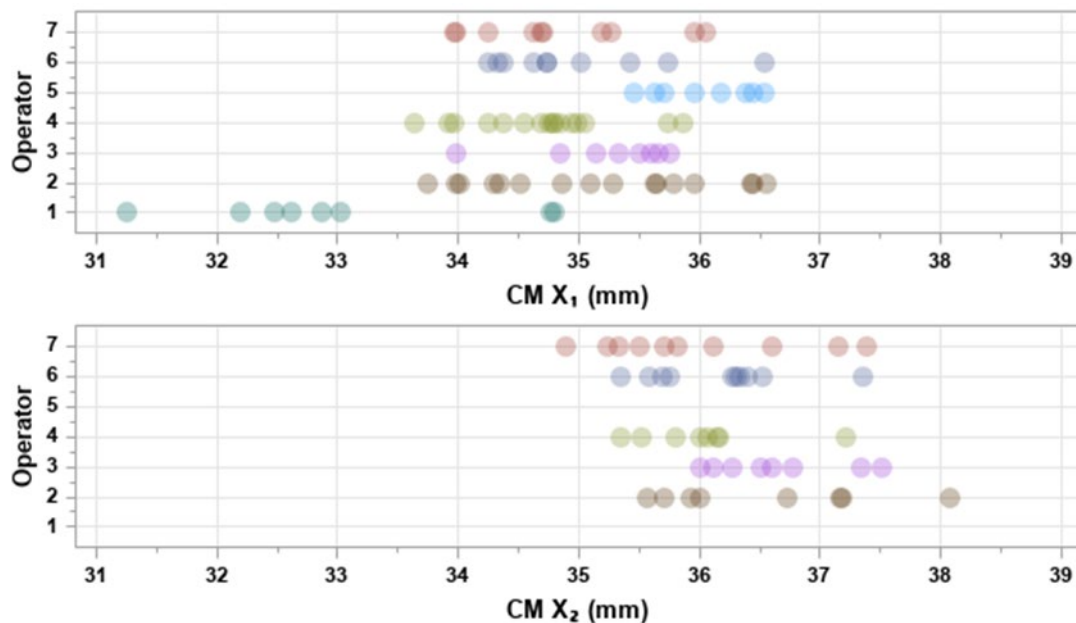


Figure 94. ACH medium with PVS-14 Deployed X_1 and X_2 center of mass measurements for all tests included in the analysis for each operator.

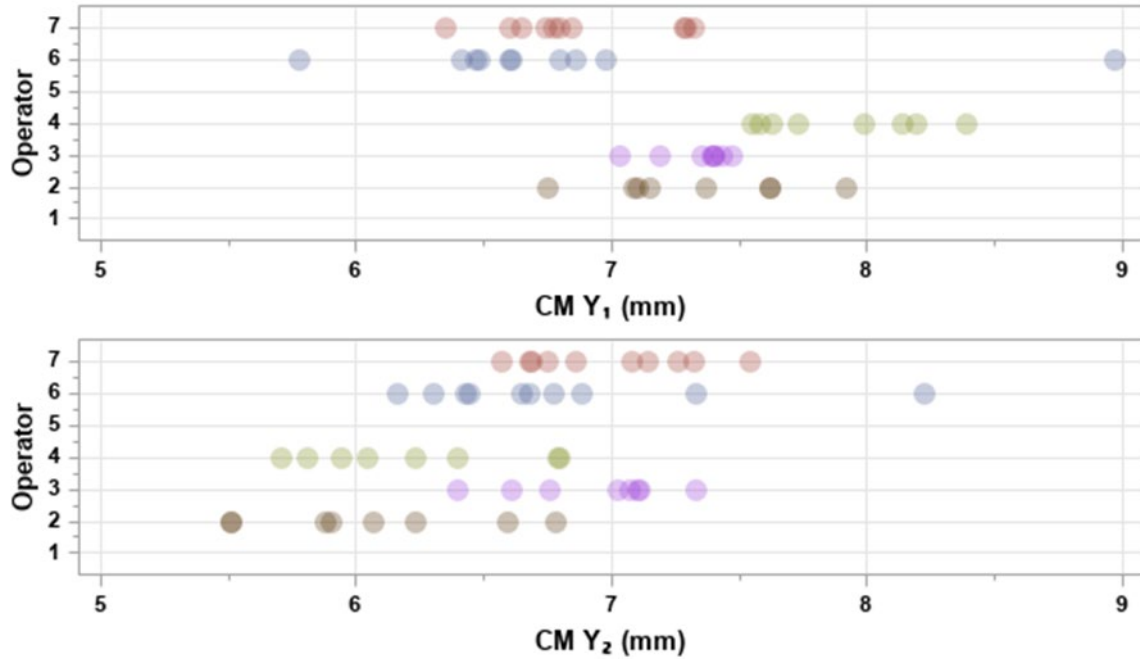


Figure 95. ACH medium with PVS-14 Deployed Y_1 and Y_2 center of mass measurements for all tests included in the analysis for each operator.

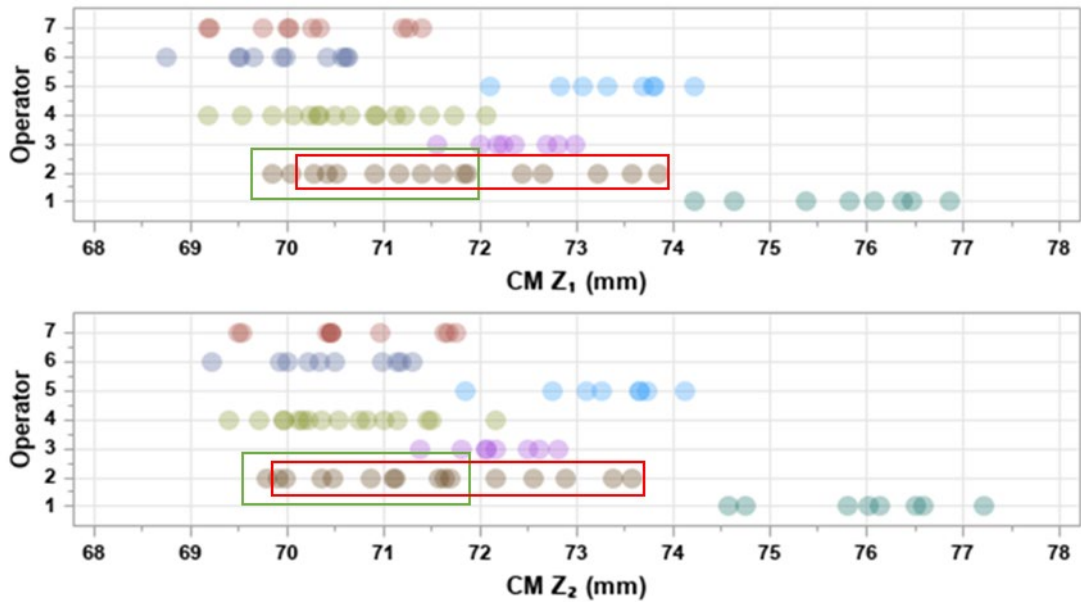


Figure 96. ACH medium with PVS-14 Deployed Z_1 and Z_2 center of mass measurements for all tests included in the analysis for each operator. The green box outlines the first test series conducted by Operator 2 and the red box is the second test series.

Table 40. ACH medium with PVS-14 Deployed breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CM Outcomes					
	X ₁ (n= 76)	X ₂ * (n= 44)	Y ₁ * (n= 44)	Y ₂ * (n= 44)	Z ₁ (n= 76)	Z ₂ (n= 76)
Fixture	0	0.0557	0.4331	0.1556	0.3865	0.1921
Operator(Fixture)	0.5519	0.0249	0.0864	0.3271	0.4867	0.6622
Error (Repeatability)	0.4481	0.9194	0.4805	0.5173	0.1268	0.1457

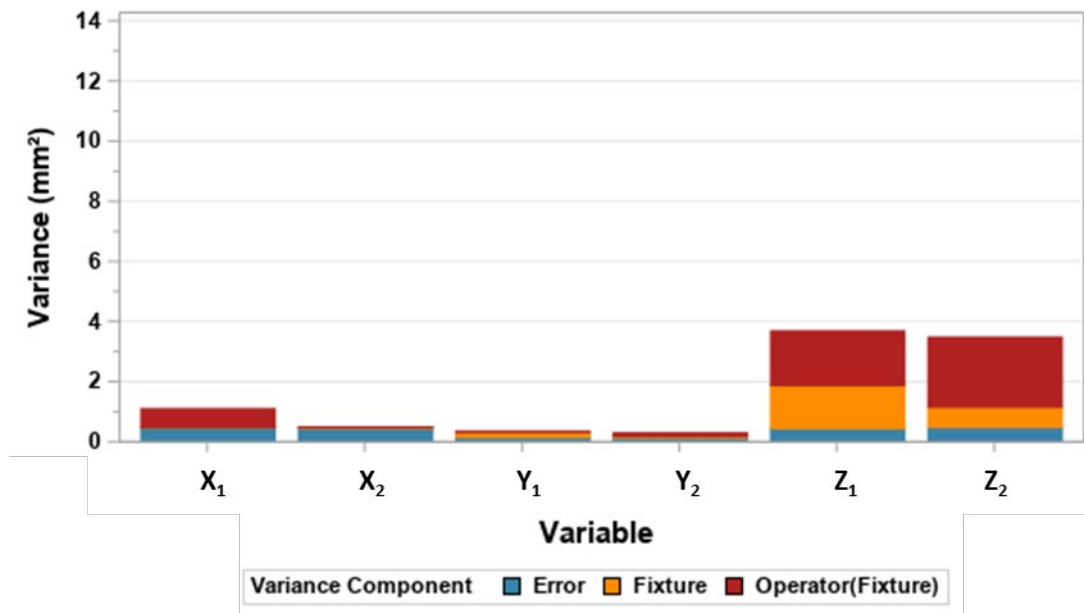


Figure 97. ACH medium with PVS-14 Deployed: breakdown of each factor indicating the contribution to total variance (mm²) for each CM variable for the helmet system.

3.8.3 ACH Medium with PVS-14 Deployed MOI Measurements

The MOI measurements from the ACH medium with PVS-14 Stowed are presented in this section. Table 41 provides the MOI means, SD, variance and CV for all seven DEVCOM SC and USAARL operators. The standard deviations are consistent across the MOIs except lxy because the USAARL Operators 6 and 7 measurements are significantly higher than Operators 1-5. The scatterplots of the MOI measures (Figure 98 and Figure 99) show that Operators 6 and 7 are consistent with each other for each MOI measurement and overlap other Operators except for lxy. The proportion of variance for each MOI measure is provided in Table 42 and plotted in Figure 100. Fixture is the largest contributor to variance for lyz and lxy as the USAARL Operators measurements are shifted lower and higher respectively. For all other MOI measurements the contributions to variance are split between Operator and Repeatability. The MOI measurements for all Operators were included in these results and the degree to which these outcomes were affected by the cradle fixture translation is not known.

Table 41. ACH medium with PVS-14 Deployed MOI Mean, SD, Variance and CV for the seven Operators.

	lzz (n= 76)	lxx (n= 76)	lyy (n= 76)	lyz (n= 76)	lxz (n= 76)	lxy (n= 76)
Mean (kg-m ²)	0.02581	0.01146	0.02526	0.02571	0.01973	0.01760
SD (kg-m ²)	0.00065	0.00074	0.00074	0.00089	0.00052	0.00180
Variance (kg-m ²) ²	4.25E-07	5.40E-07	5.49E-07	7.85E-07	2.72E-07	3.24E-06
CV %	2.5	6.4	2.9	3.4	2.6	10.2

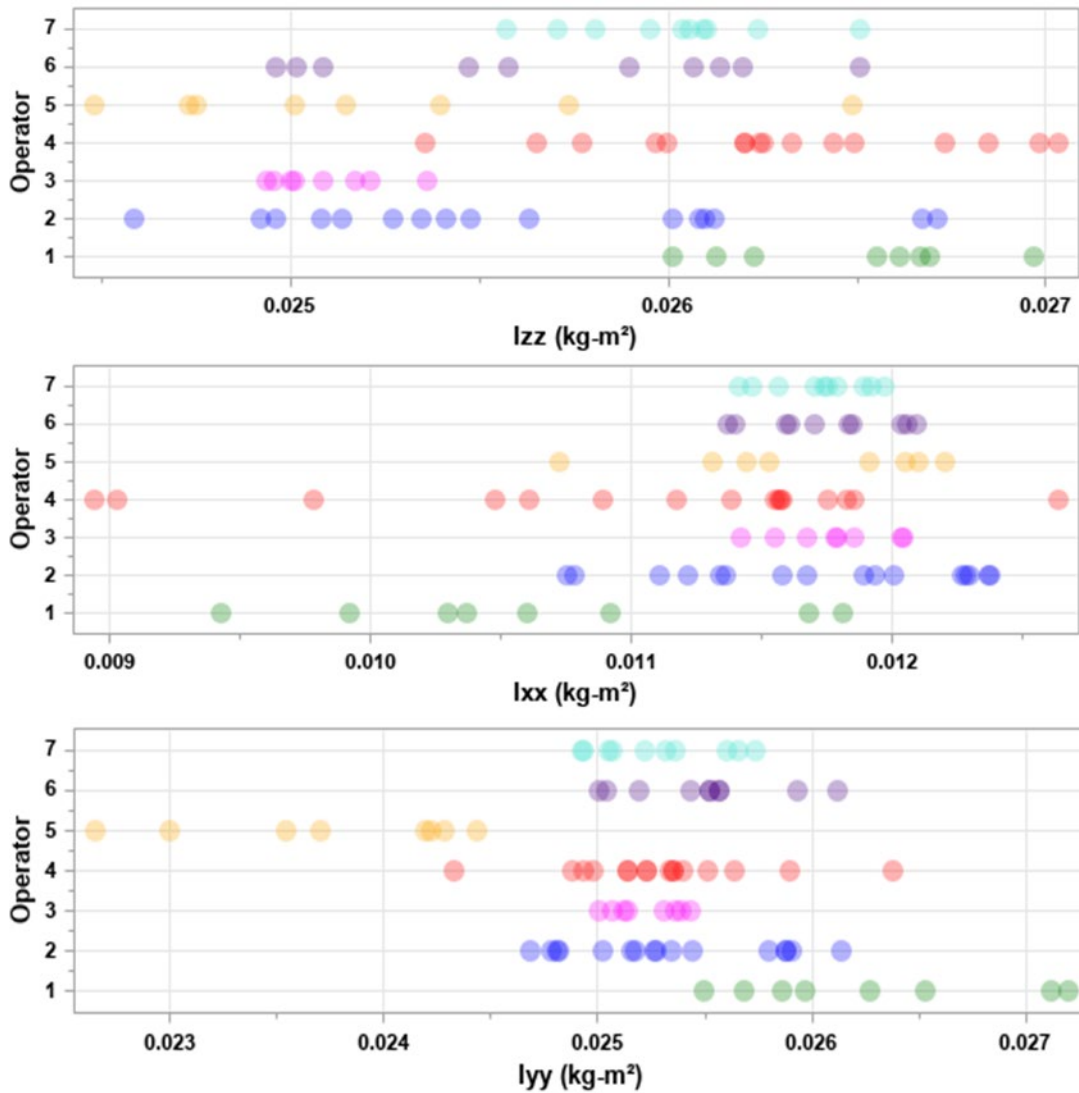


Figure 98. ACH medium with PVS-14 Deployed basic MOI lzz, lxx and lyy scatter plots of data for all seven Operators.

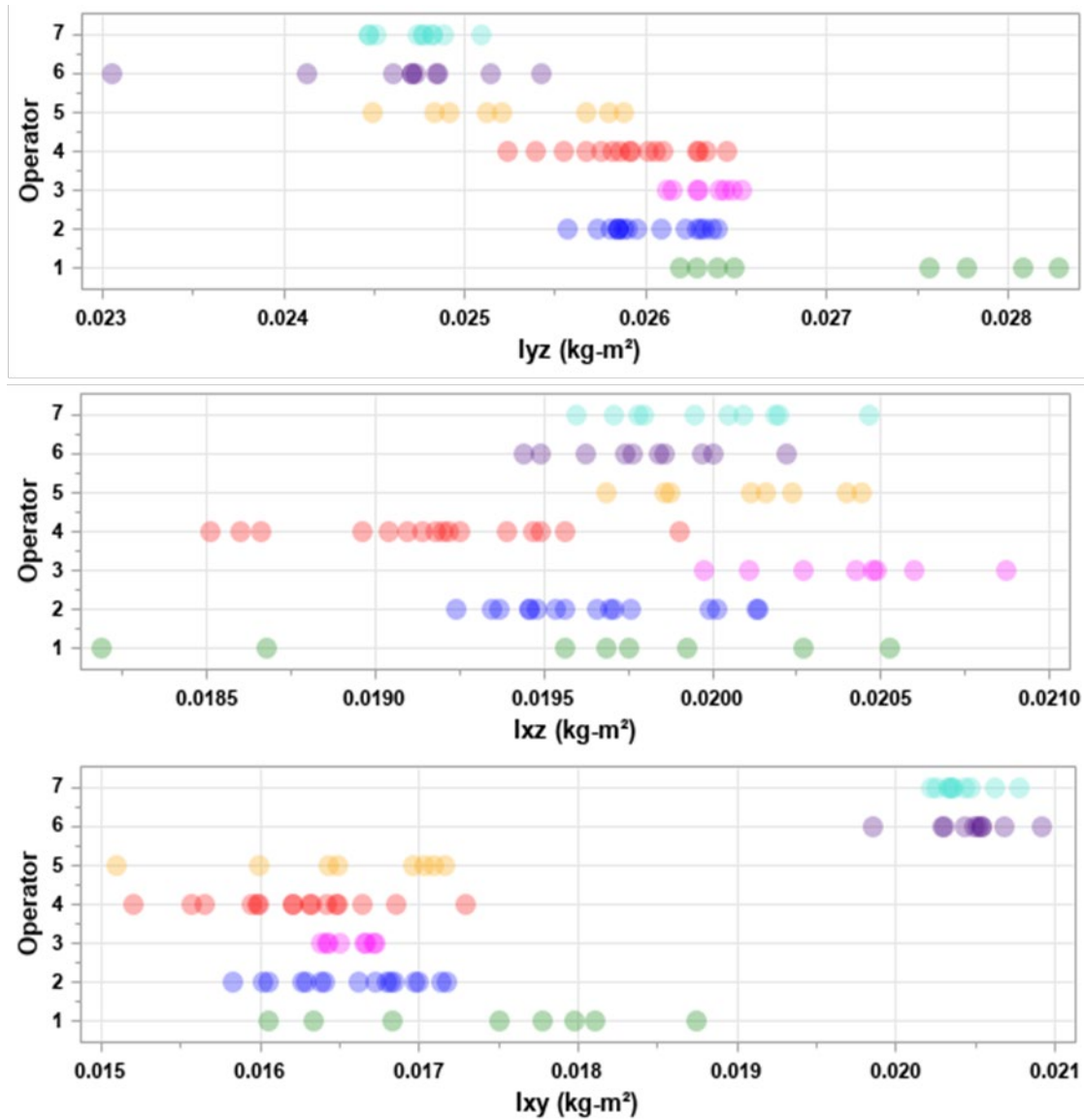


Figure 99. ACH medium with PVS-14 Deployed MOI for lyz, lxx, and lxy scatter plots of data for all seven Operators.

Table 42. ACH medium with PVS-14 Deployed helmet system breakdown of each MOI measure lxx, lxx, lyy, lyz, lxx, and lxy proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the MOI Outcomes					
	lxx (n= 76)	lxx (n= 76)	lyy (n= 76)	lyz (n= 76)	lxx (n= 76)	lxy (n= 76)
Fixture	0	0.0061	0	0.6224	0	0.9494
Operator(Fixture)	0.502	0.2676	0.7159	0.238	0.5097	0.0174
Error (Repeatability)	0.498	0.7263	0.2841	0.1395	0.4903	0.0332

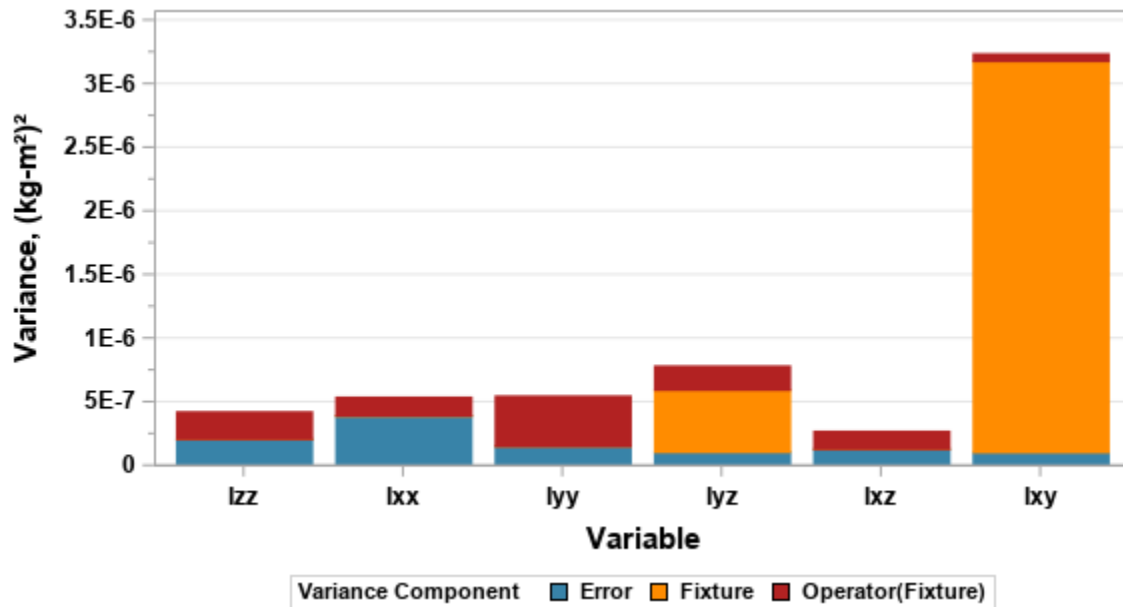


Figure 100. ACH Medium with PVS-14 Deployed: Breakdown of each factor identifying the contribution to total variance for each MOI variable.

3.9 HGU-56/P

3.9.1 HGU-56/P Headform Alignment

Figure 101 is the HGU-56/P mounted to the headform and depicts the two points: NVD mount top right hole on the helmet and the FLM, used in evaluating the alignment of the helmet to the headform. The X, Y and Z points and the resultant length between the FLM and the NVD_{MH} measured pre-mass properties tests and the difference between the pre- and post-mass properties tests were calculated and are provided in this section (Table 43). In Figure 102 to Figure 104, scatterplots of the X, Y and Z points for the NVD mount top right hole, relative to the FLM, pre-mass properties tests are presented. In viewing the X and Z data, Operator 1 and 5 are on the outer bounds of the min and max ranges. Operator 1 mounted the brim of the helmet higher and more posterior on the headform than Operator 5. Operator 1 has the largest mean length at 78.5 mm and Operator 5 has the lowest mean length of 69.5 mm. All Operators overlapped in alignment along the Y-axis. The difference in length from the FLM to NVD_{MH} pre- and post-mass property tests (Figure 105) reveal no differences were greater than .4 mm.



Figure 101. HGU-56/P aviator helmet with red squares that identify the helmet +Y and –Y points, the NVD top right mount hole point, and the forehead midpoint locations. The length between the forehead midpoint and each of the three helmet points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 43. The minimum and maximum, mean, SD, variance and CV for the X, Y and Z points and length measured from the forehead midpoint to the NVD top right mount hole on the HGU-56/P helmet. Data are provided for the measurements prior to taking the CM and MOI measurements (pre) and then for the difference in length of the pre and post CM and MOI measurements.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to NVD _{MH} Top Right	Length	Pre	67	82	74	3.1	9.4	4
X: FLM to NVD _{MH} Top Right	Point	Pre	29	47	37	4.4	19.7	12
Y: FLM to NVD _{MH} Top Right	Point	Pre	8	16	12	1.7	2.9	14
Z: FLM to NVD _{MH} Top Right	Point	Pre	52	76	63	5.3	27.8	8
FLM to NVD Mount Top Right	Length	Pre/Post Difference	-0.2	0.4	0.1	0.1	0.0	



Figure 102. Scatterplot of the difference along the X-axis of the FLM to the HGU-56/P NVD mount top right hole pre-test.



Figure 103. Scatterplot of the difference along the Y-axis of the FLM to the HGU-56/P NVD mount top right hole pre-test.

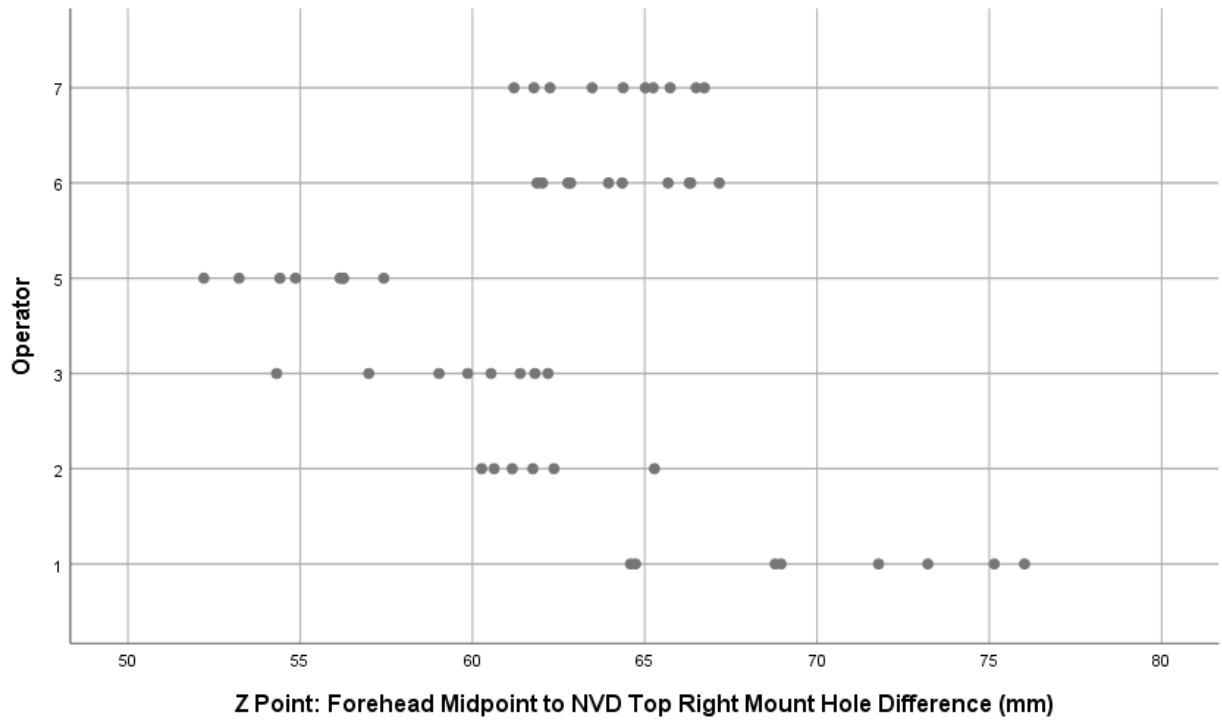


Figure 104. Scatterplot of the difference along the Z-axis of the FLM to the HGU-56/P NVD mount top right hole pre-test.

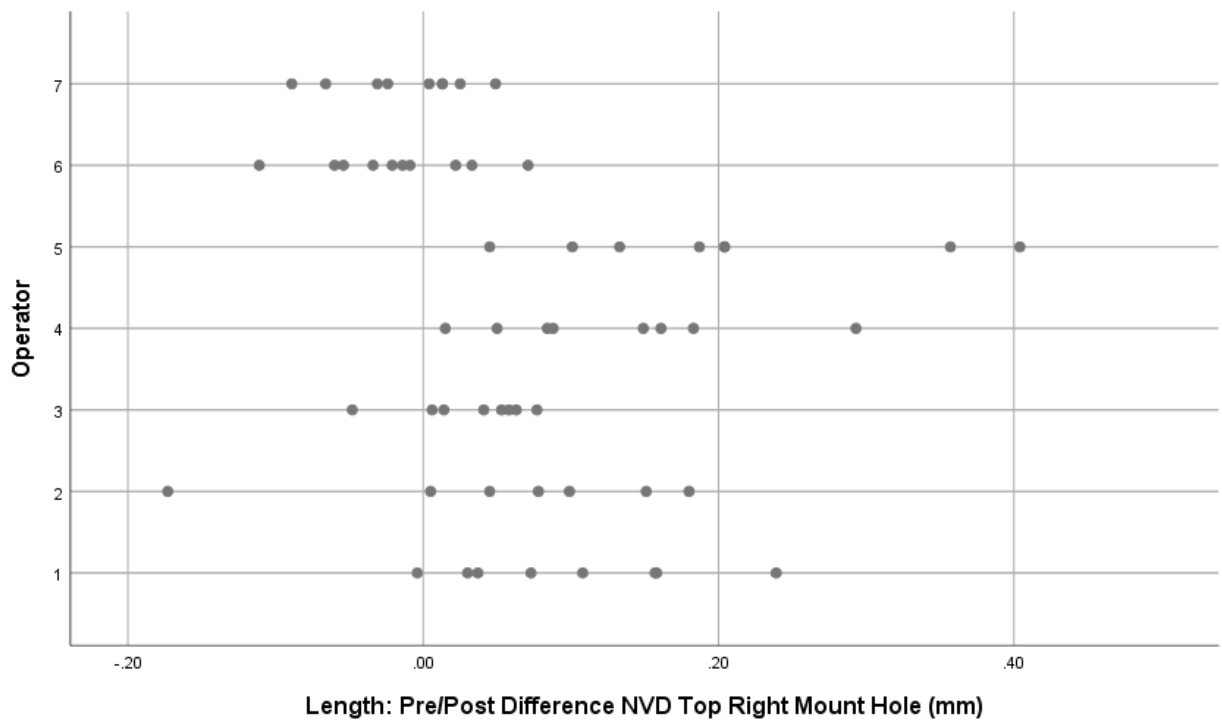


Figure 105. Scatterplot of the difference in length measured between the FLM and the HGU-56/P NVD Mount Top Right hole point, pre vs post mass property measurements for each Operator.

3.9.2 HGU-56/P CM Measurements

The CM measurements from the HGU-56/P helmet are presented in this section. Table 44 provides the CM mean, SD, variance and CV for all seven Operators for X_1 , Z_1 and Z_2 . The CM results for X_2 , Y_1 and Y_2 only include measurements from Operator 3, 6 and 7 as these Operators conducted testing post-fix of the loose bolt that caused the cradle to translate along the Y-axis. The scatterplots in Figure 106 to Figure 108 provide a visual display of the individual measurements of the Operators for each CM variable. For the X_1 CM variable, Operator 2 is significantly out of range of all other Operators and is a driving factor for the large variance (9.1 mm^2) and CV (65%) observed for X_1 . In analyzing the HGU-56/P and headform alignment measurements in Section 3.9.1, none of the measurements are good indicators for the Operator 2 results. It is possible that the positioning of the ear cups for the communication system is a contributor to the variance, but it's also possible that there was an error with the tare used by Operator 2. USAARL Operators 6 and 7 are again consistent within each CM variable. For the Z_1 and Z_2 CM variables, Operators 1-3 and 6 and 7 are closely aligned; however, Operator 4 skews towards lower CM values and Operator 5 has a higher range of CM values.

A summary of the proportion of variance for each CM variable is provided in Table 45 and Figure 109. The proportions of variance differ across the CM variables and are likely impacted by the number of Operator measurements included. The X_1 , Z_1 and Z_2 CM includes measurements from all seven Operators and has the largest proportion of variance due to Operator; while the Operators are self-consistent, they vary from each other. This indicates that helmet and equipment fitting procedures are a critical factor in the outcomes of the measurements and is an area where improvement to the guidelines should reduce Operator variability. For X_2 , Y_1 and Y_2 , Fixture is a significant contributor to the variance since the DEVCOM SC and USAARL Operators do not overlap much and for Y_1 , there is no overlap. However, the standard deviations for these measures are also small and consistent with those reported for other helmet systems measured within this study. For Y_2 , because Operators 3 and 7 have CM measurements within the same range of each other, the proportions of variance are split between Fixture and repeatability.

Table 44. HGU-56/P CM measurement means, SD, variance and CV for each X, Y and Z variable for all Operators. *Some measurements were excluded from the analysis due to the fixture y-translation.

	X_1 (n= 60)	X_2 *(n= 28)	Y_1 *(n= 28)	Y_2 *(n= 28)	Z_1 (n= 60)	Z_2 (n= 60)
Mean (mm)	4.6	4.7	5.7	4.8	43.3	43.4
SD (mm)	3.0	1.3	0.5	0.9	1.8	1.8
Variance (mm^2)	9.1	1.8	0.2	0.8	3.3	3.2
CV (%)	65	29	9	18	4	4

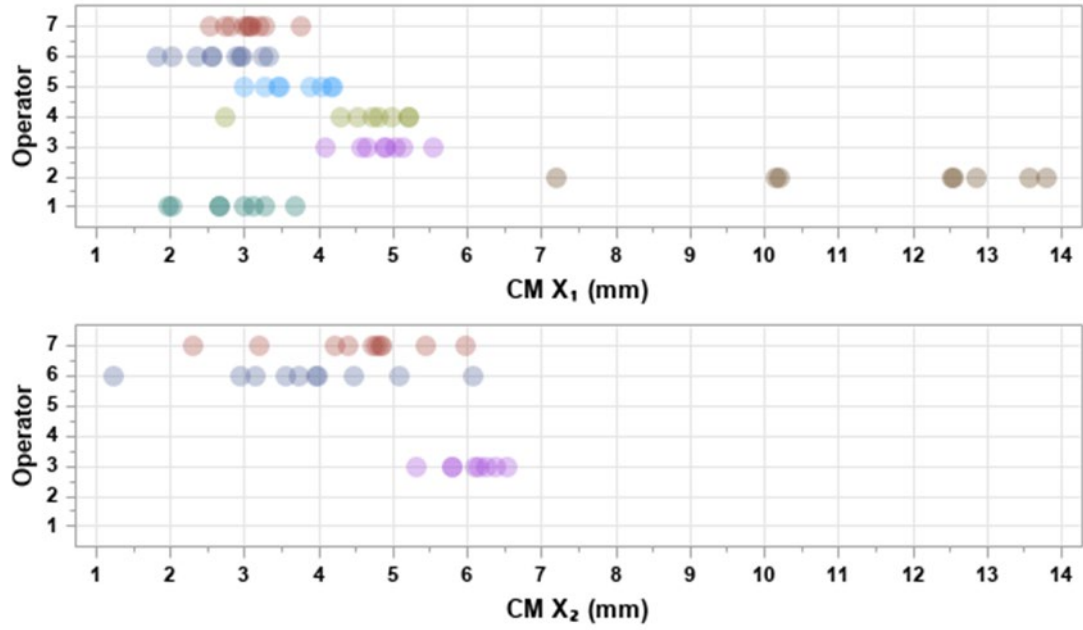


Figure 106. HGU-56/P medium X_1 and X_2 center of mass measurements for all tests included in the analysis for each Operator.

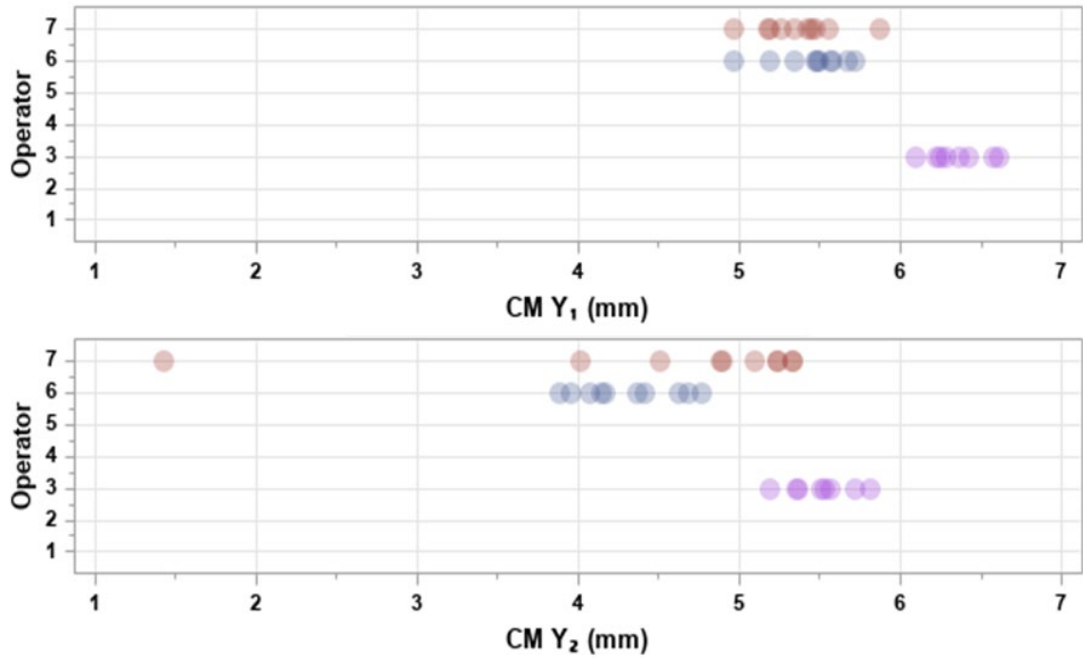


Figure 107. HGU-56/P medium Y_1 and Y_2 center of mass measurements for all tests included in the analysis for each Operator.

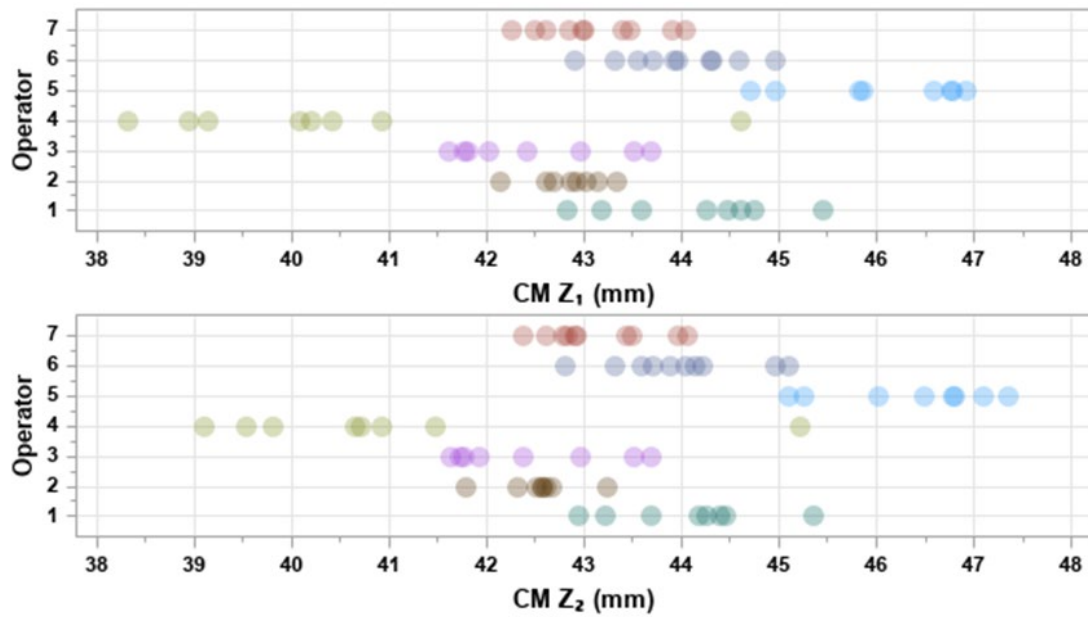


Figure 108. HGU-56/P medium Z_1 and Z_2 center of mass measurements for all tests included in the analysis for each Operator.

Table 45. HGU-56/P breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CM Outcomes					
	X_1 (n= 60)	X_2^* (n= 28)	Y_1^* (n= 28)	Y_2^* (n= 28)	Z_1 (n= 60)	Z_2 (n= 60)
Fixture	0.004	0.5855	0.9001	0.4794	0	0
Operator(Fixture)	0.9106	0.0389	0	0	0.7624	0.7552
Error (Repeatability)	0.0855	0.3756	0.0999	0.5206	0.2376	0.2448

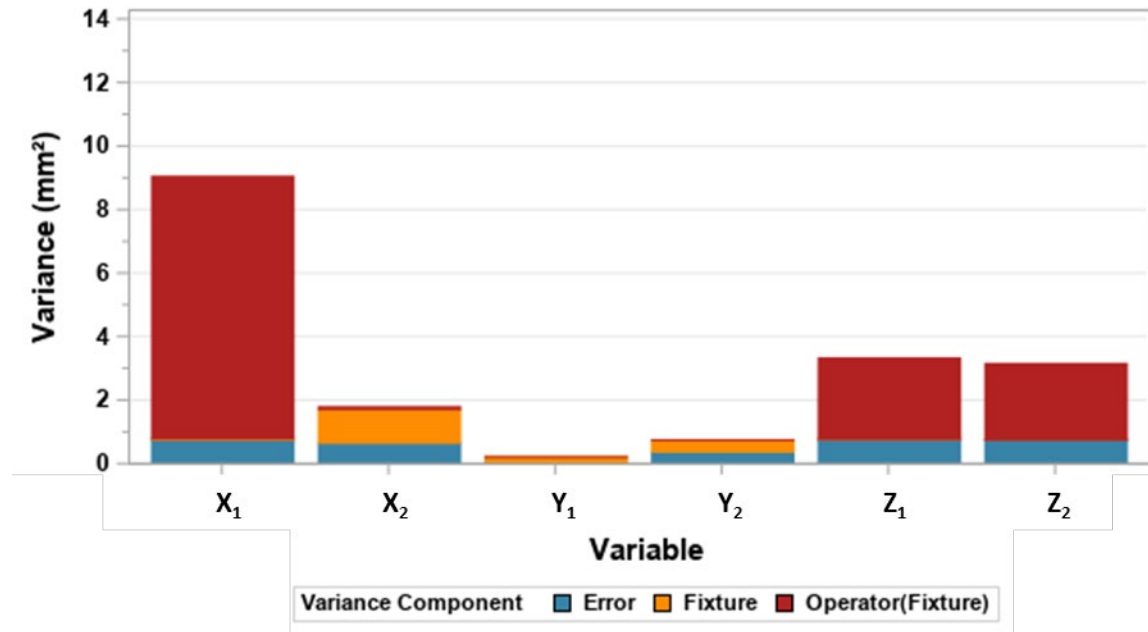


Figure 109. HGU-56/P breakdown of each CM X, Y, and Z measure proportion of variability by factor.

3.9.3 HGU-56/P MOI Measurements

The MOI measurements from the ACH medium with M-50 JSJPM are presented in this section. Table 46 provides the MOI means, SD, variance and CV for all seven DEVCOM SC and USAARL operators. The SDs are consistent across the MOIs and coefficients of variation range from 3.3 to 6.4%. The scatterplots of the MOI measures (Figure 110 and Figure 111) show that Operators 6 and 7 are consistent with each other for each MOI measurement. The overlap for DEVCOM SC Operators varies based on the MOI measurement. The proportion of variance for each MOI measure is provided in Table 47 and plotted in Figure 112. USAARL Operators overlap for all MOI measurements except Iyz, leading to this variable being the only one to exhibit any proportion of variance due to Fixture. Most of the variation for these MOI measurements is due to Operator with repeatability being an important contribution to variance for Izz, Ixx, Iyy and Ixz. The MOI measurements for all Operators were included in these results and the degree to which these outcomes were affected by the cradle fixture translation is not known.

Table 46. HGU-56/P MOI Mean, SD, Variance and CV for the seven Operators.

	Izz (n= 60)	Ixx (n= 60)	Iyy (n= 60)	Iyz (n= 60)	Ixz (n= 60)	Ixy (n= 60)
Mean (kg-m ²)	0.01619	0.01624	0.01442	0.01571	0.01487	0.01545
SD (kg-m ²)	0.00063	0.00084	0.00073	0.00101	0.00050	0.00091
Variance (kg-m ²) ²	4.00E-07	7.02E-07	5.31E-07	1.02E-06	2.48E-07	8.32E-07
CV %	3.9	5.2	5.1	6.4	3.3	5.9

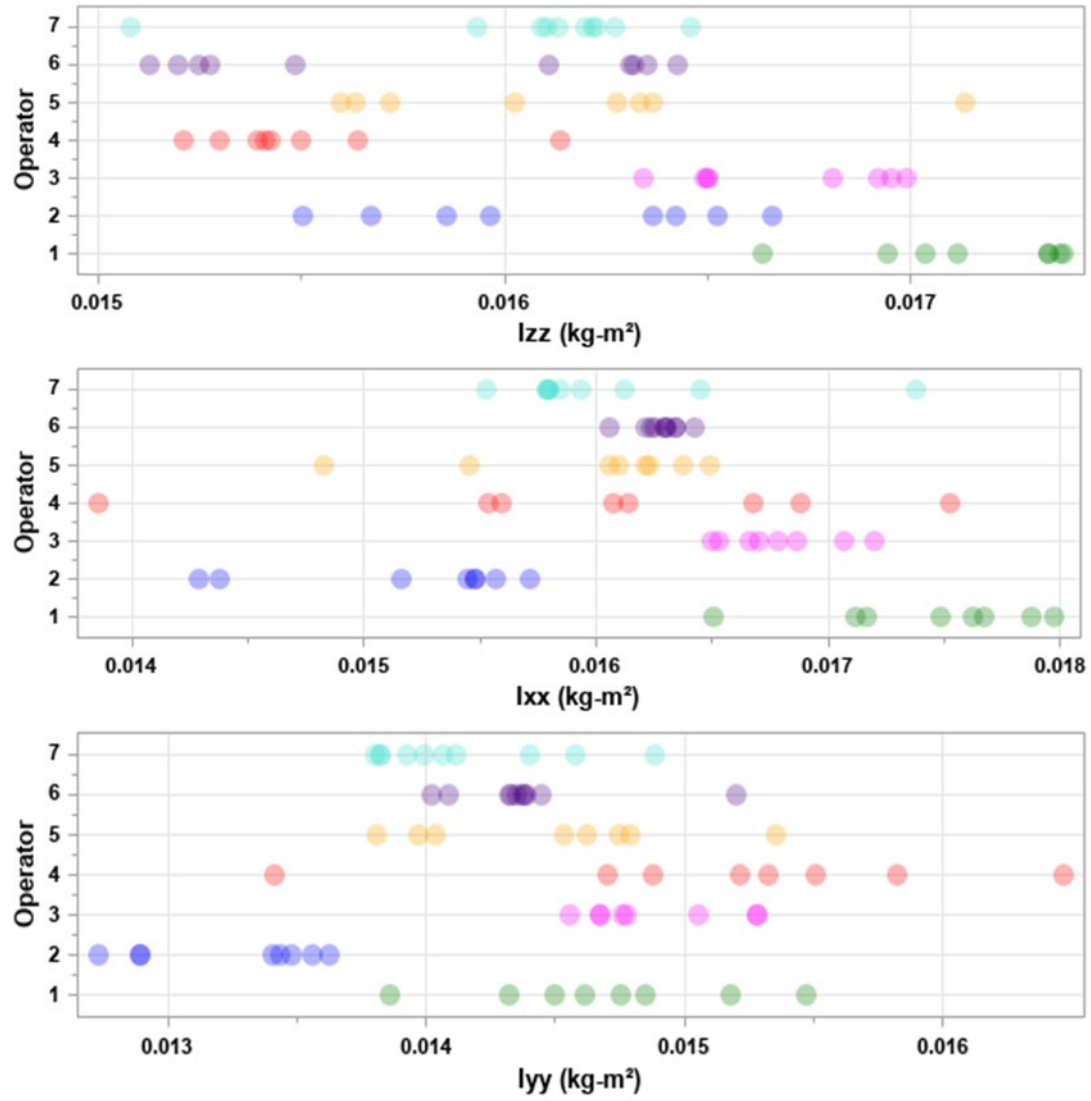


Figure 110. HGU-56/P basic MOI I_{zz} , I_{xx} and I_{yy} scatter plots of data for all seven Operators.

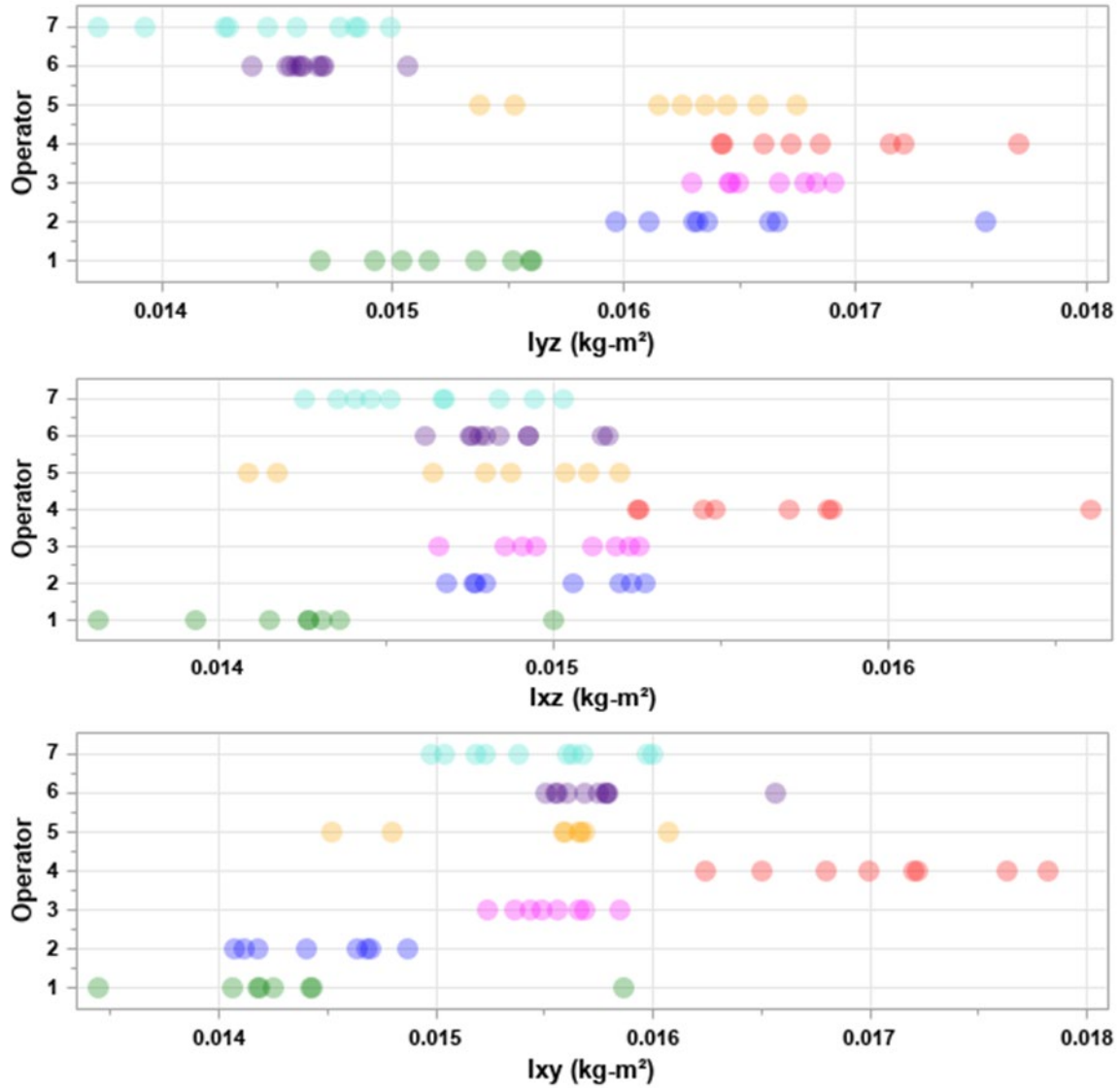


Figure 111. HGU-56/P MOI for lyz, lxz, and lxy scatter plots of data for all seven Operators.

Table 47. HGU-56/P breakdown of each MOI measure lzz, lxx, lyy, lyz, lxz, and lxy proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the MOI Outcomes					
	lzz (n= 60)	lxx (n= 60)	lyy (n= 60)	lyz (n= 60)	lxz (n= 60)	lxy (n= 60)
Fixture	0	0	0	0.7509	0	0
Operator(Fixture)	0.6314	0.5779	0.5921	0.1692	0.6463	0.8043
Error (Repeatability)	0.3686	0.4221	0.4079	0.0799	0.3537	0.1957

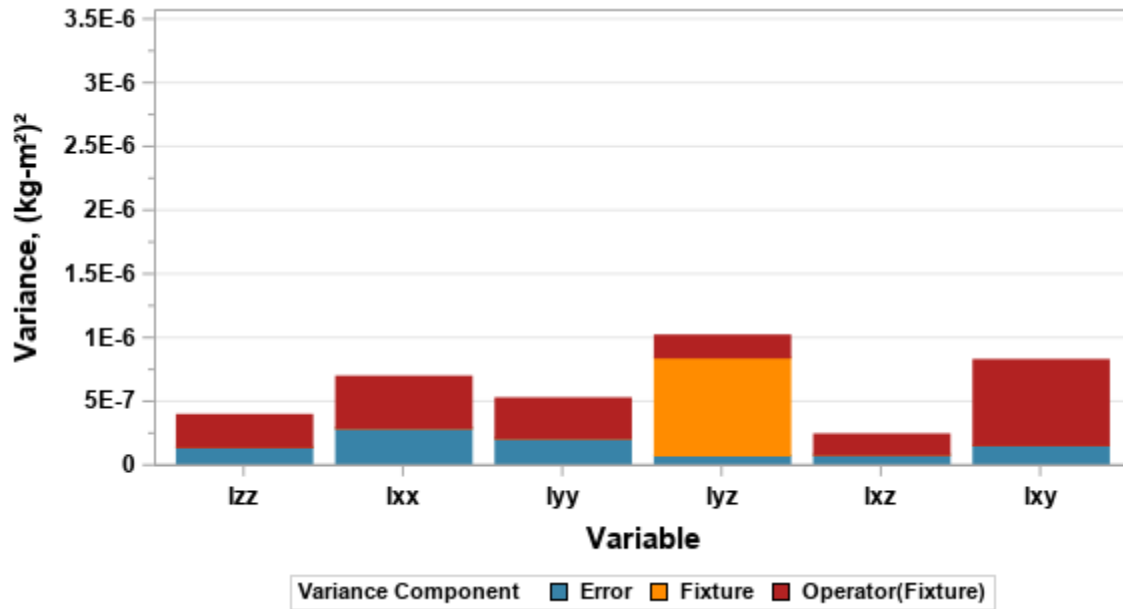


Figure 112. HGU-56/P MOI Measurements: breakdown of each factor identifying the contribution to total variance for each MOI variable.

3.10 ACH with M-50 JSGPM

3.10.1 ACH with M-50 JSGPM Headform Alignment

Figure 113 is the ACH medium with the M-50 JSGPM mounted to the headform and depicts the four points: +Y and -Y M-50 JSGPM mask points, NVD_{MH} on the ACH and the FLM used in evaluating the alignment of the equipment items to the headform. The resultant length between the FLM and each of the three points on the helmet measured pre-mass properties tests and the difference between the pre- and post-mass properties tests were calculated and are presented in this section (Table 48). In addition, the pre-mass properties measurement X, Y and Z point differences between the FLM to the NVD_{MH} and M50 +Y location are provided.

In Figure 114 to Figure 116, the X, Y and Z points for the ACH NVD_{MH} are plotted. For the X and Y measurements, Operators 4 and 5 do not overlap. For the Z measurements, Operators 5-7 do not overlap with Operators 1, 3-4. Overall, the min to max values for the point measurements range from 10-13 mm. For the length from the FLM to NVD_{MH} for pre-mass properties tests, Operators 5-7 average length measurements range from 64 to 66 mm while Operators 1, 3 and 4 are all 70 mm. The difference in length from the FLM to NVD_{MH} pre- and post-mass property tests (Figure 117) follows a similar pattern as the pre-test lengths where Operators 1, 3 and 4 had the largest shift (up to 4 mm) and are clustered together as are Operators 5-7. In Figure 118 to Figure 120, the X, Y and Z point measurements for the M-50 +Y location are plotted. A similar trend to the NVD_{MH} measurements was observed where Operator 1, 3 and 4 data aligned separately from Operator 5-7.



Figure 113. ACH medium with M-50 JSGPM mask with red squares that identify the M-50 JSGPM mask +Y and –Y points, the ACH NVD mount hole point, and the forehead midpoint locations. The length between the forehead midpoint and each of the three helmet points was calculated for each helmet mount pre- and post-mass properties measurements.

Table 48. The minimum and maximum, mean, SD, variance and CV for the lengths measured from the forehead midpoint to the two M-50 +Y and –Y points and the ACH NVD mount hole point. Data are provided for the X, Y and Z points as well as the lengths measured prior to taking the CM and MOI measurements (pre) and then for the difference of the pre and post CM and MOI measurements for all three lengths.

Measurement	Measure	Type	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Variance (mm ²)	CV%
FLM to NVD _{MH}	Length	Pre	61	73	67	3.1	9.8	5
X: FLM to NVD _{MH}	Point	Pre	2	13	9	2.2	4.8	24
Y: FLM to NVD _{MH}	Point	Pre	-4	6	0.4	2.0	3.8	444
Z: FLM to NVD _{MH}	Point	Pre	60	73	67	3.3	11.2	5
FLM to NVD _{MH}	Length	Pre/Post Difference	-0.6	4.0	1.8	0.9	0.8	
FLM to M-50 -Y	Length	Pre	47	54	49	1.5	2.3	3
FLM to M-50 +Y	Length	Pre	47	51	49	1.3	1.6	3
X: FLM to M-50 +Y	Point	Pre	19	34	24	3.5	12.1	15
Y: FLM to M-50 +Y	Point	Pre	33	42	39	2.1	4.5	5
Z: FLM to M-50 +Y	Point	Pre	6	23	16	4.4	19.3	27
FLM to M-50 +Y	Length	Pre/Post Difference	-3.2	1.9	-0.2	0.8	0.6	
FLM to M-50 -Y	Length	Pre/Post Difference	-2.4	1.5	0.0	0.6	0.4	

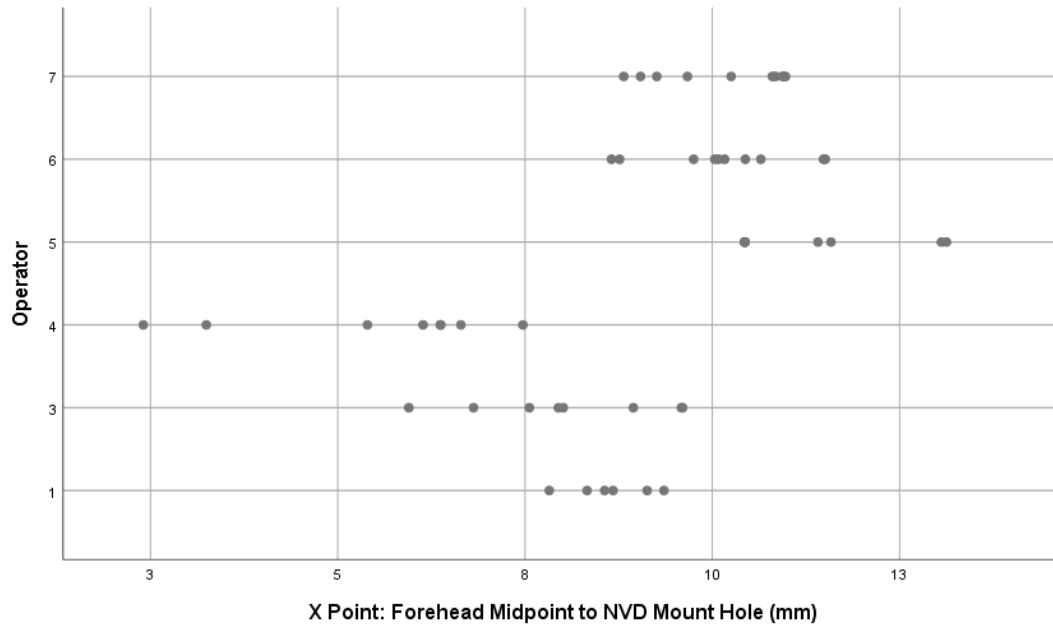


Figure 114. Scatterplot of the difference along the X-axis of the FLM to the ACH NVD mount hole pre-test. Operator 2 data were not available.

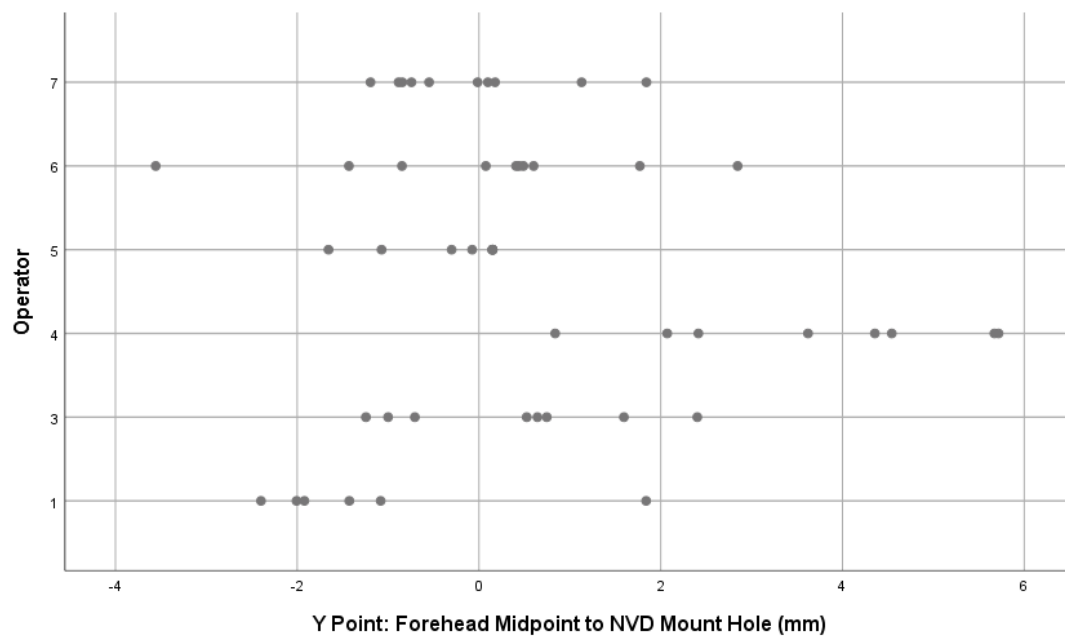


Figure 115. Scatterplot of the difference along the Y-axis of the FLM to the ACH NVD mount hole pre-test. Operator 2 data were not available.

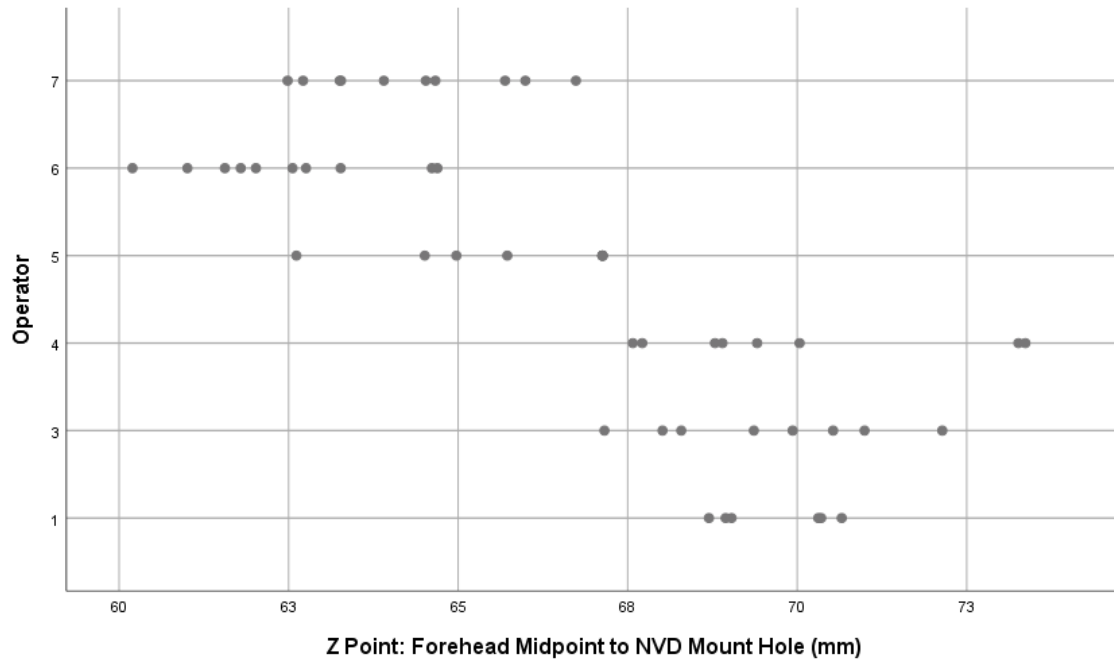


Figure 116. Scatterplot of the difference along the Z-axis of the FLM to the ACH NVD mount hole pre-test. Operator 2 data were not available.

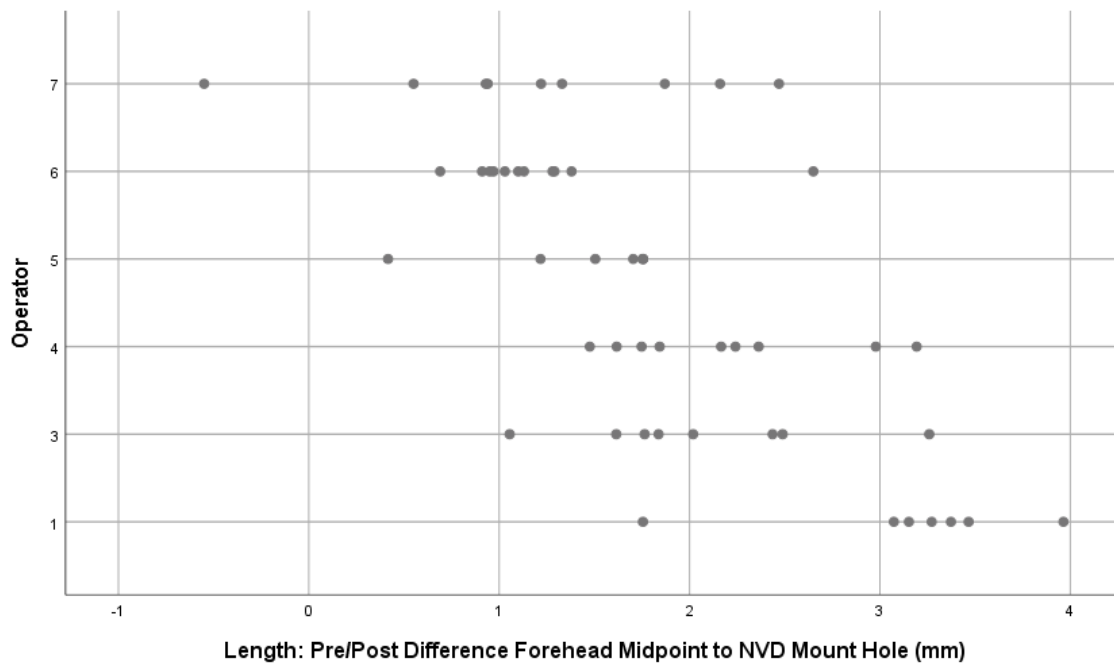


Figure 117. Scatterplot of the difference in length measured between the FLM and the ACH NVD mount hole point, pre vs post mass property measurements for each Operator. Operator 2 data were not properly recorded and are not included.

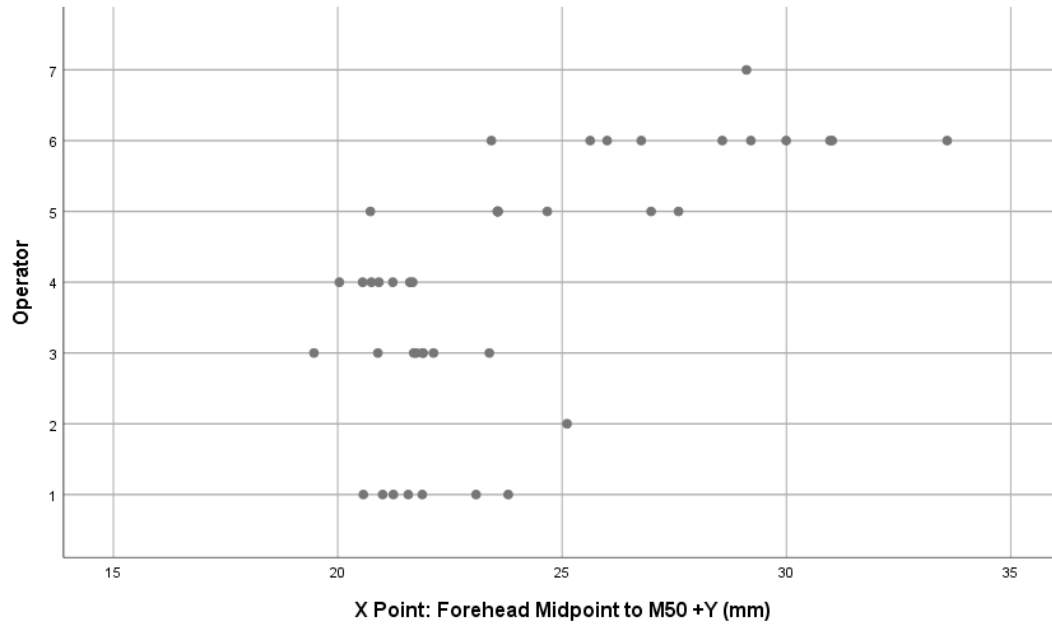


Figure 118. Scatterplot of the difference along the X-axis of the FLM to the M-50 +Y location pre-test. Limited Operator 2 and 7 data were available due to incorrect measurements.

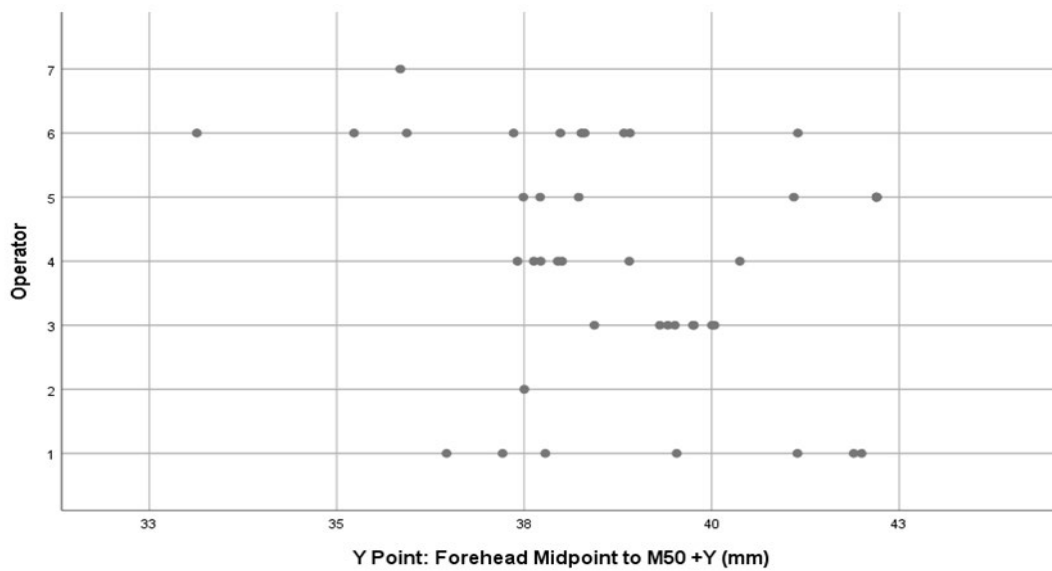


Figure 119. Scatterplot of the difference along the Y-axis of the FLM to the M-50 +Y location pre-test. Limited Operator 2 and 7 data were available due to incorrect measurements.

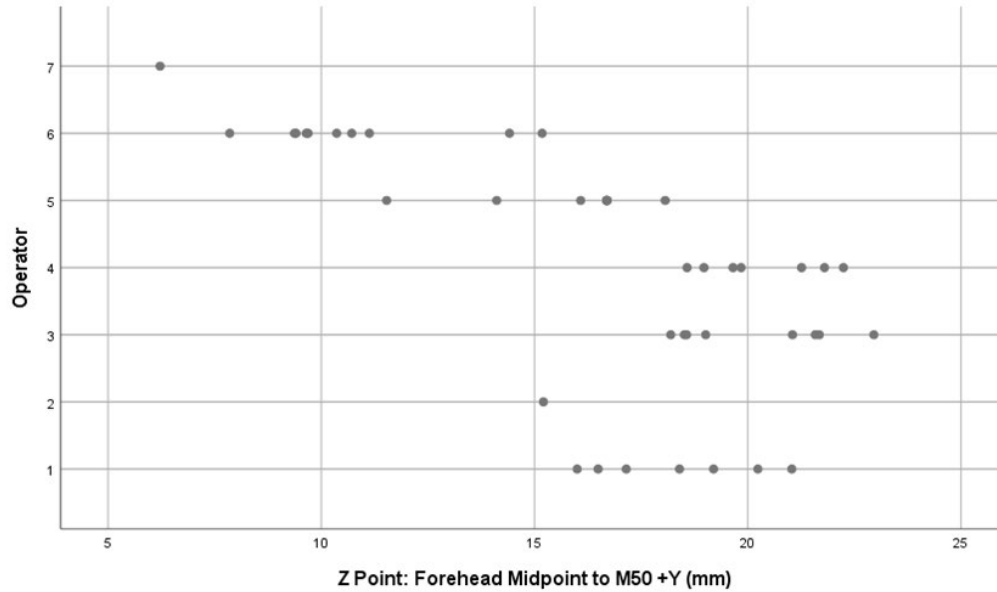


Figure 120. Scatterplot of the difference along the Z-axis of the FLM to the M-50 +Y location pre-test. Limited Operator 2 and 7 data were available due to incorrect measurements.

3.10.2 ACH with M-50 JSGPM CM Measurements

The CM measurements from the ACH medium with M-50 JSGPM mask are presented in this section. Table 49 provides the CM mean, SD, variance and CV for all seven Operators for X_1 , Z_1 and Z_2 . The CM results for X_2 , Y_1 and Y_2 only include measurements from Operator 3, 6 and 7 as these Operators conducted testing post-fix of the loose bolt that caused the cradle to translate along the Y-axis. The scatterplots in Figure 121 to Figure 123 provide a visual display of the individual measurements of the Operators for each CM variable. For the X_1 CM variable, Operator 4 does not overlap USAARL Operators 6 and 7. DEVCOM SC Operators 1-4 are skewed toward a smaller CM; however, Operator 5 from DEVCOM SC aligns with Operators 6 and 7. The CM measurements along X are consistent with the X measurements from the ACH NVD_{MH} (Figure 114) and M-50 +Y (Figure 118), where Operators 5-7 are consistent with each other versus Operators 1, 3 and 4. The X_1 and X_2 CM measurements for Operator 3 are consistent between the variables. The X_2 measurements from Operator 6 and 7 shift to larger CM values, contributing to the larger overall mean for X_2 (29.2 mm) versus the X_1 mean (27.5 mm). The CM results vary the most for the Z_1 and Z_2 variables between Operators but are consistent for each Operator. For this helmet system, the CM along the Z-axis is expected to have the largest variation since the M-50 JSGPM mask weighs .94 kg and the ACH medium weighs approximately 1.4 kg. A small shift in vertical placement of the mask on the headform could substantially change the CM along the Z-axis. The standard deviations are consistent within each X, Y and Z CM variable and relatively small. The CM values for Y are centered about zero, which is consistent with the Y point alignment measurements in Figure 115 centered about zero for the NVD_{MH} and the Operator overlap for the M-50 +Y (Figure 119). The CV values for Y are large because the means are close to zero; however, the standard deviations of .8 and .6 mm are well within expected variation.

A summary of the proportion of variance for each CM variable is provided in Table 50 and Figure 124. The proportions of variance differ across the CM variables and are likely impacted by the number of Operator measurements included. The X_1 , Z_1 and Z_2 CM data have the largest proportion of variance due to Operator; while the Operators are self-consistent, they vary from each other. These data sets are the only variables that include measurements from all seven Operators. For X_2 , the largest contributor to

variance is Fixture, as Operator 3 is the only DEVCOM SC tester and overlaps the USAARL Operators for only one measurement. However, between X_1 and X_2 , while Operator is a main factor, Repeatability is an equivalent factor for X_1 and Fixture is an equivalent factor for X_2 . For the CM measurements along the Y-axis, Y_2 is due to pure repeatability and Y_2 is split between Fixture and Repeatability; this is because the Operator measurements overlap less for Y_2 than for Y_1 . Again, helmet and equipment fitting procedures are a critical factor in the outcomes of the measurements and is an area where improvement to the guidelines should reduce Operator variability.

Table 49. ACH with M-50 JSGPM CM measurement means, SD, variance and CV for each X, Y and Z variable for all Operators.

*Some measurements were excluded from the analysis due to the fixture y-translation.

	X_1 (n= 60)	X_2 *(n= 28)	Y_1 *(n= 28)	Y_2 *(n= 28)	Z_1 (n= 60)	Z_2 (n= 60)
Mean (mm)	27.5	29.2	0.2	-0.1	33.9	34.0
SD (mm)	1.4	1.3	0.8	0.6	2.2	2.2
Variance (mm ²)	2.1	1.7	0.6	0.4	4.9	4.7
CV (%)	5	4	344	1055	7	6

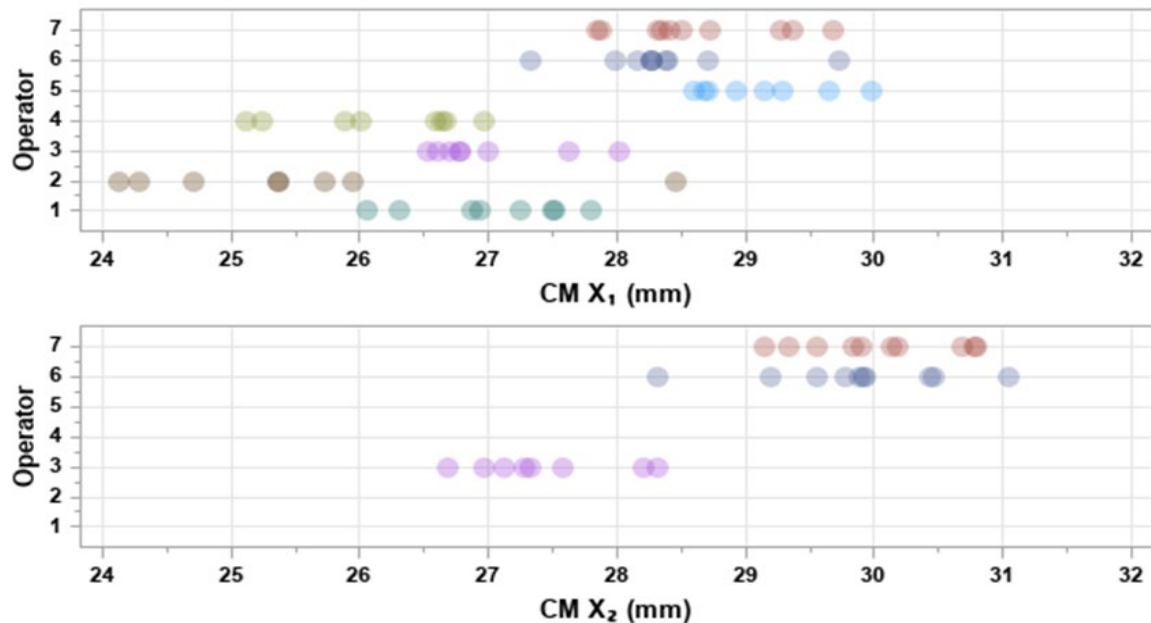


Figure 121. ACH with M-50 JSGPM X_1 and X_2 center of mass measurements for all Operator tests included in the analysis.

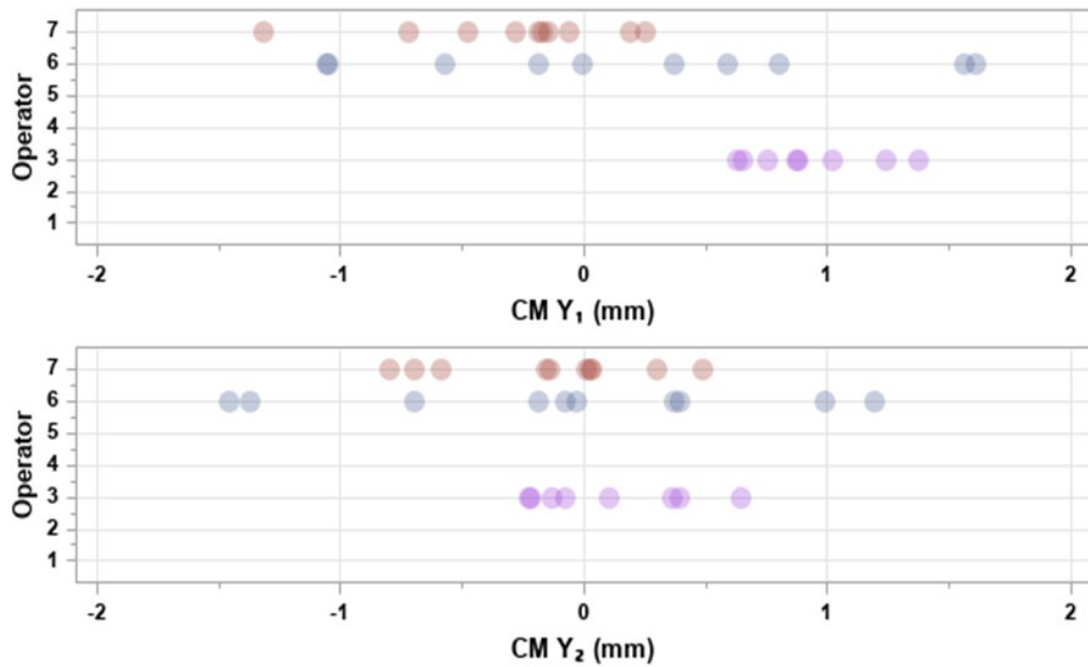


Figure 122. ACH with M-50 JSJPM Y₁ and Y₂ center of mass measurements for all Operator tests included in the analysis.

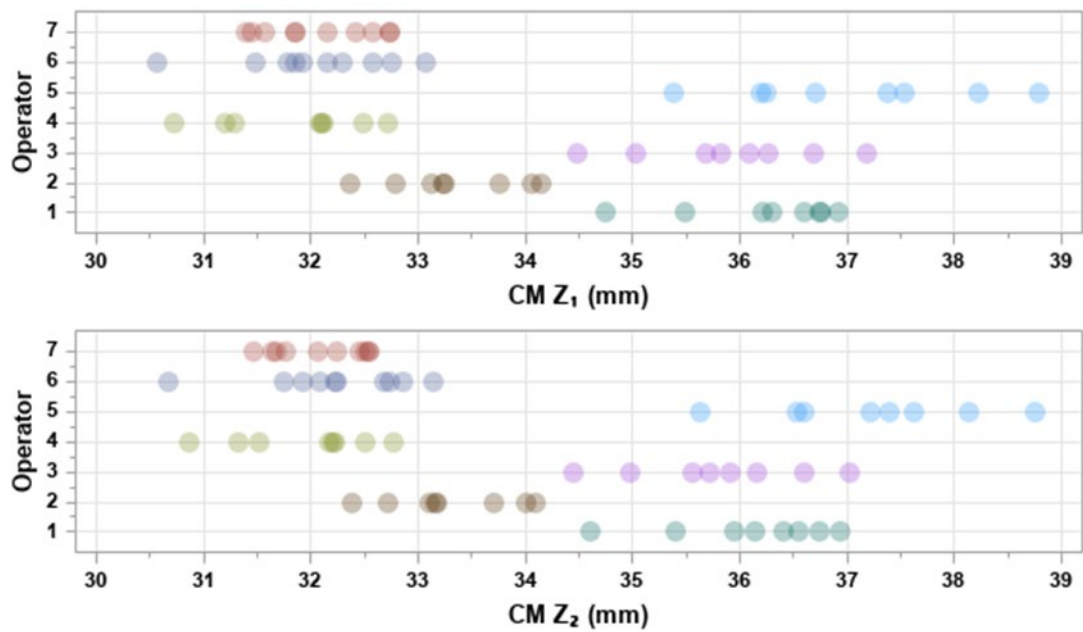


Figure 123. ACH with M-50 JSJPM Z₁ and Z₂ center of mass measurements for all tests included in the analysis for each operator.

Table 50. ACH with M-50 JSGPM breakdown of each CM X, Y, and Z measure proportion of variability by factor. The largest factors contributing to the total variance are in red. *Some measurements were excluded from the analysis due to the fixture y-translation.

Factor	Proportion of Variability Attributed to each Factor for the CM Outcomes					
	X ₁ (n= 60)	X ₂ * (n= 28)	Y ₁ * (n= 28)	Y ₂ * (n= 28)	Z ₁ (n= 60)	Z ₂ (n= 60)
Fixture	0.2467	0.8836	0.422	0	0.3759	0.3565
Operator(Fixture)	0.5429	0	0.0919	0	0.5399	0.5651
Error (Repeatability)	0.2104	0.1164	0.4861	1	0.0842	0.0783

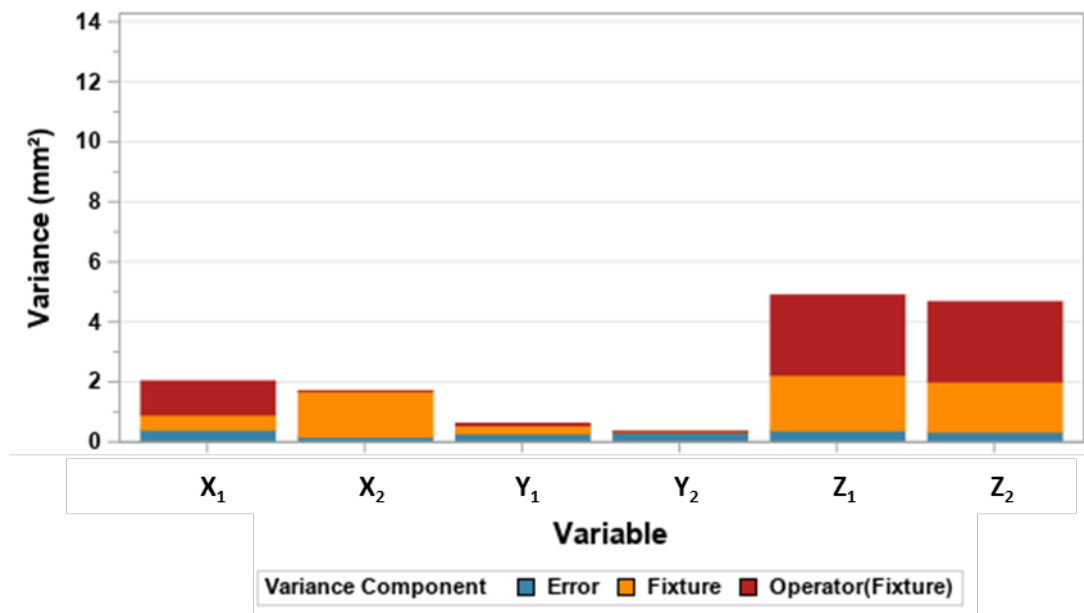


Figure 124. ACH with M-50 JSGPM helmet system CM variable total variance (mm²) breakdown of each factor contribution

3.10.3 ACH with M-50 JSGPM MOI Measurements

The MOI measurements from the ACH medium with M-50 JSGPM are presented in this section. Table 51 provides the MOI means, SD, variance and CV for all seven DEVCOM SC and USAARL operators. The standard deviations are consistent across the MOIs and coefficients of variation are low with the highest value for Ixx at 3.8%. The scatterplots of the MOI measures (Figure 125 and Figure 126) show that for Izz, Ixx and Ixy either Operator 1, 4 or 5 data do not overlap with other Operators. MOI measurements for Iyy, Ixz and Iyz have more Operator overlap leading to the proportion of variance mostly being due to repeatability. Likely these measurements were also affected by the cradle fixture translation; however, all of the MOI Operator data have been included in the report.

Table 51. ACH with M-50 JSGPM MOI Mean, SD, Variance and CV for the seven Operators.

	Izz (n= 60)	Ixx (n= 60)	Iyy (n= 60)	Iyz (n= 60)	Ixz (n= 60)	Ixy (n= 60)
Mean (kg-m ²)	0.02439	0.02811	0.03610	0.03023	0.03544	0.03191
SD (kg-m ²)	0.00071	0.00107	0.00078	0.00062	0.00097	0.00069
Variance (kg-m ²) ²	4.98E-07	1.14E-06	6.11E-07	3.82E-07	9.36E-07	4.81E-07
CV %	2.9	3.8	2.2	2.0	2.7	2.2

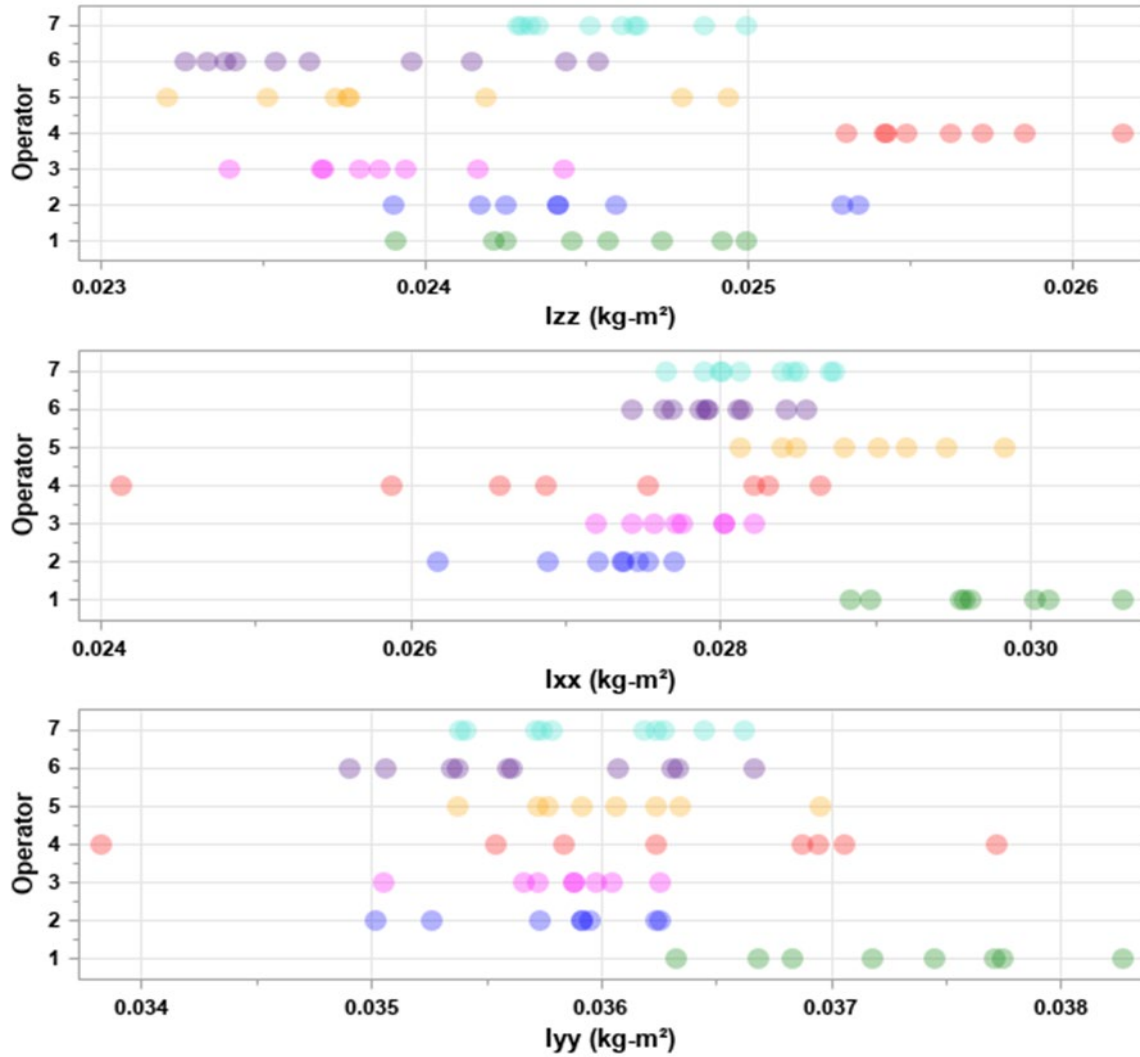


Figure 125. ACH with M-50 JSGPM basic MOI Izz, Ixx and Iyy scatter plots of data for all seven Operators.

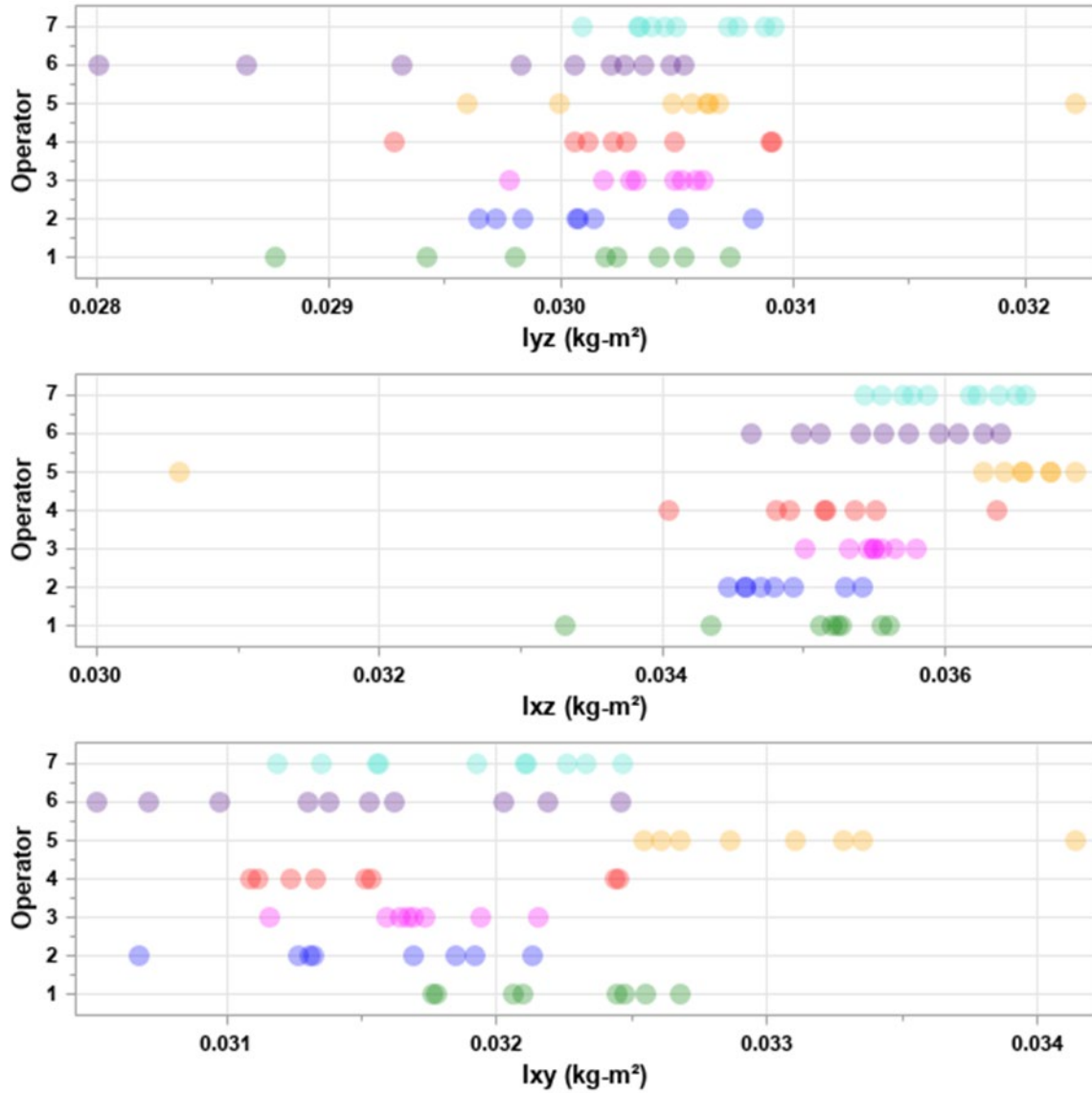


Figure 126. ACH with M-50 JSGPM MOI for I_{yz} , I_{xz} , and I_{xy} scatter plots of data for all seven Operators.

Table 52. ACH with M-50 JSGPM breakdown of each MOI measure I_{zz} , I_{xx} , I_{yy} , I_{yz} , I_{xz} , and I_{xy} proportion of variability by factor. The largest factors contributing to the total variance are in red.

Factor	Proportion of Variability Attributed to each Factor for the MOI Outcomes					
	I_{zz} (n= 60)	I_{xx} (n= 60)	I_{yy} (n= 60)	I_{yz} (n= 60)	I_{xz} (n= 60)	I_{xy} (n= 60)
Fixture	0	0	0	0	0.11	0
Operator(Fixture)	0.6858	0.6276	0.3664	0.1374	0.0448	0.557
Error (Repeatability)	0.3142	0.3724	0.6336	0.8626	0.8452	0.443

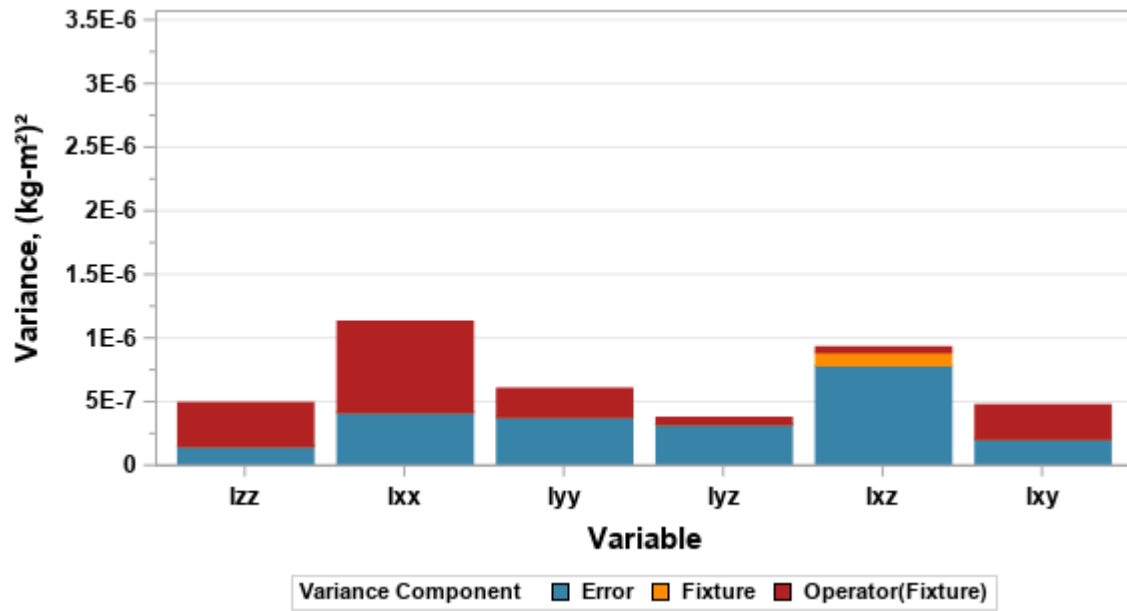


Figure 127. ACH Medium with M-50 JSGPM MOI Measurements: Breakdown of each factor identifying the contribution to total variance for each MOI variable.

4 Conclusions

This collaborative effort between DEVCOM SC and USAARL has sought to establish test equipment, test procedures and the repeatability and reproducibility of a test method for measuring CM and MOI of HBSs. While mass properties of HBSs have been measured within the Army and among the three services (Army, Navy, and Air Force) since the 1990s, the equipment, reference coordinate systems and procedures have varied, resulting in the inability to cross reference results. Having an Army standardized capability to measure mass properties for HBSs will support the Army in HBS development and acquisition activities as well as its research initiatives to understand Soldier performance outcomes and injury risks associated with head-supported mass and in optimizing head-borne equipment development.

DEVCOM SC and USAARL identified critical factors to be addressed in establishing mass properties measurement procedures for an Army test methodology. This included:

- Utilization of a MPI capable of measuring CM and MOI
- A coordinate system consistent with the MPI
- Headforms with defined anatomical markings to allow for consistent monitoring of fixture and test article alignment
- A fixture used to mount the headforms to the MPI, which reduces operator and procedure error
- Minimization of headform and fixture weights to improve fidelity of mass property measurements relative to the test article
- Systematically account for the contribution to head-borne mass properties from cables that extend from the helmet system

The KSR 330 series MPI (Space Electronics, Inc., Berlin, CT) was the equipment identified to measure the CM and MOI. Prior to this effort, both DEVCOM SC and USAARL had been using this system to measure mass properties. One significant advantage of this MPI is that it allows for both the CM and MOI to be measured from a single equipment placement. Three differently sized headforms were modified and used in the test method. The existing USAARL headforms, which are based off of a single geometry, were compared to 1988 and 2012 Army anthropometric survey (ANSUR) databases against head circumference, length and breadth. These measurements are typically used in sizing helmets. The three headforms (size II, III and IV) were determined to cover a range of head anthropometry for male Soldiers and fit the ACH size small, medium and large respectively; therefore, these headforms were adopted for use in the test method. Improvements were made to the headform functionality and ease of fabrication. This included adding reference marks such as anatomical planes (mid-sagittal, frontal and Frankfurt), right and left trignon notches, a forehead line, and horizontal lines on the neck. The headforms were scanned and transferred to STL files in Solidworks to allow for 3D printing. Additional headforms can be easily developed using the ANSUR 2012 database. To attach the headform to the MPI, a gimbal style fixture was designed to consistently align the headforms with the machine coordinate axes. This fixture includes quick connect pins to allow for headform rotation about the Y-axis to a 45° and 90° position and for full 360° rotation about the Z-axis at 45° increments while maintaining alignment of the headform ACS with the MCS. This feature also allows the HBS test items to remain on the headform for complete CM and MOI measurements between test item fittings.

Using the developed equipment and MPI, a gage R&R study was successfully performed at both DEVCOM SC and USAARL using multiple HBSs. The HBSs targeted in this study included:

- ACH sizes small, medium and large
- IHPS size large

- ACH medium with PVS-14 stowed
- ACH medium with PVS-14 deployed
- ACH medium with M-50 JSGPM
- HGU-56/P size medium

Testing with multiple HBSs ensured a robust gage R&R assessment accounting for several mass configurations. For the CM measurements, a total of six offsets were measured, two for each axis, and each were designated and assessed separately X_1 , X_2 , Y_1 , Y_2 , Z_1 and Z_2 . For the MOI measurements, six were collected: three along the primary axes (I_{zz} , I_{xx} , I_{yy}) and an additional three (I_{xz} , I_{yz} and I_{xy}) to allow for the calculation of the PMOI. The PMOI were not evaluated in this report: only the base measurements collected were assessed to understand the R&R of the test method. For each of the 12 measurements, the means, standard deviations, variances, and coefficients of variation were reported along with the R&R factor contribution to the proportion of variance. In addition to the mass properties measurements, points on the headform and HBS were digitally measured with a FaroArm to assess alignment of the helmet to the headform pre- and post-mass properties measurements. During testing at DEVCOM SC, translation of the cradle was occurring along the Y-axis; a loose bolt on the -Y side at the point of cradle rotation was determined to be the cause. The cradle shifting was resolved by replacing the standard nut with a locknut and adding spacers at the quick connect pins between the cradle and fixture side, effectively stopping the cradle from physically shifting. Upon resolving the issue and removing the X_2 , Y_1 and Y_2 measurements effected by the loose bolt, two DEVCOM SC Operators performed additional testing on a subset of HBSs: ACH Medium, IHPS, ACH M with PVS-14 stowed, and ACH M with PVS-14 deployed. Therefore, the sampling for the X_1 , Z_1 and Z_2 measures were larger than the number of measurements for X_2 , Y_1 and Y_2 . The CM and MOI data outcomes provided significant insight into the reliability of the test method and where improvements to the procedures can be implemented.

A compilation of the variances for the CM measurements is provided in Figure 128. For the CM measurements, the Z_1 and Z_2 variances were the most consistent between each variable and with respect to the X and Y measurements. For all helmet configurations, the mean differences between Z_1 and Z_2 were all .3 mm or less except for the ACH medium which was .5 mm. In addition, the average Z_1 and Z_2 standard deviation was 2 mm, all variances were less than 5.7 mm², and all coefficients of variation were less than 4% except the ACH medium with M-50 JSGPM which was 7%. The Y_1 and Y_2 CM measurements had the overall lowest variances, which is to be expected as the fit of the helmet from side-to-side is constrained by the headform. All but four of the Y variance measurements were below .8 mm² and the highest variance was 1.7 mm². However, these results are also influenced by the smaller number of tests performed which varied based on the HBS. Many of the coefficients of variation for the Y_1 and Y_2 dataset were high due to the very small CM offset value along the Y-axis; this was due to the symmetry about this axis of the HBS measured. Therefore, the standard deviations are better indicators of the precision of these measurements where the range was from .2 to 1.2 mm, with the majority being less than .9 mm. Direct comparisons of the X_1 and X_2 CM measurements are limited because these are the only measurements where the number of tests between the two measures are not equal; a portion of the X_2 measurements were removed from the dataset due to the loose bolt affecting measurements that occurred along the machine Y-axis. The variances for the X_1 and X_2 CM measurements had the largest range, from .2 to 13.7 mm². Although, all variances were less than 5.9 mm² except three measures: ACH medium with PVS-14 Stowed where $X_1 = 13.7$ mm² and $X_2 = 12$ mm² and the HGU-56/P where $X_1 = 9.1$ mm². While the ACH medium PVS-14 Stowed dataset variance was the highest, the ACH medium PVS-14 Deployed was among the smallest variances with $X_1 = 1.1$ mm² and $X_2 = .5$ mm². In addition, the ACH medium with PVS-14 Deployed had low standard deviations ($X_1 = 1.1$ mm and $X_2 = .7$

mm) and coefficients of variation of ($X_1 = 3\%$ and $X_2 = 2\%$). The small variation observed for helmet systems that have a larger mass distribution, like the ACH with PVS-14 deployed and ACH with M-50 JSGPM mask, indicate test procedures can be improved to reach this high degree of fidelity for all HBSs.

One course of action for reducing variability in mass properties measurements is in controlling the helmet placement on the headform. In evaluating the helmet to headform alignment pre-mass properties testing, positioning of HBSs was directly correlated to patterns observed in the Operator's measured CM offsets. In addition, the difference in alignment pre- vs post-mass properties testing indicated that, in some instances, the HBS shifted during testing. This likely contributed towards variation in the CM measurements, although it is not known exactly when the shift in the HBS positioning occurred during the test measurement sequence. Shifts in the helmet placement during the reorienting of the headform for the six MOI measurements can likely be improved by the use of hook and loop on the headform and inner lining of the helmet to keep the helmet in place. It is important to note that variation in HBS placement and shifting on the head is representative of how Soldiers wear head-borne equipment. This is a factor to consider when implementing this test method to characterize the mass properties of a HBS. Overall, Operator-to-Operator effects were larger than Fixture-to-Fixture effects, further supporting the conclusion that variation in CM measurements can be improved by implementing more specific procedural guidelines and encourages the use of multiple Operators to establish baseline measurements of a helmet system. In the instances where Fixture-to-Fixture effects were significant, this was influenced by the smaller number of test Operators and procedures employed at USAARL. The high reproducibility of the USAARL Operator data was partially due to a difference in operating procedures utilized, where USAARL Operators 6 and 7 conducted measurements from the same fixture mount and fit helmets consecutively, likely leading to more consistency of fit between Operators.

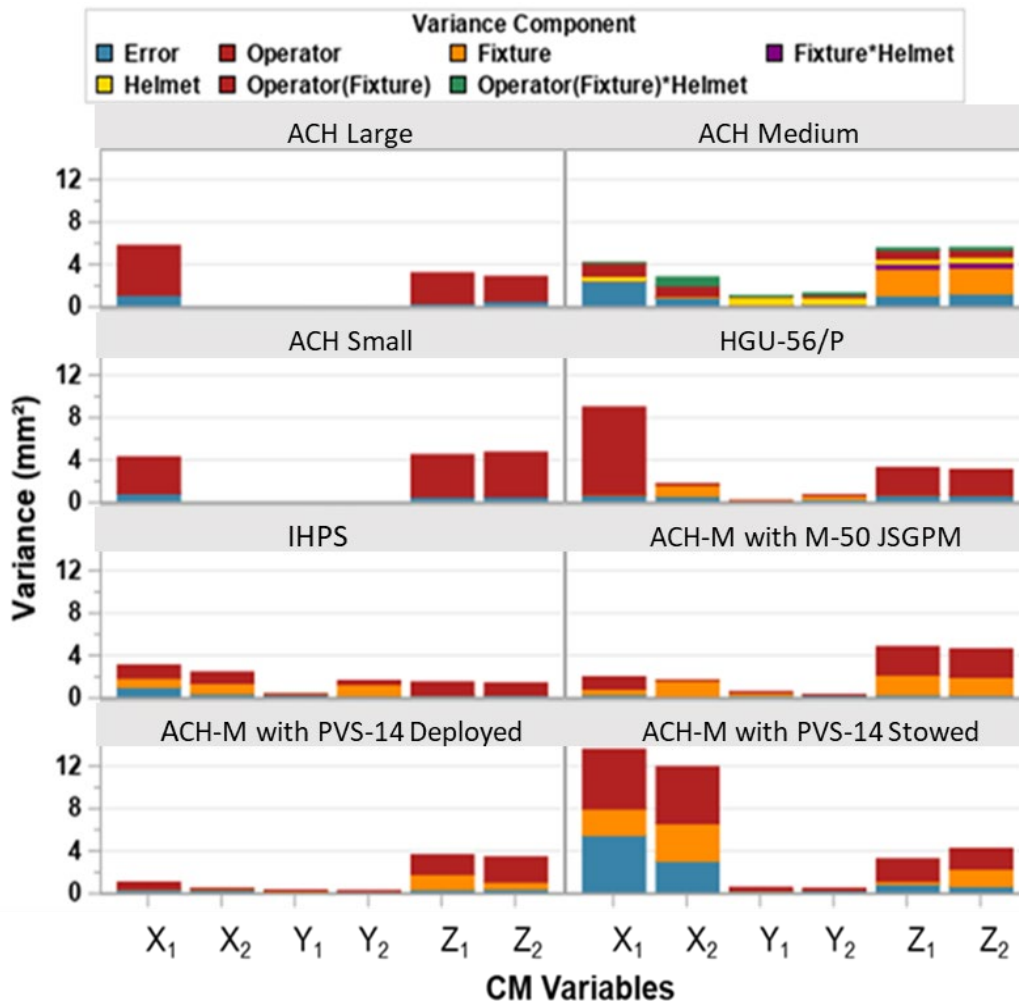


Figure 128. Compilation of CM variances for all helmet configurations tested with respect to each variance component.

A compilation of the variances for the MOI measurements of all HBSs measured in this data collection is provided in Figure 129. The data from DEVCOM SC where there was a loose bolt were included in the analysis as it was not known how much of an effect it would have on the MOIs. For the MOI data, Repeatability and Operator-to-Operator variability were the biggest contributors to variance. The ACH-M with PVS-14 stowed had the largest variances of all the HBSs. This aligns with the large variances observed in CM X-axis measurements for this condition and is expected due to the PVS-14 being in the stowed position. With the PVS-14 in the stowed position it is only supported at the helmet mount and was likely shifting with the helmet when in the different orientations. Overall, the MOI data were less variable than the CM data when considering the coefficients of variation. All MOI coefficients of variation were less than 10% except two measurements: ACH Small lxy CV = 11% and ACH-M with PVS-14 Deployed lxy CV = 10.2%. This indicates the level of repeatability of the data which would likely be improved in future testing with better defined guidelines for HBS placement and the updated fixture which restricts the cradle from shifting and resulting y-translation that occurred for some tests.

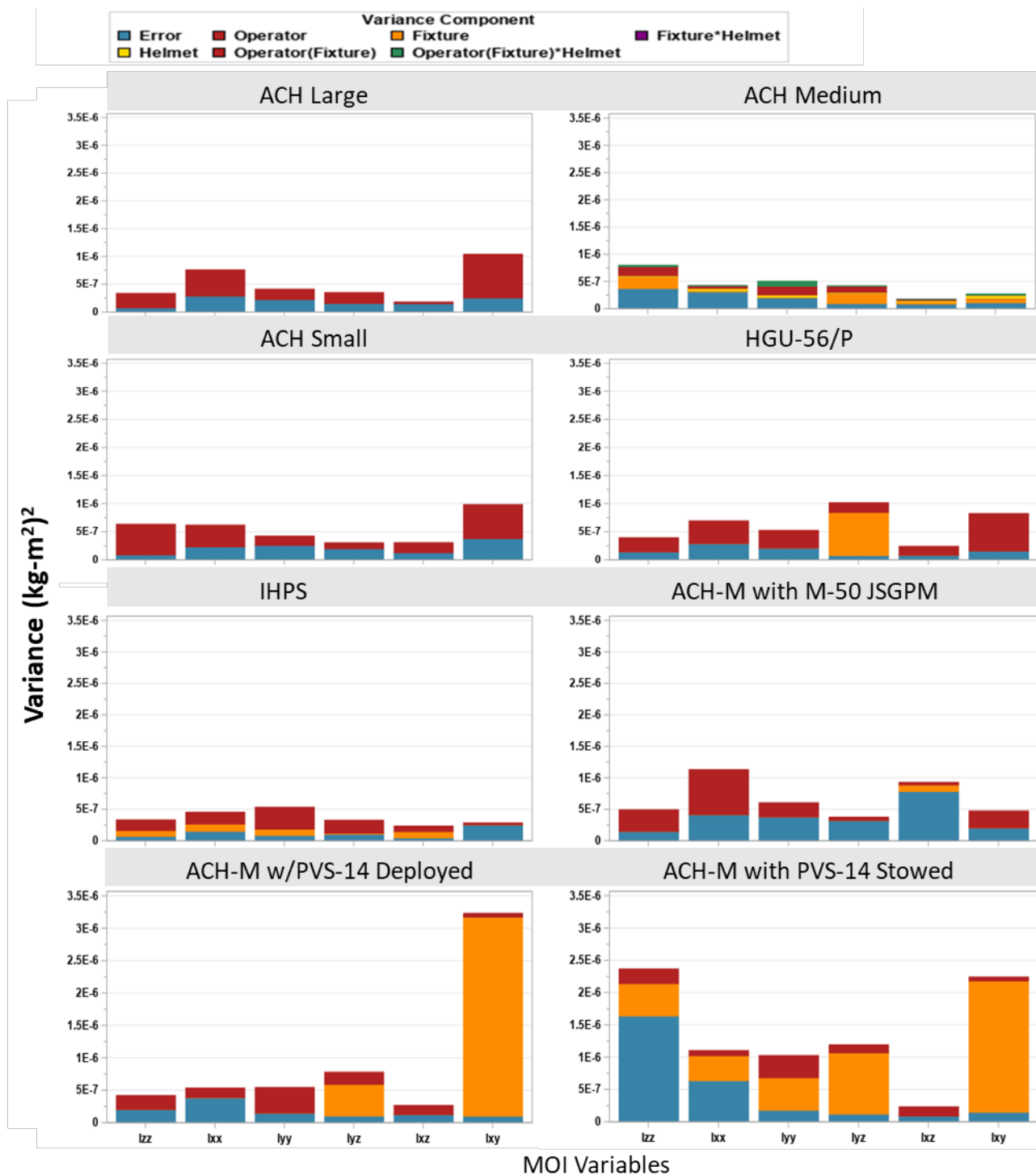


Figure 129. Compilation of MOI variances for all helmet configurations tested with respect to each variance component.

This dataset had three observed limitations:

- Due to a failure in the fixture stability allowing for translation along the y-axis for a subset of measurements, a portion of X_2 , Y_1 and Y_2 data were removed. The fixture was successfully stabilized by the addition of locknuts and the dataset was supplemented with additional

measurements. However, not all mass properties reported have the same number of measurements.

- Operators performing measurements on both fixtures would have improved the understanding of Fixture-to-Fixture variability
- Mass property measurements reported here are relative to the KSR 330 instrument centerline. A displacement of the headform trignon notch midpoint positioning of about 2 mm along the Z-axis occurred (Section 3.2). This displacement has been corrected however, the position of the head ACS origin for this dataset cannot be assumed to be properly aligned for all measurements. Thus, interpreting these results to be relative to the head anatomical origin for all orientations would not be accurate. Accuracy of the data could be improved by incorporating the known trignon notch midpoint displacements into the calculations.

In summary, a test method, to include all test equipment, was designed and fabricated, and a gage R&R assessment was successfully performed across two research laboratories at DEVCOM SC and USAARL. Factors such as Part, Operator and Fixture variability were assessed. Standardization of the headforms and addition of anatomical reference planes, anatomical landmarks, reference fit lines and CMM measurements of the HBSs on the headform greatly improved data interpretations and understanding of helmet fit variabilities. A systematic approach for assessing the contribution to a HBS's mass properties from cables extending to the body was successfully implemented. The methodology yielded similar results from the two test locations, while using the same headform and HBSs but different fixtures and Operators. Operator specific results when assessed against the helmet to headform alignment measurements indicate that the method can be influenced by the operator's fit and position of the helmet on the headform. This emphasizes the need to develop specific HBS placement guidelines when conducting testing and to record those guidelines. In general, consistency of the CM measures (X_1 vs X_2 , Y_1 vs Y_2 , and Z_1 vs Z_2) were similar; however, additional testing is needed to understand how the measures should be utilized overall. It was not clear from this dataset whether the variables should be averaged to produce a single X, Y and Z measurement or if a given measurement is more reliable based on the headform orientation; further investigation is needed.

5 Recommendations

Based on the test procedures established and data outcomes of the gage R&R study, the following recommendations regarding the test method are suggested:

- Provide knowledge transfer of the test method to another test site such as the Aberdeen Test Center to develop capability and expertise at additional facilities.
- Adjust height of each headform on pedestal to better align the tragion notch midpoint with the fixture point of rotation. Conduct measurements for all six headform orientations and establish procedures for improved monitoring of the right and left tragion notch midpoint location relative to the machine coordinate axes and cradle point of rotation.
- Conduct a limited series of testing to control variance for identified sources of error such as helmet placement and headform to fixture alignment. These tests should include stricter guidelines for aligning helmet systems to the headform and a maximum allowable tragion notch midpoint displacement from the MPI machine coordinate axes. Testing should include, at a minimum, a subset of helmets that exhibited the largest variance (e.g. HGU-56/P, ACH-M with PVS-14 Stowed) and if possible multiple Operators at both DEVCOM SC and USAARL.
- Conduct a follow-on study to clarify suitability of using average measures of the two CM variables for the X, Y and Z-axes versus one of the CM measures (e.g. X_1 vs X_2 , Y_1 vs Y_2 , and Z_1 vs Z_2)
- Shifts in helmet positioning were observed based on helmet system measurements taken pre- and post- mass property testing. This indicates that it is critical to assess helmet placement prior to and after mass properties measurements. Use of hook and loop to secure the helmet systems to the headforms should be investigated to determine whether it reduces variability.
- Widely publicize the methodology to receive input, gain acceptance and assess potential use outside the Army

This document reports research undertaken at the U.S. Army Combat Capabilities Development Command Soldier Center, Natick, MA, and has been assigned No. Natick/TR-23/007 in a series of reports approved for publication

6 References

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List of Acronyms

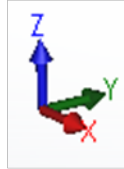
Anatomical Coordinate System (ACS)
Army Combat Helmet (ACH)
Center of Mass (CM)
Coefficient of Variation (CV)
Forehead line midpoint (FLM)
Head-borne System (HBS)
Helmet Mounted Device (HMD)
Integrated Head Protection System (IHPS)
Machine Coordinate System (MCS)
Mass Properties Instrument (MPI)
Moment of Inertia (MOI)
Mount Hole (MH)
Night Vision Device (NVD)
Night Vision Device Mount Hole (NVD_{MH})
Personal Protective Equipment (PPE)
Principal Moments of Inertia (PMOI)
Standard Deviation (SD)
Repeatability and Reproducibility (R&R)

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Appendix A

Headform Build Parameters

Modeler	Fortus 450mc
Est. build time	41 hr 43 min
Model material	ASA
Support material	SR30 support
Slice height	0.007"
Part fill style	One contour / rasters
Part interior style	Sparse
Visible surface style	Enhanced
Support style	Sparse
Contour width	0.02"
Number of contours	4
Part interior contours	1
Part raster width	0.014"
Orientation	



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Appendix B

CM and MOI Measurements

ACH Medium Helmet 1 Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	3	-19.79				88.21	88.99	0.012232	0.009131	0.010258		0.008976		0
1	4	-19.97				88.5	88.84	0.011984	0.009459	0.009805	0.010286	0.008997	0.010018	0
1	5	-20.19				88.51	88.74	0.012474	0.009949	0.010511	0.010505	0.009344	0.010566	0
1	6	-19.05				88.8	89.37	0.012318	0.009362	0.009887	0.010314	0.00936	0.010153	0
1	7	-20.02				87.53	87.86	0.012269	0.0093	0.009652	0.011084	0.009841	0.010394	0
2	1	-16.58				88.48	89.22	0.011881	0.009467	0.010677	0.01221	0.010113	0.010235	0
2	2	-16.34				88.56	89.32	0.012389	0.009173	0.010482	0.011081	0.008887	0.009083	0
2	3	-18.01				88.02	88.69	0.01218	0.009743	0.010823	0.011593	0.009644	0.010463	0
2	4	-16.91				88.73	89.34	0.012419	0.009177	0.010774	0.012345	0.010174	0.009633	0
2	5	-15.55				88.82	89.75	0.012295	0.009397	0.01055	0.011137	0.009447	0.010225	0
2	1	-19.3	-17.12	1.78	0.25	87.16	87.47	0.011989	0.009596	0.01031	0.011585	0.009972	0.010043	1
2	2	-19.83	-17.82	1.44	0.55	86.3	86.52	0.012313	0.010218	0.010587	0.01154	0.009848	0.010379	1
2	3	-20.9	-19.02	1.22	0.55	86.39	86.56	0.011702	0.010227	0.010582	0.01157	0.009896	0.010476	1
2	4	-20.53	-17.98	1.12	0.16	86.28	86.46	0.012334	0.010499	0.010806	0.011842	0.010144	0.01026	1
2	5	-21.07	-18.04	1.19	0.96	86.33	86.4	0.012619	0.01074	0.01091	0.011934	0.010333	0.011051	1
3	1	-15.92	-15.27	2.07	1.05	86.47	86.86	0.012117	0.010203	0.01125	0.01193	0.010421	0.011006	1
3	2	-16.78	-16.84	1.73	0.84	86.3	86.52	0.012341	0.010336	0.011141	0.011739	0.010293	0.010826	1
3	3	-16.89	-15.6	1.59	1.73	85.47	85.61	0.011828	0.010952	0.01176	0.01199	0.010312	0.010497	1
3	4	-18.9	-18.31	1.33	0.71	84.26	84.41	0.011942	0.009824	0.010624	0.011498	0.010152	0.01095	1
3	5	-17.17	-15.94	1.43	1.62	86.91	86.99							1
4	3	-20.09				83.87	86.4	0.012584	0.007516	0.012154	0.011498	0.009597		0
4	4	-17.26				86.35	86.19	0.013022	0.009698	0.0103	0.011757	0.00966	0.010413	0
4	5	-17.81				85.3	85.6	0.012701	0.00848	0.009726	0.010671	0.009159	0.010278	0
4	6	-18.75				85.25	85.58	0.012889	0.009198	0.010243	0.011577	0.009713	0.010647	0
4	7	-18.25				85.92	86.27	0.012528	0.009902	0.010878	0.012505	0.010248	0.010453	0
4	1	-18.79	-17.36	0.88	-0.41	85.32	85.7	0.011759	0.009663	0.010768	0.011073	0.009537	0.010268	1
4	2	-20.48	-18.31	1.71	-0.43	84.21	84.5	0.011998	0.010353	0.011176	0.011127	0.009524	0.010391	1
4	3	-19.57	-17.67	1.87	0.2	84.32	84.91	0.012147	0.010128	0.010973	0.011118	0.009541	0.010433	1
4	4	-18.37	-17.07	0.45	-0.47	84.62	85.21	0.012791	0.010173	0.011211	0.011253	0.009732	0.010481	1
4	5	-16.86	-13.32	1.86	-2.72	84.66	85.6	0.013086	0.009838	0.011297	0.011563	0.009948	0.01069	1
5	1	-17.03				90.14	90.58	0.010885	0.008652	0.009613	0.010122	0.009196	0.009921	0
5	2	-16.53				89.5	89.5	0.011031	0.010132	0.009949	0.009727	0.008962	0.010588	0
5	3	-16.41				88.31	88.53	0.010887	0.009204	0.009519	0.010533	0.009643	0.009846	0
5	4	-16.98				88.58	88.66	0.010865	0.00915	0.009239	0.010154	0.00922	0.009519	0
5	5	-16.28				88.68	88.79	0.012073	0.009217	0.009374	0.009822	0.009454	0.009673	0
6	1	-19.58	-17.66	1.53	1.04	84.78	85.26	0.013189	0.00948	0.010158	0.012322	0.010232	0.009624	1
6	2	-18.41	-16.31	0.83	0.57	86.29	86.9	0.013192	0.009698	0.010677	0.012518	0.01026	0.009886	1
6	3	-19.26	-17	1	0.62	84.59	85.24	0.013164	0.009821	0.010421	0.012511	0.010599	0.00995	1
7	1	-17.68	-16.09	1.96	2.223	85.29	85.98	0.011815	0.00968	0.010375	0.011881	0.010097	0.009837	1
7	2	-17.31	-15.85	1.56	0.53	85.7	86.18	0.012071	0.009776	0.010482	0.011022	0.010205	0.009895	1
7	3	-17.7	-16.03	1.76	1.64	83.98	84.31	0.012096	0.009913	0.010554	0.012089	0.010239	0.009898	1

ACH Medium Helmet 2 Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-19.21				90.56	90.65	0.011852	0.009985	0.010232	0.009344	0.008463	0.009104	0
1	3	-19.39				87.15	87.27	0.012018	0.009799	0.010159	0.009931	0.008988	0.009811	0
1	4	-20.32				86.82	86.94	0.012543	0.009627	0.009982	0.009835	0.008701	0.007918	0
1	5	-19.22				87.5	87.61	0.011969	0.010148	0.010257	0.010984	0.009735	0.010286	0
1	6	-21.45				84.16	84.35	0.011878	0.006986	0.006926	0.009427	0.008263	0.009058	0
2	1	-17.38				88.74	89.35	0.011682	0.008451	0.009497	0.010074	0.008791	0.008538	0
2	2	-17.54				88.34	88.91	0.011411	0.008986	0.009835	0.010695	0.0093	0.009201	0
2	3	-18.34				88.36	89.05	0.011756	0.00961	0.010415	0.011474	0.009818	0.009195	0
2	4	-17.17				88.45	88.92	0.012218	0.008984	0.010132	0.01091	0.00886	0.009411	0
2	5	-16.75				88.11	88.75	0.012067	0.008267	0.009618	0.010726	0.009166	0.009071	0
2	1	-21.22	-18.72	1.42	0.21	85.38	85.43	0.011792	0.009405	0.010054	0.011394	0.009786	0.009969	1
2	2	-20.83	-18.28	0.5	0.4	85.43	85.61	0.011666	0.00992	0.010265	0.011132	0.00967	0.009105	1
2	3	-21.16	-18.42	0.23	-0.49	85.29	85.59	0.011343	0.009938	0.010348	0.011149	0.00959	0.010073	1
2	4	-20.38	-17.95	0.67	-0.39	85.66	85.93	0.011595	0.009972	0.010281	0.011135	0.009479	0.010039	1
2	5	-21.76	-19.08	0.12	-0.05	85.29	85.53	0.011468	0.00996	0.010249	0.010724	0.009177	0.01015	1
3	1	-18.16	-17.82	0.42	0.56	89.13	89.42							1
3	2	-18.15	-16.99	-0.45	-0.23	89.17	89.49							1
3	3	-18.4	-18.55	-0.47	0.8	89.03	89.29							1
3	4	-16.63	-17.57	0.1	0.67	89.51	89.84							1
3	5	-19.38	-18.7	0.33	0.96	89.12	89.5							1
4	1	-18.38				85.64	86.14	0.011151	0.009343	0.010184	0.011649	0.009819	0.009831	0
4	2	-17.96				85.92	86.54	0.012012	0.009336	0.010302	0.011911	0.009989	0.009778	0
4	3	-17.7				86.23	86.74	0.011988	0.009371	0.010261	0.01209	0.010003	0.009619	0
4	4	-18.49				86.02	86.45	0.012337	0.009209	0.01031	0.011309	0.009531	0.009705	0
4	5	-20.14				85.36	85.99	0.011691	0.008465	0.009492	0.010118	0.008761	0.009316	0
4	1	-18.37	-15.61	0.76	-1.34	85.72	86.34	0.012152	0.009374	0.010306	0.010617	0.009142	0.008791	1
4	2	-16.5	-14.3	-0.1	-1.87	85.77	86.24	0.012138	0.00962	0.010752	0.010798	0.009479	0.009069	1
4	3	-21.25	-19.14	-0.03	-1.65	83.5	84.21	0.011709	0.009709	0.010504	0.010658	0.009108	0.009771	1
4	4	-17.69	-15.2	-0.46	-2.29	85.49	86.13	0.011631	0.009258	0.010212	0.010644	0.009228	0.009574	1
4	5	-16.95	-15.16	0.46	-1.11	86.14	86.67	0.012393	0.009464	0.010369	0.010623	0.009115	0.00946	1
5	1	-15.19				88.43	88.9	0.010524	0.009017	0.009147	0.009826	0.008916	0.009291	0
5	2	-17.25				88.47	88.86	0.010832	0.008974	0.009166	0.010098	0.008937	0.00947	0
5	3	-16.76				88.77	89.35	0.010967	0.009265	0.00971	0.010457	0.009497	0.010181	0
5	4	-15.67				89.15	89.26	0.011048	0.009112	0.008906	0.010165	0.009029	0.009265	0
5	5	-15.99				88.77	89.11	0.010624	0.008903	0.00909	0.010258	0.009072	0.009477	0
6	1	-21.37	-19.1	-0.41	-0.6	82.95	83.47	0.01215	0.007727	0.008822	0.011535	0.009343	0.008453	1
6	2	-20.56	-18.88	-0.32	-0.87	83.43	83.89	0.012466	0.009084	0.009621	0.011759	0.009817	0.009097	1
6	3	-20.73	-18.78	0.43	-0.32	82.61	83	0.012567	0.009113	0.0096	0.01153	0.009608	0.009142	1
7	1	-19.06	-18	0.57	0.5	83.22	83.75	0.0115	0.009155	0.009887	0.011592	0.009701	0.009587	1
7	2	-18.49	-17.24	-0.16	0.64	83.7	84.22	0.011632	0.009208	0.01001	0.011592	0.009634	0.009641	1
7	3	-20.06	-19.13	-0.41	-0.72	82.9	83.32	0.011572	0.009549	0.009965	0.011569	0.009652	0.008899	1

ACH Medium Helmet 3 Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lzx (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-19.3				89.42	89.44	0.011583	0.00962	0.009997	0.010837	0.009458	0.010031	0
1	2	-19.3				90.16	90.23	0.011583	0.00997	0.010413	0.009958	0.009084	0.010195	0
1	3	-21.54				87.94	88.09	0.011956	0.010069	0.010387	0.010195	0.009314	0.010595	0
1	4	-20.31				88.29	88.36	0.012055	0.010434	0.010636	0.010272	0.009481	0.010133	0
1	5	-21.27				85.69	85.93	0.011607	0.008233	0.008272	0.009421	0.008625	0.010289	0
2	1	-16.19				89.04	89.77	0.01121	0.008802	0.010069	0.011283	0.009717	0.00972	0
2	2	-17.09				88.75	89.65	0.011673	0.009121	0.010353	0.011109	0.009181	0.009687	0
2	3	-17.47				88.61	89.36	0.011343	0.008053	0.009266	0.010491	0.008789	0.009025	0
2	4	-18.17				88.33	89.09	0.011566	0.008514	0.009813	0.010628	0.009569	0.009211	0
2	5	-17.7				87.87	88.71	0.011766	0.008216	0.009491	0.010892	0.00893	0.009417	0
2	1	-21.36	-18.86	-0.94	-2.03	87.03	87.39	0.011331	0.009796	0.010359	0.01108	0.009525	0.010102	1
2	2	-22.83	-20.24	-0.55	-0.84	86.59	87.16	0.01101	0.009339	0.009692	0.010661	0.009089	0.009622	1
2	3	-21.44	-18.62	-0.65	-1.43	87.63	88.18	0.011594	0.00942	0.009918	0.010883	0.009369	0.009671	1
2	4	-20.87	-17.97	-0.67	-0.59	85.19	85.38	0.01146	0.009236	0.009822	0.010932	0.009396	0.009751	1
2	5	-21.65	-18.37	-0.49	-1.1	84.78	84.94	0.011198	0.00953	0.010045	0.010681	0.009165	0.009796	1
3	1	-18.45	-17.48	0.18	-1.08	89.15	89.35	0.011571	0.008844	0.009307	0.010652	0.009169	0.009253	1
3	2	-17.4	-17.49	0.23	-1.37	90.2	90.33	0.011336	0.009322	0.009551	0.011068	0.009554	0.009616	1
3	3	-18.57	-17.19	0.24	-1.43	89.17	89.58	0.01124	0.009378	0.009962	0.011079	0.009521	0.009764	1
3	4	-19.44	-17.11	-0.06	-1.31	88.97	89.48	0.011427	0.009662	0.010494	0.011134	0.009556	0.009794	1
3	5	-17.51	-16.41	-0.15	-1.45	89.5	89.88	0.011236	0.009515	0.009967	0.011131	0.009595	0.009725	1
4	1	-20.41				86.61	87.39	0.011628	0.009349	0.010119	0.010907	0.009535	0.0099	0
4	2	-19.44				86.49	87.09	0.011806	0.009223	0.010059	0.011277	0.009978	0.009819	0
4	3	-19.24				86.6	87.29	0.011901	0.00913	0.01007	0.011421	0.009593	0.009906	0
4	4	-19.25				85.87	86.64	0.011616	0.008812	0.009728	0.012299	0.008466	0.01038	0
4	5	-20.2				86.47	87.31	0.012396	0.009808	0.01073	0.011719	0.009212	0.010083	0
4	1	-17	-15.07	0.67	-1.2	85.1	85.67	0.012277	0.009344	0.010393	0.011166	0.009581	0.009933	1
4	2	-18.17	-16.28	1.5	0.4	84.5	84.98	0.01225	0.009231	0.010156	0.010521	0.008632	0.009374	1
4	3	-18.11	-17.55	0.67	0.37	84.11	84.74	0.012161	0.009028	0.009986	0.010572	0.00905	0.009552	1
4	4	-20.3	-18.2	-0.07	-1.83	83.09	83.78	0.012447	0.009609	0.010193	0.010557	0.009023	0.009663	1
4	5	-19.59	-17.42	0.22	-1.3	83.82	84.34	0.012283	0.009443	0.010369	0.010861	0.009293	0.009672	1
5	1	-17.64				88.43	88.71	0.01012	0.008438	0.008492	0.009356	0.00857	0.008803	0
5	2	-17.68				88.42	88.72	0.010699	0.00865	0.008654	0.009936	0.008768	0.009064	0
5	3	-16.69				89.51	89.89	0.010673	0.00961	0.009559	0.009522	0.008528	0.009961	0
5	4	-18.39				88.13	88.45	0.010642	0.009384	0.009321	0.009704	0.00995	0.009659	0
5	5	-16.69				89.15	89.5	0.01135	0.009647	0.009718	0.010723	0.009423	0.009976	0
6	1	-19.65	-17.63	-0.9	-0.7	84.96	85.33	0.01269	0.009181	0.009985	0.011469	0.009976	0.008988	1
6	2	-20.07	-15.94	0.07	-0.18	84.33	85.73	0.012624	0.008962	0.009436	0.011708	0.009911	0.008924	1
6	3	-20.52	-18.54	-0.92	-0.72	82.64	83.1	0.012598	0.008879	0.009326	0.01167	0.00936	0.008864	1
7	1	-20.13	-18.19	-0.14	-0.67	84.27	84.62	0.012318	0.008272	0.0089	0.011293	0.009234	0.008572	1
7	2	-18.91	-17.06	-0.65	-0.76	84.65	85.01	0.012545	0.008591	0.009186	0.011359	0.009441	0.008715	1
7	3	-19.55	-17.52	0.1	-0.34	84.35	84.65	0.012632	0.008779	0.009203	0.011479	0.009505	0.008781	1

ACH Medium Helmet 4 Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-19.12				87.12	87.16	0.01236	0.010453	0.010815	0.010422	0.009624	0.010784	0
1	2	-20.17				87.65	88.03	0.011964	0.009265	0.009948	0.01022	0.008935	0.009873	0
1	3	-21.01				86.13	86.59	0.011454	0.009519	0.010162	0.011252	0.009916	0.009949	0
1	4	-21.36				86.61	86.99	0.011735	0.010728	0.011636	0.010186	0.008834	0.009685	0
1	5	-21.09				87.31	87.56	0.012365	0.010972	0.011732	0.010758	0.009294	0.010114	0
2	1	-14.45				87.97	88.3	0.011539	0.008856	0.009608	0.01072	0.008702	0.009789	0
2	2	-15.48				87.53	88.15	0.011551	0.009301	0.010275	0.011025	0.009635	0.009848	0
2	3	-15.65				87.54	88.21	0.011733	0.009608	0.010613	0.010522	0.009264	0.009134	0
2	4	-16.27				87.04	87.69	0.011921	0.010187	0.010971	0.011424	0.009618	0.009376	0
2	5	-15.81				86.43	87.05	0.012144	0.009509	0.010409	0.011985	0.009964	0.010159	0
2	1	-21.26	-18.49	2.11	1.47	82.74	82.82	0.010998	0.009584	0.009927	0.010977	0.009452	0.009944	1
2	2	-20.71	-17.55	1.08	0.21	83.04	83.24	0.011462	0.009849	0.010095	0.011172	0.009646	0.009955	1
2	3	-22.22	-18.47	1.51	-0.27	81.97	82.16	0.011976	0.009775	0.010221	0.011153	0.009586	0.01005	1
2	4	-21.81	-19	1.31	0.78	81.89	81.93	0.011801	0.009952	0.010206	0.011217	0.009605	0.010169	1
2	5	-20.77	-18.52	0.95	0.69	82.5	82.45	0.012037	0.010223	0.010291	0.01128	0.009719	0.01028	1
3	1	-17.04	-16.69	2.4	1.27	86.47	86.59	0.010977	0.009368	0.009505	0.011127	0.009611	0.009696	1
3	2	-17.88	-17.5	1.97	0.96	86.22	86.34	0.011063	0.009644	0.00973	0.011267	0.009652	0.009895	1
3	3	-17.53	-17.07	2.2	1.21	86.61	86.74	0.011251	0.009723	0.009836	0.011404	0.009843	0.010004	1
3	4	-16.83	-15.46	1.75	0.89	87.02	87.13	0.011369	0.009736	0.010093	0.011324	0.009859	0.009888	1
3	5	-17.46	-16.68	2.09	1.19	86.98	87.25	0.011543	0.00979	0.009934	0.011418	0.009938	0.009904	1
4	1	-17.91				85.75	86.31	0.012433	0.009136	0.010102	0.011784	0.009557	0.009512	0
4	2	-18.78				85.65	86.13	0.01251	0.009801	0.010494	0.011452	0.009379	0.009597	0
4	3	-18.66				85.5	86.08	0.012465	0.008915	0.009822	0.010886	0.008698	0.010457	0
4	4	-18.41				85.74	86.32	0.01247	0.009743	0.010622	0.010978	0.009683	0.010466	0
4	5	-19.77				85.38	85.98	0.012681	0.010186	0.010926	0.011407	0.009399	0.00958	0
4	1	-18.37	-15.77	1.91	0.25	82.21	82.52	0.012702	0.010295	0.010894	0.011193	0.009645	0.010211	1
4	2	-19.57	-17.32	1.29	-0.7	81.32	81.81	0.011734	0.009416	0.010203	0.010792	0.009308	0.009643	1
4	3	-21.42	-19.08	1.31	-0.65	80.3	80.8	0.011855	0.009906	0.010498	0.010885	0.009298	0.009849	1
4	4	-20.79	-18.42	1.45	-0.04	80.65	81.15	0.011903	0.009788	0.01047	0.010935	0.009397	0.010205	1
4	5	-19.73	-16.88	0.8	-1.31	80.93	81.51	0.011897	0.009873	0.010623	0.011001	0.009624	0.010132	1
5	1	-17.09				87.86	88.15	0.011094	0.009579	0.009623	0.010616	0.009255	0.009906	0
5	2	-16.48				87.61	88.01	0.011587	0.01003	0.009903	0.010368	0.00978	0.010299	0
5	3	-17.54				85.91	86.42	0.010945	0.008397	0.00855	0.01037	0.009047	0.00891	0
5	4	-17.89				85.76	85.95	0.0105	0.009677	0.009382	0.009576	0.009637	0.009814	0
5	5	-16.84				86.4	86.64	0.0112	0.009636	0.00944	0.010037	0.009298	0.009886	0
6	1	-19.42	-17.35	0.74	0.78	83.21	83.56	0.012595	0.009075	0.00949	0.011786	0.009619	0.009163	1
6	2	-19.58	-18.4	0.44	-0.06	82.6	83.28	0.012755	0.009296	0.009899	0.011928	0.009571	0.009634	1
6	3	-20.32	-18.37	1.06	0.28	81.72	82.16	0.012653	0.009863	0.010174	0.0118	0.009493	0.009958	1
7	1	-16.35	-14.57	1.01	0.74	85.29	85.67	0.013045	0.009261	0.009669	0.01182	0.009742	0.009259	1
7	2	-17.28	-15.33	1.46	0.98	85.03	85.38	0.013076	0.009217	0.009649	0.011838	0.010126	0.009281	1
7	3	-17.66	-15.65	1.5	1.41	84.55	84.93	0.013021	0.009288	0.00974	0.011786	0.010063	0.00931	1

ACH Medium Helmet 5 Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lzx (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-21.18				90.3	90.88	0.012177	0.01024	0.011202	0.010124	0.008566	0.00929	0
1	2	-20.76				89.78	90.02	0.011634	0.010096	0.010938	0.010992	0.009179	0.009542	0
1	4	-21.08				90.06	90.5	0.011995	0.01005	0.011012	0.010403	0.008811	0.009531	0
1	5	-19.89				90.9	91.36	0.012111	0.010104	0.011246	0.01127	0.009572	0.0098	0
1	6	-20.63				90.75	91.17	0.012154	0.010496	0.011501	0.010555	0.009018	0.009763	0
2	1	-13.91				89.56	90.09	0.01171	0.009524	0.010722	0.012194	0.010079	0.010132	0
2	2	-14.83				89.2	89.84	0.011985	0.009269	0.0104	0.01123	0.009283	0.009709	0
2	3	-14.22				89.77	90.46	0.011148	0.008255	0.009584	0.010568	0.008978	0.00906	0
2	4	-15.41				88.14	88.84	0.011676	0.008233	0.009354	0.011071	0.009571	0.009215	0
2	5	-15.61				88.73	89.35	0.011451	0.008876	0.009917	0.01148	0.009484	0.008788	0
2	1	-22.11	-19.38	2.1	1.65	85.45	85.5	0.011149	0.009691	0.010017	0.011091	0.009441	0.009773	1
2	2	-22.05	-19.85	2.1	1.4	85.12	85.21	0.01153	0.00986	0.010101	0.010799	0.00921	0.009939	1
2	3	-21.7	-18.93	1.61	0.44	84.95	85.03	0.011595	0.009936	0.010214	0.011365	0.00981	0.01003	1
2	4	-22.39	-19.67	1.55	0.24	84.72	84.86	0.011733	0.009954	0.010321	0.011104	0.009412	0.01011	1
2	5	-22.76	-20.45	1.67	1.3	84.86	84.96	0.011278	0.009526	0.009777	0.010991	0.009144	0.009761	1
3	1	-17.5	-17.5	2.35	1.45	90.22	90.37	0.011225	0.00912	0.009696	0.010938	0.009411	0.009413	1
3	2	-19.29	-19.13	1.75	1.23	89.03	89.2	0.011295	0.009213	0.009421	0.010865	0.009362	0.009405	1
3	4	-18.81	-18.48	1.98	0.92	87.03	87.12	0.011044	0.009033	0.009281	0.010739	0.009205	0.0092	1
3	5	-20.38	-19.75	1.65	0.78	86.64	86.8	0.011057	0.009158	0.009435	0.010795	0.009184	0.009342	1
3	6	-17.62	-16.59	1.18	0.49	86.73	86.76	0.011085	0.009042	0.009408	0.010824	0.009328	0.009268	1
4	1	-19.38				87.72	88.35	0.012353	0.010216	0.010799	0.012133	0.010022	0.00988	0
4	2	-17.56				88.25	88.65	0.012735	0.010005	0.010841	0.011823	0.009136	0.009333	0
4	3	-17.6				88.08	88.47	0.012605	0.010147	0.010612	0.012171	0.01033	0.010549	0
4	4	-18.44				87.99	88.38	0.012629	0.010274	0.010909	0.011006	0.010078	0.010422	0
4	5	-21.43				86.68	87.21	0.012295	0.010358	0.010806	0.01091	0.008294	0.009523	0
4	1	-18.3	-16.53	2.4	0.94	85.39	85.71	0.011641	0.009403	0.010311	0.010858	0.009416	0.009701	1
4	2	-19.29	-15.49	2.27	-1.57	83.39	83.94	0.011434	0.008121	0.009242	0.010209	0.008658	0.009241	1
4	3	-17.16	-15.93	1.49	-0.48	84.52	85.07	0.01215	0.009221	0.010168	0.010653	0.009172	0.009334	1
4	4	-16.96	-15.36	1.5	-0.15	84.87	85.22	0.011617	0.009473	0.01028	0.010702	0.009242	0.009519	1
4	5	-17.6	-15.54	1.02	-1.52	84.85	85.39	0.012021	0.009419	0.010329	0.010525	0.00917	0.009728	1
5	1	-15.14				89.17	89.64	0.010618	0.009131	0.009256	0.009632	0.009193	0.009616	0
5	2	-16.38				90.21	90.43	0.011007	0.009432	0.009493	0.009874	0.009224	0.009901	0
5	3	-16.41				89.86	90.02	0.011233	0.009787	0.009753	0.009906	0.009266	0.010163	0
5	4	-16.24				89.06	89.55	0.010526	0.009547	0.009553	0.010759	0.009254	0.009973	0
5	5	-16.37				88.14	88.57	0.010582	0.009413	0.009393	0.009931	0.00905	0.009763	0
6	1	-19.63	-17.95	0.96	1.25	84.15	84.51	0.013253		0.00995	0.011268	0.009315	0.009613	1
6	2	-21.36	-19.19	1.38	0.47	81.94	82.27	0.012084	0.009764	0.010132	0.011047	0.009013	0.009673	1
6	3	-19.76	-15.58	1.11	1.4	82.71	83.03	0.011699	0.00908	0.009512	0.010681	0.009759	0.008919	1
7	1	-19.41	-17.41	2.4	1.49	83.68	84.08	0.012317	0.008486	0.009052	0.011311	0.009345	0.00869	1
7	2	-19.1	-17.03	2.57	2.29	83.16	83.45	0.012616	0.00868	0.009266	0.011411	0.009644	0.008874	1
7	3	-19.77	-17.37	2.28	1.77	82.53	82.89	0.012613	0.008893	0.00944	0.011517	0.009628	0.008987	1

ACH Medium Helmet 6 Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-23.02				86.19	86.48	0.012633	0.010413	0.011077	0.009899	0.008841	0.01	0
1	2	-22.29				87.63	87.76	0.012449	0.010752	0.011507	0.011773	0.01013	0.010212	0
1	3	-22.33				85.36	85.39	0.012414	0.011153	0.011744	0.010953	0.009579	0.01039	0
1	4	-20.94				83.71	83.88	0.012896	0.010741	0.011408	0.010846	0.009407	0.010333	0
1	5	-21.66				83.75	83.89	0.012764	0.010969	0.011857	0.01078	0.009548	0.010412	0
2	1	-15.32				88.46	88.89	0.012225	0.009323	0.010631	0.011483	0.009671	0.010157	0
2	2	-16.73				86.99	87.44	0.012072	0.009409	0.010551	0.011651	0.009798	0.009381	0
2	3	-17.1				86.62	87.04	0.012163	0.009668	0.010764	0.011301	0.00961	0.009613	0
2	4	-17.02				85.18	85.62	0.011809	0.008824	0.009802	0.010757	0.009042	0.009582	0
2	5	-17.51				84.91	85.48	0.011895	0.00882	0.009916	0.011127	0.009337	0.010358	0
2	1	-22.51	-19.48	0.15	-0.61	84.5	84.52	0.011917	0.010491	0.010585	0.011359	0.009891	0.010217	1
2	2	-21.92	-20.13	0.35	-0.35	84.68	84.78	0.012098	0.010479	0.010737	0.011542	0.009987	0.010622	1
2	3	-23.61	-21.48	0.17	-0.36	83.57	83.7	0.012289	0.010604	0.010772	0.011133	0.009819	0.010683	1
2	4	-23.19	-20.76	-0.07	-0.86	83.73	83.92	0.01196	0.010418	0.010805	0.011555	0.009958	0.01062	1
2	5	-24.48	-21.94	0.5	-0.36	83.13	83.17	0.011929	0.010657	0.010795	0.011539	0.009973	0.010646	1
3	1	-16.92	-15.35	0.21	-0.62	87.76	87.83	0.011652	0.009646	0.010059	0.011453	0.009903	0.009766	1
3	2	-17.84	-14.43	0.51	-0.054	87.65	87.66	0.011835	0.009848	0.010272	0.011512	0.010169	0.010112	1
3	3	-19.41	-15.85	0.36	-0.92	85.41	85.5	0.011345	0.009551	0.010033	0.011283	0.00986	0.009902	1
3	4	-17.6	-14.37	0.18	-1.08	86.55	86.71	0.012048	0.009659	0.010161	0.011268	0.009889	0.009923	1
3	5	-18.13	-16.79	-0.06	-1.43	86.13	86.1	0.011593	0.009731	0.010038	0.011297	0.009873	0.010004	1
4	1	-18.35				84.39	84.66	0.012217	0.009828	0.010734	0.011262	0.009409	0.009836	0
4	2	-20.53				82.89	83.21	0.012816	0.009631	0.010467	0.011611	0.009915	0.0108	0
4	3	-21.55				82.49	82.76	0.012642	0.010445	0.011098	0.012296	0.010253	0.01061	0
4	4	-20.49				82.92	83.23	0.012896	0.010207	0.011058	0.012233	0.009619	0.010117	0
4	5	-20.14				82.98	83.33	0.012411	0.01062	0.011288	0.011579	0.00935	0.010217	0
4	1	-18.12	-16.39	-0.04	-1.93	84.63	85.09	0.01209	0.009865	0.010731	0.010873	0.009507	0.010132	1
4	2	-19.85	-16.73	0.82	-2.12	83.39	84.01	0.012028	0.009171	0.010124	0.010584	0.009044	0.009421	1
4	3	-19.66	-17.88	0.38	-1.27	83.61	84.17	0.012433	0.00966	0.010477	0.01096	0.00937	0.009932	1
4	4	-18.63	-17.02	0.12	-1.1	84.33	84.64	0.012674	0.009475	0.010494	0.010921	0.009506	0.009776	1
4	5	-20.54	-17.96	-0.01	-1.27	83.29	83.58	0.012337	0.009677	0.010328	0.010663	0.00927	0.009754	1
5	1	-18.21				85.61	85.98	0.010839	0.008026	0.008193	0.009987	0.009323	0.008206	0
5	2	-19.18				84.82	84.99	0.011012	0.009158	0.009124	0.009993	0.009343	0.009484	0
5	3	-20.5				84.59	84.75	0.011113	0.009429	0.009501	0.010384	0.009626	0.009709	0
5	4	-19.28				84.78	84.93	0.011257	0.009143	0.007509	0.01062	0.009271	0.009706	0
5	5	-19.23				84.71	84.9	0.010785	0.010278	0.0096	0.01058	0.00974	0.009987	0
6	1	-21.06	-16.17	-0.3	2.32	83.55	83.95	0.011771	0.009458	0.009921	0.011932	0.009856	0.010135	1
6	2	-21.17	-19.44	-0.11	-0.34	83.91	84.29	0.012956	0.010178	0.010449	0.012273	0.009541	0.009918	1
6	3	-21.94	-19.2	0.7	0.19	81.38	81.79	0.012958	0.009952	0.010272	0.012082	0.009896	0.00997	1
7	1	-20.22	-18.2	0.08	-0.2	84.07	84.55	0.013189	0.009409	0.009872	0.012112	0.01011	0.009527	1
7	2	-20.08	-17.79	0.93	0.44	84.13	84.35	0.013105	0.009698	0.01001	0.012185	0.010269	0.009957	1
7	3	-20.38	-18.61	1.57	-0.1	83.8	84.21	0.012745	0.009953	0.010421	0.012171	0.010137	0.010017	1

ACH Medium Helmet 7 Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lzx (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-22.57				83.05	83.21	0.012283	0.010953	0.011501	0.010708	0.009167	0.010072	0
1	2	-22.06				83.59	83.92	0.012659	0.011188	0.011934	0.010737	0.009033	0.010223	0
1	3	-21.27				84.79	85.19	0.012572	0.011033	0.01204	0.01083	0.009648	0.010396	0
1	4	-22.19				81.83	82.14	0.012356	0.008423	0.008999	0.010972	0.008687	0.009537	0
1	5	-21.65				84.96	85.22	0.012151	0.010204	0.011131	0.01035	0.008792	0.009473	0
2	1	-16.72				86.1	86.87	0.011549	0.008154	0.009362	0.011391	0.009307	0.009368	0
2	2	-17.01				85.89	86.63	0.01164	0.009151	0.010319	0.011844	0.009716	0.008708	0
2	3	-18.18				84.85	85.61	0.011429	0.00853	0.009716	0.01137	0.009456	0.00958	0
2	4	-17.17				85.4	86.15	0.011794	0.008842	0.010019	0.011806	0.009694	0.009717	0
2	5	-18.31				85.17	85.88	0.011641	0.009035	0.010261	0.011677	0.009655	0.009443	0
2	1	-24.03	-21.64	2.61	2.28	83.46	83.69	0.011697	0.010393	0.010495	0.01135	0.009661	0.010696	1
2	2	-24.37	-22.37	3.39	3.07	83.24	83.53	0.012064	0.010434	0.010676	0.011499	0.009771	0.010556	1
2	3	-24.55	-22.39	2.87	2.1	82.72	82.99	0.010933	0.009732	0.00994	0.010839	0.009166	0.009993	1
2	4	-23.01	-20.61	3.24	2.84	83.79	84.04	0.011231	0.009825	0.010024	0.011272	0.009641	0.010065	1
2	5	-23.22	-20.82	-1.35	1.26	83.57	83.92	0.001216	0.009681	0.010188	0.011769	0.009613	0.010103	1
3	1	-18.11	-15.45	3.07	1.7	85.87	85.97	0.011304	0.009429	0.00981	0.011035	0.009543	0.009629	1
3	2	-20.5	-18.03	2.82	1.43	84.62	84.83	0.011406	0.009962	0.010098	0.01114	0.009474	0.009818	1
3	3	-19.35	-16.81	2.81	1.62	84.88	85.13	0.01134	0.009656	0.010134	0.011176	0.009551	0.009892	1
3	4	-17.17	-14.68	2.97	1.9	86.03	86.18	0.011124	0.009117	0.009635	0.010924	0.009443	0.009431	1
3	5	-19.69	-16.84	2.59	1.49	84.99	85.15	0.011341	0.009498	0.010021	0.011082	0.009607	0.009699	1
4	1	-21.39				82.66	83.23	0.012184	0.008266	0.009204	0.011638	0.009852	0.010005	0
4	2	-20.21				82.51	83.09	0.012766	0.008714	0.009578	0.011124	0.010744	0.010357	0
4	3	-20.14				82.14	82.52	0.012147	0.00972	0.010467	0.010321	0.00932	0.010632	0
4	4	-21.8				81.46	81.93	0.012755	0.010411	0.011127	0.011453	0.009999	0.011117	0
4	5	-19.62				81.48	81.96	0.012833	0.008246	0.009197	0.010843	0.009477	0.010709	0
4	1	-20.39	-18.31	2.49	0.92	82.67	83.3	0.012378	0.009731	0.010469	0.010868	0.009289	0.010053	1
4	2	-19.52	-18.11	2.08	1.32	83.27	83.84	0.012766	0.010181	0.010794	0.010957	0.009417	0.009978	1
4	3	-18.88	-17.06	2.82	0.75	82.58	83.21	0.012414	0.010041	0.010867	0.011286	0.009692	0.010181	1
4	4	-20.64	-18.16	3.28	0.91	81.92	82.67	0.012039	0.01014	0.010899	0.011185	0.00958	0.010213	1
4	5	-19.51	-17.33	2.93	1.17	82.63	83.29	0.01247	0.010618	0.011033	0.011243	0.009634	0.010234	1
5	1	-18.41				86.69	87.17	0.011306	0.009542	0.010037	0.010836	0.00971	0.010626	0
5	2	-18.82				86.12	86.24	0.011296	0.009732	0.009729	0.010694	0.00954	0.010056	0
5	3	-19.02				85.46	85.99	0.01059	0.008887	0.008725	0.010287	0.009163	0.009249	0
5	5	-20.18				84.89	85.2	0.011574	0.009288	0.009228	0.010271	0.009377	0.009616	0
6	1	-21.54	-19.61	1.97	1.5	82.27	82.61	0.012641	0.009748	0.010303	0.012003	0.009367	0.009899	1
6	2	-22.07	-20.21	1.69	0.8	81.92	82.38	0.012518	0.010053	0.010371	0.01143	0.009978	0.00999	1
6	3	-22.43	-20.74	1.97	1.45	80.57	80.93	0.012299	0.010103	0.010418	0.011833	0.009975	0.010083	1
7	1	-18.72	-16.56	2.74	1.53	83.56	83.84	0.011959	0.008762	0.009281	0.011646	0.00968	0.008991	1
7	2	-18.74	-16.73	2.18	2.18	81.59	81.67	0.012899	0.009012	0.009508	0.011788	0.009817	0.009111	1
7	3	-18.94	-17.07	2.01	1.78	82.84	83.16	0.012943	0.008991	0.009474	0.011695	0.009744	0.009035	1

IHPS Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	Izz (kg/m ²)	Ixx (kg/m ²)	Iyy (kg/m ²)	Iyz (kg/m ²)	Ixz (kg/m ²)	Ixy (kg/m ²)	Post_Fix
1	3	-20.89				79.02	79.18	0.0143481	0.0122348	0.0124137	0.0117702	0.0102794	0.0101065	0
1	4	-21.53				78.48	78.59	0.0137206	0.0123736	0.0127785	0.0116292	0.0101705	0.0114365	0
1	5	-21.31				79.01	78.97	0.0139946	0.0127525	0.012895	0.0123121	0.0105692	0.0116	0
1	6	-21.21				78.98	79.09	0.0140099	0.012816	0.0132606	0.0120513	0.0107273	0.0121761	0
1	7	-21.15				78.93	78.97	0.01451	0.0125872	0.0128826	0.0104322	0.009375	0.0116436	0
1	8	-19.84				79.37	79.47	0.0136753	0.0119069	0.0122247	0.0115977	0.0101531	0.0106266	0
1	9	-20.77				78.87	79.03	0.0136903	0.0123339	0.0128212	0.0125498	0.0104377	0.0095565	0
1	10	-21.09				78.34	78.42	0.0140719	0.0118763	0.0122254	0.0116251	0.0101689	0.0107792	0
2	1	-17.76				79.91	80.37	0.0136642	0.0108009	0.0116516	0.0130856	0.0110788	0.011146	0
2	2	-17.51				79.45	79.99	0.0137464	0.0106394	0.0113945	0.0134208	0.0113911	0.0113305	0
2	3	-16.98				79.82	80.38	0.0137881	0.0108494	0.011491	0.0130798	0.0114552	0.0109264	0
2	4	-18.1				79.42	80.05	0.0131547	0.0100602	0.0107939	0.0127954	0.0107707	0.0109893	0
2	5	-17.2				79.74	80.23	0.0135893	0.0105018	0.0113001	0.0130375	0.0111268	0.0112492	0
2	6	-17.55				79.23	79.75	0.0137858	0.0102218	0.0109373	0.012723	0.0109389	0.0108107	0
2	7	-17.92				79.5	79.94	0.0134919	0.0114718	0.011939	0.01344	0.0114824	0.0114438	0
2	8	-16.96				79.17	79.66	0.0138024	0.0102228	0.0109513	0.0127456	0.0107265	0.0112019	0
2	1	-20.03	-17.77	1.13	0.13	79.54	79.68	0.0139035	0.0112815	0.0112995	0.0124343	0.0109008	0.0112931	1
2	2	-20.42	-18.18	1.23	0.06	78.93	78.98	0.0134536	0.0113278	0.0111735	0.0124315	0.0108868	0.0112889	1
2	3	-19.95	-17.93	1.12	0.1	78.93	79.04	0.0140431	0.0113667	0.011346	0.0123866	0.0108878	0.0114736	1
2	4	-21.33	-19	1.24	0.96	78.31	78.26	0.0140072	0.0115809	0.0113295	0.012541	0.0109525	0.0115545	1
2	5	-20.82	-19.05	1.29	0.77	78.84	78.88	0.0137684	0.0116543	0.011508	0.0127086	0.0111665	0.0116056	1
2	6	-19.18	-16.9	0.25	-0.96	79.25	79.6	0.0142535	0.0116452	0.0118815	0.0126059	0.0110653	0.0115739	1
2	7	-21.53	-18.76	0.22	-1.03	78.13	78.5	0.0145522	0.011992	0.0121467	0.0127193	0.0110982	0.0119295	1
2	8	-23.6	-20.21	0.23	-1.41	76.52	76.8	0.013702	0.0124706	0.0123831	0.0125581	0.0109396	0.0121294	1
3	1	-18.8	-16.53	1.87	0.86	80.94	81.16	0.0134231	0.0112142	0.0113823	0.0126371	0.0110926	0.0112363	1
3	2	-16.52	-14.27	1.49	0.61	81.5	81.72	0.0133937	0.0109327	0.0111978	0.0127236	0.0113899	0.0111335	1
3	3	-18.18	-16.17	1.64	0.75	81.21	81.36	0.0136029	0.0113056	0.0113006	0.0128844	0.0113572	0.0113645	1
3	4	-16.91	-14.83	0.96	0.38	81.88	82.08	0.0137583	0.0113246	0.0115717	0.0130572	0.0115365	0.0113978	1
3	5	-17.26	-15.8	1.18	0.66	81.5	81.72	0.0137827	0.0114304	0.0116684	0.0131288	0.0116269	0.0115233	1
3	6	-18.76	-16.93	0.27	-0.3	80.37	80.56	0.0133152	0.0109554	0.0111467	0.0126503	0.0112548	0.0111183	1
3	7	-18.14	-15.99	0.99	0.09	80.56	80.75	0.0135382	0.011328	0.0115019	0.0128791	0.0114019	0.0113302	1
3	8	-16.86	-14.22	0.89	-0.31	80.95	81.12	0.013571	0.0114637	0.0116811	0.0128168	0.0114172	0.0112242	1
4	1	-17.36				78.38	78.65	0.0150185	0.0112212	0.0117605	0.0124777	0.0110452	0.0119061	0
4	2	-18.63				78.21	78.79	0.0147733	0.0106447	0.0112665	0.0121068	0.0108867	0.0122045	0
4	3	-18.68				79.2	79.49	0.0149763	0.0121243	0.0124529	0.0118085	0.0106226	0.0125192	0
4	4	-21.14				77.88	78.08	0.0141442	0.0116656	0.0118187	0.0126261	0.0109938	0.0115377	0
4	5	-19.37				78.18	78.65	0.0144994	0.0104944	0.0111487	0.0121121	0.0107315	0.0099866	0
4	6	-21.71				77.49	78.07	0.0145598	0.0118408	0.0120442	0.0119381	0.0105814	0.0125783	0
4	7	-19.33				77.51	77.86	0.0145752	0.010857	0.0115138	0.0118789	0.0106096	0.0123662	0
4	8	-19.9				77.82	78.36	0.0144345	0.0105548	0.0111276	0.012453	0.0108604	0.0098556	0
4	1	-20.51	-17.05	1.16	-1.34	77.84	78.21	0.0141107	0.0118886	0.0122623	0.0127768	0.0111162	0.011816	1
4	2	-20.61	-17.98	1.69	-0.93	77.04	77.49	0.0141501	0.0114379	0.0118936	0.0123949	0.0109535	0.0117094	1
4	3	-19.09	-16.69	1.85	-0.96	78.06	78.54	0.0141863	0.0119173	0.0122467	0.0126709	0.0111087	0.0119234	1
4	4	-19.77	-17.93	0.41	-1.86	77.48	77.94	0.0147203	0.0120233	0.0123398	0.0125054	0.0110597	0.0119381	1
4	5	-20.27	-18.97	1.36	-0.33	77.65	78.07	0.0148081	0.0118306	0.0121301	0.0125821	0.010572	0.0118569	1
4	6	-19.87	-17.18	0.81	-1.71	78.34	78.79	0.0132926	0.0111519	0.011562	0.0119387	0.0104933	0.0113767	1
4	7	-20.22	-17.87	0.21	-2.31	77.78	78.16	0.0141612	0.0114475	0.0118401	0.0122823	0.0107636	0.0114791	1
4	8	-21.21	-18.71	1.14	-1.41	77.21	77.655	0.0136641	0.0117444	0.0120189	0.0121978	0.0106342	0.0117838	1
5	1	-15.53				81.59	81.82	0.0130982	0.0106352	0.0103762	0.011194	0.0109189	0.0107933	0
5	2	-17.58				80.64	80.84	0.0133737	0.0108394	0.010472	0.0121101	0.0104942	0.0110685	0
5	3	-17.66				80.39	80.6	0.01285	0.0110618	0.0106825	0.0115388	0.0111684	0.011358	0
5	4	-19.04				79.89	80.15	0.0130503	0.0111788	0.0107854	0.011574	0.0105091	0.0114193	0
5	5	-18.07				80.2	80.47	0.0128623	0.0115276	0.0112251	0.0122894	0.0112761	0.0117985	0
5	6	-17.22				80.34	80.61	0.0126143	0.0102257	0.0100895	0.0102701	0.0105781	0.0106775	0
5	7	-17.18				80.33	80.62	0.0123248	0.0104878	0.0103224	0.0115619	0.0102308	0.0109316	0
5	8	-16.83				80.38	80.34	0.0128341	0.0108477	0.0102043	0.0112856	0.0103589	0.0106472	0
6	1	-17.56	-15.63	0.7	1.33	78.72	78.82	0.014451	0.010574	0.010699	0.012868	0.011723	0.011458	1
6	2	-16.6	-14.76	0.74	1.65	79.08	79.39	0.014522	0.010616	0.010629	0.012673	0.011764	0.011407	1
6	3	-16.73	-15.48	0.47	1.93	78.3	78.51	0.015067	0.010678	0.010638	0.012607	0.011386	0.011359	1
6	4	-17.05	-15.21	1.38	2.15	78.39	78.57	0.014671	0.010692	0.010795	0.012511	0.011986	0.011907	1
6	5	-17.16	-14.99	0.76	0.85	78.49	78.61	0.014233	0.011119	0.010893	0.013177	0.011857	0.011961	1
6	6	-16.64	-15.78	2.55	1.86	78.24	78.49	0.014323	0.010718	0.011219	0.013129	0.01066	0.011497	1
6	7	-16.01	-14	0.37	0.37	79.3	79.56	0.013919	0.010956	0.011125	0.012418	0.011134	0.01102	1
6	8	-16.73	-14.54	-1.09	0.57	78.9	79.23	0.01485	0.011273	0.011476	0.012534	0.011153	0.011138	1
6	9	-16.97	-14.4	1.47	1.29	77.58	77.85	0.014192	0.011408	0.011431	0.01247	0.010971	0.011262	1
6	10	-18.19	-15.89	1.33	1.28	76.99	77.28	0.014096	0.011394	0.011429	0.012678	0.011215	0.01132	

ACH Large Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-24.78				88.78	89.03	0.0136863	0.0113931	0.0117375	0.0135983	0.0101567	0.0113689	0
1	2	-23.65				89.82	90.09	0.0138181	0.0116307	0.0120573	0.0124425	0.0104497	0.0124331	0
1	3	-24.85				89.27	89.62	0.0138044	0.0109527	0.0115371	0.0133415	0.0102071	0.011865	0
1	4	-24.36				90.07	90.59	0.0141242	0.011757	0.0123884	0.0141064	0.0108637	0.0123107	0
1	5	-23.84				90.22	90.64	0.0139797	0.0119447	0.0124052	0.0139043	0.0108935	0.0125105	0
1	6	-25.03				89.5	89.86	0.0140772	0.012067	0.012438	0.0130287	0.0108373	0.0126286	0
1	7	-23.64				90.51	90.8	0.0141107	0.0120099	0.0123527	0.0139336	0.0110418	0.0126594	0
1	8	-24.18				90.01	90.38	0.0140978	0.0120873	0.0125443	0.0134296	0.0108941	0.0127167	0
2	1	-24.09				89.4	89.61	0.0138278	0.0118413	0.0121976	0.0132058	0.0107909	0.0129345	0
2	2	-24.01				88.8	89.03	0.0143535	0.0120146	0.0124904	0.013576	0.0110693	0.0123712	0
2	3	-21.13				89.27	89.58	0.0142081	0.0109002	0.011666	0.0125195	0.0101234	0.0118923	0
2	4	-21.42				89.36	89.83	0.0139658	0.0116046	0.0123994	0.0129147	0.0107935	0.0123585	0
2	5	-20.06				90.56	90.38	0.0142802	0.0123886	0.0124494	0.0134196	0.0113992	0.0120539	0
2	6	-20.7				89.68	90.06	0.0145548	0.0120907	0.0129176	0.0131444	0.0109292	0.0124492	0
2	7	-20.09				89.13	89.63	0.0146328	0.0113877	0.012111	0.0137102	0.0114195	0.0126449	0
2	8	-19.56				89.79	90.27	0.014372	0.0119202	0.0127006	0.012722	0.0107374	0.0125069	0
3	1	-24.73	-21.22	-0.01	-3.19	89.27	89.16	0.0130226	0.0112672	0.0114723	0.0123486	0.0104355	0.0121016	1
3	2	-26.2	-22.32	0.75	-1.8	88.55	88.84	0.0136652	0.0115571	0.0124626	0.0129917	0.0114553	0.0118489	1
3	3	-23.57	-21.17	0.95	-3.84	90	90.64	0.0136769	0.0110465	0.0125684	0.0129396	0.0111751	0.0111842	1
3	4	-22.75	-20.7	1.49	-3.92	89.5	90.1	0.0135508	0.0108968	0.0121938	0.0130591	0.0111507	0.0108212	1
3	5	-23.48	-21.68	0.67	-4.54	89.59	90.22	0.0139157	0.011225	0.0125158	0.0130316	0.0116093	0.0108626	1
3	6	-22.73	-20.29	0.34	-5.21	89.59	90.26	0.0143007	0.0110878	0.0125567	0.01335	0.0115824	0.0112245	1
3	7	-23.4	-21.19	0.98	-4.51	89.13	89.91	0.0134942	0.0104521	0.0119907	0.0129382	0.0110025	0.0108154	1
3	8	-21.83	-19.44	0.47	-5.07	89.76	90.33	0.0141037	0.0106051	0.0121109	0.0130901	0.0114244	0.0109306	1
4	1	-22.34				88.43	90.55	0.0133838	0.0081868	0.0113967	0.0115463	0.0101038	0.0104299	0
4	2	-24.76				86.69	87.4	0.0128152	0.0108546	0.0118472	0.0127999	0.0110637	0.0098	0
4	3	-24.26				86.83	87.47	0.0129676	0.0112541	0.0122206	0.0121338	0.0106632	0.0106812	0
4	4	-22.32				86.01	86.8	0.0130449	0.0097122	0.0105781	0.0124608	0.0120431	0.0116209	0
4	5	-23.89				84.89	85.72	0.0121306	0.009265	0.0100703	0.0129935	0.0110818	0.0090296	0
4	6	-22.6				86.43	87.14	0.0126298	0.0103582	0.011482	0.0118782	0.0104507	0.0108333	0
4	7	-21.81				86.72	87.41	0.0129447	0.0106929	0.0120212	0.0126046	0.0108826	0.0092648	0
4	8	-23.74				84.41	85.09	0.0130294	0.009266	0.0099655	0.0120427	0.0105774	0.0092312	0
5	2	-19.51				90.94	91.35	0.0137992	0.0112426	0.0120984	0.0137989	0.0110104	0.0118208	0
5	3	-17.66				91.64	92.11	0.014116	0.01113657	0.012245	0.0138585	0.0112754	0.0120214	0
5	4	-17.16				92.13	92.51	0.0141171	0.011431	0.0122556	0.0132204	0.0111543	0.0120631	0
5	5	-17.29				91.91	92.29	0.0144831	0.0114103	0.0122659	0.0132907	0.0111915	0.0120204	0
5	6	-19.41				91.19	91.74	0.0142687	0.011544	0.0123272	0.0133788	0.0110954	0.0121466	0
5	7	-18.06				91.33	91.7	0.0138525	0.0117084	0.0124314	0.0138425	0.0113089	0.0122992	0
5	8	-18.69				91.16	91.58	0.0144305	0.0116668	0.0124345	0.0133261	0.0111024	0.0122083	0

ACH Small Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	-29.25				83.84	83.94	0.0114982	0.0097921	0.00943	0.0098521	0.009189	0.0105162	0
1	2	-29.38				82.29	82.6	0.0117821	0.0096232	0.0094784	0.0097629	0.0100678	0.0110311	0
1	3	-29.76				82.29	82.45	0.0117425	0.0095696	0.009228	0.0100102	0.0088907	0.0095391	0
1	4	-31.32				81.91	81.75	0.0116587	0.0101617	0.009439	0.0095089	0.0100264	0.0111563	0
1	5	-30.35				82.84	82.94	0.0117779	0.0098012	0.0094786	0.0100748	0.0090695	0.0101993	0
1	6	-30.33				83.32	83.25	0.0118388	0.0103649	0.0098632	0.0104669	0.009338	0.0104258	0
1	7	-31.04				81.78	81.99	0.0115937	0.0099247	0.0096681	0.0100842	0.0091174	0.0097181	0
1	8	-29.32				81.46	81.03	0.0111204	0.0096661	0.0085556	0.0088208	0.0083793	0.0101023	0
2	1	-24.14				78.84	78.82	0.0099709	0.0094079	0.0097393	0.0090374	0.0080647	0.0094803	0
2	2	-26.63				79.35	79.42	0.0098516	0.0092432	0.0091736	0.0084032	0.007625	0.0088443	0
2	3	-26.74				77.92	78.16	0.0095358	0.0090366	0.0092195	0.0090327	0.0074821	0.0083829	0
2	4	-27.32				77.73	77.89	0.009534	0.0094895	0.0094061	0.0089091	0.0079064	0.0092965	0
2	5	-29.36				76.35	76.59	0.0095663	0.0094168	0.0094391	0.0093718	0.0081049	0.0094319	0
2	6	-27.7				77.47	77.67	0.0103571	0.0095179	0.0096338	0.009833	0.0085387	0.0093576	0
2	7	-28.32				77.43	77.68	0.0099776	0.0099599	0.0099382	0.0097936	0.0086278	0.0092155	0
2	8	-28.89				76.94	77.04	0.0105215	0.0098476	0.0097734	0.0102063	0.0086112	0.0095146	0
3	1	-25.27	-23.55	-1.59	-2.31	82.32	82.62	0.0110946	0.0092703	0.0093275	0.0104061	0.0091278	0.0091958	1
3	2	-26.78	-24.58	-1.62	-2.27	81.18	81.54	0.0107991	0.0092485	0.0091798	0.0102883	0.0090575	0.0092268	1
3	3	-25.83	-24.28	-1.43	-2.29	81.23	81.42	0.010984	0.0093826	0.0092396	0.0104956	0.009259	0.0093788	1
3	4	-27.02	-24.58	-1.88	-3.05	80.02	80.33	0.0100507	0.0089899	0.0089811	0.0100754	0.0088081	0.0090532	1
3	5	-26.15	-23.82	-1.62	-2.99	79.64	79.9	0.0104296	0.0094357	0.0093538	0.010318	0.0090411	0.0092794	1
3	6	-25.16	-23.41	-1.95	-3.18	79.73	79.99	0.0106122	0.0095514	0.0094328	0.0102484	0.0089327	0.0095086	1
3	7	-26.11	-24.4	-1.47	-3.08	78.93	79.28	0.010417	0.0096968	0.0096392	0.0103192	0.008966	0.0095745	1
3	8	-25.25	-23.66	-1.82	-3.28	79.67	79.92	0.0105817	0.0097349	0.0095199	0.0103515	0.0090921	0.0096066	1
4	1	-27.45				78.8	79.16	0.0109855	0.0092896	0.0095788	0.0100127	0.0087423	0.0080342	0
4	2	-30.15				77.13	77.51	0.0111858	0.009651	0.0095861	0.0091094	0.0083747	0.0076569	0
4	3	-28.16				77.68	77.99	0.0116039	0.0094122	0.009431	0.0093899	0.0083438	0.0079331	0
4	4	-29.23				78.72	79.04	0.0112974	0.0113188	0.0115391	0.0102049	0.0088933	0.0089832	0
4	5	-28.93				78.79	79.05	0.0117132	0.0113822	0.0116183	0.0105873	0.0080821	0.0077968	0
4	6	-28.66				78.88	79.18	0.0119645	0.0104366	0.0108902	0.0100754	0.0077152	0.0083799	0
4	7	-29.19				78.49	78.78	0.0121264	0.0101352	0.0105478	0.0106396	0.0082823	0.0081377	0
4	8	-28.83				76.91	77.32	0.0118798	0.010235	0.0103037	0.0103263	0.0088312	0.007953	0
5	1	-27.3				81.64	82.16	0.0097645	0.0093051	0.009949	0.0099279	0.0091149	0.0086228	0
5	2	-24.84				81.51	82.16	0.0099052	0.0087576	0.0098803	0.0105702	0.0091625	0.00744734	0
5	3	-24.94				81.78	82.31	0.0102594	0.0089028	0.009915	0.0091894	0.0088446	0.0091939	0
5	4	-24.87				82.32	83.05	0.0105222	0.0087834	0.0096902	0.0093533	0.008478	0.0073539	0
5	5	-23.93				82.29	83.16	0.0096946	0.007096	0.0080848	0.0095555	0.0088494	0.0072585	0
5	6	-24.47				82.94	83.6	0.010328	0.008219	0.0093377	0.0096233	0.008946	0.0088596	0
5	7	-25.33				82.25	82.75	0.0100594	0.0081269	0.0091023	0.0094417	0.0089232	0.0083899	0
5	8	-25.37				82.42	83.33	0.010142	0.0080208	0.0092708	0.0095355	0.0089967	0.0108849	0

HGU56/P Medium Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	1.98				45.46	45.35	0.0170371	0.0176261	0.0147529	0.0151532	0.0143618	0.0144254	0
1	2	2.67				44.47	44.4	0.0173768	0.0171694	0.0144498	0.0155163	0.0142704	0.0144302	0
1	3	3.28				44.61	44.17	0.0171142	0.0174848	0.0143184	0.0149191	0.0139313	0.0142511	0
1	4	2.98				44.74	44.45	0.0173377	0.0178784	0.0148485	0.0156057	0.0141501	0.014064	0
1	5	2.67				43.58	43.69	0.0169425	0.0171172	0.0146149	0.0150375	0.0143102	0.0141872	0
1	6	2.01				44.25	44.26	0.0173693	0.0179713	0.015178	0.0155967	0.0149978	0.015869	0
1	7	3.69				42.82	42.95	0.0173371	0.0176765	0.0154752	0.0153582	0.0142708	0.0141788	0
1	8	3.11				43.18	43.22	0.0166337	0.0165065	0.013857	0.014683	0.0136415	0.0134431	0
2	1	10.14				43.13	42.61	0.0163652	0.0154766	0.0134025	0.0159663	0.0147618	0.0146798	0
2	2	7.19				42.86	42.52	0.0159671	0.0142855	0.0127299	0.0163204	0.0146815	0.0140742	0
2	3	10.21				42.13	41.79	0.0158577	0.0143791	0.0128922	0.0175607	0.0147961	0.0141803	0
2	4	13.56				42.69	42.32	0.0155024	0.0154795	0.0134328	0.0161087	0.0150564	0.0146323	0
2	5	12.53				42.92	42.67	0.0164236	0.0155689	0.0134808	0.0163609	0.0151992	0.014703	0
2	6	12.54				42.6	42.57	0.0166586	0.0157168	0.013559	0.016666	0.0152715	0.0144048	0
2	7	12.85				43.33	43.23	0.0165233	0.0154478	0.0136246	0.0166303	0.0152353	0.0148667	0
2	8	13.79				43.02	42.56	0.015673	0.0151587	0.0128937	0.0162998	0.0147711	0.0141163	0
3	1	4.56	5.8	6.09	5.36	43.51	43.52	0.0165024	0.0165319	0.0146748	0.0164968	0.0148565	0.0152412	1
3	2	4.09	5.32	6.58	5.81	43.69	43.69	0.0168064	0.0166589	0.0146747	0.0166665	0.0151192	0.015439	1
3	3	4.64	6.16	6.61	5.72	42.97	42.96	0.0169539	0.0168664	0.0150533	0.016909	0.0152541	0.0156829	1
3	4	5.13	6.53	6.42	5.53	42.41	42.37	0.0169916	0.0170698	0.015281	0.0167816	0.0151851	0.0156593	1
3	5	4.9	5.8	6.28	5.51	42.02	41.92	0.0169192	0.0172024	0.0152778	0.0168293	0.0152272	0.0158431	1
3	6	4.87	6.09	6.22	5.56	41.61	41.62	0.0163401	0.0164965	0.0145525	0.0162903	0.0146605	0.0153631	1
3	7	5.54	6.26	6.37	5.35	41.76	41.77	0.0164931	0.0167037	0.0147782	0.0164534	0.0149076	0.0154879	1
3	8	5.02	6.39	6.25	5.19	41.81	41.73	0.0165026	0.0167814	0.014763	0.016458	0.0149472	0.015556	1
4	1	2.73				44.6	45.22	0.0161357	0.0155957	0.0147031	0.0166044	0.0152573	0.0172161	0
4	2	4.73				40.93	41.48	0.0152121	0.0166752	0.0155099	0.0164208	0.0154498	0.0167956	0
4	3	4.8				38.32	39.1	0.0154114	0.0138527	0.013414	0.0167216	0.0154816	0.0169926	0
4	4	5.21				38.95	39.53	0.0153917	0.0155339	0.0148773	0.0172061	0.0158327	0.0176354	0
4	5	4.51				40.41	40.93	0.015497	0.0168845	0.01582	0.016423	0.0152513	0.0172016	0
4	6	4.3				40.08	40.64	0.0154246	0.0161352	0.0152165	0.0177037	0.0166034	0.0165	0
4	7	4.97				39.14	39.8	0.0156369	0.0160769	0.0153253	0.0171526	0.0158192	0.017821	0
4	8	5.2				40.19	40.71	0.0153	0.017523	0.0164685	0.0168455	0.0157022	0.0162443	0
5	1	3.48				46.78	47.36	0.0163331	0.0164933	0.0153545	0.0161512	0.0151975	0.0160692	0
5	2	4.19				44.71	45.09	0.0156323	0.0154502	0.0138106	0.015528	0.0141756	0.0148007	0
5	3	3.89				45.86	46.49	0.0160262	0.0148251	0.0139707	0.016443	0.0147961	0.0145184	0
5	4	3.26				46.77	47.09	0.0157165	0.0160952	0.014749	0.0162528	0.014638	0.0155846	0
5	5	4.16				45.82	46.02	0.0163662	0.0160577	0.0146185	0.0163523	0.0148739	0.0155959	0
5	6	3				46.92	46.8	0.0171352	0.0162249	0.0140338	0.0153773	0.0140881	0.0156724	0
5	7	3.45				46.59	46.78	0.0162754	0.0162135	0.0145371	0.0165774	0.0150372	0.0156824	0
5	8	4.04				44.96	45.25	0.0155961	0.016373	0.0147917	0.0167491	0.0151065	0.0156576	0
6	1	2.93	1.23	5.19	4.14	44.58	45.09	0.016319	0.016215	0.015199	0.01506	0.015163	0.016569	1
6	2	1.82	2.94	5.67	3.88	44.97	44.96	0.016312	0.016345	0.014328	0.014702	0.014924	0.01579	1
6	3	2.01	3.14	5.34	3.95	43.96	44.03	0.016425	0.016301	0.014378	0.014675	0.015145	0.015783	1
6	4	2.36	3.98	4.96	4.07	43.93	43.88	0.01635	0.016297	0.014353	0.014611	0.014779	0.015601	1
6	5	2.96	4.48	5.58	4.41	43.55	43.58	0.01611	0.016303	0.014384	0.014585	0.014754	0.01575	1
6	6	2.56	3.74	5.47	4.68	43.7	43.71	0.015483	0.016422	0.014443	0.014387	0.014798	0.015687	1
6	7	2.89	3.95	5.49	4.62	44.32	44.21	0.015247	0.016061	0.014085	0.014539	0.014615	0.015506	1
6	8	2.55	3.55	5.72	4.76	44.29	44.14	0.015126	0.016253	0.01437	0.014561	0.014753	0.015786	1
6	9	3.25	6.07	5.57	4.17	43.32	43.32	0.015198	0.016236	0.014023	0.014604	0.014927	0.015553	1
6	10	3.31	5.09	5.48	4.37	42.9	42.81	0.015277	0.016342	0.014318	0.014696	0.014837	0.015562	1
7	1	3.2	4.82	5.26	4.51	43.9	44.06	0.016131	0.015525	0.01382	0.014289	0.014511	0.015043	1
7	2	3.07	4.73	5.34	5.33	44.03	43.97	0.016199	0.015847	0.013799	0.013931	0.014455	0.015233	1
7	3	3.76	5.97	5.45	5.24	42.26	42.37	0.016218	0.0158	0.013988	0.014273	0.014407	0.01518	1
7	4	3.05	5.43	5.55	4.88	42.49	42.83	0.016273	0.015799	0.014061	0.013725	0.014359	0.015379	1
7	5	2.52	4.4	5.47	4.89	42.61	42.6	0.016458	0.015789	0.013926	0.014839	0.01426	0.015999	1
7	6	2.73	2.31	5.42	1.42	43.48	43.44	0.016227	0.017376	0.014885	0.014587	0.014677	0.015675	1
7	7	3.1	4.84	5.87	5.09	42.98	42.93	0.01508	0.016124	0.014398	0.014856	0.015032	0.015631	1
7	8	3	4.22	4.97	5.33	42.84	42.79	0.01593	0.01579	0.013819	0.01446	0.014669	0.015606	1
7	9	3.28	4.78	5.19	5.24	43.01	42.9	0.016104	0.015931	0.014113	0.014984	0.014838	0.014978	1
7	10	2.82	3.2	5.18	4.01	43.39	43.49	0.016093	0.016451	0.014578	0.014773	0.01494	0.015974	1

ACH Medium w/ NVD Stowed Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	Izz (kg/m ²)	Ixx (kg/m ²)	Iyy (kg/m ²)	Iyz (kg/m ²)	Ixz (kg/m ²)	Ixy (kg/m ²)	Post_Fix
1	1	27.32				119.98	120.59	0.0227201	0.0165254	0.0288823	0.0233696	0.0111815	0.0206025	0
1	2	22.39				120.58	121.16	0.021526	0.0173267	0.0282939	0.0229127	0.0106349	0.021279	0
1	3	23.69				120.25	120.93	0.0217865	0.0169605	0.0284217	0.0225156	0.0100104	0.0210675	0
1	4	22.47				120.86	121.42	0.021537	0.0175257	0.0287699	0.0229264	0.0102587	0.0216426	0
1	5	20.31				120.82	121.53	0.0209089	0.0171424	0.0280865	0.0223961	0.0102316	0.0213026	0
1	6	20.58				120.68	121.33	0.02079	0.0170831	0.0279337	0.0221032	0.0098714	0.0214077	0
1	7	23.57				120.38	121.1	0.021646	0.016478	0.0280245	0.022934	0.0102224	0.0213241	0
1	8	21.96				120.74	121.34	0.0213973	0.0173122	0.0285969	0.022741	0.0109793	0.0215794	0
2	2	31.89				117.72	117.76	0.0215667	0.0198492	0.0302004	0.0251087	0.0120484	0.0235184	0
2	3	36.02				117.5	117.42	0.0225569	0.0196598	0.0301328	0.024907	0.0113515	0.023276	0
2	5	33.54				111.88	111.88	0.0214762	0.0184845	0.0291828	0.0242323	0.0117368	0.0218807	0
2	6	30.74				116.87	117.33	0.0229629	0.016478	0.0277192	0.0238886	0.0111304	0.0199879	0
2	7	31.24				116.21	116.54	0.0242859	0.0163903	0.028173	0.0244567	0.0116796	0.0204381	0
2	8	30.24				116.87	117.2	0.0235163	0.0167663	0.0281159	0.0239224	0.0109437	0.0205135	0
2	9	30.66				116.52	116.94	0.0233868	0.0165588	0.0280468	0.024238	0.0111971	0.0204352	0
2	10	29.22				116.66	117	0.0228723	0.0169285	0.0280565	0.0239126	0.0108975	0.0205291	0
2	1	23.31	25.42	7.89	6.85	118.04	118.01	0.0213739	0.0185739	0.027657	0.0229314	0.0106803	0.0215311	1
2	2	21.53	23.88	8.65	7.55	118.23	118.04	0.0216563	0.019034	0.0275702	0.0226785	0.0107758	0.0215923	1
2	3	21.81	23.37	9.25	8.14	118	117.96	0.0210703	0.0191567	0.027777	0.0226836	0.0108445	0.0217893	1
2	4	22.99	25.38	8.12	7.02	117.61	117.7	0.0221864	0.018768	0.0278997	0.0233911	0.0110851	0.0218159	1
2	5	20.8	23.43	8.1	6.51	118.11	118.14	0.0211514	0.0193759	0.0279562	0.0230609	0.0112394	0.0218492	1
2	6	26.71	28.47	7.13	7.87	118.38	118.4	0.0117333	0.0172309	0.0270679	0.023008	0.0107366	0.0203854	1
2	7	28.41	29.92	8.67	7.63	117.58	117.61	0.0222382	0.017196	0.0273753	0.0234142	0.0108235	0.0205889	1
2	8	26.79	28.67	8.42	7.01	118.13	118.08	0.0220836	0.0176713	0.0274382	0.0232628	0.0108162	0.0209797	1
3	1	32.57	34.36	8.7	7.52	118.59	118.5	0.0234915	0.0166205	0.0279678	0.0244017	0.0115949	0.0201761	1
3	2	32.48	33.78	8.26	6.95	118.47	118.62	0.023156	0.016472	0.0276696	0.024205	0.0114198	0.0201749	1
3	3	28.87	30.8	8.1	6.84	119.44	119.69	0.0225321	0.0173224	0.0277463	0.0238341	0.0113148	0.0205398	1
3	4	32.81	34.18	8.43	7.18	118.17	118.4	0.0231541	0.0167823	0.0276651	0.0241292	0.0117193	0.0201662	1
3	5	33.33	33.94	8.92	7.46	118.54	118.88	0.022835	0.0161901	0.0273725	0.0241864	0.0115101	0.0201311	1
3	7	34.51	35.05	8.32	7.65	116.88	117	0.0236105	0.0163968	0.0278924	0.0244179	0.0119483	0.0199689	1
3	8	28.35	29.01	8.82	8.22	118.33	118.61	0.0225623	0.0177461	0.0280376	0.0238729	0.011446	0.0208481	1
3	9	28.43	28.99	8.44	7.98	118.22	118.43	0.0225592	0.0177465	0.0281839	0.0240127	0.0114369	0.0210142	1
4	1	29.05				116.3	116.52	0.0233483	0.014916	0.0271693	0.0237255	0.0111843	0.021007	0
4	2	26.55				117.65	117.82	0.0232738	0.0181061	0.0283573	0.0230719	0.0110971	0.0214805	0
4	3	27.64				117.99	118.43	0.0226679	0.0162038	0.0270968	0.0224735	0.010369	0.0196342	0
4	4	27.98				118.07	118.28	0.0234747	0.0179135	0.0279006	0.023515	0.0108939	0.021138	0
4	5	29.58				117.12	117.52	0.0239451	0.0176352	0.0284632	0.0238383	0.0113927	0.0204427	0
4	6	29.9				115.8	116.15	0.0240255	0.0143661	0.026907	0.0242096	0.0118619	0.0212657	0
4	7	29.53				117.29	117.59	0.0239071	0.0177101	0.0286943	0.0239463	0.0113174	0.0215918	0
4	8	27.95				116.69	117.13	0.0236342	0.0163305	0.027865	0.0236891	0.0110068	0.0203892	0
4	9	24.14				117.93	118.39	0.0227542	0.0177846	0.0283178	0.0236761	0.0114811	0.0224551	0
4	1	29.14	30.9	9.52	7.55	115.94	116.15	0.0224789	0.0174736	0.0277771	0.0232989	0.0110084	0.0209291	1
4	2	25.86	27.79	9.69	7.9	116.36	116.46	0.0222418	0.0187343	0.0283354	0.0229711	0.0109982	0.0214578	1
4	3	28.01	29.89	9.62	7.73	115.85	115.99	0.0233879	0.0181268	0.02812	0.0234064	0.0111541	0.0206491	1
4	4	24.22	25.75	10.02	7.67	116.39	116.5	0.0222068	0.018955	0.0276019	0.0224512	0.0105624	0.0210408	1
4	5	24.5	26.67	9.22	6.84	116.39	116.55	0.0221554	0.0186522	0.0280075	0.0229409	0.011008	0.0214874	1
4	6	25.22	27.4	9.08	6.46	115.96	116.14	0.0220286	0.0188101	0.0281605	0.022986	0.0109071	0.0215036	1
4	7	24.97	26.85	9.47	7.75	115.85	116.02	0.0223107	0.0188505	0.0282155	0.022923	0.0108265	0.0212541	1
4	8	27.61	29.26	8.4	5.83	115.64	115.85	0.0221362	0.017512	0.0276305	0.0229809	0.010485	0.0208469	1
5	1	32.79				120.61	120.76	0.0226323	0.0164529	0.0263533	0.0232822	0.0105857	0.0199978	0
5	2	28.65				120.51	120.98	0.0217553	0.0166056	0.0260379	0.0225526	0.0103544	0.0199558	0
5	3	29.46				121.32	121.73	0.0224503	0.0173533	0.0263665	0.0225636	0.0104633	0.0203536	0
5	4	30.14				119.25	119.47	0.0221302	0.0169308	0.0265433	0.0229977	0.010657	0.0203924	0
5	5	29.79				119.42	119.46	0.0223351	0.0173888	0.026486	0.0232346	0.0110858	0.0204997	0
5	6	30.17				120.25	120.24	0.0221296	0.0166589	0.0253893	0.0220914	0.0100021	0.0200857	0
5	7	27.69				120.78	121.26	0.021552	0.0175382	0.0262113	0.0217122	0.0099732	0.020987	0
5	8	29.47				120.93	121.37	0.0224809	0.017411	0.0264546	0.0233305	0.0102745	0.0206864	0
6	1	26.87	21.68	7.95	7.01	120.34	119.51	0.021548	0.018643	0.026158	0.025345	0.010419	0.024019	1
6	2	22.48	21.93	6.51	5.97	120.82	119.96	0.020519	0.018385	0.026031	0.02517	0.0106691	0.023567	1
6	3	22.82	23.86	8.02	7.65	116.82	116.07	0.020648	0.018462	0.025952	0.025442	0.010968	0.024017	1
6	4	22.69	23.62	7.49	7.53	116.37	115.63	0.020613	0.018663	0.026246	0.025222	0.01091	0.024033	1
6	5	23.8	24.32	8.41	7.79	116.11	115.28	0.021311	0.0186	0.026281	0.025458	0.011011	0.024097	1
6	6	24.47	25.12	7.22	6.67	117.67	116.79	0.020775	0.018115	0.026257		0.010383	0.02381	1
6	7	25.13	26.1	7.44	6.56	117.23	116.33	0.020728	0.018274	0.026503	0.025742	0.010853	0.023914	1
6	8	23.01	25.21	7.84	7.82	117.18	116.2	0.019629	0.018454	0.025697	0.025183	0.010448	0.023727	1
6	9	25.24	26.42	7.91	7.95	116.48	115.77	0.021302	0.018267	0.026335	0.025701	0.010707	0.023881	1
6	10	22.86	23.77	7.11	6.64	117.33	116.56	0.020648	0.018834	0.026566	0.025422	0.01077	0.02413	1
7	1	26.14	27.57	8.06	8.39	117.21	116.37	0.02162	0.017714	0.026105	0.025759	0.011162	0.023684	1
7	2	27.11	28.45	8.7	8.26	117.16	116.22	0.021556	0.01727	0.026192	0.025764	0.011488	0.023863	1
7	3	24.87	25.87	8.02	7.78	115.74	114.91	0.021493	0.018626	0.026664	0.025649	0.010858	0.024317	1
7	4	25.59	26.57	8.78	8.22	115.45	114.64	0.021579	0.018647	0.026646	0.025412	0.011591	0.024219	1
7	5	25.1	26.22	9.01	8.79	115.97	115.16	0.021783	0.018517	0.026726	0.025843	0.011616	0.024401	1
7	6	22.25	22.67	8.31	8.1	117.51	116.73	0.020723	0.019022	0.025931	0.024453	0.011309	0.02403	1
7	7	23.79	24.88	9.24	9.03	116.67	115.81	0.02101	0.018436	0.025981	0.025287	0.011111	0.024012	1
7	8	24.48	25.53	6.64	6.6	115.62	115.03	0.021136	0.018388	0.026441	0.024977	0.011205	0.023925	1
7	9	24.12	24.83	8.72	8.45	115.32	114.64	0.02126	0.018509	0.026776	0.025137	0.011457	0.024268	1
7	10	22.72	23.88	9.07	8.65	116.34	115.41	0						

ACH Medium w/ NVD Deployed Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	32.62				75.82	76.02	0.0261243	0.0103698	0.0259636	0.0264888	0.0195637	0.0175053	0
1	2	33.03				76.38	76.51	0.0262276	0.0099175	0.0256827	0.0261944	0.0186767	0.0160565	0
1	3	31.26				76.86	77.22	0.0265499	0.0094297	0.0254924	0.0263954	0.0181864	0.0163373	0
1	4	32.19				76.48	76.59	0.0266145	0.010293	0.0258562	0.0262855	0.0196841	0.0177777	0
1	5	34.79				74.21	74.56	0.0260117	0.0105998	0.0262681	0.0275708	0.0202711	0.0179746	0
1	6	32.48				76.08	76.13	0.0269682	0.0109163	0.0265328	0.0277729	0.0199234	0.0181114	0
1	7	34.76				74.62	74.75	0.0266913	0.0116802	0.0271985	0.0280788	0.0205249	0.0187442	0
1	8	32.86				75.37	75.8	0.0266687	0.0118135	0.0271189	0.0282807	0.0197514	0.0168282	0
2	1	35.79				70.41	70.35	0.025411	0.011364	0.0251769	0.0258508	0.0197064	0.0158297	0
2	2	36.43				69.85	69.78	0.0252691	0.011218	0.0247813	0.0258048	0.0201355	0.0168166	0
2	3	36.44				70.05	69.91	0.0250792	0.0118892	0.0253467	0.0258948	0.0200133	0.016288	0
2	4	35.1				71.16	71.09	0.0245846	0.0111074	0.0246829	0.0255647	0.0193697	0.0160133	0
2	5	35.29				70.91	70.86	0.0249193	0.0107525	0.0248074	0.0258468	0.0192408	0.0160533	0
2	6	35.95				70.52	70.48	0.0251349	0.010784	0.0248205	0.0258509	0.0196551	0.0167277	0
2	7	34.34				71.61	71.57	0.0249616	0.0113376	0.0250233	0.0259489	0.0194591	0.0162606	0
2	8	34.29				71.86	71.68	0.0256313	0.0115758	0.0252681	0.0262247	0.0195649	0.0167926	0
2	1	35.62	37.18	7.62	6.59	72.44	72.15	0.0261202	0.0123725	0.0257974	0.0263015	0.020131	0.0169949	1
2	2	33.74	35.57	7.92	6.78	73.85	73.57	0.0260102	0.0122789	0.0258783	0.0262789	0.0193431	0.016841	1
2	3	33.98	35.7	7.15	5.88	73.57	73.38	0.02671	0.0122938	0.0258745	0.0263951	0.0194806	0.0171691	1
2	4	34.01	36.01	7.1	5.9	73.21	72.88	0.0260943	0.012375	0.0259072	0.0263282	0.0194559	0.0169704	1
2	5	34.51	35.92	6.75	5.51	72.65	72.54	0.0266729	0.0122681	0.0261406	0.0263704	0.0197594	0.0171353	1
2	6	35.65	37.16	7.37	6.07	71.82	71.62	0.0253473	0.0116707	0.0251548	0.0258806	0.0196945	0.0164119	1
2	7	36.56	38.08	7.09	5.51	70.27	69.98	0.0254776	0.0119335	0.0252671	0.0257337	0.0199912	0.0163803	1
2	8	34.86	36.72	7.62	6.23	71.4	71.11	0.0260799	0.0120039	0.0254445	0.0260829	0.0195339	0.016621	1
3	1	35.33	36.12	7.19	7.02	72.68	72.49	0.0253625	0.012041	0.0253913	0.0265268	0.0204866	0.0167287	1
3	2	35.59	36.51	7.43	7.11	72	71.81	0.0249566	0.0114226	0.0250017	0.0261154	0.0201113	0.0163866	1
3	3	35.76	36.27	7.35	7.33	72.35	72.15	0.0251709	0.0117868	0.0253576	0.0264412	0.0204259	0.0165013	1
3	4	35.14	36.6	7.4	7.07	72.18	72.06	0.0249339	0.0115502	0.0251198	0.0261433	0.0202726	0.0164129	1
3	5	33.98	36	7.47	7.1	72.99	72.81	0.0252122	0.0116725	0.02514	0.0262817	0.0199724	0.0164261	1
3	6	35.5	37.33	7.03	6.4	72.8	72.61	0.0250087	0.0117784	0.0250693	0.0262972	0.0205975	0.0166661	1
3	7	35.66	37.51	7.39	6.61	71.55	71.38	0.025	0.012037	0.0254314	0.0264047	0.0208723	0.0167124	1
3	8	34.84	36.78	7.4	6.76	72.24	72.06	0.025087	0.0118539	0.0253099	0.0264778	0.020477	0.0166518	1
4	1	34.25				71.48	71.45	0.0262392	0.0090304	0.0243223	0.0253895	0.0185114	0.0168556	0
4	2	34.94				72.06	72.16	0.0264924	0.0111735	0.0258959	0.0260574	0.0190965	0.0155713	0
4	3	35.73				69.17	69.97	0.026328	0.0089402	0.0252296	0.0262873	0.019901	0.0172967	0
4	4	34.99				70.64	70.53	0.0262504	0.0106075	0.0253945	0.0262882	0.0193922	0.016491	0
4	5	35.04				70.93	70.82	0.0267329	0.0108875	0.0256414	0.0263376	0.0194667	0.0162101	0
4	6	34.69				71.72	71.49	0.0270327	0.0126372	0.0263746	0.0264498	0.019492	0.0163279	0
4	7	34.8				69.85	69.71	0.0268498	0.0097801	0.0249332	0.0259126	0.0190409	0.0159486	0
4	8	33.96				71.11	71.01	0.0269832	0.0104781	0.0251421	0.0255547	0.0186007	0.0156524	0
4	1	35.87	37.21	7.73	6.04	69.54	69.4	0.025355	0.0115661	0.0249754	0.0256668	0.0195614	0.0163075	1
4	2	34.78	36.16	7.99	6.4	70.23	70.11	0.0262035	0.011573	0.0252293	0.0257499	0.0191796	0.0152059	1
4	3	34.75	36.01	7.63	5.94	70.5	70.36	0.0257707	0.0115753	0.025349	0.0258205	0.019142	0.0164733	1
4	4	34.54	36.14	7.55	5.71	70.33	70.22	0.0262037	0.0117496	0.0253552	0.0259188	0.0192198	0.0159819	1
4	5	33.92	35.34	7.58	5.81	71.21	71.14	0.0259975	0.011826	0.0255108	0.0260158	0.0189599	0.0166414	1
4	6	34.37	35.8	8.19	6.8	70.31	70.15	0.0259651	0.0113818	0.0248801	0.025238	0.0186621	0.0159981	1
4	7	34.84	36.06	8.39	6.79	70.06	69.96	0.02565	0.0115469	0.0251364	0.0258583	0.0192529	0.0162071	1
4	8	33.64	35.52	8.14	6.23	70.9	70.75	0.0264375	0.0118548	0.0253365	0.026091	0.0191992	0.0164206	1
5	1	35.96				72.1	71.85	0.0244793	0.011314	0.0230022	0.0251201	0.0198766	0.0159971	0
5	2	36.17				72.83	72.74	0.0257352	0.0120511	0.0241958	0.0244951	0.0202348	0.017035	0
5	3	36.53				73.06	73.09	0.0247311	0.0122052	0.0244328	0.0249134	0.0201591	0.0171664	0
5	4	35.45				73.69	73.64	0.0264862	0.0120985	0.024285	0.0258806	0.0201139	0.0169579	0
5	5	36.38				73.79	73.73	0.0250109	0.0119099	0.0242237	0.0256677	0.0204417	0.0170939	0
5	6	35.7				74.21	74.12	0.0247522	0.011438	0.0237062	0.0252044	0.0198604	0.0164928	0
5	7	35.62				73.81	73.64	0.0253964	0.010726	0.0226494	0.0248334	0.0196856	0.0150978	0
5	8	36.44				73.32	73.25	0.0251448	0.0115252	0.0235449	0.0257959	0.0203979	0.0164272	0
6	1	35.01	36.52	6.47	6.43	69.51	69.93	0.025898	0.011366	0.025005	0.02471	0.019765	0.019856	1
6	2	34.73	36.31	6.48	6.16	69.5	70.01	0.026136	0.011702	0.025189	0.024713	0.019493	0.020287	1
6	3	34.38	35.69	6.41	6.88	68.74	69.21	0.026064	0.011833	0.02557	0.024607	0.019858	0.020432	1
6	4	35.43	36.39	5.78	6.77	69.64	70.34	0.025473	0.011593	0.025563	0.024731	0.019968	0.0203	1
6	5	34.24	36.27	6.8	8.22	70.6	71.17	0.024962	0.011397	0.025039	0.023051	0.019841	0.020681	1
6	6	35.74	36.34	6.98	6.44	69.98	70.49	0.026199	0.011845	0.025933	0.025428	0.020003	0.020914	1
6	7	36.53	37.36	6.61	6.65	69.94	70.21	0.026509	0.012039	0.026122	0.024131	0.02022	0.020491	1
6	8	34.62	35.75	6.6	6.3	70.63	71.14	0.025576	0.012059	0.025437	0.025145	0.019622	0.020512	1
6	9	34.32	35.35	8.97	7.33	70.56	71.3	0.025085	0.011611	0.025521	0.024858	0.019439	0.020542	1
6	10	34.74	35.58	6.86	6.68	70.41	70.98	0.025016	0.012092	0.025522	0.024843	0.019741	0.020539	1
7	1	35.96	37.15	6.35	6.57	69.74	70.45	0.025571	0.011415	0.024933	0.024476	0.020463	0.020224	1
7	2	34.7	35.71	6.77	6.69	70.33	70.97	0.026037	0.011566	0.025359	0.024888	0.019597	0.020253	1
7	3	34.68	35.81	7.29	7.54	70.01	70.42	0.026056	0.011888	0.02532	0.024469	0.020093	0.020623	1
7	4	35.27	36.11	6.84	7.08	69.17	69.54	0.026237	0.011919	0.025659	0.025095	0.020196	0.020774	1
7	5	34.62	35.33	6.6	6.86	70.03	70.46	0.025708	0.011971	0.025733	0.024509	0.019947	0.020474	1
7	6	33.98	35.24	6.8	6.75	70.25	70.45	0.026101	0.01179	0.025218	0.024818	0.019708	0.020433	1
7	7	35.19	36.6	6.65	7.26	71.2	71.62	0.025808	0.011464	0.024924	0.024739	0.020047	0.020344	1
7	8	34.25	35.5	7.28	7.32	71.26	71.67	0.025951	0.011703	0.025052	0.024771	0.019779	0.02035	1
7	9	33.97	34.89	7.32	7.14	71.39	71.74	0.026091	0.011736	0.025064	0.024769	0.019794	0.020329	1
7	10	36.05	37.38	6.74	6.68	69.19	69.49	0.026505	0.011754	0.025603	0.024822	0.020184	0.020361	1

ACH Medium w/ JSGPM Raw Data														
Operator ID	Test #	CG_X_1 (mm)	CG_X_2 (mm)	CG_Y_1 (mm)	CG_Y_2 (mm)	CG_Z_1 (mm)	CG_Z_2 (mm)	lzz (kg/m ²)	lxx (kg/m ²)	lyy (kg/m ²)	lyz (kg/m ²)	lxz (kg/m ²)	lxy (kg/m ²)	Post_Fix
1	1	26.06				36.6	36.41	0.0244514	0.0296074	0.0371755	0.0301954	0.0355519	0.0320601	0
1	2	27.5				36.91	36.74	0.0249923	0.0295746	0.0374496	0.0304246	0.0352643	0.0324717	0
1	3	26.3				36.3	36.15	0.0239124	0.0288366	0.0363271	0.0287664	0.0333149	0.0317597	0
1	4	27.79				36.76	36.54	0.0245645	0.0289633	0.0366832	0.0298061	0.0351968	0.0317742	0
1	5	27.51				36.74	36.94	0.0242527	0.0300249	0.0377103	0.0302394	0.0351177	0.0326781	0
1	6	26.87				34.75	34.6	0.0242124	0.0301111	0.0377407	0.0307326	0.0356009	0.032549	0
1	7	27.24				35.49	35.4	0.0249173	0.0305935	0.0382667	0.0305346	0.0352337	0.0320952	0
1	8	26.93				36.22	35.94	0.0247347	0.0295398	0.0368255	0.0294203	0.0343429	0.0324445	0
2	1	28.45				34.06	34.01	0.0252871	0.0273662	0.0357265	0.0301441	0.0346946	0.031919	0
2	2	25.72				34.14	34.1	0.0253407	0.0274711	0.036237	0.0308302	0.0354159	0.0321287	0
2	3	25.37				33.24	33.16	0.0239009	0.0268809	0.0352594	0.0297227	0.0345841	0.0313064	0
2	4	24.29				33.12	33.1	0.0244089	0.0261777	0.0350135	0.0298389	0.0344634	0.0306758	0
2	5	24.7				32.79	32.72	0.0244117	0.0273738	0.0359142	0.0300725	0.034787	0.0312677	0
2	6	25.36				32.37	32.38	0.0241668	0.0272088	0.0359092	0.0300639	0.0349227	0.0313198	0
2	7	24.12				33.23	33.18	0.0245918	0.0275331	0.0362507	0.0305022	0.0352971	0.0318466	0
2	8	25.95				33.76	33.71	0.0242502	0.0277033	0.0359451	0.0296469	0.0345873	0.0316884	0
3	1	26.99	26.97	0.65	-0.13	37.18	37.02	0.0236871	0.0275635	0.0356615	0.0303224	0.0354539	0.0315945	1
3	2	26.78	27.33	0.63	0.1	36.26	36.16	0.0239426	0.0277558	0.0360401	0.0305246	0.035644	0.0317357	1
3	3	26.78	27.12	0.75	-0.23	36.08	35.92	0.0238604	0.0282166	0.0362545	0.030613	0.0357905	0.0321519	1
3	4	26.7	27.57	0.87	-0.22	36.68	36.6	0.0244272	0.0274283	0.0359785	0.0304928	0.0355466	0.0316721	1
3	5	27.63	28.32	0.88	-0.08	35.69	35.56	0.0236787	0.0280159	0.0357186	0.0301823	0.0353188	0.0319373	1
3	6	26.52	27.28	1.02	0.39	35.83	35.71	0.0241659	0.0277085	0.0358774	0.0305078	0.0354983	0.0316897	1
3	7	26.6	26.69	1.24	0.36	35.03	34.97	0.0237967	0.0280159	0.0358784	0.0302999	0.0354921	0.0316384	1
3	8	28.02	28.21	1.37	0.64	34.48	34.44	0.0233939	0.0271895	0.0350534	0.029781	0.0350036	0.0311589	1
4	1	25.11				30.73	30.86	0.0254217	0.0241267	0.0338213	0.0292849	0.034039	0.0310891	0
4	2	26.66				32.1	32.2	0.0253044	0.0283031	0.0368696	0.0301169	0.0351397	0.0315125	0
4	3	26.01				31.2	31.33	0.0254865	0.0265772	0.0355382	0.0300627	0.0348032	0.0313276	0
4	4	26.63				32.49	32.51	0.0254269	0.0286393	0.0370584	0.0302291	0.0353621	0.0315367	0
4	5	26.59				32.09	32.18	0.0256248	0.0268652	0.0362319	0.0302839	0.0349011	0.0312346	0
4	6	25.88				32.12	32.22	0.025723	0.0275347	0.0377145	0.0309025	0.03637	0.0311188	0
4	7	25.24				31.29	31.51	0.0261556	0.0258751	0.0358356	0.0309112	0.0355153	0.0324348	0
4	8	26.96				32.71	32.78	0.0258543	0.0282129	0.0369462	0.0304884	0.035152	0.0324534	0
5	1	28.59				36.7	36.6	0.0235122	0.0298357	0.0369502	0.0295972	0.03059065	0.0341399	0
5	2	28.93				36.25	36.53	0.0237233	0.0290194	0.0360617	0.0322182	0.036265	0.0331035	0
5	3	29.64				35.38	35.63	0.024935	0.0294596	0.0362329	0.0304834	0.0367429	0.0333555	0
5	4	29.29				38.78	38.75	0.0232027	0.0283958	0.0353719	0.0299941	0.036547	0.0326806	0
5	5	28.7				37.38	37.39	0.0237626	0.0284883	0.0357181	0.030639	0.0365608	0.0326069	0
5	7	28.67				38.22	38.13	0.0247965	0.0287923	0.0357697	0.0306814	0.0364254	0.0328614	0
5	8	29.15				36.19	37.22	0.0241906	0.0281184	0.0363433	0.0306337	0.0369213	0.032543	0
5	9	29.97				37.53	37.63	0.0237655	0.0292013	0.0359107	0.0305644	0.0367457	0.0332833	0
6	1	29.73	31.04	-0.19	-0.19	30.56	30.68	0.024438	0.028114	0.036074	0.029315	0.035964	0.032027	1
6	2	27.98	29.92	-1.06	-1.37	31.79	31.75	0.023538	0.027865	0.035057	0.029832	0.034634	0.031377	1
6	3	27.32	28.32	-1.05	-1.46	32.15	32.23	0.023384	0.027911	0.035369	0.028647	0.034976	0.03052	1
6	4	28.26	30.47	1.61	0.99	31.92	31.92	0.023258	0.027425	0.034905	0.028008	0.03511	0.030975	1
6	5	28.37	29.93	1.56	-0.08	32.57	32.68	0.023414	0.027637	0.035344	0.030358	0.035408	0.030712	1
6	6	28.16	29.88	-0.01	1.19	31.86	32.08	0.02333	0.027688	0.035609	0.030061	0.035561	0.0313	1
6	7	28.39	29.77	0.37	-0.03	32.29	32.86	0.023645	0.028422	0.036663	0.030477	0.036391	0.032186	1
6	8	28.7	30.43	0.59	0.37	31.49	32.24	0.024146	0.028549	0.036302	0.030528	0.036266	0.032458	1
6	9	28.26	29.2	0.8	0.39	32.75	32.73	0.024535	0.028135	0.036332	0.030272	0.036097	0.031621	1
6	10	28.26	29.55	-0.57	-0.7	33.07	33.14	0.023958	0.027917	0.03559	0.03022	0.035743	0.031527	1
7	1	27.84	29.14	0.25	0.49	32.74	32.51	0.024323	0.02789	0.035379	0.030089	0.035435	0.031353	1
7	2	28.35	29.9	-0.15	0.02	31.57	31.65	0.024658	0.028005	0.035739	0.0305	0.035769	0.031565	1
7	3	27.87	29.33	-0.72	-0.8	32.73	32.55	0.024288	0.02765	0.035408	0.030391	0.035544	0.031189	1
7	4	28.41	29.84	-0.19	-0.16	31.85	31.77	0.024302	0.028	0.035715	0.030336	0.035705	0.031559	1
7	5	28.72	30.18	-0.17	0.03	32.58	32.54	0.024992	0.028126	0.036275	0.030761	0.036385	0.032102	1
7	6	28.31	29.56	-0.28	-0.14	31.39	31.47	0.02435	0.028398	0.035782	0.030339	0.03587	0.031924	1
7	7	29.36	30.68	-0.06	0.01	31.45	31.67	0.024648	0.028494	0.036181	0.030448	0.036233	0.032261	1
7	8	29.68	30.78	-0.48	-0.59	32.41	32.46	0.024864	0.02846	0.036446	0.030922	0.036507	0.032113	1
7	9	28.51	30.13	-1.32	-0.7	32.16	32.25	0.024509	0.028704	0.036236	0.030724	0.036175	0.03233	1
7	10	29.27	30.79	0.19	0.3	31.85	32.07	0.024612	0.02873	0.03662	0.030875	0.036564	0.032462	1

