SURFACE VEHICLE INFORMATION REPORT

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SAE Instrumented Arm
User's Manual

RATIONALE

The technical report covers technology, products, or processes which are mature and not likely to change in the foreseeable future. The technical committee makes a conscious decision not to maintain the document any longer.

STABILIZED NOTICE

This document has been declared "STABILIZED" by SAE Dummy Testing and Equipment Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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INTRODUCTION

The Instrumented Arm project began late in 1995 with interest in studying arm injuries incurred in vehicle accidents involving driver's-side airbags. According to studies available at the time, injuries to the arm had increased in conjunction with the addition of driver's side airbags in new model vehicles. At the same time, there was also a strong interest in assessing potential frontal arm injury from side airbags.

According to S.M. Kuppa, *et al*, in their 1997 research paper for the SAE International (SAE), *RAID – An Investigation Tool to Study Air Bag/Upper Extremity Interactions,* arm injuries before the introduction of driver's side airbags into the mainstream automotive market accounted for about 1% of the injuries incurred. However, since their introduction, arm injury has increased to about 4%, with female drivers receiving injuries more frequently than males.

The apparent reason for this increase in injury occurrence is the interaction of the arm with the airbag. Through vehicle crash testing with human cadavers and surrogates (crash dummies) researchers have reported injuries to the upper arm, lower arm and hand caused by airbag deployment. Research has shown that arm injuries typically occur in one of two ways: 1) the arm is propelled by the deploying airbag into a pillar or beam or the occupant's head, or 2) "primary contact injuries," which occur when the driver's arm is directly in front of, or on top of, the airbag when it deploys.

The fact that the occurrence of these injuries is seen more often in women may be due to three factors: 1) women are typically shorter than men so as to cause them to be closer to the airbag module, 2) bone density in women commonly decreases with age, 3) women have smaller bones and subsequently lower bone strength.

In October of 1995 the Mechanical Human Simulation Subcommittee of the SAE International (SAE) Human Biomechanics and Simulation Standards Committee (HBSSC) formed the Arm-Airbag Interaction Task Group. The Task Group was formed to investigate and develop a practical measuring device for the study of arm injuries caused by airbags. In the Task Group's initial meeting it was agreed that the primary focus of the group should be arm interaction with current driver-passenger airbags, and future side impact airbags. This focus would entail: the review of highway data, and the development of an instrumented mechanical arm surrogate with appropriate testing procedures. Since 1995 the group, together with *Robert A. Denton, Inc.*, has worked diligently to produce a device that answers the performance criteria determined to be necessary to effectively measure injury in the given area of interest.

The current arm configuration combines many of the original ideas and concepts of the Task Group. While some of the initial ideas have not yet been incorporated, either due to compromise, impracticality or time constraints, the current arm is a usable and highly effective tool for measuring arm injury. Further details regarding use of the Instrumented Arm can be found in: ISO Technical Report (TR) number 15827. Future modifications will include: a low-profile elbow potentiometer to reduce metal-to-metal contact in rigid wall testing and an improved SID-IIs upper arm flesh to better fit at the shoulder joint attachment.

The complete arm is currently used on the SID-IIs side-impact dummy and the Hybrid III 5th percentile Small Female (HIII-5F) dummy. It can be used on either the left or right side making this arm a viable product in nearly any crash situation, anywhere in the world, where arm injury measurement is desired.

1. SCOPE

This user's manual covers the instrumented arm for the Hybrid III 5th Percentile Small Female dummy as well as the SID – IIs dummy. It is intended for technicians and engineers who have an interest in assessing arm injury from the use of frontal and side impact airbags. It covers the construction, disassembly and reassembly, available instrumentation, and segment masses.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

General Specifications

Kuppa, S., Olson, M., Yeiser, C., Taylor, L. et al., "RAID - An Investigative Tool to Study Air Bag/Upper Extremity Interactions," SAE Technical Paper 970399, 1997, https://doi.org/10.4271/970399.

SAE J211-1 Instrumentation for Impact Test - Part 1 - Electronic Instrumentation

SAE J1733 Sign Convention for Vehicle Crash Testing

SAE J2862 User's Manual for the Small Adult Female Hybrid III Test Dummy

2.1.2 ISO Publications

ISO Technical Report (TR) number 15827, Road vehicles — Test procedures — Evaluating small female dummy arm and forearm interactions with driver frontal airbags and side airbags

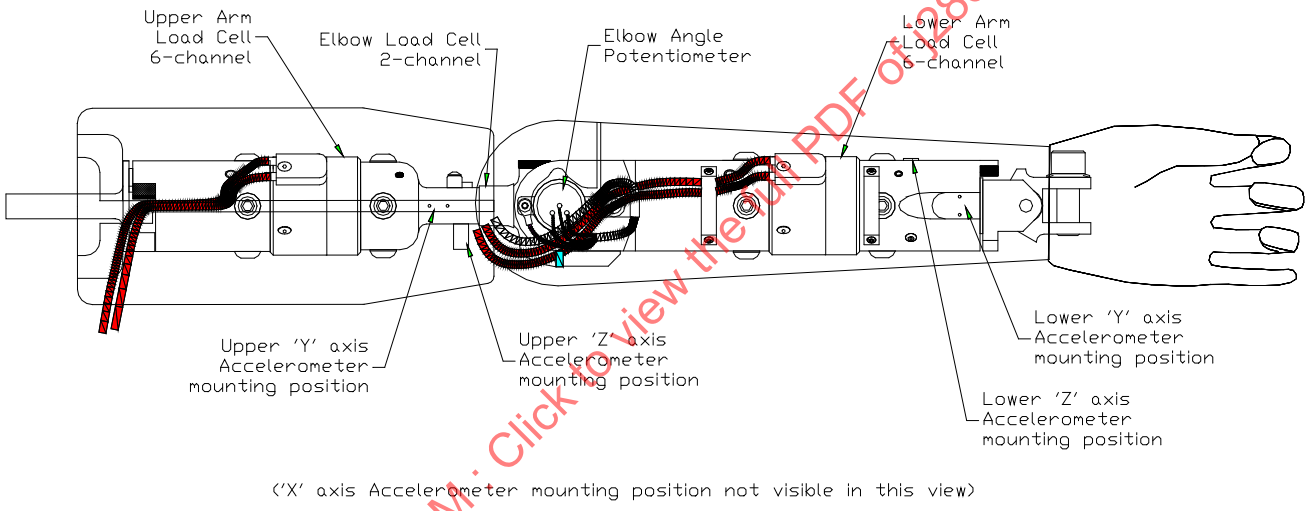

Figure 1 - Air bag interaction arm (HIII-5F left arm shown)

2.2 Instrumentation

The Instrumented Arm supports the use of:

Two (2)	Model 3780	Six-channel Load Cells; measuring: Fx, Fy, Fz, Mx, My, Mz in the Upper and Lower arm sections.
One (1)	Model 3781	Two-channel Load Cells; measuring: Mx, My at the Elbow Joint.
One (1)	Model 4077	Rotary Potentiometer; measuring Elbow rotation.
Six (6)		Uniaxial Accelerometers; **measuring X, Y, and Z at the Elbow and Wrist joints. (SA572-S4 accelerometers)
		****Accelerometers not included with Arm.**
Twenty-one (21)		Total possible data acquisition channels.

2.3 Weights

The Arm weights: (including flesh components)

Table 1 - Arm masses

	H3-5F	SID-II s
Upper Arm	1.30 kg (2.87 pounds)	1.26 kg (2.78 pounds)
Lower Arm	1.21 kg (2.67 pounds)	
Hand	0.31 kg (0.68 pounds)	
Total	2.82 kg (6.21 pounds)	2.78 kg (6.13 pounds)

The difference between the weight of the Hybrid III 5th Small Female (HIII-5F) arm and the SID-IIs is in the shoulder joint. The SID-IIs uses a lighter weight Z - Pivot (*left: 3985-1; right: 3985-2*) than the HIII-5F (*left: 3993-1; right: 3993-2*). Other than the Pivot and the Upper Arm Flesh, the Arm can be used on either dummy type.

2.4 Range of Motion

The design limits for the Range of Motion:

Table 2 - Range of motion limits

	Bumper Contact	Forced Range	Metal-to-Metal (w/o Bumper)
Shoulder Lateral Rotation	37°	43°	53°
Shoulder Medial Rotation	111°	117°	127°
Elbow Flexion	135°	141°	147°
Elbow Extension	-4.5°**	0°	3.5°
Wrist Supination	100°	105°	108°
Wrist Pronation	100°	105°	108°
Wrist Flexion	27°	31°	34°
Wrist Extension	31°	61°	64°

** Negative number for Elbow Extension Bumper Contact means that the Arm is actually flexed 4.5° when it contacts the Extension Bumper.

2.5 About the Manual

This manual has been put together to help the technician use and maintain the Instrumented Arm package. While all instructions are set forth in a "step-by-step" manner, it is also an excellent reference guide to order parts and recall key information about specific areas of the Arm's assembly/disassembly and operation.

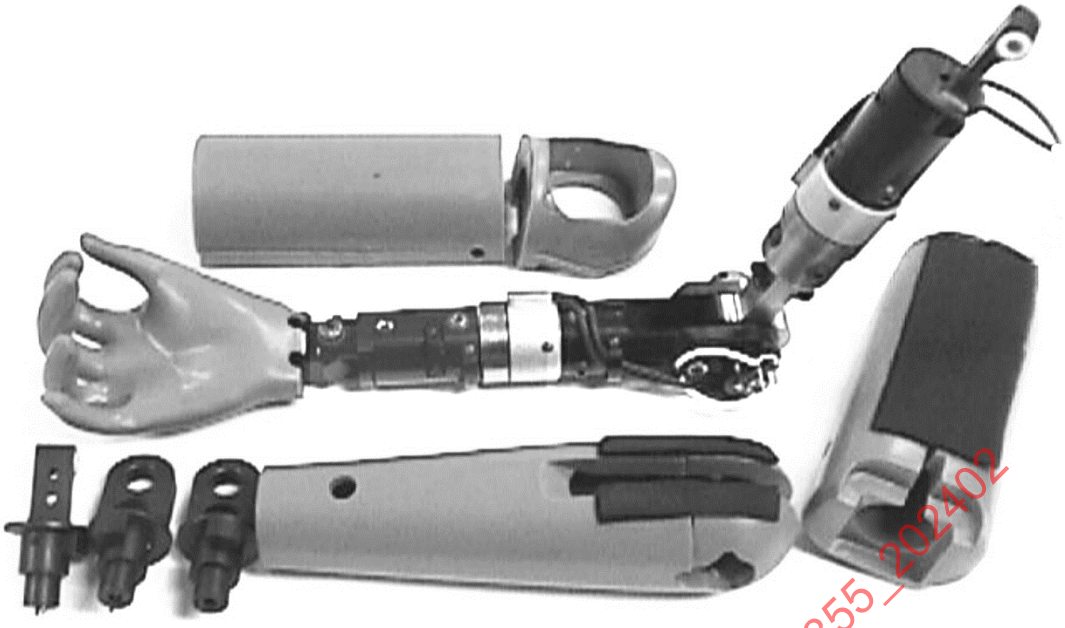

Figure 2 - Model J3525 air bag interactive arm assembly

3. DISASSEMBLY OF ARM – REMOVAL FROM ATD

The only tools necessary to completely disassemble the Arm is a full set of hex wrenches; sizes 0.050” through 7/32” and a small tipped Phillips screwdriver.

To begin the procedure the Arm must first be removed from the dummy (see Figure 3). To remove the Arm from the HIII-5F takeout the 3/8 x 1” SHSS (see Appendix A for screw head style abbreviations) pivot bolt located at the shoulder-arm joint. With the pivot bolt removed the arm can be pulled away from the assembly. Watch for the pivot and compression washers and the pivot nut, they often fall out of the joint when the arm is removed. To remove the Arm from the SID-IIs takeout the 1/4 x 1-1/4 SHSS from the shoulder-arm joint.

NOTE: During re-assembly of the SID-IIs Arm the user may notice interference between the Bushings and the Shoulder Clevis. This may cause some difficulty in assembly, however the user should be able to insert the Arm.

While the shoulder-arm joint is disassembled be sure to inspect the components. The washers are frequently damaged from improper installation. If the washers are damaged the friction adjustment for this joint may be affected. Replace all damaged parts.

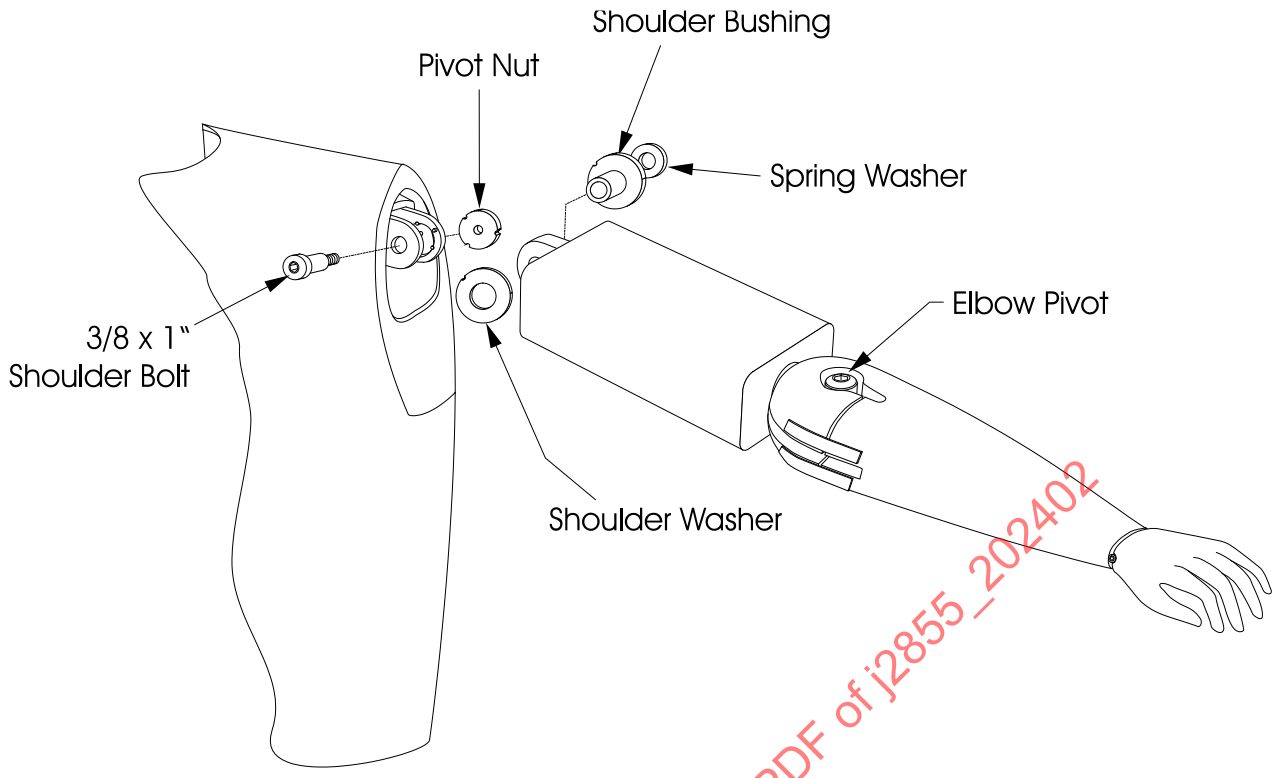

Figure 3 - Arm removal

3.1 Instrumentation Cables

Due to the large number of transducers in a relatively small area, cable paths and strain relief are an important issue. The Arm flesh, both Upper and Lower Arm, has cable guide channels to ensure that the cables are protected in each section of the Arm. Before completing the positioning of all the transducer cables, it is a good idea to mark each cable, connector end, so as to be able to easily determine which cable belongs to each transducer.

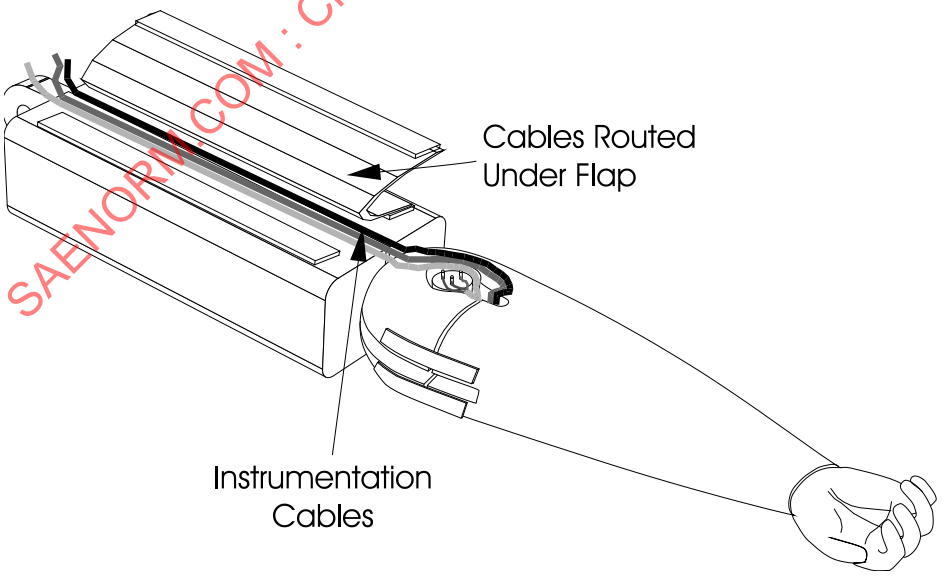

Figure 4 - Cable Routing

As shown in the Assembly drawings, included at the end the manual, all three of the accelerometer cables are routed through the cable guide located just below the Lower Arm load cell. These cables are then run through the Lower Arm flesh along the load cell toward the Elbow. On the Elbow Clevis there is a second cable guide to collect together the load cell and accelerometer cables. All five of these cables are then routed toward the Elbow and out of the Arm assembly through the cable access hole at the Elbow. The cables should be brought out of the Arm toward the inboard, the side closest to the Upper Torso, of the Arm assembly. All the Lower Arm cables, including the Potentiometer cable, are then secured under the vinyl flap on the inside surface of the Upper Arm.

The three-accelerometer cables for the Upper Arm are passed along the Upper Arm load cell toward the Upper Arm Pivot. All cables must be positioned toward the inside of the Arm.

Once all the cables are properly routed along the inside of the Arm, toward the Upper Torso, and brought together at the top of the Arm Pivot they can be “bundled” together. With all the cables bundled in one group it is easier to manage their connection to the data acquisition system.

As a final check, be sure that the cables are free to move with the Arm. If improperly positioned the cables can hinder Arm motion or be damaged during testing. Leave enough “slack” cable to ensure good, free, movement of the Arm but not enough to allow the cable to be pinched or snagged.

3.2 Disassembly of Arm-Elbow

To begin disassembly of the Arm, first detach the Lower Arm and Hand from the Upper Arm. Start this procedure by removing the potentiometer from the Arm assembly. Take out the two (2) #4-40 x 1/4” BHCS that secure the Potentiometer Body Retainers in position (shown in Figure 6). Then remove the cable strain relief and slide the assembly out of the Elbow joint.

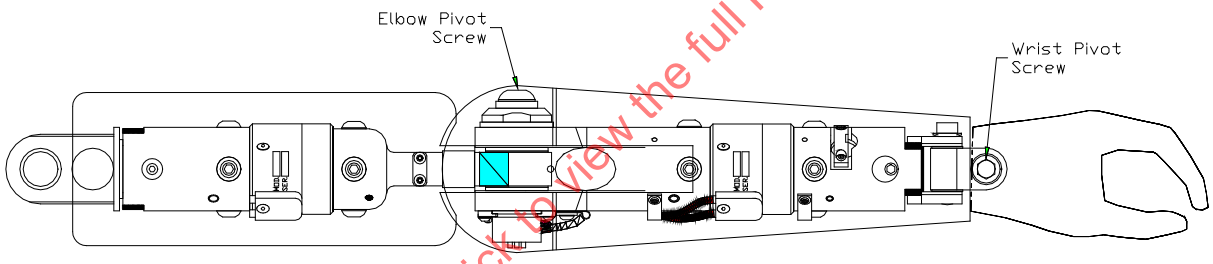

Figure 5 - Arm pivots

Remove the Elbow Pivot screw shown in Figures 5 and 6. When the Pivot screw is removed the Elbow washers will be free to be removed from the assembly.

While the Elbow Pivot washers are out of the assembly, inspect the condition of the washers. The washer immediately under the Pivot screw head is the Spring Washer. The Spring Washer is a flexible material that can be damaged from over-compression. The next washer is the Elbow Washer. This washer only requires inspection for burrs and cleaning with isopropyl alcohol. The third washer is fiberglass. This component should be checked for any damage that will affect the smooth operation of the Elbow, such as; burrs, dirt, etc. Do not apply any oil based lubricants to this joint. Oil has the tendency to attract and collect dirt. If a lubricant is deemed necessary, it generally is not, use a dry (i.e., graphite) type lubricant.

Next, rotate the Upper Arm section (see Figure 7) so that the Locking Screw, on the inside of Elbow joint, is visible. The Locking Screw is a 1/4-28 x 1/4” SSDP. Remove the Locking Screw and pull the Elbow Shaft Assembly out of the Elbow joint. Once the Elbow Pivot is removed the Upper and Lower Arm sections can be pulled apart.

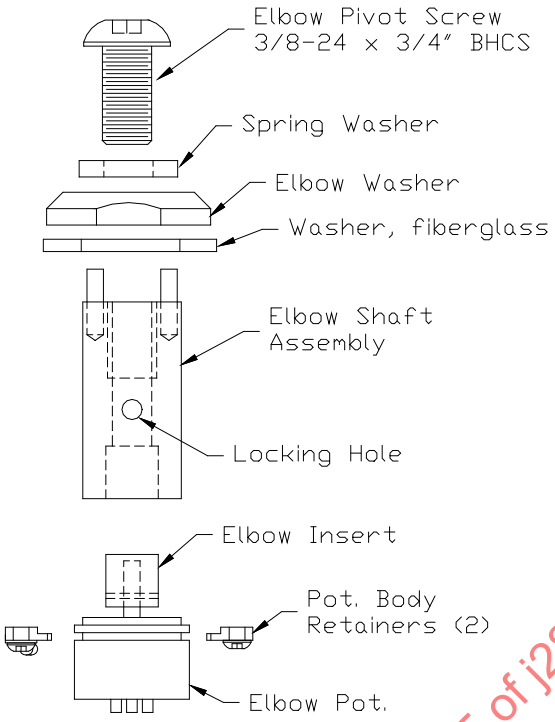

Figure 6 - Elbow pivot assembly

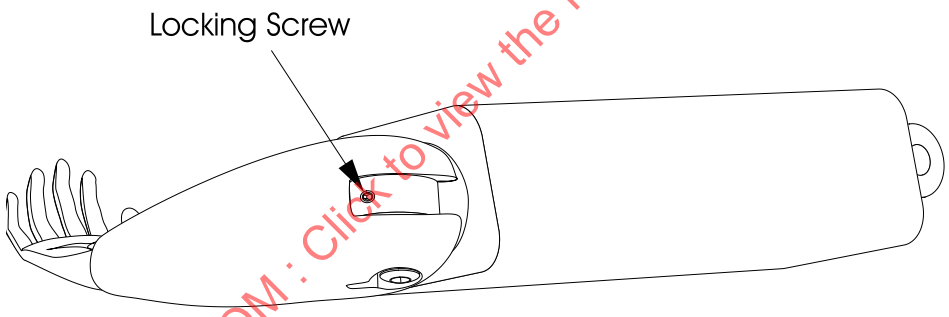

Figure 7 - Locking screw

3.2.1 Elbow

The only disassembly that can be done on the Elbow load cell (Model 3781) section is the removal of the accelerometer-mounting block. It is removed by taking out the two (2) #2-56 Phillips head screws from the mount. For easier assembly/disassembly the 'Z' axis accelerometer can be stored on the mounting block.

The Elbow Load Cell is a 2-channel (Mx, My) Moment measuring device. It is recommended that the device be re-calibrated yearly (every 12 months) and after every instance where the load capacity of the device is exceeded or the output of the device appears questionable. See Appendix B for wiring information.

3.3 Disassembly of Arm - Upper Arm

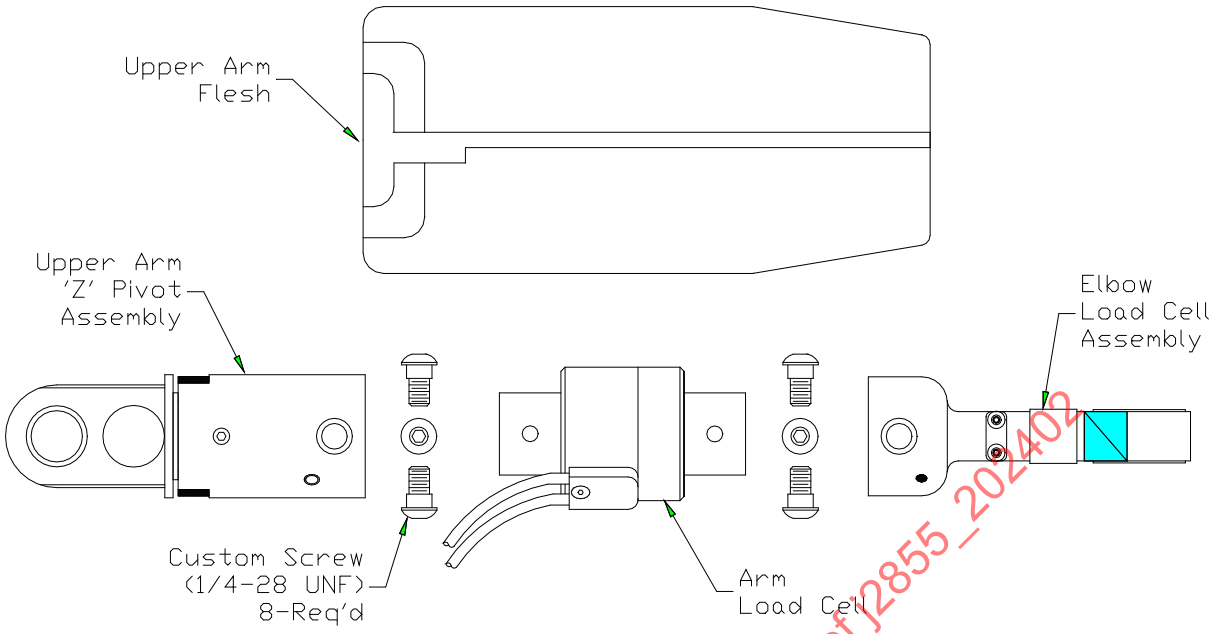

Figure 8 - Upper arm assembly

Disassembly of the Upper Arm begins with the removal of the Arm Flesh. The Flesh can be removed by first, pulling off the Velcro® flap on the inside of the Arm and then, sliding the Flesh piece off the bone structure. Be careful to avoid damaging the cables inside the Arm Flesh.

3.3.1 Upper Arm Load Cell

After the bone structure is removed from the Flesh the remainder of the Upper Arm can be disassembled. Before proceeding, be sure to remove all accelerometers, if applicable, from the assembly. This is done by taking out the two (2) #0-80 x 3/16" SHCS used to secure them in each (X, Y, Z) position. Start by taking out the eight (8) Custom Screws (shown in Figure 8) that secure the Upper Arm 'Z' Pivot Assembly and Elbow Load Cell to the Arm Load Cell, pull each component from the Arm Load Cell.

To re-install the Arm Load Cell, either the Upper or Lower, the load cell must be oriented properly. Each end of the load cell body has a machined slot to correspond to the orienting pin installed in the mating part. Notice that the end closest to the shoulder-arm joint has a larger diameter slot than the other end.

The Arm Load Cell (Model 3780) is a 6-channel (Fx, Fy, Fz, Mx, My, Mz) force/moment measuring device. The Upper and Lower Arm Load Cells are the same model type. It is recommended that the device be re-calibrated yearly (every 12 months) and after every instance where the load capacity of the device is exceeded or the output of the device appears questionable. See Appendix B for wiring information.

3.3.2 Upper Arm ‘Z’ Pivot

The Upper Arm ‘Z’ Pivot Assembly is disassembled by taking out the 1/4-20 set screw (shown in Figure 9). This set screw is used to adjust the tension on the Upper Arm rotation in the ‘Z’ axis.

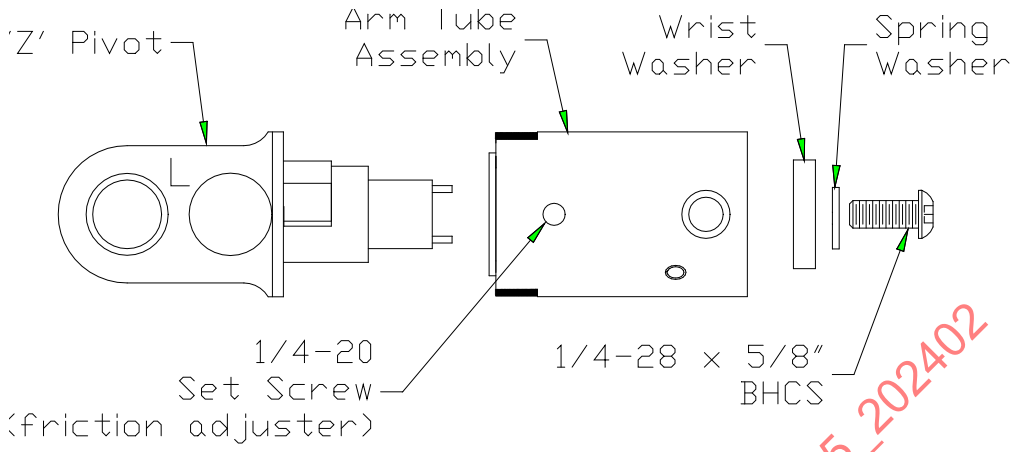

Figure 9 - Upper arm 'Z' pivot

Next, remove the 1/4-28 BHCS securing the ‘Z’ Pivot to the Arm Tube Assembly (Figure 9). Now the components can be pulled apart. However, watch for the two (2) washers in the Arm Tube; the Wrist and Spring washers.

When converting the Arm from left to right side or, to use it on SID-IIs dummies, the Upper Arm ‘Z’ Pivot must be changed to the appropriate component. The left-side ‘Z’ Pivot is stamped with the letter ‘L’ and the right side with ‘R’.

Use caution when reinstalling the wrist washer. It must be aligned with the two small pins on ‘Z’ pivot.

3.4 Disassembly Arm - Lower Arm

Since Elbow joint disassembly was discussed in a previous section (see Figure 6) it will not be repeated.

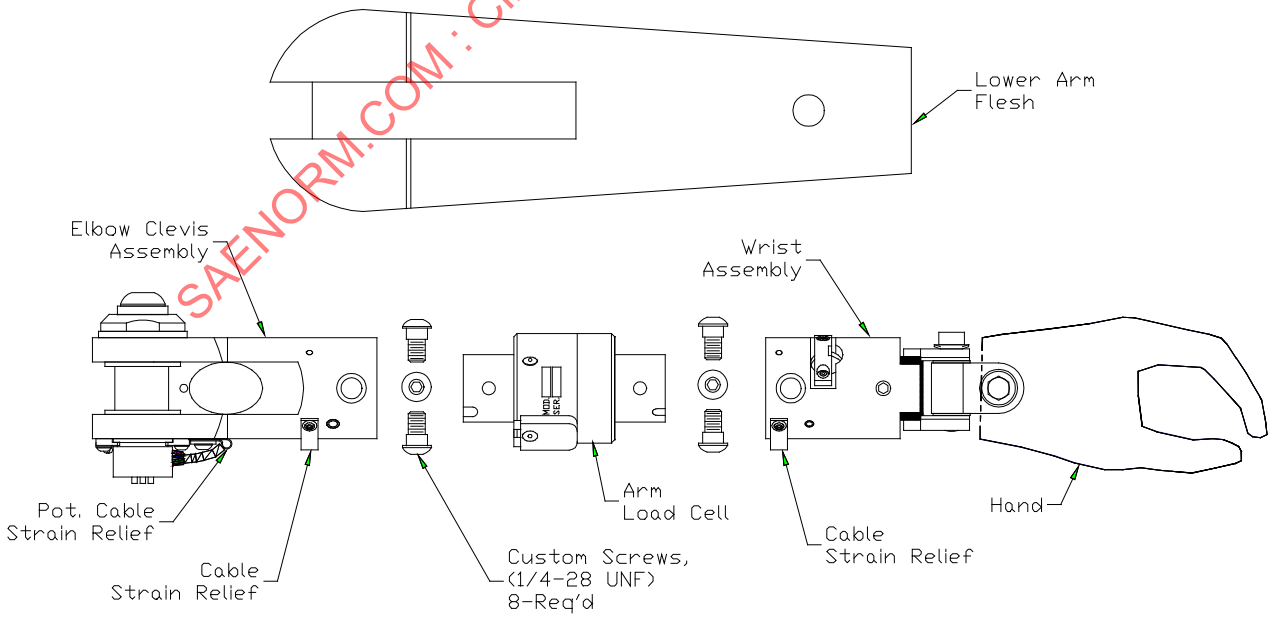

Figure 10 - Lower arm assembly

To disassemble the Lower Arm, start by removing the Hand. This is done by taking out the 3/8-16 SHCS at the Hand-Wrist pivot point and then pull the Hand from the assembly. This done, pull away the Velcro® straps that keep the Elbow Flesh in place. Next, slide the bone structure, with the instrumentation cables out of the Flesh.

3.4.1 Lower Arm Load Cell

Removing the Lower Arm Load Cell is done exactly the same way we removed the load cell from the Upper Arm. Take out the eight (8) custom Screws (see Figures 8 and 10) that hold the Elbow Clevis and the Wrist Assembly to the Arm Load Cell. Then pull each of the assemblies away from the load cell.

3.5 Disassembly of Arm - Wrist

The last section will cover the Wrist disassembly. To begin, take out the ‘Z’ axis accelerometer mount, if applicable. This is done by removing the #4-40 x 3/8” BHCS located on the lower side of the Lower Arm Tube (shown in Figure 12).

Take out the two (2) #4-40 BHCS on the upper side of the Arm Tube and the mount can be pulled out of the Arm Tube. The accelerometer mount can be stored with the accelerometer still attached or, it can be removed by taking out the two (2) #0-80 SHCS holding it in position.

There are two sets of holes on the accelerometer mount for attaching the accelerometer. Hole set ‘A’ is used to attach the SA572-S4 (7264-2000) style accelerometer. Hole set ‘B’ is used to attach the 7264A-2000 and 7264B-2000 style accelerometers (see Figure 11)

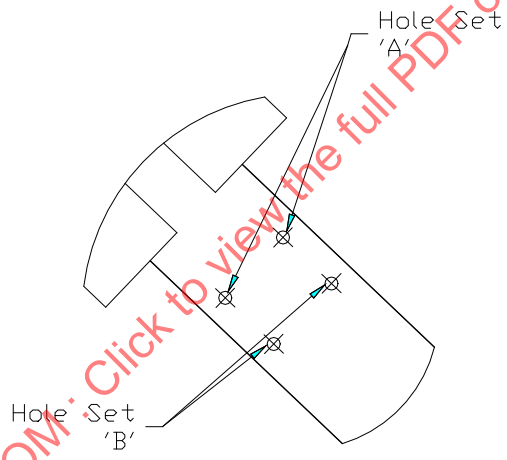

Figure 11 - Wrist 'Z' accelerometer mount

Once the accelerometers are removed from the assembly, the Wrist disassembly can be completed. The 3/8-16 x 1 inch SHCS located at the Wrist-Hand pivot is the screw used to adjust the friction between the Hand and the Wrist Clevis (see Appendix C for an explanation of the “one G adjustment”).

Before removing the Wrist Pivot Assembly, you must take out the Friction Adjustment screw (shown in Figure 12). This setscrew is used to adjust the friction between the Wrist and the Lower Arm.

Next, the 1/4-28 SHCS, (Wrist ‘Z’ Pivot Tension Screw) located inside the Arm Tube, must be taken out to detach the Wrist from the Arm Tube. When this screw is removed the Spring Washer and Wrist Washer are free to be taken out also. Pull the Wrist Assembly from the Arm Tube. The Wrist Pivot and Wrist Clevis are held together by one screw, a modified 5/16 x 1 inch SHSS.

To remove the cable guide, take out the two (2) #4-40 x 1/4” BHCS securing it in position.

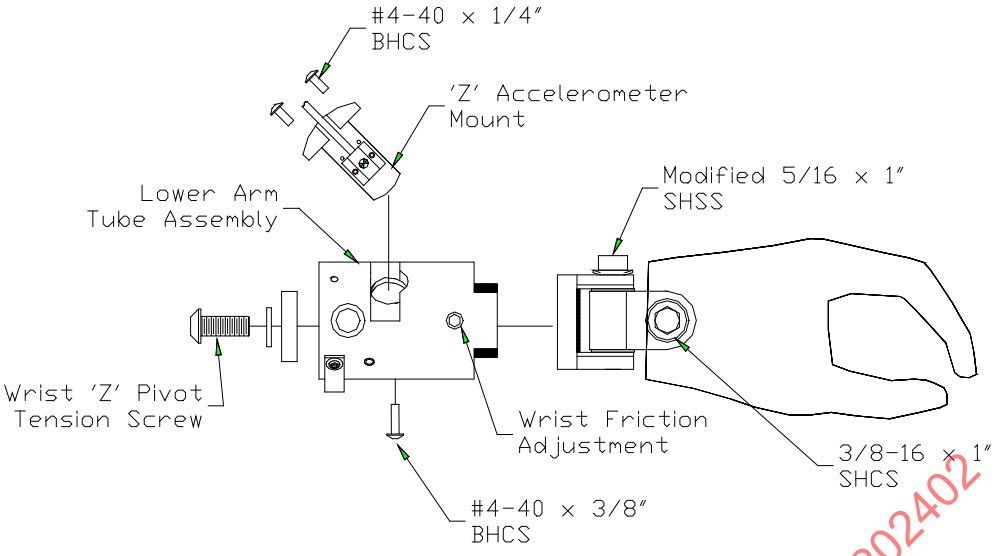

Figure 12 - Wrist assembly

3.6 Changing Attachment Side

To change the Arm position on the dummy from the left side to the right side, or vice-versa, the 'Z' Pivot must be replaced with the appropriate part. The left-side pivot is marked "L" and the right side with "R." Also, the potentiometer must be moved to the inside surface of the arm.

When changing the Arm from left side to right side, or vice-versa, the cable guides should also be moved. There are two sets of hole positions on the Lower Arm for the cable guides. Use the hole position which will guide the transducer cables toward the inside surface of the Arm, against the body. The idea is to keep the cables away from the impact side.

Also, the Upper Arm flesh must be rotated so that the Velcro® flap is always positioned toward the inside of the Arm, against the body.

The hand (left: 3965-2, right: 3965-1) must also to be changed when converting from left-to-right side impact.

3.6.1 Attaching Arm to SID-IIs

To change the instrumented arm to work on the SID-IIs dummy a couple of modifications must be made to the assembly. First, the Upper Arm Flesh must be replaced with the SID-IIs Upper Arm Flesh. Then, the appropriate 'Z' pivot assembly (left: 3985-1, right: 3985-2) must be installed at the shoulder-arm joint.

The SID-IIs dummy Upper Arm Flesh consists of two components. The Upper Flesh component (P/N: 4209) and the Lower Flesh component (P/N: 3986) (see Figure 13).

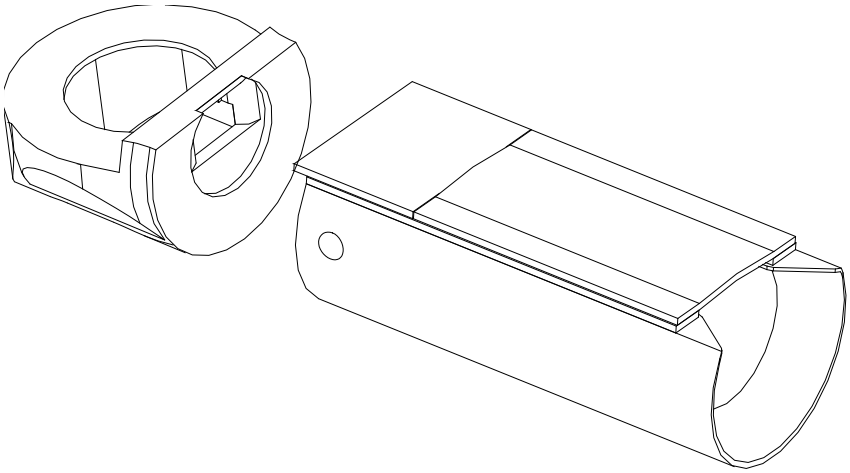

Figure 13 - SID-IIs arm flesh components

4. NOTES

4.1 Revision Indicator

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE SUBCOMMITTEE DUMMY TESTING AND EQUIPMENT STANDARDS OF THE HUMAN BIOMECHANICS AND SIMULATIONS STANDARDS COMMITTEE

APPENDIX A - SCREW TYPE ABBREVIATIONS

Table A1 - Fasteners

Abbreviation	Type Name
BHCS	Button Head Cap Screw
FHCS	Flat Head Cap Screw
SHCS	Socket Head Cap Screw
SHSS	Socket Head Shoulder Screw
SSCP	Socket Set Cup Point
SSDP	Socket Set Dog Point
SSHDP	Socket Set Half-Dog Point

APPENDIX B - ELECTRICAL WIRING

Table B1 - Arm load cell (Model 3780)

Force Cable			Moment Cable		
Channel	Connection	Wire Color	Channel	Connection	Wire Color
Fx	+Excitation	Brown	**Mx**	+Excitation	Brown
	-Excitation	Orange		-Excitation	Orange
	+Signal (+output)	Red		+Signal (+output)	Red
	-Signal (-output)	Yellow		-Signal (-output)	Yellow
Fy	+Excitation	Red/stripe	**My**	+Excitation	Red/stripe
	-Excitation	White		-Excitation	White
	+Signal (+output)	Black		+Signal (+output)	Black
	-Signal (-output)	Black/stripe		-Signal (-output)	Black/stripe
Fz	+Excitation	Green	**Mz**	+Excitation	Green
	-Excitation	Violet		-Excitation	Violet
	+Signal (+output)	Blue		+Signal (+output)	Blue
	-Signal (-output)	Grey		-Signal (-output)	Grey

Table B2 - Elbow load cell (Model 3781)

Force Cable			Moment Cable		
Channel	Connection	Wire Color	Channel	Connection	Wire Color
Mx	+Excitation	Red	**My**	+Excitation	Red
	-Excitation	Black		-Excitation	Black
	+Signal (+output)	Green		+Signal (+output)	Green
	-Signal (-output)	White		-Signal (-output)	White

Table B3 - Potentiometer (Midori America Corp.)

Pin	Connection	Wire Color
1	+Excitation	Red
2	+Signal (+output)	Green
3	-Excitation	Black
na	-Signal (-output)*	White

*-Signal attached to resistor junction.

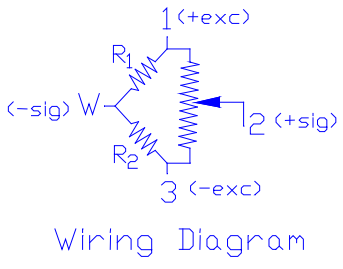

Figure B1 - Potentiometer wiring

APPENDIX C - ONE ‘G’ ADJUSTMENT

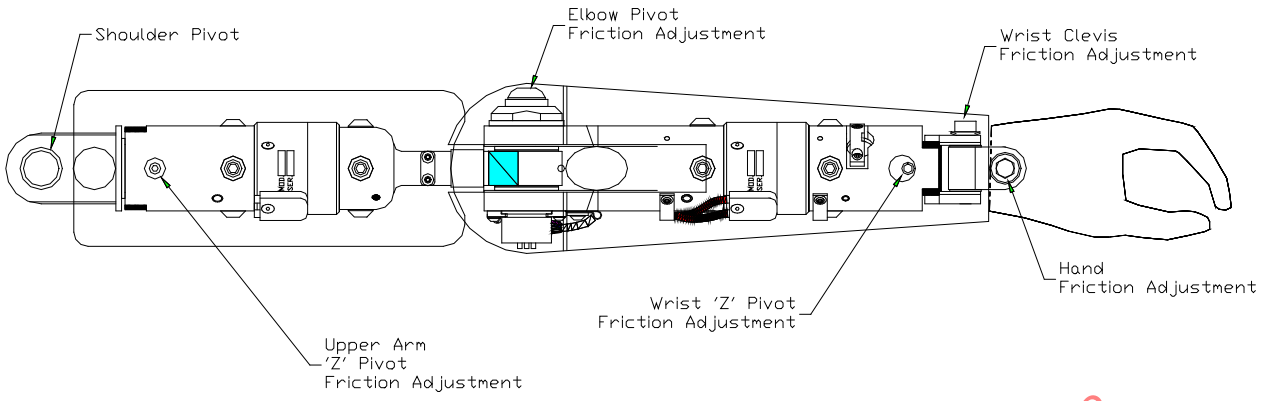

Figure C1 - Pivot friction adjustment points

Figure C1 shows each of the friction adjustment points. These are the screws that are tightened or loosened to achieve the 1 ‘G’ setting. The 1 ‘G’ setting or, one ‘G’ adjustment, is a setting used to control the movement of the arm during testing.

Think of holding your arm straight out from your body so that it is parallel to the floor. The tension in your muscles necessary to keep your arm horizontal is 1 ‘G’ or, one times the effect of gravity. This is the adjustment desired when the dummy is setup for testing.

If you were to hold the dummies arm horizontal it should be able to stay in position without support. However, a light tap to the arm in a downward direction should cause it to move.

During assembly of the arm the ‘Z’ pivots at the Wrist and Shoulder (Figures C2 and C3) are tightened to provide part of the tension necessary to adjust the entire arm. Because the 1/4-28 BHCS can only be adjusted when the arm is completely disassembled it is important to check this area every time the screws are accessible.

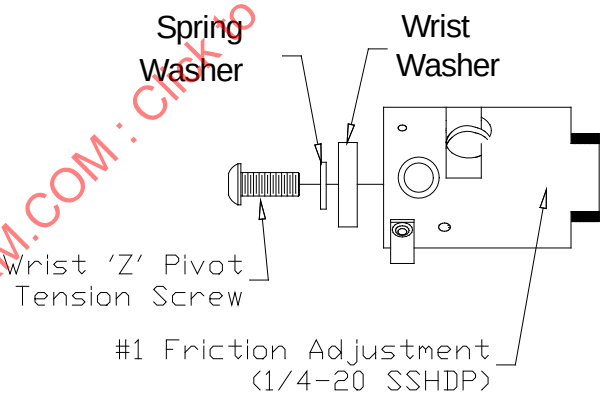

Figure C2 - Wrist 'Z' pivot tension

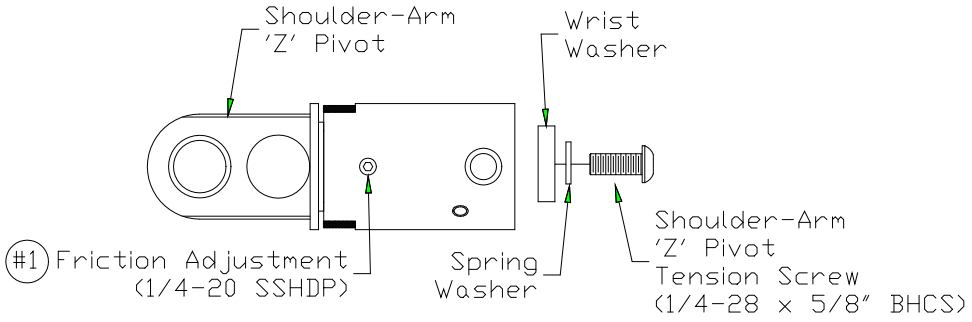

Figure C3 - Upper arm 'Z' pivot tension

C.1 ADJUSTMENT PROCEDURE

In Figure C4 is shown the standard orientation of each rotation. To begin the adjustment procedure first ensuring that the ‘Z’ pivots are properly assembled. The Urethane compression or spring washer in the ‘Z’ pivot joints cause some variability from assembly to assembly.

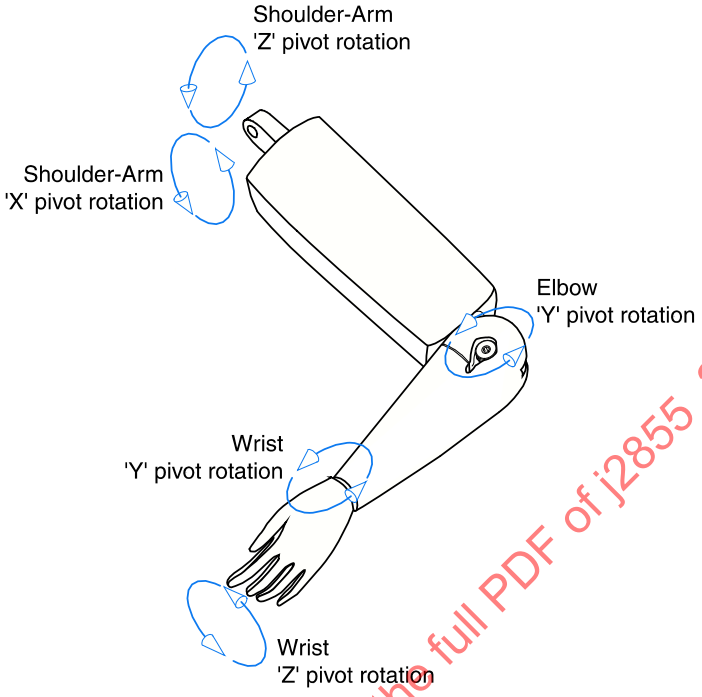

Figure C4 - Arm adjustment positions

The procedure to adjust the ‘Z’ pivot is:

1. Loosen the Friction Adjustment set screw. (Item #1 in Figures C2 and C3)

2. Tighten the ‘Z’ pivot Tension screw (1/4-28 BHCS) until there is contact. After the Wrist Washer contacts the Tube assembly turn the Tension screw 1/16th of a complete rotation to compress the Spring Washer.

The procedure detailed here is performed while the Arm is attached to the dummy.

1. **Shoulder-Arm 'Z' pivot rotation.** This is done by extending the complete arm laterally until it is parallel to the floor. Tighten the Shoulder-Arm joint bolt until the Arm is locked in this position. Bend the Arm at the Elbow so that the Lower Arm is perpendicular to the Upper but still parallel to the floor. If the 'Z' pivot is properly adjusted the Lower Arm should remain parallel to the floor but move easily when a downward force of 1 - 2 G's is applied. If it does not, the 'Z' pivot must be adjusted using the Friction Adjustment set screw (Figures C2 and C3).

2. **Shoulder-Arm 'X' pivot rotation.** The Arm is fully extended from the Dummy's Upper Torso so that the complete Arm is straight and parallel to the floor. The assembly should be approximately perpendicular to the Dummy's midsagittal plane (*line dividing left-side and right-side of full dummy*). If properly adjusted the Arm will maintain this position without support and will move freely if a downward force of 1 G's is applied. If not, the Shoulder-Arm joint pivot bolt must be adjusted. This bolt attaches the Arm assembly to the Dummy.

3. **Elbow 'Y' pivot rotation.** With the Arm fully extended from the Dummy's Upper Torso and parallel to the floor, rotate the complete Arm assembly so that the Lower Arm can move downward by flexing the Elbow joint (as shown in Figure C5). Tighten the Elbow pivot screw until the Lower Arm remains parallel to the floor until a downward force of 1 to 2 G's is applied.

4. **Wrist 'Y' and 'Z' pivot rotations.** The Wrist friction adjustments are not easily described due to the lack of mass of the components. This section is adjusted to simulate a 1 to 2 G's "feel" rather than a comparison to gravity. To adjust the Wrist friction, rotate the Hand and tighten the modified 5/16 x 1" SHSS until there is an appropriate friction in the Wrist joint.

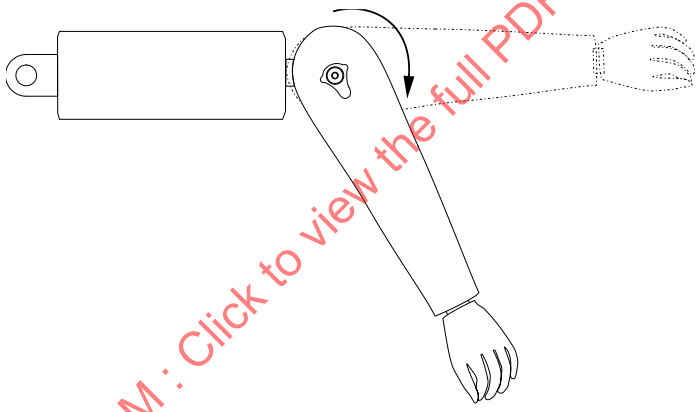

Figure C5 - Elbow friction adjustment

APPENDIX D - POTENTIOMETER CALIBRATION

Potentiometer calibration is done using the Potentiometer Calibration fixture.

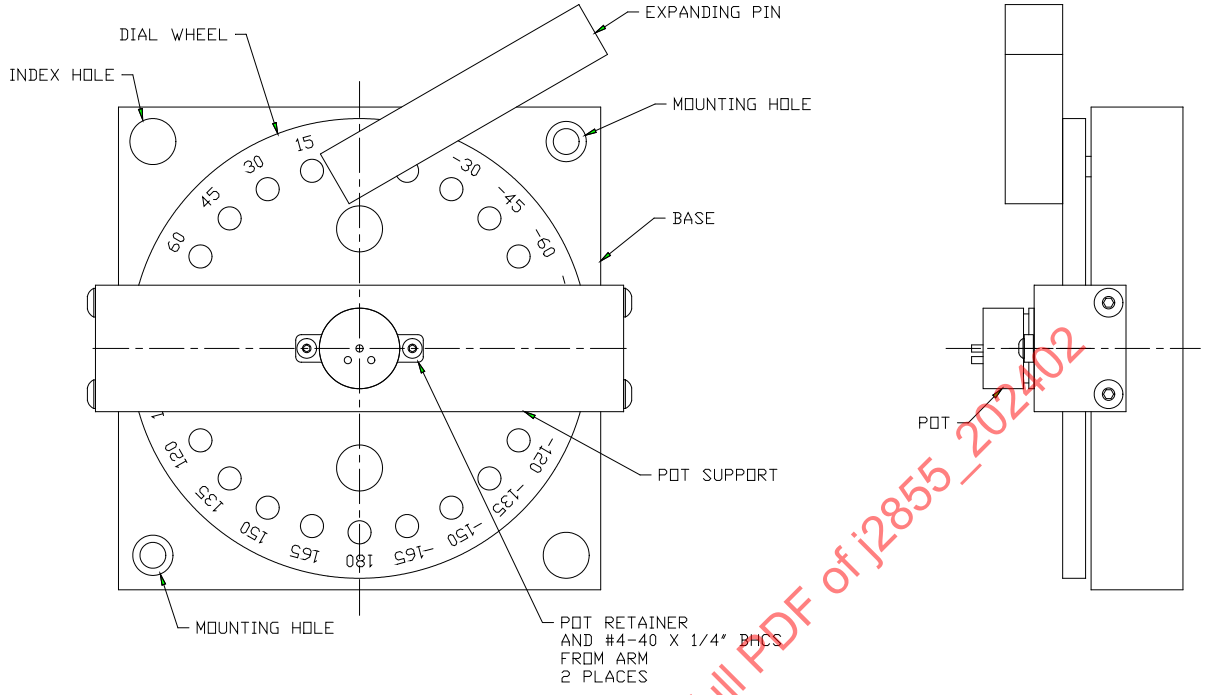

Figure D1 - Potentiometer calibration

Procedure

1. Remove the Potentiometer and Retainers from the Instrumented Arm.
2. Rotate the Dial Wheel to the Zero position, insert and expand the Pin to lock Wheel in position.
3. Install the Potentiometer into the Potentiometer Support Arm (shown in Figure D1).
4. Rotate the body of the Potentiometer until the output voltage reads approximately 0.0 V.
5. Install the Potentiometer Body Retainers to secure the Potentiometer Body to the Support Arm.
6. Connect the Potentiometer to a 10 VDC power supply and a voltage measuring device (i.e., VOM).
7. Calibrate the Potentiometer by rotating the Dial Wheel and locking it in the desired positions with the Expanding Pin. Make sure to always expand the Pin to accurately align the Dial Wheel hole with the Base hole.

***The input, or excitation, voltage must not exceed 12 V or damage to the potentiometer may occur.*