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A human factors approach towards the design of a new glovebox glove for Los Alamos National Laboratory

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Jude M. Oka

Abstract

Present day glovebox gloves at Los Alamos National Laboratory (LANL) are underdeveloped and ergonomically inaccurate. This problem results in numerous sprain and strain injuries every year for employees who perform glovebox work. In addition to injuries, using the current glovebox glove design also contributes to breaches and contamination. The current glove used today at LANL has several problems: 1) The length of the fingers is incorrect, 2) the web spacing between the fingers is nonexistent, 3) the angles between each digit on the finger are incorrect, 4) the thumb is placed inaccurately, and 5) the length of the hand is incorrect. These problems present a need to correct the current glove design to decrease the risk of injuries, breaches, and contamination. Anthropometrics were researched to help find the best range of hand measurements to fix the current glove design. Anthropometrics is the measure of the human physical variation. Anthropometrics for this study were gathered from the American National Survey (ANSUR) data that was conducted by the U.S Army in 1988. The current glovebox glove uses anthropometrics from the 95^{th} to 105^{th} percentile range which is too large so the new gloves are going to implement data from a smaller range of percentile groups. The 105^{th} percentile range represents measurements that exceed the human population but are needed to fit certain circumstance such as wearing several under gloves within the glovebox gloves. Anthropometrics used in this study include:105^{th} percentile measurements for joint circumference which was unchanged because the room for under gloves plus ease of hand insertion and extraction is needed, 80^{th} percentile measurements for crotch length to allow workers to reach the web spacing in the glove, 20^{th} percentile measurements for finger length to allow workers to reach the end of the glove, standard 10.5cm hand breadth to allow more room to accommodate under gloves, 45 degrees abduction angle for the thumb for better positioning, 45 degrees extension angle for the thumb for better positioning, and various angles for the other fingers to allow a more relaxed and natural fit. 3D modeling was used to implement the anthropometric data listed above onto an existing scanned solid model of a human hand. SolidWorks 2010 3-D modeling package was utilized to manipulate the hand model to represent the anthropometric data researched. The anthropometrics and modifications were reviewed by the University of New Mexico Department of Orthopedics hand surgeons. After all modifications and reviews were completed the model was printed out using stereolithography. The printed out model of the hand was used as a mold to create a prototype glovebox glove. The new mold was taken to Piercan USA to produce a 20mil Polyurethane/Hypalon glovebox glove. The Minnesota Dexterity test and Purdue Pegboard test were used to measure the dexterity of the prototype glovebox glove against a current 15 mil Hypalon LANL glovebox glove. Using the data from the tests a student *t* test was used to determine if there was a significant difference between the current hypalon glove results and the new prototype glove results. With a 95% confidence level the prototype showed to have a significantly lower mean difference from the current hypalon glovebox glove with the Minnesota Dexterity test. With a 95% confidence level the prototype showed to have a significantly higher mean difference from the current hypalon glovebox glove with the Purdue Pegboard test. A *p* value method was also performed to confirm the results of the student *t* test. A survey was also given to glovebox workers to determine if they preferred the new design. The best reaction from

glovebox workers was the new thumb position, 73.2% of the sample population agreed with the new thumb position. Developing a new glovebox glove will improve the ergonomics of the hand for work performed, decrease exposure time, decreasing risk of breaching, increasing productivity, reducing injuries, and improving work performance. In the future the new glovebox glove can also be implemented in other research fields such as: pharmaceutical research and development, semiconducting industry, biohazard industry, and other laboratories conducting nuclear research and development.

1.0 Introduction

1.1 Background

Gloveboxes help shield employees from hazardous material while work is being performed. Glovebox gloves are specialized gloves that are used to help employees perform glovebox duties while also shielding the employee from hazardous material. Gloveboxes are considered an "absolute barrier" or a sealed enclosure that contains hazardous material [2]. The weakest link of the glovebox is the gloves [2]. Glovebox gloves are considered weak due to the material make up of the glove. The polymer based glove has numerous modes of failure causing a breach to the enclosed system. The most common types of failures are due to: chemical attacks, cracking, cuts, blister, pinholes, punctures, and tears in the gloves. Every time a glovebox glove fails, there is a risk of hazardous materials being released into the work environment [5].

One of the most hazardous materials the glovebox gloves come into contact with is plutonium. Plutonium is an actinide metal of silvery-white appearance that corrodes when exposed to air, forming a dull coating when oxidized [8]. Plutonium requires a high degree of confinement while under constant control due to its extremely low permissible body burden [8]. Methods and equipment must be designed toward the ultimate accomplishment of preventing any worker coming into contact with plutonium. Unreleased plutonium results in contamination of the atmosphere, especially if it is in the oxide form [5]. To prevent contamination, gloveboxes are used to confine plutonium from employees while they perform their work duties. Chemical and metallurgical operations involving plutonium and other nuclear materials account for most activities performed in gloveboxes located at the Plutonium facility at technical area fifty-five (TA-55). Primary activities include the following [10]:

- **Actinide Process Chemistry–** Safely and efficiently process plutonium and other actinide compounds to meet the nation's nuclear programs [10].
- **Weapons Component Manufacturing & Surveillance–** Weapons Component Manufacturing & Surveillance is the group that supports the manufacturing processes used to produce new nuclear pits and surveillance in support of the present and future needs of the nation's stockpile [10].
- **Pit Integrated Technologies–** Provides process science and technology solutions supporting the mission requirements of Manufacturing and Engineering Technology Division for Pit Manufacturing, Certification and Surveillance, which include such capabilities as advanced design and prototyping, new equipment development, continuous process safety, security and quality improvements [10].
- **Actinide Manufacturing–** Actinide Manufacturing is the group that supports the national interests in Pu-238 heat-source and generator development, production, dismantlement, and recycling [10].

- **Pit Disposition Science and Precision Fabrication –** Pit Disposition & Precision Fabrication is the group that supports the national objectives of nuclear deterrent, nuclear disarmament, fissile material disposition, and actinide fuels development. Supporting critical missions in the dismantlement of the core of nuclear weapons (pits), the conversion of the plutonium from pits into oxides, and nuclear fuel activities [10].
- **Nuclear Materials Science**–Characterizes new and aged pit construction materials and develop technologies for advanced actinide materials characterization [10].

The operations described above surround an array of physical, chemical, and radiological hazards that Gloveboxes and gloves endure. Major hazards are listed in Table 1 [5].

Hazards		
Physical	**Chemical**	**Radiological**
Rotating Equipment	Hydrochloric Acid	Alpha Particles
Sand Blasting	Nitric Acid	Beta Particles
Welding Operations	Other Acids	Gamma Rays
Thermal Sources	Bases	Neutrons
Grinding	Bromobenzene	
Sharps	Gas Permeability	
Pinch Points		

Table 1 Major nuclear hazards

Glovebox gloves used at TA-55 are made from five types of polymer formulations: Hypalon, Hypalon with an inner lead oxide layer, Butasol, Viton, and Polyurethane coated with hypalon [1]. Finding the most compatible glove for the glovebox environment is the key to minimizing unplanned breaches. If unplanned breaches arise, it is the responsibility of line management to ensure the situation is taken care of. From a chemical standpoint, hypalon is the material of choice for most glovebox operations because it is resistant to interactions with alcohols, strong acids and bases. Hypalon also exhibits excellent mechanical properties and ultraviolet light and oxygen stability. Lead-lined Hypalon gloves are mainly used because they add extra shielding while working with radiological materials. Butasol gloves are the material of choice for gas permeability applications. Viton gloves are the material of choice for operations involving chemicals such as bromobenzene because viton exhibits excellent properties towards flammable and corrosive chemicals [1]. Lastly, Polyurethane coated gloves with hypalon are one of the newest polymer formulations out on the market. Polyurethane/ Hypalon gloves are starting to replace hypalon gloves because they show higher mechanical properties for puncture and tear resistance and higher resistance to UV Rays [1].

The TA-55 Catalog numbers for the gloves currently approved and in use at TA-55 are listed in Table 2 [1].

CAT No	Description
8BT25XX	Butasol
8F20XX	Viton
8Y15XX	Hypalon
8Y30XX	Hypalon
8YLY30XX	Hypalon, Lead Loaded
8UY20XX	Polyurethane/Hypalon

Table 2 Catalog number for glovebox gloves at TA 55

The number at the beginning represents the diameter of the gloveport. The letter or letters that follow represent the type of material. The two numbers that follow represent the thickness of the gloves in mils and XX is the length of the glove. Currently two lengths are available at LANL, 30 and 32 inches. The 30 inch glove is the LANL standard mold and the 32 inch glove is the manufacture standard form. Figure 1 shows the schematic for the LANL standard glove [1]. Table 3 shows the dimensions of the standard LANL glove and the standard manufacturers glove.

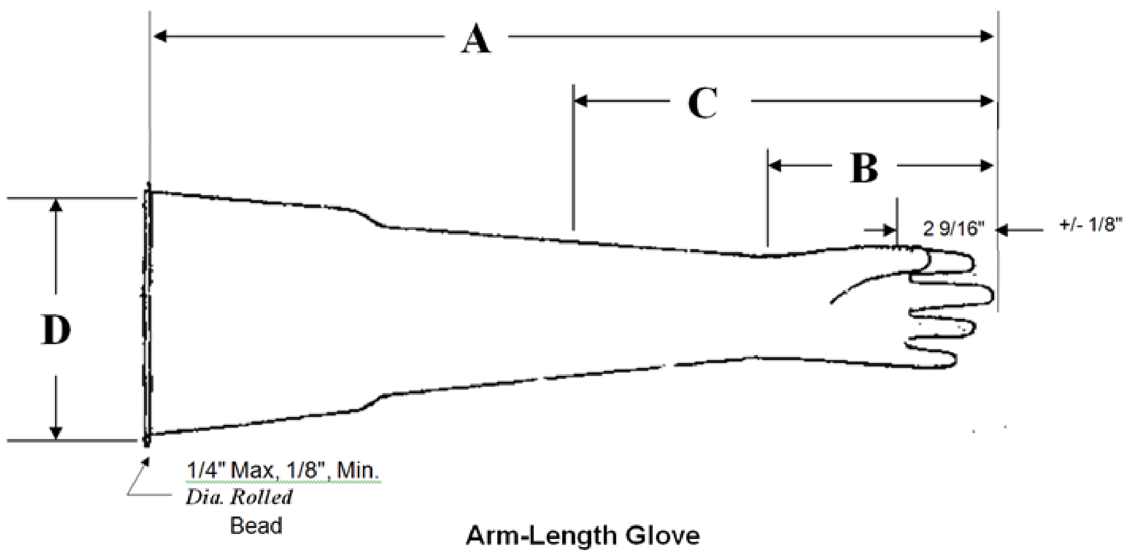

Figure 1 Dimensions for the LANL glovebox glove design

Type of Mold	A (inches)	B (at 7 ¾ in. Down) Min	B Max	C (at 19 in. Down)	D Min	D Max
LANL	30 +/-0.750	9¾ in.	10 in.	NA	8¼ in.	7-9/16 in.
		I.D. Circumference			Inside Diameter	
Standard Manufacturer's Design	32 +/-1.0	9¼ in.	10 in.	15 in. min.	8¼ in.	7¾ in.
		I.D. Circumference			Inside Diameter	

Table 3 LANL and standard measurements for glovebox gloves

At TA-55 there are over 500 gloveboxes in 68 rooms with about 8300 gloveports [2]. Within each room there are over a dozen different types of gloveboxes used. Table 4 shows the different types of gloveboxes used at TA-55 [1].

Acronym	Definition
CT	Cross-Town Trolley
DB	Dropbox
EV	Evaporator
GB	Glovebox
HV	Heating and Ventilation Plenums
MP	Metal Production Line
TN	Trolley, North Side
TE	Trolley, East Side
TS	Trolley, South Side
TW	Trolley, West Side
TU	Tunnel
TT	Transfer Trolley
XB	Introductory Glovebox or Hood

Table 4 Different gloveboxes used at TA-55

At TA-55 the Hypalon glove is the most common glove used because of its mechanical properties and protection while working with hazardous material. Table 5 shows the evolution of hypalon gloves being utilized at TA-55 [2].

Type	Before 2007	After 2007
Hypalon 15 mil.	1316	1316
Hypalon 30 mil.	249	4399
Hypalon 30 mil., Lead-Loaded	6225	2075
Butasol 25 mil.	498	498
Viton 25 mil.	12	12
Total	8300	8300

Table 5 Number of Hypalon gloves being used at TA-55

Before 2007 the Hypalon lead-lined glove was the primary glove used for most of TA-55 operations. Now, for many non ^{238}Pu operations the non-leaded hypalon 30 mil glove has replaced the lead-lined alternative, this is due to a dexterity test performed on both the hypalon and lead loaded hypalon gloves. The test proved the non-lead hypalyon gloves were 25% more efficient when the gloves were being used [1]. The risk of an ergonomic injury is higher with the lead-lined gloves thus showing the improved efficiency non-leaded gloves allowed the drastic reduction of risk of ergonomic injuries.

1.2 Current LANL glovebox glove problems

As previously stated, the current glove used today at LANL has several problems: 1) The length of the fingers is incorrect, 2) the web space between fingers is nonexistent, 3) the angles between each digit on the finger are incorrect, 4) the thumb is placed inaccurately, and 5) the length of the hand is incorrect [14]. Currently, most glove manufacturers only take into account 3 measurements of the hand to design a glove [7]. The few hand measurements used are hand length, hand breadth, or hand circumference. The new LANL design will be using 5 hand measurements. These hand measurements are joint circumference, hand breadth, crotch length, angles for each finger, and lengths for each digit of the finger. Figures 2-4 show different views of the current glovebox glove used at LANL while also showing the current problems with the glove [14].

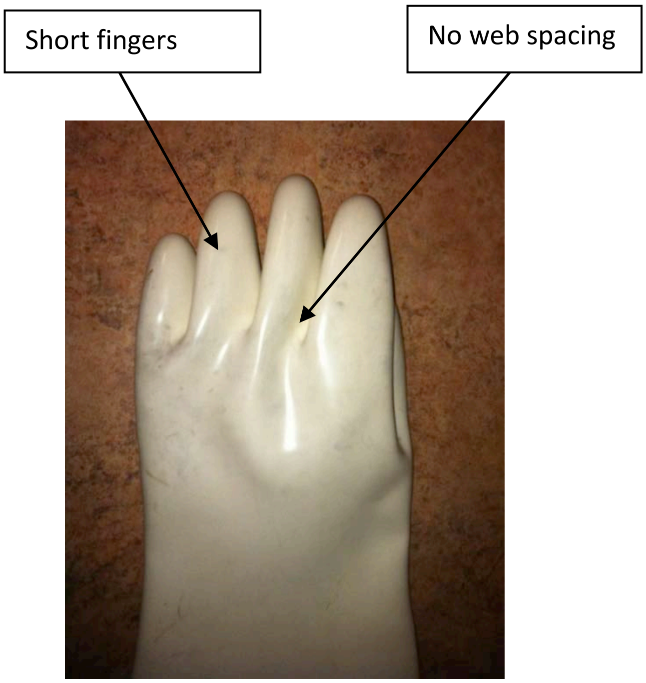

Figure 2 Top view of LANL glovebox glove.

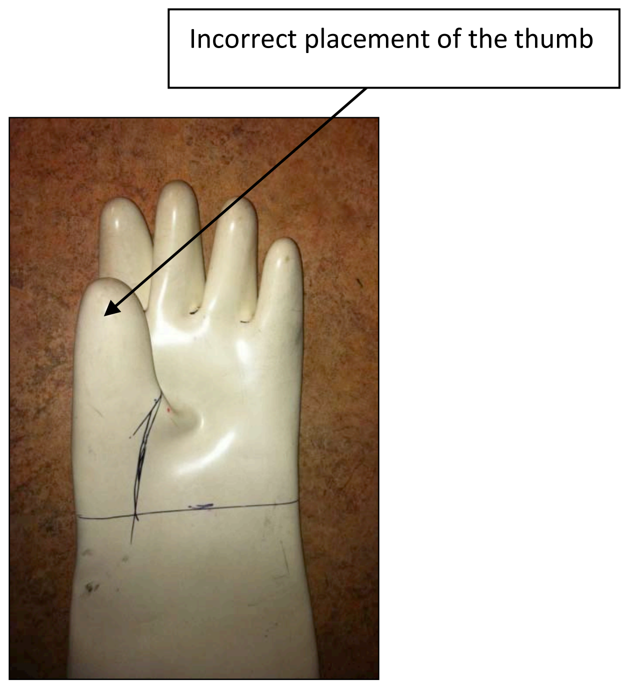

Figure 3 Bottom view of LANL glovebox glove

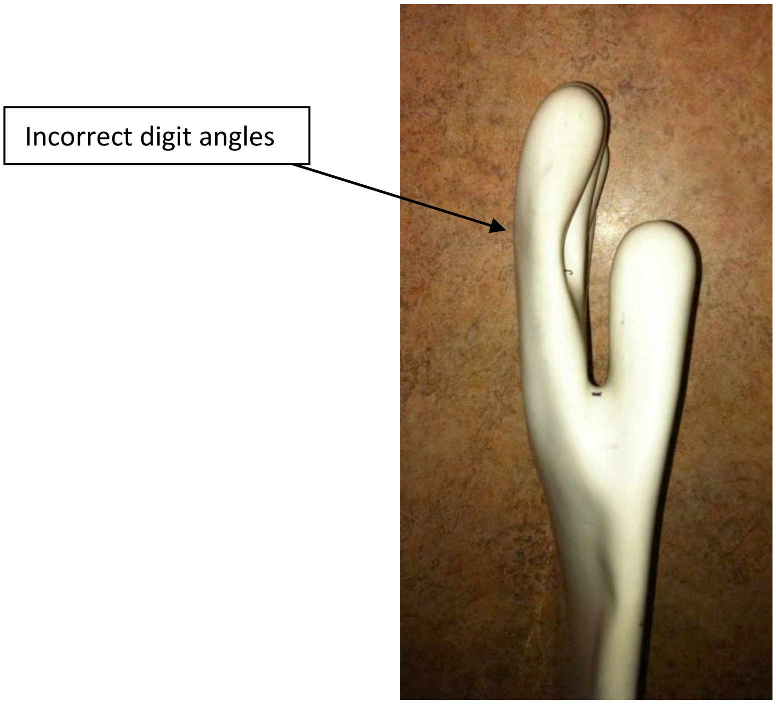

Figure 4 Side view of LANL glovebox glove

Using the new measurements to create a new glovebox glove will help improve dexterity making work easier and mitigating risk of injury. All hand measurements were defined in collaboration with hand surgeons from the University of New Mexico Hospital (UNM-H) department of Orthopedics to ensure the measurements were accurate. UNM-H also reviewed all implementations of the new measurements to ensure they were implemented correctly.

1.3 Glovebox worker injury

There are approximately 472 glovebox workers on training plans at LANL [4]. Due to the current glove design and burdensome operations at LANL there are numerous injuries a year. Recordable injuries and first aid cases are documented at Occupational Medicine, a medical clinic on site [4]. A symptom is defined as any physical pain, discomfort, tingling, or numbness that one can attribute to his/her glovebox work. Most common activities working in gloveboxes are: lateral transfer, forward reaching, gross motor skills, and fine motor skills [4]. Areas of concern within these activities are: shoulder, elbow/forearm, thumb, wrist, and hand [4]. Table 6 shows the rate of glovebox injuries dating from 2006 to 2010 at TA-55. As shown in Table 6 eighty-eight percent of first aid and recordable incidents are repetitive related incidents and only twelve percent are from a single occurrence related incident.

Repetitive	**88%**				
Single Occurance	**12%**				
	2006	**2007**	**2008**	**2009**	**2010**
First aid	0	0	2	3	3
Recordable	7	10	8	2	6
Areas of Concern					
Elbow	**Wrist**	**Hand/fingers**	**Thumb**	**Shoulder**	
8	3	5	3	17	

Table 6 LANL glovebox injury rate at TA-55

Table 6 includes the data from the ergonomic related glovebox cases(88%) indicating how many first aid and recordable cases Occupational Medicine recorded along with the body part which was injured [4]. This data demonstrates that 19 (elbow, wrist, hand/fingers, thumb) overuse injuries occurred and are most likely related to an inappropriate glove fit. In addition, an ergonomic assessment survey was developed to identify workers risk for potential injury as well as work rest cycles. All workers were required to fill out the survey. The survey revealed 55 workers in the “high risk” category. All these workers went through a medical screen to establish if they were already having symptoms which could lead to a recordable or first aid case. Particular interest to the glove modification would be workers with symptoms in the elbow, hand/fingers, and thumb. Tests for the damaged elbow include:

- Wrist Flexion
- Wrist Extension
- Medial Epicondyle Palpation
- Lateral Epicondyle Palpation

From the elbow tests one glovebox worker had medial epicondylitis and four glovebox workers had lateral epicondylitis [4]. Table 7 expresses the results from the 55 high risk glovebox workers who were screened for elbow symptoms. Table 7 also shows that lateral tenderness was the most common symptom for the high risk glovebox workers [4].

Elbow Results

Test	Location	Prevalence
Wrist Flexion	Right Only	1/55 (1.8%)
	Left Only	0/55 (0%)
	Bilateral	0/55 (0%)
Wrist Extension	Right Only	2/55 (3.6%)
	Left Only	1/55 (1.8%)
	Bilateral	1/55 (1.8%)
Medial Epicondyle	Right Only	4/55 (7.3%)
	Left Only	5/55 (9.1%)
	Bilateral	3/55 (5.5%)
Lateral Epicondyle	Right Only	11/55 (20%)
	Left Only	2/55 (3.6%)
	Bilateral	14/55 (25.5%)

Table 7 Tests results from the damaged elbow tests

Another factor for worker injury is the number of years of service for glovebox workers. The more years of service a glovebox worker has accomplished, the chances of obtaining an injury increases drastically [4]. Figure 5 shows the number of years of service from a glovebox worker versus the number of reported symptoms. The graph demonstrates that glovebox workers with more years of service are more likely to have an injury from glovebox work [4]. Another contributing factor is the amount of time spent working in a glovebox per day. Table 8 shows the number of workers with symptoms versus the amount of time working in a glovebox per day. Looking at table 8 one can see the risk of injury increases with an increase amount of time working in a glovebox 4].

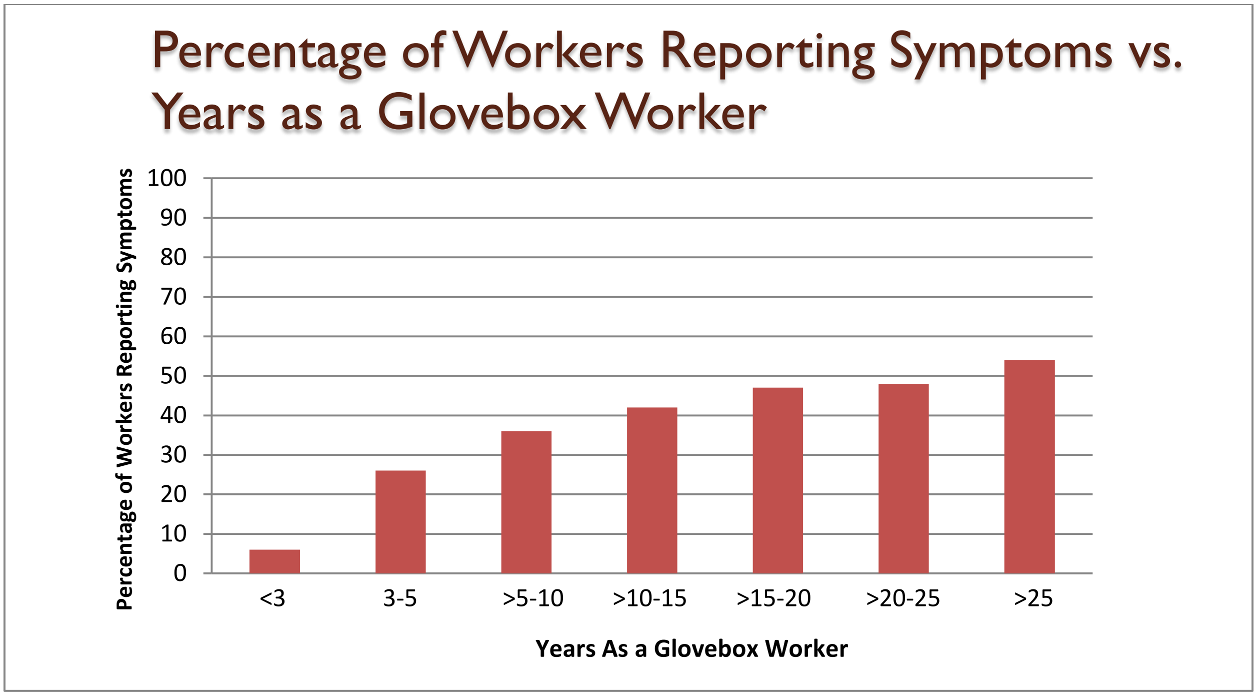

Figure 5 Bar graph showing the number of symptoms vs number of years of service

Number of Workers With Symptoms vs. Amount of Time In the Glovebox Per Day

Number of Workers Reporting Symptoms	Amount of Time in the GB/day
12/116 (10%)	≤ 1 hour
10/46 (22%)	1-2 hours
19/53 (36%)	2-3 hours
13/27 (48%)	3-4 hours
18/36 (50%)	4-5 hours
17/27 (63%)	5-6 hours
27/42 (64%)	>6 hours

Table 8 Table showing number of workers with symptoms vs amount of time working in the glovebox

2.0 Previous Work

2.1 Glovebox glove manufacturing process

Glovebox gloves are typically made from porcelain molds. Most porcelain molds are made within their own company such as Piercan USA [9]. Latex gloves are produced on porcelain molds that are dipped in a dispersion of natural rubber in water. Advanced composite laminates are generally 0.03” to 0.04” thick. In addition, thicker gloves can be produced but the time element increases greatly. After the dipping process is complete the gloves are then cured in an oven at about 220°F for approximately 20-25 hours [9]. The high temperature resistant latex takes longer to cure at about 25-30 hours at 250°F. Lastly, after the gloves are cured they are manually removed from the porcelain molds by stretching and pulling on the open end, or using compressed air to help separate the latex from the porcelain molds. Some companies such as Piercan USA have developed a formulation for natural rubber that can be re-useable for many composite curing applications [9].

More information on the glove suppliers can be found at their respective web sites:

- http://www.northsafety.com
- www.piercanusa.com/
- www.mapaglove.com

2.2 Hand sizes

In ergonomics, sizes are generated using anthropometrics for garments such as gloves and other protective equipment. Anthropometrics is the measurement of the human physical variation [17]. Anthropometrics is used because they can be adjusted for each individual’s particular dimensions. This can be very difficult because the human population has large amounts of variation. Critical dimensions are defined by the manufacture or researchers as a list of key dimensions that determines the geometry of garments [7].The sizes must be organized from the critical dimensions to account for as much of the variation as possible [7]. In some cases there can be a large number of critical dimensions. This makes the selection of critical variables difficult for designers. It is most difficult to use the critical dimensions to define and describe the population. The most common method for defining the sizes for garments and protective equipment is the percentiles method [15]. This method is used for very large populations that are represented on a normal curve. The normal curve is plotted along an x axis scaled to a standard deviation. The normal curve extends to negative infinity on the left and positive infinity on the right. Percentiles represent the area under the normal curve, increasing from left to right [19]. Each standard deviation represents a fixed percentile. For example, -3 on the x axis or 3 standard deviations to the left can be represented by the 0.13^{th} percentile. Zero on the x axis represents the 50^{th} percentile also knows as the mean of the distribution. And positive 3 on the x axis or 3 standard deviations to the right represent the 99.87^{th} percentile [18].

2.3 Traditional Methods of Sizing for Gloves

It is ultimately the manufacturer's decision to choose the number of critical dimensions that will determine the garments geometry. The glove manufacturing industry currently uses three measurements in the design of gloves. The three measurements are hand length, hand breadth or hand circumference [15]. Varying the value of the measurements allows the manufacturer to make multiple sizes of gloves. The sizes are usually divided into small, medium and large although there are some manufacturers that include extra-small and extra-large sizes. There are no standards in the manufacturing industry for glove sizes, so it can be challenging for designers to determine the critical dimensions for glove design [15]. Manufacturers often use different methods of sorting anthropometric data to help determine glove sizing. Robinette and Annis created nine sizes for chemical defense gloves to be used by U.S Air Force men and women for protection against hazardous chemicals [12]. The measurements used for these gloves were hand length and hand circumference, using a bivariate model for gloves sizing the researchers were able to determine which percentile group would fit for each size. From the bivariate model twenty-two values for hand length and hand circumference were calculated for each size category [12]. Rosenblad-Wallin developed a similar sizing system to Robinette and Annis using the hand length and hand circumference dimensions [13]. The system was designed for military hand mittens to be used by men and women in extreme cold weather environments. A survey was constructed on the intended users and user populations were generated for key dimensions. The system was designed for thick thermal material and the fitting tolerance between the hand and mitten was adjusted accordingly [13]. Only two sizes were created from the research, but tested well among the large trial groups. Hidson produced a computer-aided glove design constructed from 50 hand dimensions gathered from a small sample of subjects [3]. The design was created to show that CAD/CAM systems can be used to generate models of the human hand. The model created did not produce a sizing system, but developed a system to which computer models can be created from information that has been collected from large databases of anthropometric data [3]. Similar models have been built off of landmark dimension to help aid glove design [6]. These models can help validate future CAD/CAM systems that will be used to generate hand models for glove sizing [6].

2.4 Today's methods of sizing gloves

Science and technology are ever changing and it is important to refer to the most recent advances in the area of sizing when developing a new sizing system. Researchers used the ANSUR data from 1988 to devise a system using two of the three measurements that are most often used in manufacturing gloves [15]. This data contains eighty-six length, width, height, and circumference measurements of the human hand for one thousand male subjects and thirteen hundred female subjects. Eliminating redundant measurements reduced the data to forty-six essential measurements. Factor analysis grouped the variables to form three factors [15]. The factors were used to generate hand sizes by using percentiles along each factor axis [15]. Two different sizing systems were created. The first system contains 125 sizes for male and female. The second system contains 7 sizes for males and 14 sizes for females. The sizing systems were compared to another hand sizing system that was created using the ANSUR database indicating that the systems created using factor analysis provide a better fit [15].

3.0 Theory

3.1 SolidWorks modeling

Human factors engineering is the discipline of applying what is known about human capabilities and limitations to the design of products, processes, systems, and work environments by the implementation of tools such as ergonomics [17]. Ergonomics is defined as the science relating to man and his work, embodying the anatomic, physiologic, psychologic, and mechanical principles affecting the efficient use of human energy [17]. Using tools such as ergonomics will help create a model that will represent critical measurements carefully chosen from anthropometrics. SolidWorks 2010 was utilized in the design of a new glovebox glove. SolidWorks is a 3D modeling package that allows engineers to create, modify, and simulate parts in three dimensions. This project used an existing scanned solid model of a human hand plus forearm, which was redefined to represent the anthropometric data researched in correspondence with UNM-H. Figure 6 shows the original hand model for this project.

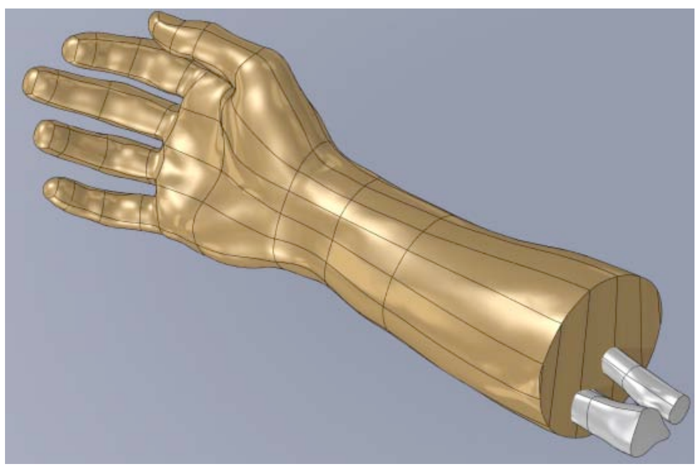

Figure 6 Original hand model

3.2 Tolerances and percent error

Before any modifications were done to the model, tolerances were defined. A tolerance for each modification was set forth by Cindy Lawton, the lead glovebox ergonomist at TA-55. The tolerances were given as ± 3 degrees for angle modifications and ± 3 millimeters for translation modifications. In addition, for each modification the percent error was found to see how close the theoretical value was to the experimental value. The anthropometric data could not be implemented 100% accurately because the geometry is too complex for each modification. The time element increases drastically for each modification because the anthropometrics on the original hand are a lot smaller than the researched anthropometrics. All modifications done are within tolerance and below 1% error to ensure the anthropometric data was implemented accurately. The equation for percent error is as follows:

$$\%Error = \frac{|Experimental - Theoretical|}{Theoretical} * 100 \quad (1)$$

Where:
Experimental= the experimental value of the anthropometric measurement after modification
Theoretical= the theoretical value of the researched anthropometric measurement

3.3 Hand measurement definitions, anthropometrics, and SolidWorks hand modeling

The following sections describe each modification done to the model. Modifications include: joint circumference, crotch lengths, finger length, finger angles, and hand breadth. The description will include: definition of each modification, anthropometric data set chosen, description of the steps taken in SolidWorks to create the modification and the calculated percent error.

3.3.1 Joint circumference

In medical terms, the first finger refers to the thumb, the second finger refers to the index finger, the third finger refers to the middle finger, the fourth finger refers to the ring finger, and the fifth finger refers to the pinky. The first joint of each finger from the palm is known as the metacarpal-phalange (MP), the second joint distally from the MP is known as the proximal inter-phalange (PIP), the last joint from the PIP is known as the distal inter-phalange (DIP) [14], [15]. Joint circumference is the measured circumference around the joint of interest. The joint circumference on the current glovebox glove does not seem to be a problem. Table 9 shows anthropometric measurements of joint circumferences of various percentiles. An extremely high percentile group was selected for joint circumference that showed close relationship with current glovebox glove joint measurements. The yellow shaded values are measurements of the 105th percentile group; these measurements have a very close relationship with the current glovebox glove circumferences. The 105th percentile represents measurements that exceed the human population but are needed to allow insertion and extraction of the hand and it allows more room for under gloves. Glovebox workers typically wear two under gloves, one for extra protection and the other for sweat control. Table 10 shows joint circumference measurements of current glovebox gloves used at TA-55. Table 11 shows values for joint circumference measurements after modification as well as calculated percent errors.

The original model was solid therefore modifications were not feasible because of its current state. Solid models do not allow components to loft back together after each modification, lofting components requires the user to work with surfaces. Lofting in SolidWorks is a tool used for patching surfaces back together. Modifications such as rotations, translations, scaling, lofting, deforming, and surface patching are also impossible with the solid model. The most feasible way to modify the original model is to work with surfaces. To work with surfaces the model had to be hollow. A zero distance offset was used to hollow the model; this feature in SolidWorks left just the surface of the hand. Within SolidWorks joint circumference was modified by scaling up each digit of the finger separately. Each finger was cut in between each joint making 3 independent segments for each finger. With the three independent segments the scaling tool was utilized to scale each joint of the finger to the desired anthropometric measurement. After scaling up each digit lofting was used to patch each segment back together. Circumference was measured using the measure tool in SolidWorks. Design reviews with UNM-H confirmed each joint circumference measurement was implemented accurately.

Anthropometric data for fingers									
	Joint circumference								
	Digit 2 (index)		Digit 3 (middle)		Digit 4 (ring)		Digit 5 (pinky)		Digit1(thumb)
Percentile	DIP (distal)	PIP (Proximal)	DIP (distal)	PIP (Proximal)	DIP (distal)	PIP (Proximal)	DIP (distal)	PIP (Proximal)	DIP (distal)
50th	58.78	70.3	58.18	70.21	53.67	65.24	50.15	59.01	72.27
75th	57.33	68.4	60.4	72.97	55.63	68.02	48.69	56.57	72.27
95th	61.81	73.16	60.4	72.97	55.33	67.07	50.15	59.01	74.47
80th	58.45	69.59	60.4	72.97	55.555	67.7825	49.055	57.18	72.82
105th	69	80.5	68.3	80.3	61.7	73.7	56.4	64.9	82
	Measurements in millimeters								

Table 9 Anthropometric measurements of joint circumferences

Glove 1 (in centimeters) North hypalon			
	DIP joint circumference	PIP joint circumference	crotch length to tip of the fingers
1st finger	9.2	n/a	5.6
2nd finger	7.6	7.6	6.1
3rd finger	7.7	7.95	6.4
4th finger	7.65	7.8	6.2
5th finger	6.7	7.1	5
Glove 2 (in centimeters) North Polyurethane/Hypalon			
	DIP joint circumference	PIP joint circumference	crotch length to tip of the fingers
1st finger	8.4	n/a	6.6
2nd finger	6.5	7.0	7.1
3rd finger	7	7.4	7.4
4th finger	6.8	7.2	6.8
5th finger	6.4	7.0	5.7
Glove 3 (in centimeters) Piercan Polyurethane/Hypalon			
	DIP joint circumference	PIP joint circumference	crotch length to tip of the fingers
1rst finger	9.1	n/a	7.7
2nd finger	7.9	8.1	7.3
3rd finger	8.0	8.6	7.5
4th finger	7.7	8.0	7.4
5th finger	7.55	7.6	6.5

Table 10 Joint circumference measurements of current glovebox gloves

	Joint circumference data from the model								
	Digit 2 (index)		Digit 3 (index)		Digit 4 (index)		Digit 5 (index)		Digit 1 (thumb)
	DIP (distal)	PIP (Proximal)	DIP (distal)	PIP (Proximal)	DIP (distal)	PIP (Proximal)	DIP (distal)	PIP (Proximal)	NA
105th percentile	69	80.5	68.3	80.3	61.7	73.7	56.4	64.9	82
After Modification	68.7	80.5	68.2	79.9	61.3	74	56.2	65.1	81.9
% error	0.4347826	0	0.1464128	0.4981320	0.648298	0.407056	0.35461	0.308166	0.12195122
Measurements are in millimeters									

Table 11 Joint circumference modification measurements and calculated percent error

3.3.2 Crotch area

The crotch area of the human hand refers to the web spacing between each finger [14], [15]. Crotch length is the perpendicular distance from the wrist crease to the web space between each finger. Crotch 1 length refers to the distance from the wrist crease to the web spacing between the first and second fingers. Crotch 2 length refers to the distance from the wrist to the web spacing between the second and third fingers. Crotch 3 length refers to the distance from the wrist to the web spacing between the third and fourth fingers. Lastly, crotch 4 length refers to the distance from the wrist to the web spacing between the fourth and fifth fingers [14], [15]. Within SolidWorks the crotch length was hard to define because the model has a high wrist crease landmark. This resulted in low measurement values of crotch lengths within SolidWorks. To obtain an accurate crotch length, a wrist crease was drawn on a 3D print out of the human hand. Next, crotch lengths were measured directly on the printed model; these measurements can be seen as Printed Model Measurements in Table 12. The crotch lengths in SolidWorks were also measured and are labeled SolidWorks Model Measurements in Table 12. Next, the crotch lengths from the printed model were subtracted from the crotch lengths of the SolidWorks model. The average from these differences was taken and subtracted from the 80th percentile to help compensate for the low wrist crease. The average found from the difference between each set of crotch lengths was 11.05mm which was subtracted from the 80th percentile. The new 80th percentile measurements can be found in table 12 labeled as 80th with compensation. These new measurements now can be implemented in SolidWorks using the high wrist crease without creating a new wrist crease in SolidWorks.

Crotch length modifications were done by using the copy/move feature in SolidWorks. The modification was done by first cutting the palm parallel to the wrist. The cut was located between the wrist and the crotch area. This cut was done solely to modify the lengths of crotch 2, crotch 3, and crotch 4. After cutting the palm the hand was in two pieces. One piece includes the upper part of the hand with all 4 fingers and respective crotch areas; the second piece includes the lower part of the hand with the 1st finger, wrist, and forearm. 3D sketch dots were placed above each crotch area indicating where the crotch area should fit the 80th percentile measurements. Using the copy/move feature a translation modification was performed that moved the upper portion of the hand until each crotch area matched the 3D sketch dots. Lofting was done to re-combine the two pieces back to one uniform hand. To modify crotch 1 a second cut had to be made between fingers 1 and 2 that is perpendicular the wrist crease. Crotch 1 length had to be reduced to fit the 80th percentile so this portion of the hand was not included in the previous translation modification. Due to the second cut the hand was in two pieces again, one piece included just the first finger and the second piece included the rest of the hand. As previously stated, a 3D sketch dot was placed where the 80th percentile measurement for crotch length 1 should be. Another translation modification was performed reducing the length of crotch 1 to fit the 80th percentile measurement. Lofting was done to re-combine the two pieces back to one uniform hand. Design reviews with UNM-H confirmed each crotch length measurement was implemented accurately.

Crotch length (The perpendicular distance from the wrist crease to the web space of each finger)				
	Crotch			
Percentile	Crotch 1 (thumb)	Crotch 2 (first finger)	Crotch 3 (second finger)	Crotch 4 (third finger)
50th	69	108	106	93
75th	70	112	112	100
95th	76	119	115	105
80th	71.5	113.75	112.75	101.25
Printed Model Measurements	81	108	106	95
SolidWorks Model Measurements	67.77	95.00	95.44	87.59
80th with compensation	60.45	102.7	101.7	90.2
After modification	59.88	101.77	100.76	91.03
% error	0.943	0.905	0.924	0.920
Measurements in millimeters				

Table 12 Anthropometric measurements of crotch lengths, after modification measurements and calculated percent errors

3.3.3 Finger length

Finger length is the distance from the crotch area to the tip of the finger [14], [15]. In this study finger length was broken up to phalanx distances. The proximal phalanx refers to the distance from the MP to the PIP. The middle phalanx refers to the distance from the PIP to the DIP. The distal phalanx refers to the distance from the DIP to the tip of the finger [14], [15]. Each distance is measured from the beginning of one joint to the beginning of the next joint. The 80th percentile values were proven to be too long. The current hypalon glovebox gloves needs longer fingers but using the 80th percentile range would prevent workers from reaching the end of the gloves. In contrast, the current polyurethane/hypalon glovebox glove fingers are too long. Table 13 shows the values for the 20th percentile for each joint to joint distance. The 20th percentile is appropriate for the prototype glove because the lengths are much smaller than the 80th percentile but still give the glovebox gloves the length it needs. Using the 20th percentile measurements will allow glovebox workers to reach the end of the glove. Table 13 also shows the total length of each finger which is the sum of the phalanx lengths. Table 14 shows the measurements for each finger after modification and the calculated percent error.

Finger length modifications were done by using the copy/move feature in SolidWorks. The cuts that were made for joint circumference modification were re-opened for this modification. Once a finger had three independent segments a sketch line was drawn through the center of all the joints. This line provided a path for the copy/move feature to follow for the translation modification as well as a reference to measure the distances from joint to joint. The copy/move feature was used by selecting one segment of the finger and using the sketched line as a guide for the translation path. The distance of each finger segment was modified to fit the 20th percentile measurements. After each finger was moved to the desired anthropometrics the segments were lofted back together. Design reviews with UNM-H confirmed each finger length measurement was implemented accurately.

Finger length data										
percentile	**finger 1 length**		**finger 2 length**		**finger 3 length**		**finger 4 length**		**finger 5 length**	
20th	distal phalanx	3.23	distal phalanx	2.65	distal phalanx	2.65	distal phalanx	2.76	distal phalanx	2.54
	proximal phalanx	3.34	middle phalanx	2.06	middle phalanx	2.4	middle phalanx	2.21	middle phalanx	1.57
	finger 1 length	6.57	proximal phalanx	2.4	proximal phalanx	2.87	proximal phalanx	2.51	proximal phalanx	1.59
			finger 2 length	7.11	finger 3 length	7.92	finger 4 length	7.48	finger 5 length	6.06
20th percentile										
All measurements are in (cm)										

Table 13 20th percentile measurements for finger length

Finger measurements after modification									
Finger 1		Finger 2		Finger 3		Finger 4		Finger 5	
distal phalanx	3.26	distal phalanx	2.63	distal phalanx	2.63	distal phalanx	2.74	distal phalanx	2.54
middle phalanx	3.37	middle phalanx	2.08	middle phalanx	2.42	middle phalanx	2.23	middle phalanx	1.59
`	**%error**	proximal phalanx (PIP)	2.40	proximal phalanx	2.86	proximal phalanx	2.53	proximal phalanx	1.93
distal phalanx (DIP)	0.929		**%error**		**%error**		**%error**		**%error**
middle phalanx	0.868	distal phalanx	0.755	distal phalanx	0.830	distal phalanx	0.906	distal phalanx	0.196
		middle phalanx	0.922	middle phalanx	0.833	middle phalanx	0.905	middle phalanx	0.955
		proximal phalanx	0.167	proximal phalanx	0.418	proximal phalanx	0.797	proximal phalanx	0.820

Table 14 Finger length modification measurements and calculated percent errors

3.3.4 Finger angles

An angle on a finger refers to the angle made between each phalanx [14]. Table 15 shows angles between each phalanx for all five fingers. An angle for each finger is measured dorsally from the top of each finger. Finger angles were not gathered using the ANSUR data but instead with the help of UNM-H. Angles of the hand for the new prototype glove will represent the geometry of the hand reaching out and grabbing a can [14]. These particular angles will help the glove ergonomically by giving the new glove more relaxed angles on each finger. Relaxed angles will give the glove more usability by allowing a better fit for the workers. UNM-H has done studies that accurately measures angles on the hand for grasping motions. With the results from these studies UNM-H has been able to accurately obtain angles for this research project [14].

In SolidWorks angle modification was implemented 100% accurately. The time element for this modification was not an issue for this modification because this modification was easier to complete than other modifications. Finger angle modification was done by using the copy/move feature in SolidWorks. First a plane had to be created for fingers 2, 3, 4 and 5 that would go through the center of the fingers; these planes are perpendicular to the palm. A separate plane had to be created for the first finger due to its orientation and position. This plane was created parallel to the palm. These planes allowed line sketches to be made on top of each finger that would allow the measurement of each angle to be taken. The lofts for finger length and joint circumference modifications were hidden so each segment can be rotated to the desired angles. With the lofts from previous modification hidden each finger was broken up into 3 segments again. The copy/move feature was used by selecting the segment that was going to be rotated, selecting the center point of each joint as the point of rotation and selecting the plane that was created for each finger as the direction of rotation. A series of 3D points were placed in the middle of each joint to serve as the point of rotation for each angle modification. Using the copy/move feature each segment of the hand was rotated to fit the desired angle measurements. After each modification was complete the lofting was brought back to reconnect each segment of the finger back together. The lofting did not need any new modifications because the lofting was already defined in the previous modification. Design reviews with UNM-H confirmed each angle measurement was implemented accurately.

	Angles for fingers in degrees(measured dorsally from top of each finger)				
	1st finger	2nd finger	3rd finger	4th finger	5th finger
MP (metacarpal)	25	25	14	14	10
PIP (Proximal)	N/A	30	32	40	40
DIP (Distal)	10	5	5	5	5

Table 15 Angle measurements for each finger

3.3.5 Abduction and Extension angles of the 1st finger

Hand anatomy uses additional angle measurements to help describe the position of the first finger (thumb) [14], [15]. Using additional angle measurements is critical because the first finger has more degrees of freedom than the other fingers. Abduction is the angle that describes the planar motion perpendicular to the palm. Extension is the angle that describes the planar motion parallel to the palm [14], [15]. These additional angles help describe the thumb in a position for the hand reaching out and grabbing a can. Table 16 shows angles for abduction and extension for the first finger.

In SolidWorks the abduction and extension modifications were also implemented 100% accurately. The time element for this modification was also not an issue for this modification because this modification was also easier to complete than other modifications. This modification was done by using the copy/move feature to rotate the thumb in the abduction and extension directions. The lofts that reconnected the finger segments for the crotch 1 length modification will be hidden so the additional angles for finger 1 can be implemented. A 3D sketch point was placed at the location of the carpometacarpal (CMC) joint that connects the first finger to the wrist. This point will serve as the rotation point for the angles to be implemented. The extension angle was modified using the copy/move feature by selecting the first finger, the 3D sketch point for rotation and the plane created for the first finger from the previous angle modifications for direction. The abduction angle was modified by first creating a plane that was perpendicular to the palm. This new plane will help rotate the first finger in the abduction direction. The copy/move feature was used by selecting the first finger, the 3D sketch point for ration and the new plane for direction. After both modifications were completed the lofts were brought back to reconnect the first finger to the rest of the hand. Design reviews with UNM-H confirmed each angle measurement was implemented accurately.

	Other thumb angles in degrees
abduction	45
extension	45

Table 16 Abduction and Extension angles for the first finger

3.3.6 Hand breadth

Hand breadth refers to the distance or width of an individual's hand. Measuring hand breadth is done by measuring linearly across the palm of the hand that captures all four fingers excluding the first finger. Standard hand breadth sizes for glovebox gloves from Piercan USA are; 8.5cm, 9.75cm and 10.5cm [9]. The model was modified for 10.5cm. Standard gloves at LANL have a hand breadth of 9.75cm and the new glove will be implementing a hand breadth of 10.5cm. The new hand breadth will create more room to accommodate two under gloves worn by glovebox workers for extra protection and sweat control. Table 17 shows the original hand breadth measurement from the model, the hand breadth measurement after modification and the calculated percent error.

In SolidWorks the hand breadth modification was done by using the copy/move feature to expand fingers 2, 3, 4 and 5 laterally with the palm and forearm equal distances to achieve 10.5cm. This was accomplished by first cutting the palm in 3 different places. The first cut was done between fingers 2 and 3, the second cut was done between fingers 3 and 4 and the third cut was done between fingers 4 and 5. Each cut was perpendicular to the wrist crease and the length ranged from the crotch area throughout the whole forearm. With the new cuts the hand was in four pieces; the first piece included the first and second finger along with a portion of the palm and forearm, the second piece included the third finger with a portion of the palm and forearm, the third piece included the fourth finger with a portion of the palm and forearm, and the fourth piece included the fifth finger with a portion of the palm and forearm. The copy/move feature was used by selecting each cut piece of the hand and translating the piece out equally spaces until the wrist breadth was approximately 10.5cm. After all the segments were translated out, the hand was lofted back together to obtain one uniform hand again. Design reviews with UNM-H confirmed the hand breadth measurement was implemented accurately.

Hand Breadth = 10.5cm	
Original measurement	9.04cm
After modification	10.58cm
%error	0.76190476

Table 17 Hand breadth measurement, after modification measurement and calculated percent error

3.4 Completed hand model

Figure 7 shows the final model after completing all the modifications. The model was used to create a mold to also help create a prototype glovebox glove. The model was printed out using stereolithography and was dipped in several polymer formulations at Piercan USA to represent the prototype glovebox glove.

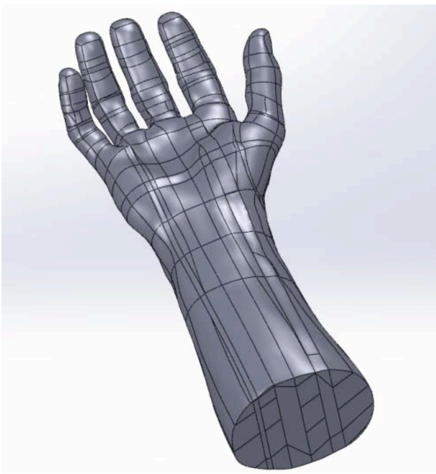

Figure 7 Final model after modifications

4.0 Experimental Evaluation

4.1 3D printing

The model was sent to Quickparts for printing. Quickparts is a company that specializes in 3D printing for customers to obtain rapid prototyping for displaying and testing [19]. They offer an array of different printing techniques as well as various materials. The mold was printed using stereolithography because it is the state of the art printing for high precision parts with a smooth surface finish. The material used is called Accura Bluestone. This material comes from a nano-composite resin that demonstrates exceptional stiffness, high temperature resistance and excellent dimensional accuracy [19]. The finished mold needs to be able to have a high melting point due to the curing process and a smooth finish so the latex can stick slightly. Accura Bluestone has a melting point of approximately 500F and stereolithography will ensure a smooth finish [19].

4.2 Glovebox glove prototyping

The prototype glovebox glove was made at Piercan USA where the mold was staged on a pallet and went through several processes to make the glove [9]. There were two stages in making the prototype glove, the dipping stage and curing stage. The dipping stage consisted of 11 separate dips. The mold went through 8 dips of Polyurethane formula and 3 dips of Hypalon formula. The combination created a 20mil Polyurethane/Hypalon glovebox glove. The Polyurethane dipping process took approximately 16 hours and the Hypalon dipping process took approximately 13 hours [9]. After the dipping process there were 2 hours of delay for workers to create beads for each glove. Beads are the cuffs located at the open end of the glove and each bead is tailor made individually by workers. After the prototype glove was beaded, the glove was then placed in an oven for curing. The curing process took approximately 24 hours at a max temperature of 280F. After the curing process the glove was manually removed from the mold. Figure 8 shows a picture of the final glovebox glove prototype produced by Piercan [9].

Figure 8 Prototype glovebox glove

The prototype was measured for thickness in various spots on the hand and forearm area. Table 18 shows the thickness at various areas of the prototype glove. The thickness of each area was measured using calipers. The prototype glove shows to be thinner than a typical 20 mil glove for a several reasons [9].

Area of prototype glove	Thickness
Fingers	21 mils
Palm	18 mils
Below wrist (between wrist and bead area)	9 mils
Bead area	14 mils

Table 18 Thickness measurements of current glovebox glove

The mold was dipped and exposed to less than half of the latex tank. The fluid on the upper half of the tank has a lower viscosity [9]. This results in less material sticking to the mold [9]. In addition, removing the prototype glove from the mold required the cuff area to be stretched so it can overcome the position of the first finger. The prototype glove was cut and glued onto another 20 mil Polyurethane/Hypalon glovebox glove sleeve to obtain a full glovebox glove. Figure 9 shows the prototype glued onto another glovebox glove sleeve. The 1st and 5th finger on the prototype glove proved to be longer than expected. A piece of tape was used to reduce the length of the 1st finger to the original desired length. This had to be done so glovebox workers can experience the prototype glove with all the desired measurements. Further investigations will have to be done to fix the problem.

Figure 9 Picture of the prototype glove glued to a glove sleeve to make a whole glovebox glove.

4.3 Minnesota Dexterity test and Purdue Pegboard test

Two tests were done to evaluate the dexterity of the glove. The first test is called the Minnesota dexterity test. This test helps measure gross motors skills for any particular subject or employee. The results evaluates hand and arm functions of turning, placing and displacing of disk shaped objects with one or two hands [11]. There are various versions of the Minnesota test used in industry. The Minnesota test used has been defined by the LANL glovebox ergonomist Cindy Lawton. This test requires employees to pick up disks, rotating the disks and transferring the disks while the test is timed. This Minnesota test used for this study only used a one handed test due to only one prototype glove. The Purdue pegboard test is the second method used for testing. This test measures fine gross movements of hands, fingers, arms, and finger tips [11]. The Purdue pegboard test calls for the dominant hand to be tested. In this case there is only one right hand prototype glovebox glove. The test requires employees to pick up small pegs and place them into a hole where they stand vertically. Employees are given 30 seconds to place as many pegs as possible on the board [11]. Below describes the directions given to employees for each test. A survey was also created to obtain some qualitative results from the new prototype glovebox glove. The survey asked a total of 7 questions pertaining to all the modification done to the glove. The survey used can be viewed in the appendix section.

Minnesota Dexterity Test *"One-Hand Turning and Placing Test"*

-Using your right hand, pick up the disk in right hand corner of upper board
-Turn disk over using same hand
-Place in right hand corner of lower board
-Pick up second disk in the column and flip
-Place the disk below the first one
-Start each new column from the top row
-Test is complete when all disks are flipped

Purdue Pegboard *"Dominant Hand Test"*

-Pick up 1 pin with right hand
-Place pin in hole
-Continue this pattern making sure not to skip holes. Work in only ONE column
-If a pin is dropped during the test, do not stop to pick it up, pick up another
-Test is complete once 30 sec has elapsed

There were 30 glovebox workers that tried on the new prototype glovebox glove. Twenty-nine of the thirty glovebox workers participated in the Minnesota dexterity test and Purdue pegboard test. The testing took approximately 14 hours to complete. The prototype glove was tested against a 15 mil hypalon glove. Since the prototype is thinner than expected a 15 mil hypalon glove is appropriate. Thickness of the glove will make a difference in dexterity testing.

4.4 Dexterity test results

Table 19 shows the recorded data from both the Minnesota Dexterity test and Purdue Pegboard test.

Minnesota Dexterity Test						Purdue Pegboard Test	
		Gloves				Gloves	
Participant #		Hyp/ 15mil	Prototype	Hyp/ 15mil	Prototype	Hyp/ 15mil	Prototype
		Time in minutes		**Time converted into decimals**		Number of Pegs	
1	trial 1	0:01:34	0:01:24	1.57	1.40	8	8
	trial 2	0:01:27	0:01:19	1.45	1.31	7	8
	trial 3	0:01:23	0:01:14	1.38	1.23	7	9
	Average	0:01:25	0:01:19	1.42	1.32	7.33	8.33

2	trial 1	0:01:28	0:01:14	1.467	1.23	6	6
	trial 2	0:01:18	0:01:19	1.30	1.32	5	6
	trial 3	0:01:30	0:01:14	1.50	1.23	6	7
	Average	0:01:25	0:01:16	1.42	1.267	5.67	6.33
3	trail 1	0:01:19	0:01:22	1.32	1.37	5	9
	trail 2	0:01:12	0:01:20	1.20	1.33	9	10
	trail 3	0:01:02	0:01:20	1.03	1.33	9	10
	Average	0:01:07	0:01:21	1.12	1.35	7.67	9.67
4	trail 1	0:00:57	0:01:06	0.95	1.10	10	10
	trail 2	0:01:04	0:00:59	1.01	0.98	9	10
	trail 3	0:01:03	0:00:57	1.05	0.95	10	12
	Average	0:01:01	0:00:58	1.02	0.97	9.67	10.67
5	trial 1	0:01:00	0:01:20	1.00	1.33	7	7
	trial 2	0:01:12	0:01:14	1.20	1.23	6	7
	trial 3	0:01:04	0:01:08	1.01	1.13	7	8
	Average	0:01:08	0:01:14	1.13	1.23	6.67	7.33
6	trial 1	0:01:52	0:01:36	1.87	1.60	6	8
	trial 2	0:01:30	0:01:34	1.50	1.57	8	7
	trial 3	0:01:33	0:01:24	1.55	1.40	8	5
	Average	0:01:31	0:01:31	1.52	1.52	7.33	6.67
7	trial 1	0:01:35	0:01:12	1.58	1.20	9	10
	trial 2	0:01:21	0:01:13	1.35	1.22	12	11
	trial 3	0:01:21	0:01:10	1.35	1.12	10	11
	Average	0:01:21	0:01:12	1.35	1.20	10.33	10.67
8	trial 1	0:01:15	0:01:25	1.25	1.42	8	6
	trial 2	0:01:15	0:01:16	1.25	1.27	8	9
	trial 3	0:01:08	0:01:21	1.13	1.35	9	8
	Average	0:01:13	0:01:19	1.22	1.32	8.33	7.67
9	trial 1	0:01:20	0:01:20	1.33	1.33	9	10
	trial 2	0:01:12	0:01:15	1.20	1.25	9	8
	trial 3	0:01:07	0:01:01	1.12	1.02	9	9
	Average	0:01:10	0:01:12	1.17	1.20	9	9
10	trial 1	0:01:51	0:01:36	1.85	1.60	7	6
	trial 2	0:02:09	0:01:34	2.15	1.57	9	5
	trial 3	0:01:37	0:01:28	1.62	1.47	9	8
	Average	0:01:53	0:01:33	1.88	1.55	8.33	6.33
11	trial 1	0:01:26	0:01:31	1.43	1.52	9	6
	trial 2	0:01:18	0:01:29	1.30	1.48	10	8
	trial 3	0:01:17	0:01:18	1.28	1.30	9	9
	Average	0:01:20	0:01:23	1.33	1.38	9.33	7.66
12	trial 1	0:01:38	0:01:28	1.63	1.47	8	8

	trial 2	0:01:28	0:01:22	1.47	1.37	8	11
	trial 3	0:01:22	0:01:26	1.37	1.43	7	7
	Average	0:01:25	0:01:25	1.42	1.42	7.67	8.67
13	trial 1	0:01:20	0:01:52	1.33	1.87	11	10
	trial 2	0:01:17	0:01:39	1.28	1.65	12	10
	trial 3	0:01:21	0:01:28	1.35	1.47	9	12
	Average	0:01:19	0:01:34	1.32	1.57	10.67	10.67
14	trial 1	0:02:26	0:01:30	2.43	1.50	7	8
	trial 2	0:01:17	0:01:08	1.28	1.13	9	10
	trial 3	0:01:18	0:01:00	1.30	1.00	10	10
	Average	0:01:18	0:01:13	1.30	1.22	8.67	9.33
15	trial 1	0:01:06	0:01:15	1.10	1.25	11	9
	trial 2	0:01:05	0:01:08	1.08	1.13	14	9
	trial 3	0:01:05	0:01:05	1.08	1.08	12	12
	Average	0:01:05	0:01:06	1.08	1.10	12.33	10
16	trial 1	0:01:24	0:01:12	1.40	1.20	7	11
	trial 2	0:01:21	0:01:06	1.35	1.10	9	8
	trial 3	0:01:21	0:01:02	1.35	1.03	9	8
	Average	0:01:22	0:01:04	1.37	1.07	8.33	9
17	trial 1	0:01:31	0:00:56	1.52	0.93	5	12
	trial 2	0:01:26	0:00:51	1.43	0.85	9	11
	trial 3	0:01:12	0:00:49	1.20	0.82	9	10
	Average	0:01:19	0:00:52	1.32	0.87	7.67	11
18	trial 1	0:02:00	0:01:26	2.00	1.43	9	10
	trial 2	0:01:48	0:01:04	1.80	1.07	8	11
	trial 3	0:01:04	0:01:04	1.07	1.07	7	10
	Average	0:01:26	0:01:11	1.43	1.18	8	10.33
19	trial 1	0:01:30	0:01:23	1.50	1.38	10	10
	trial 2	0:01:27	0:01:22	1.45	1.37	10	12
	trial 3	0:01:20	0:01:21	1.33	1.35	10	9
	Average	0:01:26	0:01:22	1.43	1.37	10	10.33
20	trial 1	0:01:50	0:01:28	1.83	1.47	9	9
	trial 2	0:01:46	0:01:27	1.77	1.45	10	10
	trial 3	0:01:35	0:01:18	1.58	1.30	9	9
	Average	0:01:41	0:01:24	1.68	1.40	9.33	9.33
21	trial 1	0:01:32	0:01:26	1.53	1.43	7	7
	trial 2	0:01:30	0:01:33	1.50	1.55	5	9
	trial 3	N/A	0:01:29	N/A	1.48	8	8
	Average	0:01:31	0:01:31	1.52	1.52	6.67	8
22	trial 1	0:01:31	0:01:54	1.52	1.90	7	8
	trial 2	0:01:32	0:01:31	1.53	1.52	7	4

	trial 3	0:01:22	0:01:27	1.37	1.45	6	7
	Average	0:01:28	0:01:29	1.47	1.48	6.67	6.33
23	trial 1	0:01:39	0:01:18	1.65	1.30	6	7
	trial 2	0:01:27	0:01:19	1.45	1.32	8	8
	trial 3	0:01:26	0:01:13	1.43	1.22	9	7
	Average	0:01:26	0:01:17	1.43	1.28	7.67	7.33
24	trial 1	0:01:40	0:01:16	1.67	1.27	6	10
	trial 2	0:01:26	0:01:15	1.43	1.25	10	9
	trial 3	0:01:11	0:01:12	1.18	1.20	8	11
	Average	0:01:18	0:01:14	1.30	1.23	8	10
25	trial 1	0:01:28	0:01:35	1.47	1.58	6	6
	trial 2	0:01:24	0:01:33	1.40	1.55	5	6
	trial 3	0:01:21	0:01:37	1.35	1.62	8	8
	Average	0:01:24	0:01:35	1.40	1.58	6.33	6.67
26	trial 1	0:02:07	0:01:36	2.12	1.60	5	7
	trial 2	0:01:45	0:01:28	1.75	1.47	7	9
	trial 3	0:01:47	0:01:22	1.78	1.37	6	8
	Average	0:01:46	0:01:29	1.77	1.48	6	8
27	trial 1	0:01:29	0:01:20	1.48	1.33	7	5
	trial 2	0:01:21	0:01:11	1.35	1.18	5	9
	trial 3	0:01:12	0:01:12	1.20	1.20	10	8
	Average	0:01:16	0:01:14	1.27	1.23	7.33	7.33
28	trial 1	0:02:18	0:01:46	2.30	1.77	5	5
	trial 2	0:01:45	0:01:40	1.75	1.67	5	5
	trial 3	0:01:37	0:01:28	1.62	1.47	8	8
	Average	0:01:53	0:01:34	1.88	1.57	6	6
29	trial 1	0:01:48	0:01:20	1.80	1.33	8	9
	trial 2	0:01:35	0:01:15	1.58	1.25	9	10
	trial 3	0:01:23	0:00:00	1.38	0	9	8
	Average	0:01:29	0:01:18	1.48	1.30	8.67	9
	Total average	0:01:24	0:01:19	1.39	1.32	8.13	8.54

(yellow)	Average of each trial
(blue)	Deleted outlier

Table 19 Recorded data from the Minnesota Dexterity test and Purdue Pegboard test

From table 19 one can see the average time and average number of pegs for each participant shaded in yellow. These averages will be used as a single datum point for each participant. The boxes shaded in blue are the deleted outliers. Outliers are data that seem to vary far from the mean of all the other samples [16]. These datum points are considered outliers because each participant underwent a learning curve between the first trial and the rest of the trials. The learning curve shows that participants had a dramatic decrease in time from the first trial to the second trial of the Minnesota Dexterity test. The first trial can be a high value that does not represent the average well; therefore the first trail is considered an outlier. Taking note of which glove the participant used first for the Minnesota Dexterity test helped determine where the outlier occurred. Outliers only occurred in the Minnesota Dexterity test. To help make calculations easer the time values were converted into decimal format. The unit of time was first in minutes then converted into decimal format.

4.5 Student T test

To test the significance between the means for each glove, a student T test was performed. The student T test or simply *t* test is used to give an indication of how separate two sets of measurements are [16]. This analysis is appropriate for studies that meet the following criteria: comparing the means of two groups, small sample size, normally distributed, and the samples are simply random samples. The *t* test uses a standard statistical procedure that tests a hypothesis to indicate how different two means are [16]. A hypothesis is defined by a claim or statement about a property of a population. There are typically two hypothesis established for the *t* test. Hypothesis 1 is set by the user usually indicating there is a difference between the two means. Hypothesis 2 is typically known as the null hypothesis and it usually indicates that there is no difference between the means [16]. The formula for the *t* test is a ratio. The ratio is the difference between the two means divided by the standard error of the differences between the two means. This ratio is known as the *t* statistic. Once the *t* statistic is known it can be compared to a critical value from a *t* distribution chart. To find the critical value the level of confidence has to be set and the degrees of freedom must be found. The level of confidence is the probability that the test statistic will fall in the critical region. The critical region is the set of all values of the *t* statistic that would cause rejection of the null hypothesis. Industry typically uses a confidence level of 0.05 which is 95% confident the result will be within range [18]. The number of degrees of freedom is the number of sample values that can vary after certain restrictions have been imposed on all data values. The degrees of freedom is n-1 where n is the number of samples [18]. Using the confident level value with the degrees of freedom value one can use the *t* distribution chart to find the critical value. The test will show a significance between the two means if the absolute *t* static value is larger than the critical value. If so, the *t* statistic falls within the critical region of the standard normal distribution. This means the probability of running the same tests over will prove the user's hypothesis right again. This result is called rejecting the null hypothesis. If the *t* test shows that there is no difference between the means the result is called failing to reject the null hypothesis [16].

4.6 P value method

To confirm the conclusion of the *t* test a *p* value method was also applied to assure the null hypothesis should or should not be rejected [16]. The *p* value is the probability of getting a value of the test statistic that is at least as extreme as the one representing the sample data. This is correct if the null hypothesis remains true. The null hypothesis is rejected if the *p* value is smaller than the level of confidence. To find the *p* value the type of hypothesis test conducted must be determined. There are three possibilities: the left tailed test, right tailed test, or the two tailed test. The user must also find the *t* statistic. For the left tailed test, the *p* value equals the area to the left of the *t* statistic on a standard normal distribution. For the right tailed test the *p* value equals the area to the right of the *t* statistic on a standard normal distribution. The two tailed test requires the user to determine if the *t* statistic is to the right or left of the mean. If the *t* statistic is on the left the *p* value equals twice the area to the left of the *t* statistic on a standard normal distribution. If the *t* statistic is on the right the *p* value equals twice the area to the right of the *t* statistic on a standard normal distribution. Once the *p* value is found it can be compared to the level of confidence to confirm the conclusion of the hypothesis [16].

4.7 Normal distribution determination

Before computing the *t* test, the data from the dexterity tests had to be tested for normality [16]. Two ways of testing the data for normality is to make a histogram of the data and to make a quantile plot of the data. A histogram plot shows vertical bars representing the frequency distribution of a set of data [18]. If the histogram shows to have a bell shaped curve it is considered to be a normal distribution. To make the histogram all the data had to be sorted from the smallest value to the largest value. Next the frequency of each datum point was found. The frequency and data were then plotted together. A quantile plot is a graph of points (x,y) where each x value is from the original set of sample data, and the y value is a z score corresponding to a quantile value of the standard normal distribution [16]. If the points in the quantile plot do not lie close to a straight line, or if the points exhibit some systematic pattern that is not a straight-line, then the data appears to come from a population that is not normally distributed [16]. To make a quantile plot first the data had to be sorted from the smallest value to the largest value. With a sample size n, each value represents a proportion of 1/n of the sample. Using the sample size n, the areas had to be identified by 1/2n, 3/2n, 5/2n, 7/2n, and so on [16]. These values represent the cumulative areas to the left of the corresponding sample values. Next, a standard normal distribution was used to find the z scores that correspond to the areas just calculated. Then match the sorted data to the corresponding z scores found. Plot the data and examine if the points are reasonably close to a straight line. The user ultimately makes the judgment if datum points deviate too far from the straight line to be considered outliers [16].

4.7.1 Histograms

Figure 10 shows the histogram plot of the hypalon glove data for the Minnesota Dexterity test. The plot seems to show the bell shaped curve around its average of approximately 1.4, the data can be assumed to be normally distributed. Figure 11 shows the histogram plot of the prototype glove data for the Minnesota Dexterity test. This plot seems to show the bell shaped curve around its average of approximately 1.3, the data can be assumed to be normally distributed. Figure 12 shows the histogram plot of the hypalon glove data for the Purdue Pegboard test. The plot seems to show the bell shaped curve around its average of approximately 8.1 pegs, the data can be assumed to be normally distributed. Figure 13 shows the histogram plot of the prototype glove data for the Purdue Pegboard test. The bell shaped curve is harder to see around its average of approximately 8.5 pegs, the quantile plot should help make a better decision.

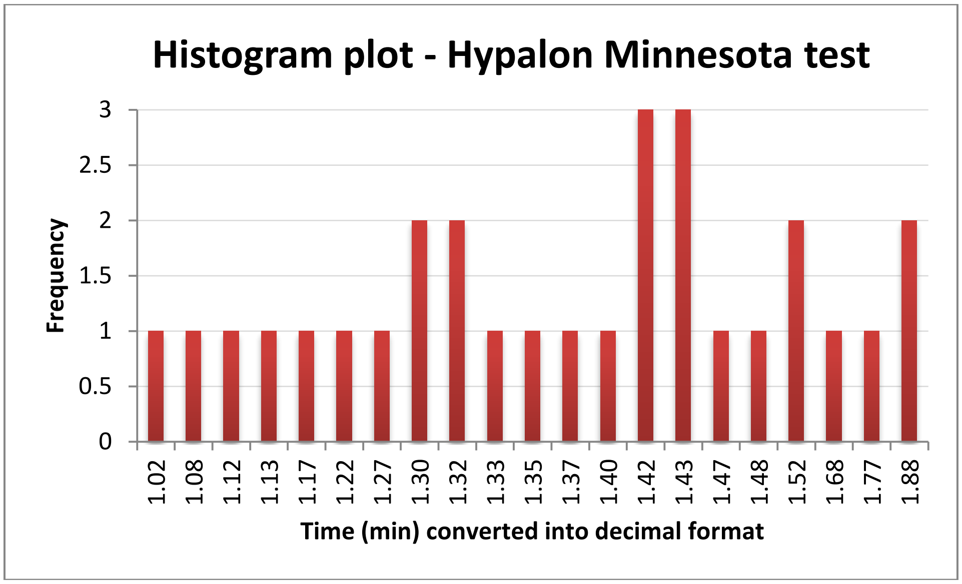

Figure 10 Histogram plot of the hypalon glove for the Minnesota Dexterity test

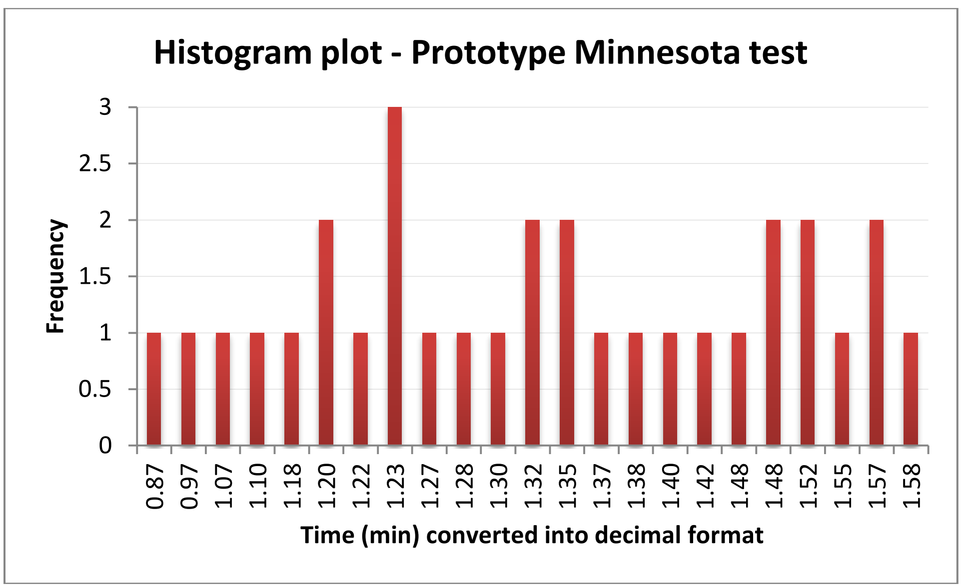

Figure 11 Histogram plot of the prototype glove for the Minnesota Dexterity test

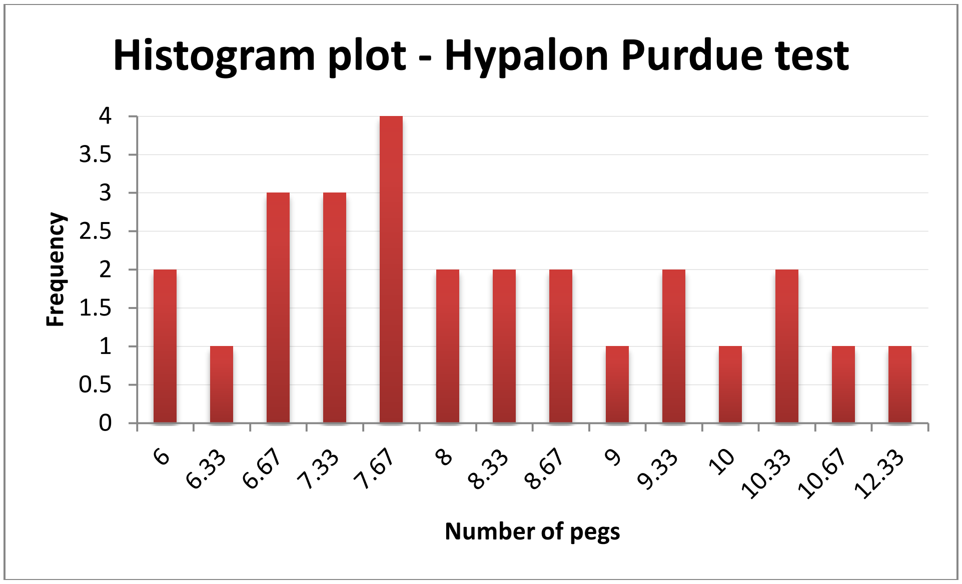

Figure 12 Histogram plot of the hypalon glove for the Purdue Pegboard test

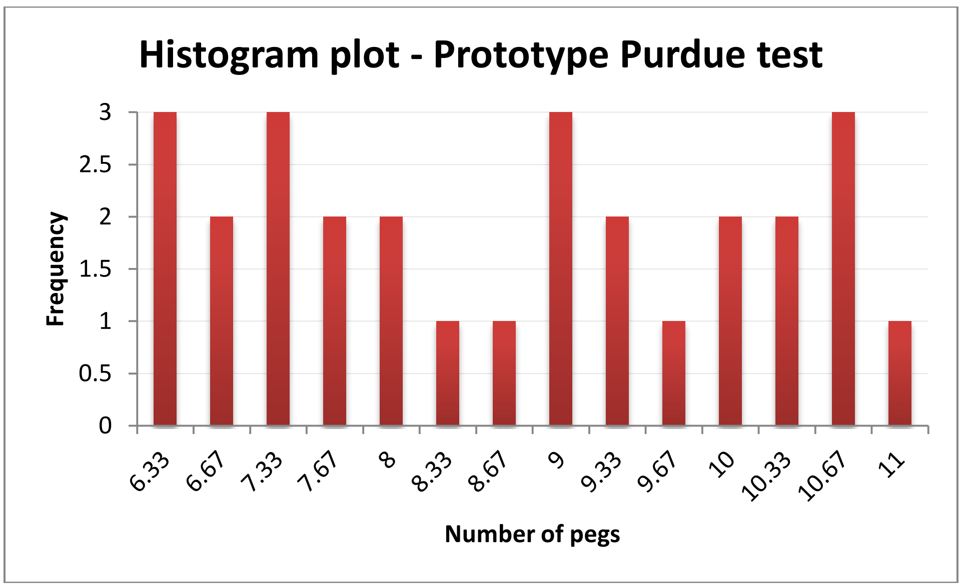

Figure 13 Histogram plot of the prototype glove for the Purdue Pegboard test

4.7.2 Quantile plots

Figure 14 shows the quantile plot of the hypalon glove for the Minnesota Dexterity test. This plot shows a trend line to see where the points are located relative to the trend line. From figure 14 one can see the majority of the points follow the straight line. There are a few data points that deviate from the straight line. The exceptional few that deviate from the straight line are not considered outliers because these are data that represent real performances from glovebox workers at TA 55. Excluding these data points would not represent the sample population of glovebox workers at TA 55 [16]. The points do follow the direction of the straight line and do not deviate far enough from the trend line to dismiss the normality claim. The data in figure 14 is assumed to be normally distributed. Figure 15 shows the quantile plot of the prototype glove for the Minnesota Dexterity test. This plot also shows the majority of the data points following the trend line. As described above the data points that deviate from the trend line are not considered outliers and are not considered to deviate too far from the trend line. The data in Figure 15 is assumed to be normally distributed. Figure 16 shows the quantile plot of the hypalon glove for the Purdue Pegboard test. The data from this plot can be assumed to be normally distributed for reasons listed above. Figure 17 shows the quantile plot of the prototype glove for the Purdue Pegboard test. The data from this plot can be assumed normally distributed for reasons listed above.

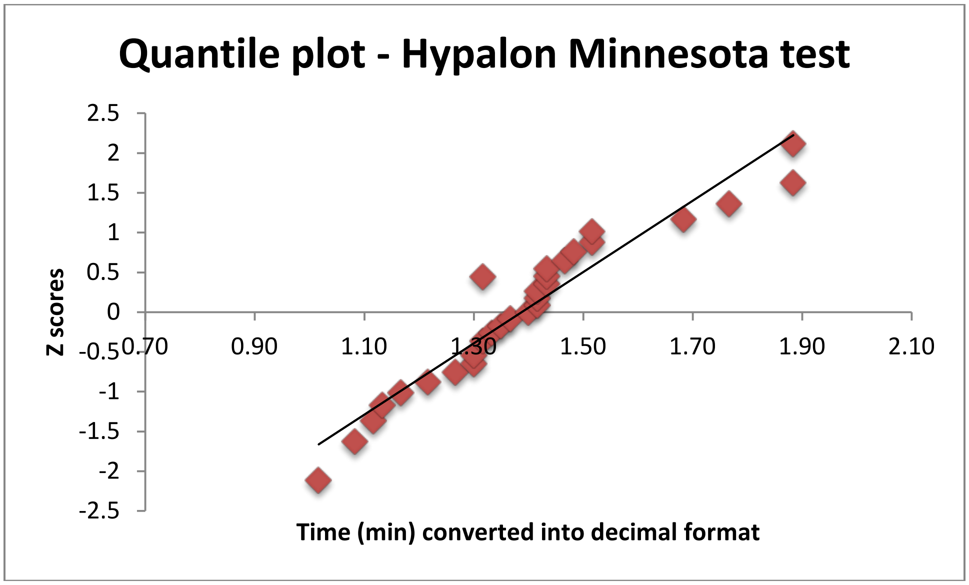

Figure 14 Quantile plot of the hypalon glove for the Minnesota Dexterity test

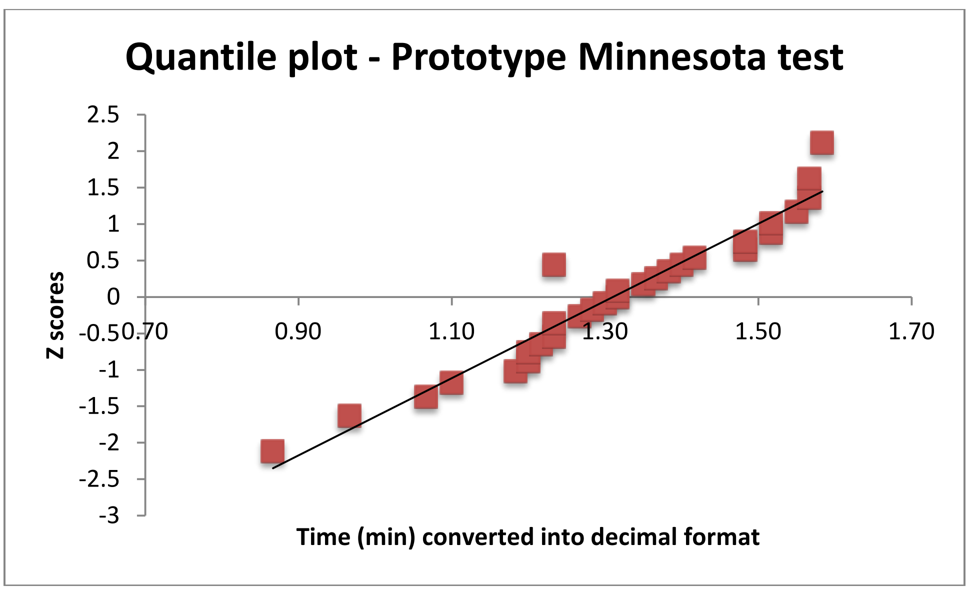

Figure 15 Quantile plot of the prototype glove for the Minnesota Dexterity test

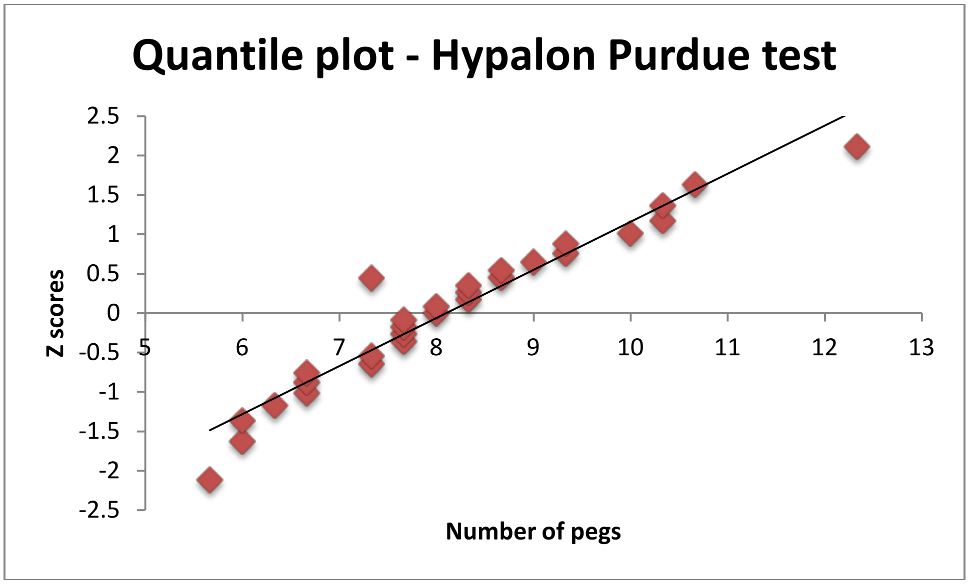

Figure 16 Quantile plot of the hypalon glove for the Purdue test

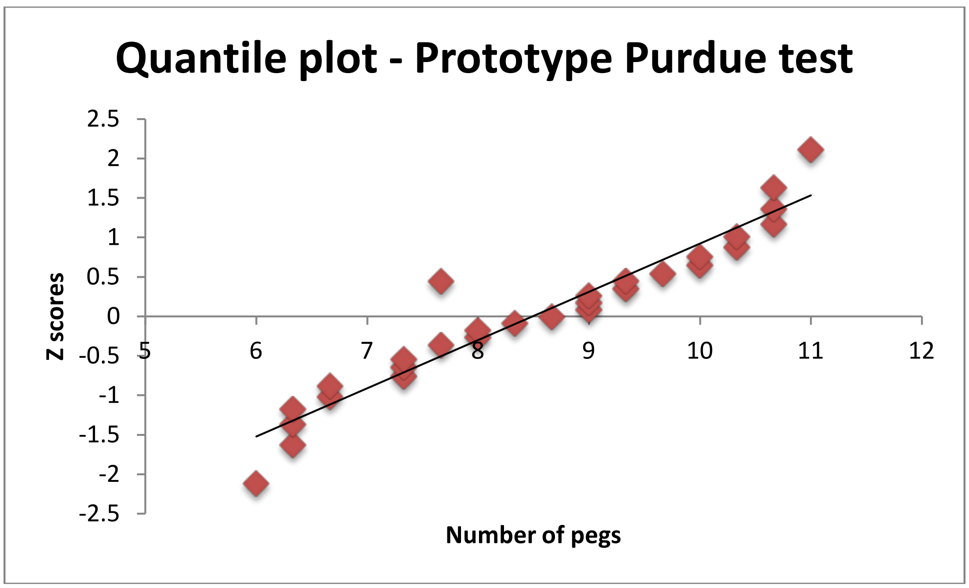

Figure 17 Quantile plot of the prototype glove for the Purdue test

4.8 T test results and P value method

The *t* test known as “Matched pairs for dependent pairs” concludes any significant difference between matched pairs [16]. Match pairs show some relationship so that each value in one sample is paired with a corresponding value in the other sample. The same samples of glovebox workers were given both tests for each glovebox glove making this set of data matched dependent pairs. The *t* test for both the Minnesota Dexterity test and Purdue Pegboard test are described below.

Minnesota Dexterity test

Nomenclature:

d = Individual difference between the two values in a single matched pair
$\bar{d}$ = Average of all d values
$\mu_{prototype}$ = Mean time of the prototype glove
$\mu_{hypalon}$ = Mean time of the hypalon glove
μ_d = Mean time of the differences d for the population of all matched pairs
s_d = Standard deviation of the difference d for all matched pairs
n = Number of matched pairs
α = Confidence level
df = Degrees of freedom

Assumptions for matched pair's *t* test:

1. Data collected are matched pairs
2. The data are simply random samples
3. The data are normally distributed.

Hypothesis:
H1: The hypalon glove mean is larger than the mean for the prototype glove. $\mu_{hypalon} > \mu_{prototype}$ (Right tail test)
H2: The null hypotheses is $\mu_d = 0$, there is no significance difference between the two means.

Confidence level:
$\alpha = 0.05$, we are 95% confident the mean for the prototype glove will always be lower than the mean for the hypalon glove. This level of confidence is typically used in industry [16]. The degree of freedom is simply n-1 for matched pairs.

Test statistic:

The *t* statistic (*t* stat) equation is:

$$t = \frac{\bar{d} - \mu_d}{\frac{s_d}{\sqrt{n}}} \qquad (2)$$

Results:
Table 20 summarizes the results for the *t* test of matched pairs for the Minnesota Dexterity test:

t-Test: Matched pairs for Minnesota Dexterity test

	Hypalon glove	*Prototype glove*
Mean	1.394253	1.316092
$\bar{d}$	0.078161	
s_d	0.174751	
df	28	
t Stat	2.40863	
P(T<=t) one-tail	0.01142	
t Critical one-tail	1.701131	

Table 20 T test results for Minnesota Dexterity test

Conclusion:
The *t* stat value is larger than the *t* critical one tail value; this means that 95% of the time the *t* stat will fall in the critical region. Due to the *t* stat value falling in the critical region the mean of the hypalon glove is indeed larger than the mean of the prototype glove. The verdict of the *t* test is to reject the null hypothesis. The *p* value was obtained by using the *t* stat value and a standard normal distribution chart. The *p* value equals the area to the right of the *t* stat value on the standard normal distribution chart. Comparing the *p* value to the confidence level value shows clearly that the *p* value is smaller. From this, the null hypothesis is rejected. The *t* test and *p* value method conclude the mean for the current hypalon glove is significantly larger than the mean for the prototype glove.

Purdue Pegboard test

Nomenclature:

$d =$ Individual difference between the two values in a single matched pair
$\bar{d}$ = Average of all d values
$\mu_{prototype} =$ Mean number of pegs for the prototype glove
$\mu_{hypalon} =$ Mean number of pegs for the hypalon glove
$\mu_d =$ Mean number of pegs of the differences d for the population of all matched pairs
$s_d =$ Standard deviation of the difference d for all matched pairs
$n =$ Number of matched pairs
$\alpha =$ Confidence level

df = Degrees of freedom

Assumptions for matched pair's t test:

1. Data collected are matched pairs
2. The data is simply random samples
3. The data are normally distributed.

Hypothesis:
H1: The hypalon glove mean is smaller than the mean for the prototype glove. $\mu_{hypalon} < \mu_{prototype}$ (Left tail test)
H2: The null hypotheses is $\mu_d = 0$, there is no significance difference between the two means.

Confidence level:
$\alpha = 0.05$, we are 95% confident the mean for the prototype glove will always be higher than the mean for the hypalon glove. This level of confidence is typically used in industry [16]. The degree of freedom is simply n-1 for matched pairs.

Test statistic:

The t statistic (t stat) equation is:

$$t = \frac{\bar{d} - \mu_d}{\frac{s_d}{\sqrt{n}}} \quad (2)$$

Results:
Table 21 summarizes the results for the t test of matched pairs for the Purdue Pegboard test:

t-Test: Matched pairs for Purdue Pegboard test

	Hypalon glove	*Prototype glove*
Mean	8.126437	8.54023
$\bar{d}$	-0.41379	
s_d	1.252474	
df	28	
t Stat	-1.77915	
P(T<=t) one-tail	0.043037	
t Critical one-tail	1.701131	

Table 21 T test results for Purdue Pegboard test

Conclusion:

The absolute *t* stat value is larger than the *t* critical one tail value; this means that 95% of the time the *t* stat will fall in the critical region. Due to the *t* stat value falling in the critical region the mean of the hypalon glove is indeed smaller than the mean of the prototype glove. The verdict of the *t* test is to reject the null hypothesis. The *p* value was obtained by using the *t* stat value and a standard normal distribution chart. The *p* value equals the area to the left of the *t* stat value on the standard normal distribution chart. Comparing the *p* value to the confidence level shows that the *p* value is smaller. From this, the null hypothesis is rejected. The *t* test and *p* value method conclude the mean for the current hypalon glove is significantly smaller than the mean for the prototype glove.

4.9 Survey

A survey was also given to all 30 glovebox workers who tested with both gloves or at least tried them on. The survey helped gather qualitative data to show what they liked about the new prototype glove. The survey consisted of 7 questions comparing the current hypalon glove and the new prototype glove. Along with each question the glovebox workers were asked to rate the answer they gave for each question. This will help give a measure of how well they preferred the new modifications. The questions asked can be viewed below and the completed survey can be viewed in the appendix. Glove 1 was the hypalon glove and glove 2 was the new prototype glove.

1. Which glove allows for easier hand insertion?

   Glove 1 Glove 2

   On a scale of 0 to 10 (where 0 is worse, 1 is no change, and 10 is *much* easier), how much easier is the insertion?____________________

2. Which glove allows for easier hand extraction?

   Glove 1 Glove 2

   On a scale of 0 to 10 (where 0 is worse, 1 is no change, and 10 is *much* easier), how much easier is the extraction?____________________

3. Which glove exhibits the best positioning for the fingers when relaxed (i.e., when resting, not performing any tasks)?

   Glove 1 Glove 2

   On a scale of 0 to 10 (where 0 is worse, 1 is no change, 10 is "I love this"), just how much better is the positioning?_____________________

4. Which glove exhibits the best thumb positioning?

   Glove 1 Glove 2

   Please check the box that is most similar with your own opinion on the following statement: *Glove 1 has better thumb positioning than Glove 2.*
   [ ] Strongly agree [ ] Agree [ ] Neutral [ ] Disagree [ ] Strongly disagree

5. Which glove offers a better hand-breadth?
   Glove 1 Glove 2

   On a scale of 0 to 10 (0 is worse, 1 is no change, 10 is *much* better), how much better is the hand-breadth?___________________

6. In which glove do your fingers have the easiest time reaching the end of the glove?
   Glove 1 Glove 2

   On a scale of 0 to 10 (0 is worse, 1 is no change, 10 is *much* better), how much easier is the reach?___________________

7. In which glove does the web spacing between the fingers best fit the crotch area of the glove?
   Glove 1 Glove 2

   On a scale of 0 to 10 (0 is worse, 1 is no change, 10 is *much* better), how much better is the spacing?___________________

For gloves, what changes, if any, would you make?
____
____
____
____

Additional comments
____
____
____
____

4.9.1 Survey results

Figure 18 shows the results from the survey. The results show that highest percentage of positive feedback was the new thumb position, 73.2% of the sample population liked the new thumb position. Followed by 63.3% feel the prototype glove gives easier insertion, 66.7% feel the prototype glove gives easier extraction, 63.3% like the new relaxed angles on the fingers, 60% like the new hand breadth measurement, 63.3% feel it is easier to reach the end of the prototype glove, and 63.3% feel the new prototype has better web spacing. The green bars in figure 18 represent the small percentage of glovebox workers who felt there was no improvement.

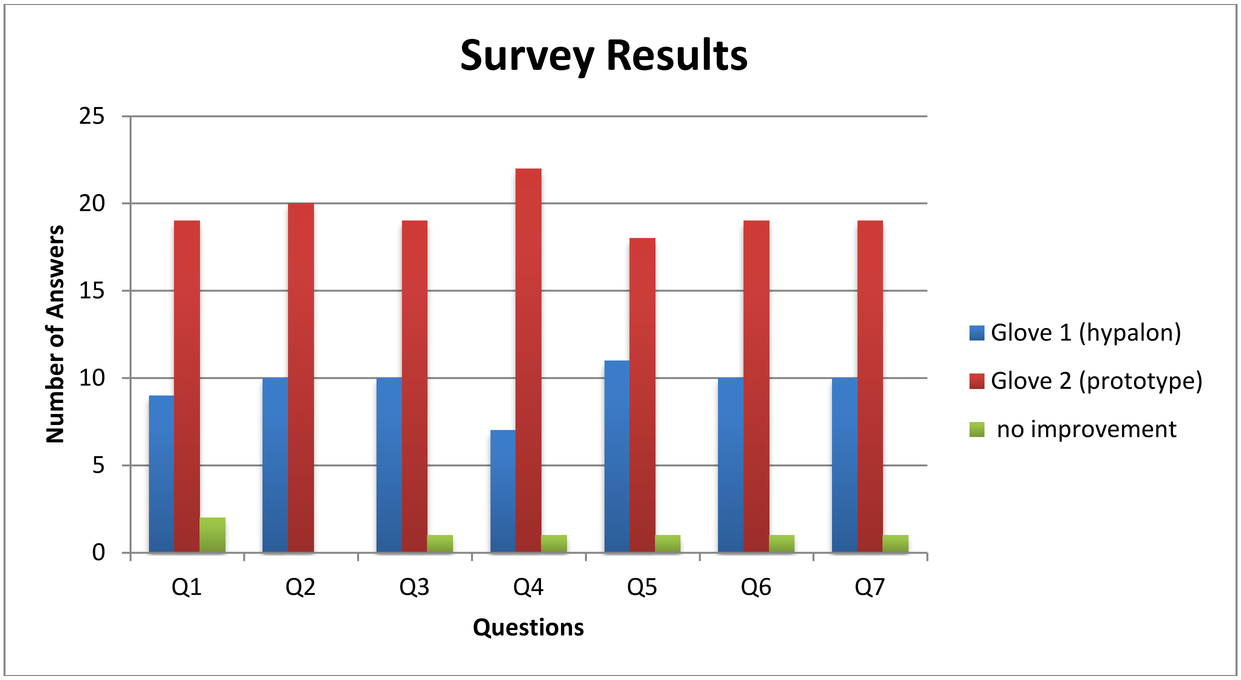

Figure 18 Survey results

Table 22 shows the average rating for each question from the survey of glovebox workers you who prefer glove 1 (hypalon glove) over glove 2 (prototype).

Question	Average score
Q1	4
Q2	5
Q3	6
Q4	Agree
Q5	5
Q6	6
Q7	5

Table 22 Averaged rating for each question for glovebox workers who prefer glove 1 (hypalon) better

Table 23 also shows the average rating for each question from the survey of glovebox workers you who prefer glove 2 (prototype glove) over glove 1 (hypalon glove).

Question	Average score
Q1	6
Q2	6
Q3	8
Q4	Disagree
Q5	7
Q6	8
Q7	8

Table 23 Averaged rating for each question for glovebox workers who prefer glove 2 (prototype) better

Glovebox workers who prefer glove 1 (hypalon) for each question show a lower rating average compared to those who prefer glove 2 (prototype) for each question. This information suggests that glovebox workers who prefer glove 2 (prototype) have a high degree of appreciation for each modification done to the new prototype glove. In contrast, glovebox workers who prefer glove 1(hypalon) over glove 2(prototype) demonstrated a less noticeable difference than the current glovebox glove over the new prototype.

5.0 Conclusion

The existing LANL glovebox glove increases stress to the forearm, hand, muscles, and joints. At TA-55 the existing glove is a major contributor to worker injury for glovebox work. It is difficult to use because of the poor biomechanics due to the lack of research and development. The new glovebox glove has shown to have increased dexterity compared to the current glovebox glove. The new glovebox glove will mitigate the risk of worker injury and the risk of breaches.

Testing both glovebox gloves using the Minnesota Dexterity test and Purdue Pegboard test helped obtain data that showed positive results for the prototype glove. The average total time for the Minnesota Dexterity test was 5 seconds faster while using the new prototype glove. The Purdue Pegboard test showed the prototype averaged approximately 2/5 a peg more than the current hypalon glove. Using the student *t* test for matched dependent pairs proved that there is a significant difference between the current hypalon glove average and the new prototype glove average. Using a 95% confident level the *t* test proved the average time for the hypalon glove is significantly greater than the mean for the prototype glove using the Minnesota Dexterity test. The Purdue Pegboard test results showed that the average for the hypalon glove is significantly smaller than the average for the prototype glove with a 95% confidence level. The *t* test proved that running these test 100 times again, 95 out of 100 times the average time for the prototype glove will be smaller than the current hypalon glove time for the Minnesota Dexterity test, and the average time will be greater for the prototype glove than the current hypalon glove time for the Purdue Pegboard test. To ensure the *t* test results were valid the *p* value method was also implemented. The *p* value method showed the *p* value's for both test were indeed smaller than the level of confidence set for both test. The *p* value also showed that each test can be tested with a higher level of confidence. The *t* test along with the *p* value method concluded the better glove is indeed the new prototype glove.

The new biomechanical glovebox glove will have potential to improve work performed, decreasing exposure time, decreasing risk of breaching, increasing productivity, and reducing injuries. In the future the new glovebox glove can also be implemented in other research fields such as: pharmaceutical research and development, semiconducting industry, biohazard industry, and other laboratories conducting nuclear research and development.

6.0 Future Work

6.1 Hand model refining

Future work includes refining the current hand model to correct the lengths of the 1st and 5th finger. Correcting these lengths will better represent the data set used for finger length and it will allow the glovebox workers to get a better fit while performing glovebox work. The next step is to add the glovebox glove sleeve to the model. The sleeve section of the glove needs to be researched to select the best tapering from the glove port to the wrist. The sleeve taper of the glove starts at the glove port and decreases to the wrist. Applying the best taper for the sleeve can potentially increase the functionality of the glovebox glove. With a better sleeve, glovebox workers can reduce the amount of buildup of material as they retract and protract their arms for reaching in a glovebox. After the finger length is corrected and the sleeve is modeled, the new refined model should be prototyped and tested again. The refined prototype glovebox glove should have better lengths for the 1st and 5th finger and a new sleeve to correctly mimic the new and improved glovebox glove for LANL.

6.2 Future female glovebox glove

After the new glovebox glove is in use the next step of glovebox glove design is to implement female anthropometrics. Making a male and female glovebox glove at LANL would benefit both genders. The male glove can use higher percentile groups of anthropometrics to better fit the male population. The female glove can have smaller percentile groups of anthropometrics to better fit the female population. Glove fit is crucial for proper work performance, obtaining a female and male glove using appropriate gender anthropometrics will only improve the operators ability to perform work.

7.0 References

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8.0 Appendix

The following figures show snap shots of dimensions after all the modifications were completed.

8.1 Finger length: Measurements are in centimeters

5th finger length

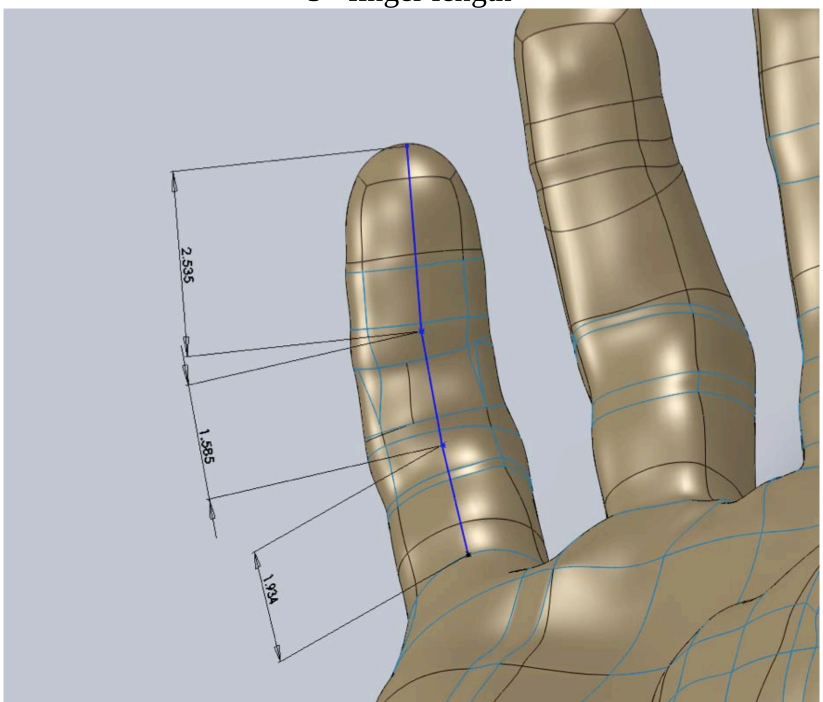

Figure 19 Dimensions for the 5th finger showing finger length

4th finger length

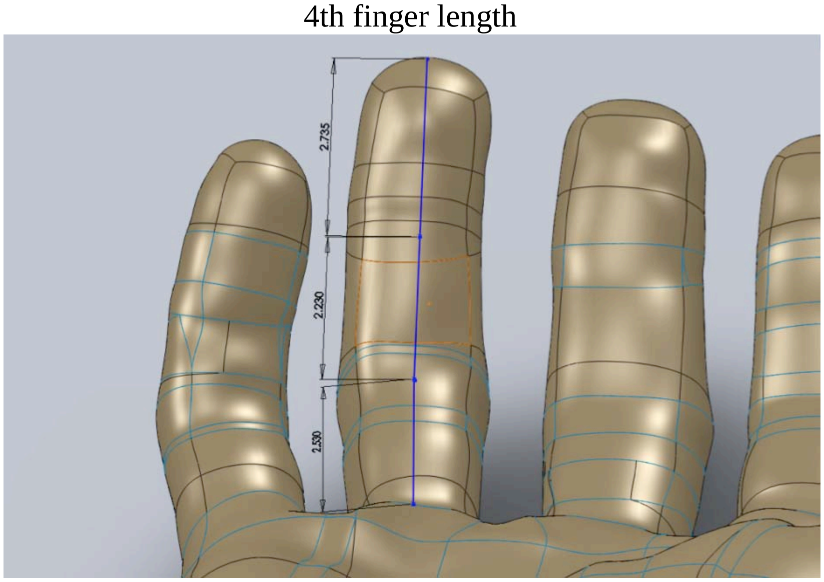

Figure 20 Dimensions for the 4th finger showing finger length

3rd finger length

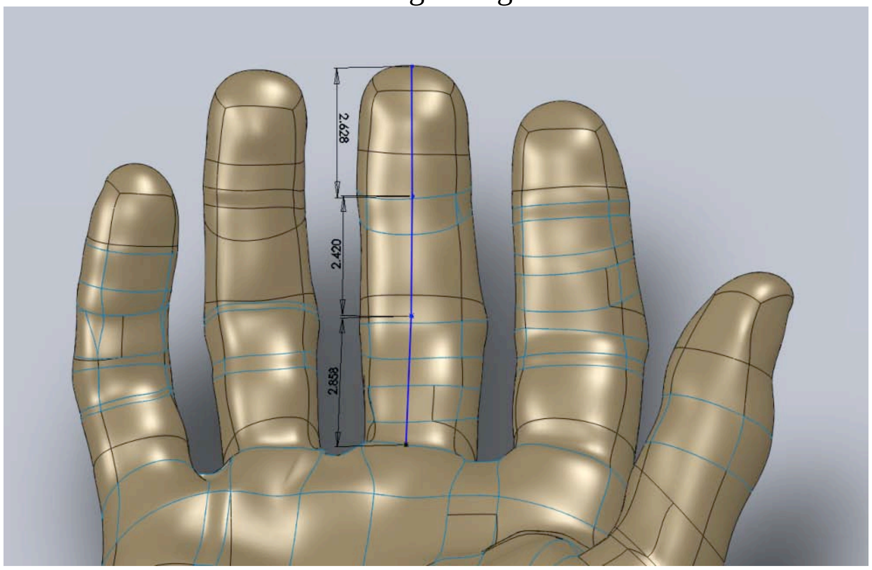

Figure 21 Dimensions for the 3rd finger showing finger length

2nd finger length

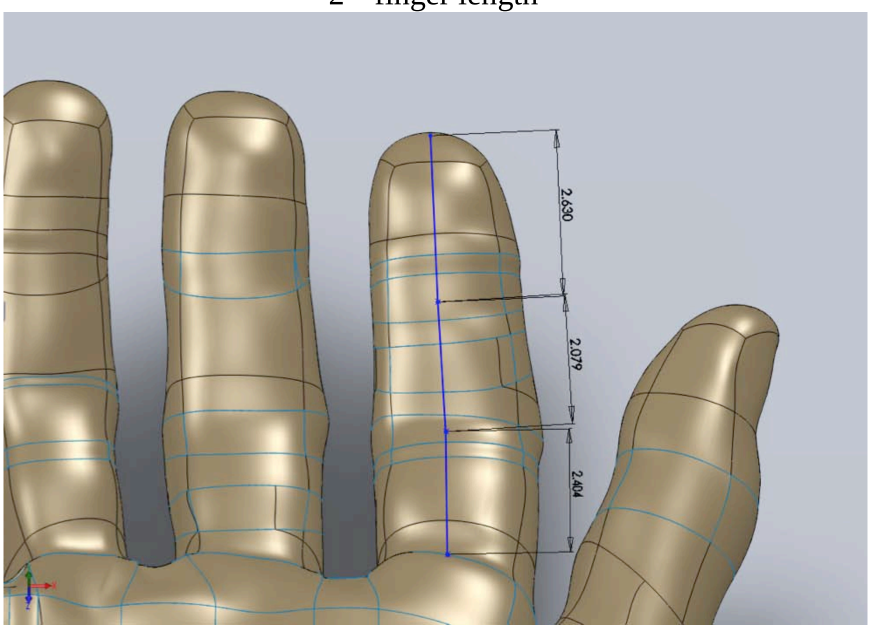

Figure 22 Dimensions for the 2nd finger showing finger length

1st finger length

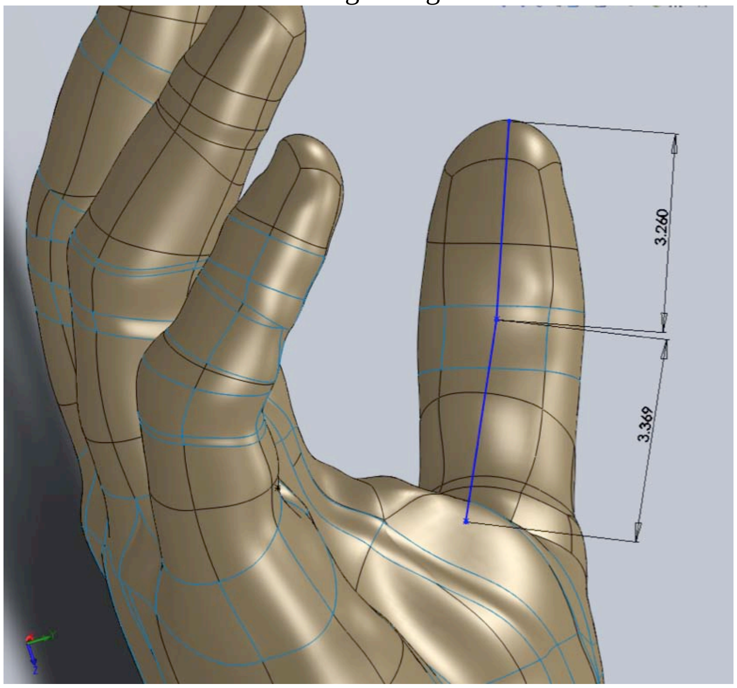

Figure 23 Dimensions for the 1st finger showing finger length

8.2 Crotch length:Measurements are in millimeters

Crotch 4 length

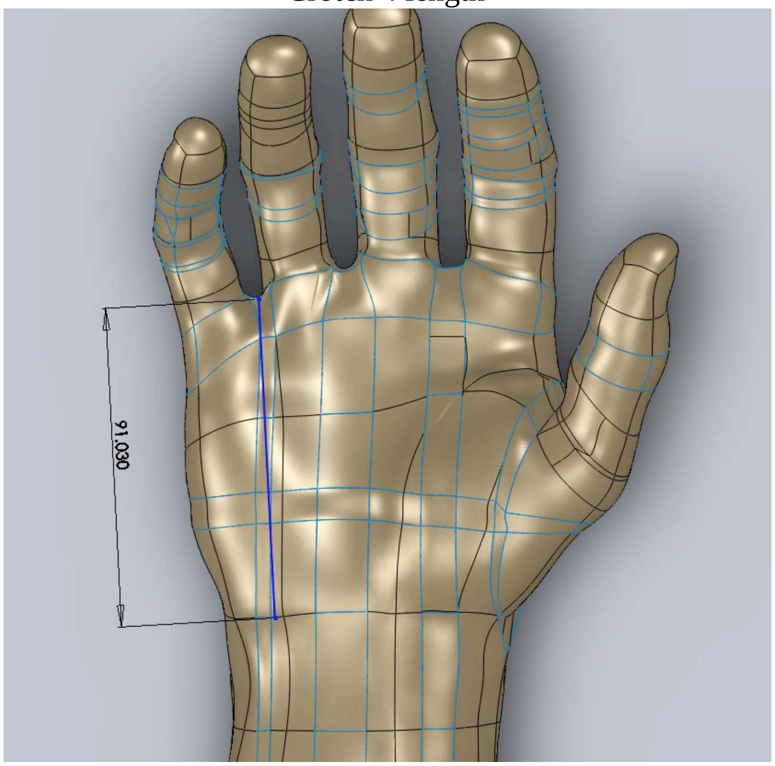

Figure 24 Crotch 4 length

Crotch 3 length

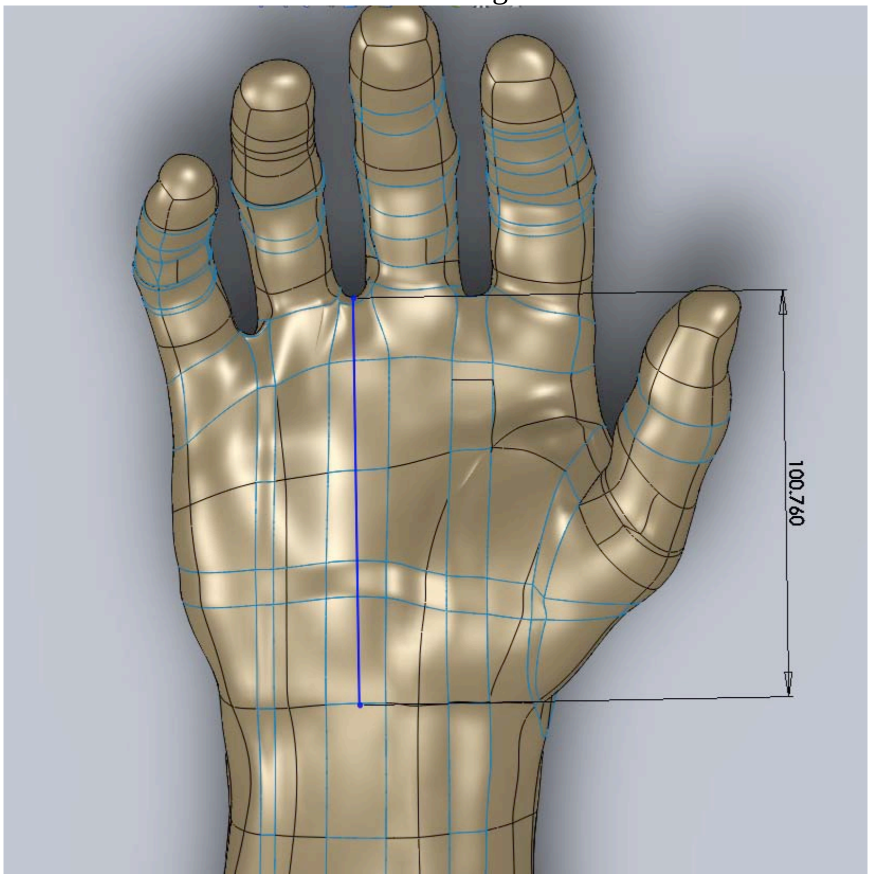

Figure 25 Crotch 3 length

Crotch 2 length

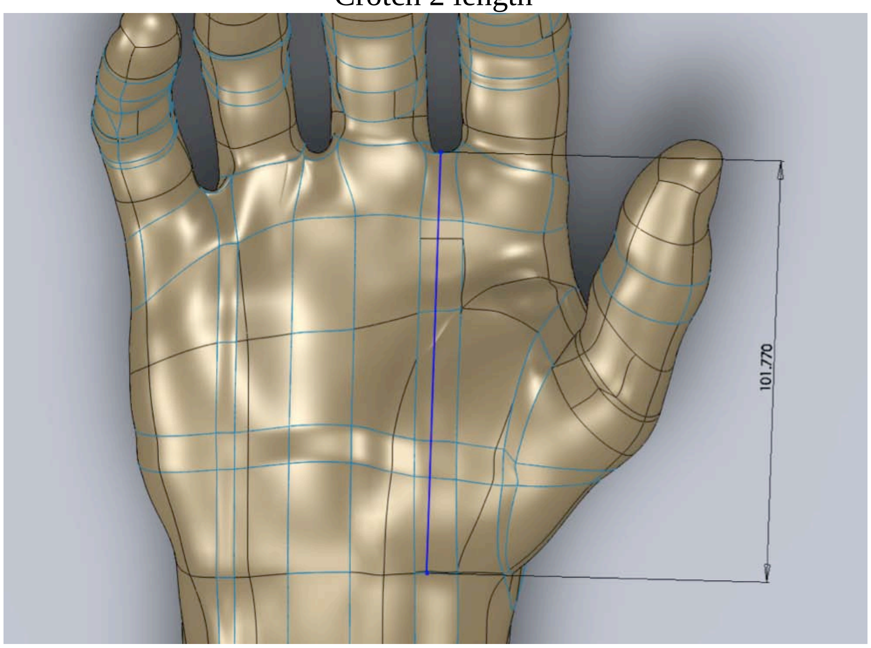

Figure 26 Crotch 2 length

Crotch 1 length

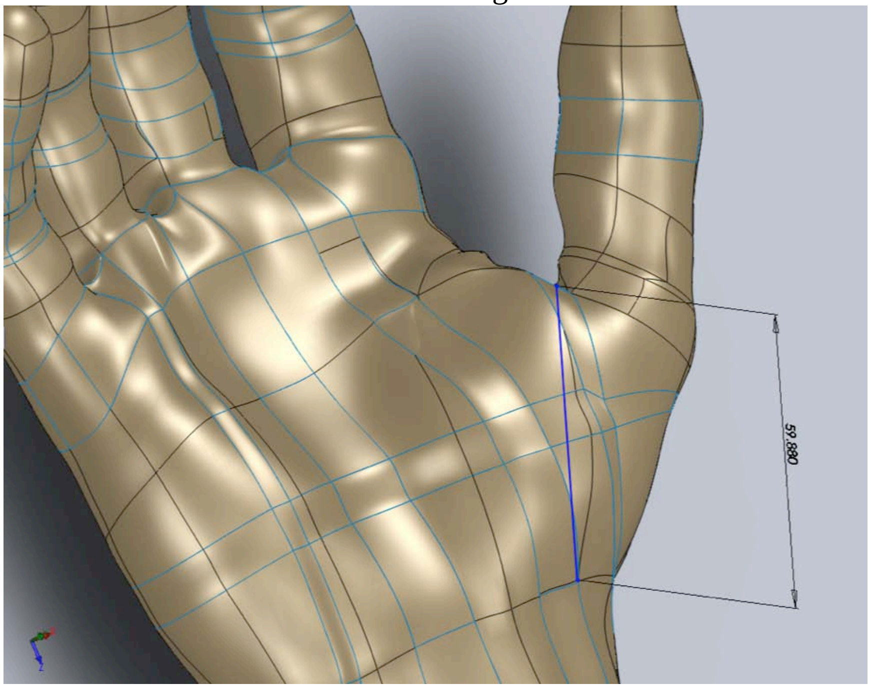

Figure 27 Crotch 1 length

8.3 Hand breadth: Measurement is in centimeters

Hand breadth measurement

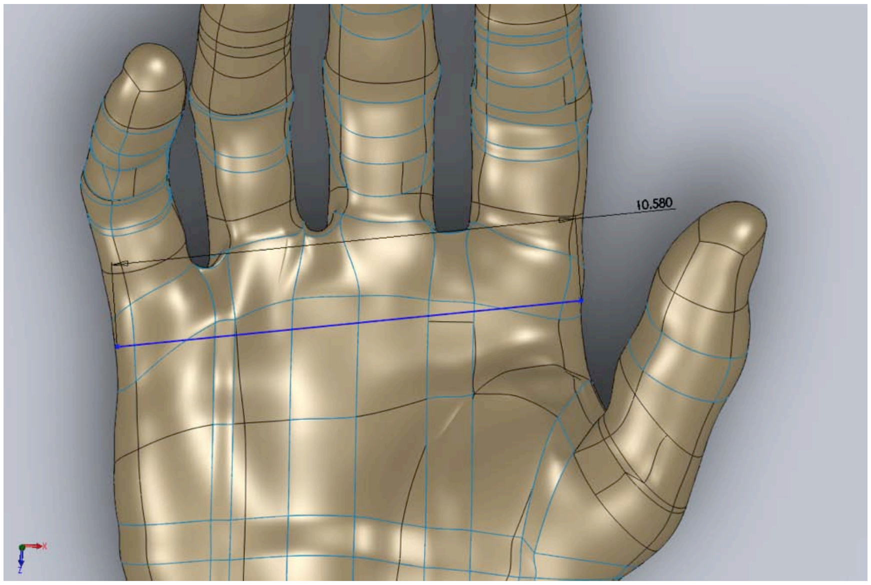

Figure 28 Dimensions for hand breadth

8.4 Finger Angles: Measurements are in degrees

2nd finger angles

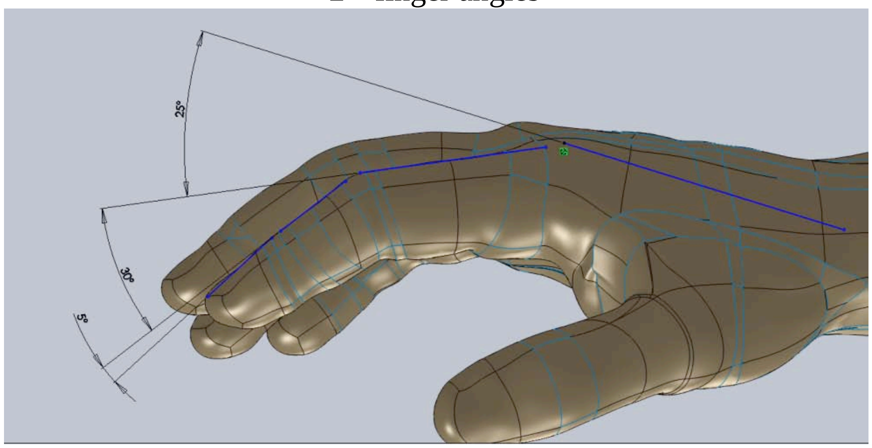

Figure 29 Dimensions for angles on finger 2

3rd finger angles

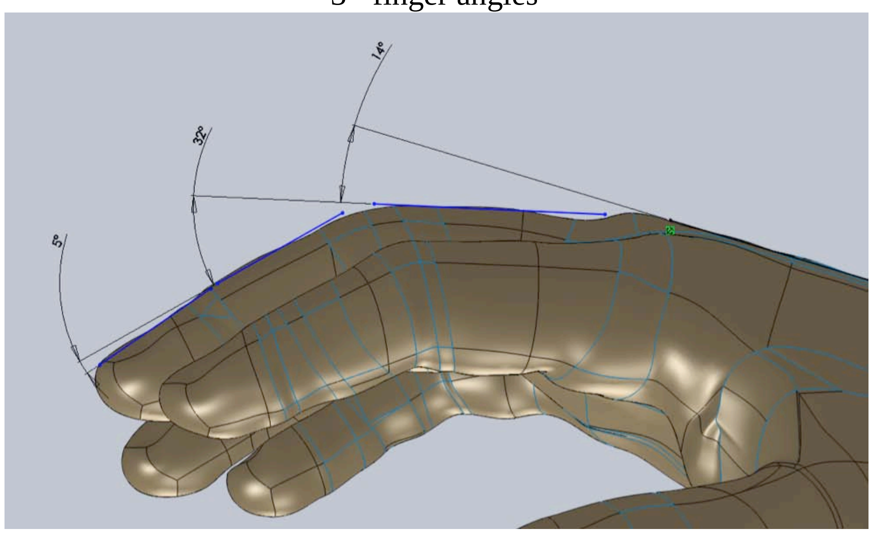

Figure 30 Dimensions for angles on finger 3

4th finger angles

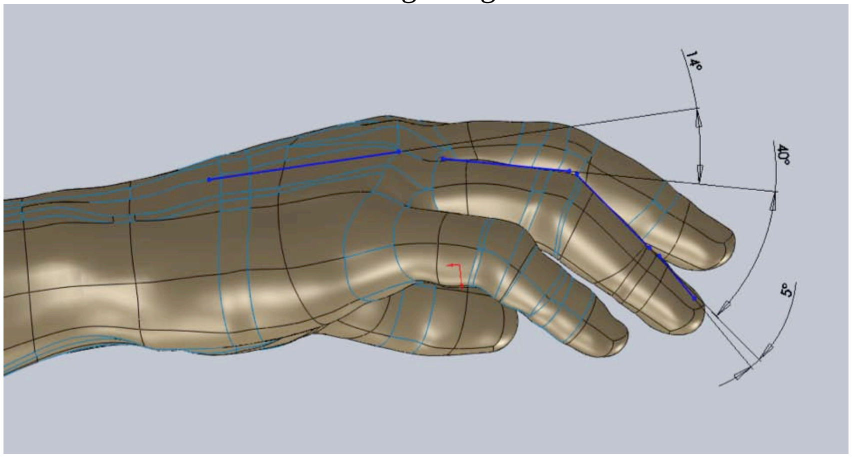

Figure 31 Dimensions for angles on finger 4

5th finger angles

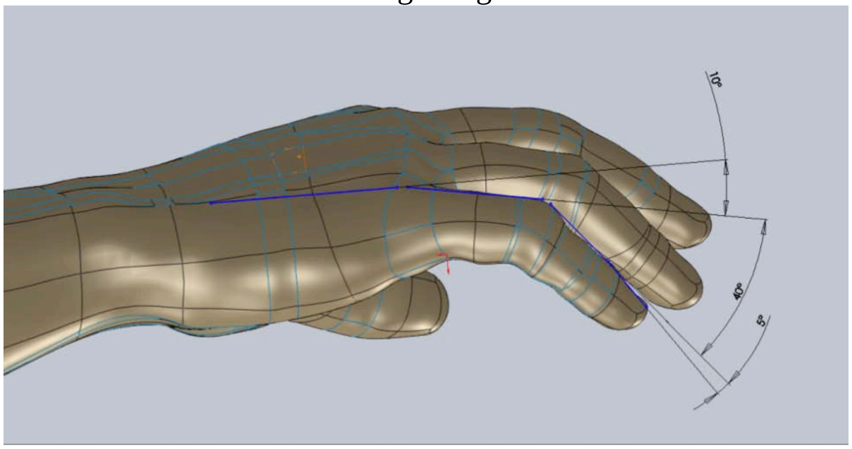

Figure 32 Dimensions for angles on finger 5

1st finger angles

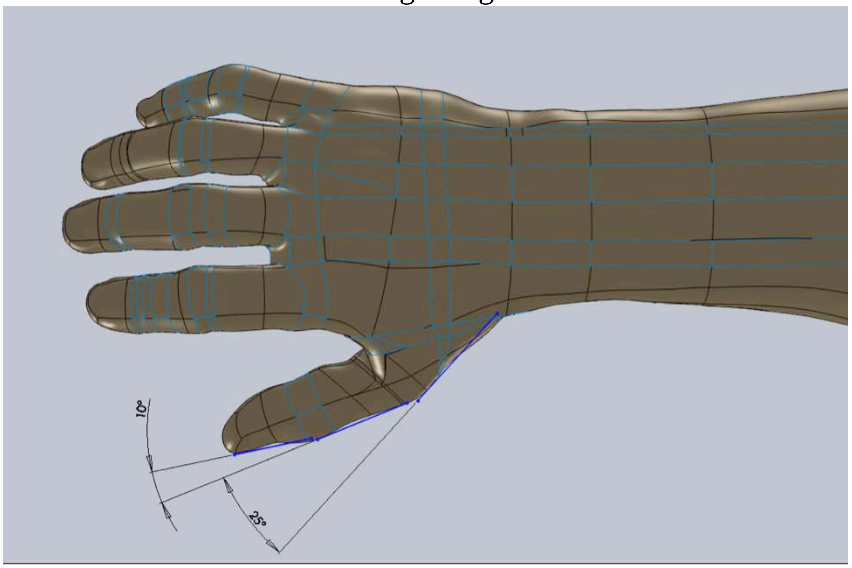

Figure 33 Dimensions for angles on finger 1

8.5 Extension angle: Measurement is in degrees

Extension angle for the 1rst finger

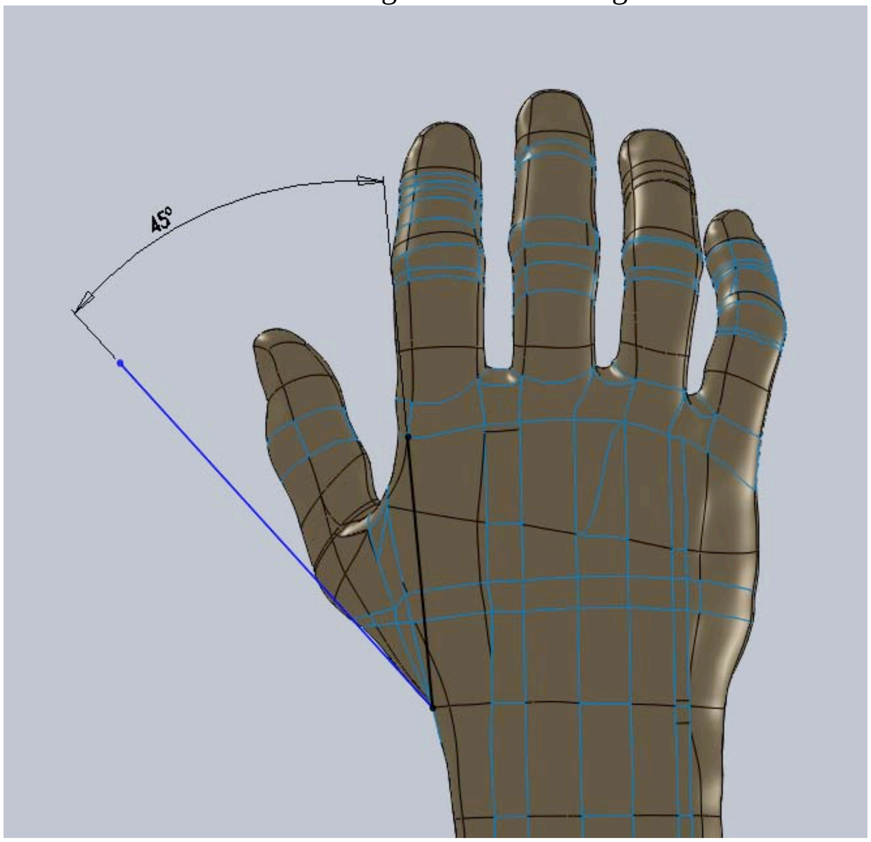

Figure 34 Extension angle on finger 1

8.6 Abduction angle:Measurement is in degrees

Abduction angle for the 1rst finger

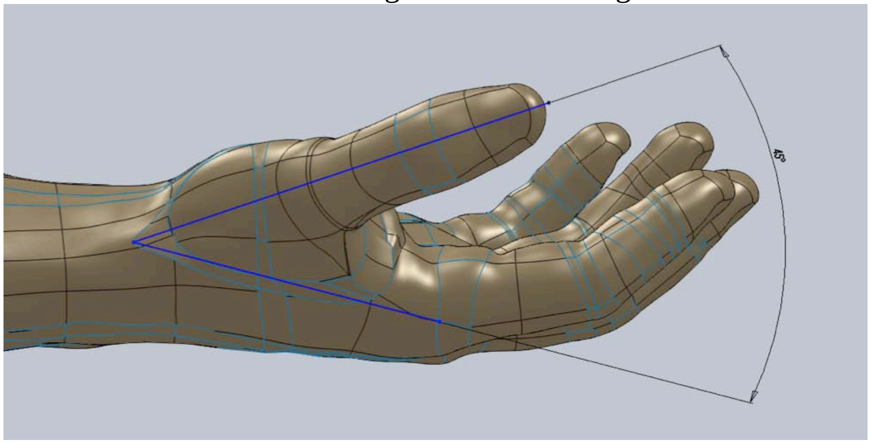

Figure 35 Abduction angle on finger 1

8.7 Joint circumference:

Joint circumference was measured by using a cutting plane and measuring the circumference around each joint. Each joint required creating a plane that runs through the middle of each joint. Then the plane is used as a cutting plane. Cutting planes are used to hide components by cutting into a part to allow designers and engineers to work with the inside of a part. The measure tool in SolidWorks only measures one arc segment at a time. There are several segments that make up the circumference of each joint. Each segment had to be measured independently then summed to get the total length of the circumference. Figure 36 shows the PIP joint of the 2nd finger using the cutting plane to expose the inside of the joint. The arc length is the measurement taken from the measuring tool bar used for joint circumference. The measuring tool bar can be seen showing the arc length of each segment. The sum total of all arc lengths in figure 36 is 8.05cm. The joint circumference data referred in the report is in millimeters.

2nd finger PIP joint circumference measurement

Total Length= 8.05cm=80.5mm

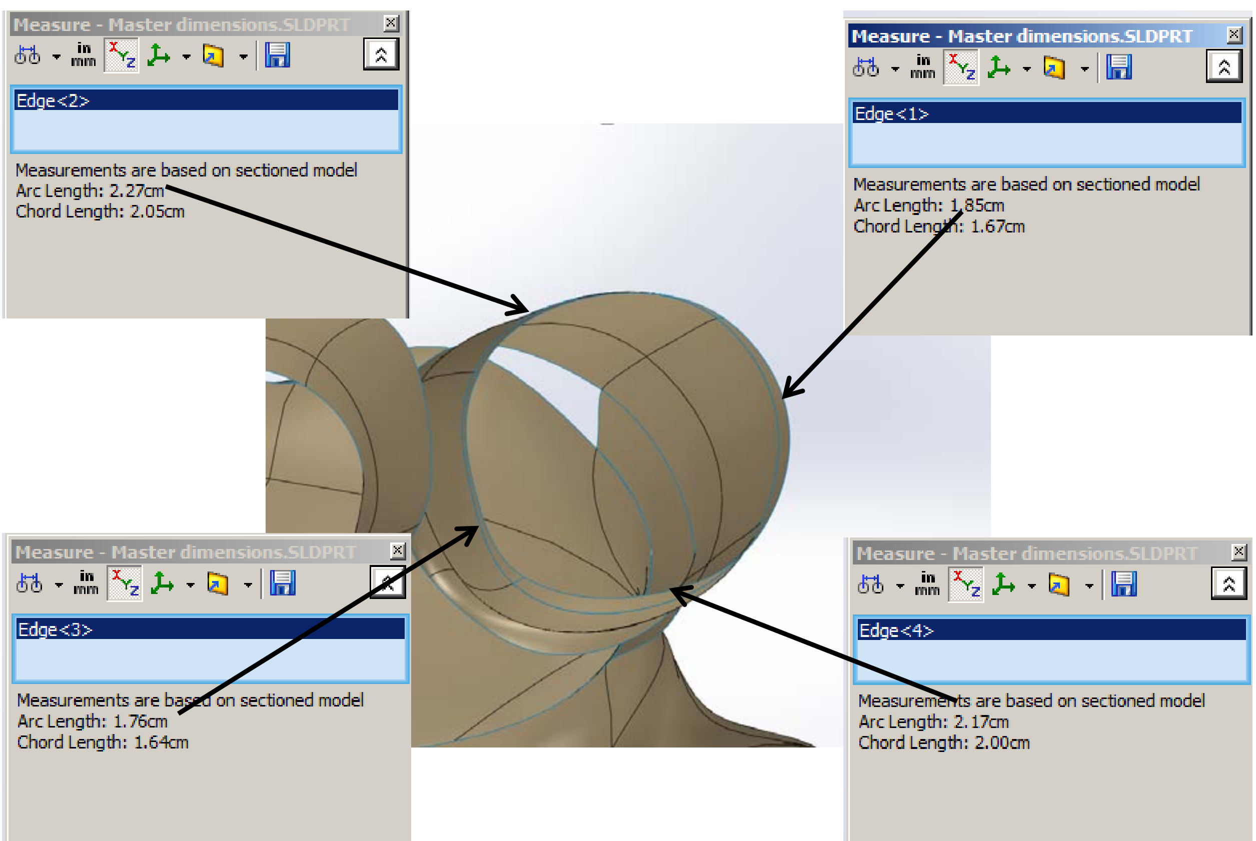

Figure 36 Circumference measurement of the PIP joint on the 2nd finger

2nd finger DIP joint circumference measurement

Total Length= 6.87cm=68.7mm

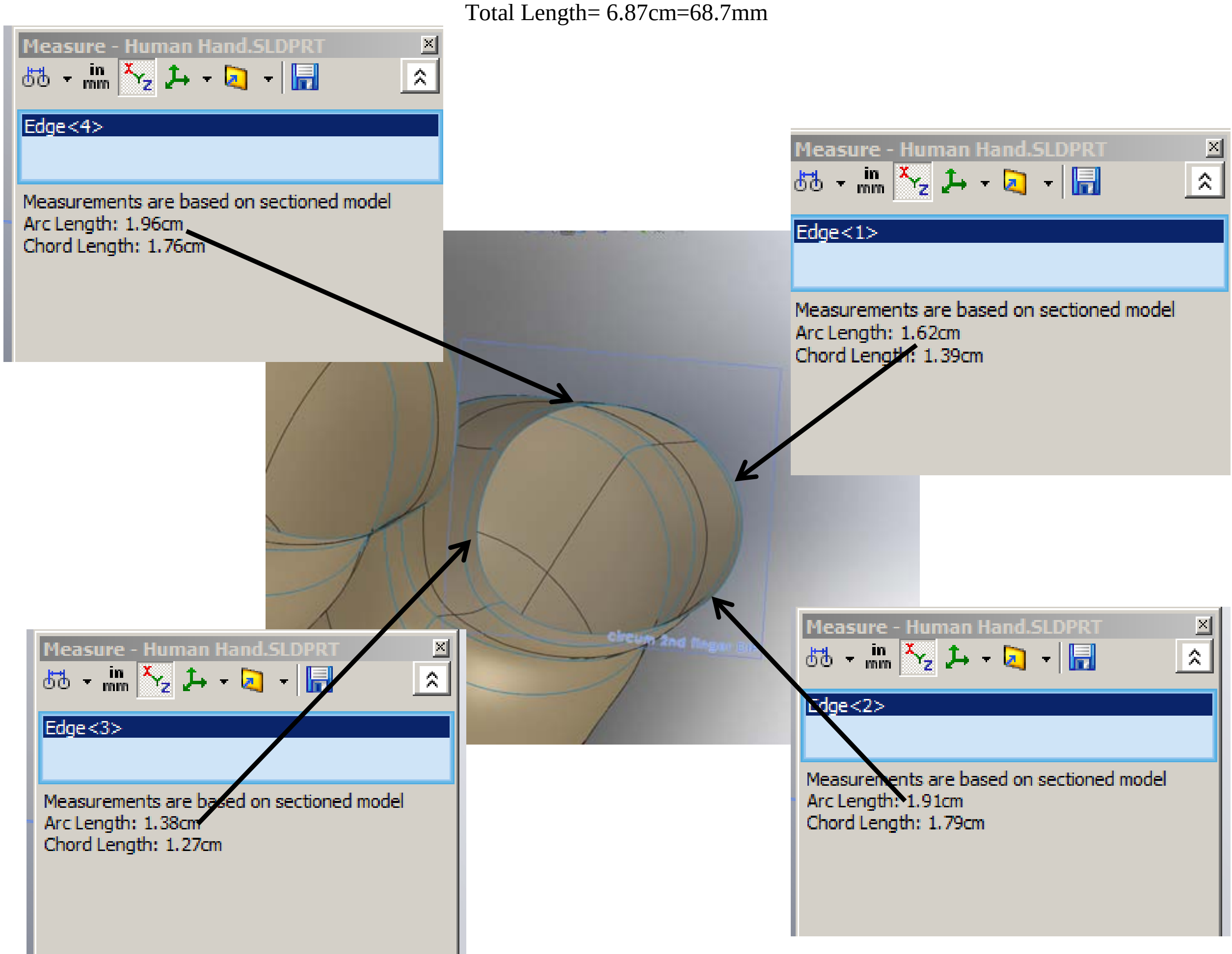

Figure 37 Circumference measurement of the DIP joint on the 2nd finger

3rd finger PIP joint circumference measurement

Total Length= 7.99cm=79.9mm

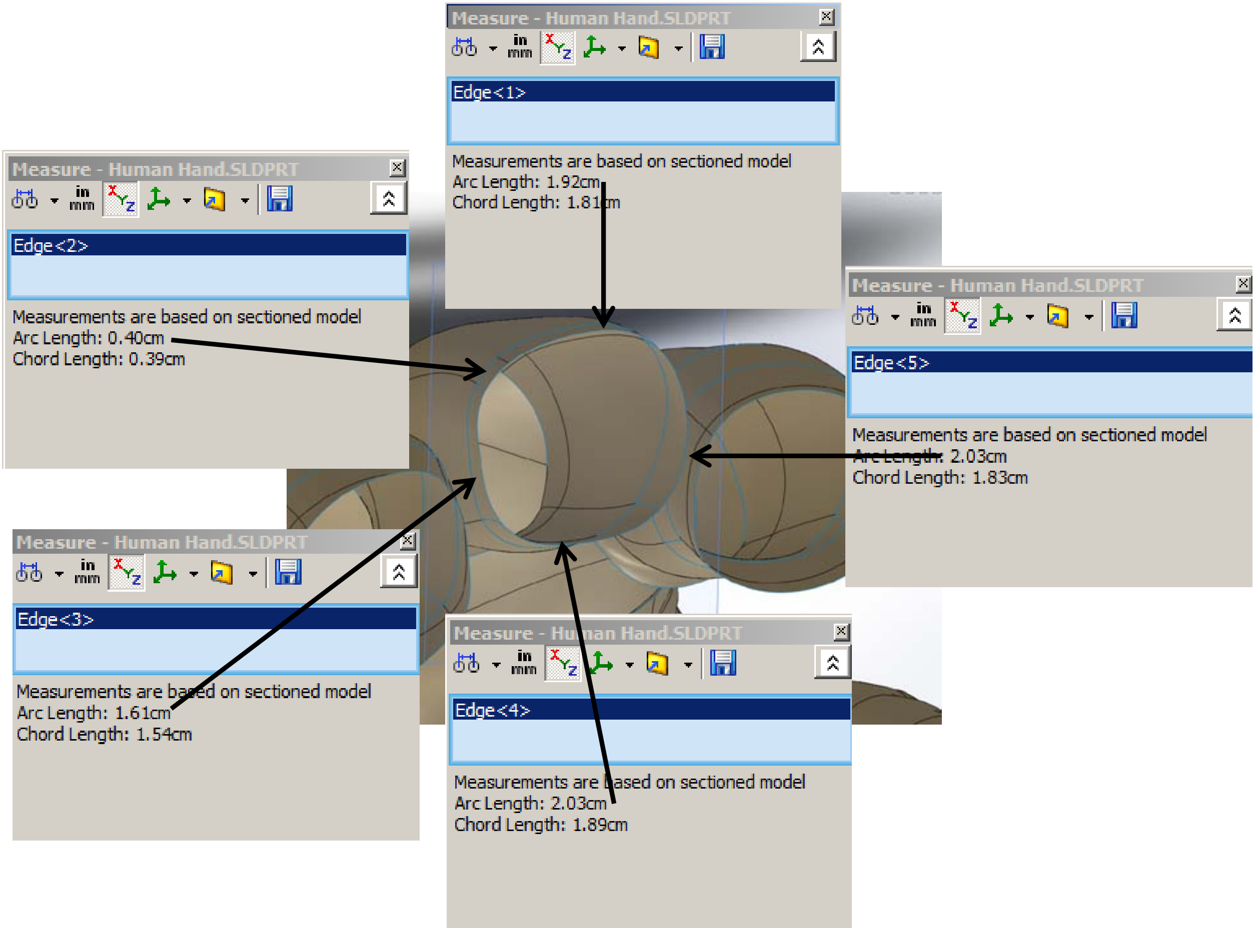

Figure 38 Circumference measurement of the PIP joint on the 3rd finger

3rd finger DIP joint circumference measurement

Total Length= 6.82cm=68.2mm

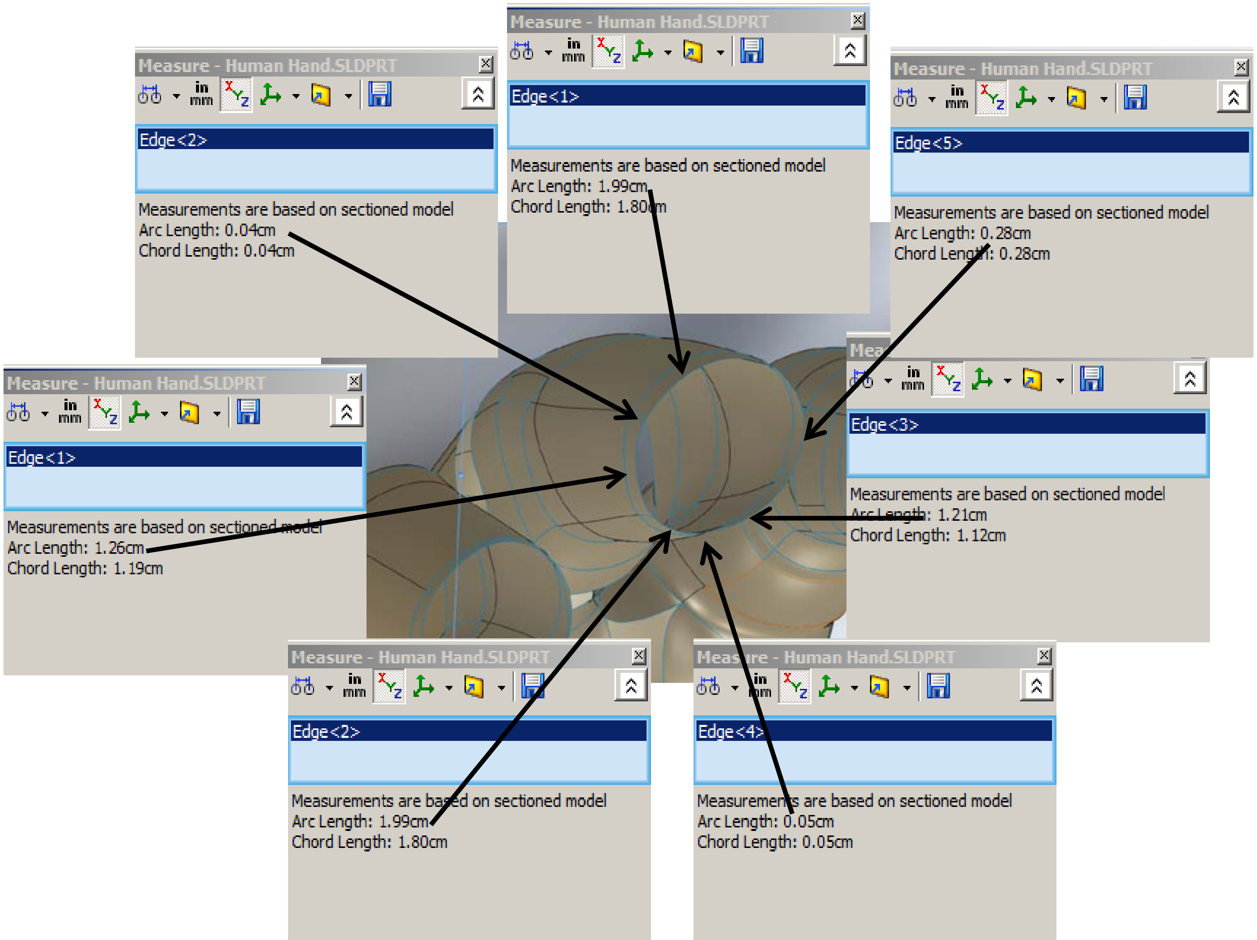

Figure 39 Circumference measurement of the DIP joint on the 3rd finger

4th finger PIP joint circumference measurement
Total Length= 7.4cm=74.0mm

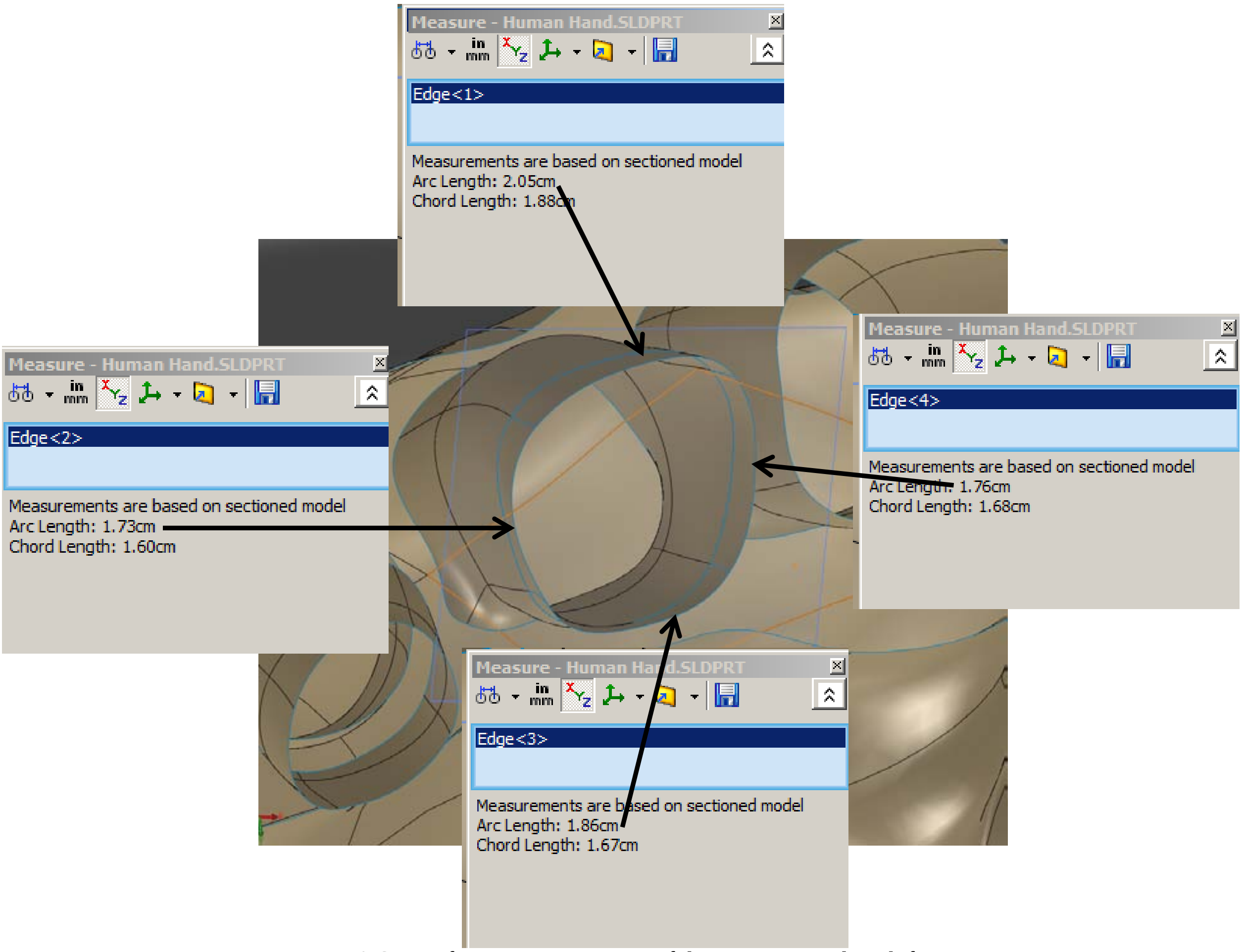

Figure 40 Circumference measurement of the PIP joint on the 4th finger

4th finger DIP joint circumference measurement
Total Length= 6.13cm=61.3mm

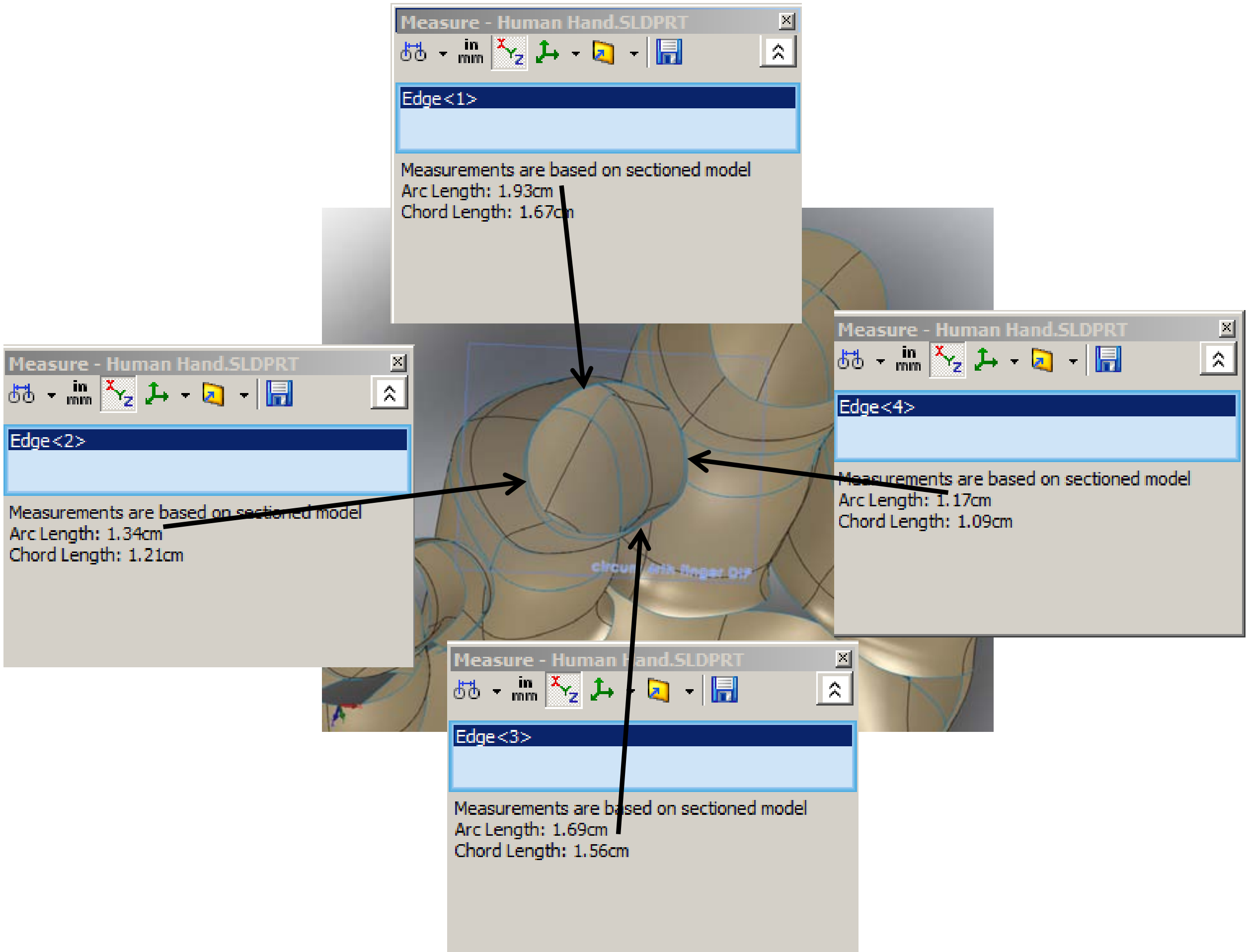

Figure 41 Circumference measurement of the DIP joint on the 4th finger

5th finger PIP joint circumference measurement

Total Length= 6.51cm= 65.1mm

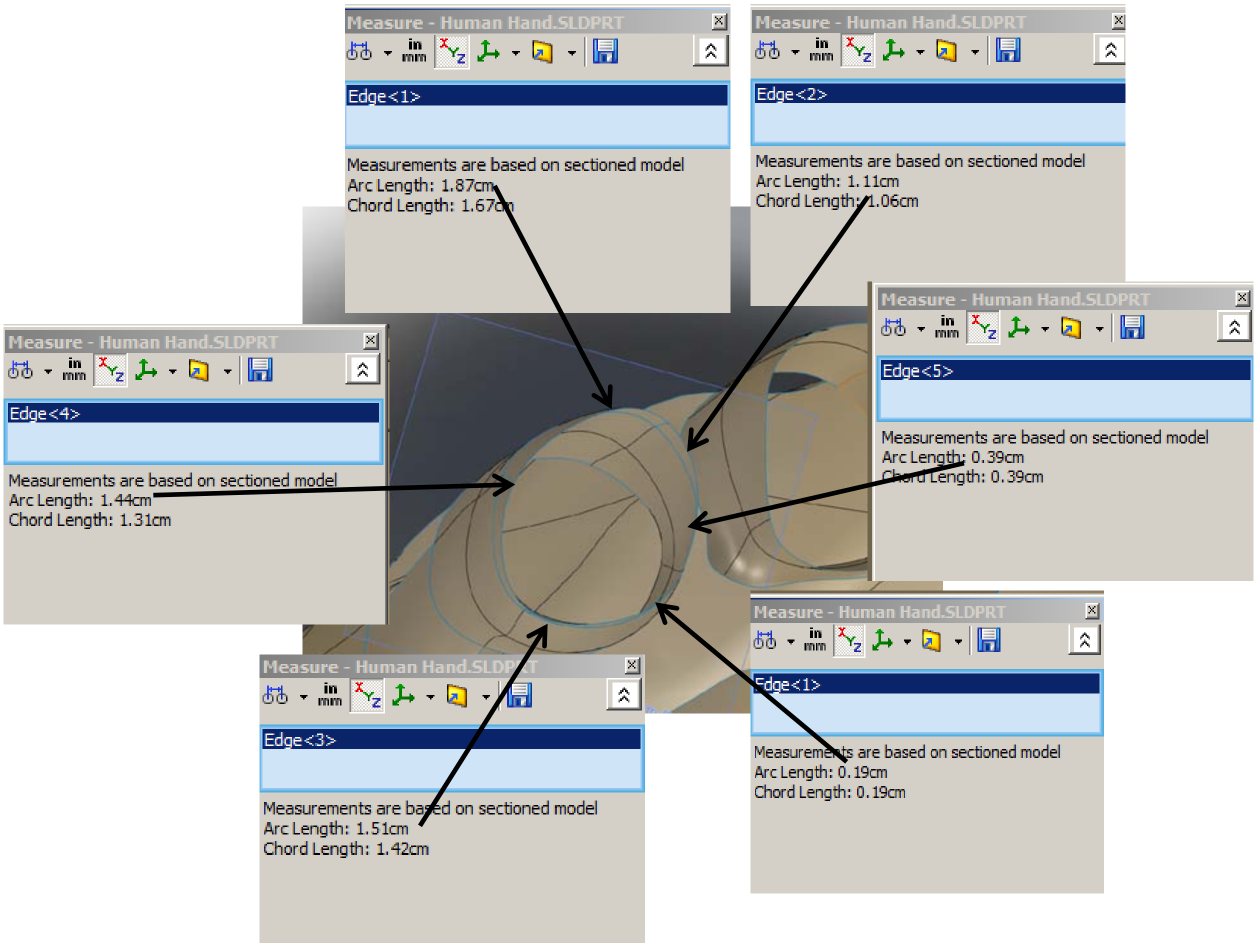

Figure 42 Circumference measurement of the PIP joint on the 5th finger

5th finger DIP joint circumference measurement
Total Length= 5.62cm=56.2mm

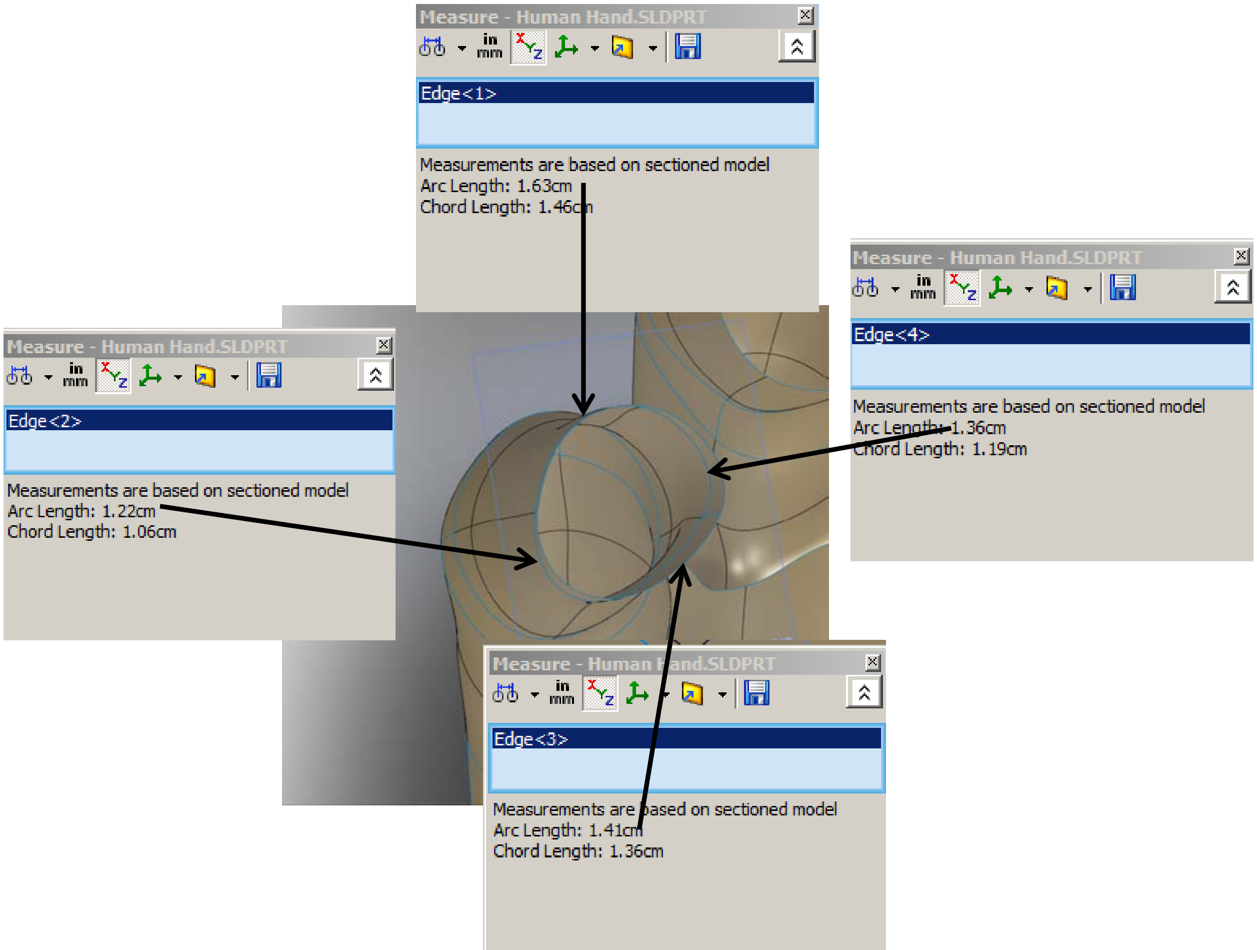

Figure 43 Circumference measurement of the DIP joint on the 5th finger

1st finger joint circumference measurement
Total Length= 8.19cm=81.9mm

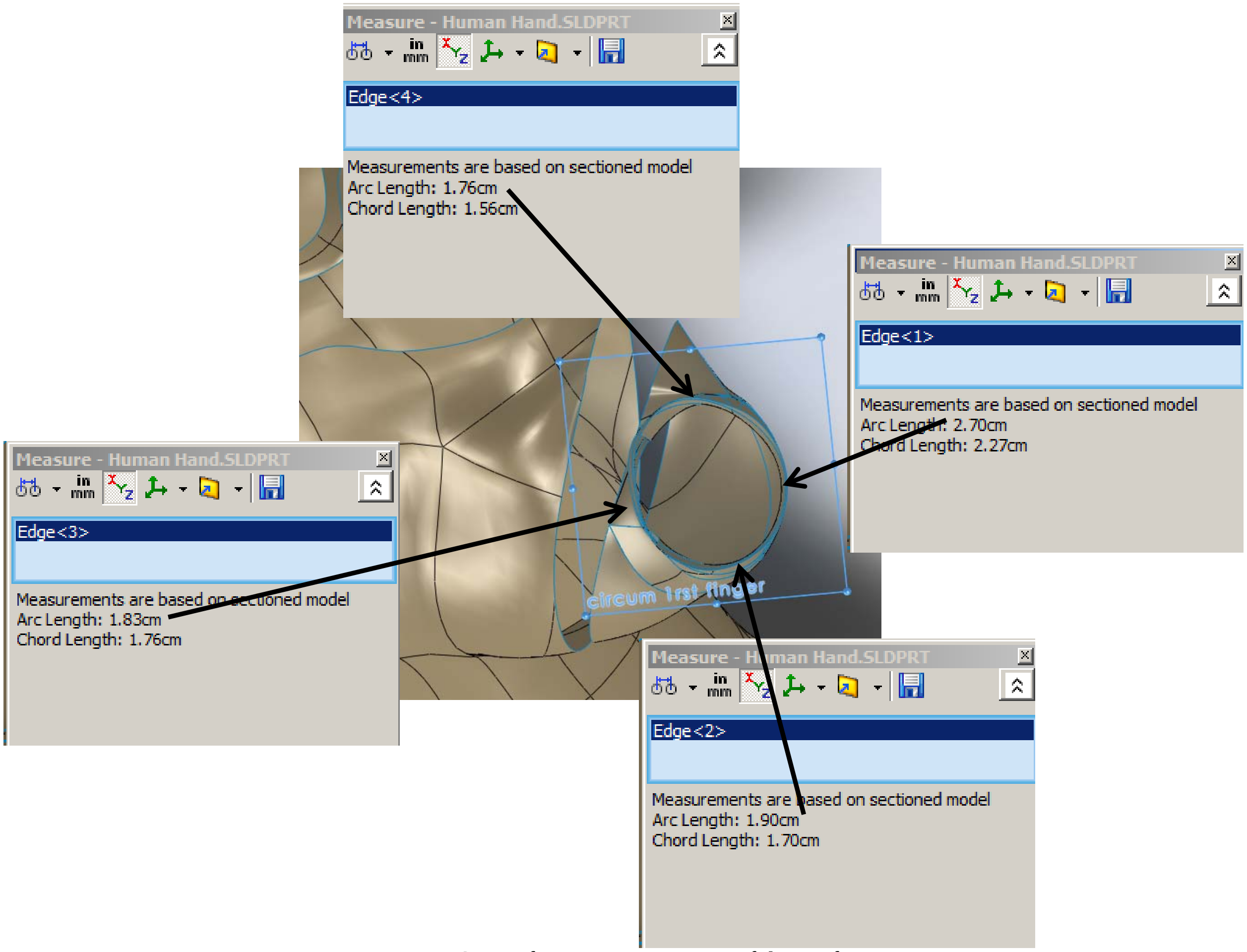

Figure 44 Circumference measurement of the 1st finger

8.8 Consent form used for the dexterity tests

Glovebox Dexterity Study

We would like to thank you for agreeing to participate in our study. If at any time during the study's progression you feel discomfort, please stop. There are no known additional risks of performing operations in the practice lab located outside the radiological facility. All information obtained is strictly confidential and cannot be tracked back to the participant. The tests should take around 20-30 minutes, with breaks between each test. We will be exploring the dexterity, qualities, and comfort of 15 mil hypalon gloves and a new prototype by using two methods; the right-handed Minnesota Dexterity Test and the right-handed Purdue Pegboard Test. If you are left-handed, please let us know. Each test is summarized below. Each participant will be given a chance to practice the tests, in addition to visual examples, that will ensure each participants understanding of how to perform each test.

Minnesota Dexterity Test ***"One-Hand Turning and Placing Test"***

-Using your right hand, pick up the disk in right hand corner of upper board
-Turn disk over using same hand
-Place in right hand corner of lower board
-Pick up second disk in the column and flip
-Place the disk below the first one
-Start each new column from the top row
-Test is complete when all disks are flipped

Purdue Pegboard ***"Dominant Hand Test"***

-Pick up 1 pin with right hand
-Place pin in hole
-Continue this pattern making sure not to skip holes. Work in only ONE column
-If a pin is dropped during the test, do not stop to pick it up, pick up another
-Test is complete once 30 sec has elapsed

For questions about the study or a research-related injury, contact Cindy Lawton, 505-667-0252.

Name:	Signature:	Date:

8.9 The score sheet used for the dexterity test

Study Number_________

<u>Have you checked to make sure everything is visible and within reach?</u>

First test? __________

Minnesota Dexterity Test				
Hypalon 15 mil. Thickness 30 in.	Trial 1	Trial 2	Trial 3	Average
Right Hand				
Prototype				
Right Hand				

First test? __________

Purdue Pegboard Dexterity Test				
Hypalon 15 mil. Thickness 30 in.	Trial 1	Trial 2	Trial 3	Average
Right Hand (30 sec)				
Prototype				
Right hand (30 sec)				

8.10 Survey used for the dexterity test:

Circle your answer for the first part of each question and then either fill in or check off you answer for the second part of each question.

Thank you! ☺

1. Which glove allows for easier hand insertion?
   Glove 1 Glove 2

   On a scale of 0 to 10 (where 0 is worse, 1 is no change, and 10 is *much* easier), how much easier is the insertion?____________________

2. Which glove allows for easier hand extraction?
   Glove 1 Glove 2

   On a scale of 0 to 10 (where 0 is worse, 1 is no change, and 10 is *much* easier), how much easier is the extraction?____________________

3. Which glove exhibits the best positioning for the fingers when relaxed (i.e., when resting, not performing any tasks)?
   Glove 1 Glove 2

   On a scale of 0 to 10 (where 0 is worse, 1 is no change, 10 is "I love this"), just how much better is the positioning?_____________________

4. Which glove exhibits the best thumb positioning?
   Glove 1 Glove 2

   Please check the box that is most similar with your own opinion on the following statement:
   Glove 1 has better thumb positioning than Glove 2.
   [ ] Strongly agree [ ] Agree [ ] Neutral [ ] Disagree [ ] Strongly disagree

5. Which glove offers a better hand-breadth?
   Glove 1 Glove 2

   On a scale of 0 to 10 (0 is worse, 1 is no change, 10 is *much* better), how much better is the hand-breadth?____________________

6. In which glove do your fingers have the easiest time reaching the end of the glove?
   Glove 1 Glove 2

   On a scale of 0 to 10 (0 is worse, 1 is no change, 10 is *much* better), how much easier is the reach?____________________

7. In which glove does the web spacing between the fingers best fit the crotch area of the glove?
   Glove 1 Glove 2

   On a scale of 0 to 10 (0 is worse, 1 is no change, 10 is *much* better), how much better is the spacing?____________________

For gloves, what changes, if any, would you make?

Additional comments