NIST GCR 08-919

Pilot Study of Firefighter Three-Dimensional Anthropometry to Improve Seatbelt Safety

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Notice

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PILOT STUDY OF FIREFIGHTER THREE-DIMENSIONAL ANTHROPOMETRY TO IMPROVE SEATBELT SAFETY

FINAL REPORT
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"This is our one shot to really do some good here."

Lt. Mike Wilbur

EXECUTIVE SUMMARY

The second leading cause of line-of-duty deaths for US firefighters is attributed to vehicular accidents, and a number of those firefighters who died were not wearing their seatbelt. It has been proven that many firefighters are not physically able to reach, manage, or maneuver their seatbelt such that they are safely restrained within the fire engine. Seat belts have been proven to save lives and yet this level of protection is not offered to all firefighters. Current seat specifications are inadequate due to outdated anthropometry, inappropriate use of percentiles, and lack of attention to the fact that the firefighter is outfitted in equipment adding considerable bulk and weight. Furthermore, US firefighters are one of the few populations never characterized using anthropometry. Fortunately, innovative methods used to capture and appropriately measure a population to improve their specific protective gear have been refined to create optimum fit. Characterizing the firefighter's volume, given the added bulk, required 3D anthropometry, selective image analysis, and advanced statistical solutions, all of which have been provided through this study.

The multi-dimensional space that describes the shape and size of the seated, encumbered firefighter was captured using 3D whole body surface scanning. Additional postures with and without gear were captured as well to better understand and quantify the "bulk factor" added by the turnout gear. Traditional anthropometry was measured such that this data base can be compared and enhanced by other anthropometric database information. This facilitates the ability to characterize firefighters, for instance, with respect to other occupations. The sampling strategy was designed to carefully select each subject in order to most likely capture the variability that is the firefighting population. The success of this approach was highlighted in a comparison with the large national survey of thousands of civilians. Summary statistics were generated for all measurements to provide an overview of the population. Comparison of these statistics revealed potential problems with the FAMA self-reported anthropometric study.

Anatomical landmarks on the standing and seated unencumbered scans were located and recorded for future modeling and measurement use. The dimensions that relate to seat and restraint design were identified and extracted from the seated, encumbered scans in the form of bounding boxes. A principal component analysis (PCA) was performed on these data and multivariate models generated to most succinctly describe and present cases (models) to use with ergonomic designs of fire apparatus. A physical representation of these models has been presented as an innovative design tool for existing and prototyped fire apparatus.

1. Introduction

1.1 The Problem

The International Association of Fire Chiefs (IAFC) recently reported that approximately 25% of the current firefighter population are unable to fasten their seatbelts, and as a result, "36 of 52 firefighter collision fatalities were not wearing belts." There are an estimated 1,078,000 firefighters in the U.S., based on the National Fire Protection Association (NFPA) 2001 National Fire Experience Survey. From 1990 through 1999 there were 966 firefighter fatalities, which is equivalent to an annual rate of 8.9 fatalities per 100,000 FTEs and is significantly higher than the average of 4.0 fatalities for all occupations combined (BLS 2005). Motor-vehicle-related incidents are the second leading cause of firefighter line-of-duty fatalities. Firefighter anthropometry for automotive fire apparatus design has been recognized as a pressing issue to prevent firefighters from being killed in crashes and rollover incidents, as well as from ejections or falls from moving vehicles. Various concerned parties--the National Fallen Firefighters Foundation (NFFF), the International Association of Fire Chiefs (IAFC), the Safety Task Force of the NFPA 1901 Fire Apparatus Standards Committee, and the Fire Apparatus Manufacturers Association (FAMA)--jointly advocated for an anthropometric survey of U.S. firefighters to address this design issue. In a white paper issued in 2006, the authors noted that the current configuration of crew-compartment seat arrangements and seatbelt placement made it difficult or impossible for firefighters wearing protective clothing to reach and fasten their seatbelts while operating automotive fire apparatus. The problem of accessing seat belts was further complicated by the presence of self contained breathing apparatus (SCBA), which was integrated into the backs of many fire apparatus seats. The typical SCBA would add an additional set of shoulder straps and a waist belt to be accommodated, as well as several hoses, attachments and accessories. The joint stakeholders emphasized that all of these factors must be taken into consideration in the design of cabs, seats, seatbelts and even SCBA straps, and have requested that NIOSH consider this matter as urgent and critical. They urge NIOSH to conduct this line of research to reduce firefighter fatalities, as quickly as possible.

1.2 The Technology

Anthropometry is the science of measuring the human body. Often, these measurements can be used to improve the fit and performance of equipment that must interface with the body. Historically, instruments such as calipers and tape measures have been used to capture these measurements. Fortunately, the ability to record the entire surface of the body is now possible through non-contact rapid surface scanning. The Cyberware WB4 is a state-of-the-art, leading edge accomplishment of scanning technology. In 15 seconds, the entire human body can be accurately, reliably, and safely scanned at a very high resolution. While this is impressive, it is not a turnkey system. The whole body scanner will not solve a fit issue like the lack of accommodation noted by the IACF. However, the application of whole body scanning when used in concert with experienced and knowledgeable investigators, can certainly identify and measure the geometric fit, and using advanced statistics, can produce effective design specifications and electronic tools to aid in the remedy of seatbelt fit issues.

1.3 The Approach

NIOSH has identified seatbelt safety as an issue for firefighters and is proposing to address this and other equipment interface and integration problems during FY09. This proposed study will not solve the current seatbelt problem. However, the current study (n=122) will serve to provide

up-to-date database to drive specifications for new and retro-fit seat/seatbelt systems. Results from this study will reveal new fit criteria for seat/seatbelt systems in the form of an anthropometric guide for users and designers, which will advance firefighter protection.

In addition, this pilot study has provided an opportunity to establish appropriate measurement methodologies for the firefighter community. It is now established that firefighters while wearing their bunker gear can be reliably measuring using surface scanning without artifacts caused by the reflective tape or bulky material. The small population of subjects (n=122), strategically sampled based on gender, height, weight, and ethnicity, represents a great deal of variability within the firefighter population. Shown in Figure 1 is a bivariate plot of height and weight for male subjects from the CAESAR survey. The Civilian American and European Survey of Anthropometric Research (CAESAR) is recent survey of non-military subjects, collected from wide-spread geographic locations in the US and Europe, using traditional and scanning methods. This study is considered the most updated representation of the US population. The male subjects (n=85) from the firefighter study are superimposed and exhibit large variability in subject selection. In other words, the male firefighter subjects recruited for this study included mean and extreme body sizes. Likewise, the female subjects are plotted against CAESAR data as shown in Figure 2. The results from this study support the approach utilized and the need for a large-scale anthropometric study of firefighters.

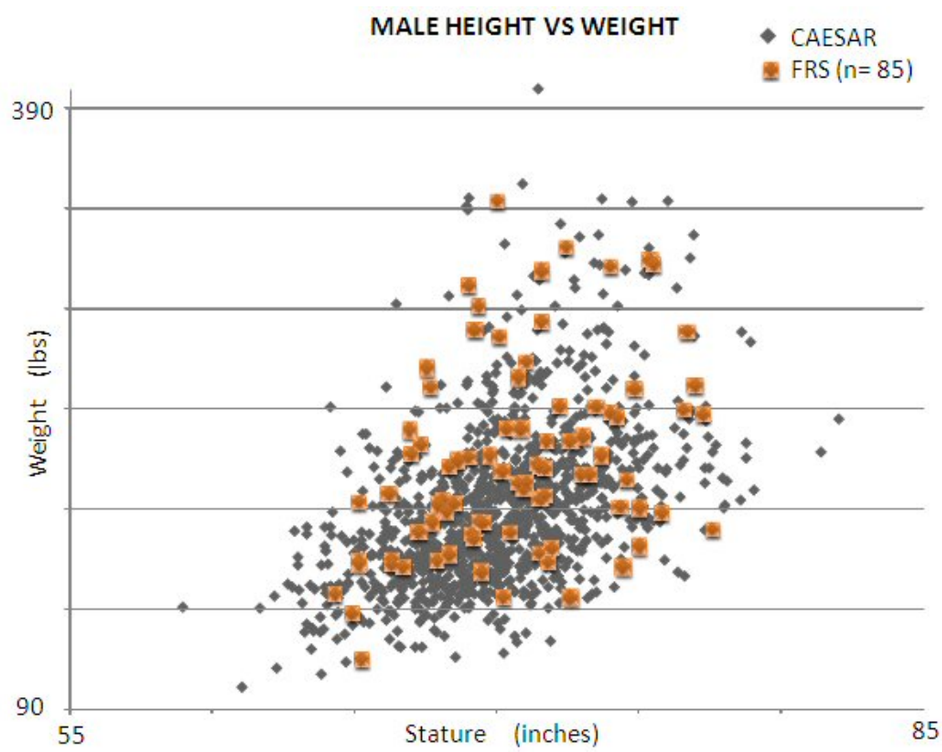

Figure 1. The CAESAR height and weight anthropometry are plotted with the firefighter study data. This plot demonstrates the wide range of body size variability represented by this small study.

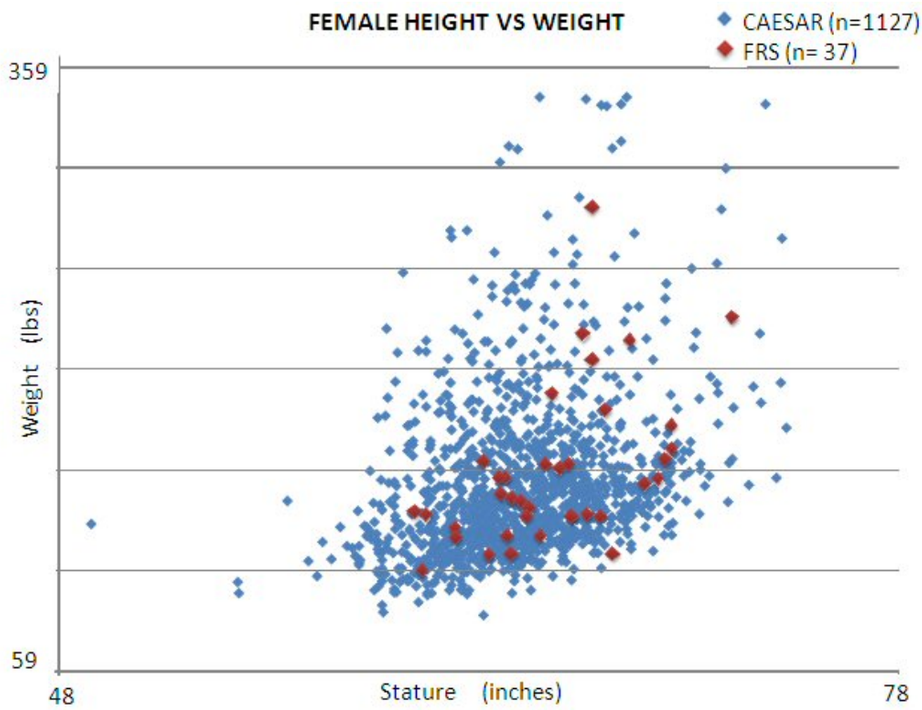

Figure 2. The CAESAR height and weight anthropometry for the female subjects are plotted with the firefighter study data. This plot demonstrates the wide range of body size variability represented by the females surveyed.

Data collection, analysis, and design methods developed during this project have direct application for a large-scale, nationwide survey of firefighters. One hundred and twenty-two firefighters were recruited based on pre-determined demographics and captured using both traditional (calipers and tape measures) and three-dimensional (Cyberware Model WB4) anthropometric measuring devices. The participants were measured with and without their personal protective gear while in standing and seated positions, and their demographic information recorded.

The source population for this pilot study included both career and volunteer firefighters selected from Ohio (Wright-Patterson Air Force Base) and Texas (Randolph Air Force Base

2. Problem Definition

2.1 Lack of Seatbelt Use

The National Fire Protection Association (NFPA) standard 1500 specifies safety procedures for members involved in rescue, fire suppression, and related activities, and includes wearing the seat belt while the engine is in motion as standard operating procedure (SOP). The updated 1500 includes an enhanced chapter with an emphasis on safe arrival at the scene. Dating back to 1994, NIOSH published a CDC alert that listed "following established fire-fighting policies and procedures" as the number one deficiency creating life-threatening situations for firefighters. The National Fire Protection Association (NFPA) 1901 Safety Task Group organized to establish recommended practices for firefighters has recently identified seatbelts as a new safety initiative.

The U.S. Fire Administration under the Homeland Security Department published a summary of firefighter fatalities for 2005. It was reported that while 115 firefighters were killed while on duty, "some 60 firefighters died while engaged directly in the delivery of emergency services." As found in previous years, the second leading cause of fatal injury was vehicle crashes, including many firefighters who were not wearing seatbelts either riding in the fire engine or in personal vehicles while responding to emergencies. Furthermore, USFA states "these deaths involved excessive speed and lack of seatbelt use." Additionally, since 2002, eight firefighters have died as a result of falls from vehicles.

At the 2006 Fire Department Conference, the International Association of Fire Chiefs (IAFC) presented deficiencies associated with seatbelt safety. They reported that since 2000 "36 of 52 firefighter collision fatalities were not wearing belts." While the reasons for not wearing a seat belt could be attributed to department culture, inherent risk-taking personalities of firefighters, and donning their equipment while en route, the IAFC identified an additional reason - the inability to find or fasten their belt. They identified that approximately 25% of firefighters surveyed were unable to buckle their seatbelts while outfitted in protective gear.

2.2 Lack of Updated Firefighter Anthropometry

Body size data generated by the military for other applications has become the normative basis for commercial sizing specifications. However, military populations cannot represent the firefighter population because of relatively strict anthropometric armed forces entry requirements and height/weight guidelines for troop retention. Also, body dimensions gathered 30 or more years ago do not reflect the increase of height by 1 in per decade. Furthermore, as reported by Hsiao, et al., firefighters are heavier (15 lbs heavier for males and 22 lbs for females) than those in all nonmilitary occupations combined. Seats and seatbelt systems designed and sized for a military population may not provide the same level of protection to firefighters because of the greater diversity in body size and shape exhibited by the firefighter population.

Furthermore, dimensions measured and tabulated by traditional methods are not linked to one another. For instance, bi-deltoid breadth (shoulder width) measurements do not give the designer shoulder location relative to the seat. No current firefighter anthropometric database exists, either traditional or three-dimensional, and updated body size measurements are needed.

2.3 Lack of Reliable Fire Engine Seat/Seatbelt Design Specifications

Fire apparatus manufacturers have few requirements with which to comply for new equipment design. Current specifications for seat design in the automotive fire apparatus state :

14.1.9.1 Each seating space shall have a minimum width of 22 in. (560 mm) at the shoulder level.

14.1.9.2 Seat cushions shall be a minimum of 18 in. (460 mm) in width and 15 in. (380 mm) from the front of the cushion to the face of the seat back.

The specifications are based on outdated anthropometric data, do not account for demographic changes in the firefighter population, and do not include increased personal space volume requirements as a result of wearing protective equipment. Another source of specifications is the MIL-STD-1472, Human Engineering, a military standard for human factors design. Developed

during the 70's under the Department of Defense Human Factors Engineering Technical Advisory Group, the standard is outdated not only in current anthropometry as detailed in the MIL-HDBK759, Human Engineering Design for Military Material, but also in specified anthropometry for design, inappropriately advising designers to employ the use of percentiles for workstation design.

Anthropometry has advanced over the last ten years in that what was once considered specifications for anthropometric design is now considered mathematically impossible. The use of percentiles has been widely documented, taught in human factors course, and included, as previously mentioned, in specifications for workstation and protective equipment design criteria. However, we now realize that a "5th percentile" female, for instance, can not physically have all 5th percentile univariate measurements including a 5th percentile standing height that equals all other 5th percentile anthropometric measurements. Further, the use of percentiles results in a limited portion of the population that is actually accommodated. As shown in Figure 3, using a sitting height measurement that meets the 5th through the 95th percentile results in accommodation of 90% of the population. However, individuals who actually fall within all of the 5th to 95th percentile values of the 5 body dimensions specified is only 67% of the population.

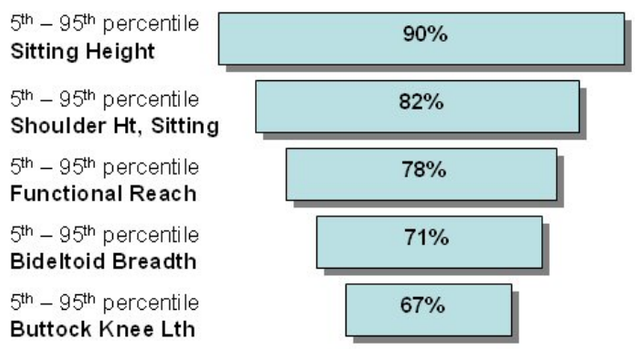

Figure 3. This figure demonstrates typical results of applying percentiles for designs that require accommodation of many variables. The resulting accommodation is limited.

Moreover, if only the extremes of univariate dimensions are used, those with unusual proportions are not represented. Long torso, short extremities and, conversely, short torso, long extremities are not modeled. An individual with a long buttock-knee length coupled with small abdominal depth would have different accommodation needs than a short buttock-knee length, large abdominal depth combination. These extreme ratios present difficult problems when accommodating firefighters within their crewstation. A workstation or equipment item that will interface with the complex shapes and sizes of the human body requires a multivariate solution. For instance, instead of using 5th through 95th percentile requirements, designs are now stipulated to accommodate, for instance, 98% of the population. A method of reaching this accommodation level is multivariate modeling techniques or principal component analysis (PCA).

2.4 Lack of Reliable Human Body Models

Human body modeling exhibits limitations for the application of workstation design such as the firefighter seat system. A study conducted by TNO of The Netherlands and USAF, and presented at the Survival and Flight Equipment (SAFE) 2002 annual conference, examine five of the most sophisticated human body models in the area of cockpit accommodation. The work was performed to determine the accuracy of these human body models when used as tools in assessing accommodation in aircraft cockpits and to develop a standardized method of verification and validation in a cockpit application. This was a 2-year effort using 1998 versions of Boeing's BHMS, RAMSIS, Safework, JACK, and Combiman software, designed to (1) verify anthropometric engines, (2) validate their reach algorithms using an F-16 cockpit model, and (3) determine accommodation in the F-16.

They measured reach performance and anthropometry of 8 subjects ranging in size from 5' to just over 6'5". The anthropometry engines for all of the models were flawed, including some input variables that were directly programmed revealed errors. Derived variables had error as well. One model demonstrated 0.5 to 8.4% error from direct input anthropometry, but after reworking the engine that generates the manikin link system, they reduced the error to 0% to 11 critical dimensions. The models were tested with reach to control tasks, head clearance, shin clearance, adequate vision, and rudder control. As an example of modeling capabilities, differences in control reach from model to subject ranged from under 1 cm to over 12 cm. Sources of error are attributed to anthropometry engine; initial seated position; initial posture; tissue deformation (e.g., thigh compression); subject flexibility; and posture during reach.

For the estimation of needed eye height, the models generally underestimated the results, by as much as 5 cm. For the required leg length, the model generally overestimated the results as much as 8.5 cm. The maximum sitting height was generally underestimated (~2 cm). The maximum buttock-knee length, however, was pretty well estimated by all of the models.

This study represents a snapshot of the modeling capability for the purpose of workstation mapping in 2000. Other human body model evaluations since this period reveal similar dysfunctional abilities for modeling the human in a workstation environment. A 2003 Digital Human Modeling conference was the most recent forum for publishing state-of-the-art human body modeling research. An ergonomic evaluation of sewing machine operators using JACK found that the model was "very sensitive to movement when the workstation arrangements were changed; manual adjustment of the posture change were difficult; and it was difficult to characterize the modeled postures against maximum or minimum criteria." They suggested that the model needs an ability to react and adjust posture when collisions occur between the human model and workstation, or when viewing obstructions occur. BMW designers using RAMSIS evaluated seat track position, head clearances, arm rests, reach to controls, and view on instruments. They found that the unreliability is due to the biggest challenges faced by human body modeling today; posture prediction and integration into the design process.

Unfortunately, many of the papers presented demonstrated results without validation or verification. "Users, through need or ignorance, routinely push models beyond their original

purpose. (Initial) Validation can not prevent misuse and can not certify all potential applications. Consequently, model validation should be viewed in the context of a continuous process not an end goal." The complexity of modeling human movement requires that we capture and record as many of the variables as possible, and make educated representation for those that we cannot. The errors associated with design, operation, and application can be reduced through refinement of one model for one application. Therefore, to employ the use of modeling for either design or evaluation, one human body model should be selected with capabilities that match the requirements for modeling firefighter workstation accommodation and, working with the model developer, evolve and refine this model for firefighters through validation and verification studies.

3. Alternative Solutions

3.1 Principal Component Analysis, Feature Envelopes, and Geometric Fit

Principal Component Analysis (PCA) is a statistical approach which operates on multiple variables, reducing them to smaller set of factors based on correlation or covariance. For instance, military aircraft cockpits must take into account multiple dimensions including sitting height, eye height sitting, shoulder height sitting, thumbtip reach, buttock-knee length, and popliteal height sitting. PCA describes the multivariate structure given this single population, providing the solution to a specific kind of eigenproblem, resulting in 8 representative cases that accommodate 98% of the population. These "surface" cases represent the extreme proportions of the population. To accomplish 98% accommodation, it is also important to define the multivariate mean as well. PCA used in combination with feature envelopes can translate the anthropometry results into effective design tools. These techniques have been successfully implemented for many workstation and crewstation design applications and, with updated firefighter anthropometry, can overcome the problems current firefighter apparatus manufacturers are experiencing using "percentiles."

3.2 Feature Envelopes

Feature envelopes are a second means of representing the complex variability within a population in an easily discernable manner. Feature envelopes have been used in a number of applications, reducing concentrations of coordinate data to a simple model of mean location and ellipsoidal axes dimensions. Feature envelopes were used to describe the variation in facial landmark distribution with reference to a military helmet system as shown in Figure 4. Feature envelopes have also been used to describe variability of agricultural workers in a tractor cab.

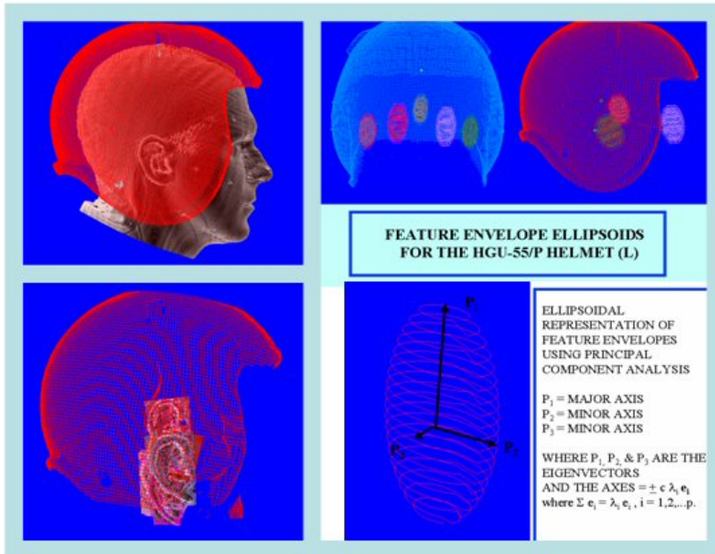

Figure 4. This figure illustrates the use of feature envelopes to define simple ellipsoids representing variability in a population of thousands.

3.3 Geometric Fit

Geometric fit, afforded by 3D scanning and advanced image processing, can illuminate an interface problem beyond what is capable with subjective evaluations. The example shown in Figure 5 reveals that capturing the interface geometry can be quite useful for visualizing and quantifying fit. The subject is scanned with the mask (unencumbered) as shown in the upper right panel of the figure. The subject is fit with the mask and scanned as shown in the lower left panel. (A photograph documents the subject wearing the mask as shown in the upper left panel). The two scans, unencumbered and with the mask, are aligned using surfaces common to both. This provides an “x-ray” vision into the fit of the mask, allowing visualization of fit. Additionally, quantification of fit can be extracted from the aligned scans such as the distance from pronasale (tip of the nose) to the mask’s surface. Geometric fit can be useful for individual fit issues or identified for a population and reduced to manageable specifications and design tools.

Figure 5. Shown in this figure is a subject scanned with and without his mask. The two scans are merged to provide an 'x-ray' image of the geometric fit.

4. 3D Anthropometry Proven Useful for Workstation and Protective Equipment Design

Three-dimensional anthropometry surmounts several problems inherent with the use of traditional anthropometry. Scanning is rapid and accurate, and potentially more consistent than measurements made by different measurers (i.e., traditional anthropometry). Additionally, surface data provides shape information as well as the location of an infinite number of linear measurements relative to each other.

The application of 3D anthropometry for equipment and workstation design involves three-dimensional surface scanning, thoughtful measurement extraction, and appropriate statistical analyses. NIOSH conducted a number of successful 3D anthropometric studies that directly impact product safety. NIOSH recently completed a 3D anthropometric study of agricultural workers to enhance tractor safety and performance. Improved human-tractor-interface designs can enhance operator productivity, comfort, and safety. This study investigated farm-worker anthropometry and determined the critical anthropometric measures and 3D feature envelopes of body landmarks for the design of tractor operator enclosures. One hundred agricultural workers were scanned using 3D laser measurements; key parameters extracted from 3D data were established; and principal component analysis (PCA) was used to identify 15 representative body models for digitally assessing tractor-cab accommodation. Additionally, feature envelopes or a set of centroid coordinates of thirty-four 3D anatomical landmarks and the 95% confidence semiaxis-length for each cluster of landmark locations, were produced to guide tractor designers in their placement of tractor control components to accommodate the user population. PCA and feature envelopes ensure valid accommodation rates, identify true "worst case" sizes and shapes, and provide proportionally realistic design values.

NIOSH is also improving fall protection harness fit through 3D anthropometry. Successive and increasingly revealing studies assessing the fit of the fall protection harness for male and female construction workers have resulted in improved specifications for new harness designs. Current harness systems are not accommodating today's diverse construction workforce, particularly lacking in sizes that fit women. Three-dimensional scans, traditional anthropometry, innovative 3D fit criteria, and carefully extracted measurements were obtained for 216 subjects (108 women, 108 men). The human-harness interfaces, both static and suspended, were captured digitally using the Cyberware WB4. It was shown that traditional anthropometry failed to adequately predict fit or performance. However, a combination of weight, height, gender and three-dimensional "bounding box" dimensions yielded a logistic regression model that correctly classified more than 96% of participants to their best fit size in validation tests. Additionally, thigh strap angle and back D-ring location, both 3D fit criteria, were found to be correlated to post-fall human-harness dynamic fit. This study resulted in a revised sizing system designed to accommodate the current construction work population.

5. Study Justification

5.1 Firefighter Equipment Integration and Sizing Issues

Beyond seatbelt safety, firefighters work in varied and dangerous environments and face unique health hazards that increase their risk for line-of-duty injury and death. The firefighter is exposed to high noise levels, changing thermal conditions, and hazardous breathing atmospheres. Many of today's protective equipment such as helmet systems worn by fire fighters have been developed using the same flawed design practices and traditional anthropometry as previously described which reveal no information regarding shape and fit. As a result, these systems do not adequately fit the target population nor do they integrate well with other equipment items. To further complicate helmet fit, as with the military, the firefighting profession is being joined by more women and minorities who represent very different sizes and shapes of the head and body. The firefighter, whose protective equipment on the head can include a self-contained breathing apparatus (SCBA), eye protection, protective Nomex hood, and communication devices as well as an impact-protection helmet, is burdened with a large profile, heavy system that must be donned in layers, and removed in part to represent different functionality. A survey conducted by the Women in the Fire Service, Inc. found 31% of the women indicated that the SCBA bottle routinely knocked their helmet forward or off. Others noted the SCBA facepiece/helmet interference. Additionally, the bunker coats and pants do not fit the female shape. In general, they found that the helmets, boots, gloves, and SCBA facepieces are too large and inappropriately proportioned. Poorly-fitting protective equipment can actually impose limitations on efficiency and performance, and ultimately, can affect safety.

5.2 Need for Large Scale Firefighter 3D Anthropometric and Human Factors Survey

A large number of anthropometric studies using traditional measurement methods have been conducted since the 1950s and 60s, mostly in the USA but also in Europe and elsewhere. HSIAC, at Wright-Patterson Air Force Base (Dayton, Ohio) is the repository for the data from these surveys consisting of over fifty US and international anthropometric surveys on both military and civilian populations. These surveys represent more than fifty years of research and account for hundreds of measurements on thousands of individuals. The database covers a wide range of anthropometric surveys, including for example, the 1990 male flyers survey for the USAF, the 1968 survey of USAF women, 1988 US Army female personnel, 1968 study of the German Air

Force and the 1971 survey of the Royal Australian Air Force. To add to this wealth of human body data, the advent of whole body surface scanning and successful application of 3D anthropometry for equipment design has now led to 3D anthropometric surveys. Recently, a consortium of industry and government, with mostly US representation, supported an anthropometric survey of 2300 civilians from North America, and additional subjects from Italy and the Netherlands. Known as the CAESAR (Civilian American and European Surface Anthropometry Resource) project, this survey is meant to serve as a source of anthropometry data for not only the government, but also the automotive and garment industries. Unfortunately, the occupation "firefighter" was not an option for the participants. The survey does provide a reference to which the current firefighter survey may be compared. Additionally, methods developed during the CAESAR and NIOSH surveys were applied for the current study of firefighters, and will be implemented in the larger nationwide survey of firefighters.

What is known about the current firefighter demographic makeup can be derived from the US Census Bureau. A 2000 survey of 242,395 US firefighters reported that 79.6% are Caucasian males; 7.7% Black males; 5.9% Hispanic males; 0.6% Asian males; and 2.6% Other, for a total of 96.4% of the firefighters are reported male. The female firefighter population comprises 3.6% of the total sampled US firefighter population of which 2.8% are Caucasian; 0.4% Black; 0.2% Hispanic; no Asian; and 0.2% Other. These demographics make up a unique population, certainly not representative of, for instance, total protective service populations as shown in Figure 6. A current anthropometric survey of today's US firefighters coupled with appropriate statistical analysis and fit testing can improve the efficacy and safety of fire fighter protective equipment.

DEMOGRAPHIC	ALL PROTECTIVE SERVICE	FIREFIGHTERS
Women	20.7%	3.6%
Black	18.7%	8.2%
Asian	1.5%	0.4%
Hispanic	10.1%	6.2%

Figure 6. The unique demographics for firefighters are shown in this figure.

6. The Study

6.1 Overview

The pilot study has been completed and 122 firefighters were measured, using traditional methods and 3D surface scanning, with and without their protective gear while in both standing and seated positions. Firefighters were carefully selected based on pre-determined demographics, and recruited only if they fulfilled a cell within the sampling strategy.

A number of activities occurred simultaneously and interactively during the planning stages of the study. A sampling strategy (Section 6.2) was created to acquire a full range of anthropometric variability while measuring a small number of firefighters. The Cyberware whole body scanner, while owned by the USAF, was accessible through a Cooperative Research and Development Agreement (CRADA) offered by the local contractor, General Dynamics. An agreement was

reached whereby personnel from General Dynamics would assist in data collection at a fixed fee per subject. A protocol was developed, describing in detail, the testing protocol for review by the USAF Internal Review Board (IRB) and Surgeon General's office. The protocol included Informed Consent document, study questionnaires, survey documents, and subject recruitment materials. The protocol is found in Appendix A. Human Use Training was completed by the Prime contractor to ensure protection of human research subjects and a letter of assurance was completed to be reviewed by the Surgeon General's office prior to data collection. Multiple anthropometric training sessions were conducted to clearly define anatomical landmarks used and measurements collected, and to ensure reliability in the data collection. The whole body scanning system was evaluated using the GEOmetric MANikin (GEOMAN), a manikin of known geometric shapes used to determine accuracy and coverage of the scanner. Two fire engine seats were acquired for the study and a seat support frame was constructed to (1) place the fire engine seat at a 12" height and to (2) place the seat in a consistent position with respect to the scanning volume. The second seat was constructed with a seat belt used to evaluate the subject's ability to buckle his/her seatbelt.

Recruitment efforts were extensive. Presentations were made at multiple fire stations, conferences for the Fire Alliance, and classrooms at the local training centers. Announcements for the study were made via radio and TV. Study advertisements were developed as flyers, FAX forms, and web sites. Widespread email announcements reached firefighters throughout the country, many of whom responded with email or phone calls expressing their interest. Initially, the response was overwhelming. Hundreds of firefighters responded, but most were not geographically appropriate for the study as the cost of travel was prohibitive. However, their demographic information was recorded in spreadsheet form to aid in understanding the current makeup of the US firefighter population. Screening and scheduling subjects were handled through email or phone calls. Once the subject was deemed appropriate for the study and scheduled, they were sent instructions on how to prepare for the study and a map of the facility at Wright-Patterson AFB. The subject was called the day before the appointment as a reminder and confirmation of their participation. Unfortunately, many scheduled subjects failed to show up for the appointment. Some has reasons while others simply did not respond to subsequent emails or phone calls. This lack of follow-through extended the data collection phase considerably. Furthermore, once the White male population had been captured, it became increasingly difficult to identify and recruit minority male and female firefighters. To facilitate data collection, eight minority male firefighters were transported from New York to Ohio via bus to participate in the study. Fortunately, the whole body scanner was moved to Randolph Air Force Base in San Antonio, Texas for a USAF anthropometry study of pilots. With tremendous support from the San Antonio firefighters, twenty-three firefighters were measured at Randolph AFB and included minorities and female firefighters. All but 3 firefighters were paid $40 for their time.

6.2 Sampling Strategy

The sampling strategy is comprised of one or more sample selection matrices used to determine who and how many volunteers will be selected for the study. As this is an anthropometric study, it is important to ensure that the full range of anthropometric variability observed in the firefighter population is represented in the study sample. Without doing so, a random sample of firefighters might represent only a segment of the range of variability. Any conclusions of the study would then be relevant to only that segment of the population. Height and weight are frequently used to represent anthropometric variability and are commonly known to a potential subject. For recruiting purposes, volunteers were selected based on height and weight.

There exists very little information on the height and weight of the current firefighter population. Extensive Internet searches and inquiries with several firefighter organizations did not result in sufficient information. While NHANES III (USDHHS, 1996) does contain data on subjects in the protective services, there are only 12 subjects in the firefighter occupational category, insufficient information for developing a sampling plan. Additionally, the CAESAR (reference) database does not contain data on firefighters either. However, there is evidence that male firefighters are on the average 15 pounds heavier than males in all other occupations (Hongwei, et al. (2002)). This same paper also found that female firefighters are on the average 22 pounds heavier than females in all other occupations.

The only raw data on firefighter anthropometry was the sample pool of firefighters who were calling to express their interest in participating in the study. Race, gender, age, height, and weight were recorded for the majority of the volunteers. The sample of 248 firefighters are shown in Table 1. As shown in the table, most of the volunteers were white males. However, there were 164 volunteers in the sample pool for which race, gender, height and weight were not recorded. Often, selection matrices are generated for each gender and race category to be represented in a sample. Given the gender and race frequencies in Table 1, drawing a large response from nonwhite male volunteers or female volunteers regardless of race for this study would be difficult. As such, it is pointless to develop selection matrices for each gender and race category, but instead generate one selection matrix for white males and one for all females.

Table 1. Bivariate Frequency of Gender and Race for Study Volunteers.

			Race			
Gender	Unknown	Asian	Black	Hispanic	White	Total
Unknown	164	0	0	0	0	164
Female	3	0	0	0	23	26
Male	8	1	1	3	145	158
Total	175	1	1	3	168	348

Height and weight data from the volunteers were adjusted with modifications based on the U.S. population adjusted by the information from the Hongwei, et.al. paper. Construction of the matrices considered five items:

1) The height and weight distribution for the volunteer sample; 2) The height and weight distribution for the entire NHANES III adult sample to ensure that the sample would represent the full range of variability in height and weight expected in the firefighter population; 3) The information provided in the Hongwei, et.al. 2002 research paper; 4) The total target sample size of approximately 120 subjects; and 5) The projected ability to select subjects in particular height and weight ranges.

Height and Height and Weight Distributions

Figure 7 contains a height by weight bivariate plot for the male volunteers. The point at which the short dashed lines intersect indicates the mean height and weight for the entire male volunteer sample. The point at which the long dashed lines intersect indicates the mean height and weight for the NHANES III sample of all adult males. The solid red lines indicate height and weight cell boundaries for **white male** subject selection. The cells are numbered to correspond with the

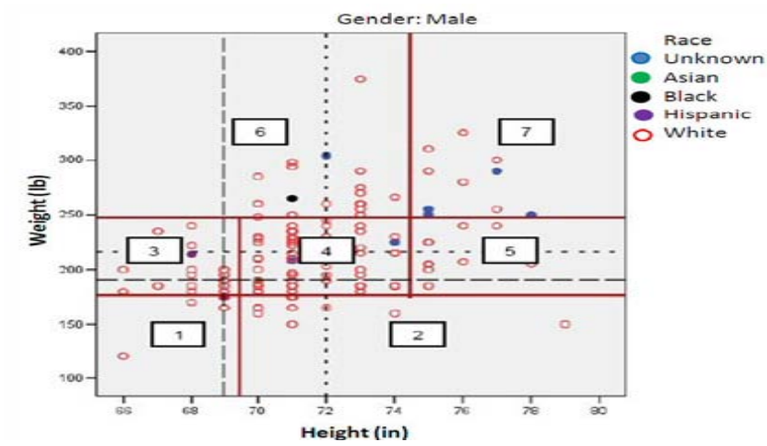

Figure 7. Bivariate Frequency of Gender and Race for Male Study Volunteers.

Figure 8 contains a height by weight bivariate plot for the female volunteers. Again, the point at which the short dashed lines intersect indicates the mean height and weight for the entire female volunteer sample. The point at which the long dashed lines intersect indicates the mean height and weight for the NHANES III sample of all adult females. The solid red lines indicate height and weight cell boundaries for all female subject selection. The cells are numbered to correspond with the sample selection matrix for females.

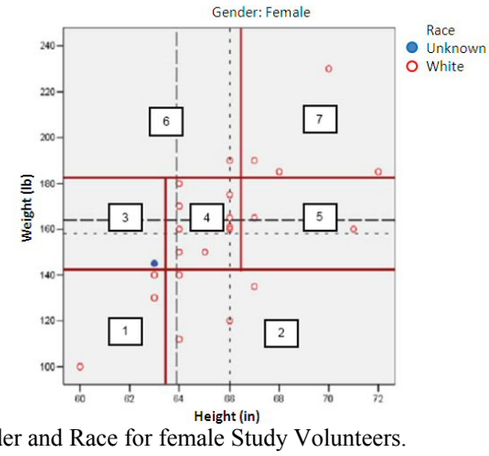

Figure 8. Bivariate Frequency of Gender and Race for female Study Volunteers.

Sample Selection Matrices

Males:

As previously mentioned, the selection matrix was provided for white males (see Table 2), demonstrating a target sample size for white males of 50 subjects.

Table 2. Selection Matrix for White Males (n = 50)

Cell	Height (inches)	Weight (lbs)	n
1	Any < 69.4	Any < 176.4	7
2	69.5 < any	Any < 176.4	7
3	any < 69.4	176 < any < 247.4	7
4	69.5 < any < 74.4	176 < any < 247.4	8
5	74.5 < any	176 < any < 247.4	7
6	any < 74.4	247.5 < any	7
7	74.5 < any	247.5 < any	7

For determining where a white male fits into the matrix, the subject was queried about his height and weight during the recruiting process. If he stated that he is, for example, 5 feet 9.5 inches tall and less than 247 pounds, then he should was further questioned about whether he is exactly 9.5 inches tall, slightly more than 9.5 inches tall, or slightly less than 9.5 inches tall. If he is either exactly 9.5 inches or slightly more, then he will fall within cells 2 or 4. However, if he is slightly less than 9.5 inches tall, then he will be within either cell 1 or 3. In this same manner, anyone who stated than he is about 176 or 247 pounds was questioned further to determine into which cell he should be placed. Based on the current information reflected in Table 2, all non-white males that volunteered were selected regardless of height and weight with a goal of reaching 35 non-white male subjects.

Females:
Table 3 contains the selection matrix for all females. The target sample size for females is 35 to 37 subjects. Based on the information shown in Figure 9, there may not be enough subjects available to fill two of the cells (3 and 6). We need to get at least four subjects in each of those cells in order to conduct statistical analyses with their data, but no more than five are required.

Table 3. Selection Matrix for Females (n = 35 to 37)

Cell	Height (inches)	Weight (lbs)	n
1	Any < 63.4	Any < 142.4	5
2	63.5 < any	Any < 142.4	5
3	any < 63.4	142.5 < any < 182.4	4-5
4	69.5 < any < 66.4	142.5 < any < 182.4	7
5	66.5 < any	142.5 < any < 182.4	5
6	any < 66.4	182.5 < any	4-5
7	66.5 < any	182.5 < any	5

6.3 Recruiting Subjects
Preliminary recruitment efforts were met with an unprecedented response in anthropometric population studies. All of the local fire stations contacted expressed an interest in the study. Mike Wilbur, in a speaking engagement with two different Ohio fire departments, received over 100 volunteers who submitted their names, phone numbers, email addresses and expressed their interest in participating in the study. Deputy Chief Billy Goldfeder of the Loveland-Symmes Fire Department in Ohio sent an email announcement on behalf of the study to recipients of a well established firefighter network and over 200 emails were received in only 2 days. Many of the emails were logged in a spreadsheet to record whatever demographics were provided as well as contact information. Many of these would-be subjects were not in a geographically desirable location, but the demographic information was useful for creating the sampling strategy. A total of 122 firefighters (85 male and 37 female) have been measured, using traditional methods and 3D surface scanning, with and without their protective gear while in both a standing and seated position. Firefighters were carefully selected based on pre-determined demographics, and recruited only if they fulfilled a cell within the sampling strategy. The cells for the white male subjects were the first to fill in. However, identifying, recruiting, and scheduling minority firefighters from southwest Ohio proved to be a difficult task. As a result, 8 male minority firefighters were transported from New York to Ohio via bus to participate in the study. Additionally, the Cyberware WB4 whole body scanner was moved to Texas for Air Force pilot testing. A number of minority male and female firefighters were measured in Texas. No subjects withdrew from the study and none complained of adverse affects from the study.

Study participants were both career and volunteer firefighters, mostly recruited from stations in cities and villages within a 100 mile radius of the Wright-Patterson area. A few subjects,

however, traveled from out of state to participate in the study. Subjects were recruited through information provided in the form of flyers posted at fire stations, invited presentations made at fire stations and local conferences, web site notices, and newspaper advertisements. Presentations and announcements followed the published FDA guidance on subject recruiting. Examples of the advertisements are shown in Figure 9. This study required 120 subjects, the selection of which was based on demographics determined by the stratified sampling plan. This distribution of subjects was meant to allow for sufficient variability within each of the largest categories (White Male and Black Male) while also obtaining a general idea of the anthropometric variability within the smaller groups.

Figure 10. Information used to recruit potential firefighter anthropometry subjects.

Figure 9. Flyer and web page used to recruit potential firefighter subjects.

Selection of the subjects was coordinated through the station's fire chief to assist in predetermining demographics of potential participants. Subjects were excluded only as the cells representing their demographics were filled. Additionally, women who are pregnant and therefore, not actively firefighting, and subjects under 18 years of age were excluded. Each potential subject was interviewed by phone using the information as described in Figure 10. The individual was informed that their 3D image, a recognizable photographic representation of themselves, will be most definitely be made available to the public for unrestricted use.

We need your help in an effort to provide better protection for firefighters. The National Fallen Firefighters Foundation (NFFF), the International Association of Firefighters (IAFF), the National Fire Protection Association (NFPA), and the Fire Apparatus Manufacturers Association (FAMA) have jointly determined that fire engine seats and seatbelt systems are not designed to fit many firefighters. Injuries and even fatalities have occurred as a result of poorly-fitting seats/seatbelts systems. Further investigation revealed that firefighters have never been measured as a population. This landmark effort is the first anthropometric (body size) study of firefighters ever conducted! Through your willingness to volunteer for body measurements and whole body 3D scanning, you are helping to provide new guidelines to improve the fit and performance of all safety equipment for firefighters. With your help, we can reduce future line of duty deaths due to poorly fitting fire apparatus seat/seatbelt systems.

Please understand that this study will involve taking standard body measurements (height, waist circumference, etc.) and digital photographs while the participant is wearing close fitting "biker" shorts and sports bra, where applicable. We will also collect a 3D color full-body image of you. Please know that you will be recognizable from this 3D scanned image. The scan data, your age, race, and gender may become part of a national database that will become public domain for restricted/unlimited use. Your name will not be released with this information. No personal information will be released. As a participant you may elect to not have your digital photographs included with your study information. If, after reading this, you have decided not to participate, that's not a problem as this is a volunteer effort.

The study takes place at Wright-Patterson Air Force Base using their state-of-the-art imaging equipment. You would need to travel to Wright-Patterson and bring with you your turnout gear including your helmet, boots, and anything you normally wear in your pockets (ropes, etc.). Also, wear your uniform or clothing that you would normally wear under your protective gear. You do not need to bring your SCBA. If you choose to participate, we would need to schedule you for an appointment. We are scheduling Monday through Friday from 8 to 4. (We will schedule a few Saturdays and evenings if necessary to accommodate those unable to make the regularly scheduled times.) Please call David Devilbiss at (937) 855-6107 or email David at david@totalcontact.com for an appointment. Thank you for your willingness to help us with this effort. Firefighters are in need of protection designed for their body size and certainly, this is a study whose time has come.

Specifically, their scanned image, age, race, and gender will become public domain. No other identifiable information will be released (e.g., date of birth). An additional option, if they grant permission to the researchers, is that their digital photographs could be made available for publication purposes. If the subject was comfortable with these terms, even if they decline release of their digital photos, and if their demographics meet the current requirements of the study, they were scheduled for testing. Their name was recorded on the Subject Inquiry form and used for scheduling purposes only. The Subject Inquiry forms were shredded at the conclusion of the study and the subject's name was not recorded on any other document (with the exception of the consent form). During the phone interview, they were instructed to bring their turnout gear, including helmet, boots, and any tools that they typically carry, to the study session. Total Contact worked closely with General Dynamics' personnel to schedule subject measurement sessions. The subjects were called and/or emailed the day before their scheduled appointment as a reminder. Even with the reminder, however, approximately 1 in 3 subjects failed to show up. Some rescheduled while others did not return the calls. Subjects were $20 per hour with a maximum compensation of $40 for a 1-2 hour measurement session. Most subjects received $40. If subjects were active duty, they required approval from their commander for off-duty employment. Active duty subjects were also paid $20 per hour with a maximum compensation of $40 for a 1-2 hour session. Subjects were paid by Total Contact.

6.4 Data Collection

Subject throughput is important for minimizing required subject time and maximizing data collection effort given a 3-person investigator team. The timeline of the firefighter's activities as a

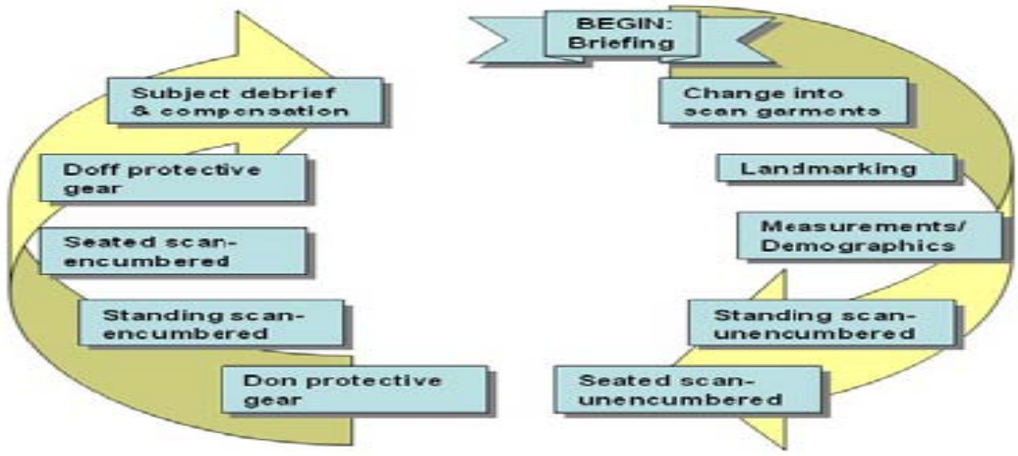

Figure 12 demonstrates the subject working through the various steps of the measurement session. The subject was first briefed on the study including the purpose and what to expect throughout the duration of the measurement session. Each participant had the opportunity to ask questions before signing an informed consent and completing the questionnaire. Examples of the consent form and questionnaire are shown below.

Figure 12. This photographs show the series of events required for the subject to participate in the study. The subject would provide consent, change into measurement shorts, stand and sit for traditionally acquired anthropometric measurements, and don their bunker gear for additional encumbered measurements.

Firefighter Study Participant Questionnaire

Subject No:_____ M F Age:_____

Race: non-Hispanic White non-Hispanic Black Hispanic Other specify:_____

1. State the manufacturer of your protective coat and pants _____
2. Describe what you are wearing under your protective gear_____

2. Have you ever had difficulty finding the seatbelt in the fire apparatus? Y ☐ N ☐
3. Have you ever had difficulty fastening the seatbelt of the fire apparatus? Y ☐ N ☐
If yes, was the problem due to insufficient seatbelt length? Y N ☐
4. Please check the items you are wearing with your protective gear. Check the second box if you experience fit issues with these items.

Wearing the item?		Fit problems with the item?
Helmet		_____
Flame Retardant Hood		_____
Face Mask	☐	_____
Protective Jacket		_____
Protective Pants		_____
Boots	☐	_____
Gloves		_____
SCBA		_____
Radio	☐	_____
PASS		_____
Door Chock (s)	☐	_____
Rope (s)	☐	_____
Rescue Knife		_____
Webbing/Carabiners	☐	_____

Other items included with gear_____

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Informed Consent Document For Anthropometric Survey of Firefighters to Improve Seatbelt Safety

AFRL/HEPA, Wright-Patterson Air Force Base, Ohio

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1. Nature and purpose: You have been offered the opportunity to participate in the "Anthropometric Survey of Firefighters to Improve Seatbelt Safety" research study. Your participation will occur at the Computerized Anthropometric Research and Design (CARD) Laboratory located at Wright-Patterson AFB. The purpose of this research is to determine body size dimensions of firefighters in order to derive design tools for improving fit and performance of safety equipment such as seatbelts. In fact, injuries and fatalities have been related to poorly fitting seatbelts. This study will assist fire engine seat/seatbelt designers to safely protect firefighters while wearing their turnout gear.

The time requirement for each volunteer subject is anticipated to be a total of 1 visit of approximately one hour. A total of approximately 120 subjects will be enrolled in this study.

2. Experimental procedures: If you decide to participate, you will be asked to complete a questionnaire containing general questions (sex, age, etc.) as well as questions about your experience with fire engine seat and seatbelt fit. You will then be escorted to a dressing room to change into bike shorts (with a sports bra for women) to be worn during the measurement session. An investigator who is the same sex as you will locate some skeletal landmarks on your skin, by gently feeling for some bone and joints. An example of such a landmark is the tip of your shoulder. These landmarks will be lightly marked with a grease pencil and then covered with a small adhesive sticker, both of which will be removed when the measurement session is completed. You will be measured for 15 body dimensions, such as height and waist circumference, using anthropometric tools such as a tape measure. You will then be measured using a three-dimensional whole body surface scanning system. This is a simple process during which you will stand still for 15 seconds on a platform as multiple cameras record your body's surface contours. You will then be asked to assume a seated position and the scanner will record this position. Following this portion of the measurement session, you will change back into your street clothes and then don your turnout gear. This includes whatever you normally wear when called to a fire. You will be scanned in the same standing and seated positions while wearing your gear. You will be asked to sit in a fire engine seat mockup and asked to find and buckle the seatbelt. This process will be recorded using digital photography. You will then doff your turnout gear and be escorted to the visitor center.

3. Discomfort and risks: During this study the risk of injury is very low. You will not be performing any strenuous physical tasks. The three-dimensional surface scanner does not pose any known risk. The light source is a Class 1 laser which is FDA approved for unsupervised public use. Thousands of subjects have been scanned using this system with no adverse affects. Some subjects have experienced slight skin irritation from the adhesive markers. You are encouraged to ask for rest breaks or water if needed.

4. Precautions for female subjects: There are no precautions for female subjects.

5. Benefits: You are not expected to benefit directly from participation in this research study. However, you are helping to improve the safety of future firefighter protective equipment such as fire engine seatbelt fit and function.

6. You will be compensated $20 per hour for your participation for up to 2 hours for a maximum of $40.

8. Alternatives: Choosing not to participate is an alternative to volunteering for this study.

8. **Entitlements and confidentiality:**

Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations. Your personal information will be stored in a locked cabinet in an office that is locked when not occupied. Electronic files containing your personal information will be password protected and stored safely on a computer. Initially, it is intended that the only people having access to your information will be the researchers named above and the AFRL Wright Site IRB or any other IRB involved in the review and approval of this protocol. However, you should know that you will be recognizable from the 3D scanned image. Starting next year, your scan data, age, race, and gender will become part of a national database that will become public domain for unrestricted/unlimited use. Your name will not, nor will any other identifiable information, be released with this information. Complete confidentiality for military personnel cannot be promised because information bearing on your health may be required to be reported to appropriate medical or command authorities.

Your entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if you desire further information you may contact the base legal office (88 ABW/JA, 257-6142 for Wright-Patterson AFB). In the event of a research related injury, you may contact the medical monitor, Major Eric Hermes, of this research study at (937) 2555365.

If an unanticipated event (medical misadventure) occurs during your participation in this study, you will be informed. If you are not competent at the time to understand the nature of the event, such information will be brought to the attention of your next of kin.

Next of kin or designated health care agent (if needed):

Name Phone#_____

The decision to participate in this research is completely voluntary on your part. No one may coerce or intimidate you into participating in this program. You are participating because you want to. Jennifer Whitestone, Principal Investigator, or an associate, has adequately answered any and all questions you have about this study, your participation, and the procedures involved. Jennifer Whitestone can be reached at (937) 855-6107. Jennifer Whitestone, or an associate, will be available to answer any questions concerning procedures throughout this study. If significant new findings develop during the course of this research, which may relate to your decision to continue participation, you will be informed. You may withdraw this consent at any time and discontinue further participation in this study without prejudice to your entitlements. The investigator or medical monitor of this study may terminate your participation in this study if she or he feels this to be in your best interest. If you have any questions or concerns about your participation in this study or your rights as a research subject, please contact Major Jeff Bidinger at (937) 656-5449 or jeffrey.bidinger@wpafb.af.mil.

Your participation in this study may be photographed, filmed or audio/videotaped. You consent to the use of these media for training and data collection purposes. Any release of records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 55 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to unauthorized source without your permission. These recordings will be used for presentation or publication. They will be stored in a locked cabinet in a room that is locked when not occupied. Only the investigators of this study will have access to these media.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer Signature_____**Date**_____

Volunteer Name (printed)_____

Volunteer Social Security No. (Optional)_____

Advising Investigator Signature _____ **Date** _____

Investigator Name (printed)_____

Witness Signature _____**Date** _____

Witness Name (printed)_____ We may wish to present some of the video/audio recordings from this study at scientific conventions or use photographs in journal publications. If you consent to the use of your image for publication or presentation in a scientific or academic setting, please sign below.

Volunteer Signature_____**Date**_____

Privacy Act Statement

Authority: We are requesting disclosure of personal information, to include your Social Security Number. Researchers are authorized to collect personal information (including social security numbers) on research subjects under The Privacy Act-5 USC 552a, 10 USC 55, 10 USC 8013, 32 CFR 219, 45 CFR Part 46, and EO 9397, November 1943. **Purpose**: It is possible that latent risks or injuries inherent in this experiment will not be discovered until some time in the future. The purpose of collecting this information is to aid researchers in locating you at a future date if further disclosures are appropriate. **Routine Uses**: Information (including name and SSN) may be furnished to Federal, State and local agencies for any uses published by the Air Force in the Federal Register, 52 FR 16431, to include, furtherance of the research involved with this study and to provide medical care. **Disclosure**: Disclosure of the requested information is voluntary. No adverse action whatsoever will be taken against you, and no privilege will be denied you based on the fact you do not disclose this information. However, your participation in this study may be impacted by a refusal to provide this information.

The subject would then move to the dressing room to change into grey biker shorts (and sports bra for female subjects). A form-fitted cap was fit to their head to compress the hair for 3D scanning. The investigator would palpate the subject's skin to identify the locations of bony prominences and joints. Grease pencil marks were placed on these locations for measurement reference purposes. The investigators would then measure and record the traditional dimensions; one measuring and another recording. Each of the measurements had been determined to have either relevance to the seat system fit or to gather data in support of the projected large firefighter anthropometric survey. The data collection form is shown in Figure
13. Descriptions of the measurements are found in Appendix B. The landmark definitions are found in Appendix C.

After the subject was measured to record traditional dimensions, the subject's landmark locations previously indicated by pencil marks, were then covered with a 1 cm sticky marker that is easily identified from the scan image. The subject moved to the scanning platform and was asked to place their heels against the foot rests while standing in the scanning volume space. The sway stick, a vertical head rest that gently rests on the subject's head, is used to make contact with the subject to minimize swaying during the 15 second scan as shown in Figure 14. The subject was asked to extend their arms at a 30 degree abduction angle prior to scanning, and rest their hands on the vertical hand supports fabricated for the study. The level hand supports were design with a measurement feature such that the height of the support could be recorded for the subject. In this way, when the subject returned for the encumbered scan, the arms could be place in the same orientation. For the duration of the 15 second scan, the subject was asked to hold their breath to minimize torso movement during respiration. A quick view of the image by the investigator confirmed that the data meet quality control standards. If, at any time during the scanning process, the image did not meet QC, the subject was asked to repeat the scan. The subject then stepped off of the platform while the chair, a modified fire engine seat, was placed in the middle of the scanning volume. The subject was then asked to sit comfortably, but with their back touching the back of the chair. The subject was asked to abduct their arms at a 30 degree angle from the torso, again using the vertical hand supports, and to hold this position while the scan takes place. Again, the quality of the image was verified before proceeding to the next step.

Figure 14. The subject is scanned in the standing and seated positions. The feet are placed in the heel rests and the arms are abducted at a comfortable 30 degree angle using the vertical hand supports. A sway stick is used to support the subject during the standing scan to prevent movement during the 15 second scan.

Anthropometric Survey of Firefighters to Improve Seatbelt Safety ANTHROPOMETRY Subject No._____ Measurer_____ Recorder _____ Date:_____

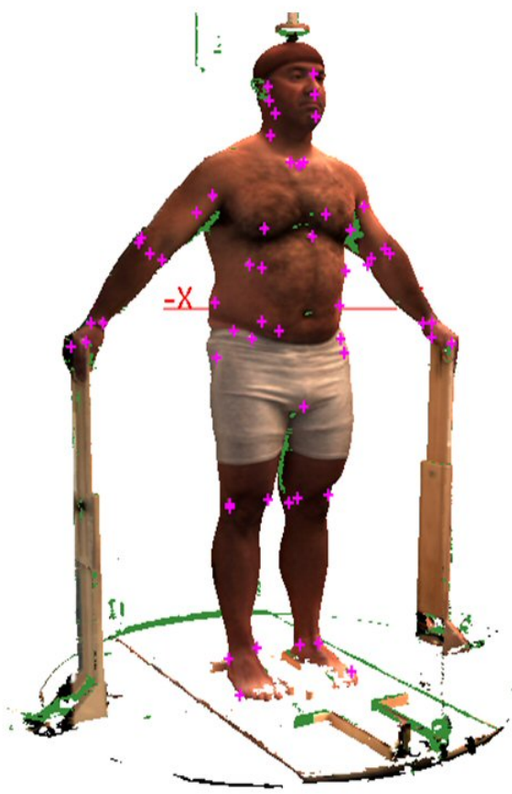
Weight	_____
Stature	_____
Chest Circumference	_____
Waist Circumference, Preferred	_____
Waist Height at Preferred Waist	_____
Biacromial Breadth	_____
Chest Breadth	_____
Waist Breadth	_____
Chest Depth	_____
Waist Depth	_____
Sitting Height	_____
Sitting Height, with Helmet	_____
Midshoulder Height, Sitting	_____
Knee Height, Sitting	_____
Hip Breadth, Sitting	_____
Abdominal Extension Depth, Sitting	_____
Buttock-Knee Length	_____
Encumbered Weight	_____

Seatbelt Fit? Yes No Missed Distance_____

The anatomical landmarks, indicated in the scan data by the presence of the white sticky labels, are located using Integrate, the coordinates of which are saved in a separate text file. Each of the A and B pose scans were evaluated for landmark located and a landmark file saved. An example is shown in Figure . Using the landmark locations, it is possible to extract additional measurements not recorded during the traditional measurement session. Examples of such measurements are shown in Table below; including the mean, standard deviation, minimum, and maximum.

landmark based measurements	mean	std dev	min	max
bi-tragion	5.82	0.55	5.14	9.22
bi-gonion	5.06	0.63	3.81	6.62
suprasternale to substernale	8.53	0.85	6.25	10.12
bi-thelion	9.29	1.89	6.50	19.50
bi-10th rib	9.61	1.75	7.00	14.70
bi-asis	10.13	1.35	7.95	14.31
bi-iliocristale	13.36	2.36	9.04	19.23
bi-trochanterion	14.61	1.80	9.22	18.86
bi-axilla	16.23	2.10	4.17	20.57
cervicale ht	58.83	4.11	38.43	66.14
rt 10th rib ht	44.72	2.70	38.27	51.57
rt thelion ht	49.57	3.06	38.43	56.38
rt asis ht	38.29	2.09	33.54	42.52
rt iliocristale ht	41.58	2.38	35.51	47.48
rt trochanterion ht	35.76	2.05	31.65	41.18
waist preferred, post ht	40.61	2.56	35.67	47.32
rt radiale to ulnar styloid	10.36	3.11	8.05	29.98
crotch ht	31.16	1.99	26.61	35.20
knee ht	19.06	1.32	15.91	21.97

The subject was then asked to don their protective gear including helmet. They first changed into their street clothes or uniform to obtain a photographic record of what they were wearing under their gear. A second photograph recording their turnout gear and subject number was taken. They resumed the same standing position on the platform including an abduction of the arms. They were scanned and the image evaluated. The subject then stepped down from the scanning platform and the chair was placed on the platform. The subject resumed the seated position to the best of their ability given the possible helmet and protective equipment interference with the seat. The subject was scanned in this position. The subject was then asked to sit in the second fire engine seat and attempt to fasten the seat belt. They were then asked to doff their gear, were debriefed, compensated, and escorted to security for dismissal.



ACTIVE OBJECT AUXILIARY LANDMARKS

Z 1	Sellion	79.9	606.0	92.6
Z 5	Rt. Tragion	-32.7	578.0	59.6
Z 6	Rt. Gonion	-13.3	508.0	62.6
Z 7	Lt. Tragion	87.5	578.0	-20.0
Z 8	Lt. Gonion	90.1	514.0	-5.6
Z 9	Nuchale	-29.8	570.0	-66.6
Z10	Rt. Clavicale	22.9	384.0	48.2
Z11	Suprasternale	46.7	376.0	38.5
Z12	Lt. Clavicale	57.4	388.0	21.5
Z13	Rt. Thelion/Bustpoint	-39.5	204.0	141.5
Z14	Lt. Thelion/Bustpoint	177.4	208.0	21.2
Z15	Substernale	76.6	188.0	92.2
Z16	Rt. 10th Rib	-76.8	114.0	118.6
Z17	Rt. ASIS	-71.9	-76.0	111.6
Z18	Lt. 10th Rib	168.3	102.0	-21.2
Z19	Lt. ASIS	154.1	-78.0	-9.8
Z20	Rt. Iliocristale	-165.4	18.0	57.4
Z21	Rt. Trochanterion	-160.8	-126.0	73.1
Z22	Lt. Iliocristale	154.9	10.0	-113.1
Z23	Lt. Trochanterion	167.2	-120.0	-88.4
Z24	Cervicale	-28.7	474.0	-66.4
Z25	10th Rib Midspine	-50.3	114.0	-114.8
Z26	Rt. PSIS	-127.2	-58.0	-98.4
Z27	Lt. PSIS	-4.7	-62.0	-161.3
Z28	Waist, Preferred, Post.	-51.6	-32.0	-119.5
Z30	Rt. Axilla, Ant	-166.6	288.0	126.8
Z31	Rt. Radial Styloid	-416.9	-32.0	234.1
Z32	Rt. Axilla, Post.	-218.1	258.0	-1.9
Z33	Rt. Olecranon	-326.4	146.0	79.3
Z34	Rt. Humeral Lateral Epicn	-341.5	182.0	120.2
Z35	Rt. Humeral Medial Epicn	-296.1	126.0	88.5
Z36	Rt. Radiale	-349.0	168.0	125.7
Z37	Rt. Metacarpal Phal. II	-449.6	-78.0	280.6
Z39	Rt. Ulnar Styloid	-453.3	-34.0	190.8
Z40	Rt. Metacarpal-Phal. V	-497.8	-92.0	211.1
Z42	Lt. Axilla, Ant	220.1	286.0	-103.7
Z43	Lt. Radial Styloid	423.4	-40.0	-249.4
Z44	Lt. Axilla, Post.	122.9	272.0	-213.8
Z45	Lt. Olecranon	255.7	150.0	-252.5
Z46	Lt. Humeral Lateral Epicn	292.3	176.0	-243.7
Z47	Lt. Humeral Medial Epicn	241.5	130.0	-218.5
Z48	Lt. Radiale	305.0	162.0	-248.4
Z49	Lt. Metacarpal-Phal. II	478.3	-100.0	-237.7
Z51	Lt. Ulnar Styloid	404.4	-38.0	-297.4
Z52	Lt. Metacarpal-Phal. V	434.8	-84.0	-321.3
Z53	Rt. Knee Crease	-131.6	-532.0	-39.7

Figure 16. The subject changes from his measurement shorts into his street clothes or uniform prior to donning the protective gear. Photographs were taken to record what the subject was wearing under his bunker gear. The gear was then donned and a second photograph was captured.

Figure 17. The subject is scanned in the standing and seated positions while wearing their protective gear. The feet are placed in the heel rests and the arms are abducted at a comfortable 30 degree angle using the vertical hand supports in the same position used when scanned in shorts.

Figure 18. The subject is asked to buckle the seatbelt. Any difficulties when attempting to buckle the seatbelt were recorded on the data collection forms.

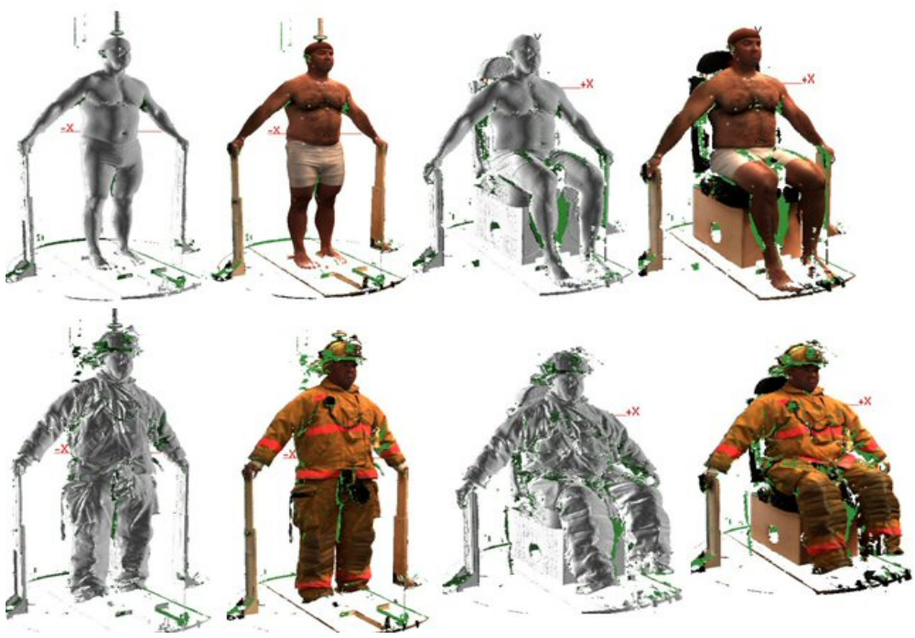


Figure 19. The four scans are shown above. The standing scans are visualized as contour data and surface data with color superimposed.

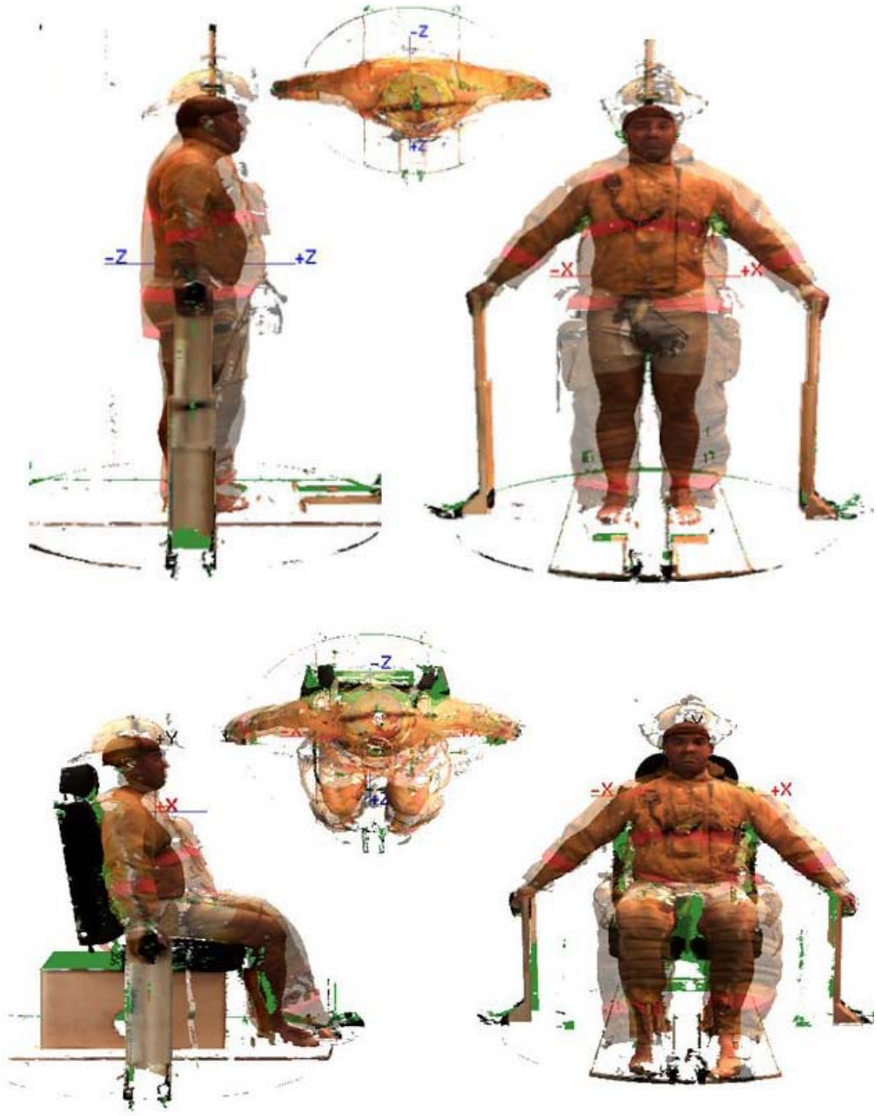


Figure 20. By superimposing the scans, it is possible to visualize and measure the additional bulk co
turnout gear.

6.5 Study Sample

As mentioned, the subjects were both career and volunteer, and primarily reside in southwest Ohio or San Antonio, Texas. A concerted effort was made to fill the cells required by the sampling strategy. If a potential subject's anthropometry indicated that they belonged in a cell already filled, they were not scheduled with a few exceptions. For instance, if they were bringing a subject needed to fill a cell, they were included in the study as well. Results of the sample are shown in Tables 5 through 7. Although all minority males were accepted regardless of height or weight, this small sample does exhibit much ht-wt variability as shown in Table 6.

Table 5. Matrix of White Male Subjects Measured (n=63)

Cell	Height (inches)	Weight (lbs)	n
1	Any < 69.4	Any < 176.4	8
2	69.5 < any	Any < 176.4	7
3	any < 69.4	176 < any < 247.4	10
4	69.5 < any < 74.4	176 < any < 247.4	15
5	74.5 < any	176 < any < 247.4	7
6	any < 74.4	247.5 < any	11
7	74.5 < any	247.5 < any	5

Table 6. Matrix of Minority Male Subjects Measured (n=22)

Cell	Height (inches)	Weight (lbs)	n
1	Any < 69.4	Any < 176.4	3
2	69.5 < any	Any < 176.4	1
3	any < 69.4	176 < any < 247.4	6
4	69.5 < any < 74.4	176 < any < 247.4	10
5	74.5 < any	176 < any < 247.4	0
6	any < 74.4	247.5 < any	2
7	74.5 < any	247.5 < any	0

Table 7 Matrix of Female Subjects Measured (n=37)

Cell	Height (inches)	Weight (lbs)	n
1	Any < 63.4	Any < 142.4	5
2	63.5 < any	Any < 142.4	11
3	any < 63.4	142.5 < any < 182.4	1
4	69.5 < any < 66.4	142.5 < any < 182.4	8
5	66.5 < any	142.5 < any < 182.4	5
6	any < 66.4	182.5 < any	1
7	66.5 < any	182.5 < any	6

Another way to view the firefighter sample is to create a bivariate plot of their height versus weight. Figures 21 and 22 show the white males and minority males as compared to the targeted cells. AS shown in these figures, the careful subject recruitment resulted in a wide distribution of height/weight ratios for both populations. Bivariate plots also allow easy identification of outliers and extreme individuals that may be candidates for seat/seatbelt design specifications. After all, accommodating the mean is rather easy. Accommodating the extremes is the difficult

design task.

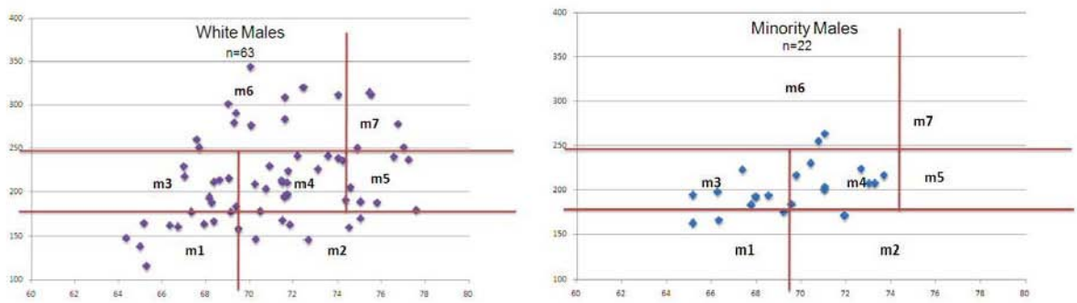


Figure 21. Height-weight bivariate plots of the white male and minority male populations projected onto the target cells.

Height and weight distributions for the female population (n=37) is shown in Figure 22. Again, a wide distribution of height and weight are exhibited in this plot. All three populations are plotted together in Figure 22 to demonstrate both the overlap and differences among the three groups.

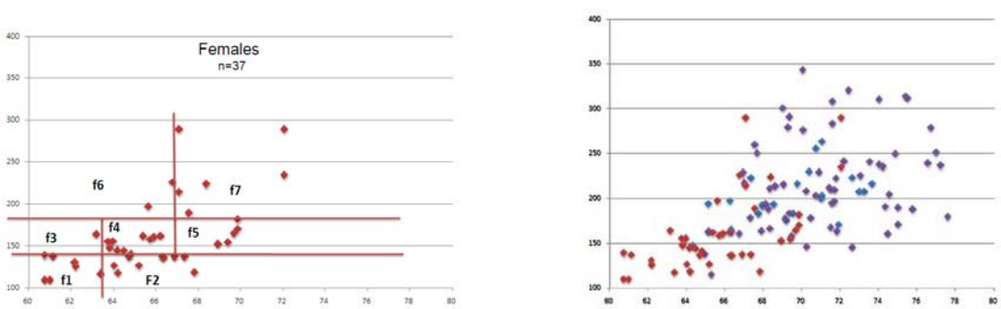


Figure 22 . Height-weight bivariate plots of the female population are shown on the left. All three groups, white males, minority males, and females, are plotted together to demonstrate overlap and differences.

Another perspective is to determine the percentage that each group represents. All 8 groups are shown in Table 8 and the contribution of each group to the sample is calculated as a percentage. White males, of course, constitute the majority, but only by 51%. White females make up 25% while Black males represent 9%. The pie chart in Figure 23 demonstrates the representation as well.

Table 8. Makeup of firefighter anthropometry survey.

subjects	abbr.	n	percentage
White male	wm	63	51.64%
White female	wf	31	25.41%
Black male	bm	11	9.02%
Black female	bf	2	1.64%
Hispanic male	hm	9	7.38%
Hispanic female	hf	1	0.82%
other male	om	2	1.64%
other female	of	3	2.46%

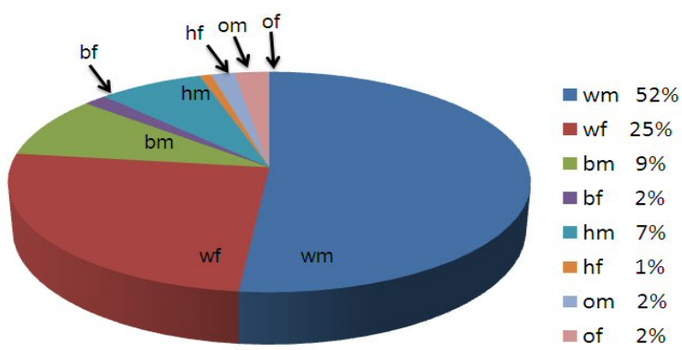


Figure 23. Representation from each of the 8 groups toward the entire study sample.

Further subdividing the population into male and female groups, the makeup was plotted in the form of a pie chart. Shown in Figure 23 is the representation from both of the two groups. Roughly ¾ of the female population is White. The male population is 84% White with a minority representation of 16%. The pie charts reflect the attempt to acquire minority data.

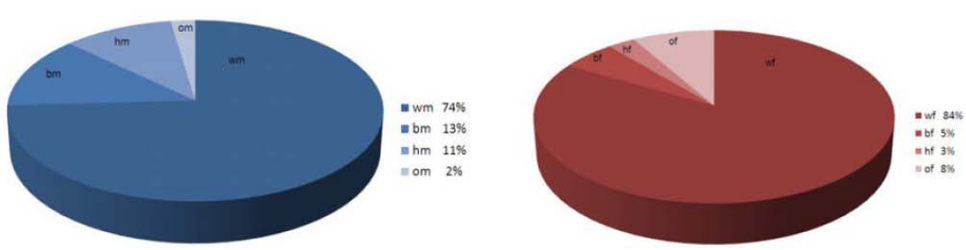


Figure24 . Representation from each of the 4 groups toward the female (on left) and male (on right) populations.

6.6 Summary Statistics for Traditional Anthropometry

Summary statistics including mean, standard deviation, minimum, and maximum values are listed in Tables 9 through 12. Table 9 summarizes measurements for the entire study population (n=122) in mm, with dimensions in Table 11 reported in inches. Tables 10 and 12 summarize measurements for male and female subjects separately. Differences in the mean values are reported in Table 13.

It should be noted that all of the mean values are larger in the male population with the exception of hip width. Female subjects are on average 0.14" larger in hip width than the male subjects. The male subjects are approximately 55 lbs heavier than the female subjects. However, the encumbered weight (with clothing, turnout gear, boots, helmets, and tools) is heavier for men, on average, by 60 lbs. The additional 5 lbs is most likely due to slightly heavier gear based on additional material used to cover the firefighter, as well as the number of tools carried by the male firefighter. Male firefighters are, on average, 4" taller than the female firefighter, and their sitting height is 2" taller both with and without their bunker gear and helmet. Chest and waist circumference for the male firefighter are 4" and 4.5" larger than the female population. Biacromial distance (shoulder width), chest width, and waist width are 1.4", 1.6", and 0.9" larger, on average, for the male population than the female population. Chest depth is 0.5" larger for males while the waist depth is 1.81" larger than females, and when sitting, the abdominal depth is 2.35" larger for the men. The mid-shoulder height, sitting, for men on average is 1.6" higher. The legs are longer, on average, for the male study group as demonstrated by the larger mean knee height, sitting (2.2") and the larger buttock-knee length, sitting (1.5").

While the differences in the mean values demonstrate a distinction between the two genders, it is also important to note the minimum, maximum, and values for standard deviation. The standard deviations for both groups are similar. The standard deviation for the male study group is slightly larger by only 0.5" or less for all measurements, with the exception of chest circumference and chest depth. This is supported by the differences in the minimum values. The minimum values for the female study group are less than the male group except for chest circumference, chest depth, and hip width. Finally, the maximum values are all larger for the male group with the exception of chest depth (14.2" versus 15.4").

Table 9. Summary Statistics for Study Survey

Dimensions in mm	mean	std dev	min	max	N
weight	196.71	51.35	109.8	343.9	122
stature	175.73	9.77	154.3	197.1	122
chest circ	107.35	13.81	81.8	144.9	122
waist circ	95.21	14.07	71.1	141.1	122
waist height	103.76	7.02	86.8	120.6	122
biacromial	40.27	3.24	33.1	58.7	122
chest width	34.41	4.23	23.6	47.5	122
waist width	33.21	4.04	25.8	46.6	122
chest depth	26.73	3.87	19.1	39.1	122
waist depth	25.92	5.79	17.2	44.8	122
sitting height	92.21	4.20	83.1	103.6	122
mid-shoulder ht	64.12	3.34	57.2	72.9	122
knee height	55.29	3.92	46.8	64.3	122
hip width	41.66	4.68	33.4	56.6	122
abd depth	27.53	6.66	17.5	54.8	122
butt-knee lth	62.25	4.07	53	73	122
encumbered wt	225.29	53.68	131.7	373	122
encumbered ht	102.57	4.58	91.8	113	122

Table 10. Summary Statistics for male and female subjects separately

	male					female				
	mean	std dev	min	max	n	mean	std dev	min	max	n
weight	213.29	47.39	115.4	343.90	84	158.63	38.52	109.80	289.40	37
stature	177.21	17.98	163.4	197.10	84	166.93	6.91	154.30	183.00	37
chest circ	110.80	12.66	101.20	144.90	84	99.41	13.18	81.80	142.90	37
waist circ	98.17	13.84	97.10	141.10	84	88.43	12.25	71.10	129.00	37
waist height	105.94	6.42	97.30	120.60	84	98.73	5.69	86.80	109.10	37
biacromial	41.41	3.01	34.5	58.70	84	37.66	2.05	33.10	42.20	37
chest width	35.64	3.84	23.6	47.50	84	31.58	3.71	26.60	43.70	37
waist width	33.92	4.00	33.20	46.60	84	31.59	3.70	25.80	42.30	37
chest depth	27.13	3.72	19.1	36.00	84	25.82	4.09	19.70	39.10	37
waist depth	27.32	5.80	25.50	44.80	84	22.71	4.36	17.20	37.70	37
sitting height	93.78	3.64	88.50	103.60	84	88.59	3.00	83.10	94.90	37
midshoulder ht	65.34	2.88	61.40	72.90	84	61.32	2.59	57.20	66.90	37
knee height	56.94	3.20	54.00	64.30	84	51.48	2.53	46.80	56.50	37
hip width	41.55	4.87	33.4	56.60	84	41.91	4.25	35.70	53.20	37
abd depth	29.34	6.66	24.80	54.80	84	23.37	4.49	17.50	38.70	37
butt-knee lth	63.41	3.76	57.00	73.00	84	59.52	3.46	53.00	68.00	37
encumbered wt	243.42	48.75	194.40	373.00	84	183.63	39.74	131.70	319.00	37
encumbered ht	104.32	3.78	98.80	113.00	84	98.57	3.66	91.80	106.50	37

Table 11. Summary Statistics for Study Survey in inches

INCHES/LBS	differences				
	mean	std dev	min	max	n
weight	54.66	8.87	5.60	54.50	122
stature	4.05	4.36	3.58	5.55	122
chest circ	4.48	-0.21	7.64	0.79	122
waist circ	3.83	0.63	10.24	4.76	122
waist height	2.84	0.29	4.13	4.53	122
biacromial	0.47	0.37	0.55	6.50	122
chest width	1.60	0.05	-1.18	1.50	122
waist width	0.92	0.12	2.91	1.69	122
chest depth	0.51	-0.15	-0.24	-1.22	122
waist depth	1.81	0.57	3.27	2.80	122
sitting height	2.04	0.25	2.13	3.43	122
midshoulder ht	1.58	0.12	1.65	2.36	122
knee height	2.15	0.27	2.83	3.07	122
hip width	-0.14	0.24	-0.91	1.34	122
abd depth	2.35	0.86	2.87	6.34	122
butt-knee lth	1.53	0.12	1.57	1.97	122
encumbered wt	59.79	9.01	62.70	54.00	122
encumbered ht	2.26	0.05	2.76	2.56	122

Table 12. Summary Statistics for male and female subjects separately

INCHES/LBS	male					female					
	mean	std dev	min	max	n	mean	std dev	min	max	n	diff mean
weight	213.29	47.39	115.40	343.90	85	158.63	38.52	109.80	289.40	37	54.66
stature	69.77	7.08	64.33	77.60	85	65.72	2.72	60.75	72.05	37	4.05
chest circ	43.62	4.98	39.84	57.05	85	39.14	5.19	32.20	56.26	37	4.48
waist circ	38.65	5.45	38.23	55.55	85	34.81	4.82	27.99	50.79	37	3.83
waist height	41.71	2.53	38.31	47.48	85	38.87	2.24	34.17	42.95	37	2.84
biacromial	16.3	1.18	13.58	23.11	85	14.83	0.81	13.03	16.61	37	1.39
chest width	14.03	1.51	9.29	18.70	85	12.43	1.46	10.47	17.20	37	1.60
waist width	13.35	1.58	13.07	18.35	85	12.44	1.46	10.16	16.65	37	0.92
chest depth	10.68	1.47	7.52	14.17	85	10.17	1.61	7.76	15.39	37	0.51
waist depth	10.75	2.28	10.04	17.64	85	8.94	1.72	6.77	14.84	37	1.81
sitting height	36.92	1.43	34.84	40.79	85	34.88	1.18	32.72	37.36	37	2.04
midshoulder ht	25.72	1.13	24.17	28.70	85	24.14	1.02	22.52	26.34	37	1.58
knee height	22.42	1.26	21.26	25.31	85	20.27	1.00	18.43	22.24	37	2.15
hip width	16.36	1.92	13.15	22.28	85	16.50	1.68	14.06	20.94	37	-0.14
abd depth	11.55	2.62	9.76	21.57	85	9.20	1.77	6.89	15.24	37	2.35
butt-knee lth	24.96	1.48	22.44	28.74	85	23.43	1.36	20.87	26.77	37	1.53
encumbered wt	243.42	48.75	194.40	373.00	85	183.63	39.74	131.70	319.00	37	59.79
encumbered ht	41.07	1.49	38.90	44.49	85	38.81	1.44	36.14	41.93	37	2.26

7. Comparison of NFFF and FAMA

The Fire Apparatus Manufacturers' Association (FAMA) received measurements reported by firefighters of firefighters from 15 fire departments, for a total of 737 subjects. Of these, 682 are male and 55 are female. Ethnicity was not reported. Data collected on the 86 male subjects from the NFFF study were used to compare to the FAMA male data. While all of the measurements are not defined in exactly the same way, some are comparable. The measurement techniques are described and the resulting measurement values are discussed.

In summary, the measurements recorded for the FAMA population appear to be comparable to the NFFF population with the exception of weight, weight with bunker gear, sitting height with helmet, and hip width. Table 13 shows average measurements for each of the body dimensions and differences between the average measurements. While some of the average measurements differ by a few inches, the differences can possibly be explained by the addition of bunker gear. For instance, average knee height, sitting for FAMA subjects is approximately 1.4 inches higher than NFFF subjects. This larger dimension can, in part, be attributed to the addition of the boots and pants. However, a mean difference of 3.6" was determined comparing traditional and scan data (Section 6.6). There are other dimensions, such as hip width, that do not compare as expected. Some of these measurements should be examined more carefully.

The sampling strategy for the NFFF population is to ensure that a full range of anthropometric variability found in the current firefighter population is represented by the sample. A random sample might only represent a segment of the population, and any specifications derived from these data would only accommodate this segment. A bivariate plot height and weight of the NFFF male population is shown in Figure 25. The subjects have been carefully selected and represent a diverse combination of height and weight, not just typical "m4" subjects. By deliberately including minorities, the final population data is likely to represent the variability in proportions that affect workstation design, such as sitting height and leg length combinations.

As the catalyst for this study has been concern over specifications for seats and seatbelts, the average dimensions for hip width, sitting require some examination. The average hip width, sitting dimensions between the two populations are almost identical. However, the NFFF subjects are wearing only shorts while the FAMA subjects are fully outfitted in clothing and bunker gear. Upon inspection of an NFFF subject scanned with and without his gear (see Figure 26), the hip width increases considerably (7.3 inches). Both populations (NFFF and FAMA) were asked to bring all necessary equipment (e.g., tools in pockets) for a realistic view of the volume required to safely encumber the firefighter. This additional equipment clearly adds bulk to the measurement. Therefore, the reported average hip width for FAMA subjects appears doubtful.

Furthermore, Hongwei, et. al.(2002) found that male firefighters are on the average 15 pounds heavier than males in all other non-military populations. The NFFF firefighters wearing only shorts were found to be 5 pounds heavier, on average, than the clothed firefighters measured through FAMA. In addition, the fully encumbered firefighters for both populations, while defined the same, differ by 13 pounds. When looking at the different weight between the two samples, it appears the NFFF population is considerably heavier than the FAMA sample. This is

a common occurrence with subject reported weight. To examine this more closely, four samples were examined where both *subject reported* Height and Weight and *measured* Height and Weight were taken. These surveys were the 1977, 1968, 1967, and 1965 Anthropometric Surveys of the US ARMY and US Air Force. For these surveys, the average difference between Reported Weight and Measured Weight was 1.3lbs. This does not fully explain the 13 lb or 22 lb difference, especially when the FAMA subjects were fully clothed for this measurement. At the interim point of this study, the reported FAMA weight appears suspect.

Table 13. Average dimensions for selected anthropometric measurements of NFFF and FAMA firefighter populations.

measure	NFFF	FAMA	diff	expected	unexpected
height	70.69	70.2	-0.49		
weight	213.29	208	-5.29		
enc wt	243.42	230	-13.42		
eq wt	30.13	23	-7.13		
sit ht	36.92	36.1	-0.82		
sit ht helm	41.07	39.3	-1.77		
helmet ht	4.15	3.2	-0.95		
shldr ht sit	25.72	25.7	-0.02		
knee ht sit	22.42	23.8	1.38		
shldr width	16.22	20.8	4.58		
torso width	14.03	15	0.97		
hip width	16.36	16.6	0.24		
chest depth	10.68	12.5	1.82		
waist depth	10.75	13.4	2.65		
waist circ	38.65	48.9	10.25		

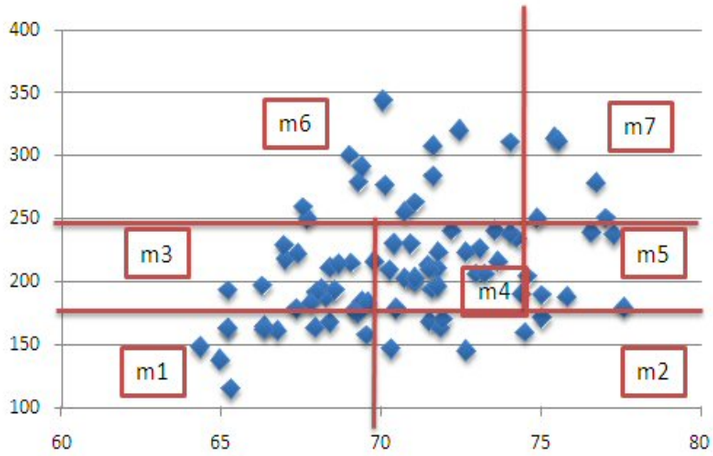


Figure 25. Height and weight bivariate plot for NFFF male subjects

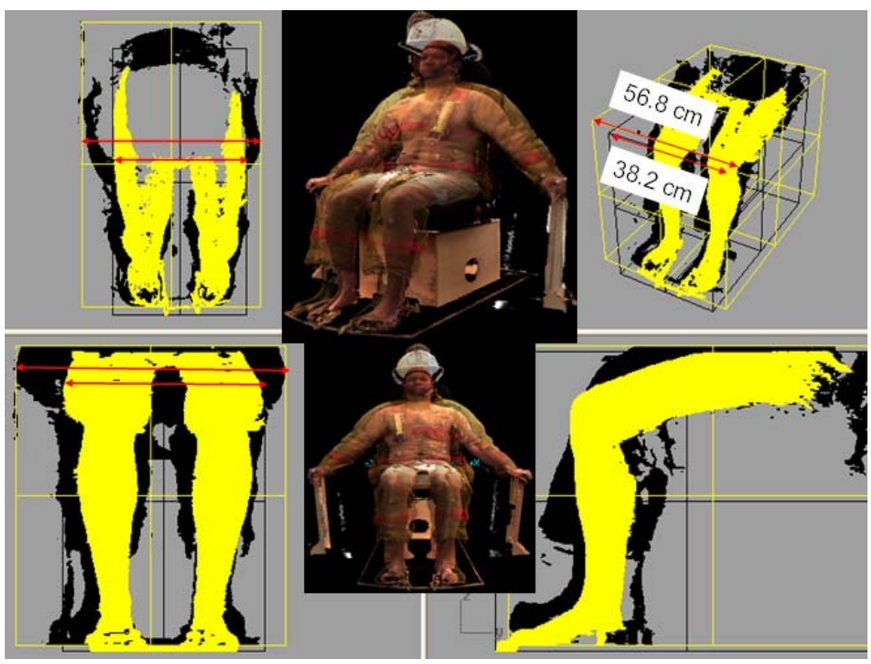


Figure 26. Two scans of NFFF firefighter, with and without clothing and bunker gear, superimposed in same three-dimensional space. The upper body in this example is eliminated for CAD measurements of hip width, sitting. The gold surface represents the unencumbered firefighter. The black surface represents the encumbered (with clothing and bunker gear) firefighter.

WEIGHT

METHODS:

Subjects in the NFFF study were weighed with a calibrated scale wearing only grey shorts. In the FAMA study, subjects were asked to weigh themselves with their street clothes. The NFFF subjects were also weighed with their clothes and bunker gear, including helmets, boots, and anything they would normally carry in their pockets. The FAMA subjects were asked to weigh themselves with their clothes and bunker gear including helmets, boots, and any typical accessory gear that would add bulk to the subject. The NFFF equipment weight includes street clothes or uniforms worn under the bunker gear, while the FAMA equipment weight measurement includes bunker gear.

RESULTS: While the FAMA firefighters were weighed with their clothing, the NFFF firefighter weights are unexpectedly, on average, 5 lbs heavier for men. For the additional encumbered weight, which should be equivalent, the NFFF firefighter average weight is 13 lbs heavier. The average equipment weight for FAMA firefighters is 23 lbs while the average NFFF equipment weight is consistently 30 lbs, with an average difference of 7 lbs. This difference is probably due to the addition of street clothes or uniform included with the bunker gear measurement for NFFF subjects. In summary, on average, the NFFF subjects are heavier by 5 lbs (even without street clothes), and when fully outfitted in bunker gear, by 13 lbs.

WEIGHT				**ENC WEIGHT**				**EQ WEIGHT**			
MEAS	NFFF	FAMA	WT	MEAS	NFFF	FAMA	ENC WT	MEAS	NFFF	FAMA	EQ WT
avg	213.29	208.00	5.29	avg	243.42	230.00	13.42	avg	30.13	23	7.13
std dev	47.39	31.00	16.39	std dev	48.75	31.00	17.75	std dev	3.82	4	-0.18
min	115.40	140.00	-24.60	min	139.50	162.00	-22.50	min	22.70	10	12.70
max	343.90	335.00	8.90	max	373.00	360.00	13.00	max	42.30	40	2.30
median	206.25	205.00	1.25	median	236.80	227.00	9.80	median	30.15	23	7.15
5th perc	150.20	165.00	-14.80	5th perc	178.04	186.00	-7.96	5th perc	24.44	17	7.44
50th per	207.50	205.00	2.50	50th per	237.20	227.00	10.20	50th per	30.1	23	7.10
95 perc	310.76	263.00	47.76	95 perc	343.94	287.00	56.94	95 perc	35.46	30	5.46

STATURE

METHODS:

Stature should be roughly equivalent, with the only difference in clothing being possibly socks. The NFFF subjects are measured with their heels together and the head held such that the orientation of the Frankfurt plane is horizontal. The measurer stands at one side of the subject and uses an anthropometer to measure the vertical distance between the standing surface and the top of the head, by moving the blade of the anthropometer across the top of the head to ensure measurement of the maximum distance. The FAMA subjects are measured using a level and tape measure. The subject is positioned with his/her back against the wall with boots removed, and with the level resting on his/her head, a tape measure is used to record height from floor to the bottom edge of the level.

RESULTS:

The average stature for the NFFF subjects is only 0.4 inches taller than the FAMA subjects. The two populations appear to be similar, although FAMA has at least one subject 3 inches shorter than the shortest measured by NFFF and at least one subject 2.2 inches taller than the tallest NFFF subject.

	HEIGHT		
MEAS	NFFF	FAMA	diff
average	69.77	70.20	0.43
std dev	7.08	2.70	-4.38
min	64.33	61.30	-3.03
max	77.60	79.80	2.20
median	70.75	70.30	-0.45
5th perc	65.18	65.80	0.62
50th per	70.75	70.30	-0.45
95 perc	76.42	74.50	-1.92

SITTING HEIGHT

METHODS:

Sitting height should be equivalent. Sitting height for the NFFF subjects requires that the subject be sitting up straight and their head angled such that Frankfurt plane is horizontal. The measurer stands at the right rear of the subject and uses an anthropometer to measure the vertical distance between the sitting surface and the top of the subject's head. The measurement is made at the maximum point of quiet respiration. The FAMA subjects are measured in the seated position as well. The subject is seated with his/her back against the wall. The measurer sets a carpenter's square on the subject's head with the other leg against the wall. A tape measure is used to measure from the floor to the bottom of the square. The assumption is that the seat height was measured and the height of the seat subtracted to derive seated height. The seated measurements with helmet are measured as described previously, only with the subjects wearing their bunker gear and helmet.

RESULTS:

The average sitting height for the NFFF subjects is 0.8 inches higher. With the addition of the helmet, our average sitting height is 1.8 inches higher. In theory, the difference should be approximately the same. The almost 2" difference is significant if you consider that, on average, helmets should be about the same size. The standard deviations are approximately the same for this measurement.

SITTING-HEIGHT				SITTING-HT W/HELMET			
MEAS	NFFF	FAMA	diff	MEAS	NFFF	FAMA	diff
avg	36.92	36.1	0.8	avg	41.1	39.3	1.8
std dev	1.43	1.5	-0.1	std dev	1.5	1.6	-0.1
min	33.86	31.8	2.1	min	37.8	34.8	3.0
max	40.79	40.8	0.0	max	44.5	44.8	-0.3
median	37.01	36.3	0.7	median	41.0	39.3	1.7
5th perc	34.49	34	0.5	5th perc	38.6	37	1.6
50th per	37.01	36.3	0.7	50th per	41.1	39.3	1.8
95 perc	39.11	38.8	0.3	95 perc	43.3	42	1.3

SHOULDER HEIGHT, SITTING

METHODS:

Sitting shoulder height for the NFFF subjects is measured at mid-shoulder as located from at the half-way point between the neck line and acromion (tip of the shoulder), with the subject sitting upright. The neck chain is used for the shoulder height, sitting measurement. The neck chain is placed around the subject's neck at the base of the neck and acromion is marked in pencil. A tape measure is used to determine the midway point between the two landmarks. The measurement is taken at the maximum point of quiet respiration. Shoulder height for the FAMA subjects is measured by positioning the subject with their back against the wall. One leg of the square is set on the subject's shoulder with the other leg against the wall. The distance from the floor to the bottom of the square is measured. The assumption is that the distance of the seat is subtracted from the total shoulder height measurement.

RESULTS:
Although the definitions of the measurements are somewhat different, the average measurements are identical and the standard deviations very similar (1.1" for NFFF and 1.4" for FAMA). It would be expected that the NFFF average shoulder height, sitting measurement would be larger as this dimension is made halfway up the shoulder. However, the addition of clothing and gear could add height to the FAMA average shoulder height, sitting. Additionally, at least one FAMA subject is 2.1" shorter than the smallest NFFF subject and at least one FAMA subject is 3.3" higher than the NFFF subjects. The median values are also very similar and only differ by 0.1".

SITTING SHOULDER HT			
MEAS	NFFF	FAMA	diff
avg	25.7	25.7	0.0
std dev	1.1	1.4	-0.3
min	23.1	21	2.1
max	28.7	32	-3.3
median	25.8	25.8	0.0
5th perc	23.8	23.5	0.3
50th per	25.7	25.8	-0.1
95 perc	27.6	28	-0.4

KNEE HEIGHT, SITTING

METHODS:

Subjects from the NFFF study were measured in bike shorts only for knee height, sitting. Subject sits with the thighs parallel and horizontal, the knees flexed 90 degrees, and the feet in line with the thighs. The thigh is elevated to place it in the horizontal position with the use of foot blocks. The arms are relaxed at the sides. The measurer stands at the right of the subject and uses an anthropometer to measure the vertical distance between the footrest surface and the drawn suprapatella landmark at the top of the knee (NOTE: the landmark is drawn after the subject is seated). The FAMA subjects were measured with bunker gear including boots. The FAMA subjects were placed with their backs against the wall and a level set across the subject's knees with the lower legs vertical. The tape measure is used to record the distance from the floor to the bottom of the level.

RESULTS: The average knee height, sitting for FAMA subjects is 1.4 inches higher on average than the NFFF subjects. The larger FAMA average knee height, sitting is expected to be at least a few inches larger due to the addition of the boots and pants.

KNEE HEIGHT, SITTING			
MEAS	NFFF	FAMA	diff
avg	22.4	23.8	-1.4
std dev	1.3	1.1	0.2
min	19.4	20.5	-1.1
max	25.3	28.5	-3.2
median	22.4	23.8	-1.4
5th perc	20.3	22	-1.7
50th per	22.4	23.8	-1.4
95 perc	24.5	25.5	-1.0

SHOULDER WIDTH

METHODS:

The NFFF subjects are measured from acromion to acromion while wearing only the biker shorts. The subject is placed in the anthropometric position. The measurer stands behind the subject and uses a beam caliper to measure the distance between the drawn right and left acromion landmarks at the tips of the shoulders. The measurement is taken at the maximum point of quiet respiration. Only sufficient pressure is used to maintain firm contact with the skin. The FAMA subjects are measured on the edge of the shoulders with full bunker gear. The FAMA subjects are placed with their back against the wall. Two carpenter's squares are placed against each of the subject's shoulders with the remaining leg held against the wall. A tape measure is used to record the distance between the edges of the squares.

RESULTS:

The average shoulder width for NFFF subjects is 4.6 inches smaller than the FAMA subjects. The addition of the bunker gear obviously contributes to the larger dimension from FAMA subjects. The median values are also 4.6 inches different which implies that the FAMA subjects are measured consistently larger with their gear. Additionally, the FAMA measurements are taken at the level of what could be bi-deltoid which would also add considerable width.

SHOULDER WIDTH			
MEAS	NFFF	FAMA	diff
avg	16.22	20.80	-4.58
std dev	1.39	1.40	-0.01
min	9.49	17.30	-7.81
max	23.11	26.00	-2.89
median	16.22	20.80	-4.58
5th perc	14.78	18.50	-3.72
			-4.5

WAIST CIRCUMFERENCE AND WAIST DEPTH

METHODS:

Waist circumference is measured on NFFF subjects at the level of preferred waist. The subjects are given a loose elastic band and asked to place it on their waist at the level at which they like their waistband to fit comfortably. This is generally below the belly button and slightly higher in the back. The subject stands in the anthropometric position. The subject stands erect looking straight ahead breathing quietly. The upper arms hang relaxed at the sides, and the abdominal muscles are relaxed. The measurer exerts only enough tension on the tape to maintain contact between the tape and the body. The measurement is made at the maximum point of quiet respiration. The subject must not tense the abdominal muscles. The FAMA subjects were measured with their bunker gear and at a level at or higher than belly button. A tape measure is used to record the circumference of the stomach.

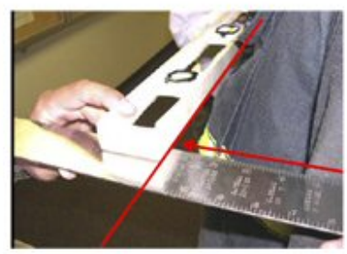
Waist depth is measured for the NFFF subjects at the level of belly button maintaining the calipers at a horizontal level. With the subject in the anthropometric standing position, the measurer stands in front of the subject and use a bean caliper to measure the horizontal breadth of the waist from the right side of band marking the preferred waist to the left side of band marking the preferred waist. The measurer exerts only enough pressure to attain contact between the caliper and the skin. The measurement is taken at the maximum point of quiet respiration. The FAMA subjects are measured with bunker gear. The subject is asked to place their back against the wall. Two carpenter's squares are place on either side of the subject's torso. A straight edge is held against the subject's stomach and held parallel to the wall such that the same reading is obtained on both legs of the squares. The distance from the wall to the edge of the straight edge is recorded using the carpenter's squares.

RESULTS:
The average waist circumference for FAMA subjects is 10.3 inches larger than the NFFF subjects. The median waist circumference for FAMA subjects is 11.8 inches larger than the NFFF subjects. The larger FAMA circumference is larger due to clothing and bunker gear, and the position of the measurement on the body. The average waist depth for FAMA subjects is
2.6 inches larger than the average waist depth for the NFFF subjects, most likely due to the added bulk of bunker gear, and location of the measurement.

WAIST CIRC				WAIST DEPTH			
MEAS	NFFF	FAMA	diff	MEAS	NFFF	FAMA	diff
avg	38.65	48.90	-10.25	avg	10.75	13.40	-2.65
std dev	5.45	4.30	1.15	std dev	2.28	1.70	0.58
min	28.82	36.00	-7.18	min	6.77	6.30	0.47
max	55.55	66.00	-10.45	max	17.64	19.50	-1.86
median	37.17	49.00	-11.83	median	10.20	13.30	-3.10
5th perc	32.54	42.00	-9.46	5th perc	8.10	10.80	-2.70
50th per	37.17	49.00	-11.83	50th per	10.20	13.30	-3.10
95 perc	49.39	56.00	-6.61	95 perc	15.25	16.00	-0.75

CHEST DEPTH

METHODS:



Chest depth is measured for NFFF subjects at the level of nipple without clothing. The subject is placed in the anthropometric standing position. The measurer stands at the right of the subject and uses a beam caliper to measure the horizontal distance between the chest at the level of the right bustpoint on women and nipple on men (bustpoint/thelion, right) and the back at the same level. The fixed blade of the caliper is placed on the back. The bustpoint/thelion landmark is drawn on the bra for female subjects; it is not drawn on male subjects. This measurement is taken at the maximum point of quiet respiration. The measurer exerts only enough pressure to maintain contact between the caliper and the skin (or bra). Chest depth is measured for FAMA subjects with clothing and bunker gear. The subject is placed with their back against the wall. Two carpenter's squares are held against each of the subject's arms with the remaining leg against the wall. A straight edge is held against the chest and held parallel to the wall such that

the same reading is obtained on both legs of the squares. The distance from the wall to the edge of the straight edge is recorded using the carpenter's squares.

RESULTS:
The average chest depth for the FAMA subjects is 1.8 inches larger than the average chest depth for NFFF subjects, most likely due to the addition of bunker gear.

CHEST DEPTH			
MEAS	NFFF	FAMA	diff
avg	10.68	12.50	-1.82
std dev	1.47	1.40	0.07
min	7.52	8.80	-1.28
max	14.17	21.50	-7.33
median	10.47	12.50	-2.03
5th perc	8.35	10.50	-2.15
50th per	10.47	12.50	-2.03
95 perc	13.53	15.00	-1.47

HIP WIDTH AND TORSO WIDTH

METHODS:

The NFFF subject is measured in shorts only. The subject sits erect with the thighs parallel (to each other) but not touching. The arms are crossed over the chest or hang relaxed at the sides. The measurer stands in front of the subject and uses a beam caliper to measure the most lateral points on the hips or thighs (whichever are broader). The blades of the caliper are kept at approximately a 45-degree angle to the horizontal and moved up and down to locate the maximum breadth. The measurer exerts only enough pressure to ensure that the caliper blades are touching both sides of the body. The FAMA subjects are measured in the seated position with their bunker gear donned. The subject is position with their back against the wall. Two carpenter's squares are held on either side of the subject's hips with the remaining legs placed against the wall. A tape measure is used to record the distance between the two inner surfaces of the squares.

The NFFF subjects are measured with shorts only. The subjects stands erect looking straight ahead with the heels together and the weight distributed on both feet. The arms are held away from the body just enough to allow clearance between the arms and a beam caliper used to make the measurement. The measurer stands in front of the subject and measures the maximum horizontal breadth of the chest at the level of the drawn right bustpoint landmark (women) or nipple (men). The measurement is made at the maximum point of quiet respiration. The measurer exerts only enough pressure to attain contact between the caliper and the skin (or bra). Breast tissue is not included in this measurement. This can be avoided, when necessary, by tilting the blades of the caliper upwards and approaching the bony sides of the chest from below the breasts. On some male subjects the latissimus dorsi, heavy muscles at the back of the armpit, may bulge beyond the bony sides of the chest. These muscles are not included in the measurement either. The FAMA subjects are measured with bunker gear. The subject is asked to place their back against the wall and extend their arms. Two carpenter's squares are place on either side of the subject's torso. A tape measure is used to record the distance between the two inner surfaces of the squares.

RESULTS:

The average hip widths for the two populations differ by only .24". This is unexpected as the FAMA subjects should have considerably larger hip width given that they are measured with street clothes plus bunker gear versus wearing only shorts (NFFF). The average torso widths are also similar (less than 1" difference), however, the added bunker gear for the FAMA subjects should result in larger torso widths.

HIP WIDTH				**TORSO WIDTH**			
MEAS	NFFF	FAMA	diff	MEAS	NFFF	FAMA	diff
avg	16.36	16.60	-0.24	avg	14.03	15.00	-0.97
std dev	1.92	1.70	0.22	std dev	1.51	1.70	-0.19
min	13.15	12.30	0.85	min	9.29	11.50	-2.21
max	22.28	24.00	-1.72	max	18.70	29.00	-10.30
median	15.98	16.30	-0.32	median	13.90	15.00	-1.10
5th perc	14.07	14.30	-0.23	5th perc	12.24	12.50	-0.26
50th per	15.98	16.30	-0.32	50th per	13.90	15.00	-1.10
95 perc	20.68	19.50	1.18	95 perc	16.62	18.00	-1.38

8.0 Bounding Box Dimensions

8.1 Segmentation of the Bounding Box

Three-dimensional surface scan data of the firefighter fully equipped with bunker gear including tools, helmet, and boots provides volumetric information not obtainable using traditional anthropometric methods. Particularly, positioning the firefighter in gear while sitting in a fire engine seat with a realistic seat pan height and seat back angle captures exactly the shape and volume which must be protected. For this reason, each subject was scanned fully encumbered while sitting in the fire engine seat and the image data were interrogated using "bounding box" methods. Each seated body scan was divided into upper and lower segments, and further subdivided into fore and aft segments as shown in Figure 27. The dimensions (length x width x height) of a box bounding the maximum surface data for each of the segments were recorded. From these dimensions, it is possible to get maximum breadth, depth, and height measurements.

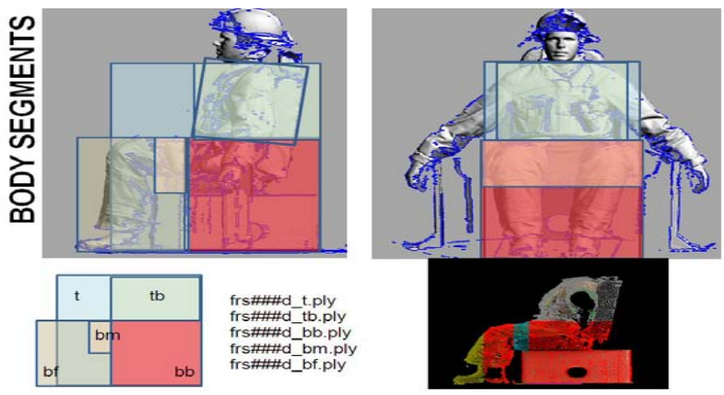


Figure 27. The seated encumbered scans (Scan C) were segmented as shown in the figure and include a top segment (_t); top-back segment (_tb); a bottom-back segment (_bb); a bottom middle segment (_bm); and a bottom front segment (_bf).

As an example, hip width should be measured at the maximum distance perpendicular to the long axis of the legs, contained within the pelvic region. In Figure 28 is the segmentation scheme used to determine hip width. The bottom-back (bb) segment was measured for maximum breadth as shown. Hip width reflects the firefighter with his/her bunker gear including any tools they typically carry.

Leg width was also measured to determine if this dimension was at any time larger than what should be considered for hip width. Figure 28 shows the bounding box, bottom-front (bf), used to measure leg width. However, the mean leg width dimension, even with tools and equipment found in the sides pockets, was 1.6" less than the mean hip width dimension. This confirms the importance of accurately representing and measuring hip width for the encumbered firefighter.

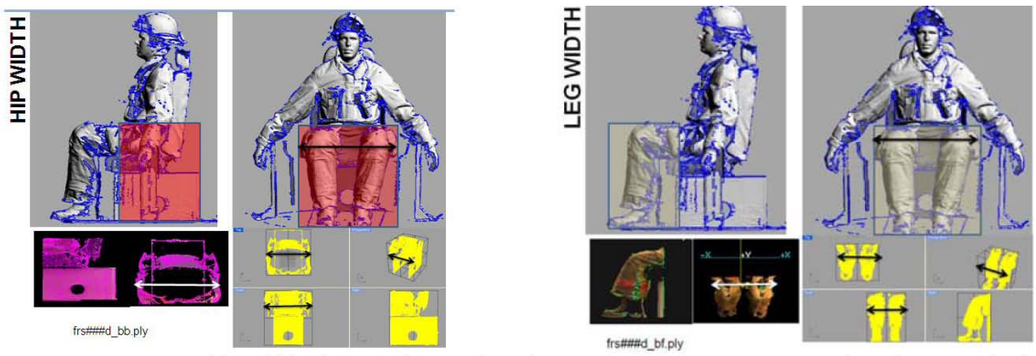


Figure 28. To measure hip width, the seated encumbered scans (Scan C) were segmented as shown on the left as the bottom-back segment (_bb). The bottom front segment (_bf) was used to measure leg width.

The fire engine seat was mocked up to represent a 12" seat pan height, and to some extent, dictated the level of the leg height. To maintain consistent leg posture, brackets placed on the scanning platform were used to place the firefighters' feet in the same location. The leg length would then determine if the thigh remained horizontal (average leg length), angled slightly up from the horizontal plane (longer leg length), or angled slightly downward (shorter leg length). In a few cases, the subjects' feet did not actually touch the floor. For this reason, the leg height was recorded from the bottom-front (bf) segment as shown in Figure 29.

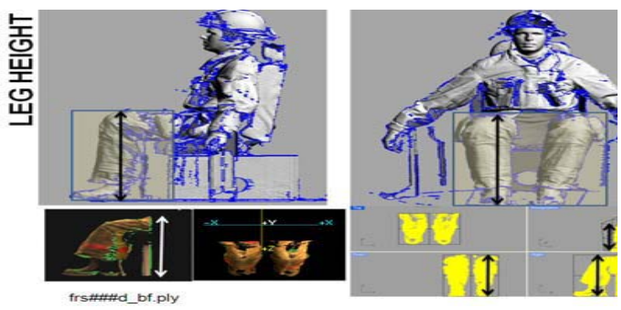


Figure 29. Leg height was measured from the bottom-front (bf) segment of the Scan C position.

Buttock-toe and buttock-knee lengths were extracted from the bottom segment and the top segment as shown in Figure 30. The buttock-toe length is a realistic depiction of the firefighter sitting in the seat and allows for accommodation of their boots. The buttock-knee was approximated using the top segment. The final dimensions account for 10" to account for the seat back. Buttock-knee length is typically measured using a spreading caliper from the back of the subject to the most prominent point on their knee, holding the caliper in the horizontal plane. The 3D scan dimension differs slightly in that the back point is the front of the seat. The buttocks are actually sitting a little further back as the subject compresses both the seat cushion on the bottom and on the back of the seat. However, these dimensions are meant to be realistic representation of the firefighter in the fire apparatus in which case, the cushions will be compressed. The study was designed and the dimensions extracted from the 3D data to be intended for design use.

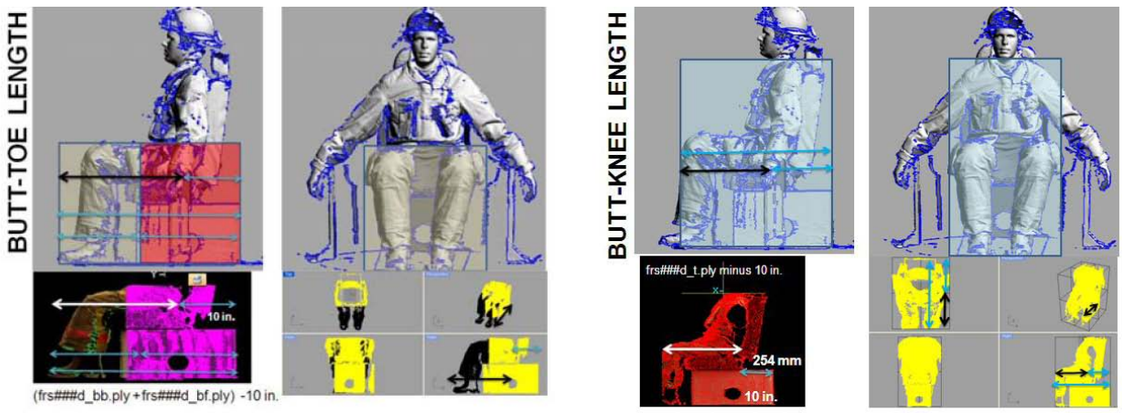


Figure 30. Buttock-toe length and buttock-knee lengths are measured using the bottom and top segments. The seat back including the cushion is subtracted from the dimensions to provide a common reference for design purposes.

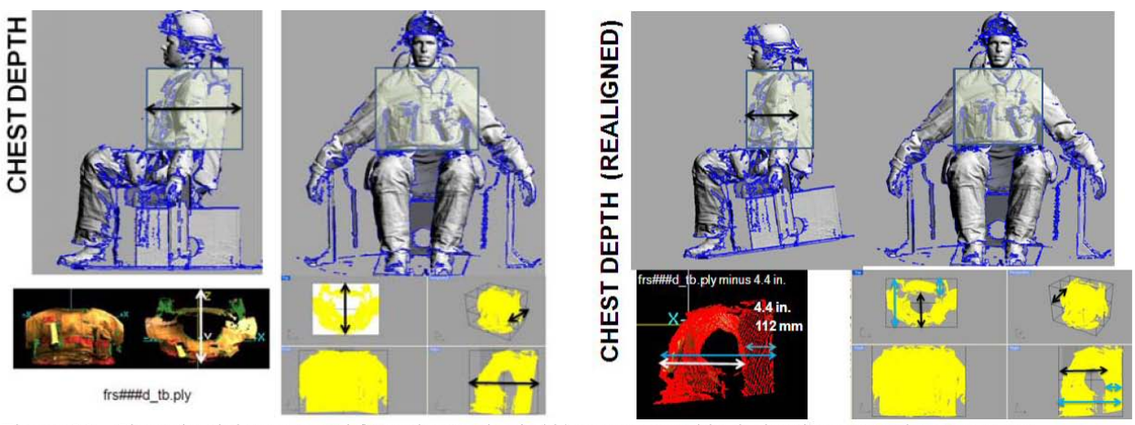


Figure 31. Chest depth is measured from the top-back (tb) segment and includes the seat and seat support dimensions. The realigned segment (tb) is used to extract chest depth measurements using the back of the seat as the reference.

Chest depth is an important consideration for the design of seat/seatbelt systems required to safely protect the encumbered firefighter. Chest depth was measured from the top-back (tb) segment, but included the seat and seat support system as shown in Figure 31. The maximum chest depth varied vertically in the location of the largest dimension. For example, for some female subjects, the maximum chest depth was located at the location of thelion (chest) while most of the male subjects demonstrated a maximum distance at the level of omphalion (belly). To calculate the chest depth relative to the seat back, the top-back (tb) segment was rotated as shown in Figure 31. The chest depth measurement was recalculated at this angle and the seat back dimensions subtracted. Both dimensions will be useful for designing seats and seatbelt systems, depending on the reference and assumed angle of inclination for the firefighter's seat. Similarly, the shoulder height dimension is important for understanding the variability of torso length for designers of seats and seatbelt systems. The shoulder height was measured using the top (t) segment and subtracting the seat and seat support (Figure 32). This segment was also realigned to simulate a 90^{0} seat back angle. For this measurement, the seat cushion was subtracted as shown in Figure 32.

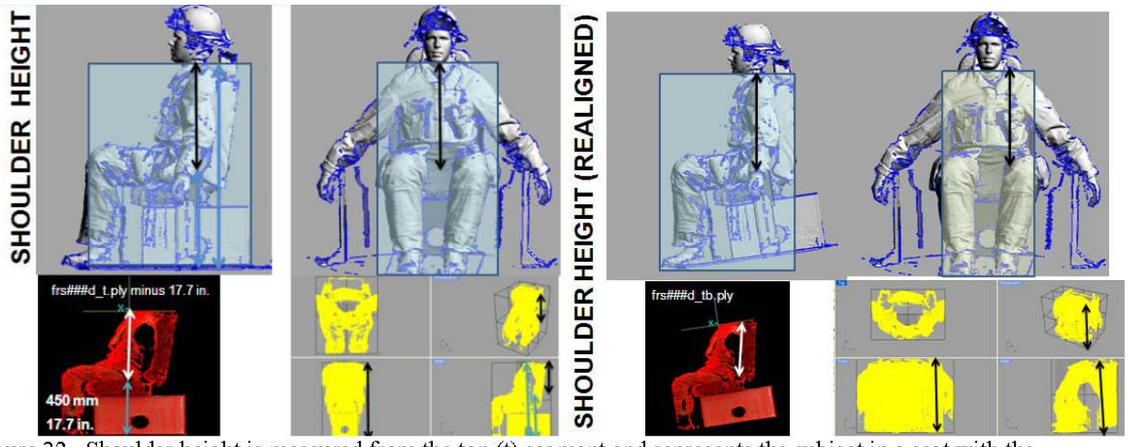


Figure 32. Shoulder height is measured from the top (t) segment and represents the subject in a seat with the ___ angle of inclination. The realigned segment (tb) is used to simulate a 90^0 angle seat back.

Seat pan depth is important dimension in seat design. The seat pan must be long enough to accommodate long upper leg length, but not so deep as to prevent firefighters with shorter legs from bending their knees and fitting comfortably and safely in the seat. The popliteal (point at knee crease) length was measured as shown in Figure 33. Using the bottom-back (bb) and the bottom-middle (bm) segments, the dimensions for popliteal length (as estimated under the bunker gear) were determined. Popliteal height, however, was difficult to obtain from the bottom-middle segment due to the artifacts, voids, and noise found in the scan data from this region. Instead, popliteal height was measured using Integrate. It should be noted that popliteal height is an estimate given the bulk of the turnout gear, but does, in fact, account for the gear as well.

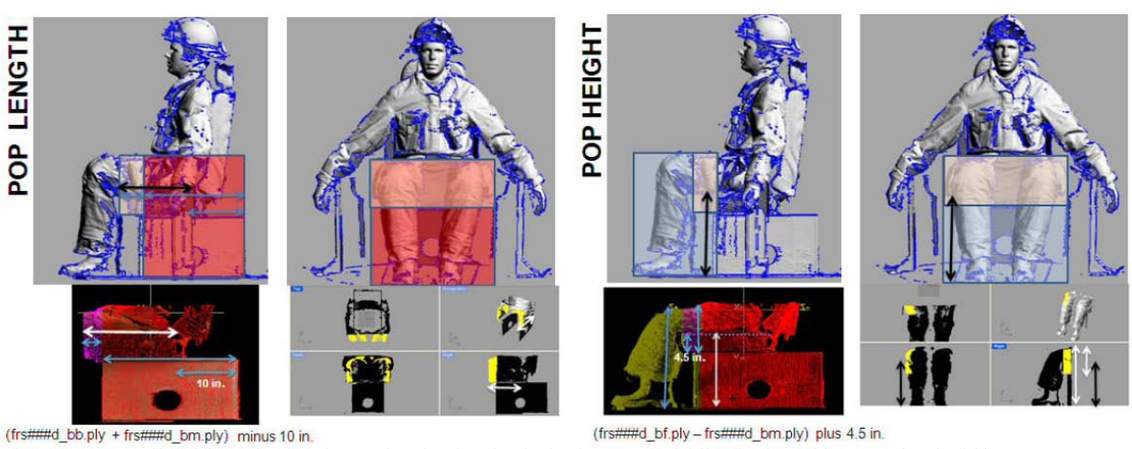


Figure 33. Popliteal length was determined using both the bottom-middle (bm) and bottom-back (bb) segments. The seat system was subtracted from this dimension. Popliteal height, however, was too difficult to measure reliably using bounding box methods. Instead, popliteal height was extracted from each subject's scan using Integrate.

8.2 Summary Statistics for Bounding Box Measurements

Shown in the following tables are measurements extracted from the boxes bounding the outer surfaces of each segment as described in Section 8.1. The measurements have been summarized and presented as mean, standard deviation, minimum and maximum values. Tables 14 and 15 report the measurements per gender. Shown in Table 16 are the differences between the genders. The male population, when outfitted in turnout gear with tools, helmets, and boots, demonstrates larger dimensions overall. Summary statistics reported in Section 6.6 revealed that men are larger, on average, for the anthropometry measured with the exception of hip width which was slightly larger for women.

Traditional anthropometric measurements are essential in understanding the size and proportion of a population. As this is the first US firefighter anthropometric study, it is important that the traditional measurements of this population were recorded. However, the design issue at hand requires understanding the size and proportion of a population given their operational attire. In this case, the bounding box data is key to providing specifications for new seat and seatbelt designs. The dimensions chosen from the bounding boxes relate to how the encumbered firefighter is positioned and constrained with the configuration of the seat system. These dimensions relate to seat width, seat height, seat belt placement, position of seat with respect to opposing seat or dash, and seat belt length. The measurements are also summarized for the entire study population (n=120) and are shown in Table 17. This table is quite revealing. Mean hip width for the population is 25”. Hip width is, on average, 7” greater than the 18” currently specified for seat width. Even the specified minimum spacing at shoulder level of 22” does not accommodate this population. Furthermore, maximum values for hip width are 32” for men and 27” for women. These individuals far exceed the seating space. The seat pan depth is specified as 15”. The popliteal length is, on average, 17.5” with a maximum value of 20” potentially extending 5” beyond the seat pan. Shoulder height for the study group ranges from 24.7” to 30.3”, a range of over 5”. While attempting to place the seatbelt at over 30” to accommodate the maximum value, the shortest firefighters may have over 5” from the seatbelt point of contact to their shoulder.

Table 14. Summary statistics for bounding box dimensions for male subjects

FRS male population	mean	sd	min	max	n
hip width	25.53	2.33	19.91	32.04	84
leg width	23.74	1.91	19.27	28.91	84
leg ht	26.02	1.01	23.70	29.21	84
pop ht	17.69	1.10	13.86	20.47	84
pop length	17.79	1.03	16.05	20.52	84
butt-toe length	30.27	0.75	28.46	32.70	84
shoulder ht original w/o seat dimensions	24.68	1.20	22.61	27.65	84
shoulder ht realigned w/o seat dimensions	27.05	1.19	24.95	30.27	84
chest width original	24.25	1.71	21.20	29.48	84
chest depth realigned w/o seat dimensions	14.87	2.55	11.13	22.73	84
butt-knee length	24.05	1.86	20.48	30.19	84

Table 15. Summary statistics for bounding box dimensions for female subjects

FRS female population	mean	sd	min	max	n
hip wdth	23.89	1.84	20.47	27.32	36
leg width	22.18	1.84	18.63	26.91	36
leg ht	25.02	0.95	23.23	26.85	36
pop ht	17.48	0.95	15.83	20.31	36
pop lgth	17.01	0.68	15.53	18.80	36
butt-toe lth	28.83	0.67	27.43	29.97	36
shoulder ht original w/o seat dimensions	23.41	1.02	22.22	26.31	36
shoulder ht realigned w/o seat dimensions	25.68	0.86	24.68	28.46	36
chest wdth original	22.65	1.21	20.84	25.90	36
chest depth realigned w/o seat dimensions	13.22	1.64	10.93	19.46	36
butt-knee lgth	22.45	1.67	19.27	27.98	36

Table 16. Differences between male and female subjects' bounding box dimensions

FRS difference between male and female	mean	sd	min	max
hip wdth	1.64	0.49	-0.56	4.71
leg width	1.56	0.07	0.64	1.99
leg ht	1.01	0.06	0.47	2.36
pop ht	0.21	0.15	-1.97	0.16
pop lgth	0.77	0.35	0.51	1.72
butt-toe lth	1.44	0.07	1.03	2.73
shoulder ht original w/o seat dimensions	1.26	0.18	0.39	1.34
shoulder ht realigned w/o seat dimensions	1.37	0.33	0.27	1.80
chest wdth original	1.60	0.49	0.37	3.58
chest depth realigned w/o seat dimensions	1.66	0.91	0.20	3.27
butt-knee lgth	1.60	0.19	1.21	2.21

Table 17. Summary statistics for bounding box dimensions

FRS both male and female	mean	sd	min	max	n
hip wdth	25.04	2.31	19.91	32.04	120
leg width	23.28	2.02	18.63	28.91	120
leg ht	25.72	1.09	23.23	29.21	120
pop ht	17.63	1.06	13.86	20.47	120
pop lgth	17.55	1.00	15.53	20.52	120
butt-toe lth	29.84	0.98	27.43	32.70	120
shoulder ht original w/o seat dimensions	24.30	1.29	22.22	27.65	120
shoulder ht realigned w/o seat dimensions	26.64	1.27	24.68	30.27	120
chest wdth original	23.77	1.74	20.84	29.48	120
chest depth realigned w/o seat dimensions	14.38	2.43	10.93	22.73	120
butt-knee lgth	23.57	1.94	19.27	30.19	120

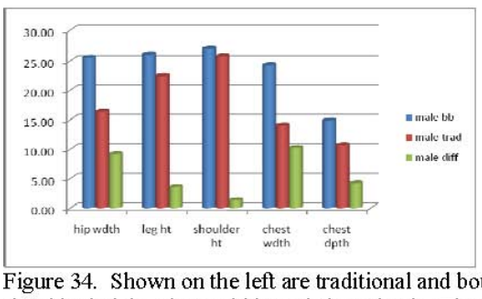
8.3 Bulk Factor

A number of the bounding box dimensions can be compared directly to a traditional anthropometric measurement counterpart. For instance, hip width measured using calipers, is compared to hip width extracted from the scan data using the bounding box technique. The comparable measurements and differences between the mean values for men and women are shown in Table 18. These values are particularly important in understanding the bulk that added when outfitted in turnout gear. The dimensions include hip width, leg height, shoulder height, chest width, chest depth, and buttock-knee length. The mean values for the bounding box measurements are all larger with the exception of buttock-knee length. This is due to the differences in the measurement approach. Traditionally measured, buttock-knee length is capture using a caliper held horizontally from the back of the buttocks to the front of the knee. The fire engine seat allowed the firefighter to shift back into the seat (it was cut out), creating a buttocks-knee measurement that is slightly smaller than traditionally measured. Otherwise, the bounding box dimensions reveal the "bulk factor" as shown in Figures 34 and 35. Table 19 reports the bulk factor for hip width as 9.2" and 7.4" inches for men and women, respectively. Leg height is larger by 3.6" for the male population and 4.8" the female subjects. Shoulder height is 1.3" and 1.5" larger for male and female populations, respectively. Chest width for both increase by 10" and chest depth by 4" and 3" for men and women.

Table 18. Differences between bounding box dimensions and traditional anthropometry

	male bb	male trad	male diff	female bb	female trad	female diff
FRS dimensions	mean	mean	mean diff	mean	mean	mean diff
hip width	25.53	16.36	9.17	23.89	16.50	7.39
leg ht	26.02	22.42	3.61	25.02	20.27	4.75
shoulder ht realigned w/o seat dimensions	27.05	25.72	1.33	25.68	24.14	1.54
chest width original	24.25	14.03	10.22	22.65	12.43	10.21
chest depth realigned w/o seat dimensions	14.87	10.68	4.19	13.22	10.17	3.05
butt-knee length	24.05	24.96	-0.92	22.45	23.43	-0.99

Table 19. Comparison of differences between bounding box dimensions and traditional anthropometry for male and female subjects.



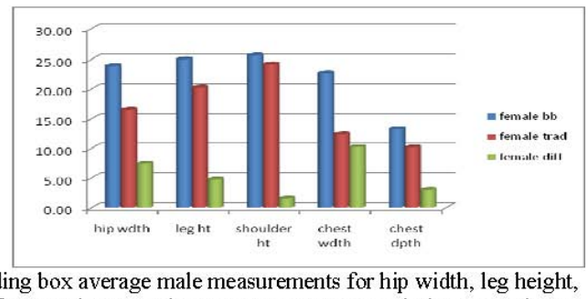


Figure 34. Shown on the left are traditional and bounding box average male measurements for hip width, leg height, shoulder height, chest width, and chest depth. The differences between the two measurements techniques are shown in green. On the right is the same graph for female subjects.

	male diff	female diff
hip width	9.17	7.39
leg height	3.61	4.75
shoulder height	1.33	1.54
chest width	10.22	10.21
chest depth	4.19	3.05

Figure 34. Shown on the left are traditional and bounding box average male measurements for hip width, leg height, shoulder height, chest width, and chest depth. The differences between the two measurements techniques are shown in green. On the right is the same graph for female subjects.

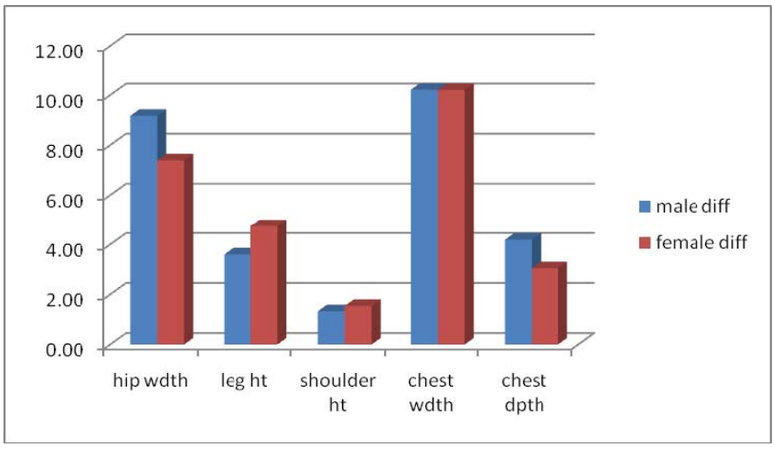


Figure 35. The differences between these five measurements for male and female subjects are shown above. These differences can be considered the "bulk factor" per measurement. They are very similar for both the male and female subjects.

9. Principal Component Analysis

A subset of the bounding box dimensions were selected as the anthropometric variable considered relevant to seat and seatbelt design. The variables selected were hip width, leg height, popliteal length, shoulder height realigned, chest width, chest depth realigned, and buttock-knee length. The summary statistics including the mean, standard deviation, minimum, and maximum values for these variables are shown in Table 20. Seven variables, however, are a lot to consider when attempting to interrogate the firefighter database for design candidates. Instead, a PCA was run on the sample of men and women separately to identify and quantify the important variation found in the 7 variables. The PCA is a multivariate analysis that fins and simplifies the simultaneous variation in a large set of variables by reducing them to a smaller set of new variables called "principal components."

FRS BB Summary Statistics from PCA

	MALES n=84 (in)				FEMALES n=36 (in)			
Variable	MIN	Mean	SD	MAX	MIN	Mean	SD	MAX
HIPWDTH	19.915	25.531	2.316	32.036	20.475	23.89	1.818	27.323
LEGHT	23.701	26.025	1	29.213	23.228	25.017	0.936	26.85
POPLTH	16.047	17.787	1.021	20.517	15.533	17.013	0.667	18.801
AL-SHLDR	24.95	27.05	1.186	30.265	24.682	25.684	0.85	28.461
O-CHSTWDTH	21.203	24.248	1.698	29.479	20.836	22.646	1.197	25.902
Al-CHSTDPTH	11.132	14.874	2.535	22.732	10.933	13.216	1.618	19.462
BUTKNEL	20.483	24.046	1.846	30.191	19.269	22.449	1.648	27.984

As shown in Table 21, the first component (axis) for all seven variables for the male subjects increase or decrease together. This overall size component accounts for 43% of the variability with this population. For the second component (PC2), there appears to be a contrast in torso size and leg length. As the legs lengthen, the torso appears to become thinner, and as the legs shorten, the torso becomes larger. The result is that using the 2 components, 62% of the variation in the male population can be explained. Table 22 shows the PCA for the female population. The first component is overall large or small, and the second component shows the same trend as the male population. Combined, PC1 and PC2 account for 61% of the variation within the population of female firefighters.

Table 21. PCA analysis for the male population (n=84).

Male Factor Correlation Matrices

	MALES					
Variable	PC1	PC2	PC3	PC4	PC5	PC6
HIPWDTH	**0.73782**	**0.23694**	0.41623	0.24142	0.22267	-0.15049
LEGHT	**0.36179**	**-0.80508**	0.18559	-0.11301	-0.17384	-0.37243
POPLTH	**0.67378**	**-0.32773**	-0.31922	0.38672	0.37947	0.06444
AL-SHLDR	**0.71861**	0.03396	-0.5762	-0.22955	-0.12916	-0.07496
O-CHSTWDTH	**0.69059**	**0.25956**	0.15557	-0.55965	0.27651	0.02188
AI-CHSTDPTH	**0.60407**	**0.58119**	-0.02016	0.23455	-0.38467	-0.18451
BUTKNEL	**0.74281**	**-0.29275**	0.21492	0.01609	-0.3	0.47465
Eigen Value	3.03924	1.30371	0.7124	0.64178	0.55491	0.43093
Variance Expl. %	43.42%	18.62%	10.18%	9.17%	7.93%	6.16%

Males

- PC1 represents "Overall Size,"
- PC2 represents a contrast between "Torso Size *and* Leg Length"
  (*Long Legs and Thin Torso* VS. *Short Legs and Robust Torso*)
- Total Variance explained by PC1 and PC2 is 62.0% (6 variables reduced to 2 new ones)

Table 22. PCA analysis for the male population (n=84).

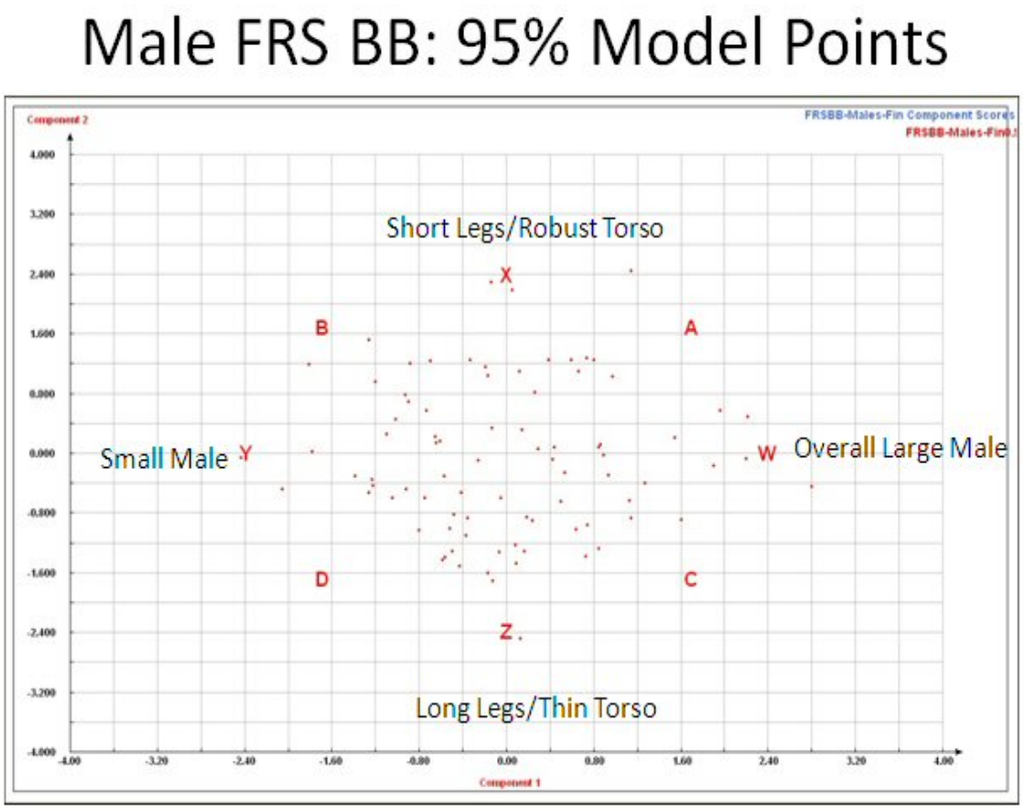
Female Factor Correlation Matrices

	FEMALES					
Variable	PC1	PC2	PC3	PC4	PC5	PC6
HIPWDTH	**0.76742**	0.04712	0.354	0.3073	-0.2341	0.3165
LEGHT	**0.70759**	**0.33227**	0.2542	0.0736	0.5458	-0.13239
POPLTH	**0.4351**	**0.52089**	-0.5762	0.42254	-0.09812	-0.0275
AL-SHLDR	**0.76039**	**-0.27626**	-0.23942	-0.32712	0.15696	0.35192
O-CHSTWDTH	**0.76027**	**-0.2768**	0.39804	0.0541	-0.21712	-0.29033
AI-CHSTDPTH	**0.41008**	**-0.73224**	-0.4275	0.2238	0.08542	-0.15988
BUTKNEL	**0.68199**	**0.32681**	-0.21422	-0.52187	-0.22459	-0.17382
Eigen Value	3.06841	1.17986	0.96634	0.71076	0.49184	0.38238
Variance Expl. %	43.83%	16.86%	13.80%	10.15%	7.03%	5.46%

Females

- PC1 represents "Overall Size"
- PC2 represents a contrast between "Torso Size *and* Leg Length"
  (*Long Legs and Thin Torso* VS. *Short Legs and Robust Torso*)
- Total Variance explained by PC1 and PC2 is 60.7% (6 variables reduced to 2 new ones)

Representative cases from the distribution are selected base on the accommodation level desired in the workspace, or in this case, the fire engine seat. For this application, both 95% and 90% accommodation were examined. As a large part of the variability can be accounted for with 2 components, a plot of the 95% accommodation distribution is shown in Figure 36 for the male population. The population demonstrates an even distribution in this component space, and 8 models can be identified. These models describe body proportions such as big all over (W), small all over (Y), short legs with robust torso (X), and long legs with thin torso (Z). If the models are accommodated in the design, all other subjects fall within the circle of accommodation. Instead of evaluating all 85 subjects, only 8 need to be tested



Values for the model point variables are shown in Table 23. These values are calculated using statistics, but do not represent a subject. Therefore, a method of find the "nearest neighbor" is used to represent each case realistically. The nearest neighbors for each case are shown in Appendix D. Two cases for the male population were selected and are large all over and long legs/long torso. These subjects are shown pictorially in Figure 37. As shown on the plot, their dimensions are almost exactly the target points of the models. The exact values can be found in Appendix D.

Table 23. Model point variable values for male subjects.

95% Male Boundary Model Points

	Males: 95% Boundary Case Anthropometric Values (Inches)							
Variable	A	B	C	D	W	X	Y	Z
HIPWDTH	29.06	23.72	27.34	22	29.31	26.74	21.75	24.32
LEGHT	25.33	24.2	27.85	26.72	26.82	24.24	25.22	27.8
POPLTH	18.34	16.19	19.38	17.23	19.31	17.05	16.27	18.53
AL-SHLDR	28.44	25.78	28.32	25.66	28.93	27.14	25.17	26.96
O-CHSTWDTH	26.77	23.1	25.39	21.73	26.84	25.22	21.66	23.27
AI-CHSTDPTH	19.57	14.78	14.96	10.18	18.26	18.13	11.49	11.62
BUTKNEL	25.34	21.06	27.03	22.75	27.08	22.85	21.02	25.24

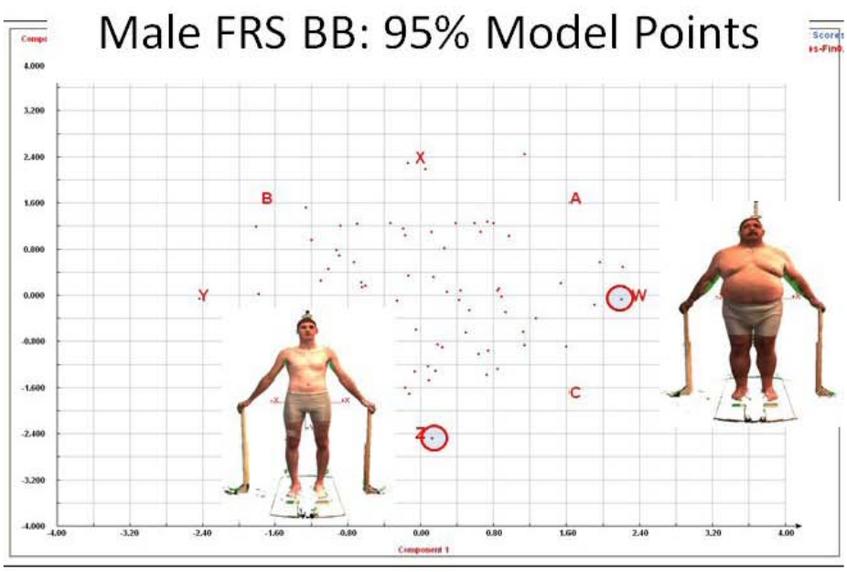


Figure 37. 95% accommodation space for male subjects.

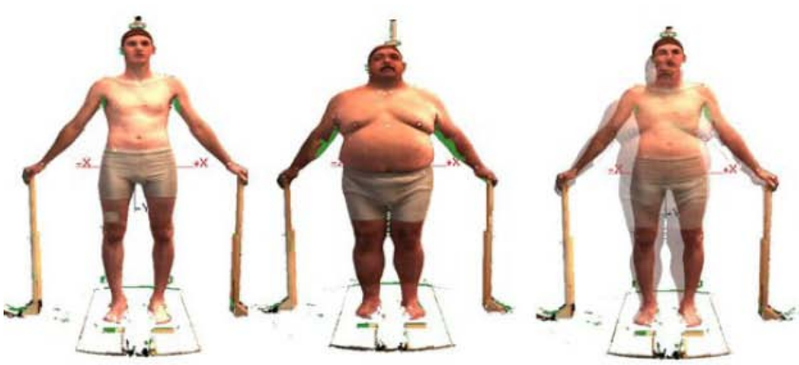


Figure 38. Subjects for Models Z and W are identified and visualized in the A scan pose to demonstrate differences in extreme body proportions.

The PCA was also performed on the female data resulting in 8 model descriptions. The dimensions for these variables according to each model are shown in Table 24. The model points are plotted in the PCA component space as shown in Figure 39. The plot is similar to the male population, although the axes are flipped and the values are smaller. As the female population was a small sample (n=36), the accommodation level was dropped to 90% to tighten the boundary and identify actual subjects within the study who most closely represented the important model points. Table 25 and Figure 40 show the results of the 90% accommodation analysis. Two female subjects were selected as the small case and the short legs/robust torso combination. These subjects are shown in Figures 40 and 41. All four cases, 2 for male and 2 for female subjects, are shown in Table 25. The differences between the predicted (model) dimensions and the subject's measurements are found in Appendix A. The four subjects are shown in their seated scans in Figure 43.

Table 24. Models for the female distribution at 95% accommodation.

95% Female Boundary Model Points

	Males: 95% Boundary Case Anthropometric Values (Inches)							
Variable	A	B	C	D	W	X	Y	Z
HIPWDTH	26.61	21.48	26.3	21.17	27.52	24.11	20.26	23.67
LEGHT	26.81	24.37	25.66	23.23	26.74	25.83	23.3	24.21
POPLTH	18.18	17.12	16.91	15.84	17.77	17.92	16.26	16.11
AL-SHLDR	26.44	24.06	27.3	24.93	27.36	25.07	24	26.29
O-CHSTWDTH	23.71	20.36	24.93	21.58	25.01	21.78	20.28	23.51
AI-CHSTDPTH	12.26	9.82	16.61	14.17	14.94	10.14	11.49	16.3
BUTKNEL	25.51	21.37	23.53	19.39	25.37	23.85	19.53	21.05

Female FRS BB: 95% Model Points

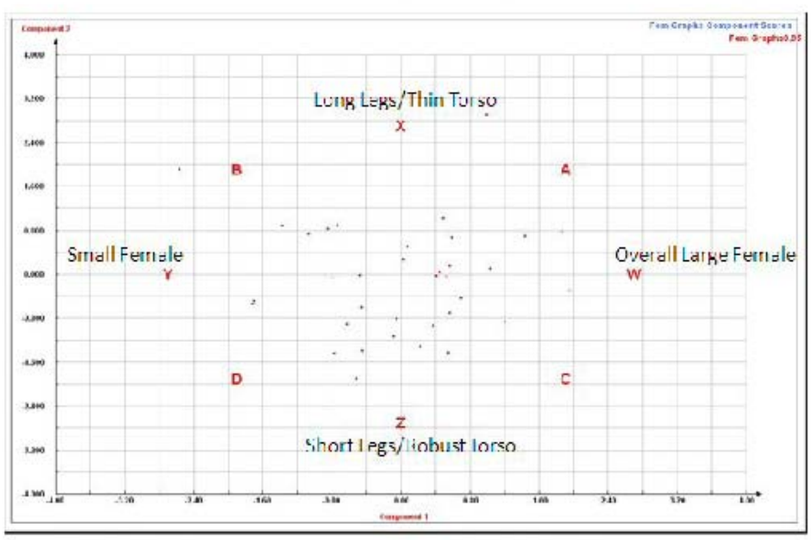
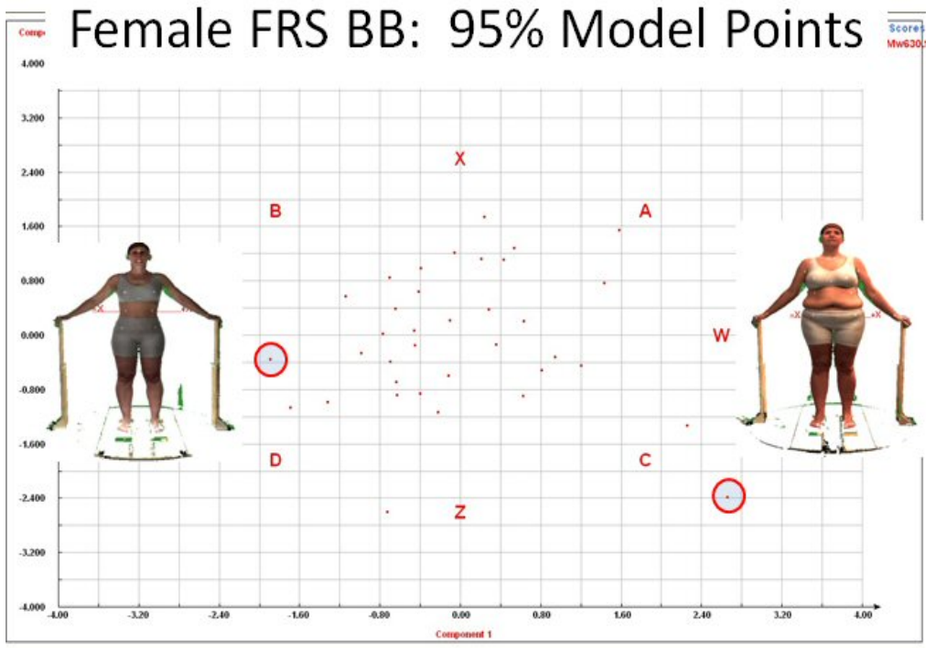


Figure 39. 95% accommodation space for female subjects.

Figure 41. 95% accommodation space for female subjects.


Female FRS BB: 95% Model Points
X
B
A
W
D
C
Z
Component 1

-X
+X

Table 26. The four cases selected for seat and seat system restraint design

Suggested FRS BB 95% Boundary Cases

	Female FRS BB Boundary Cases		Male FRS BB Boundary Cases	
Model Point	Y	Z	Z	W
Variable	**Case-1**	**Case-2**	**Case-3**	**Case-4**
HIPWDTH	20.26	23.67	24.22	29.61
LEGHT	23.3	24.21	27.95	26.89
POPLTH	16.26	16.11	18.59	19.43
AL-SHLDR	24	26.29	26.95	29.09
O-CHSTWDTH	20.28	23.51	23.19	27.05
AI-CHSTDPTH	11.49	16.3	11.35	18.53
BUTKNEL	19.53	21.05	25.34	27.32

Females:
Case 1 – Overall Small
Case 2 – Female Short Legs/Robust Torso

Males:
Case 3 – Male Long Legs/Thin Torso
Case 4 – Overall Large

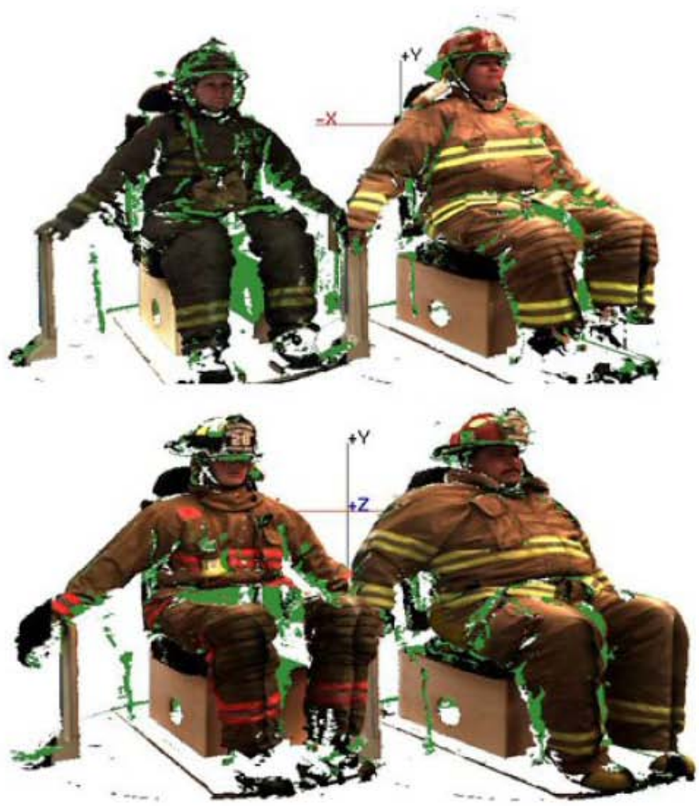


Figure 43. Four "model" subjects shown in their seated, encumbered scan pose.

10. Design Tools

There are a number of opportunities for applying these data described previously. Summary statistics are important in understanding the range of variation that can be found univariately (single variable) within a population. The summary statistics can be used to compare to other population databases as well to get an idea of the similarities and differences between firefighters and other occupations. The bounding box dimensions, particularly differences between the bounding box dimensions and the corresponding unencumbered measurements, can be used as a "bulk factor" to acknowledge the added bulk when designing around subjects or modeling. The integer value provided should be considered when allowing for hip room, etc. The bounding box data as the ideal model points from the principal component analysis (PCA) can be used in any computer-aided design modeling and as they are simply "boxes" to accommodate, can be very easily generated and implemented in any design process. The small female boxes and the large male boxes are shown below in Figure 44. The black (very dense) surface data is a subset of the large male subject's whole body seated and encumbered scan. This image is superimposed with the small female's corresponding bounding box. Differences in these extreme dimensions are shown in this figure. For instance, hip width for the small female is 20.20" while the hip width for the male is 29.6", showing a range of 9". These boxes represent the ideal model values, but can be changed to also represent the actual subject measurements. If a different level of accommodation is desired, again the PCA can be run on the existing or new anthropometric data, and these values quickly changed to generate a new design tool. For a more sophisticated model, the actual scan data from the selected subjects can be formatted as input as a digital human model. Using the anatomical landmarks, joint centers can be estimated and used to articulate the scan within the model. Whatever the level of design capability, the data can be adjusted to meet the needs of the designers. Suggestions and advertisements for use of the data are shown in Appendix E. As this is the only US firefighter anthropometry study in existence, it is important to publicize the availability of the data for improving fire apparatus and equipment safety.

A physical, geometric representation of these models is important as well for testing existing equipment or prototyped designs. Shown in Figure 45 is Fireman Mike. This manikin is carved from foam and therefore, is very lightweight. The body is an ellipsoidal shape representing, in this case, maximum shoulder height, hip width, and chest breadth. The head is optional if overhead clearance is under consideration. The legs are simply placed in the sockets and are used to check seat pan clearance and possibly, clearance with opposing seats. The lower legs telescope out of the upper legs and drop down to examine the ability to contact the floor. As shown in Figure 46, there are firefighters who are unable to sit properly in the seat with their feet flat on the floor, an obvious safety hazard. The head and legs are stored inside the Fireman Mike torso to easily transport the test manikin.

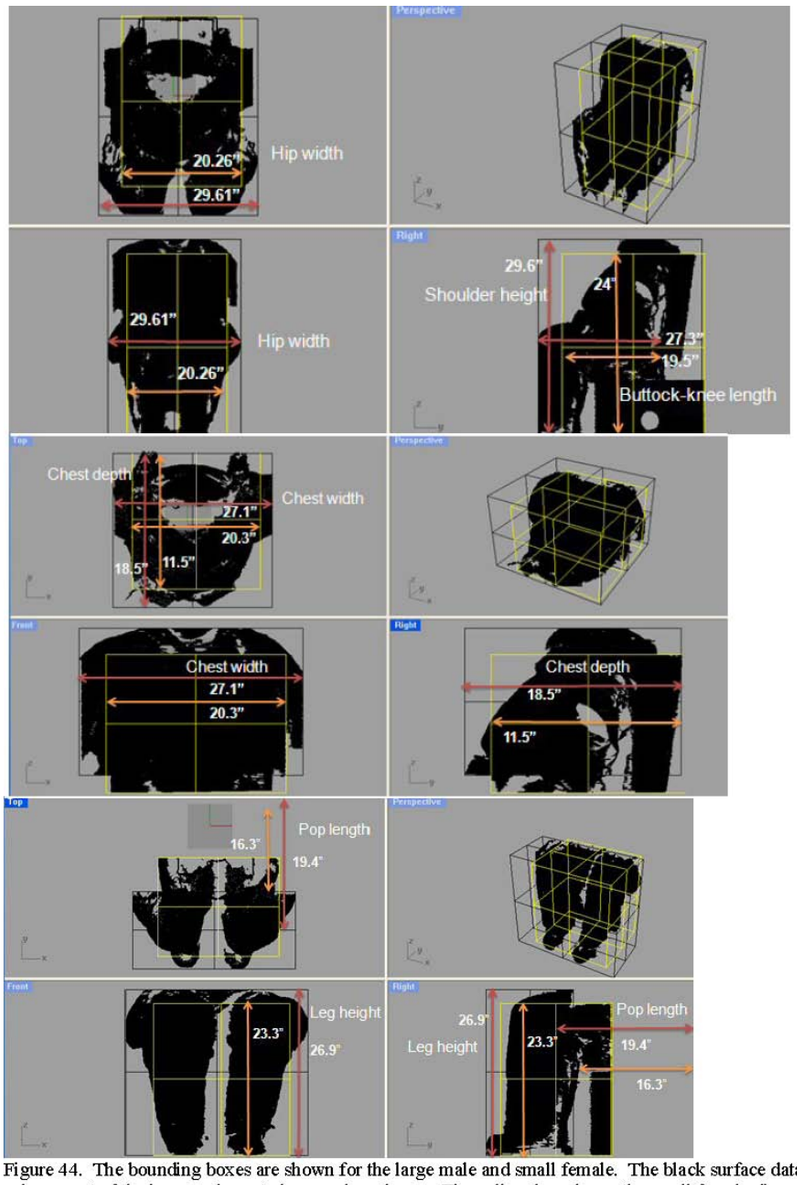
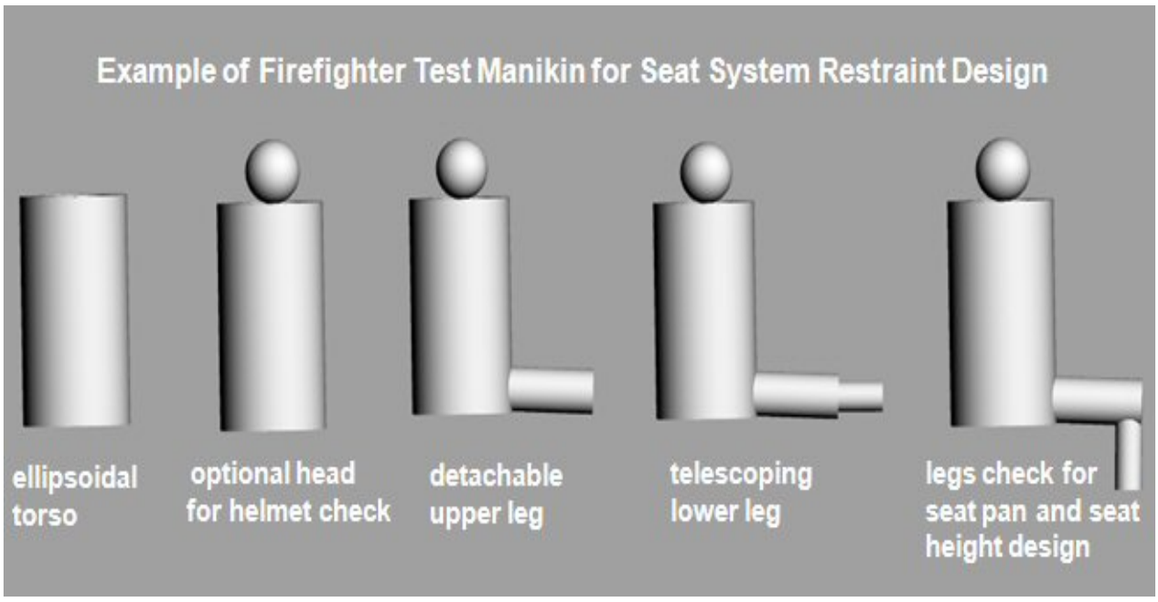


Figure 44. The bounding boxes are shown for the large male and small female. The black surface data is a subsegment of the large male seated, encumbered scan. The yellow box shows the small female dimensions in comparison.



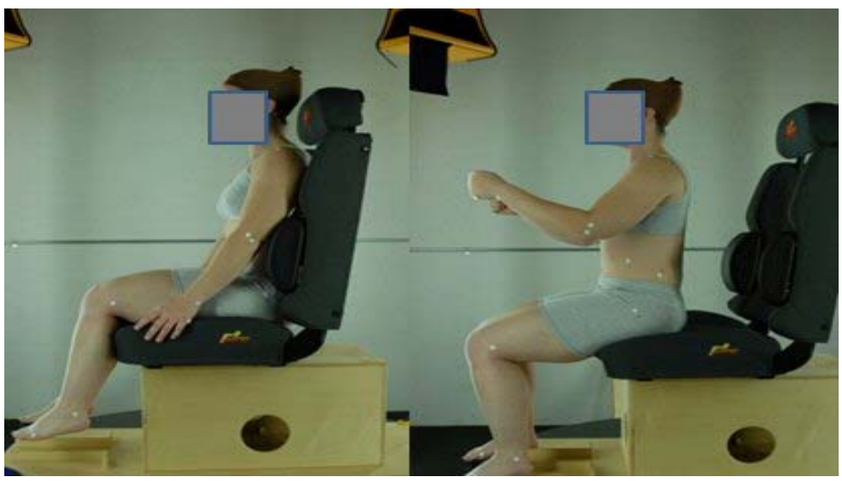


Figure 46. A small female firefighter demonstrates her inability to touch the floor while sitting back in the seat. Only when she sits forward can she touch the floor.

11. Summary

The second leading cause of line-of-duty deaths for US firefighters is attributed to vehicular accidents, and many firefighters who died were not wearing their seatbelt. It has been proven that many firefighters are not physically able to reach, manage, or maneuver their seatbelt such that they are safely restrained within the fire engine. Seat belts have been proven to save lives and yet this level of protection is not offered to the firefighter. Current seat specifications are inadequate due to outdated anthropometry, inappropriate use of percentiles, and lack of attention to the fact that the firefighter is outfitted in equipment adding considerable bulk and weight. As shown in Table 27 it is fairly straightforward to estimate the added weight and height to a typical firefighter's reported height and weight given the addition of turnout gear, tools, helmet, and boots. However, charactering the firefighter's volume given the added bulk requires 3D anthropometry, selective image analysis, and advanced statistical solutions which have been provided with this study.

Table 27. Differences in mean weight and height for the encumbered and unencumbered firefighter.

	mean	std dev	min	max	n
weight	196.71	51.35	109.80	343.90	122
encumbered wt	225.29	53.68	131.70	373.00	122
wt difference	**28.57**	**2.33**	**21.90**	**29.10**	122
sitting ht	36.30	1.65	32.72	40.79	122
encumbered ht	40.38	1.80	36.14	44.49	122
ht difference	**4.08**	**0.15**	**3.43**	**3.70**	122

The multi-dimensional space that describes the shape and size of the seated, encumbered firefighter were captured using 3D whole body surface scanning. Additional postures with and without gear were captured as well to better understand and quantify the "bulk factor" added by the turnout gear. Traditional anthropometry was measured such that this data base can be compared and enhanced by other anthropometric database information. This facilitates the ability to characterize firefighters, for instance, with respect to other occupations. The sampling strategy was designed to carefully select each subject in order to most likely capture the variability that is the firefighting population. The success of this approach was highlighted in a comparison with the large national survey of thousands of civilians. Summary statistics were generated for all measurements to provide an overview of the population. Comparison of these statistics revealed potential problems with the FAMA self-reported anthropometric study.

Anatomical landmarks on the standing and seated unencumbered scans were located and recorded for future modeling and measurement use. The dimensions that related to seat and restraint design were identified and extracted from the seated, encumbered scans in the form of bounding boxes. A principal component analysis (PCA) was performed on these data and multivariate models generated to most succinctly describe and present cases (models) to use with ergonomic designs of fire apparatus. A physical representation of these models has been presented as an innovative design tool for existing and prototyped fire apparatus.

APPENDIX A

Anthropometric Survey of Firefighters to Improve Seatbelt Safety

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2. Associate Investigators

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3. Medical Consultant or Monitor

Major Eric Hermes, AFRL/HEPA, DSN 785-5365, eric.hermes@wpafb.af.mil

4. Facility/Contractor Total Contact will recruit and schedule firefighter volunteer subjects, coordinating measurement sessions through the General Dynamics' Cooperative Research and Development Agreement (CRADA) for use of Air Force Research Laboratory (AFRL) facilities. The subjects will be escorted from the visitor's center to the USAF facilities in Building 824, Area B. Principal Investigator Jennifer Whitestone and Associate Investigators, as listed in Item 2, will perform research activities. Analyses using the project's data will be performed at the Total Contact facility located in Germantown, Ohio. Additional statistical analysis will be conducted at the Tailored Statistical Solutions (TSS) facility located in Beavercreek, Ohio; however, the statistician will not be receiving any identifiable subject information. As stated in the TSS subcontract, ***TCI-FRS-02***, TSS will receive measurement data extracted from 3D scans, fit results, and demographic information, all in spreadsheet form. Therefore, TSS is not listed as an Associate Investigator. Resumes of Investigators not on file are found in Attachment B. Password protected computers as well as locked cabinets reside at both offsite facilities for safekeeping of subject data. Funding for this project is provided by the National Fallen Firefighters Foundation (NFFF).

5. Objective The three objectives of this protocol are: 1) to measure a small, but demographically representative sub-segment of the current US firefighter population using both traditional and three-dimensional (3D) anthropometric techniques; 2) to derive anthropometric design tools from these data to assist emergency apparatus manufacturers in developing fire engine seat/seatbelt systems that safely contain the encumbered firefighter; and 3) to demonstrate the utility of an updated firefighter anthropometric database using modern measurement technology and advanced statistics that can improve the performance and safety of all firefighter protective equipment.

6. Background Firefighter anthropometry for automotive fire apparatus design has been recognized as a pressing issue to prevent firefighters from being killed in crashes and rollover incidents, as well as from ejections or falls from moving vehicles. The International Association of Fire Chiefs (IAFC) recently reported that approximately 25% of the current firefighter population are unable to fasten their seatbelts, and as a result, "36 of 52 firefighter collision fatalities (for 2006) were not wearing belts". In fact, motor-vehicle-related incidents are the second leading cause of firefighter line-of-duty fatalities. The National Fallen Firefighters Foundation (NFFF), the International Association of Fire Chiefs (IAFC), the Safety Task Force of the NFPA 1901 Fire Apparatus Standards Committee, and the Fire Apparatus Manufacturers Association (FAMA) have jointly advocated for an anthropometric survey of U.S. firefighters to address this design issue. In a white paper issued in 2006, the authors note that the current configuration of crew-compartment seat arrangements and seatbelt placement make it difficult or impossible for firefighters wearing protective clothing to reach and fasten their seatbelts while operating automotive fire apparatus. The problem of accessing seat belts was further complicated by the presence of the self contained breathing apparatus (SCBA), which is integrated into the backs of many fire apparatus seats, and adds an additional set of shoulder straps and a waist belt to be accommodated, as well as several hoses, attachments and accessories. The joint stakeholders emphasized that all of these factors must be taken into consideration in the design of cabs, seats, seatbelts and even SCBA straps.

In general, fire apparatus specifications are based on outdated anthropometric data, do not account for demographic changes in the firefighter population, and do not include increased personal space volume requirements as a result of wearing protective equipment. While body size data generated by the military have become the normative basis for commercial sizing specifications, military populations cannot represent the firefighter population because of relatively strict anthropometric armed forces entry requirements and height/weight guidelines for troop retention. Seats and seatbelt systems designed and sized for a military population do not provide the same level of protection to firefighters because of the greater diversity in body size and shape exhibited by the firefighter population, particularly when outfitted in turnout gear. Civilian anthropometric surveys of firefighters, gathered 30 or more years ago, do not reflect the increase of height by 1 inch per decade; nor do they account for the fact that firefighters are now heavier (15 lbs heavier for males and 22 lbs for females) than those in all non-military occupations combined. In addition, these surveys are based on limited measurement techniques (traditional anthropometry) and applications of these measurements (e.g., the use of percentiles) that have since been proven to be ineffective and misleading for the design process.

It has been demonstrated that high resolution surface scanning, when used with thoughtful measurement extraction and appropriate statistical analysis, can overcome problems associated with traditional data collection and anthropometric design specification. Scanning has been established as a rapid, accurate, and repeatable means of providing shape and contour information. Traditional measurements can also be extracted from 3D surface data, with the added value of knowing their spatial relationships. Measurements

are judiciously selected, and used with methods such as principal component analysis (PCA) or feature envelopes (FE). This approach has been demonstrated as a valuable design tool for protective equipment and workstations. Three-dimensional anthropometric surveys of civilians, such as the CAESAR (Civilian American and European Surface Anthropometry Resource) project, have not included "firefighter" as a recorded occupation. Therefore, none of these data are useful for the firefighter community. An anthropometric survey of firefighters, with and without their turnout gear, is needed to improve the fit and performance of automotive fire apparatus.

7. Impact Results from this study will provide information regarding the most effective and efficient methods of applying 3D anthropometry for increasing seat/seatbelt safety among firefighters, resulting in new specifications for seat and seatbelt design. Data collected under this CRADA will be made available to the Air Force anthropometry program to enhance their existing anthropometric database. This small study will also lay the groundwork for a larger, nationwide study of firefighters to address fit and integration issues associated with other protective equipment and apparatus.

8. Experimental Plan

a. Equipment:

The anthropometric facilities at Wright-Patterson Air Force Base in building 824 will be employed for this survey and include both traditional measurement and 3D anthropometric tools. The traditional instruments include the anthropometer, sliding and spreading calipers, tape measure, pupilometer, scale, measuring table, and adjustable foot supports.

The 3D scanner is the Cyberware WB4 model, a laser-based surface imaging system. In 17 seconds, the scanning system acquires approximately two million points at a 3 millimeter resolution over the entire body, while simultaneously recording color or luminance information. The WB4 scans a cylindrical volume 2 meters (79") high with a diameter of 1.2 meters (47") and is classified by the United States Food & Drug Administration (FDA) as a Class I device. In fact, Cyberware limits the laser power so that there is a substantial margin of safety within the limits of the Class I specifications. Because there are no known hazards associated with Class I laser products, the FDA does not require that a hazard warning be affixed to the Cyberware WB4 (Federal Register Part III, 21 CFR 1040.10 and 1040.11). The FDA Department of Health and Human Services Center of Devices and Radiological Health states that they have no concerns with the compliance of this product with the performance standard at this time.

Software used to perform image processing will include *Integrate*, a 3D visualization, analysis, and manipulation tool developed by the Air Force specifically for 3D anthropometry; *Rhino*, a commercial free-form 3D modeling tool for extracting measurements and creating NURB surfaces; and *CyEat*, a Cyberware software tool for editing 3D surface data. Base SAS, SAS/STAT and SAS/GRAPH as well as SPSS will be used to analyze and graphically present the data.

Two fire engine seats will be used during the study. One seat will be securely placed on the scanning platform for positioning the subject during the seated scans. This seat will ensure that all subjects are positioned in a similar orientation. The second seat is attached to a simulated seatbelt system. The subject will be asked to sit in the seat and attempt to buckle the standard-size seatbelt. If the subject is unable to buckle the seatbelt, this failure will be recorded as part of the fit portion of the study. Additionally, the subjects will be asked to don study-provided straps from the SCBA over their turnout gear prior to testing the seatbelt.

b. Subjects:

Study participants will be both career and volunteer firefighters recruited from fire stations in cities and villages within a 100 mile radius of the Wright-Patterson area. Subjects will be recruited through information provided in the form of flyers posted at fire stations, invited presentations made by Total Contact, web site notices, newspaper advertisements, and radio announcements. Presentations and radio announcements will follow the published FDA guidance on subject recruiting. This study requires 120 subjects, the selection of which is based on demographics determined by the stratified sampling plan. The planned distribution of subjects is 30 in each of the following categories: White Male, Black Male, Other Male, and Females. This distribution of subjects will allow for sufficient variability within each of the largest categories (White Male and Black Male) while also obtaining a general idea of the anthropometric variability within the smaller groups. While these sample sizes should be easily achievable within the two largest categories, they may only be the target sizes for the smaller groups. Note that even though Other Males includes Hispanic and Asian Males as well as other unidentified racial categories, race will be recorded for each subject in the sample.

Selection of the subjects will be coordinated through the station's fire chief to assist in pre-determining demographics of potential participants. Subjects will be excluded only as the cells representing their demographics are filled. Additionally, women who are pregnant and therefore, not actively firefighting, and subjects under 18 years of age are excluded. Subjects will be recruited using newspaper advertisements, web site notices, flyers, and radio announcements provided by Total Contact. Examples of the advertisements are located in Attachment D. Each potential subject will be interviewed by phone using the template found in Attachment D entitled Participant Inquiry. The individual will be informed that their 3D image, a recognizable photographic representation of themselves, will be most definitely be made available to the public for unrestricted use. Specifically, their scanned image, age, race, and gender will become public domain. No other identifiable information will be released (e.g., date of birth). An additional option, if they grant permission to the researchers, is that their digital photographs would be made available for publication purposes. If the subject is comfortable with these terms, even if they decline release of their digital photos, and if their demographics meet the current requirements of the study, they will be scheduled for testing. Their name will be recorded on the Subject Inquiry form and used for scheduling purposes only. The Subject Inquiry forms will be shredded at the conclusion of the study and the subject's name will not be recorded on any other document (with the exception of

the consent form). During the phone interview, they will be instructed to bring their turnout gear, including helmet, to the study session. Total Contact will work closely with General Dynamics to schedule subject measurement sessions. Subjects will be paid $20 per hour with a maximum compensation of $40 for a 1-2 hour measurement session. If subjects are active duty, they will need written approval from their commander for off-duty employment. Active duty subjects will also be compensated $20 per hour with a maximum compensation of $40 for a 1-2 hour session. Subjects will be paid by Total Contact.

c. Duration:

The duration of the study will be 6 months from the start of data collection. Each subject will require 1-2 hours for testing. However, due to concurrent studies using the USAF facilities and projected difficulties with scheduling subjects, the data collection should take 2-3 months. At the end of the study, data collection, analysis, and final reporting will be complete.

d. Description of experiment, data collection, and analysis:

Subject throughput is important for minimizing required subject time and maximizing data collection effort given a 2-person investigator team. Upon arrival, the subject will be briefed on the study requirements. Each participant will have an opportunity to ask questions before signing an informed consent (Attachment A) and completing the questionnaire (Attachment C). The subject will then move to the dressing room to change into biker shorts (and sports bra for female subjects). A form-fitted cap will be fit to their head to compress the hair for 3D scanning. The investigator, the same sex as the subject, will palpate the subject's skin to identify the locations of bony prominences and joints. These anatomical landmarks will be marked with a grease pencil. The investigators will then measure and record the traditional dimensions; one measuring and another recording. Each of the measurements has been determined to have either relevance to the seat system fit or to gather data in support of the projected large firefighter anthropometric survey. A list of the measurements is found in Attachment C.

After the subject is measured to record traditional dimensions, the subject's landmark locations previously indicated by pencil marks, are then covered with a 1 cm adhesive sticker that is easily identified from the scan image. The subject moves to the scanning platform and is asked to place their feet on the footprint illustrations while standing in the scanning volume space. The sway stick, a vertical head rest that gently rests on the subject's head, is lowered to make contact with the subject to minimize swaying during the 17 second scan. The subject is asked to extend their arms at a 30 degree abduction angle prior to scanning. The subject is asked to hold their breath during the scan again to minimize torso movement during respiration. A quick view of the image by the investigator is required to confirm that the data meet quality control (QC) standards. If, at any time during the scanning process, the image does not meet QC, the subject is asked to

repeat the scan. The subject then steps off of the platform while the chair, a fire engine seat modified to safely and securely hold the subject, is placed in the middle of the scanning volume. The subject is then asked to sit comfortably, but with their back touching the back of the chair. The subject is asked to abduct their arms at a 30 degree angle from the torso and to hold this position while the scan takes place. Again, the quality of the image is verified before proceeding to the next step.

The subject is asked to change back into their street clothes and don their turnout gear, including helmet. They resume the same standing position on the platform including an abduction of the arms. The subject is scanned and the image evaluated. The subject then steps down from the scanning platform and the chair is placed on the platform. The subject resumes the seated position to the best of their ability given possible helmet and protective equipment interference. The subject is scanned in this position. The subject is asked to don the study-provided straps from an SCBA. They are then instructed to sit in a second fire engine seat mockup and attempt to fasten the seat belt. Their ability to fasten the seatbelt is recorded. They are then asked to doff their gear, are debriefed, compensated, and escorted to security for dismissal.

After data collection is complete, the sample will have post-stratification weights applied in order to make the sample representative of the national population of firefighters. Univariate summary statistics will be computed to summarize the sampled population. For the investigation of traditional and 3D anthropometry that correlates with seat/seatbelt system fit, the traditional and extracted 3D measurements will be the independent variables, and fit the dependent variable. PCA models do not have traditional independent or dependent variables due to the nature of the analysis. Analysis techniques similar to those that have been successfully used with previous 3D anthropometric studies will be applied for this application. The expectation is that using extracted dimensions from the scan data, PCA, and feature envelopes, design specifications and design tools for fire apparatus design will be produced.

Safety monitoring:

Confidentiality protection:

Medical monitoring is not required for this study. If safety or medical issues arise, the Medical Monitor will be consulted.

The investigators will take precautions pertaining to handling and storing of subject data. The subject information and data will include seatbelt fit test results, demographics, traditional anthropometry, and surface scans of the subject with and without their turnout gear, as well as digital photographs of the subjects. The data will not include subject's

name, date-of-birth, social security number, or any other identifiable information. The data will be for research purposes only and will be closely guarded by members of the research team. The data will be saved on the laboratory's desktop computer under a password-guarded account. Only investigators on the project will have access to the account. Two backup disks per testing day will be made and stored in a locked environment. All paper copies will be stored in a locked cabinet.

Total Contact's primary product is a durable medical equipment device made available to patients only through a physician's prescription, letter of medical necessity, and private patient information. As such, Total Contact has safeguards in place to ensure patient confidentiality and privacy. Research subject data accuracy, confidentiality, and security are of the utmost importance to Total Contact. While a copy of one complete data set per subject (including the traditionally acquired dimensions, demographic questionnaire, digital photographs, and scan data) will be made by the Principal Investigator to be used for data analysis, these data will be stored at the Total Contact facility on one password-protected computer for the digital information and in a locked filing cabinet for the paper copies.

Tailored Statistical Solutions is a subcontractor performing statistical analyses using a subset of the study data. As a subcontract with Total Contact, Tailored Statistical Solutions has signed a contract agreeing to protect the integrity and confidentiality of the shared and/or exchanged data. One copy of the data containing only demographic information, fit results, and measurements extracted from 3D images will be made for

Tailored Statistical Solutions to be used for statistical analysis. This information will be stored on a password guarded computer at the Tailored Statistical Solutions facility in Beavercreek, Ohio.

Additionally, although the digital photographic images clearly show the subject's face, the facial scans will not be published without full consent of the subject. At the completion of the study, one complete copy of all of the data, including scans, photographs, and derived information will be delivered to the National Fallen Firefighters Foundation. All data associated with this study will be managed to prevent theft, fraud, misuse, or misappropriation.

9. Risk Analysis Cyberware equipment has been in use for scanning the human body for over two decades and tens of thousands of people have been scanned. There have been no reported cases of injury. No one has even reported any sensation of after-image, such as is normally experienced after looking at an ordinary light bulb or a photoflash. Grocery store and library scanners are comparable. All study investigators who will conduct the scanning portion of the study are competently trained to safely operate the scanner, including required checks to confirm that the scanner's lenses are intact, hence, maintaining the Class I classification. Additionally, there is no risk associated with measurements made using traditional anthropometric tools, nor is there a danger in attempting to buckle the seatbelt.

10. References

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Whitestone J., and Robinette K. (1997). Chapter 7: Fitting to Maximize Performance of HMD Systems, Head Mounted Displays; Designing for the User, Melzer, J.E. and Moffit, Ed., McGraw Hill, NY, NY.

11. Attachments

Informed Consent Document
Curriculum vitae of investigators (if not on file with IRB administrator)
Questionnaires or surveys (if applicable)
Subject recruiting materials (if applicable)
Other attachments if applicable, such as: letters of collaborative support, IND/IDE supportive documents, contractor assurances, and any other supportive documentation.

ATTACHMENT A INFORMED
CONSENT DOCUMENT

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Informed Consent Document For Anthropometric Survey of Firefighters to Improve Seatbelt Safety

AFRL/HEPA, Wright-Patterson Air Force Base, Ohio

Principal Investigator: Jennifer Whitestone, (937) 855-6107, Total Contact, Inc. jen@totalcontact.com

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9. Nature and purpose: You have been offered the opportunity to participate in the "Anthropometric Survey of Firefighters to Improve Seatbelt Safety" research study. Your participation will occur at the Computerized Anthropometric Research and Design (CARD) Laboratory located at Wright-Patterson AFB.

The purpose of this research is to determine body size dimensions of firefighters in order to derive design tools for improving fit and performance of safety equipment such as seatbelts. In fact, injuries and fatalities have been related to poorly fitting seatbelts. This study will assist fire engine seat/seatbelt designers to safely protect firefighters while wearing their turnout gear.

The time requirement for each volunteer subject is anticipated to be a total of 1 visit of approximately one hour. A total of approximately 120 subjects will be enrolled in this study.

10. Experimental procedures: If you decide to participate, you will be asked to complete a questionnaire containing general questions (sex, age, etc.) as well as questions about your experience with fire engine seat and seatbelt fit. You will then be escorted to a dressing room to change into bike shorts (with a sports bra for women) to be worn during the measurement

session. An investigator who is the same sex as you will locate some skeletal landmarks on your skin, by gently feeling for some bone and joints. An example of such a landmark is the tip of your shoulder. These landmarks will be lightly marked with a grease pencil and then covered with a small adhesive sticker, both of which will be removed when the measurement session is completed. You will be measured for 15 body dimensions, such as height and waist circumference, using anthropometric tools such as a tape measure. You will then be measured using a three-dimensional whole body surface scanning system. This is a simple process during which you will stand still for 15 seconds on a platform as multiple cameras record your body's surface contours. You will then be asked to assume a seated position and the scanner will record this position. Following this portion of the measurement session, you will change back into your street clothes and then don your turnout gear. This includes whatever you normally wear when called to a fire. You will be scanned in the same standing and seated positions while wearing your gear. You will be asked to sit in a fire engine seat mockup and asked to find and buckle the seatbelt. This process will be recorded using digital photography. You will then doff your turnout gear and be escorted to the visitor center.

11. Discomfort and risks: During this study the risk of injury is very low. You will not be performing any strenuous physical tasks. The three-dimensional surface scanner does not pose any known risk. The light source is a Class 1 laser which is FDA approved for unsupervised public use. Thousands of subjects have been scanned using this system with no adverse affects. Some subjects have experienced slight skin irritation from the adhesive markers. You are encouraged to ask for rest breaks or water if needed.

12. Precautions for female subjects: There are no precautions for female subjects.

13. Benefits: You are not expected to benefit directly from participation in this research study. However, you are helping to improve the safety of future firefighter protective equipment such as fire engine seatbelt fit and function.

14. Compensation: You will be compensated $20 per hour for a maximum of $40 for a 1 to 2 hour session. If you are active duty military you will need your commander's written approval for off-duty employment and will be compensated for your time at $20 per hour. .

15. Alternatives: Choosing not to participate is an alternative to volunteering for this study.

12. **Entitlements and confidentiality:**

d. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations. Your personal information will be stored in a locked cabinet in an office that is locked when not occupied. Electronic files containing your personal information will be password protected and stored safely on a computer. Initially, it is intended that the only people having access to your information will be the researchers named above and the AFRL Wright Site IRB or any other IRB involved in the review and approval of this protocol. However, you should know that you will be recognizable from the 3D scanned image.

Starting next year, your scan data, age, race, and gender will become part of a national database that will become public domain for unrestricted/unlimited use. Your name will not, nor will any other identifiable information, be released with this information. Complete confidentiality for military personnel cannot be promised because information bearing on your health may be required to be reported to appropriate medical or command authorities.

Your entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if you desire further information you may contact the base legal office (88 ABW/JA, 257-6142 for Wright-Patterson AFB). In the event of a research related injury, you may contact the medical monitor, Major Eric Hermes, of this research study at (937) 255-5365.

If an unanticipated event (medical misadventure) occurs during your participation in this study, you will be informed. If you are not competent at the time to understand the nature of the event, such information will be brought to the attention of your next of kin.

Next of kin or designated health care agent (if needed):

Name Phone#_____

The decision to participate in this research is completely voluntary on your part. No one may coerce or intimidate you into participating in this program. You are participating because you want to. Jennifer Whitestone, Principal Investigator, or an associate, has adequately answered any and all questions you have about this study, your participation, and the procedures involved. Jennifer Whitestone can be reached at (937) 855-6107. Jennifer Whitestone, or an associate, will be available to answer any questions concerning procedures throughout this study. If significant new findings develop during the course of this research, which may relate to your decision to continue participation, you will be informed. You may withdraw this consent at any time and discontinue further participation in this study without prejudice to your entitlements. The investigator or medical monitor of this study may terminate your participation in this study if she or he feels this to be in your best interest. If you have any questions or concerns about your participation in this study or your rights as a research subject, please contact Major Jeff Bidinger at (937) 656-5449 or jeffrey.bidinger@wpafb.af.mil.

Your participation in this study may be photographed, filmed or audio/videotaped. You consent to the use of these media for training and data collection purposes. Any release of records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 55 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to unauthorized source without your permission. These recordings will be used for presentation or publication. They will be stored in a locked cabinet in a room that is locked when not occupied. Only the investigators of this study will have access to these media.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer Signature_____Date_____

Volunteer Name (printed)_____

Volunteer Social Security No. (Optional)_____

Advising Investigator Signature _____ Date _____

Investigator Name (printed)_____

Witness Signature _____Date _____

Witness Name (printed)_____

We may wish to present some of the video/audio recordings from this study at scientific conventions or use photographs in journal publications. If you consent to the use of your image for publication or presentation in a scientific or academic setting, please sign below.

Volunteer Signature_____Date_____

Privacy Act Statement

Authority: We are requesting disclosure of personal information, to include your Social Security Number. Researchers are authorized to collect personal information (including social security numbers) on research subjects under The Privacy Act-5 USC 552a, 10 USC 55, 10 USC 8013, 32 CFR 219, 45 CFR Part 46, and EO 9397, November 1943. **Purpose**: It is possible that latent risks or injuries inherent in this experiment will not be discovered until some time in the future. The purpose of collecting this information is to aid researchers in locating you at a future date if further disclosures are appropriate. **Routine Uses**: Information (including name and SSN) may be furnished to Federal, State and local agencies for any uses published by the Air Force in the Federal Register, 52 FR 16431, to include, furtherance of the research involved with this study and to provide medical care. **Disclosure**: Disclosure of the requested information is voluntary. No adverse action whatsoever will be taken against you, and no privilege will be denied you based on the fact you do not disclose this information. However, your participation in this study may be impacted by a refusal to provide this information.

ATTACHMENT B CURRICULUM VITAE OF INVESTIGATORS

TOTAL CONTACT, INC.

CURRICULUM VITAE

Jennifer J. Whitestone President, Total Contact, Inc. DOB 05/04/63

Virginia Polytechnic Institute BS 1985 Engineering Science and Mechanics (Biomedical)
Wright State University MS 1996 Biomedical Engineering

1985-1989 Biomedical Engineer, Biodynamics Division, SRL, WPAFB, OH As Director of the Manikin Testing Facility, Jennifer planned, developed, directed, and executed research in the area of advanced biodynamics testing involving humans and manikins. Jennifer also ran simulations using the Articulated Total Body (ATB) model.

1989-1998 Biomedical Engineer, Human Engineering Div., USAF, WPAFB, OH

-Jennifer led a multi-disciplinary government/contractor team for the Computerized Anthropometric Research and Design (CARD) laboratory, applying three-dimensional anthropometry to improve protective equipment for aircrew. She successfully produced software products for analyzing 3-D surface data now used worldwide by establishing Technical Area Plans (TAP), with milestones and budgets, and by developing a Configuration Control Board (CCB) through which all software development was directed, monitored, and documented. Jennifer conducted extensive 3-D scan and fit assessment survey of USAF aircrew and their protective equipment. Jennifer was the technical lead for rapid whole body surface scanning system (WB4) and related software requirements; responsible for reliable and accurate implementation of Cyberware's WB4 whole body scanner as a data acquisition tool for an international survey. Jennifer also developed automated post processing and data acquisition requirements for determining anthropometric measurements from high resolution whole body surface data. Jennifer has authored many publications on the application of human body surface data.

-1998-Present President of Total Contact, Inc.

Jennifer started Total Contact, Inc. in 1998 for the purpose of transferring surface scanning technology for commercial applications. Total Contact's primary product is the custom Total Contact burn mask custom-made to treat hypertrophic scarring due to severe burns or trauma. Total Contact has also applied surface scanning to quantify skin anomalies such as cellulite, scars, wounds, and burn scars. Total Contact has also worked closely with the National Institutes for Occupational Safety and Health (NIOSH) to implement surface scanning to improve roll-over protection during tractor rollovers as well as fall protection harness performance.

CURRICULUM VITAE

Jenniffer Manning Scanning Specialist, Total Contact, Inc. DOB 08/08/74

University of South Florida BA 1997

1995-1998 Assistant Office Manager, Dr. Michael W. Rowe, Tampa, FL Jenniffer provided patient care, office staff training, front office and back office, organized patient consultations, implemented an inventory control system and served as Acting Office Manager in absence of Office Manager.

1998-2002 Clinical Coordinator, Dr. Daniel Burstein, Jonesboro, GA Jenniffer's responsibilities included managing clinic and staff schedules, clinical inventory control, maintaining patient records and front office and back office staff training. Jenniffer also performed tracing and angulation of cephalometric and panoramic x-ray of patients.

2005-Present Scanning Specialist, Total Contact, Inc., Germantown, OH

Performs patient scheduling and conducts scanning of patients acquiring transparent orthotics, coordinating with physicians, therapists, and insurance companies. In her role as billing specialist for Total Contact, she is responsible for protecting patient data and implementing privacy policies and procedures. She also conducts image analysis tasks for surface scan-based research applications.

ATTACHMENT C
QUESTIONNAIRES/SURVEYS

Firefighter Study Participant Questionnaire

Subject No:_____ M F Age:_____

Race: non-Hispanic White non-Hispanic Black Hispanic Other specify:_____

Height:_____ft. in Weight: lbs

1. State the manufacturer of your protective coat and pants _____
2. Describe what you are wearing under your protective gear_____

1. Have you ever had difficulty finding the seatbelt in the fire apparatus? Y N

Have you ever had difficulty fastening the seatbelt of the fire apparatus? Y N

If yes, was the problem due to insufficient seatbelt length? Y N

4. Please check the items you are wearing with your protective gear. Check the second box if you experience fit issues with these items.

Wearing the item? Fit problems with the item? Helmet

_____ Flame Retardant Hood _____ Face Mask

_____ Protective Jacket

_____ Protective Pants

_____ Boots

_____ Gloves

_____ SCBA

_____ Radio

_____ PASS

_____ Door Chock (s)

_____ Rope (s)

_____ Rescue Knife

_____

Webbing/Carabiners _____ Other items included with gear_____

Anthropometric Survey of Firefighters to Improve Seatbelt Safety ANTHROPOMETRY

Subject No._____ Measurer_____ Recorder _____ Date:_____

Weight _____

Stature _____

Chest Circumference _____

Waist Circumference, Preferred _____

Waist Height at Preferred Waist _____

Biacromial Breadth _____

Chest Breadth _____

Waist Breadth _____

Chest Depth _____

Waist Depth _____

Sitting Height _____

Sitting Height, with Helmet _____

Midshoulder Height, Sitting _____

Knee Height, Sitting _____

Hip Breadth, Sitting _____

Abdominal Extension Depth, Sitting _____

Buttock-Knee Length _____

Encumbered Weight _____

Seatbelt Fit? Yes No Missed Distance_____

ATTACHMENT D SUBJECT
RECRUITING MATERIALS

Total Contact, Inc.

Rehabilitation Through Non-Contact Surface Scanning

Recruiting Firefighters

for Safety Study

120 FIREFIGHTERS NEEDED!

Total Contact, Inc. has been contracted by the National Fallen Firefighters Foundation to conduct a study of fire fighters at Wright-Patterson Air Force Base in Beavercreek, Ohio. Through body measurements and whole body 3D scanning, we will provide new guidelines to improve the fit and performance of all safety equipment for fire fighters. The data will become publicly available for unrestricted use.

Help Solve the Problem

by Being Part of the Solution

+ Cash compensation for your time
+ All types of Fire Fighters needed
+ Career or Volunteer
+ Ideal for 18 years or older
+ Only 1-2 hours

Contact: Jenniffer Manning
Phone: (937) 855-6107
Fax: (937) 855-6903
Email: jenniffer@totalcontact.com

Total Contact, Inc.
41 N. Main Street
Germantown, OH 45327

120 FIREFIGHTERS NEEDED FOR SAFETY STUDY

Career and volunteer firefighters needed for a study supported by the National Fallen Firefighters Foundation, the International Association of Fire Chiefs, National Fire Protection Association and Fire Apparatus Manufacturers' Association. The study is to be conducted by Total Contact, Inc. at Wright-Patterson Air Force Base in Beavercreek, Ohio and will serve to provide new guidelines to improve the fit and performance of all safety equipment for firefighters. The study involves collecting standard body measurements. Participants will also be scanned using a 3D whole body scanner. The 3D whole body scanner will be used to record size and shape information of the participants both with and without their protective gear. In the future, the data will become publicly available for unrestricted use. All types of firefighters are needed, but must be 18 years or older. Study participants will be compensated for their direct time involved in data collection. Please allow 1-2 hours.

Call Jenniffer Manning at (937) 855-6107 for more information.

Anthropometric Survey of Firefighters to Improve Seatbelt Safety
Participant Inquiry

Name_____ Fire

Station_____ Phone

Number_____

Gender_____ Age_____ Race_____ Height _____ Weight _____ Email:

"Please understand that this study will involve taking standard body measurements (height, waist circumference, etc.) and digital photographs while the participant is wearing close fitting "biker" shorts and sports bra, where applicable. We will also collect a 3D color full-body image of you. Please know that you will be recognizable from this 3D scanned image. The scan data, your age, race, and gender will become part of a national database that will become public domain for unrestricted/unlimited use. Your name will not be released with this information. As a participant you may elect to not have your digital photographs included with your study information."

Do you understand the information that has been presented?

Do you have any questions? Are you comfortable having your

image in this database? Include

Exclude REASON:

_____

APPENDIX B

WEIGHT

PROCEDURE: Subject stands on the footprints of the platform of the scale. Stand in front of the subject and take the weight of the subject to the nearest tenth of a kilogram *(or to the nearest pound, depending on the scale used)*.

STATURE

ORIGIN-TERMINATION: Standing surface – top of head.

PROCEDURE: Subject is in the anthropometric standing position with the head in the Frankfort plane. Stand at one side of the subject and use an anthropometer to measure the vertical distance between the standing surface and the top of the head. Move the blade of the anthropometer across the top of the head to ensure measurement of the maximum distance. Use firm pressure to compress the subject's hair. The measurement is taken at the maximum point of quiet respiration.

CAUTION: Be sure that the head is in the Frankfort plane.

CHEST CIRCUMFERENCE

LANDMARK(S) ENCOMPASSED: Bustpoint/thelion, right:

PROCEDURE: Subject is in the anthropometric standing position in front of a mirror. Stand in front of the subject and use a tape to measure the horizontal circumference of the chest at the level of the bustpoint on women and the nipple on men (bustpoint/ thelion, right). For women, the landmark is drawn on the bra. It is not drawn on male subjects. This dimension will cross very soft tissue at the armpit and bust, and some compression of the tissue will inevitably occur. Be sure, however, to keep this to a minimum. Exert only enough tension on the tape to maintain contact between the tape and the skin. The tape will span body hollows in this measurement. The measurement is taken at the maximum point of quiet respiration.

CAUTION: This must be a horizontal measurement. It will not necessarily cross the left bustpoint/thelion landmark.

WAIST CIRCUMFERENCE (PREFERRED)

DESCRIPTION: Circumference of the waist at the subject’s preferred waist level.

PROCEDURE: The maximum horizontal circumference of the waist is measured at the level of the waist established by the subject placing an elastic tape at his or her preferred waist level (*preferred waist level*). The subject is in the anthropometric standing position. The subject stands erect looking straight ahead breathing quietly. The upper arms hang relaxed at the sides, and the abdominal muscles are relaxed. The measurer has the subject adjust the waist band to the subject’s preferred waist level. The recorder places

a mark on the subject's back underneath the waist band (the *Anterior Waist Preferred* landmark. The measurer exerts only enough tension on the tape to maintain contact between the tape and the body.

The measurement is made at the maximum point of quiet respiration.

CAUTION: The subject must not tense the abdominal muscles.

WAIST HEIGHT at PREFERRED WAIST

DESCRIPTION: Height of the circumference of the waist at the subject's preferred waist level. **(NOTE: ANSUR includes** *Waist Height, Omphalion* **and** *Waist Height, Natural Indentation* **measures only)**

ORIGIN-TERMINATION: Standing surface – an anterior waist (preferred) landmark

PROCEDURE: Subject is in the anthropometric standing position. The subject stands erect looking straight ahead breathing quietly. The upper arms hang relaxed at the sides, and the abdominal muscles are relaxed. Stand behind the subject and use an anthropometer to measure the vertical distance between the standing surface and the center of the preferred waist at the posterior landmark. The measurement is taken at the maximum point of quiet respiration.

CAUTION: The subject must not tense the abdominal muscles.

BIACROMIAL BREADTH

ORIGIN-TERMINATION: Acromion, right - acromion, left

PROCEDURE: Subject is in the anthropometric sitting position. Stand behind the subject and use a beam caliper to measure the distance between the drawn right and left acromion landmarks at the tips of the shoulders. If the acromial landmarks cannot be seen from behind, stand in front of the subject. The measurement is taken at the maximum point of quiet respiration. Use sufficient pressure to maintain firm contact with the skin.

CAUTION: The subject must not change the position of the shoulders.

CHEST BREADTH

DESCRIPTION: The maximum horizontal breadth of the chest at the level of the right bustpoint/thelion landmark.

PROCEDURE: Subject stands erect looking straight ahead with the heels together and the weight distributed on both feet. The arms are held away from the body just enough to allow clearance between the arms and a beam caliper used to make the measure-ment.

Stand in front of the subject and measure the maximum horizontal breadth of the chest at the level of the drawn right bustpoint landmark (women) or nipple (men). The measurement is made at the maximum point of quiet respiration. Exert only enough pressure to attain contact between the caliper and the skin (or bra).

CAUTION: Breast tissue should NOT be included in this measurement. This can be avoided, when necessary, by tilting the blades of the caliper upwards and approaching the bony sides of the chest from below the breasts. On some male subjects the latissimus dorsi, heavy muscles at the back of the armpit, may bulge beyond the bony sides of the chest. These muscles should not be included in the measurement either.

WAIST BREADTH

ORIGIN-TERMINATION: Waist (preferred), right -- waist (preferred), left.

PROCEDURE: Subject is in the anthropometric standing position. Stand in front of the subject and use a bean caliper to measure the horizontal breadth of the waist from the right side of band marking the preferred waist to the left side of band marking the preferred waist. Exert only enough pressure to attain contact between the caliper and the skin. The measurement is taken at the maximum point of quiet respiration.

CAUTION: Care must be taken not to compress the soft tissue.

CHEST DEPTH

ORIGIN-TERMINATION: Plane of the back -- bustpoint/thelion, right.

PROCEDURE: Subject is in the anthropometric standing position. Stand at the right of the subject and use a beam caliper to measure the horizontal distance between the chest at the level of the right bustpoint on women and nipple on men (bustpoint/thelion, right) and the back at the same level. Place the fixed blade of the caliper on the back. The bustpoint/thelion landmark is drawn on the bra for female subjects; it is not drawn on male subjects. This measurement is taken at the maximum point of quiet respiration. Exert only enough pressure to maintain contact between the caliper and the skin (or bra).

CAUTION: Subject must not be allowed to change the position of the shoulders.

WAIST DEPTH

ORIGIN-TERMINATION: Waist (preferred), posterior -- waist (preferred), anterior.

PROCEDURE: Subject is in the anthropometric standing position but with the right hand on the chest. Stand at the right of the subject and use a beam caliper to measure the horizontal distance between the drawn landmarks at posterior waist (preferred), and

anterior waist (preferred). The fixed blade of the caliper is held on the back. The measurer exerts only enough pressure to maintain contact between the caliper and the skin.

The measurement is taken at the maximum point of quiet respiration.

CAUTION: Car must be taken not to compress the soft tissue. (NOTE: the waist band may be removed after this dimension is measured.)

SITTING HEIGHT

ORIGIN-TERMINATION: *Sitting* surface - top of head.

PROCEDURE: Subject is in the anthropometric sitting position with the head in the Frankfort plane. Stand at the right rear of the subject and use an anthropometer to measure the vertical distance between the sitting surface and the top of the head. Use sufficient pressure to compress the hair. The measurement is made at the maximum point of quiet respiration.

CAUTION: Be sure the head is in the Frankfort plane.

MIDSHOULDER HEIGHT, SITTING

ORIGIN-TERMINATION: Sitting surface -- midshoulder.

PROCEDURE: Subject is in the anthropometric sitting position. Stand behind the subject and use an anthropometer to measure the vertical distance between the sitting surface and the drawn midshoulder landmark at the middle of the top of the right shoulder. The measurement is taken at the maximum point of quiet respiration.

CAUTION: The subject must not be allowed to change the position of the shoulders.

KNEE HEIGHT, SITTING

ORIGIN-TERMINATION: Foot rest surface -- suprapatella.

PROCEDURE: Subject sits with the thighs parallel, the knees flexed 90 degrees, and the feet in line with the thighs. The arms are relaxed at the sides. Stand at the right of the subject and use an anthropometer to measure the vertical distance between the footrest surface and the drawn suprapatella landmark at the top of the knee (NOTE: the landmark is drawn after the subject is seated).

HIP BREADTH SITTING

DESCRIPTION: Maximum hip (or thigh) breadth of a seated subject.

PROCEDURE: Subject sits erect with the thighs parallel (to each other) but not touching). The arms are crossed over the chest or hang relaxed at the sides. Stand in front of the subject and use a beam caliper to measure the most lateral points on the hips or thighs (whichever are broader). The blades of the caliper are kept at approximately a 45-degree angle to the horizontal and moved up and down to locate the maximum breadth. Exert only enough pressure to ensure that the caliper blades are touching both sides of the body.

ABDOMINAL EXTENSION DEPTH, SITTING

ORIGIN-TERMINATION: Abdominal point, anterior -- plane of the back.

PROCEDURE: Subject is in the anthropometric sitting position but the right hand is placed on the chest. Stand at the subject's right and use a beam caliper to measure the horizontal distance between the anterior point of the abdomen and the back at the same level. The fixed blade of the caliper is placed on the back. The measurement is made at the maximum point of quiet respiration, with the blades of the instrument just touching the skin.

CAUTION: Make sure the subject does not tense the abdominal muscles.

BUTTOCK-KNEE LENGTH

ORIGIN-TERMINATION: Buttock plate -- knee point, anterior.

PROCEDURE: Subject is in the anthropometric sitting position but with arms relaxed on the lap. Stand at the right of the subject and slide the buttock plate toward the subject until it makes light contact with the most posterior point on either buttock. When the plate is in position, lock it in place. Use an anthropometer to measure the horizontal distance between the back and the front of (the most protruding point on) the knee (knee point, anterior). The fixed blade of the anthropometer is anchored on the buttock point, and the measurer exerts only enough pressure on the instrument to maintain contact between the anthropometer blade and the knee.

CAUTION: To ensure that the anthropometer is horizontal, be sure that the base of the anthropometer is fully against the buttock plate.

WEIGHT, ENCUMBERED

PROCEDURE: Encumbered subject stands on the footprints of the platform of the scale. Stand in front of the subject and take the weight of the subject to the nearest tenth of a kilogram *(or to the nearest pound, depending on the scale used)*.

SITTING HEIGHT, HELMET

ORIGIN-TERMINATION: *Sitting* surface - top of head.

PROCEDURE: A forward-looking, encumbered subject sits in the anthropometric sitting position with the head position approximated to be in the Frankfort plane. The measurer stands at the right rear of the subject and uses an anthropometer to measure the vertical distance between the sitting surface and the top of the subject's helmeted head. The measurement is made at the maximum point of quiet respiration.

CAUTION: Be sure the head is in the Frankfort plane.

LANDMARKS

Acromion, Right and Left

DESCRIPTION: The point of intersection of the lateral border of the acromial process and a line running down the middle of the shoulder from the neck to the tip of the shoulder.

PROCEDURE: Subject is in the anthropometric standing position. Stand behind the subject and palpate the tips of both shoulders simultaneously. Draw a line along the lateral bony border of each shoulder. Then stand at the right of the subject and lay a tape on the shoulder originating at the trapezius point (at the base of the neck), passing so that the front edge of the tape lies over the clavicle (collar bone) point, and crosses the drawn acromial border at the tip of the shoulder. Draw a short line along the front edge of the tape where it crosses the acromial border. Repeat the process for the left shoulder.

Bustpoint/Thelion, Right and Left

DESCRIPTION: The anterior points of the bra cups.

PROCEDURE: Subject is in the anthropometric standing position. Stand at the right of the subject and sight the most protruding point of the bra over each breast. Draw a dot on each landmark.

Infraorbitale

DESCRIPTION: The lowest point on the anterior border of the bony eye socket, marked directly beneath the pupil.

PROCEDURE: Subject stands, looking straight ahead. Stand in front of the subject and palpate the bony eye socket under the pupil of the eye to locate its lowest point. Draw a dot on lower eyelid marking the landmark.

CAUTION: Subjects may be apprehensive when you palpate near their eyes. Care must be taken in locating this landmark to reduce the subject's concern.

Midshoulder

DESCRIPTION: The point on top of the right shoulder midway between the neck (right trapezius point) and the tip of the shoulder (acromion, right).

PROCEDURE: Subject stands in the anthropometric standing position. Stand behind the subject and lay a tape along the top of the shoulder from the trapezius point, at the juncture of the neck and shoulder, to the acromion landmark at the tip of the shoulder. Note one-half the measured distance and draw a line from front to back across the shoulder at that point. Make sure the line crosses over the top of the trapezius muscle at that location.

Suprapatella

DESCRIPTION: The superior point of the patella (kneecap).

PROCEDURE: Subject stands erect on a table with the patella relaxed. Stand in front of the subject and grasp the sides of the patella between the thumb and third finger, using the index finger to locate the top of the patella. In trying to locate the upper border of the patella, it may help to run your thumb and third finger up and down along its upper sides. When the top of the kneecap has been located draw a short horizontal line through the point.

CAUTION: Subjects will tend to lock their knees when this landmark is being located. If the subject has difficulty relaxing the knee, firmly grasp the subject's thigh a few inches above the knee and then let go. This usually has the effect of relaxing the patella. If the subject is still unable to relax the knee, move on to other landmarks and then try the patella landmark again.

Tragion, Right and Left

DESCRIPTION: The superior point on the juncture of the cartilaginous flap (tragus) of the ear with the head.

PROCEDURE: Palpate each tragus to find the superior point of attachment to the head. Place a dot on each landmark.

CAUTION: Avoid distorting the soft tissue in this area while drawing the landmark.

Waist, Preferred

DESCRIPTION: the level of the waist established by the subject placing an elastic tape at his or her preferred waist level.

PROCEDURE: The subject is instructed to place an elastic band directly on the skin (i.e., not on top of the shorts or other clothing) at the level where he or she would prefer the waist band of their clothing to be.

OTHER

Neck Chain

DESCRIPTION: The neck chain is used for the Midshoulder Height, Sitting measurement.

PROCEDURE: The neck chain is placed around the subject's neck at the base of the neck.

Waist Band

DESCRIPTION: The waist band is put in place for the *Waist Circumference (Preferred)* measure and remains in place through the dimension *Waist Depth*.

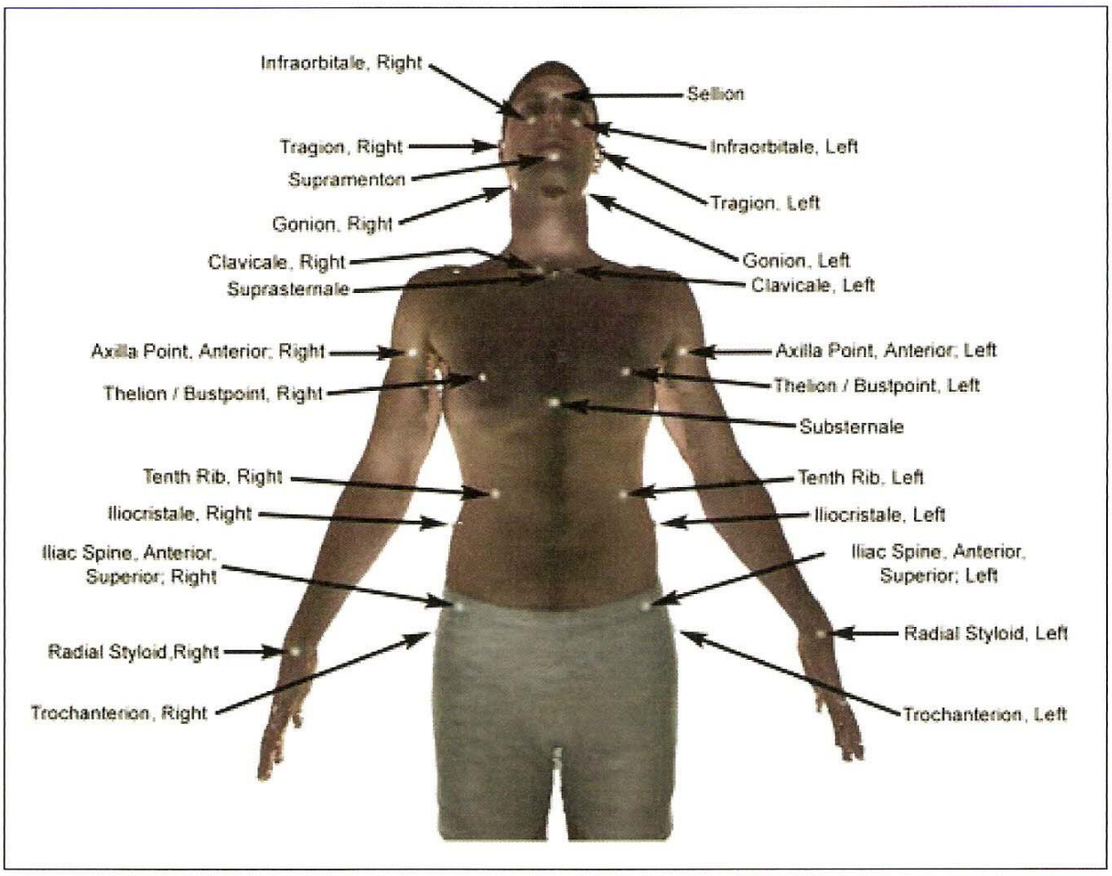
PROCEDURE: Subject is asked, essentially, to place the band where he or she prefers the waist on their clothes. If the band is placed on the shorts, the subject is asked to hike the shorts down just enough to expose the skin at the preferred waist level. The subject is then asked to replace the band so it lies directly on his or her skin. A mark is placed on the subject's back underneath the waist band (posterior waist preferred landmark).

APPENDIX C

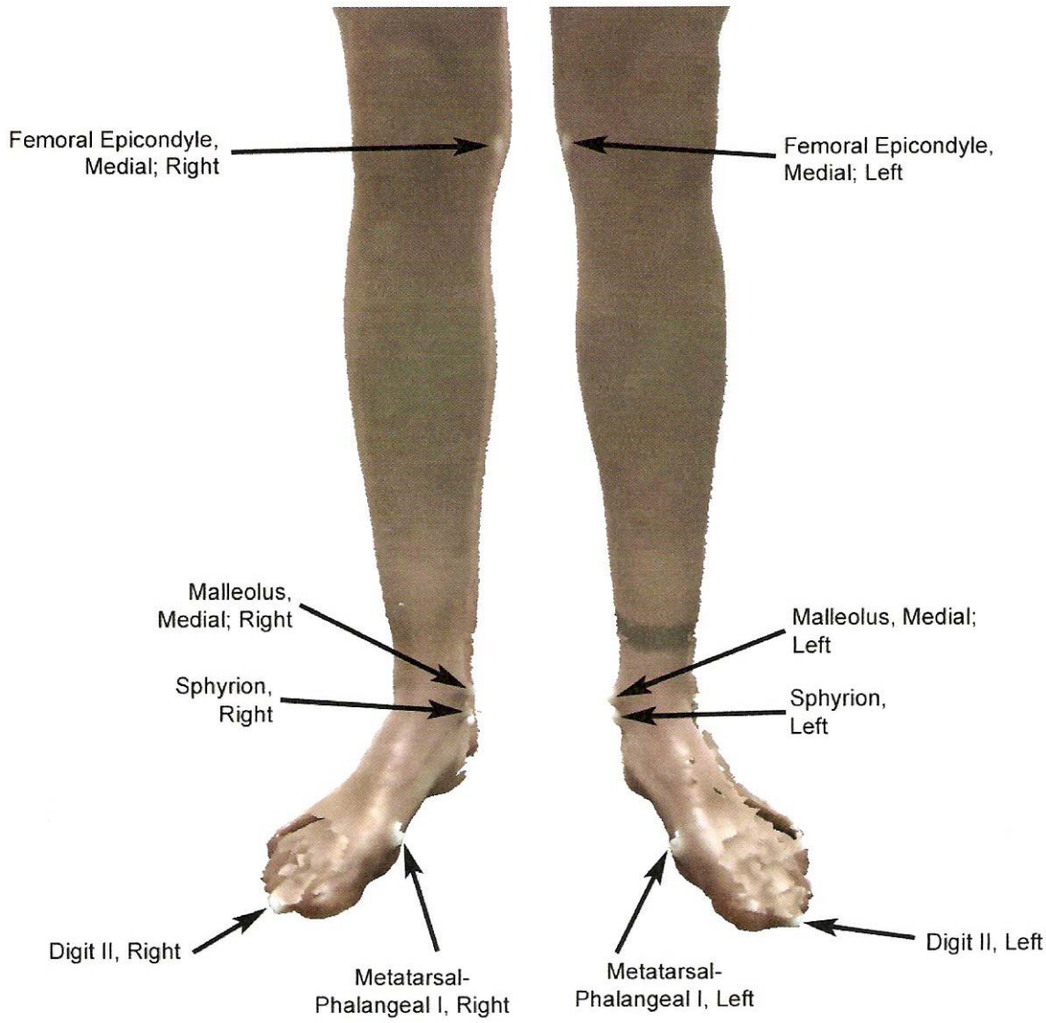
List of 3-D Landmarks

	CAESAR Name	ISO Name	Data File Name
Z1	SELLION	Nasion; Sellion	Sellion
Z2	INFRAORBITALE, RIGHT		Rt. Infraorbitale
Z3	INFRAORBITALE, LEFT		Lt. Infraorbitale
Z4	SUPRAMENTON		Supramenton
Z5	TRAGION, RIGHT	Tragion	Rt. Tragion
Z6	GONION, RIGHT		Rt. Gonion
Z7	TRAGION, LEFT	Tragion	Lt. Tragion
Z8	GONION, LEFT		Lt. Gonion
Z9	NUCHALE		Nuchale
Z10	CLAVICALE, RIGHT		Rt. Clavicale
Z11	SUPRASTERNALE		Suprasternale
Z12	CLAVICALE, LEFT		Lt. Clavicale
Z13	THELION/BUSTPOINT, RIGHT		Rt. Thelion/Bustpoint
Z14	THELION/BUSTPOINT, LEFT		Lt. Thelion/Bustpoint
Z15	SUBSTERNALE		Substernale
Z16	TENTH RIB, RIGHT		Rt. 10th Rib
Z17	ILIAC SPINE, ANTERIOR, SUPERIOR; RIGHT		Rt. ASIS
Z18	TENTH RIB, LEFT		Lt. 10th Rib
Z19	ILIAC SPINE, ANTERIOR, SUPERIOR; LEFT		Lt. ASIS
Z20	ILIOCRISTALE, RIGHT		Rt. Iliocristale
Z21	TROCHANTERION, RIGHT		Rt. Trochanterion
Z22	ILIOCRISTALE, LEFT		Lt. Iliocristale
Z23	TROCHANTERION, LEFT		Lt. Trochanterion
Z24	CERVICALE	Cervicale	Cervicale
Z25	TENTH RIB, MIDSPINE		10th Rib Midspine
Z26	ILIAC SPINE, POSTERIOR, SUPERIOR; RIGHT		Rt. PSIS
Z27	ILIAC SPINE, POSTERIOR, SUPERIOR; LEFT		Lt. PSIS
Z28	WAIST, PREFERRED, POSTERIOR		Waist, Preferred, Post.
Z29	ACROMION, RIGHT	Acromion	Rt. Acromion
Z30	AXILLA POINT, ANTERIOR; RIGHT		Rt. Axilla, Ant
Z31	RADIAL STYLOID, RIGHT		Rt. Radial Styloid
Z32	AXILLA POINT, POSTERIOR; RIGHT		Rt. Axilla, Post.
Z33	OLECRANON, RIGHT		Rt. Olecranon
Z34	HUMERAL EPICONDYLE, LATERAL; RIGHT		Rt. Humeral Lateral Epicn
Z35	HUMERAL EPICONDYLE, MEDIAL; RIGHT		Rt. Humeral Medial Epicn
Z36	RADIALE, RIGHT		Rt. Radiale
Z37	METACARPAL-PHALANGEAL II, RIGHT		Rt. Metacarpal Phal. II
Z38	DACTYLION, RIGHT		Rt. Dactylion
Z39	ULNAR STYLOID, RIGHT		Rt. Ulnar Styloid
Z40	METACARPAL-PHALANGEAL V, RIGHT		Rt. Metacarpal-Phal. V
Z41	ACROMION, LEFT	Acromion	Lt. Acromion
Z42	AXILLA POINT, ANTERIOR; LEFT		Lt. Axilla, Ant
Z43	RADIAL STYLOID, LEFT		Lt. Radial Styloid
Z44	AXILLA POINT, POSTERIOR; LEFT		Lt. Axilla, Post.
Z45	OLECRANON, LEFT		Lt. Olecranon

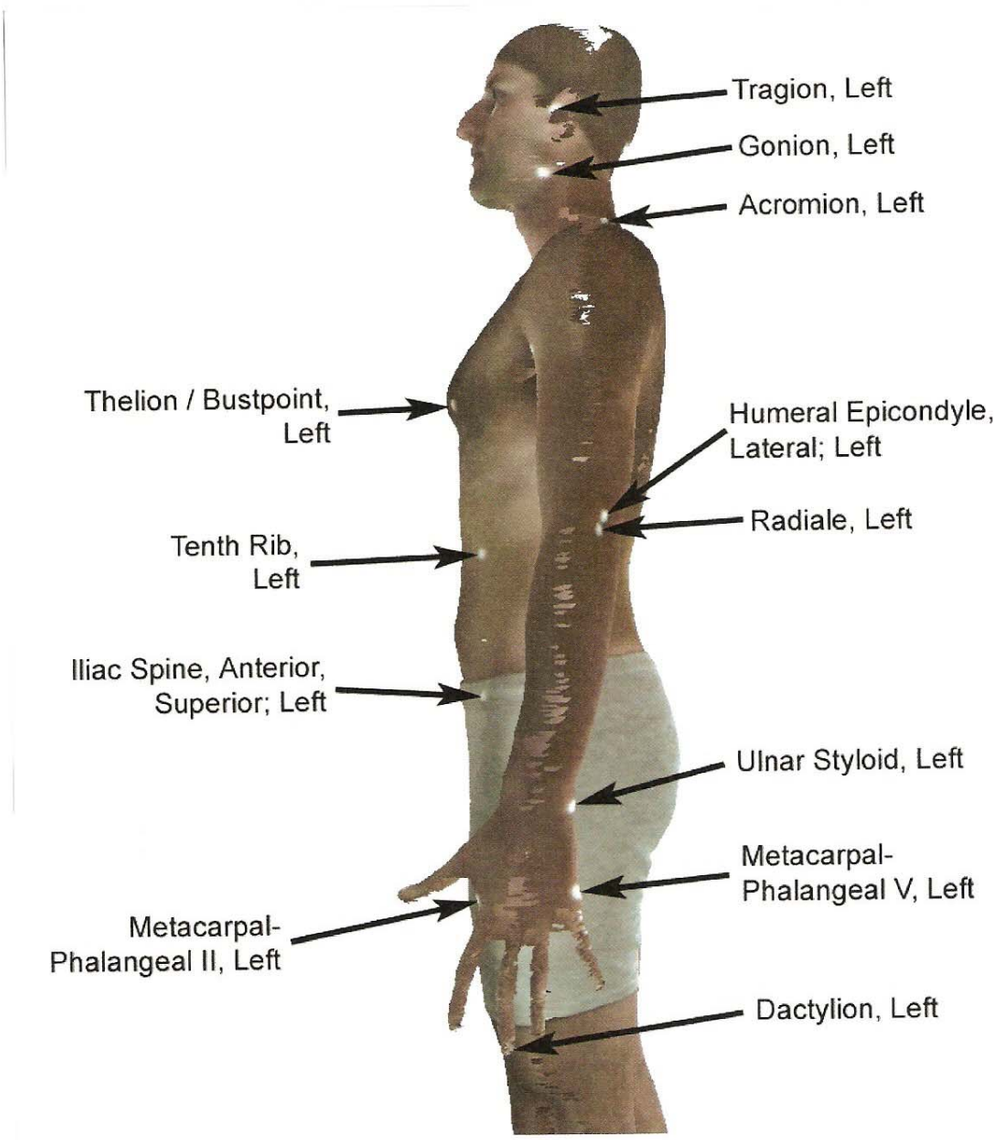
	CAESAR Name	ISO Name	Data File Name
Z46	HUMERAL EPICONDYLE, LATERAL; LEFT		Lt. Humeral Lateral Epicn
Z47	HUMERAL EPICONDYLE, MEDIAL; LEFT		Lt. Humeral Medial Epicn
Z48	RADIALE, LEFT		Lt. Radiale
Z49	METACARPAL-PHALANGEAL II, LEFT		Lt. Metacarpal-Phal. II
Z50	DACTYLION, LEFT		Lt. Dactylion
Z51	ULNAR STYLOID, LEFT		Lt. Ulnar Styloid
Z52	METACARPAL-PHALANGEAL V, LEFT		Lt. Metacarpal-Phal. V
Z53	KNEE CREASE, RIGHT		Rt. Knee Crease
Z54	FEMORAL EPICONDYLE, LATERAL; RIGHT		Rt. Femoral Lateral Epicn
Z55	FEMORAL EPICONDYLE, MEDIAL; RIGHT		Rt. Femoral Medial Epicn
Z56	METATARSAL-PHALANGEAL V, RIGHT		Rt. Metatarsal-Phal. V
Z57	MALLEOLUS, LATERAL; RIGHT		Rt. Lateral Malleolus
Z58	MALLEOLUS, MEDIAL; RIGHT		Rt. Medial Malleolus
Z59	SPHYRION, RIGHT		Rt. Sphyrion
Z60	METATARSAL-PHALANGEAL I, RIGHT		Rt. Metatarsal-Phal. I
Z61	CALCANEUS, POSTERIOR; RIGHT		Rt. Calcaneous, Post.
Z62	DIGIT II, RIGHT		Rt. Digit II
Z63	KNEE CREASE, LEFT		Lt. Knee Crease
Z64	FEMORAL EPICONDYLE, LATERAL; LEFT		Lt. Femoral Lateral Epicn
Z65	FEMORAL EPICONDYLE, MEDIAL; LEFT		Lt. Femoral Medial Epicn
Z66	METATARSAL-PHALANGEAL V, LEFT		Lt. Metatarsal-Phal. V
Z67	MALLEOLUS, LATERAL; LEFT		Lt. Lateral Malleolus
Z68	MALLEOLUS, MEDIAL; LEFT		Lt. Medial Malleolus
Z69	SPHYRION, LEFT		Lt. Sphyrion
Z70	METATARSAL-PHALANGEAL I, LEFT		Lt. Metatarsal-Phal. I
Z71	CALCANEUS, POSTERIOR; LEFT		Lt. Calcaneous, Post.
Z72	DIGIT II, LEFT		Lt. Digit II
Z73	CROTCH *(Calculated Point only)*		Crotch
Z74	BUTT BLOCK		Functional Butt Block



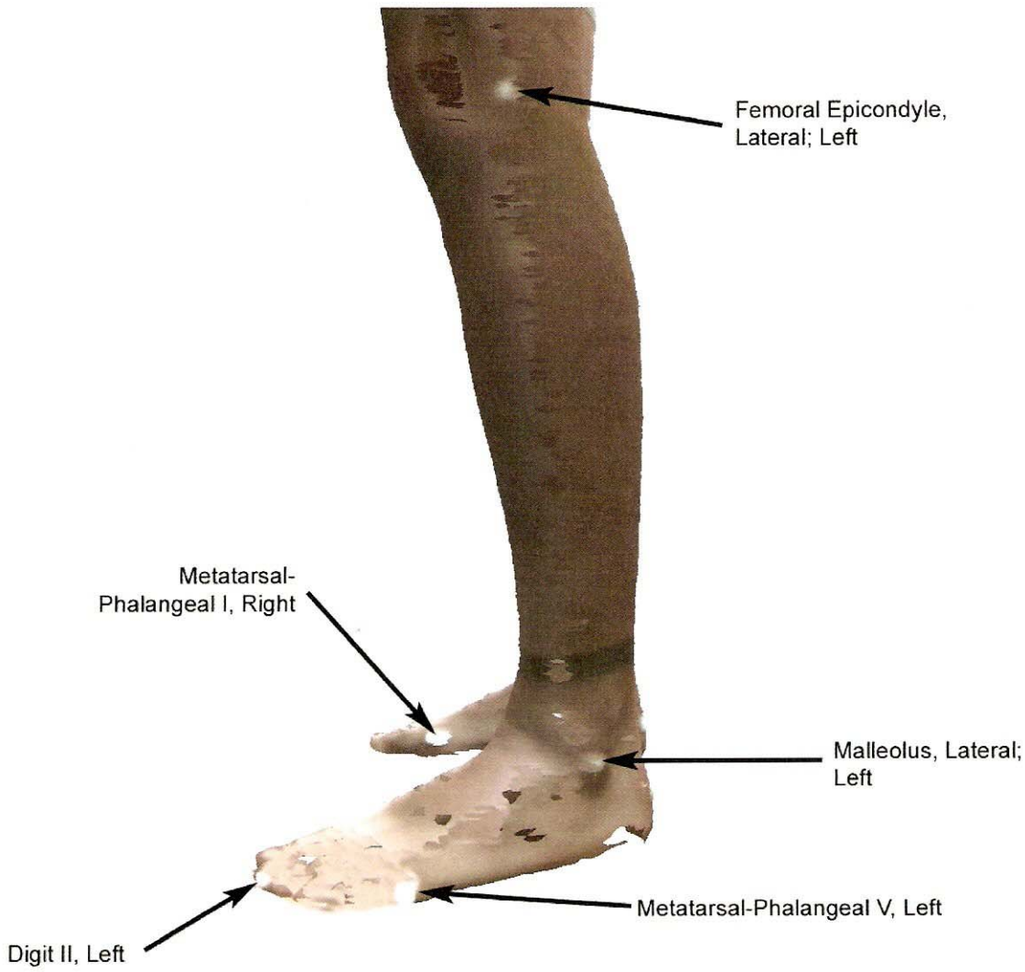
Visual Index of the 3-D Landmarks, Pose A, Upper Body, Front View



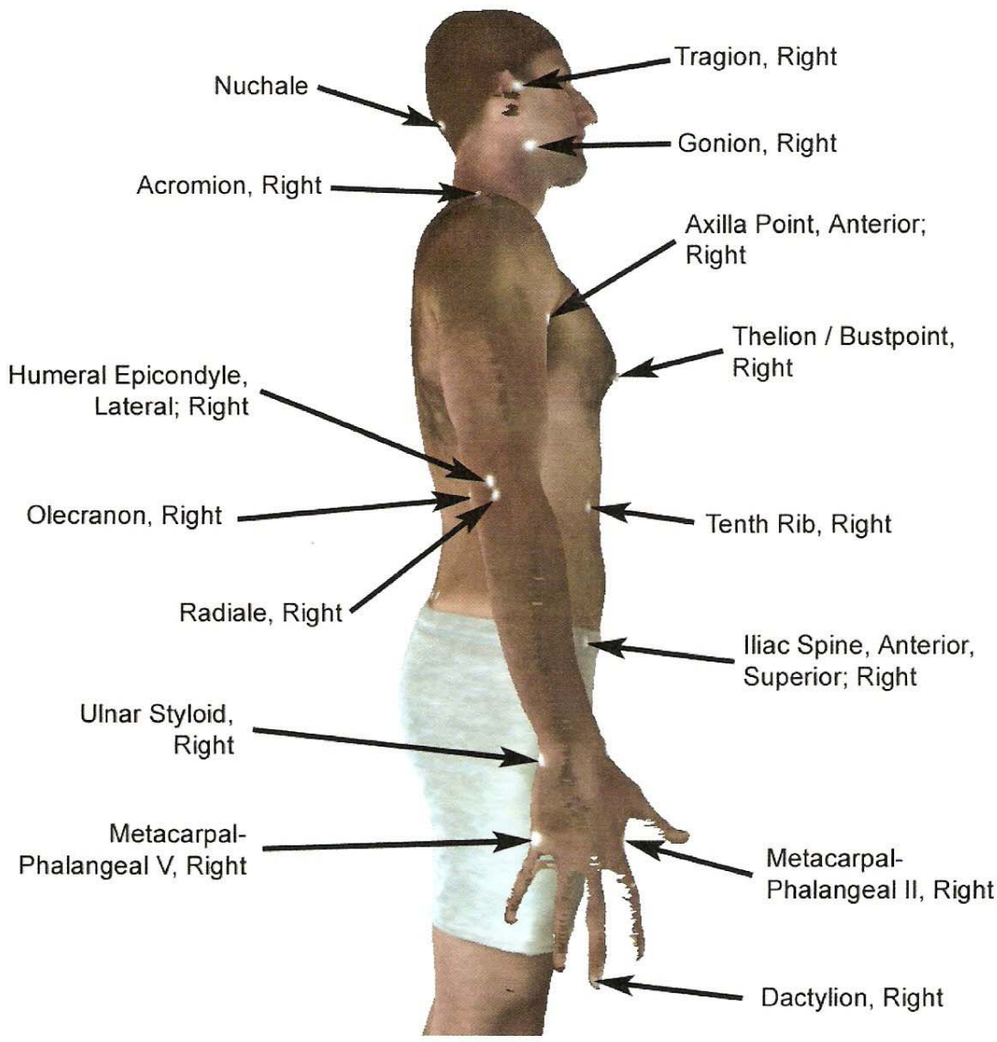
Visual Index of the 3-D Landmarks, Pose A, Lower Body, Front View



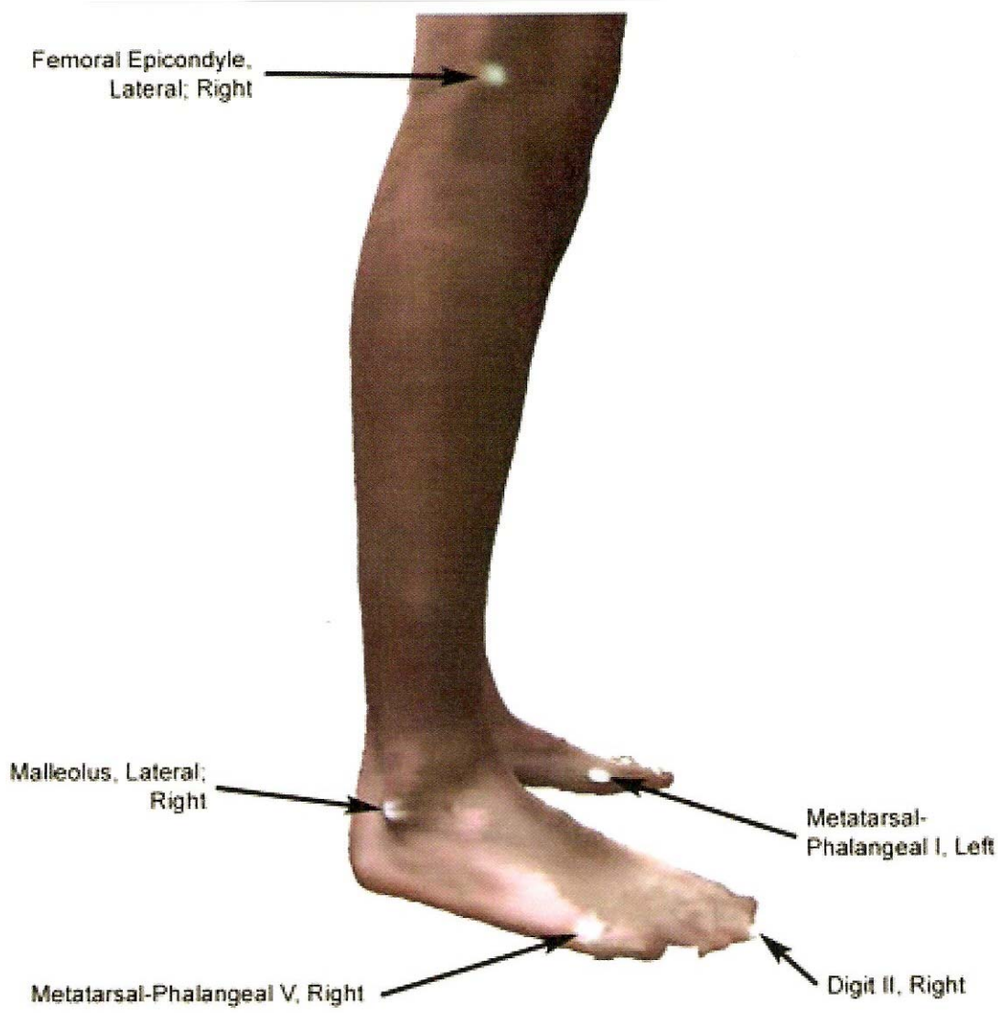
Visual Index of the 3-D Landmarks, Pose A, Upper Body, Left Side View



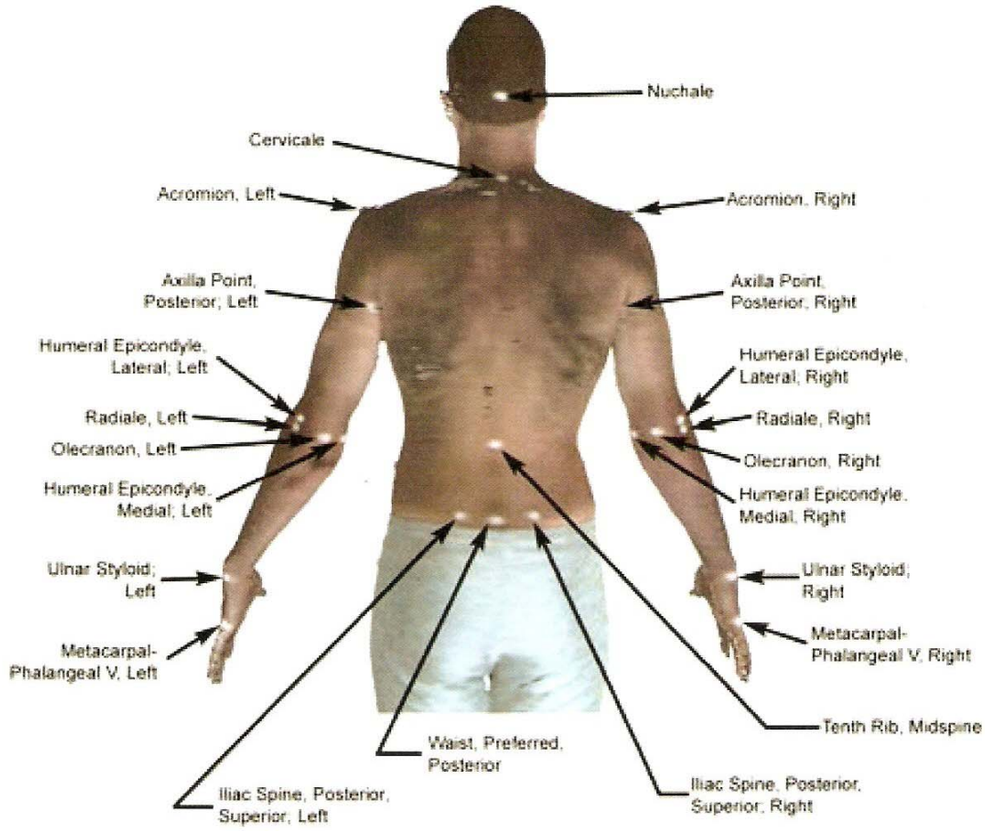
Visual Index of the 3-D Landmarks, Pose A, Lower Body, Left Side View



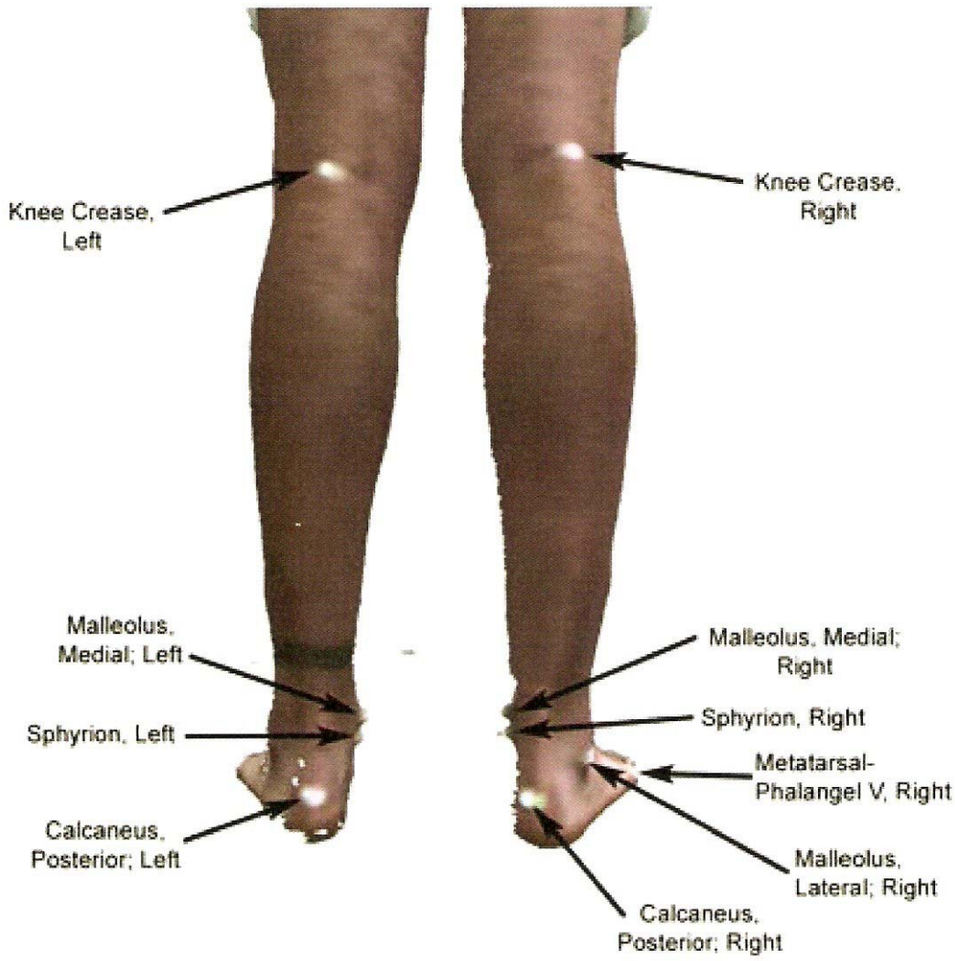
Visual Index of the 3-D Landmarks, Pose A, Upper Body, Right Side View



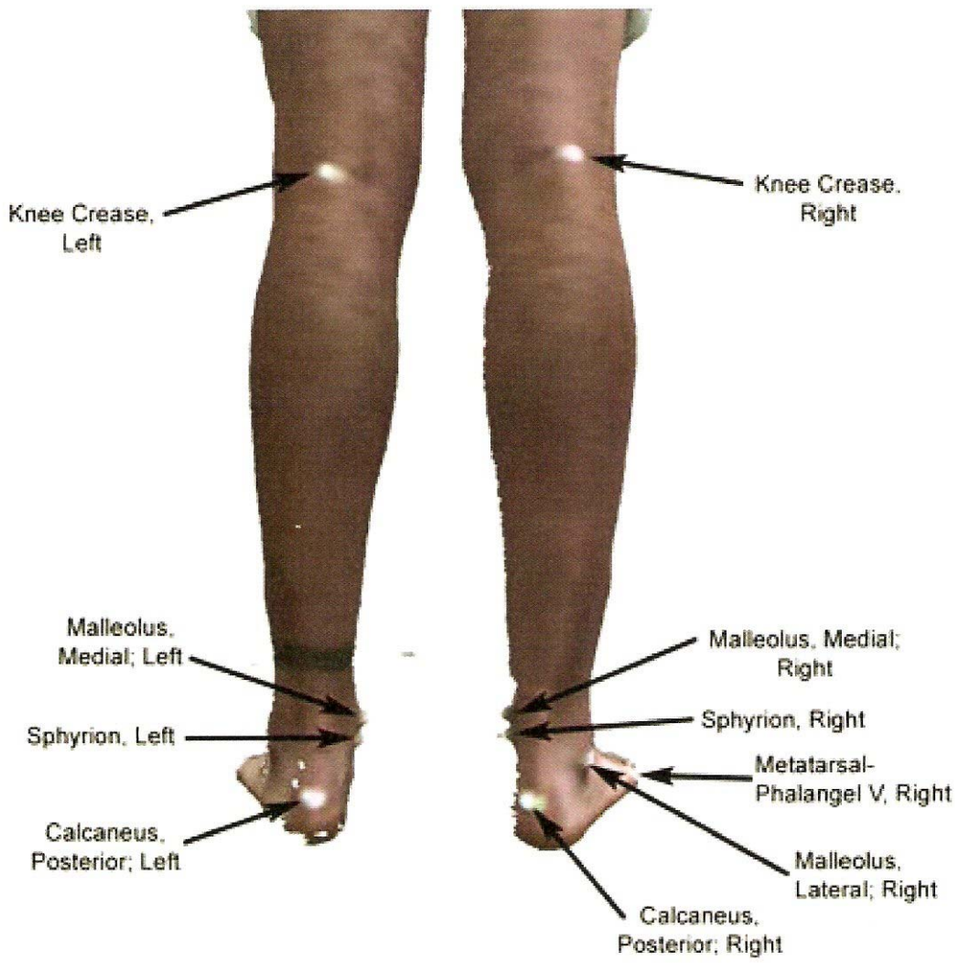
Visual Index of the 3-D Landmarks, Pose A, Lower Body, Right Side View



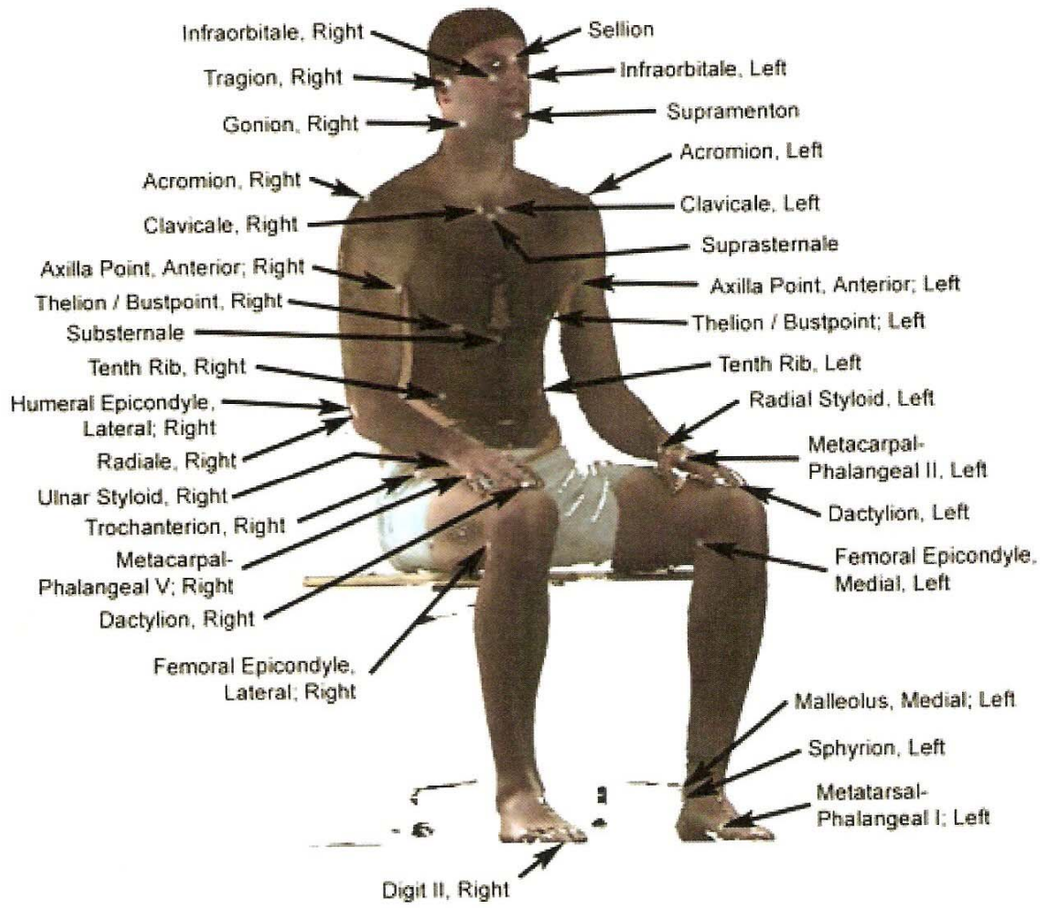
Visual Index of the 3-D Landmarks, Pose A, Upper Body, Back View



Visual Index of the 3-D Landmarks, Pose A, Lower Body, Back View



Visual Index of the 3-D Landmarks, Pose A, Lower Body, Back View



Visual Index of the 3-D Landmarks, Pose B, Upper Body, Right View

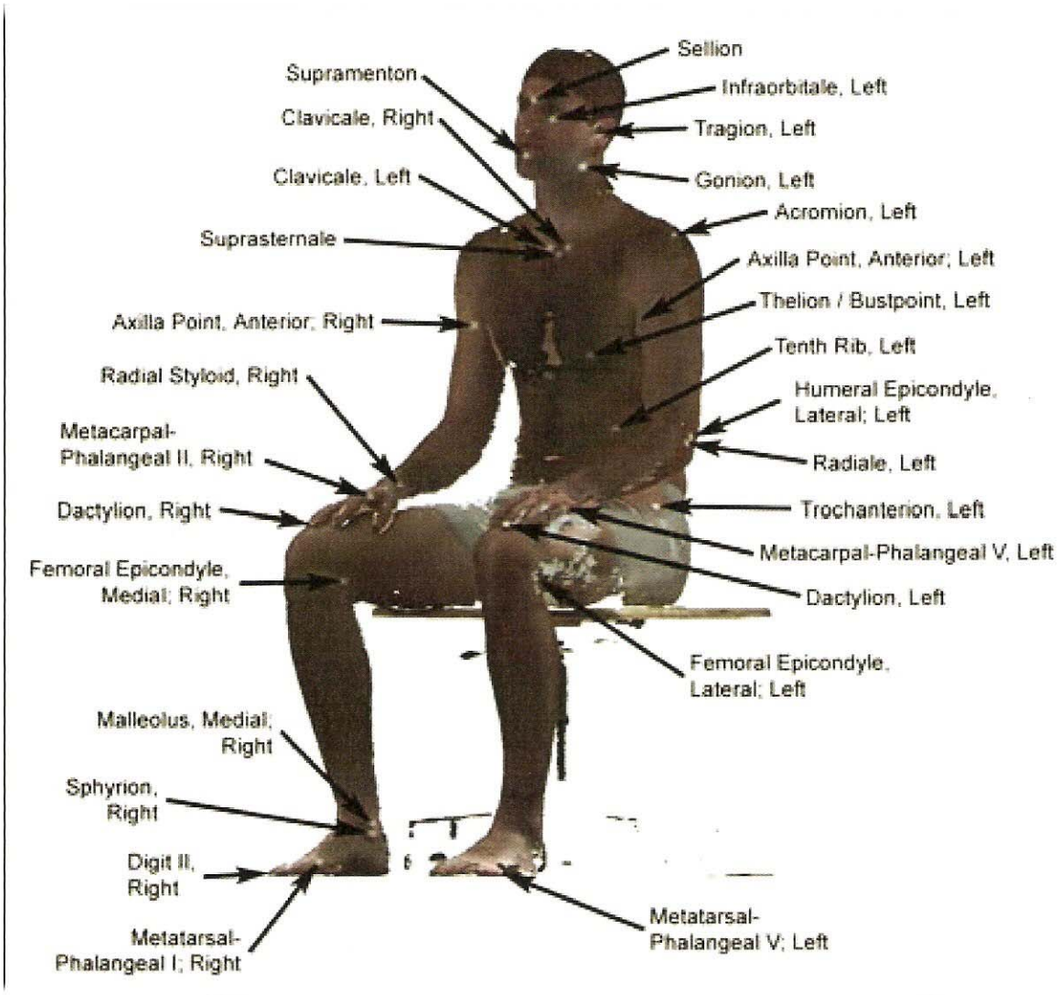
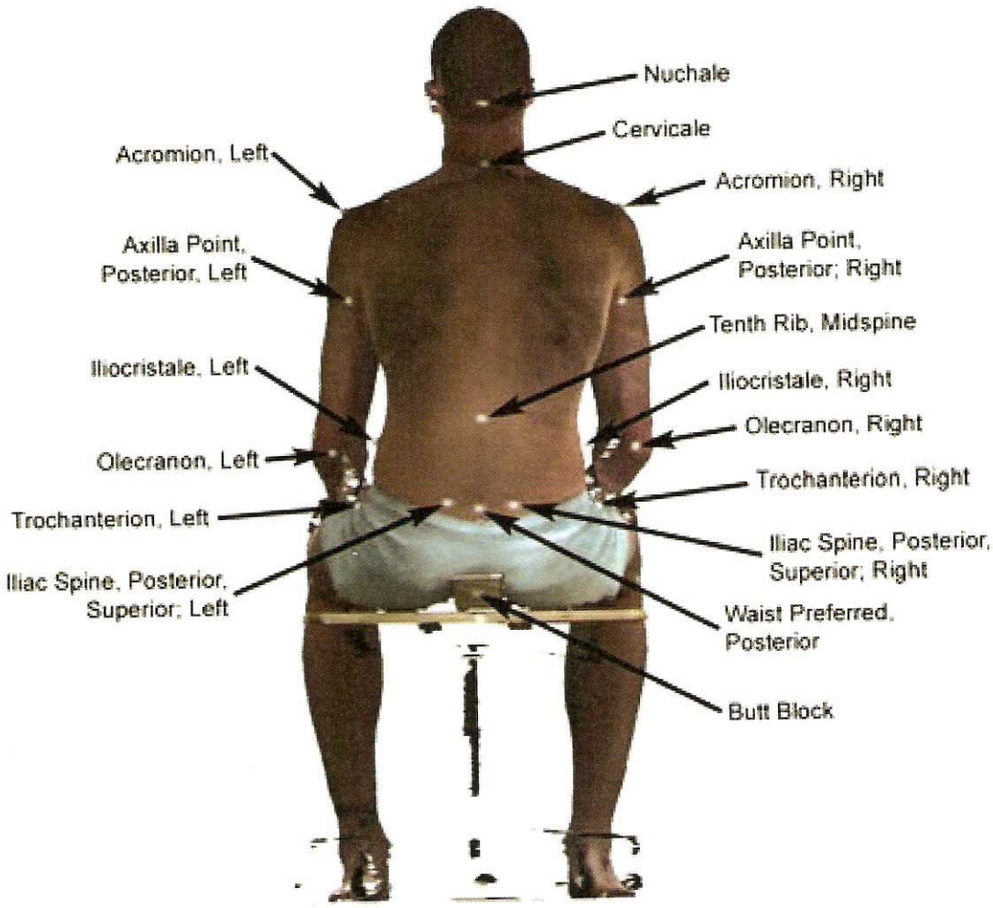


Figure 16. Visual Index of the 3-D Landmarks, Pose B, Left View



Visual Index of the 3-D Landmarks, Pose B, Back View.

APPENDIX D

FRSBB-Males-Fin Fri Sep 26 16:21:45
2008Input File: FRSBB-Males-Final.csv

MODEL POINT REPORT 95%
Accommodation At Radius 2.390

VARIABLE Z-SCORES FOR '2-D MAN' MODEL POINTS

MID-RANGE POINTS

A B C D

HIPWDTH 1.647 -0.846 0.846 -1.647 LEGHT -0.749 -1.972 1.972 0.749 POPLTH 0.585 -1.693 1.693 -0.585 Al-SHLDRHT 1.272 -1.157 1.157 -1.272 O-CHSTWDTH 1.606 -0.728 0.728 -1.606 Al-CHSTDPTH 2.003 -0.039 0.039 -2.003 BUTKNEL 0.761 -1.750 1.750 -0.761

AXIS INTERCEPT POINTS

W X Y Z

HIPWDTH 1.763 0.566 -1.763 -0.566 LEGHT 0.865 -1.924 -0.865 1.924 POPLTH 1.610 -0.783 -1.610 0.783 Al-SHLDRHT 1.717 0.081 -1.717 -0.081 O-CHSTWDTH 1.651 0.620 -1.651 -0.620 Al-CHSTDPTH 1.444 1.389 -1.444 -1.389 BUTKNEL 1.775 -0.700 -1.775 0.700

PERCENTILE VALUES FOR '2-D MAN' MODEL POINTS

MID-RANGE POINTS

	A	B	C	D
HIPWDTH	95	19	80	4
LEGHT	22	2	97	77
POPLTH	72	4	95	27
Al-SHLDRHT	89	12	87	10
O-CHSTWDTH	94	23	76	5
Al-CHSTDPTH	97	48	51	2
BUTKNEL	77	4	95	22

AXIS INTERCEPT POINTS

	W	X	Y	Z
HIPWDTH	96	71	3	28
LEGHT	80	2	19	97

POPLTH	94	21	5	78
Al-SHLDRHT	95	53	4	46
O-CHSTWDTH	95	73	4	26
Al-CHSTDPTH	92	91	7	8
BUTKNEL	96	24	3	75

VARIABLE VALUES FOR '2-D MAN' MODEL POINTS

MID-RANGE POINTS

A B C D

HIPWDTH 29.35 23.57 27.49 21.72 LEGHT 25.28 24.05 28.00 26.77
POPLTH 18.38 16.06 19.51 17.19 Al-SHLDRHT 28.56 25.68 28.42 25.54
O-CHSTWDTH 26.97 23.01 25.49 21.52 Al-CHSTDPTH 19.95 14.78 14.97
9.80 BUTKNEL 25.45 20.82 27.28 22.64

AXIS INTERCEPT POINTS

W X Y Z

HIPWDTH 29.61 26.84 21.45 24.22 LEGHT 26.89 24.10 25.16 27.95
POPLTH 19.43 16.99 16.14 18.59 Al-SHLDRHT 29.09 27.15 25.01 26.95
O-CHSTWDTH 27.05 25.30 21.45 23.19 Al-CHSTDPTH 18.53 18.40 11.21
11.35 BUTKNEL 27.32 22.75 20.77 25.34

FRSBB-Males-Fin Fri Sep 26 16:24:08 2008Input File: FRSBB-Males-Final.csv

NEAREST NEIGHBORS REPORT

Model Point A Delta Dist 43 25 48 7 5 ---------- -------- -------- -------- -------- --------

(1.69) Component 1 -0.57 -0.88 0.83 0.39 -0.24 (1.69) Component 2 -0.37 -0.88 0.34 0.39 -0.24 ---------- -------- -------- -------- -------- -------- HIPWDTH 2.69 -1.90 1.06 -2.86 -0.52 LEGHT 0.63 -0.47 -0.39 -0.39 0.87 POPLTH -0.81 0.11 -0.50 -1.97 0.58 Al-SHLDRHT -1.13 -0.98 -1.48 -2.35 0.72 O-CHSTWDTH -3.01 -2.12 -1.71 -0.41 2.50

Al-CHSTDPTH -1.84 -1.42 2.60 -1.69 -3.95 BUTKNEL -0.88 -0.43 -1.31 3.66 -0.51

Model Point B Delta Dist 59 94 61 16 14 ---------- -------- -------- -------- -------- --------

(-1.69) Component 1 -0.11 0.44 0.50 0.82 1.00 (1.69) Component 2 -0.41 -0.09 -0.65 -0.40 -0.37 ---------- -------- -------- -------- -------- -------- HIPWDTH -0.37 2.93 0.10 0.98 0.40 LEGHT -0.35 -0.35 0.75 0.67 0.99 POPLTH 0.67 0.72 0.18 0.74 0.42 Al-SHLDRHT -0.03 -0.50 0.87 -0.27 1.66 O-CHSTWDTH -1.30 2.75 0.90 2.17 1.02

Al-CHSTDPTH -1.12 -3.64 -0.86 0.36 1.68 BUTKNEL 0.67 0.22 1.01 1.60 1.14

Model Point C Delta Dist 4 102 97 8 44 ---------- -------- -------- -------- -------- --------

(1.69) Component 1 -0.08 -0.83 -0.95 -0.54 -0.94 (-1.69) Component 2 0.88 0.50 0.40 0.91 0.82 ---------- -------- -------- -------- -------- --------HIPWDTH -0.31 -2.12 -0.88 -3.35 -1.16 LEGHT -0.75 0.19 -0.99 -1.38 -0.44 POPLTH -0.43 -1.47 -0.64 0.30 -1.29 Al-SHLDRHT -0.25 1.03 -1.01 1.84 0.10 O-CHSTWDTH 2.35 -0.94 -0.06 0.42 -2.33

Al-CHSTDPTH -0.22 0.60 -2.56 -0.69 1.68 BUTKNEL -0.85 -3.35 -1.46 -3.49 -2.44

Model Point D Delta Dist 111 108 84 82 81

---------- -------- -------- -------- -------- --------(-1.69) Component 1 0.89 1.11 1.13 1.20 1.26 (-1.69) Component 2 0.75 0.35 0.37 0.46 0.26

---------- -------- -------- -------- -------- --------

HIPWDTH 1.85 1.66 2.99 2.78 1.40 LEGHT -0.00 0.31 0.31 0.86 0.47 POPLTH -0.12 0.64 1.44 0.40 1.17 Al-SHLDRHT 0.43 1.39 -0.19 0.24 0.25 O-CHSTWDTH 2.22 1.98 1.05 1.76 1.83 Al-CHSTDPTH 2.48 2.05 3.65 4.29 3.97 BUTKNEL 1.12 0.45 0.61 0.75 1.52

Model Point W Delta Dist 42 21 66 22 5 ---------- -------- -------- -------- -------- --------

(2.39) Component 1 -0.18 -0.49 0.42 -0.17 -0.43 (-0.00) Component 2 0.01 -0.09 -0.36 0.57 0.65 ---------- -------- -------- -------- -------- --------HIPWDTH 0.76 -1.52 2.37 -1.39 -0.78 LEGHT -0.83 -0.20 0.51 -0.75 -0.75 POPLTH -0.81 0.49 1.09 1.00 -0.47 Al-SHLDRHT -0.52 -1.41 -1.23 -0.44 0.19 O-CHSTWDTH -1.09 1.26 0.37 0.17 2.43

Al-CHSTDPTH -1.52 -1.45 0.31 1.50 -2.53 BUTKNEL 2.87 -1.39 0.31 -1.54 -2.39

Model Point X Delta Dist 49 28 50 20 48 ---------- -------- -------- -------- -------- --------

(-0.00) Component 1 -0.13 0.06 -0.33 0.39 1.15
(2.39) Component 2 -0.01 -0.13 -1.06 -1.05 0.13 ---------- -------- -------- -------- -------- --------HIPWDTH -0.03 -3.17 -0.27 0.84 3.56 LEGHT -0.08 0.55 1.10 1.65 0.78 POPLTH 1.04 0.34 1.26 -0.75 0.90 Al-SHLDRHT 0.54 0.23 -0.77 0.63 -0.07 O-CHSTWDTH -1.54 -1.43 -1.54 2.56 -0.04

Al-CHSTDPTH 0.54 4.34 -0.67 -3.16 4.15 BUTKNEL -2.19 0.47 -2.19 0.38 1.39

Model Point Y Delta Dist 89 45 35 110 17 ---------- -------- -------- -------- -------- --------

(-2.39) Component 1 -0.04 0.34 0.62 1.01 1.16
(0.00) Component 2 0.03 -0.40 0.11 -0.23 -0.27 ---------- -------- -------- -------- -------- --------HIPWDTH -1.53 -0.07 1.06 0.85 -0.26 LEGHT -0.36 1.06 0.04 0.35 0.12 POPLTH 0.50 0.10 0.35 0.59 1.78 Al-SHLDRHT 0.10 0.78 -0.06 2.39 0.78 O-CHSTWDTH 0.25 -0.24 1.34 1.04 1.44

Al-CHSTDPTH 0.09 1.49 0.88 0.07 1.94 BUTKNEL -0.01 -0.29 1.43 0.96 2.18

Model Point Z Delta Dist 80 46 116 71 81 ---------- -------- -------- -------- -------- --------

(0.00) Component 1 0.13 -0.12 -0.17 0.10 -0.43

(-2.39) Component 2 -0.00 0.77 0.87 1.00 0.96 ---------- -------- -------- -------- -------- -------- HIPWDTH 2.39 -0.81 1.23 -0.21 -1.10 LEGHT 1.26 -1.57 -0.15 -1.18 -0.71 POPLTH -0.34 0.91 -1.16 0.70 -0.22 Al-SHLDRHT -1.62 -0.96 -0.61 1.00 -1.16 O-CHSTWDTH 1.37 0.46 -0.22 -0.92 0.16 Al-CHSTDPTH 1.33 0.55 2.23 2.31 2.41 BUTKNEL -1.21 0.34 -0.36 -1.14 -1.18

FRSBB-FEMw63 Fri Sep 26 22:28:40 2008Input File: FRS_BB_Females_w63.csv

MODEL POINT REPORT 95% Accommodation
At Radius 2.600

VARIABLE Z-SCORES FOR '2-D MAN' MODEL POINTS

MID-RANGE POINTS

A B C D

HIPWDTH 1.498 -1.324 1.324 -1.498 LEGHT 1.912 -0.690 0.690 -1.912 POPLTH 1.758 0.158 -0.158 -1.758 AL-SHLDR 0.890 -1.906 1.906 -0.890 O-CHSTWDTH 0.889 -1.907 1.907 -0.889 Al-CHSTDPTH -0.592 -2.100 2.100 0.592 BUTKNEL 1.855 -0.653 0.653 -1.855

AXIS INTERCEPT POINTS

W X Y Z

HIPWDTH 1.995 0.123 -1.995 -0.123 LEGHT 1.840 0.864 -1.840 -0.864 POPLTH 1.131 1.354 -1.131 -1.354 AL-SHLDR 1.977 -0.718 -1.977 0.718 O-CHSTWDTH 1.977 -0.720 -1.977 0.720 Al-CHSTDPTH 1.066 -1.904 -1.066 1.904 BUTKNEL 1.773 0.850 -1.773 -0.850

PERCENTILE VALUES FOR '2-D MAN' MODEL POINTS

MID-RANGE POINTS

	A	B	C	D
HIPWDTH	93	9	90	6
LEGHT	97	24	75	2
POPLTH	96	56	43	3
AL-SHLDR	81	2	97	18
O-CHSTWDTH	81	2	97	18
Al-CHSTDPTH	27	1	98	72
BUTKNEL	96	25	74	3

AXIS INTERCEPT POINTS

	W	X	Y	Z
HIPWDTH	97	54	2	45
LEGHT	96	80	3	19

POPLTH	87	91	12	8
AL-SHLDR	97	23	2	76
O-CHSTWDTH	97	23	2	76
Al-CHSTDPTH	85	2	14	97
BUTKNEL	96	80	3	19

VARIABLE VALUES FOR '2-D MAN' MODEL POINTS

MID-RANGE POINTS

A B C D

HIPWDTH 26.61 21.48 26.30 21.17 LEGHT 26.81 24.37 25.66 23.23 POPLTH 18.18 17.12 16.91 15.84 AL-SHLDR 26.44 24.06 27.30 24.93 O-CHSTWDTH 23.71 20.36 24.93 21.58 Al-CHSTDPTH 12.26 9.82 16.61 14.17 BUTKNEL 25.51 21.37 23.53 19.39

AXIS INTERCEPT POINTS

W X Y Z

HIPWDTH 27.52 24.11 20.26 23.67 LEGHT 26.74 25.83 23.30 24.21 POPLTH 17.77 17.92 16.26 16.11 AL-SHLDR 27.36 25.07 24.00 26.29 O-CHSTWDTH 25.01 21.78 20.28 23.51 Al-CHSTDPTH 14.94 10.14 11.49 16.30 BUTKNEL 25.37 23.85 19.53 21.05

FRSBB-FEMw63 Fri Sep 26 22:28:53 2008Input File: FRS_BB_Females_w63.csv

NEAREST NEIGHBORS REPORT

Model Point A Delta Dist 53 119 109 62 41 ---------- -------- -------- -------- -------- --------

(1.84) Component 2 -0.21 -0.98 -0.47 -0.65 -0.02 ---------- -------- -------- -------- -------- -------- HIPWDTH -1.52 -0.13 -1.59 -2.92 -3.06 LEGHT 0.04 0.04 -1.45 -0.59 -1.53 POPLTH 0.62 -0.68 -0.12 -0.18 -1.60 AL-SHLDR 0.25 -0.72 -0.30 -1.40 -1.59 O-CHSTWDTH -1.85 0.38 -0.36 -1.41 -1.78

(1.84) Component 1

Al-CHSTDPTH 2.25 1.07 -0.56 0.07 -1.32 BUTKNEL -0.29 -1.53 -2.51 -2.27 2.48

Model Point B Delta Dist 60 88 57 96 76 ---------- -------- -------- -------- -------- --------

(-1.84) Component 1 0.70 1.14 1.45 1.43 1.20 (1.84) Component 2 -1.18 -0.91 -0.77 -1.12 -1.37 ---------- -------- -------- -------- -------- -------- HIPWDTH -0.47 2.78 1.89 3.54 0.65 LEGHT -0.91 0.20 1.14 -0.51 0.51 POPLTH 0.53 -0.06 0.25 0.57 -0.22 AL-SHLDR 0.81 1.03 1.03 1.28 0.63 O-CHSTWDTH 0.84 1.47 2.06 1.03 2.15

Al-CHSTDPTH 2.96 1.16 1.63 2.71 2.67 BUTKNEL 1.66 0.17 -0.01 1.01 1.35

Model Point C Delta Dist 6 63 72 117 70 ---------- -------- -------- -------- -------- --------

(1.84) Component 1 0.43 0.82 -1.21 -0.63 -1.02 (-1.84) Component 2 0.59 -0.47 1.02 1.47 1.41 ---------- -------- -------- -------- -------- --------HIPWDTH -1.18 1.02 -0.14 -0.00 -2.51 LEGHT 0.48 -0.23 -0.62 0.16 -0.70 POPLTH -0.88 0.93 -0.08 0.09 0.83 AL-SHLDR 1.16 -0.17 -1.08 0.43 -1.22 O-CHSTWDTH 0.63 0.97 -1.30 -2.33 -0.88

Al-CHSTDPTH -2.58 2.85 -2.57 -2.96 -1.64 BUTKNEL 3.00 1.16 -1.64 -0.67 -0.05

Model Point D Delta Dist 67 91 121 93 120

---------- -------- -------- -------- -------- --------(-1.84) Component 1 0.15 0.53 1.12 -0.04 1.21 (-1.84) Component 2 0.85 0.94 -0.69 1.56 1.03

---------- -------- -------- -------- -------- --------

HIPWDTH -0.57 -0.13 0.33 -0.69 2.81 LEGHT 0.39 -0.00 0.71 0.39 2.68 POPLTH 0.55 0.73 0.44 0.54 0.25 AL-SHLDR 0.14 0.73 0.98 -0.25 -0.04 O-CHSTWDTH -0.75 -0.37 0.35 -0.37 0.90 Al-CHSTDPTH -0.22 -0.55 2.92 -2.00 -0.50 BUTKNEL 1.11 2.23 1.55 1.13 -0.12

Model Point W Delta Dist 6 117 119 68 70 ---------- -------- -------- -------- -------- --------

(0.60) Component 1 -0.37 -0.39 0.18 0.26 0.45 (-0.00) Component 2 -0.56 -0.12 -0.14 0.78 ---------- -------- -------- -------- -------- --------
HIPWDTH -2.40 -1.22 -1.03 -3.29 -3.73 LEGHT -0.60 -0.91 0.11 -1.15 -1.78 POPLTH -1.74 -0.77 -0.27 -0.35 -0.03 AL-SHLDR 1.10 0.37 -1.64 -0.17 -1.28 O-CHSTWDTH 0.54 -2.42 -0.92 -1.84 -0.96

Al-CHSTDPTH -0.90 -1.28 -1.62 -1.05 0.04 BUTKNEL 1.15 -2.51 -1.40 -2.37 -1.89

Model Point X Delta Dist 41 77 109 107 62 ---------- -------- -------- -------- -------- --------

(0.60) Component 1 0.27 0.48 0.10 0.50 -1.23 (-0.00) Component 2 0.22 0.40 0.43 1.41 ---------- -------- -------- -------- -------- --------
HIPWDTH -0.56 -0.75 0.91 0.86 -0.42 LEGHT -0.55 -0.39 -0.47 0.08 0.39 POPLTH -1.33 -0.24 0.15 -0.53 -0.34 AL-SHLDR 0.30 1.27 0.57 -0.16 0.90 O-CHSTWDTH 0.15 -0.69 1.57 1.47 0.51

Al-CHSTDPTH 0.80 1.58 1.57 1.57 2.20 BUTKNEL 4.14 -1.13 -0.86 -1.46 -0.61

Model Point Y Delta Dist 93 67 91 60 92 ---------- -------- -------- -------- -------- --------

(-2.60) Component 1 0.72 0.92 1.29 1.46 1.62 (-0.00) Component 2 -0.28 -0.99 -0.90 0.66 -0.19 ---------- -------- -------- -------- -------- --------HIPWDTH 0.21 0.34 0.78 0.75 1.46 LEGHT 0.33 0.33 -0.07 0.17 0.96 POPLTH 0.12 0.13 0.31 1.38 0.62 AL-SHLDR 0.68 1.07 1.65 0.88 1.51 O-CHSTWDTH 0.93 0.56 0.93 0.93 0.95 Al-CHSTDPTH 0.68 2.46 2.13 1.29 1.71 BUTKNEL 1.00 0.97 2.09 3.51 2.05

Model Point Z Delta Dist 121 37 52 72 120 ---------- -------- -------- -------- -------- --------

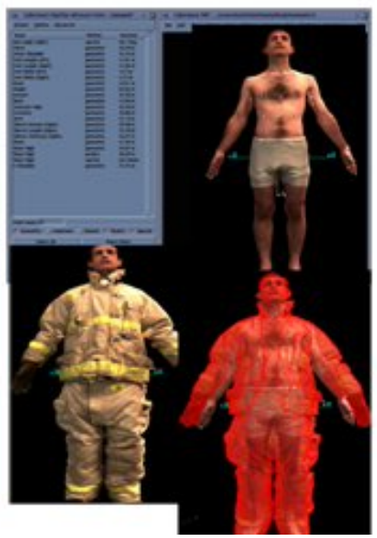
(-0.00) Component 1 -0.72 -0.22 -0.39 0.63 -0.62

(-2.60) Component 2 0.07 1.54 1.82 1.78 1.80 ---------- -------- -------- -------- -------- -------- HIPWDTH -2.17 2.87 0.76 2.49 0.31 LEGHT -0.27 0.59 0.44 0.83 1.70 POPLTH 0.17 -0.36 0.78 0.72 -0.02 AL-SHLDR -0.39 -1.33 -0.52 -0.07 -1.41 O-CHSTWDTH -1.58 0.25 -2.53 0.12 -1.03 Al-CHSTDPTH 0.80 -3.40 -1.32 -2.25 -2.62 BUTKNEL -0.11 -0.49 0.09 0.84 -1.78

APPENDIX E

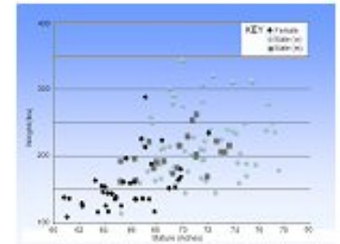
Firefighter CAD models

Summary statistics and multivariate CAD models are available to improve your fire apparatus or equipment designs. We can also customize the data for your specific design needs. Measurements not traditionally captured can be extracted from the 3D data and formatted for your design process.



The National Fallen Firefighters Foundation (NFFF), The International Association of Fire Chiefs (IAFC), the NFPA 1901 Standards Committee, and the Fire Apparatus Manufacturers Association (FAMA) have jointly advocated for a study of firefighter anthropometry. Over 120 firefighters, including women and minorities, have been measured using a state-of-the-art three-dimensional surface scanning system. These data are available to designers of fire apparatus and other fire equipment to improve fit, performance, and safety.

3D Scans:
- allow for infinite number of measurements
- provide framework for body modeling in CAD
- provide visualization of firefighters with gear
- provide raw data for specific design application
- provide population and individual measures



NATIONAL FALLEN FIREFIGHTERS FOUNDATION

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Fax 301-447-1645
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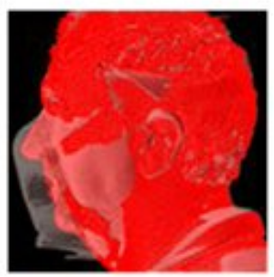
Head and Face Models

Head mounted apparatus such as helmets and masks require fidelity of fit in order to provide the intended protection. Head scan models can be imported into the CAD process or created as physical models to assess fit and accommodation.



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NATIONAL FALLEN FIREFIGHTERS FOUNDATION

FIREFIGHTER BODY SIZE DATA

Tel: 301-447-1365

Firefighter Anthropometry Data

National Fallen Firefighters Foundation

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- Service List
- Project List

Home

Today's firefighting force is a widely diverse population that includes both men and women. To safely accommodate this population, we have measured a small, but demographically representative group of firefighters. Traditional measurements such as stature and waist circumference were recorded for each firefighter. Additionally three-dimensional surface scanning was used to capture each firefighter with and without their bunker gear while in both a standing and seated posture. Three-dimensional scan has been used historically to improve protective gear for the military and civilian workers. Now, for the first time, we have 3D data of firefighters suited for CAD design of fire apparatus and other fire gear!

Fire apparatus and fire gear must fit the wide range of firefighter body size to offer ultimate protection for today's firefighting population.

To contact us:

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