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F-35 Protective Equipment Fit Assessment: Light Weight Coverall

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14. ABSTRACT

At the request of the F-35 JPO, a Fit Mapping test on the JSF Light Weight Coverall (RFDB prototype flight suit) was performed during 2009. This test was carried out to determine: if the coverall gave pilots an adequate fit, if there were an appropriate number of sizes to cover the target population, if the size chart is accurate and user friendly, and how many of each size should be procured (Size tariff). A total of 110 subjects participated. Out of the 110 subjects, 17 subjects (15.45%) failed overall due to unavailability of wider or taller sizes in RFDB prototype flight suits. An additional ten subjects (9.09%) aesthetically failed. 83 subjects (75.45%) received a passing fit in one or more test flight suits. Out of the 83 passing fit-test subjects, 48 subjects passed in their RFDB originally predicted size. This equates to 58.53% of the people received a passing fit. It also must be pointed out that nearly all test participants reported arm movement restrictions caused by the design of the armpit (scye) area of the flight suit. For those reasons, a revised sizing chart has been constructed based on these 83 passing fit-test subjects, a pattern change in the scye area is recommended, and additional sizes are requested.

15. SUBJECT TERMS
Anthropometry, Fit-Mapping, Protective Equipment, fit-testing

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This publication is an application of USAF Technical Report AFRL-RH-WP-TR-2010-0005, "A manual for the Performance of Protective Equipment Fit-Mapping," that describes the methods used in this publication. This report represents a group effort with a data gathering team consisting of Lori Brattin, Tyce Ma, and Rachel Mattis of the F-35/JPO, Robin Bertling of Lockheed Martin, Norma Staples from RFD Beaufort, and Jeff Hudson from InfoSciTex. They each participated during four data collection trips with the authors, and along with Ken Waugh of Lockheed-Martin, also helped by reviewing numerous drafts of this report.

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PREFACE

The F-35 Lightning II Program, also known as the Joint Strike Fighter (JSF), is a joint effort between the United States and a number of international partners including: United Kingdom, Italy, Netherlands, Turkey, Canada, Australia, Denmark, and Norway. The JSF is being designed and developed by Lockheed Martin Aeronautics Company with partners Northrop Grumman and BAE Systems.

The JSF consists of three variants: a conventional take-off and landing (CTOL) aircraft for the US Air Force, a carrier variant (CV) for the US Navy, and a short take-off and vertical landing (STOVL) aircraft for the US Marine Corps and the Royal Navy. The intent is for the USAF F-35A CTOL to complement the F-22 while replacing F-16 and A-10; the USMC F-35B STOVL will replace the F/A-18B/C and AV-8B; the US Navy F-35C will complement the F/A-18E/F while replacing the F/A-18B/C and A-6; and the UK RN F-35C STOVL will replace their Sea Harriers.

The goal of the F-35 program is to provide a family of three distinct variants of a multi-role 5th generation fighter that use a 70% to 90% common airframe to reduce production and maintenance costs. However, due to the requirement for a safe ejection up to 600 knots for a wider range of body size requirements (4'10" 103 pounds to 6'5" 245 pounds versus legacy 5'6" 140 pounds to 6'2" 211 pounds) many of the JSF pilot systems products are unique compared to the legacy fighter aircraft predecessors. Incidentally, the escape and life support systems in addition to the pilot flight and survival equipment are being designed by various vendors specifically for the F-35 Lightning II.

Typically the USAF Clothing Division conducts assessments of individual garments designed for and donned by military members. Since the F-35 Light Weight Coverall (flight suit) has unique requirements for a built in arm restraint system, the JPO (JSF Program Office) elected to have the AFRL 711th Human Performance Wing conduct this fit assessment as the first step in a series of evaluations for the F-35 ensemble. Ultimately, the goal is to complete integration and compatibility assessments for the flight suit, anti-G suit, flight jacket, immersion suit, as well as the chemical and biological protection ensemble. AFRL is also conducting a fit assessment of the F-35 Helmet Mounted Display and F-35 specific Joint Service Aircrew Mask (JSAM).

Proper fit and functionality of flight and protective equipment for the intended F-35 pilot population is critical to mission effectiveness. By accomplishing fit assessments of the various pilot flight equipment configurations, the intended users will have confidence that the products being fielded provide comfort, mobility, adequate field-of-view, and reduced heat stress. This will enhance overall mission success.

EXECUTIVE SUMMARY

At the request of the F-35 JPO, a Fit Mapping test on the JSF Light Weight Coverall (RFDB prototype flight suit) was performed during 2009. This test was carried out to determine: if the coverall gave pilots an adequate fit, if there were an appropriate number of sizes to cover the population, and how many of each size should be procured. A total of 110 subjects participated. It must be pointed out up-front that nearly all pilots tested reported arm movement restrictions caused by the design of the armpit (scye) area of the flight suit. This problem would have resulted in very high failure rates for the coverall and was not included in the accommodation results below. A pattern change in this area is necessary. (This is discussed in sections 0 3.3.3 Sleeve and 0 3.3.4 Scye)

For fit-testing purposes, a "test sample" is not a completely random sample and their accommodation (passing fit) percentages do not reflect the accommodation rate that will be experienced by the actual pilot population. The results from this test sample are used to calculate the actual accommodation pass/fail rates for pilots. The "test sample" included 44 USAF pilot/aircrew subjects (36 males, 8 females), 51 USMC pilot/aircrew subjects (37 males, 14 females) and 15 civilian volunteers of specific body sizes (6 males, 9 females). All sizes of RFDB prototype flight suit were available to be tested. Each size of coverall was tested on an average of 14.7 people (ranging from two people up to 34 people per size). Quantitative fit criteria ranges were constructed based on the fit measurements made on each subject and pilot subjects' assessments of fit in multiple body areas. These user-defined fit ranges were applied to each tested size tried by each subject to determine the overall pass/fail rates. Out of the 110 subjects in the "test sample", 17 subjects (15.45%) failed overall due to unavailability of wider and/or taller sizes in RFDB prototype flight suits. An additional ten subjects (9.09%) aesthetically failed. This means they could do all mobility tasks and passed all safety related aspects, but the suit was judged as either too tight or too loose based on the fit ranges constructed using the pilot's assessments. 83 subjects (75.45%) received a passing fit in one or more test flight suits.

The results were next applied to two body size distributions to determine the estimated accommodation rates for pilots: 1) the JSF CAESAR population and 2) the 2008 Aircrew Sizing Survey. The JSF sample is the F-35 requirement and was extracted from civilian body measurement data from the late 1990's. The 2008 Aircrew Sizing Survey data was not available to be a JSF requirement but was measured on actual aircrew at a later date. The estimated accommodation rates for JSF CAESAR and the Aircrew Sizing Survey were 94.73% and 85.37%, respectively. The estimated accommodation rate for the JSF CAESAR population is high enough to be acceptable, but the rate for the 2008 Aircrew Survey is not. (For a discussion of the differences in these samples, see sections 0 and 0)

It must be noted that because of the F-35 body-size requirements, the RFDB prototype flight suit is required to accommodate people with shorter statures than are currently allowed into USAF or USN flight training. Essentially all of these small people will get a fit. However, nearly all of the 5% not accommodated in the JSF sample had either very large Chests or tall Statures.

This trend was obvious when the fit mapping results were applied to the (USAF) Aircrew Sizing Survey data. 14.63% of that small sample (n=294) of current Aircrew would not be accommodated. This is problematic - not just because the disaccommodated percentage is high, but because RFDB prototype flight suit does not accommodate people who are currently Air Force pilots and are accommodated in their current flight suit 27P. For that reason, the authors suggest adding additional large sizes. (See sections 0 3.5.1 Predicted Accommodation for Two Target Populations and 0 3.5.2 Comparison Between JSF CAESAR and Aircrew Sizing Survey for more discussion)

Another area evaluated by the fit-mapping process is the adequacy of the size assignment chart – also called a size roll. Out of the 83 passing fit-test subjects, 48 subjects passed in their RFDB originally predicted size. This equates to 58.53% of the people received a passing fit or only 43.63% of the entire test sample. For that reason, a revised sizing chart has been constructed based on the 83 subjects who passed in one or more test sizes. This reflects a difference in the original fit criteria used by RFDB and the user defined fit-criteria constructed in this study.

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1.0 INTRODUCTION

1.1 Objective of the Test

The objective of this assessment was to determine the quality of fit of the F-35 Light Weight Coverall (RFDB prototype flight suit) for JSF aircrew personnel. This testing was done to determine 1) quantitative fit ranges for evaluating the test flight suits which reflect pilots' fit preferences, 2) accommodation (passing fit) rates that represent the total coverage of test subjects, and eventually the Pilot population, 3) whether we need all of the prototype sizes or if we need to add more sizes, 4) a size chart that describes who wears which size, and 5) a size tariff that represents how many of each size to buy.

1.2 Target Populations and Test Subjects

There are two target populations in this study. The first target population can be defined as an expanded aircrew population represented by the JSF Multivariate boundary cases 1 through 8 (Appendix A. JSF Multivariate Cases). JSF Multivariate cases are extracted from JSF CAESAR dataset. Since there has not been a large scale body size survey of the USAF or USN since the 1960's, the JSF sample was extracted from civilian body measurement data (CAESAR) from the late 1990's to represent pilot body size variability. It must be kept in mind that the size requirements for the JSF were set to accommodate individuals that are smaller than current US Air Force and US Navy body-size entrance requirements for pilots. Individuals smaller than 60 inches in Stature must be accommodated in JSF equipment. The second target population is the 2008 Aircrew Sizing Survey data measured on nearly 300 USAF aircrew. This dataset was not available to be a JSF requirement but was measured on actual aircrew at a later date. While a small sample, it shows the same trend as the US civilian population – it is getting slightly taller, but is significantly heavier. In this study, both datasets were used to determine the estimated accommodation rate.

It is critical to have experienced test-subjects who are familiar with the items or class of items under evaluation. A test-subject who has no experience wearing a light weight coverall or an Anti G-Suit can rarely be objective with regard to comfort or preference. This lack of experience limits the ability of these subjects to determine the difference between existing equipment and the new test item. In comparison, an aircrew member who has worn such an item for several years will have an operational perspective and can determine if the item is better or worse than similar items. More importantly, that person will be knowledgeable as to how well the test item will integrate with the other items of the personal-protective clothing and equipment normally worn and whether it will allow effective function (McConville et al., 1979).

In the current study, participants who had experience wearing protective gear (44 USAF and 28 USMC pilots and aircrew subjects) evaluated the flight suit using subjective assessments (Refer to section 0). Along with quantitative fit evaluation data collected by the fit evaluator, their evaluations were used as the reference to calculate the quantitative ranges of the fit criteria. Additional opinions from pilot subjects were the basis for documenting comments on the pattern of the test flight suit (Refer to section 0). 15 civilian subjects who had little or no experience wearing protective gear, and 23 USMC pilot candidates who do not yet have any experience wearing a flight suit were only used for fit-evaluations. Their opinions and comments about fit and function were not solicited.

1.3 Protective Equipment and a Test Item

In general, protective equipment is the gear that will be donned by aircrew prior to a mission (Figure 1). This gear includes protective respiratory equipment, helmet, gloves, boots, and a garment ensemble such as a flight suit, G-suit, survival vest, etc. The purpose of this protective equipment ensemble is to enable and enhance military personnel's ability to accomplish their assigned missions by protecting them from G-forces, fire, chemical, biological, and radioactive hazards, etc.

Figure 1. Examples of Protective Equipment Ensemble (Burnett, A.F., 2006)

In the current study, the F-35 Light Weight Coverall (RFDB prototype flight suit) with Arm Restraint System (ARS) was tested (Figure 2). This prototype flight suit was developed in the U.K. by RFD Beaufort (RFDB). The biggest difference between the RFDB prototype flight suit and the current CWU-27P flight suit worn by USAF personnel is the Arm Restraint system (ARS) that is attached to the RFDB prototype flight suit. This restraint system consists of a sleeve-webbing, a captive ring on the flight suit, and Arm Restraint Extension Lines (AREL). The ARELs are attached to the arm restraint webbings on the flight suit or carrier waistcoat sleeves by means of a larks head knot threaded through captive rings which are attached to the arm restraint webbings on the sleeves (Figure 3).

Figure 2. F-35 Light Weight Coverall

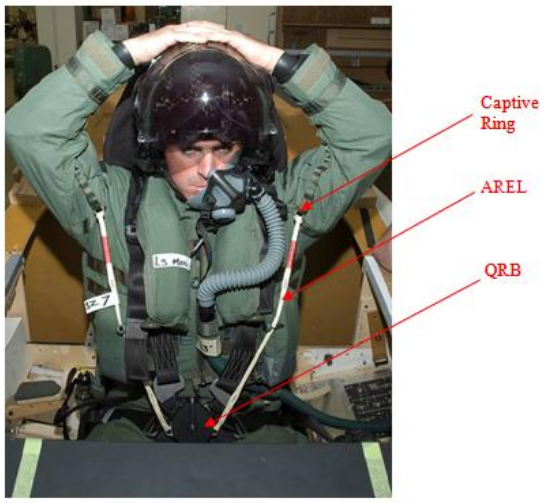

Figure 3. F-35 Arm Restraint System

The main function of the ARS is to hold the pilot's arms adjacent to the pull handle during ejection. During the cockpit 'strapping in' procedure, the arm restraint extension lines are connected to the harness Quick Release Buckle (QRB) which in turn is connected to a pair of webbing lanyards which are anchored to the floor of the aircraft. At the onset of ejection the upwards thrust of the seat tensions the webbing lanyards and effectively restrains the pilot's arms in a position adjacent to the pull handle, where they are restrained until seat/man separation takes place.

In the current study, the location of the webbing was visually inspected since a mock-up ejection seat was not available for the fit evaluation. Refer to Appendix H. Concept of fit for JSF Flight suit (Light Weight Coverall) for evaluating the Arm Restraint fit.

1.4 Scope of Test Approach

The JSF Specification defined flight equipment as items covering the body below the neck, which includes most clothing types of equipment. Thus, the method used for fit assessment on potential test items is similar to that for garment fit assessments. However, functional/safety aspects of the garment must be considered as having priority over aesthetic aspects.

According to a 1996 Advisory Publication of the Air Standardization Coordination Committee (ASCC 61/105/14), when testing the fit of protective equipment there are four different types of assessments necessary for covering all aspects of fitting. They are: Static, Dynamic, Occupation specific, and Integration/Compatibility assessments.

Static assessments test garment features by checking whether they are correctly located on the body, i.e. sleeve length relative to the wrist bone (Ulnar Styloid) or an arm-hole seam location relative to the Acromion process on the shoulder. There are two critical points that should be made prior to undertaking static fit measurement. First, subject postures must be consistent. Each wearer should adopt a pre-determined posture for each of the static assessments listed. For example, have the subject stand with arms outstretched forward and horizontal, then assess the sleeve end position relative to the wrist bone (Ulnar Styloid). Second, each type of assessment must be performed with the garment worn over the correct underlying layers (if appropriate). In this study, the RFDB prototype flight suit was worn over a T-shirt with their underwear, which is similar to how pilots wear them.

Dynamic assessments are essentially performance tests. These tests can be generic - such as general mobility tests, while others should be grossly similar to the occupation of the wearer. This could include things such as reach envelopes, dexterity testing, climbing ladders, and simulation of crude maintenance or pre-flight activities.

Occupation specific assessments are similar to Dynamic assessments, but are much more detailed and specific to a job requirement. Examples of this type include the need to reach parachute risers or aircraft switches, or to quickly escape from an aircraft.

Integration/Compatibility assessments assess whether the clothing/equipment can be used in conjunction with other clothing layers or equipment. This assessment will be necessary when more than one layer of equipment is worn and will investigate compatibility among layers of gear. For example, the fit of the Anti G-suit will be assessed when donned over the flight suit or immersion suit in later studies.

In the current study, these four assessments were the basis for constructing the fit criteria for testing the fit of flight suit (Refer to Section 0 for more detailed information about Fit criteria and Appendix H. Concept of fit for JSF Flight suit (Light Weight Coverall). It should be pointed out that the Integration/Compatibility assessment will be more seriously considered during evaluation of the next layer (such as Anti G-suit or Cold water immersion suit). This current study evaluated only the first layer of protective equipment gear, the Light Weight Coverall. Dynamic and Occupation specific assessments were tested through four mobility tests and specific fit criteria were evaluated using Static assessments.

2.0 FIT MAPPING ASSESSMENT METHOD

Data collection was conducted in three steps, in-briefing, anthropometric measurements, and fit assessments. Anthropometric measurements included traditional anthropometric measurements and 3-D body scans when practical. If it was not practical to scan the subject, photos that include front, side and back views on each trial size of garment were taken. The study was conducted by a total of five individuals in three stations including: in-briefing, a measurer and a recorder for traditional body measurements, a fitter and a fit evaluator for evaluating the prototypes (Refer to Appendix F. Role and Responsibility of Fit Mapping Team Members).

2.1 Test subjects and the initial coverage of size roll

The test subjects for this study were recruited by random sampling as well as by additional stratified sampling to ensure the boundary cases (Appendix A. JSF Multivariate Cases) are represented in the tests. There were a total of 110 participations in this study. Out of this total, there were 95 military personnel (Table 1). The test subjects included as many pilots/aircrew and pilot candidates[1] as feasible, augmented by non-pilot subjects where necessary to match the JSF size range. Most of the aircrew recruited in this study had experience wearing protective equipment.

This study initially included 44 randomly selected USAF pilots/aircrew subjects with 15 civilian subjects. The civilians were added to fill specific areas of the size distribution and to add additional female subjects. Based on the results of that testing, 51 USMC pilots and aircrew were added to the sample. This was done primarily to provide wider or taller body sizes, and to add additional female aircrew. Therefore, this portion of the study was not a random sample and calculated accommodation percentages should be used cautiously.

Table 1. Fit Mapping Test Subjects

Branch	Position	Male	Female	Row Totals
USAF	Pilot	35	6	41
	Aircrew	1	2	3
	USAF Total	**36**	**8**	**44**
USMC	Pilot	17	1	18
	Aircrew	5	5	10
	Pilot Candidate	15	8	23
	USMC Total	**37**	**14**	**51**
Civilian		6	9	15
	Civilian Total	**6**	**9**	**15**
Total		**79**	**31**	**110**

[1] In this study, aircrew members refer to the people who are not pilots but back-seaters who had experience wearing protective equipment. Pilot candidates refer to people who do not have experience wearing protective equipment - but should be accommodated as a part the target population.

Maximum Chest Circumferences[2] and Statures of the 95 USAF and USMC subjects were plotted (Figure 4) with respect to a 95% (confidence) range of JSF CAESAR (Hudson et al., 2003) and a 95% range for the 2008 Aircrew Sizing Survey (Zehner et al., 2008, and Choi et al., 2009). Figure 4 shows that nearly all of the 95 pilot/aircrew subjects fell within the combined area of the JSF CAESAR and the 2008 Aircrew Sizing Survey. The bottom left area (shaded) of the plot shows the area of "expanded coverage" where small statured pilots would fall if they were currently allowed into USAF flight training.

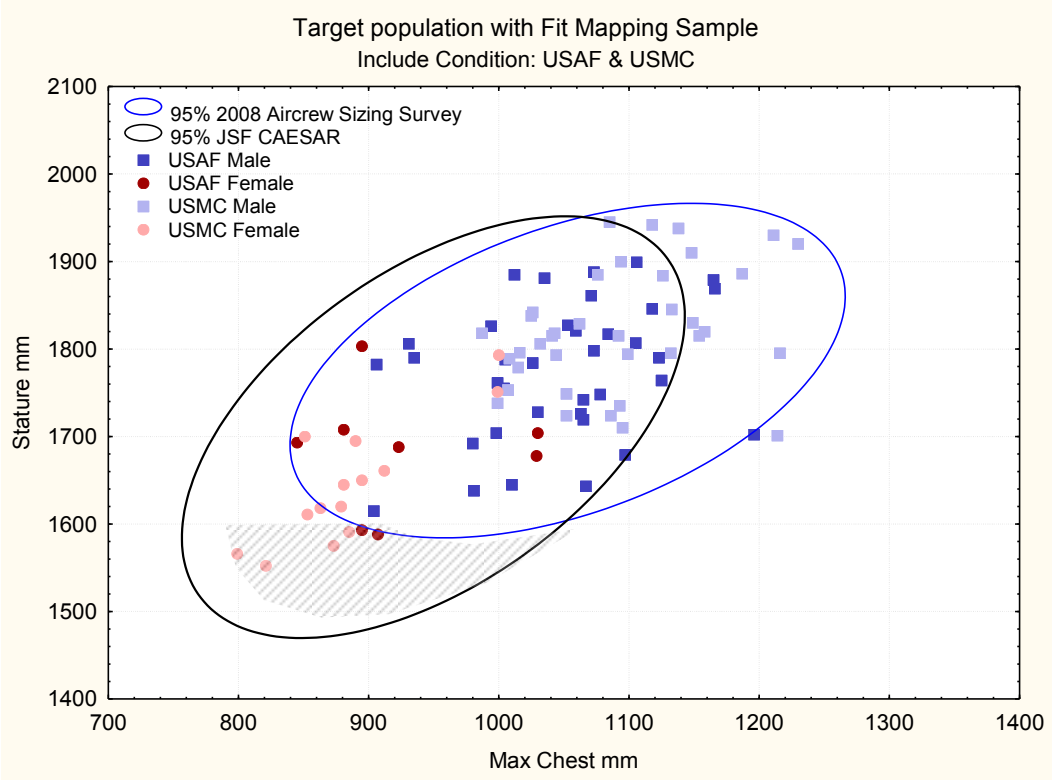

Figure 4. Fit mapping pilot and aircrew subjects

In general, the size range of fit mapping subjects should be wider than the target population so that the fit mapping results (i.e. the accommodation rate) can be conservatively applied to the entire aircrew population. Thus, additional subjects who would possibly add to the ranges of Stature and Maximum Chest Circumference and represent the expanded size range for JSF were recruited. The size areas that needed to be filled by the stratified sampling were: small overall, narrow, wide, and overall large. A total of 15 civilian subjects that included 6 males and 9 females were recruited. Together with the 95 military subjects, the new total of 110 fit-mapping subjects better covered the more extreme sizes (such as short in Stature or narrow in the Chest or tall in Stature). This is shown in Figure 5.

[2] There were two measurements in chest area, "Chest Circumference at scye" and "Bust/Chest Circumference". For male subjects, Chest Circumference at scye was always greater, while Bust/Chest Circumference was greater for most of female subjects. Maximum Chest Circumference refers to the bigger circumference out of these two measurements.

Figure 6 shows the projected initial accommodation coverage based on the original RFDB size roll. This figure shows that 102 out of 110 subjects (about 92.7%) were covered in the initial RFDB design scheme. Eight test subjects (two civilian and six military participants) fell outside of the initial (predicted) coverage of the size roll. This point will be discussed later in section 0 3.4.4 Additional necessary sizes.

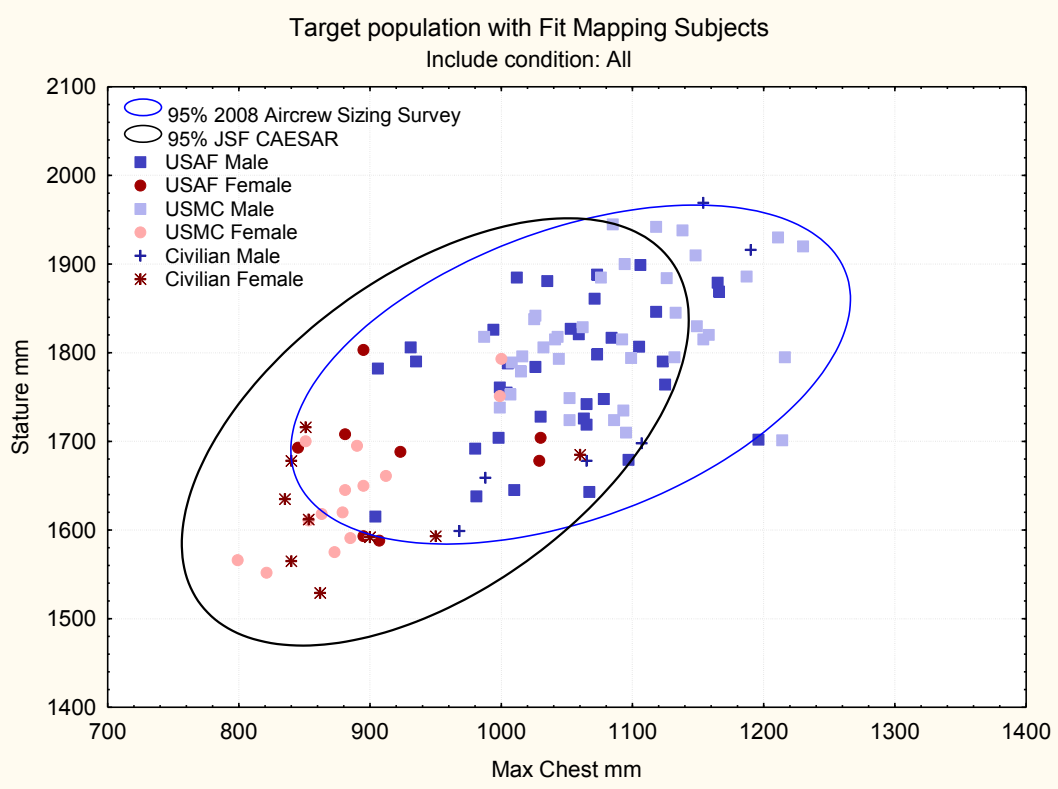

Figure 5. Plot of all fit mapping subjects including civilian subjects

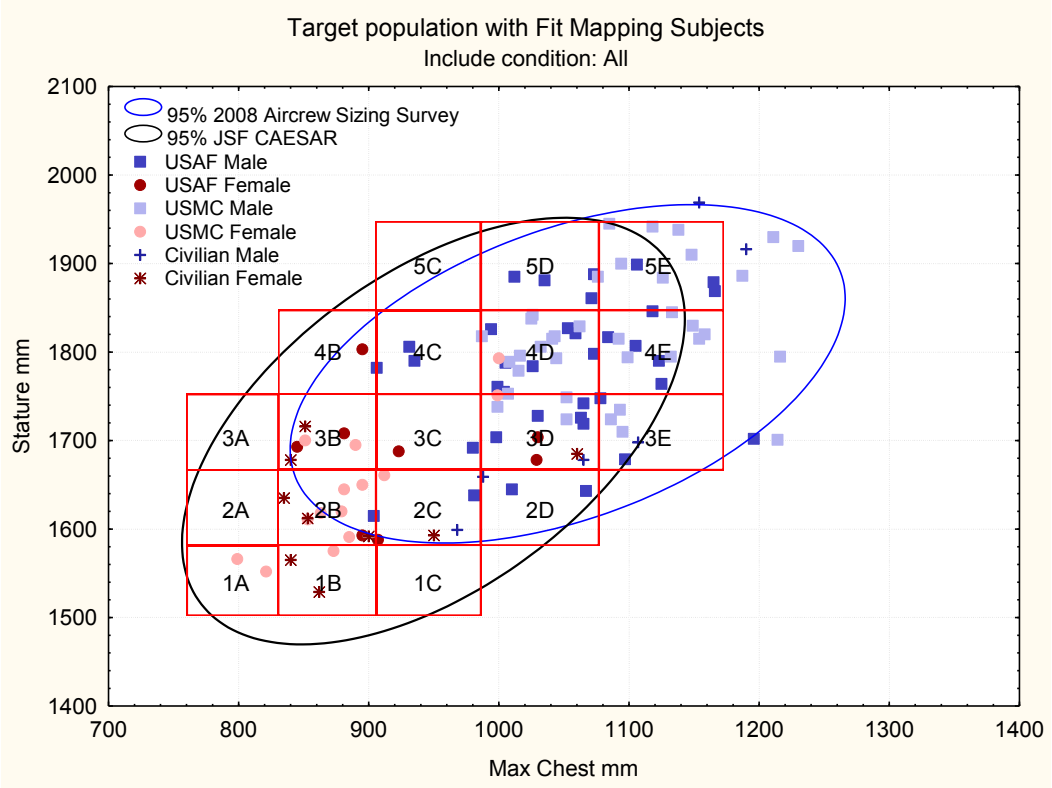

Figure 6. Initial size roll with fit mapping subjects

2.2 Experiment schedule and location

There were a total of 4 locations visited to recruit pilots/aircrew subjects. The first experiment was done at Laughlin AFB, Texas for two weeks from the 9th of March to the 20th of March, 2009. Additional experiments were done at Wright Patterson AFB, Ohio during May and June, 2009. As a result of initial analysis of this data, subjects with wider and taller body sizes were sought. Three additional experiments were done at Marine Corps bases that include Pensacola NAS, Florida in July 2009, MCAS Beaufort, SC and MCAS Cherry Point, NC, in November 2009.

2.3 Anthropometric measurements

2.3.1 Traditional anthropometric measurements

A total of 58 anthropometric dimensions were measured using traditional tools (Calipers etc.). 13 of them were seated measurements. These measurements include all necessary key dimensions for garment design and assignment as well as detailed body dimensions that make it possible to compare the test subjects with existing aircrew anthropometric databases.

(Refer to Appendix D. Traditional Anthropometric Measurement Worksheet for 2008-2009 Aircrew Sizing Survey)

2.3.2 Capture of body shapes

In lieu of 3D scans, multiple photos from three views (front-arms down and arms out, side, and back-arms down and arms up) were taken of each subject in a standing posture. Along with these photos, the additional civilian subjects recruited at Wright-Patterson AFB were surface scanned in each test flight suit. These photos can be used at a later time to confirm fit issues.

2.4 Fit Assessment

2.4.1 Test garment preparation and operation

2.4.1.1 Size preparation and verification

The RFDB prototype flight suit comes in a total of 19 basic sizes (27 when considering sleeve length variation). All sizes of test flight suit were available and used for the fit evaluations. There were three types of classification in the sizing system. They include: five Stature classes (1 through 5), five Chest Circumference classes (A through E) and three Sleeve length classes (Short, Long, and Regular). Appendix B. Size Roll (RFD Beaufort Light Weight Coverall) shows the detailed size roll of RFDB prototype flight suit. A test subject's predicted size was initially determined based on that size roll. It shows the range of body dimensions that should be accommodated in each flight suit size.

2.4.1.2 Test size selection

Each test subject was evaluated in between one and five sizes of the flight suit. Ideally, fit tests should be performed in the originally predicted size as well as all adjacent sizes. That would include a combination of one size longer, one shorter, one narrower and one wider than the originally predicted size. Based on the body size of the subject, not all of these combinations are necessary or even possible. The bottom line is that all potential sizes that would possibly fit the test subject should be tested.

By testing more than one predicted size, the test items were assessed in two ways: testing multiple sizes on one individual and testing each size of garment on multiple test subjects. While they seem to be two separate evaluation procedures, they are simultaneously performed during a fit evaluation. Testing multiple sizes on one person determines the number of different sizes that could provide a range of acceptable fit for the individual. After gathering data on many subjects, analysis determines the number of necessary sizes required to accommodate a given percentage of the user population. Each size of the garment is also tested on multiple test subjects by testing multiple sizes on one person. This allows determination of the anthropometric dimension range that fits into each size of the garment at specific body locations (i.e. the range of passing fit Hip Circumferences at Hip Circumference level for each size). This size assessment method helps establish a realistic size roll for assignment of the garment and may also identify areas of the pattern that need modification.

In this study, subjects were tested in multiple sizes of RFDB prototype flight suits from one size up to five sizes. Thus, the total number of fit trials is greater than total number of fit mapping subjects. This multiple trial method resulted in each size being tested between two and 34 times, on average 14.7 times per each size (Table 2). The most frequently tested size was 4D (4DL-24 times, 4DS-10 times) followed by 5E, 4E (4EL-16 times, 4ES-12 times), 5D and 3D (3DL-10 times, 3DS-13times) (Colored blue in Table 2).

Table 2. Trial number per size

	Chest Circumference Class					
Stature	A	B	C	D	E	Total
5			16	27	31	74
4		8	14	34	28	84
3	6	10	19	23	14	72
2	8	16	11	3		38
1	4	6	2			12
Total	18	40	62	87	73	280

2.4.2 Fit Criteria

Fit Criteria (also referred to as a "concept of fit") are simply the way in which an item is expected or required to fit (Choi, Zehner, & Hudson, 2009). In a fit mapping experiment, fit criteria consist of the list of requirements. This document should guide the fit evaluator as to what, where, and how to evaluate the fit requirements of a test item, and should be developed individually per each test item. Thus, fit criteria vary depending upon the test item.

For any fit test, there are two phases needed to construct the final fit criteria. The first phase is a step by step procedure to list all the requirements and measurements that should be assessed during the fit test and to translate them into a consistent and measurable form by which fit can be evaluated and quantified (Choi, Zehner, and Hudson, 2009). The second phase is to assign quantitative ranges to each requirement by which fit evaluator can determine the pass or fail for each requirement. These ranges can be determined by preliminary test or the actual fit evaluation.

The final fit criteria for a test item should be the composite form of a document that includes fit requirements with detailed instructions on the method to be used, and the pass/fail fit ranges of the requirements. In this study, the fit ranges for each requirement were calculated from the actual fit evaluation data. Refer to Appendix E. Fit assessment data collection sheet, and to Appendix H. Concept of fit for JSF Flight suit (Light Weight Coverall) (RFDB Light Weight Coverall).

2.4.2.1 Mobility/Performance Test

Four mobility tests were used to confirm basic capabilities in the flight suit including: Arm and Hand movement, Leg Movement, Torso Movement, and Head Movement. Arm and Hand movement assessed the overall whole body physical fit of the prototype flight suit especially focusing on the fit around the crotch area. Leg Movement assessed the fit around the lower body that include thigh and knee area, crotch, buttock and overall back length. Torso Movement assessed the fit around the abdominal area and shoulder when bending over while seated. Finally, Head Movement detected the fit around elbow, under arm and the overall upper body when checking 6. These mobility tests movements were designed by observation of routine actions performed by pilots (Figure 7).

Figure 7. Simulated routine actions by pilots

Each performance was evaluated by the Fit evaluator with three categories, Pass, Marginally Pass, and Fail. These tests were also evaluated by the pilot subject with three categories, Good, Acceptable (Tight/Loose), and Mobility- Restricted (Tight/Loose). Refer to Appendix H. Concept of fit for JSF Flight suit (Light Weight Coverall) for a detailed illustration of the Mobility tests, and to Appendix E for data collection input form.

2.4.2.2 Specific (garment) Location Test

All assessments were conducted with the garment positioned where it fell on the subject when they were done with mobility tests. The coverall was not relocated to reflect "correct" position such as waist height, hip height, etc. Specific location tests included: the location of the Arm Restraint system, 5 Line Locations, (Figure 8) and 5 Ease Locations (Figure 9). Assessment of "Line" refers to evaluating the garment fit by measuring the distance from the location of seams or hem lines relative to body landmarks. "Ease" refers to the extra room around certain locations (i.e. Chest, Waist or Hip). To assess ease, excess fabric around those locations is measured. Refer to Appendix G. Specific Location Assessments for detailed information. All locations were assessed and measured by the fit evaluator and recorded in metric units.

Except for the Arm Restraint system, the ten specific location tests as well as its overall appearance were assessed by pilot subjects[3] using a 5-point scale assessment:

1-Cannot wear it,
2-Noticible discomfort but wearable for 2-3 hours
3-Noticible discomfort but wearable for all day
4-OK (Minimal issues which can be ignored)
5-Excellent (no fit issues)

[3] The test flight suits (RFDB) were brand new and had not been washed, while a pilot subject's personal flight suit (27P) was washed many times. Thus, the tactile sensation between 27P and RFDB Test flight suits was different. 10 specific location tests were performed independently and the subject's assessment score at each specific location was tied to the measurement at that location. Hence, it is believed that the difference in tactile sensation would not affect the subject assessment scores at each location. However, the subject assessments might have been affected when they were visually evaluating the appearance for overall evaluation. Thus, subject's overall evaluation rates were used only as a reference in this study.

Refer to Appendix H. Concept of fit for JSF Flight suit (Light Weight Coverall) for a detailed description of the Specific (garment) location tests.

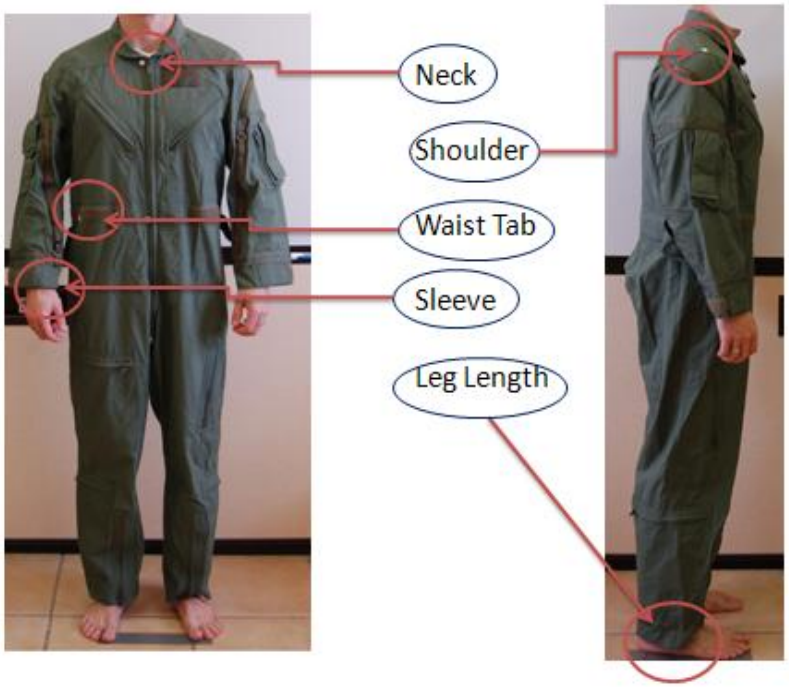

Figure 8. Locations of line measurements

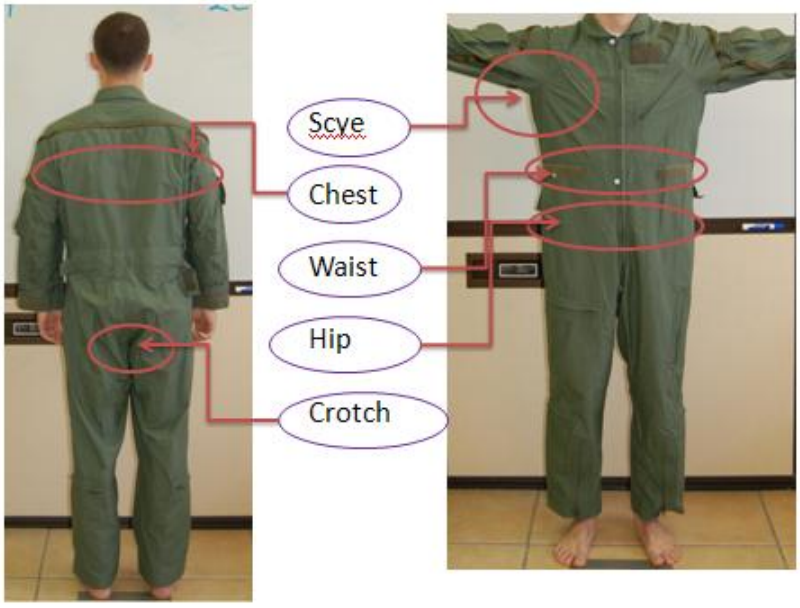

Figure 9. Locations of ease measurements

2.5 Experiment Procedure

Male and Female pilots/aircrew at Laughlin AFB, Pensacola NAS, Beaufort MCAS, and Cherry Point MCAS volunteered and signed up for the test. Civilian volunteers were measured at Wright Patterson AFB. At the first station, subjects were briefed on the reasons for collecting anthropometric data on aircrew and for the fit evaluation of F-35 Light Weight coverall. Subjects were then asked to read and sign a consent form and fill out a brief questionnaire (Appendix C. Aircrew Sizing Survey Questionnaire) on demographic information. After the briefing, subjects were given a pair of shorts (Male) or a sport bra top and shorts (Female) to change into. Lab coats were available in the changing station if any participants felt the need for modesty.

At the second station, various anatomical landmarks for traditional anthropometric measurements were located by palpation or visual inspection and marked on the subjects with an eyeliner pencil. Traditional anthropometric data were collected. This station was staffed by a measurer and a recorder. The recorder filled out the measurement sheet as the values were called out by the measurer. The recorder also assisted in measuring and positioning the subjects. When all the traditional measurements were completed, subjects were given a T-shirt of their size to wear during subsequent evaluations.

The third station tested the Prototype F-35 Light Weight Coverall. During this session, subject mobility performance scores in test flight suits, and line and ease measurements were taken. Subjects donned the T-shirt on top of their measuring garment and were asked to perform the four mobility tests in the measuring garment to ensure their capability and to give a baseline comfort for their subjective evaluation of mobility tests.

The mobility tests and specific location tests were performed in their own 27P flight suit and then all test flight suits. To keep consistency across all subjects, all zippers (Center and pockets) were closed up and all Velcro (Wrist and Waist) was undone. If applicable, sleeves were unrolled. When the fit evaluation was conducted at USMC bases, an additional set of mobility tests was done. USMC participants performed a second set (identical) of mobility tests while wearing flight suits the way they normally wear them for flying (Velcro on waist or wrist were fastened, etc).

For specific location tests, white dots were placed on the subject's flight suit to represent the Suprasternale level (if applicable), Acromion level (L, R), and Omphalion level. Subject's assessment scores were taken along with fit evaluator's measurements. After taking all the assessments and measurements, photos were taken from the front, side and back. To assure measurement consistency, one fit evaluator assessed the fit of all 44 USAF subjects, 51 USMC subjects, and the 15 additional civilian subjects.

Additional subjects recruited at Wright Patterson AFB were also scanned with a Cyberware WB4 to capture their 3-D images before they were photographed. The subject's assessment data were not collected from these civilian subjects. Obviously, they could not be tested in their current 27P flight suit, so they were only tested in their predicted and adjacent sizes of the RFDB prototype flight suit.

When all the fit evaluations were completed, white dots were removed and subjects were escorted to the changing station and thanked.

3.0 RESULTS

3.1 Quantitative fit ranges for Fit Criteria, "Concept of Fit (COF)"

3.1.1 Tests of scale consistency

Three sets of ANOVA tests were performed to answer the following questions pertinent to construction of the quantitative pass/fail ranges for fit criteria.

- Are the subject's assessments consistent?
- Are subjects aware of any differences between the 27P and RFDB prototype flight suit?
- Are there any differences between male and female aircrew as well as between USAF and USMC subjects regarding the well-fit criteria?

3.1.1.1 Test 1: Consistency of subject's assessment

Are the subject's assessments consistent? To see whether the five categories of subject assessment scores are different from one another and consistent in terms of scoring ease and line amounts, measurements (line or ease) were compared with subject assessment numbers. For example, if they were consistent, the ease amount for the rating of "loose" at the chest level should be greater than that for "tight", etc.

There was a statistical difference between tight scores (2-tight, 3-tight) and loose scores (2-loose, 3-loose). The ease or line measurements when subject scores were 2 or 3-tight were significantly smaller than when they were when scored 2-loose or 3-loose. This means that subjects in this assessment evaluated the fit at each location consistently using the 5-point scale. However, there was no statistical difference between 4 and 5 (OK and Excellent), between 2 tight and 3 tight, and between 2 loose and 3 loose (Figure 10). Therefore, these scores were combined and assigned a new number. Scores of "4" and "5" were coded as "5", scores on the loose/longer side as "7", and scores on the tight/short side as "3" (Figure 11).

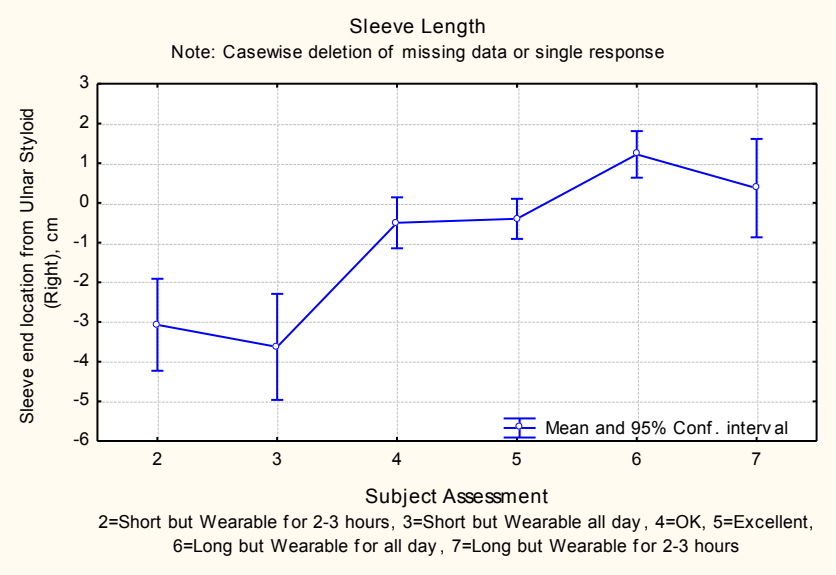

Figure 10. Before combining the Subject Scales (Example: Sleeve length assessment for males)

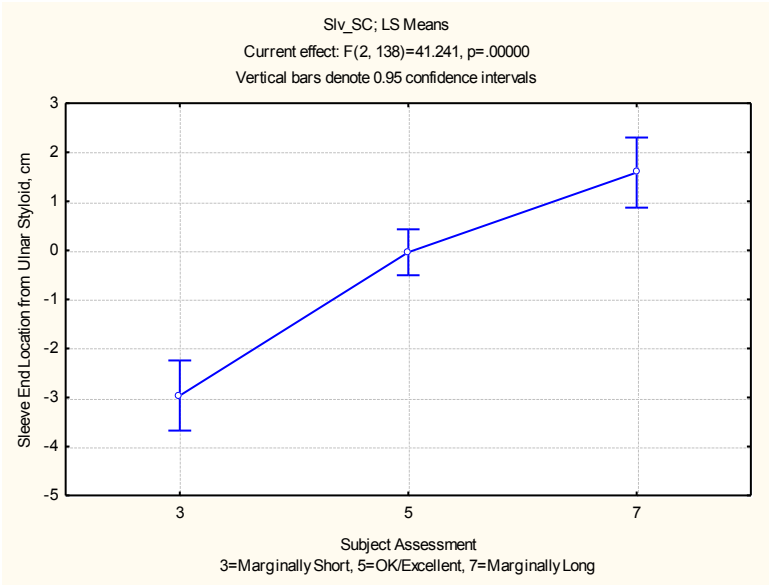

Figure 11. After combining the Subject Scales (Example: Sleeve length assessment for males)

3.1.1.2 Test 2: Comparison between 27P and RFDB prototype flight suit

Are subjects aware of any fit differences between the 27P and RFDB prototype flight suit? To see whether the subject assessments of ease and line amounts were statistically equivalent between the 27P and RFDB prototype flight suit, ease and line amounts were compared between the 27P and RFDB prototype flight suit when the subject assessment score was ranked as an excellent fit (score=5).

There were significant differences between the two flight suits for line or ease amounts at the Neck (Male), Shoulder, Chest, and Waist (Male). These differences could mean that there are noticeable differences in the patterns of the 27P and RFDB prototype flight suit. The pattern of 27P has a relatively wider shoulder with a narrower waist and hip than the RFDB prototype flight suit, therefore the *location* of the shoulder or ease amount at the Waist for score of "5" can be different even though pilots think both have good/excellent fit.

For that reason, when constructing the final concept of fit for RFDB prototype flight suit, the pass/fail range for ease or line measures were calculated based only on the RFDB prototype flight suit results.

3.1.1.3 Test 3: Comparisons between Males and Females

Is there any difference between male and female aircrew regarding the definition of the well-fit condition? To see whether the ease or line amounts were statistically equivalent between males (n=58) and females (n=14), ease and line amounts were compared between male and female aircrew when the subject assessment scores were classified as an excellent fit (score=5).

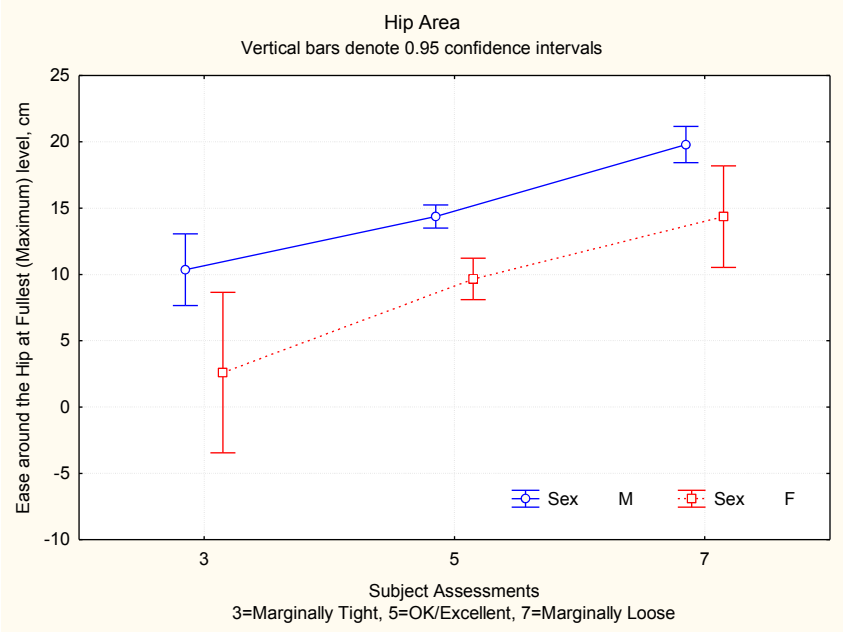

Figure 12. Gender differences in Subject Assessments (Example: Hip area)

Significant differences showed up for line and ease amounts at the Neck, Waist and Hip. Figure 12 shows the example of the Hip area fit. These differences indicate different fit preferences (Waist and Hip) between men and women or very different body sizes relative to the garment size (Neck). Females preferred a tighter fit. When constructing the final concept of fit, the pass/fail range for ease or line measures were calculated separately for men and women where necessary.

3.1.1.4 Test 4: Comparisons between USAF and USMC

To see whether the ease or line amounts were statistically equivalent between USAF (Male=36, Female=8) and USMC (Male=22, Female=6) pilots, ease and line amounts were compared between USAF and USMC when the subject assessment scores were classified as an excellent fit (score=5). Since the fit ranges for Neck, Waist and Hip areas are known to be different between Male and Female subjects, these areas are compared only between same genders. There was no significant difference in subject assessments between USAF and USMC subjects at any location (Figure 13). Thus, all the pilot/aircrew comments were combined for the USAF and USMC when constructing the final quantitative fit criteria.

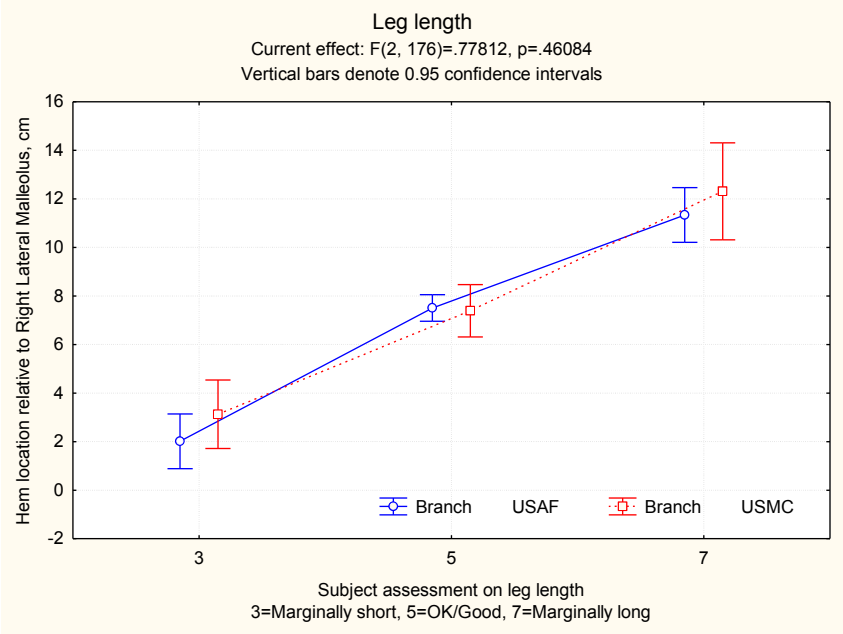

Figure 13. Differences in subject assessment between USAF and USMC (Example: Leg Length)

3.1.2 Constructing the Pass/Fail range for each assessment location

For each assessment location, a line graph was made to represent the line or ease amount for scores of 3(tight/short), 5(OK and Excellent), and 7(Loose/Long).

The classification ranges for good (OK), marginally tight/short, or long/loose were determined based on the mean values for subject assessment scores of 5, 3, and 7, respectively. Separate ranges for males and females were calculated at Waist and Hip locations. The OK range was determined from the line or ease measurements for subject scores of 5 (Ok or Perfect). The mean value (or the closest integer) for subject scores of "5" was used as the center point of the OK range. The Standard Deviation value (or the closest integer) was utilized for constructing the upper and lower end of the OK range.

The endpoints of the OK range were used to determine the starting points for the marginal ranges. For example, the OK range for Sleeve length is centered at the wrist landmark (0cm). The standard deviation was +/- 1cm. Thus, the range for an OK fit for Sleeve length is 2cm. The upper boundary for marginally passing was determined by adding an additional range

of 2cm to the upper boundary of the OK range. The lower boundary for marginally passing was determined in the same way. These categories were selected based on the distribution of user assessments and are intentionally conservative. In some areas of fit – for example the shoulder area – users had an overlapping range of responses. For other areas such as hip, waist, or the lengths, the responses were very consistent.

Body size variation was taken into account when constructing the fit range for leg length and crotch area. The general fit criterion for leg length was such that the "good" range is when the hem falls from 5.5cm to 9.5cm (7.5cm ± 2.5cm) below the ankle bone. Accordingly, the ranges for marginally short and long fit are from 1.5cm to 5.5cm, and 9.5cm to 13.5cm, below the ankle bone respectively. However, for short people (Stature class 1) a hem location of 9.5cm to 13.5cm below ankle bone is too long to be acceptable relative to their height. Also, for tall people, (Stature class 4 or 5) 1.5cm to 5.5cm below the ankle bone is too short relative to their stature. Thus, the leg length fit criterion was modified relative to height classes within the original fit range (Table 3).

The same rule was applied to the ease amount at Crotch area. The "good" range is from 11cm to 15cm (13cm ± 2cm), with marginally tight (7cm ~ 11cm) and marginally loose (15cm~19cm) ranges. As was true for leg length, 7cm of ease around Crotch is too tight for tall people (stature class 4 or 5), and 19cm of ease around crotch is too loose for small people resulting in a low crotch location for the flight suit. Therefore, the criterion for the ease around Crotch was also applied differently relative to their height classes within the original distribution (Table 4).

Final ranges of good fit and marginal fit are listed below in Table 3 and Table 4. Any fit measurements outside of these ranges are considered failing or aesthetically failing depending on the location. Fit range graphs for all assessment locations except for the Scye location are presented in Appendix I. Fit range plots. When applicable, pictures for each score at each fit assessment location are included to help visualize the fit.

Note that the Scye area was excluded from these ranges in the final fit criteria (Table 4). This area was consistently pointed out as a problem area that caused restricted motion for nearly all test subjects - especially by Marine pilots/aircrew. The pattern for the RFDB sleeve and shoulder area is different than that of the 27P. The RFDB prototype flight suit hangs low under the arm which causes arm movement difficulty. Subjects felt it pulled down on the arms during mobility tests and general arm movements. Since the fit of this area needs to be reviewed in terms of a possible pattern modification for all sizes, the overall fit evaluation was done without assessing fit issues in this area. However, it should be noted that the fit problem in ***Scye*** area occurs in all sizes. The Scye area will be discussed separately in section 0. 3.3 General Comments on the Pattern.

Table 3. Fit ranges for Line measurements

Unit : cm

	Short/High	Good	Long/Low
Sleeve	Distance from the end of sleeve to Ulnar Styloid (Right)		
	-3	-1~1	3
Neck/Collar	Distance from the end of Zipper to Suprasternale		
	-2.25	-0.75~2.25	3.75
Shoulder	Distance from the Arm-hole seam (top) to Acromion		
	-2	0~2	4
Waist Tab	Distance from the waist band to Omphalion level		
	-2.5	0.5-3.5	6.5
Leg Length	Distance from the Right Lateral Malleolous down to hem		
Stature Class1	1.5	4.5~7.5	10.5
Stature Class 2,3	2.5	5.5~8.5	11.5
Stature Class 4,5	3	6.5~10	13.5

Table 4. Fit ranges for Ease Measurements

Unit: cm

	Tight	Good	Loose
Chest	Ease around the Chest at nipple level(most protruding)		
	15	21~27	33
Waist	Ease around the waist at Omphalion		
Male	10	16~22	28
Female	4	10~16	22
Hip	Ease around the fullest part of hip		
Male	4	10~16	22
Female	2	6~10	14
Crotch	Ease around Crotch		
Stature Class 1	7	10.5~14	17.5
Stature Class 2, 3	7.5	11~14.5	18
Stature Class 4, 5	8	11.5~15.5	19

3.1.3 Comparison between the original RFDB Fit Criteria and the current study

This project was based on a user assessment of the well-fitted condition. These fit criteria (user Fit criteria) were then compared back to the initial RFDB fit criteria (RFD Beaufort, 2005) which were supplied to help form a foundation for generating these fit criteria (Staples, 2009). While the Chest, Waist, and Hip fit criteria in the initial RFDB fit criteria were only verbal descriptions, quantitative fit ranges for Sleeve Length and Leg Length fit were suggested. The fit metrics at these two locations were compared next.

The user Fit criteria, defined the range of an "acceptable" fit for sleeve length as 3cm up and down from the Ulnar Styloid (Wrist bone) (Table 3). In comparison to this 6 cm range, the RFDB fit criteria suggested a 5cm range - 2cm above (toward the elbow) the Ulnar Styloid to 3cm below (toward the fingers) Ulnar Styloid (Table 5). The user Fit criteria further define the

"Good" range as 1cm up and down from Ulnar Styloid, and "marginally passing" range as 2cm up and down from the upper and lower bounds of the Good Range. Based on user assessments, 3cm up and down from the Ulnar Styloid is a conservative range, since the observed minimum and maximum sleeve length for subject assessment scores of 5 (OK and Excellent) were from -4.8cm to 4.9cm for men and from -4cm to 3.6cm for women, respectively.

The fit range for leg length determined by RFDB was also smaller (more strict) than the user fit criteria (Table 3 and Table 5). The user fit criterion accepts a leg hem that is as small as 1.5cm to as large as 13.5cm below the Lateral Malleolous (Ankle bone). The overall "Good" range falls from 4.5cm to 10cm below the landmark. In comparison to this 12 cm range, the suggested RFDB Fit criterion for the Leg hem location has a 7.5cm range and falls from 2.5cm *above* the Lateral Malleolous (Ankle bone) down to 5cm below the ankle. These two criteria for leg length are different in two ways, the total range RFDB suggested is much smaller, and the hem location for marginally acceptable is much higher on the leg. The user fit criterion expects the hem location to be at least 1.5 cm below the Ankle bone while the RFDB criterion suggests that 2.5 cm above the Ankle bone is acceptable. The preferred length for most US pilots was when the hem was located just above the floor when standing.

Since leg length measurements are closely related to Stature - which is one of the representative body dimensions for the size roll graph in Figure 6 - the initial size roll prediction chart developed by RFDB should be revised to reflect differences in the user-defined criteria.

Table 5. RFD Beaufort Fit Criteria for Light Weight Coverall

Garment	Component	Criterion	Consequence of Non Adherence to Criterion	Criterion Number
Lightweight Coverall	Chest Girth	During full inspiration the garment should be a comfortable fit.	If too tight, there will be a compromised ability to breathe. Excessive quantities of material should be avoided.	14
	Waist and Buttock Girth	Should be a comfortable fit.	If too tight – discomfort and compromised mobility. Excessive quantities of material should be avoided.	15
	Sleeve length	With the hands clasped together in the lap, the sleeve length shall not be greater than 20mm below the wrist bone or 30mm above the wrist bone.	If too short there will be compromised fire protection. If too long, there will be compromised dexterity.	16
	Leg Length	The leg length shall be between 25mm above or 50mm below the ankle bone.	If too long, there will be excessive quantities of material.	17

3.2 Fit Mapping

3.2.1 Overall Fit Evaluation

An overall fit assessment score on the test garments should be assigned to determine overall pass/fail decision per each test coverall. To do this, all assessments for each test subject's mobility and specific location tests in each size of garment tested should be converted into scores so that the overall pass/fail decision for the test garment can be determined based on the total sum of these scores.

First, each "fit requirement" was categorized in terms of importance: Functional, Safety or Aesthetic aspects. All the mobility tests were considered to test Functional aspects. "Safety" Aspects of fit include Arm Restraint location, Sleeve length, Neck, Shoulder, Leg Length, and crotch length. "Comfort or Aesthetic" aspects of fit include Waist Tab Height[4], Chest ease, Waist ease, and Hip ease. Then, scores for each testing item are determined by type. All Functional and Safety aspects were scored "5" for pass, "3" for marginally pass[5], and "0" for fail. However, if the aspect of fit included only "Aesthetics", it was scored "3" for Good" ranges, "1.5" for marginal ranges and "0" for measurements outside of the fit ranges. This was done so that aesthetics carried less weight than safety and function during the overall assessment. At the end of the assessment, all the points that the subject received were added up, and final pass/fail decisions were made.

Second, the overall fit assessment had three categories: Fail, Pass, and Aesthetically Fail. In general, subjects have to pass on all functional and safety aspects of the fit requirements to get an overall passing fit. If a subject passed or marginally passed all the mobility and safety requirement tests, and the total score was equal or greater than 40[6], it was recorded as a "PASS", if a subject failed any one of mobility tests or safety requirements and/or the total score was less than 40 that was recorded as an "Overall FAIL". "Aesthetically FAIL" was assigned when a subject passed or marginally passed all the mobility and safety requirement tests and the total score was still equal to or greater than 40, but failed one or more of the Aesthetics related specific location tests.

3.2.2 Accommodation Rates

In this study, the accommodation rates were calculated in four ways: Accommodation rate for the military test subjects (Table 6), for randomly recruited subjects (Table 8), for all civilian test subjects (Table 9), and for all test subjects.

First, the accommodation rate for the (non-random) 95 Military test subjects was calculated, and is shown in Table 6. Two things are being examined here. First, what the overall accommodation rate was (what percentage of subjects can get a passing fit in at least one size of the flight suit), and next, how well the RFDB size prediction chart worked given the user defined fit criteria.

Seventy subjects (53 men and 17 women) received an overall passing fit in one or more test flight suits (73.68%). Out of these 70 subjects, 38 subjects (29 men and 9 women) received a passing fit in their RFDB predicted size, and 32 subjects (24 men and 8 women) did not get a

[4] Since no one failed "waist tab", this aspect of fit was excluded from the overall evaluation (total sum).

[5] "Marginal ranges" includes both the loose/long and tight/short sides of the fit range.

[6] The total score when a subject receives a passing fit with "good" at all fit requirements is 59 (5 points per four mobility tests and six safety aspects, and 3 points per three aesthetical aspects). Passing quality was determined as above 67.5% of this total score, thus, 40 (67.8%) was decided as a cut-off value.

passing fit in their predicted size. Ten subjects (5 men and 5 women) could only get a fit scored as aesthetically failing (this can also be considered marginally passing) in any of the test flight suits (10.53%). Out of these ten subjects, six subjects (3 men and 3 women) actually failed in their predicted size while the other four subjects (2 men and 2 women) aesthetically failed in their predicted size.

Table 6. Accommodation rate for Military test subjects

Overall Pass in one or more test flight suits			**73.68%**
	Men	**Women**	**Total**
Pass in RFDB predicted size	29	9	38
Fail or Aesthetically Fail in RFDB predicted size	24	8	32
Sub-Total	53	17	70
Only Aesthetically fail in one or more test flight suit			**10.53%**
Aesthetically Fail in RFDB predicted size	2	2	4
Fail in RFDB predicted size	3	3	6
Sub-Total	5	5	10
Overall Fail			**15.79%**
Fail in RFDB predicted size	9	0	9
Size not available	6	0	6
Sub-Total	15	0	15
Total	**73**	**22**	**95**

There were fifteen male subjects who failed overall in all flight suits tested (15.79%). Six of these fifteen people were so large that they did not even have a predicted size in the RFDB prototype flight suit. All of them wore 46L size or larger in the 27P. There are no RFDB coveralls of a size similar to the 27P size 48 or larger. The other nine of them failed in their RFDB predicted size and 5E, the Largest RFDB size. These nine people wore size 44L or 46L or larger in the 27P. Their Chest circumference or Stature were less than the maximum listed for the RFDB flight suit, 1170mm and 1950mm, respectively, but their mobility was very restricted. The anthropometric characteristics of these people were either: taller than 1900mm in stature, wider than 1150mm in Maximum Chest Circumference, or over 225 pounds in body weight (Table 7).

Table 7. Description of people who failed in all test sizes including their predicted size

Branch	Sub	27P	RFDB Pred. Size	Stature	Weight	Max. Chest Circ.	Test Size	Reasons for Final Fail/Aesthetically Fail
USAF	10	44L	5E	1879	227.6	1165	5E	Crtch_T (7.8cm), Chst_T
USAF	30	46L	5E	1869	208.9	1166	5E	Mobility, Scr<40
USMC	18	NA	5E	1938	229.7	1138	5E	Lg_S, Scr<40
USMC	37	48L	5E	1910	231.0	1148	5E	Mobility, Scr<40
USMC	38	46L	5E	1942	238.0	1118	5E	Mobility, Lg_S, Crtch_T, Scr<40
USMC	39	46L	4E	1845	237.5	1133	4EL	Mobility, Lg_S, Wst_T, Scr<40
							5E	Mobility, Slv_S, Crtch_T, Wst_T, Scr<40
USMC	45	46L	5E	1900	216.4	1094	5E	Mobility, Scr<40
USMC	47	42XL	5E	1945	211.7	1085	5E	Mobility, Slv_S, Lg_S, Wst_L, Scr<40
USMC	49	44L	4E	1815	204.0	1154	4ES	Mobility, Crtch_T, Scr<40
							5E	Slv_L, Scr<40

Crtch_T: Crotch Too Tight, Chst_T: Chest area too tight, Lg_L: Leg Length too long,
Lg_S: Leg length too short, Mobility: Mobility restricted and failed, Slv_L: Sleeve length too long,
Slv_S: Sleeve length too short, Scr<40: Total score is under 40, Wst_L: Waist area too loose,
Wst_T: Waist area too tight

It must be reiterated that in this study, USAF pilots/Aircrew subjects were randomly recruited but test subjects from the USMC were stratified to confirm the margins of body size that can be accommodated by RFDB prototype flight suits. The rate of "Overall fail" ("Size not Available" and "Fail in RFDB predicted size") in the accommodation table is not a fair estimate to apply to the entire target population. Thus, the accommodation rate based only on the "random" USAF test sample was also calculated (Table 8). When considered only randomly recruited samples, there were total of 44 random subjects. Out of the 44 subjects, 3 subjects (6.82%) failed, 3 subjects (6.82%) were only able to be classified as aesthetically fail and 38 subjects (86.36%) passed in one or more test flight suits. Out of the 38 passing subjects, 27 subjects passed in their originally predicted size (61.36% of all random test subjects, 71.05% of the overall passing random subjects).

Since the JSF size requirements go below and above the size range of current USAF pilots, it was necessary to fill out the size distribution for this test with 15 additional subjects from Wright Patterson AFB (6 males and 9 females). Table 9 shows that 13 of the subjects (4 men and 9 women) received an overall passing fit in one or more test flight suits. Out of these 13 subjects, 10 subjects (3 men and 7 women) received a passing fit in their predicted size, and 3 subjects (1 man and 2 women) did not get a passing fit in their predicted size. There were two subjects who failed overall in all flight suits tested, and both were outside of the RFDB predicted size roll either because of Stature or Chest class. They were within the body size range of the 8 JSF Multivariate Cases (Appendix A. JSF Multivariate Cases).

When combining all test samples, military and civilian, there were total of 110 total subjects. Out of the 110 subjects, 17 subjects (15.45%) failed, 10 subjects (9.09%) were only able to be classified as aesthetically fail and 83 subjects (75.45%) passed in one or more test

flight suits. Out of the 83 passing subjects, 48 subjects passed in their originally predicted size (43.63% of all test subjects, 58.53% of the overall passing group).

Table 8. Accommodation rate for USAF test subjects

Overall Pass in one or more test flight suits			**86.36%**
	Men	**Women**	**Total**
Pass in RFDB predicted size	21	6	27
Fail or Aesthetically Fail in RFDB predicted size	10	1	11
Sub-Total	31	7	38
Only Aesthetically fail in one or more test flight suit			**6.82%**
Aesthetically Fail in RFDB predicted size	1	0	1
Fail in RFDB predicted size	1	1	2
Sub-Total	2	1	3
Overall Fail			**6.82%**
Fail in RFDB predicted size	2	0	2
Size not available	1	0	1
Sub-Total	3	0	3
Total	**36**	**8**	**44**

Table 9. Accommodation rate for Civilian test subjects

Overall Pass in one or more test flight suits			**86.67%**
	Men	**Women**	**Total**
Pass in RFDB predicted size	3	7	10
Fail or Aesthetically Fail in RFDB predicted size	1	2	3
Sub-Total	4	9	13
Only Aesthetically fail in one or more test flight suit			**0%**
Aesthetically Fail in RFDB predicted size	0	0	0
Fail in RFDB predicted size	0	0	0
Sub-Total	0	0	0
Overall Fail			**13.33%**
Fail all tried sizes	0	0	0
Size not available	2	0	2
Sub-Total	2	0	2
Total	**6**	**9**	**15**

3.2.3 Accommodation Plots

To begin examination of the coverage of each size of the flight suit for the actual pilot population, the fit range for each size of test flight suit was plotted against Stature and Chest Circumference. The plots show overall pass, fail, and aesthetical fail ratings of the test subjects superimposed on the RFDB size roll and with a new suggested accommodation envelope. This procedure was followed for each size of flight suit (Figure 14).

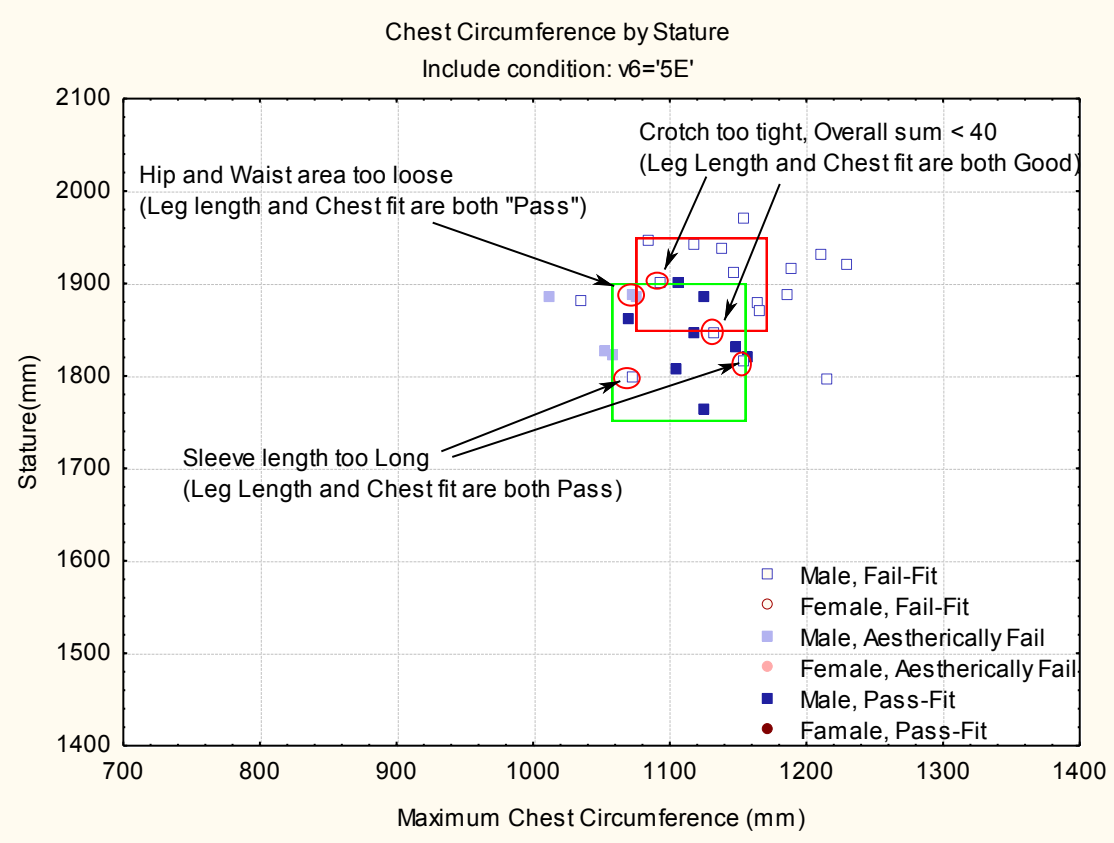

Figure 14. Accommodation plot Size 5E

Circles in the figure represent female subjects and squares represent male subjects. Overall evaluation results were denoted by color: all the "Pass" cases are represented as a dark solid, "Fail" hollow, and "Aesthetical Fail" light solid. The red box represents the predicted accommodation envelope based on the original RFDB size roll, and the suggested Fit Mapping Accommodation Envelope is boxed in green. This green box represents the maximum accommodation range of each size in terms of Chest area and Leg Length fit. Any subjects who failed but are included within the green envelope were denoted with the reason for the failing fit. Figure 14 shows the accommodation plot for size 5E. There are four subjects who are included in the accommodation envelope but received an overall failing-fit. Two of them received a failing-fit due to the sleeve length (too long), the other two failed because the crotch area was too tight and their overall total score was less than 40. The chest fit and leg length fit for these four subjects was acceptable. There were also two subjects who received aesthetically failing-fit scores due to hip and waist fit. The chest fit and leg length fit for these two subjects was acceptable, but the waist to hip area was too loose. This process was repeated for each coverall size. Refer to Appendix J. Accommodation plots for plots of the other sizes.

3.3 General Comments on the Pattern

The passing fit rate for all 110 test subjects was 73.68%. With the probable addition of the 10.53 % that are currently called "Aesthetically Fail", this totals to an 84.21%

accommodation rate. The 15.79% failure rate is clearly due to lack of larger or taller sizes in RFDB prototype flight suit. A pattern modification for improving the accommodation rates does not seem necessary with the exception of the fit issues around Scye area which will be discussed below.

3.3.1 Neck and Collar

In general, RFDB prototype flight suit fits better than the 27P around the neck when completely closing the zipper. "Closing the zipper" was problematic in the 27P fit trial for most male test subjects. The way that pilots wear their flight suits (zipper opened 2-3 inches below Suprasternale) is not only out of habit, but because it is usually too tight around the neck to close the zipper all the way up.

In Figure 15 (a-b). Subject #28, Male (a) 27P-size 42R (Left), (b) RFDB-Size 4E Predicted size (Right), the white dots represent the Suprasternale level. Notice the difference in coverage of the front of the neck.

Figure 15 (a-b). Subject #28, Male (a) 27P-size 42R (Left), (b) RFDB-Size 4E Predicted size (Right)

3.3.2 Shoulder

When subjects received a passing fit in this area, the arm-hole seam location was at or around their acromion. On average, the RFDB arm-hole seam was about 0.84 cm below the Acromion (Calculated only from overall passing fit flight suits). By comparison, the 27P fits differently. On average, the location of arm-hole seam was about 3cm below their acromion (for both USAF and USMC subjects). This will make a difference in the length of the sleeve. The fit differences around the shoulder will be discussed again with the fit around the Scye area.

In Figure 16 (a-b). Subject #44, Male (a) 27P-size 38R (Left), (b) RFDB-size 3CL predicted size (Right), the white dots and top arrows represent the Acromion location. The bottom arrows show the seam location.

Figure 16 (a-b). Subject #44, Male (a) 27P-size 38R (Left), (b) RFDB-size 3CL predicted size (Right)

3.3.3 Sleeve

In general, the sleeve length of the RFBD test flight suits fit the target population better than the 27P in Stature classes 4 and shorter. Pilots typically roll up their 27P sleeves. In some cases, especially for females, this was because the sleeve was too long. With two options (Short and Long) for sleeve length for some of the sizes, the RFDB prototype flight suit reduced the number of failing fits due to sleeve length (Figure 17 (a-b). Subject #20, Female. (a) 27P-size 34R (Left), (b) RFDB-size 3CS predicted size (Right)).

Figure 17 (a-b). Subject #20, Female. (a) 27P-size 34R (Left), (b) RFDB-size 3CS predicted size (Right)

Another observation made was the shape and location of the arm-hole seam. In comparison to the 27P, the RFDB Arm-hole seam is more curved and longer. This makes the sleeve wider. This fit issue will be also discussed below with Scye area fit.

3.3.4 Scye

The Scye area represents the area under arm where the sleeve, front bodice, and back bodice are connected. During the fit mapping experiment, the fit of this area was pointed out by nearly all test subjects as an issue. Two sizes of 27P and RFDB prototype flight suit were

compared below. They are the 36-Short (27P) and 2B (RFDB). These two sizes were selected because test subjects who wore the 36-Short in the 27P were predicted to wear size 2B (based on the RFDB size roll) and received a passing fit in that size.

The general pattern difference in the Scye area was first examined by comparing the flattened figures of the RFDB prototype flight suit with that of the 27P. The most frequently observed differences in fit around Scye between 27P and RFDB prototype flight suit are the ease amount and the shape of the seam. When two flight suits were superimposed, the length of Scye area of RFBD flight suit was longer (Figure 18). The ease amounts around the Scye area in RFDB prototype flight suit are generally greater than those in 27P.

Figure 18. Scye ease comparison between 27P and RFDB (Top is 27P size 36S and bottom is RFDB size 2B, about 5cm difference)

Figure 19. (a-d). Shape of the Scye seam comparison. a) Front view of 27P size 36S (Top left), b) Front view of RFDB size 2B (Top right), c) Back view of 27P size 36S (Bottom left), d) Back view of RFDB size 2B (Bottom right)

The direction from the top of arm-hole seam to the bottom of arm-hole seam (arm pit) is close to a vertical line in 27P, but the RFDB prototype flight suit tracks diagonally. Figure 19 visualizes this difference. The discrepancy in "direction of arm-hole seam" is due to the different relationship between shoulder fit and chest ease in the flight suits. In Figure 19, the end of the shoulder location (top arrow) and the bottom of the arm-hole (bottom arrow) which is also the outer edge of chest area are almost parallel to the center line (zipper) of the 27P flight suit. Both ends are located about the same distance from the center of the coverall (zipper). However, in the RFDB prototype flight suit, the end of shoulder is a lot narrower than the outer edge of chest area. In other words, the pattern of the RFDB prototype flight suit shows a narrower shoulder relative to its chest area.

Figure 20. Shoulder area comparison between 27P (Bottom, 16.2cm) and RFDB (Top, 12.3cm) test flight suit (Aligned at the center line-Zipper)

When the 27P is overlaid on top of RFDB to show this difference, as shown in Figure 20, the shoulder width of 27P is wider than that of a similarly sized RFDB prototype flight suit. In addition, due to the pattern of armhole seam, the width across the chest of 27P (approximately the mid-way from the top of the armhole [shoulder seam] to the bottom of the armhole [armpit]) is also wider than the RFDB prototype.

Together with the longer arm-hole seam, the RFDB prototype flight suit hangs lower under the arm with a relatively narrow front cross chest area which causes restricted arm movements. Subjects felt it pulled down on their arms during mobility tests that included raising their arms up and down. This was especially true for wide chested test subjects who felt that area was very tight when stretching out their arms to both sides at chest level with their elbows bent. This caused the upper chest area to feel tight even though there was plenty of ease at the nipple level.

This phenomenon increased as test subjects tried-on larger chest class sizes (i.e. from 4B to 4C to 4D). This is because the shoulder and upper chest width does not increase as much proportionally as the lower chest area as the sizes move from narrow to wide. Thus, as each size gets wider, the lower Scye seam becomes more prominent - which causes the garment arm-pit to sit lower and farther from the body. This is illustrated in the Figure 21.

27P (38L)

RFDB (4B)

RFDB (4C)

RFDB (4D)

Figure 21 (a-d). Subject #46, Male. Comparison of chest and arm-pit area fit. a) 27P size 38L(Top first), b) RFDB size 4B (Second from the top), c) RFDB size 4C (Second from the bottom), d) RFDB size 4D (Bottom)

In summary, the difference in fit around the Scye area is not only because the sleeve hangs low, but it is the consequence of the interrelation between shoulder and chest cut. The narrow shoulder could be assumed to be the starting point of this problem because the narrow shoulder causes the Armhole seam to be shaped diagonally between the end of shoulder and the outer edge of the chest area, as well as longer.

It must be pointed out why the RFDB prototype flight suit needs a relatively narrow shoulder width. The biggest difference in design elements between the 27P and the RFDB prototype flight suit is the Arm Restraint System (ARS). The fit of the ARS is assessed based on visual inspection. The correct location for the strap is between a point a little below the

acromion (Location 2 in Figure 22) and a point a little above the arm pit level (Location 4 in Figure 22). To control the ARS location, the Armhole seam should be fixed at or around the Acromion. Thus, the narrow shoulder of the RFDB prototype flight suit pattern is required to keep the AR location correct.

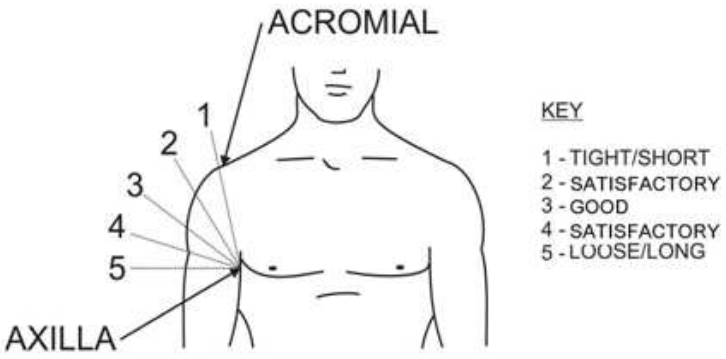

Figure 22. Fit assessment of Arm Restraint

Fit in the Scye area affects two out of four mobility tests. They are 1) hand and arm movement and 2) head and shoulder movement. Both movements involve an arm raising motion. In normal situations, arm movement is a very basic and fundamental motion and comfort should be guaranteed. Based on comments from our test subjects, the biggest issue with this test flight suit is that the fit around the Scye area restricts basic arm movements. Many of our pilots made a comment that they would like a more loose fit around the chest, however when the chest area is loose, the arm pit hangs lower and sticks out more – this could be a problem if it interferes with the survival vest when the arms are raised.

Another problem related to this issue is the possible change in sleeve length. To reduce the discomfort during reaching due to this low arm pit, pilots may pull the arm pit toward their body, causing the sleeve length to become shorter than before.

This fit issue around the Scye area was raised by nearly all of our 44 USAF Pilot/Aircrew subjects and the 51 USMC test subjects. The Marine Pilots also raised the snug/tight fit at the level of front cross chest as a common fit issue. Therefore, the shape of armhole seam must be redesigned to guarantee comfortable/functional arm mobility.

3.4 Size Chart

3.4.1 Maximum accommodation coverage of RFDB prototype flight suit

A new Size Roll for the RFDB prototype flight suit was constructed based on these fit mapping results. First, the same lettered sizes were compared (i.e. a comparison of 1C, 2C, 3C, 4C, and 5C). The same lettered Chest classes showed an almost identical accommodation range in terms of the Chest Circumference regardless of the Stature classes. Next, the same numbered Stature classes were compared (i.e. 3A, 3B, 3C, 3D, and 3E). Within the same Stature class (i.e. Stature class 3) different chest class sizes (i.e. A or B etc) accommodated different Stature ranges. As Chest Circumference gets larger, the bigger chest sizes also accommodate taller subjects. A size chart based on Chest Circumference and Stature is shown below (Table 10). Because this

size chart shows the maximum range of accommodation, the coverage of Chest Circumference and Stature of each size overlaps with adjacent sizes.

Table 10. Revised Size Roll –Maximum accommodation envelopes

		Stature				
Chest	Circumference	1	2	3	4	5
A	760-860	1500-1590	1520-1620	1600-1700		
B	820-960	1500-1620	1520-1620	1600-1720	1690-1810	
C	850-1030	1500-1590	1540-1650	1590-1700	1690-1810	1755-1895
D	980-1130		1540-1660	1640-1740	1710-1790	1760-1900
E	1060-1150			1640-1740	1720-1830	1760-1900

As was shown in Table 10, the accommodation coverage of each test flight suit size can overlap with up to four adjacent sizes (one size taller, shorter, narrower and wider). To provide a user friendly size chart, it is necessary to reduce the overlaps between adjacent sizes as much as possible. There are two ways to come up with a size chart with unique coverage for each size. One would be to select a fit model or a center point for each size and expand the range from that point. This method is suitable when two body dimensions well represent the predicted coverage of the test item (i.e. Waist circumference and inseam for pants). This is a relatively quick and easy way that can spread out the coverage fairly across all sizes. The other way would be to plot subjects in their best fit size so that the coverage of each size can be represented by all the body dimensions. This method more realistically represents the coverage of each size. For this study, the second method was selected. This is because the flight suit is a one piece coverall that covers both the upper and lower part of the body. For this type of garment, it is common to represent body dimensions with a plot consisting of two dimensions, one for upper part (Chest Circumference) and the other one for the total length (Stature). This requires plotting the actual fit results by body dimensions to ensure the lower part of the body is also accommodated.

3.4.2 Select the Best Fit size

If a subject received a passing fit in multiple flight suits, one best fit size can be determined. Usually, if there are more than two sizes that fit, individuals will select one based on their personal fit preference. Since that information was gathered during the fit evaluation, subject's personal preference was utilized as one of the criteria to select the best fit size. First, all the passing sizes for one person were compared based on the overall scores. The highest scored size was selected as best fit size for that person. However, if there was a tie, then each fit requirement was revisited. If one of the ties received a higher score for the mobility tests, that size was selected as the best fit size for that person. If the overall score and mobility scores were the same, then the first priority was the one that has the better leg length fit, followed by chest fit. By doing this when the subject's Chest circumference and Stature are plotted by size, the body dimensions are located more toward the middle of the accommodation range reducing the overlap between adjacent sizes. Most of the time the best fit size selected through this process matched the subject selected best fit size.

The 83 subjects who received a passing fit in one or more RFDB prototype flight suit are plotted below in their best fit size to show the accommodation range of each size (Figure 23). The accommodation range of each size is summarized in a suggested size chart (Table 11).

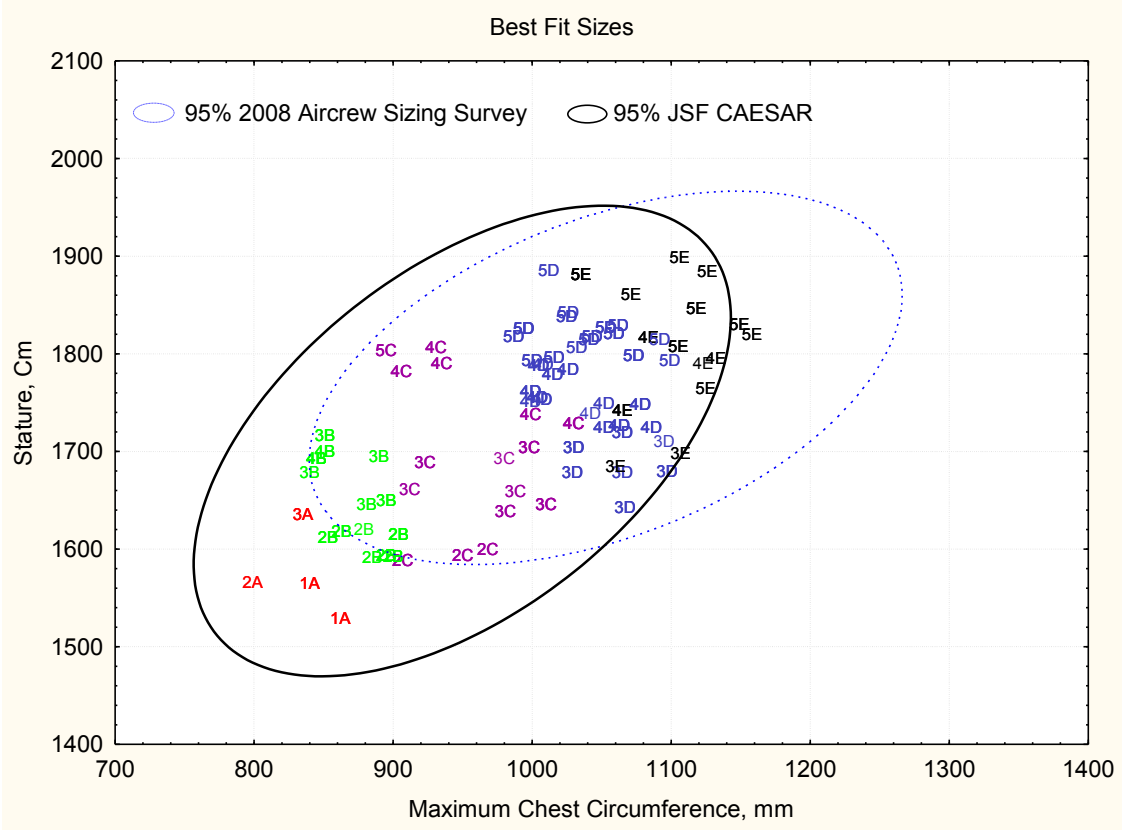

Figure 23. Best Fit Sizes

Table 11. Final suggested size chart for RFDB prototype flight suits

Stature		Chest Class							
Class	mm	A	A/B	B	B/C	C	C/D	D/E	E
1	up to 1570 (1560-1580)	760-840	840-860	860-890	890-910	910-970			
2	to 1620 (1610-1630)	760-840	840-860	860-890	890-910	910-970	970-1030	1030-1100	
3	to 1720 (1710-1730)	760-840	840-860	860-890	890-910	910-970	970-1030	1030-1100	1100-1150
4	to 1800 (1785-1815)			860-890	890-910	910-970	970-1030	1030-1100	1100-1150
5	to 1900 (1885-1900)					910-970	970-1030	1030-1100	1100-1150

It should be noted that there is still some overlap of Chest coverage between sizes A and B, B and C, C and D, and D and E, even though Table 11 is constructed from the best fit size plot. This is because the size chart is constructed with only two dimensions. Chest Circumference can predict the fit of the upper part of flight suit, but not necessarily the fit of the lower part. Depending on the fit of the lower part of flight suit, it is possible to get a passing fit on two adjacent sizes - as long as the fit around the chest is acceptable. Another reason is that we have gender specific fit criteria for the waist and hip area. This would assign a passing fit to a female who has a smaller Chest relative to her hips. This makes the chest coverage of each size appear wider. Therefore, it is not nearly possible to construct a size chart without any overlap with adjacent sizes. Stature classes also overlap. This is because the Stature class was categorized by

a person's overall height when the actual coverage of the flight suit begins at the level of base of the neck (Cervicale). Two people of the same Stature can have different coverage depending on their Head and Neck height. Thus, a 2cm-3cm overlap (1-1.5cm up and down of the boundary values of categories) was allowed in Table 11.

In summary, RFDB prototype flight suit accommodated from Stature 1500mm to 1900mm, with Chest Circumference 760mm to 1150mm. This range is smaller than the originally predicted accommodation range shown in RFDB predicted size roll due to the different "fit-criteria" developed in this study. Refer to the original RFDB size roll in Appendix B. Size Roll (RFD Beaufort Light Weight Coverall) and Figure 6. Initial size roll with fit mapping subjects. According to the RFDB Size roll, the range of Chest Circumferences that should be accommodated is from 760mm to 1170mm with the range of Stature from 1500mm to 1950mm. As noted in Table 10 and Table 11, the actual accommodation range of size 5E is shorter than the predicted maximum value of Stature and narrower than the predicted Maximum Chest Circumference. This was also true in the other chest size classes of this Stature class (i.e. 5C, 5D). Therefore, in order to meet the original design specification, it is recommended that more sizes be added to accommodate wider chests and/or taller heights. This issue is discussed further in section 0 3.4.4 Additional necessary sizes.

3.4.3 Comparison between the RFDB Size Roll and the CWU 27P Size Roll

Next, a size chart that shows the relationship between RFDB prototype flight suit and CWU 27P was constructed. This cross comparison will enable pilots to select the RFDB prototype flight suit size based on their current flight suit size.

Table 12. CWU 27P Size Roll (inches)

Size	1/2 Chest Circ.	1/2 Hip Circ.	Sleeve Inseam			Leg Inseam		
	All	All	S	R	L	S	R	L
32	18 3/8	19 1/8	21	22 1/2	***24***	28	30	***32***
34	19 3/8	20 1/8	21 1/8	22 5/8	***24.125***	28 1/8	30 1/8	***32.125***
36	20 3/8	21 1/4	21 1/4	22 3/4	24 1/4	28 1/4	30 1/4	32 1/4
38	21 3/8	22 1/4	21 3/8	22 7/8	24 3/8	28 3/8	30 3/8	32 3/8
40	22 3/8	23 1/4	21 1/2	23	24 1/2	28 1/2	30 1/2	32 1/2
42	23 3/8	24 3/8	21 5/8	23 1/8	24 5/8	28 5/8	30 5/8	32 5/8
44	24 3/8	25 3/8	21 3/4	23 1/4	24 3/4	28 3/4	30 3/4	32 3/4
46	25 3/8	26 3/8	21 7/8	23 3/8	24 7/8	28 7/8	30 7/8	32 7/8
48	26 3/8	27 1/2	***22***	23 1/2	25	***29***	31	33
50	27 3/8	28 1/2		23 5/8	25 1/8		31 1/8	33 1/8
52	28 3/8	29 5/8		23 3/4	25 1/4		31 1/4	33 1/4

First, the CWU 27P size chart was reviewed (Table 12). The CWU 27P flight suit is assigned by Chest Circumference (in inches) and leg length classes (S, R, and L). The accommodation range for Chest Circumference is from a minimum of 32 inches to maximum of 52 inches. Depending on the leg length class, the full range of sizes can be from 32S to 46S, from 32R to 52R, and from 36L to 52 L. Thus, there are total of 28 sizes based on the size chart. However, three additional sizes 48S, 32L, and 34L (Italicized in Table 12) were reported by test subjects in questionnaires collected during this evaluation, the actual total number of CWU 27P sizes appears to be 31. To determine whether all sizes shown in Table 12 are actively being used,

the frequencies of CWU 27P sizes for the 2008 Aircrew Sizing Survey were counted and organized in a table by Chest size and Leg length class. These data were collected by Questionnaire (Appendix C. Aircrew Sizing Survey Questionnaire). Out of 278 subjects, 241 subjects answered with their flight suit size. Except for Chest size 52, almost all chest sizes were reported (Table 13).

Table 13. Observed Frequencies of 27P size for Aircrew Sizing Survey Data (with %)

	CWU 27P Chest Sizes										
27P Leg Sizes	32	34	36	38	40	42	44	46	48	50	**Row Totals**
S (Short)			5 (2.1%)	6 (2.1%)	10 (4.1%)	4 (1.7%)	1 (0.4%)		1 (0.4%)		26 (10.8%)
R (Regular)	5 (2%)	6 (2%)	8 (3.3%)	13 (5.4%)	28 (11.6%)	32 (13.3%)	22 (9.1%)	10 (4.1%)	3 (1.2%)	2 (0.8%)	128 (53.1%)
L (Long)	1 (0.4%)	2 (0.8%)	4 (1.7%)	9 (3.7%)	7 (2.9%)	20 (8.3%)	28 (11.6%)	11 (4.6%)	2 (0.8%)	2 (0.8%)	86 (35.7%)
WR (Women's Regular)					1 (0.4%)						1 (0.4%)
Totals	6 (2.5%)	7 (2.9%)	17 (7.1%)	27 (11.2%)	46 (19.1%)	56 (23.2%)	51 (21.2%)	21 (8.7%)	6 (2.5%)	4 (1.7%)	241 (100%)

Next, instead of comparing the predicted body size between CWU 27P and RFDB prototype flight suit sizes, we matched the test subjects' passing sizes of RFDB prototype flight suit with their current 27P flight suit sizes (Table 14). The 27P Leg length classes were compared with RFDB Stature classes. In the RFDB size roll, Stature class 1 accommodates people whose height is between 1500cm-1580cm (4'9'' to 5'2''). These sizes (1A, 1B and 1C) accommodate people smaller than current pilot size requirements. They are shorter than the people who are currently wearing the Short leg length class of the 27P. The length of RFDB Stature Class 2 size was close to the "Short" leg length class of 27P. Stature class 3 was between the 27P Leg class "Short" and "Regular". Stature class 4 was close to 27P Leg class "Regular". Stature class 5 was between the 27P Leg class "Regular" and "Long", but a bit closer to 27P Leg class "Long".

Table 14. Size Comparison between 27P and RFDB prototype flight suit

27P	**RFDB**	**Stature**	A	B	C	D	E	F	G
X-Short*	1	up to 1565mm	32-34	36-38	38-40				
Short	2	1625mm	32-34	36-38	38-40	40-44			
Regular/Short**	3	1725mm	32-34	36-38	38-40	40-44	42-44		
Regular	4	1800mm		36-38	38-40	40-44	42-44	***44-48?***	
Regular/Long***	5	1900mm			38-40	40-44	42-46****	***44-48?***	***46-50?***
Long	***6***	***1995mm***					***42-46?***	***44-48?***	***46-50?***

*X-short is shorter than the current Short size

**When S(Short) is too short, the hem falls around the ankle level, but the R(Regular) is too long

***When R(Regular) is too short, it falls just below the ankle level, and Long is on the floor.

****46-Regular size only

RFDB Chest classes were also compared with 27P. The chest area accommodation range covered by each size of RFDB size is wider than each size of 27P. It was observed that two people who were wearing two adjacent Chest sizes of 27P were accommodated in the same size in RFDB prototype flight suit. This is because the five Chest classes in RFDB prototype flight

suit accommodate the Chest circumference range covered by seven 27P Chest classes as shown in Table 14. For example, if your current 27P size is 40R and it fits a bit tight in the chest and is a bit too long in leg length, the closest RFDB prototype flight suit size to the current 27P would be size 4C. If you prefer a bit looser fit in the Chest area with a bit shorter length than the fit of current 27P flight suit, 3D would be appropriate.

3.4.4 Additional necessary sizes

It should be noted that there were a total of 15 pilot/aircrew subjects and two civilian subjects who failed to get a passing fit in any of the RFDB sizes. Nine of these 15 pilot/aircrew subjects tried on and failed the RFDB predicted prototype flight suits, and six of these 15 pilot/aircrew subjects were outside of RFDB initial size roll. (Refer to Table 7. Description of people who failed in all test sizes including their predicted size, for detailed information). All 15 pilot/aircrew subjects who failed in all test sizes were taller than 1900cm in Stature, and/or wider than 1150mm Chest Circumference and/or heavier than 225lb weight. The two civilian subjects who received failing fit ratings were too tall and/or too wide to be accommodated. Their Stature and/or Chest Circumferences were above and beyond the RFDB size chart but are still included within the 95% range for the 2008 Aircrew Sizing Survey population. In other words, these two civilian subjects as well as 15 pilot/aircrew subjects are as tall and/or wide as currently enrolled Air Force personnel being accommodated by CWU 27P flight suit, but were not accommodated by RFDB prototype flight suit because there were no available sizes for them.

Another observation can be made concerning the sleeve length. The eight sizes (2B, 2C, 3B, 3C, 3D, 4C, 4D, 4E) that have two sleeve lengths (Short and Long) accommodate arm length well. In the eleven sizes (1A, 1B, 1C, 2A, 2D, 3A, 3E, 4B, 5C, 5D, 5E) that only have “Regular” sleeve lengths, it was observed that there were a number of subjects who failed to receive a passing fit only because of the sleeve length. This was especially true in Stature class 5 (Refer to Appendix J. Accommodation plots).

In summary, it is clear that pilots above Chest Circumferences of 1150mm can be accommodated in the 27P in size 46 inches or bigger, but not in the RFDB prototype flight suit. Pilots taller than 1900mm are also accommodated in the 27P but not in the RFDB prototype flight suit. Accommodation of Sleeve length was acceptable in Stature class 4 and lower, but not always in Stature class 5 of RFDB prototype flight suit. Thus, adding taller and wider sizes to the RFDB prototype flight suit with a reconsideration of an additional sleeve length for Stature class 5 (or taller if applicable) appears to be necessary.

Based on this evaluation, it is apparent that one additional Stature class (Stature class 6), and possibly two wider chest classes (Chest class F and G) should be added to the available sizes of RFDB prototype flight suit. Potentially, 3F, 4F, 5F, 5G, 6E, 6F and 6G, and two types of sleeve length at least for Stature class 5 (and possibly any taller sizes than Stature class 5 if applicable) should be seriously considered. This issue of additional (bigger) sizes will be discussed again in Section “0 3.5.1 Predicted Accommodation for Two Target Populations”

3.5 Size Tariff

A size tariff determines the percentage of each size of the coverall needed to be produced or procured. When there is more than one available target population, it is recommended to make a separate table for each population. If the results of size tariff are different among multiple populations, it is necessary to compare the populations and document the differences.

This size tariff table is a good indicator for the most popular sizes, unnecessary sizes, and additional sizes to include (Choi, Zehner, and Hudson, 2009).

3.5.1 Predicted Accommodation for Two Target Populations

To reiterate, the JSF sample was extracted from civilian data gathered in the late 1990's. Strict Height and Weight criteria were applied to that group to assure they fell in the USAF and USN Height and Weight regulations of the time. The 2008 Aircrew Sizing Survey was a sample of actual USAF aircrew measured in 2008 – but it is a small sample (n=294). While neither of these samples represents a good design population, they are all that is currently available.

The Table 11 final suggested size chart was applied to both of these samples to show the percentage fitting into each size as well as the potential predicted accommodation rates. Table 15 shows the 246 males and 48 females from the 2008 Aircrew Sizing Survey, sub-grouped based on the final suggested size chart[7].

Table 15. Size Tariff for 2008 Aircrew Sizing Survey

	Chest Class									Row
Stature	A	A/B	B	B/C	C	C/D	D/E	E	Beyond E	Totals
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	0.00%	0.68%	0.00%	1.36%	0.34%	0.68%	0.00%	0.00%	0.00%	3.06%
3	0.68%	1.02%	2.04%	2.04%	4.42%	7.14%	4.76%	1.36%	0.68%	24.15%
4	0.00%	0.00%	0.34%	1.36%	5.44%	9.52%	15.99%	6.80%	3.06%	42.52%
5	0.00%	0.00%	0.00%	0.34%	1.70%	2.38%	9.86%	5.10%	6.12%	25.51%
Beyond 5	0.00%	0.00%	0.00%	0.00%	0.00%	0.68%	1.70%	1.36%	1.02%	4.76%
Totals	0.68%	1.70%	2.38%	5.10%	11.90%	20.41%	32.31%	14.63%	10.88%	100.00%

85.37% of the 294 subjects were included within the final suggested size chart coverage (accommodated). Stature class 4 is the most popular size followed by Stature class 5 and 3. Chest class D or E are the most frequently observed sizes. For both Stature and Chest circumference, 4D/4E are the most frequently assigned size. As noted in previous sections (0 3.4.3 Comparison between the RFDB Size Roll and the CWU 27P Size Roll, and 0 3.4.4 Additional necessary sizes), people who are taller than Stature class 5 and/or wider than Chest class E (shaded in Table 15) could not be assigned to any available size of the RFDB prototype flight suit. These people added up to 14.63% of the Aircrew population when compared to this sample.

[7] 51 USMC subjects were not included for this Size tariff table. Since they were stratified samples to add wider chested or/and taller subjects, including them might bias the estimation.

Table 16. Size Tariff for JSF CAESAR

Stature	Chest Class										
	Narrow	A	A/B	B	B/C	C	C/D	D/E	E	Beyond E	Row Totals
Below 1	0.0%	0.00%	0.00%	0.07%	0.07%	0.45%	0.00%	0.00%	0.00%	0.00%	0.60%
1	0.0%	1.19%	0.75%	0.97%	0.67%	1.72%	0.67%	0.22%	0.00%	0.00%	6.19%
2	0.0%	2.01%	1.04%	2.09%	1.72%	4.47%	1.86%	0.30%	0.00%	0.00%	13.50%
3	0.0%	3.06%	2.68%	5.74%	3.43%	8.72%	6.94%	3.65%	0.30%	0.07%	34.60%
4	0.0%	0.52%	0.60%	1.57%	1.04%	6.79%	7.90%	6.34%	1.27%	0.22%	26.25%
5	0.0%	0.07%	0.07%	0.15%	0.30%	2.09%	3.95%	5.22%	2.61%	0.75%	15.21%
Beyond 5	0.0%	0.00%	0.00%	0.00%	0.00%	0.30%	0.89%	1.42%	0.82%	0.22%	3.65%
All Grps	0.0%	6.86%	5.15%	10.59%	7.23%	24.53%	22.22%	17.15%	5.00%	1.27%	100.00%

Table 16 shows the JSF CAESAR data (646 males and 695 females), sub-grouped based on the final suggested size chart. 94.73% of 1341 subjects were included within the revised size chart (accommodated). The most popular size for JSF CAESAR is 3C. A total of 5.3% (71 cases) were not accommodated. That group includes people who have a Chest Circumference beyond Chest class E, who are shorter than Stature class 1, and taller than Stature class 5.

3.5.2 Comparison Between JSF CAESAR and Aircrew Sizing Survey

While the maximum Bust/Chest Circumference and maximum Chest Circumference at Scye in the JSF CAESAR sample are 1173mm (46.18 inches) and 1234mm (48.58 inches), those dimensions in the 2008 Aircrew Sizing Survey are 1300mm (51.18 inches) and 1305mm (51.37 inches), respectively. In Table 15 and Table 16 above, notice the proportion of "beyond E" individuals, there are many more people whose Chest Circumference is above 1150mm in 2008 Aircrew Sizing Survey than in JSF CAESAR.

The next question is whether Aircrew Sizing Survey subjects are proportionally different than those in JSF CAESAR. To answer this question, we derived two variables, "Chest to Waist ratio" and "Chest to Hip ratio", and compared them between surveys. Neither one way ANOVA test for Chest to Waist ratio ($F(1, 740)=2.53$, $p=0.11$), or for Chest to Hip ratio ($F(1.740)=2.61$, $p=0.10$), was significant. This means that the subjects in the JSF CAESAR and the 2008 Aircrew Sizing Survey are not different proportionally. Thus, the extreme Chest Circumference cases observed in the 2008 Aircrew Sizing Survey appear to reflect reality. Although the 2008 Aircrew Sizing Survey is relatively small in sample size and the results derived from this dataset should be applied with caution, adding bigger chest sizes to RFDB light weight coverall should be seriously considered.

Finally, the actual size tariff forwarded from the 648 AESS (Air Force Uniform Office) that includes the total number of each size of 27P coverall ordered during 2009 is displayed in Table 17. The portions of size 46 or wider for the Green and Tan colored flight suits are 16.17% and 26.80%, respectively. The combined portion is about 20% of the total amount needed for year 2009. Based on Table 17, it can be concluded that roughly 16% of the total amount of flight suits manufactured would have to be special ordered unless wider and/or taller sizes are added to current RFDB prototype flight suit. Given the surprising number of flight suits shown in this table, it would be a substantial amount.

Table 17. 27P USAF Size Tariff 2009

	Green								Tan								Green+Tan	
Chest	Short		Regular		Large		Total		Short		Regular		Large		Total		Total	
Circ.	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
32	208	1.75	175	0.37			383	0.42	243	2.94	280	0.85			523	0.80	906	0.58
34	482	4.05	822	1.72			1304	1.41	454	5.49	588	1.80			1042	1.60	2346	1.49
36	1298	10.91	2679	5.62	1024	3.13	5001	5.42	721	8.72	1372	4.19	518	2.14	2611	4.00	7612	4.84
38	2608	21.93	7621	15.99	4283	13.11	14512	15.73	1090	13.18	2749	8.39	969	4.01	4808	7.37	19320	12.27
40	2814	23.66	8415	17.66	4798	14.68	16027	17.38	1521	18.39	5026	15.35	2873	11.88	9420	14.45	25447	16.16
42	2305	19.38	12158	25.51	8643	26.45	23106	25.05	1970	23.82	7560	23.08	5859	24.23	15389	23.60	38495	24.45
44	1477	12.42	8723	18.30	6786	20.77	16986	18.42	1262	15.26	7096	21.67	5582	23.08	13940	21.38	30926	19.64
46	701	5.89	4050	8.50	3951	12.09	8702	9.44	1010	12.21	4184	12.77	4553	18.83	9747	14.95	18449	11.72
48			2278	4.78	2235	6.84	4513	4.89			2224	6.79	2103	8.70	4327	6.64	8840	5.62
50			507	1.06	588	1.80	1095	1.19			895	2.73	845	3.49	1740	2.67	2835	1.80
52			228	0.48	371	1.14	599	0.65			779	2.38	881	3.64	1660	2.55	2259	1.43
Total	11893	100	47656	100	32679	100	92228	100	8271	100	32753	100	24183	100	65207	100	157435	100
Total amount of sizes 46, 48, 50, and 52							14909	16.17	Total amount of sizes 46, 48, 50, and 52						17474	26.80	32383	20.57

4.0 CONCLUSIONS

A Fit Mapping experiment on the JSF Light Weight Coverall (RFDB prototype flight suit) was performed with a total of 110 subjects. Quantitative ranges of fit criteria were constructed based on fit measurements and pilot subjects' assessments. The constructed fit ranges were applied to each tested size to determine the overall pass/fail rates. Out of 110 subjects, 17 subjects (15.45%) failed overall due to unavailability of wider and/or taller sizes in RFDB prototype flight suit. Ten subjects (9.09%) aesthetically failed. This means they could do all mobility tasks and passed in safety related aspects, but the suit was either too tight or too loose based on the fit criteria. 83 subjects (75.45%) received a passing fit in one or more test flight suits. Out of these 83 subjects, 48 subjects (43.63% of all test samples, 58.53% of overall passing group) passed in their RFDB originally predicted size. A revised sizing chart has been constructed based on 83 subjects who passed in one or more test sizes.

This initial fit mapping accommodation rate on this NON-RANDOM SAMPLE will add up to 84.54% if the additional 9.09 % currently called "Aesthetically Fail" are included. If only the random portion of this sample (the USAF sample from Laughlin AFB) is used the accommodation rate is up to 93% (Overall Pass-86.36% and Aesthetically Fail-6.82%).

4.1 Target Population

Fit mapping results from this sample were applied to JSF CAESAR (the F-35 requirement population) and to the 2008 Aircrew Sizing Survey data. The estimated rates of passing plus aesthetically fail categories for JSF CAESAR and the Aircrew Sizing Survey data were 95% and 85.37%, respectively. As shown in section 0 (3.5 Size Tariff), the acceptability of current RFDB test flight sizes is different depending on the target population. The predicted accommodation rate for the JSF CAESAR population is high enough to be acceptable.

Based on the JSF requirements, the RFDB prototype flight suit is expected to accommodate shorter statured people than would be accommodated by the 27P. It should be noted that most of disaccommodated cases in JSF CAESAR were due to large chests or tall Statures (4.7%). This trend was more apparent when the fit mapping results were applied to the

Aircrew Sizing Survey data. 14.63% of that sample (n=294) of current Aircrew would not be accommodated. This is problematic not just because the disaccommodated percentage is high, but because RFDB prototype flight suit does not accommodate people who are currently military pilots and are accommodated by the current flight suit (Refer to Table 14. Size Comparison between 27P and RFDB prototype flight suit). This percentage (~15%) was reinforced by the order rates for current flight suits sizes 46 and larger based on Air Force Clothing Office data. Moreover, the maximum Statures and Chest circumferences that the RFDB prototype flight suit fit were shorter and narrower than the values predicted by the RFDB size roll. This is due to the application of different fit-criteria in this study. Therefore, adding additional sizes to the RFDB prototype flight suit should be seriously considered (Refer to Section 0. 3.4.4 Additional necessary sizes for further discussion).

4.2 Fit around the Scye Area

Another issue is about the fit quality. There was a common fit issue around the Scye area (armpit) which was consistently observed in most test flight suit sizes by nearly all pilot/aircrew subjects from USAF and USMC. The fit of the Scye area affects basic arm movements that involve an arm raising motion. In a flight environment, arm movement is a very basic and fundamental motion and comfort should be guaranteed. Based on comments from our pilot subjects, the biggest issue with this test flight suit was that the fit around Scye area restricted basic arm movements.

The current accommodation rate would drastically drop regardless of target population if the fit of this area is counted as safety criteria. People who had broad shoulders with wide Chests wearing size 46 or wider 27P made comments about not just the restricted arm movement, but also felt tightness across the chest at the Scye level. Therefore, it must be concluded that a pattern modification around the Scye area is unavoidable.

REFERENCES

- Choi, H-J, Zehner, G.F., and Hudson J.A. (2009). A manual for the performance of protective equipment fit-mapping. AFRL-RH-WP-TR-2010-0005
- Choi, H-J, Zehner, G., Hudson, J., and Fleming, S (October, 2009). Trends in Anthropometric measures in U.S. Air Force aircrew survey data, Proceedings of *Human Factors and Ergonomics Society 53rd Annual Meeting*.
- Hudson, J., Zehner, G. and Robinette, K (2003). JSF CAESAR: Construction of 3-D Anthropometric sample for design and sizing of joint strike fighter pilot clothing and protective equipment.AFRL-HE-WP-TR-2003-0142
- McConville, J. T., Tebbets, I., Alexander, M., 1979, Guideline for fit-testing and evaluation of USAF personal-protective clothing and equipment, Aerospace Medical Research Laboratory, Wright-Patterson AFB, AMRL-TR-79-2
- RFD Beaufort (June 2005) Manual 252: Fit Mapping Questionnaire for JSF PFE (Block 0)
- Staples, N. (2009) RE: RFDB Fit question, Personal communication to Joo Choi, 16 June 2009.
- Zehner, G. F., Fleming, S. M, Choi, H-J, Hudson, J. A. (October 2008) US Air Force Aircrew Sizing Survey, Podium presented at the *46th SAFE Symposium*, Reno, Nevada.
- 1996 Advisory Publication of the Air Standardization Coordination Committee, Methodology for Assessing Fit of Aircrew Clothing. ASCC 61/105/14

REFERENCES FOR FIGURES

- Burnett, A.F. (2006). Integrated Aircrew Ensemble (IAE), Aeronautic System Center
- JSF Final PFE Standard GARMENT Descriptions BASE JSF /029/26 Iss 4 April 2008
- JSF Final PFE Standard Operating and Maintenance Instruction
- PFE PBS 2ZCZ51001, Rev. D
- SDRL J0637 PFE Acceptance Test Plan and Procedures
- SDRL J0810 PFE Maintenance Plan

ACRONYM

AREL	Arm Restraint Extension Line
ARS	Arm Restraint System
ASCC	Air Standardization Coordination Committee
CAESAR	Civilian American European Surface Anthropometric Resources
JSF	Joint Strike Fighter
QRB	Quick Release Buckle
RFDB	RFD Beaufort

Appendix A. JSF Multivariate Cases

	Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8
	Small	Medium Build Short	Medium Build Long	Tall Sitting Height Short	Overall Large	Longest Limb	Overall Small	Largest Torso
Thumb Tip Reach	27	27.6	33.9	29.7	35.6	36	26.1	33.3
Buttock-Knee Length	21.3	21.3	26.5	22.7	27.4	27.9	20.8	25.4
Knee-height Sitting	18.7	19.1	23.3	20.6	24.7	24.8	18.1	23.2
Sitting Height	32.8	35.5	34.9	38.5	40	38	31	41
Eye Height sitting	28	30.7	30.2	33.4	35	32.9	26.8	35.9
Shoulder Height sitting	20.6	22.7	22.6	25.2	26.9	25	19.5	27.6
Shoulder Breadth Range	14.7-18.1	16.4-20.6	16.2-21.2	16.8-21.7	16.9-22.6	16.8-22.5	14.2-18.0	16.9-22.6
Chest Depth Range	7.4-10.9	6.9-10.6	7.2-11.3	7.1-11.0	7.3-12.1	7.4-12.2	7.2-10.2	7.4-12.4
Thigh Circumference Range	18.5-25	17.1-25.0	20.2-27.6	17.6-26.3	18.6-29.2	19.1-29.7	17.8-25.2	18.6-29.1
Weight Range	103 lbs to 245 lbs							
Note: All units are in inches unless otherwise specified.								

Appendix B. Size Roll (RFD Beaufort Light Weight Coverall)

JOINT STRIKE FIGHTER PILOT FLIGHT EQUIPMENT														
PROPORTIONAL SIZE ROLL FOR ONE PIECE COVERALL														
WEARER SIZES			GIRTHS				LENGTHS							
SIZE	STATURE	CHEST CIRC.	CHEST CIRC.	WAIST CIRC.	BUTTOCK CIRC.	INTER SCYE DIMENSION	CERV. TO AXILLA HT.	CERV. TO WAIST HT.	CERV. TO CROTCH HT.	AXILLA TO WRIST HT.	ARM LGTH	WAIST HT. TO CROTCH HT.	CROTCH HT.	WAIST HT.
1A	1500 - 1580	760-830	830	720	970	350	162	370	590	430	565	220	740	960
1B		830-905	905	805	1020	378	167	370	595		570	225	745	970
1C		905-985	985	900	1065	408	173	370	600		575	230	750	980
2A	1580 - 1665	760-830	830	720	970	350	164	390	615	445	585	225	770	995
2BS		830-905	905	805	1020	378	169	390	620	415	560	230	775	1005
2BL										465	610			
2CS		905-985	985	900	1065	408	175	390	625	415	565	235	780	1015
2CL										465	615			
2D		985-1075	1075	1005	1120	440	181	390	635	445	600	240	780	1020
3A	1665 - 1755	760-830	830	700	895	350	167	390	655	465	610	265	790	1055
3BS		830-905	905	790	960	378	172	400	665	435	585	265	795	1060
3BL										485	635			
3CS		905-985	985	890	1020	408	178	405	675	435	590	270	800	1070
3CL										485	640			
3DS		985-1075	1075	1000	1090	440	184	410	685	435	595	275	795	1070
3DL										485	645			
3E		1075-1170	1170	1090	1170	474	189	415	685	465	630	270	790	1060
4B	1755 - 1850	830-905	905	790	960	378	176	420	690	490	645	270	850	1120
4CS		905-985	985	890	1020	408	182	425	695	460	620	270	855	1125
4CL										510	670			
4DS		985-1075	1075	1000	1090	440	188	425	700	460	625	275	850	1125
4DL										510	675			
4ES		1075-1170	1170	1090	1170	474	193	430	710	460	630	280	850	1130
4EL										510	680			
5C	1850 - 1950	905-985	985	890	1020	408	187	445	730	515	680	285	895	1180
5D		985-1075	1075	1000	1090	440	193	450	735		685	285	900	1185
5E		1075-1170	1170	1090	1170	474	198	445	735		690	290	900	1190

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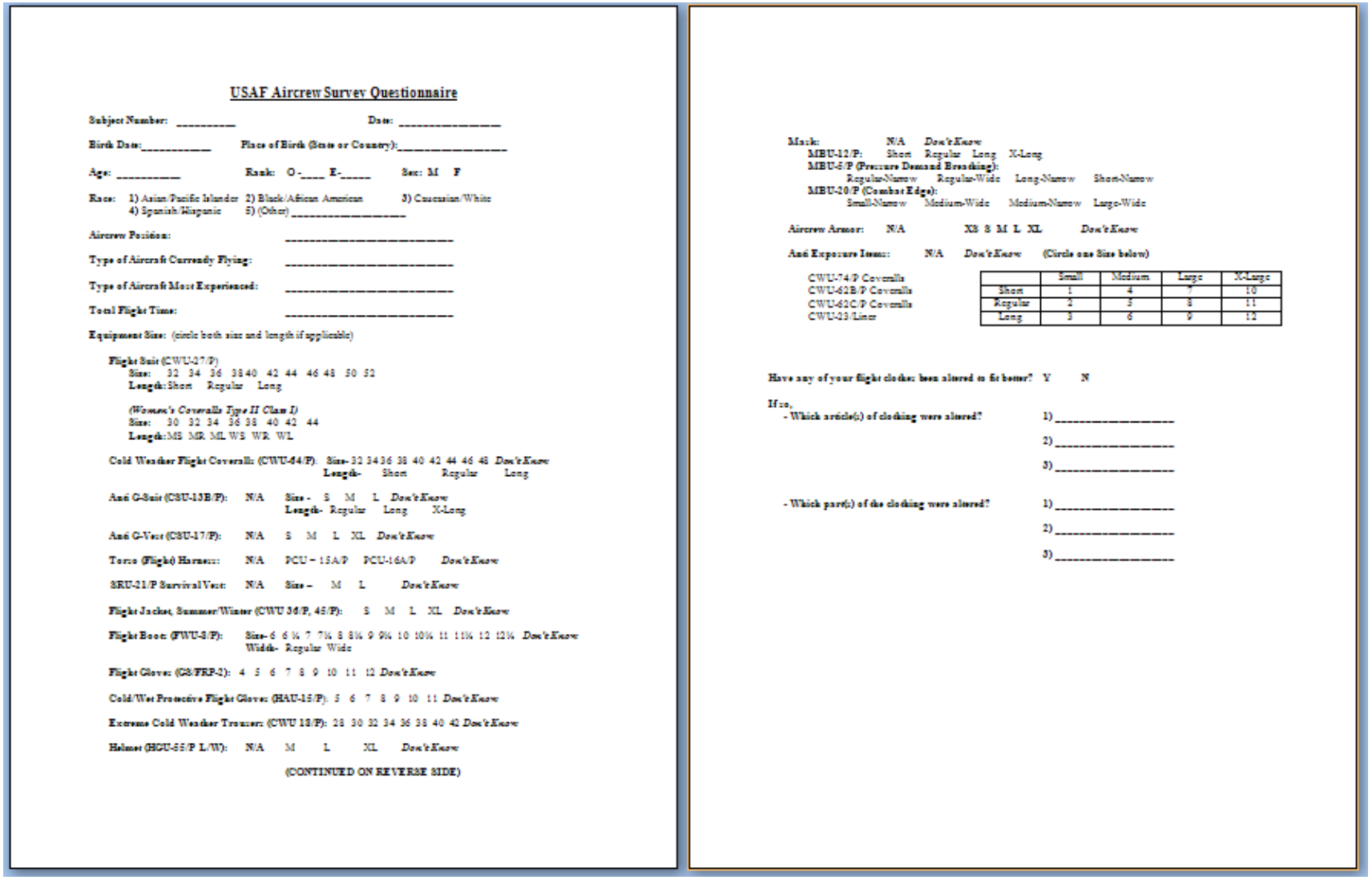
Appendix C. Aircrew Sizing Survey Questionnaire



USAF Aircrew Survey Questionnaire

Subject Number: _____ **Date:** _____

Birth Date:_____ **Place of Birth (State or Country):**_____

Age: _____ **Rank:** O-____ E-_____ **Sex:** M F

Race: 1) Asian/Pacific Islander 2) Black/African American 3) Caucasian/White
4) Spanish/Hispanic 5) (Other) _____

Aircrew Position: _____

Type of Aircraft Currently Flying: _____

Type of Aircraft Most Experienced: _____

Total Flight Time: _____

Equipment Size: (circle both size and length if applicable)

Flight Suit (CWU-27/P)
Size: 32 34 36 38 40 42 44 46 48 50 52
Length: Short Regular Long

(Women's Coveralls Type II Class I)
Size: 30 32 34 36 38 40 42 44
Length: MS MR ML WS WR WL

Cold Weather Flight Coverall: (CWU-64/P) **Size-** 32 34 36 38 40 42 44 46 48 *Don't Know*
Length- Short Regular Long

Anti G-Suit (CSU-13B/P): N/A **Size -** S M L *Don't Know*
Length- Regular Long X-Long

Anti G-Vest (CSU-17/P): N/A S M L XL *Don't Know*

Torso (Flight) Harness: N/A PCU – 15A/P PCU-16A/P *Don't Know*

SRU-21/P Survival Vest: N/A **Size –** M L *Don't Know*

Flight Jacket, Summer/Winter (CWU 36/P, 45/P): S M L XL *Don't Know*

Flight Boot: (FWU-8/P): **Size-** 6 6½ 7 7½ 8 8½ 9 9½ 10 10½ 11 11½ 12 12½ *Don't Know*
Width- Regular Wide

Flight Glove: (GS/FRP-2): 4 5 6 7 8 9 10 11 12 *Don't Know*

Cold/Wet Protective Flight Glove: (HAU-15/P): 5 6 7 8 9 10 11 *Don't Know*

Extreme Cold Weather Trouser: (CWU 18/P): 28 30 32 34 36 38 40 42 *Don't Know*

Helmet (HGU-55/P L/W): N/A M L XL *Don't Know*

(CONTINUED ON REVERSE SIDE)

Mask: N/A *Don't Know*
MBU-12/P: Short Regular Long X-Long
MBU-5/P (Pressure Demand Breathing):
Regular-Narrow Regular-Wide Long-Narrow Short-Narrow
MBU-20/P (Combat Edge):
Small-Narrow Medium-Wide Medium-Narrow Large-Wide

Aircrew Armor: N/A XS S M L XL *Don't Know*

Anti Exposure Issue:: N/A *Don't Know* (Circle one Size below)

CWU-74/P Coveralls
CWU-62B/P Coveralls
CWU-62C/P Coveralls
CWU-23 Liner

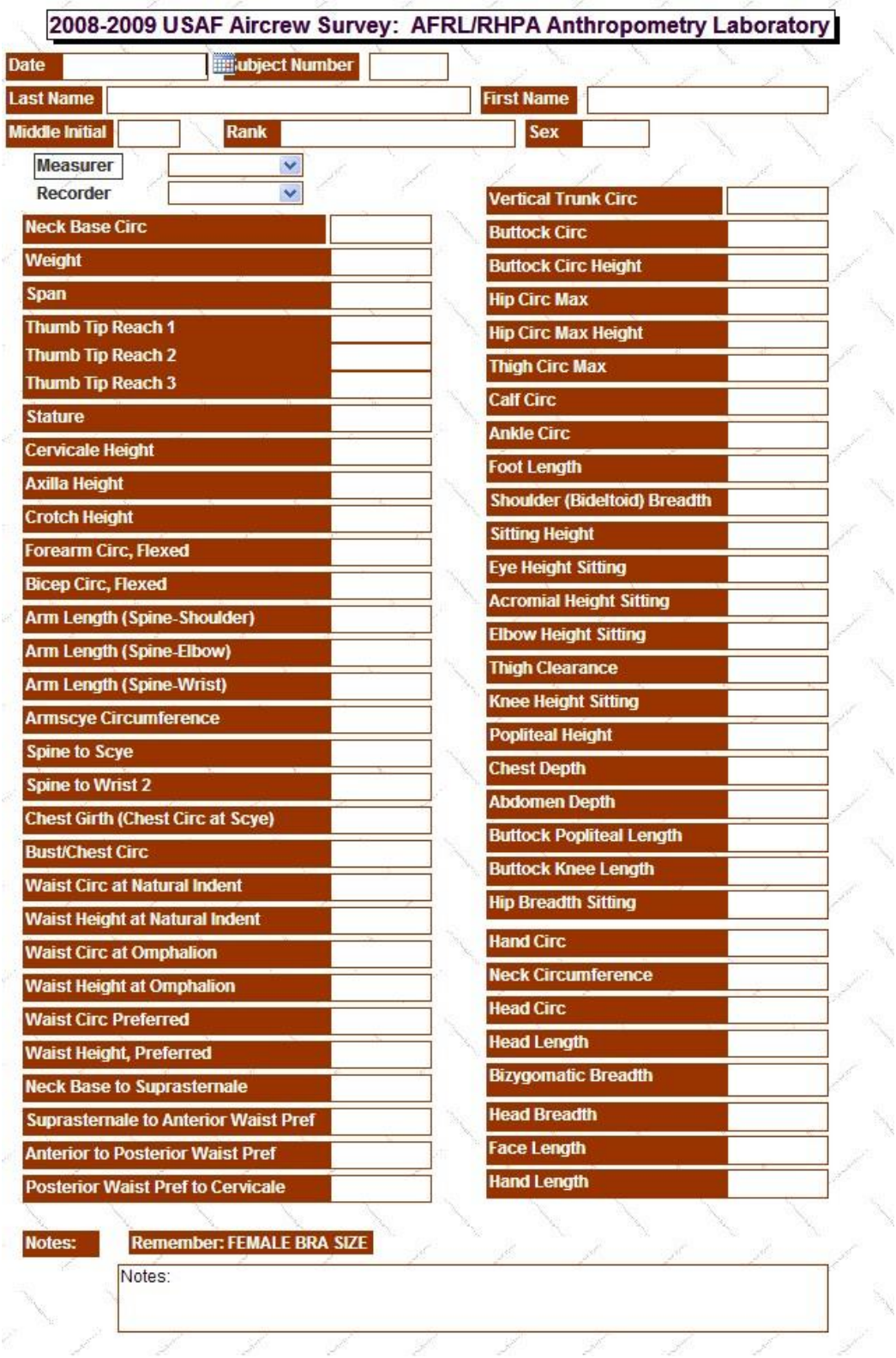
	Small	Medium	Large	X-Large
Short	1	4	7	10
Regular	2	5	8	11
Long	3	6	9	12

Have any of your flight clothes been altered to fit better? Y N

If so,
- Which article(s) of clothing were altered? 1) _____
2) _____
3) _____

- Which part(s) of the clothing were altered? 1) _____
2) _____
3) _____

Appendix D. Traditional Anthropometric Measurement Worksheet



2008-2009 USAF Aircrew Survey: AFRL/RHPA Anthropometry Laboratory

Date | Subject Number | Last Name | First Name | Middle Initial | Rank | Sex | Measurer | Recorder

Neck Base Circ
Weight
Span
Thumb Tip Reach 1
Thumb Tip Reach 2
Thumb Tip Reach 3
Stature
Cervicale Height
Axilla Height
Crotch Height
Forearm Circ, Flexed
Bicep Circ, Flexed
Arm Length (Spine-Shoulder)
Arm Length (Spine-Elbow)
Arm Length (Spine-Wrist)
Armscye Circumference
Spine to Scye
Spine to Wrist 2
Chest Girth (Chest Circ at Scye)
Bust/Chest Circ
Waist Circ at Natural Indent
Waist Height at Natural Indent
Waist Circ at Omphalion
Waist Height at Omphalion
Waist Circ Preferred
Waist Height, Preferred
Neck Base to Suprasternale
Suprasternale to Anterior Waist Pref
Anterior to Posterior Waist Pref
Posterior Waist Pref to Cervicale

Vertical Trunk Circ
Buttock Circ
Buttock Circ Height
Hip Circ Max
Hip Circ Max Height
Thigh Circ Max
Calf Circ
Ankle Circ
Foot Length
Shoulder (Bideltoid) Breadth
Sitting Height
Eye Height Sitting
Acromial Height Sitting
Elbow Height Sitting
Thigh Clearance
Knee Height Sitting
Popliteal Height
Chest Depth
Abdomen Depth
Buttock Popliteal Length
Buttock Knee Length
Hip Breadth Sitting
Hand Circ
Neck Circumference
Head Circ
Head Length
Bizygomatic Breadth
Head Breadth
Face Length
Hand Length

Notes: Remember: FEMALE BRA SIZE

Notes:

Appendix E. Fit assessment data collection sheet

E.1. Form1 (USAF)

Capable of Mobility in Scan Garments (Circle) Yes No Subject Number : _____ Page : _____

	Fit Evaluation		Current		Size :_____		Size :_____	
	Assessment	Type (Landmark)	Fitter	Subject	Fitter	Subject	Fitter	Subject
Mobility	Hand and arm movement	Assessment1						
	Torso length	Assessment1						
	Leg movement (0.62m step)	Pass/Mrgnl Pass/Fail						
	Torso Movement (seated)	Pass/Mrgnl Pass/Fail						
	Head Movement	Pass/Mrgnl Pass/Fail						
Safety	*Arm Restraint*	Direction						
	Sleeve length	Line (Ulna Styloid)						
Location	Neck and Collar	Line (Suprasternale)						
	Shoulder	Line (Acromion)						
	Waist Height	Line (Omphalio)						
	Leg Length	Line (Lateral Malleolous)						
	Armscye	Ease (Axilla)	___.___		___.___		___.___	
	Chest	Ease (Thelion Level)	___.___		___.___		___.___	
	Waist	Ease (Omphalion Level)	___.___		___.___		___.___	
	Hip	Ease (Max Hip level)	___.___		___.___		___.___	
	Crotch	Ease (PSIS level)	___.___		___.___		___.___	
Overall	Subject's evaluation	Assessment2						
Photos Front, Side and Back.								

*Measurements
When the garment location is lower or longer than the corresponding landmark --> Positive value
When the garment location is Higher or shorter than the corresponding landmark --> Negative value

<comments>

E.2. Form2 (USMC)

Capable of Mobility in Scan Garments (Circle) Yes No Subject Number: _____ Size: _____

Mobility Test		Test1 : Zip-up with velcro opened			Test 2: Whatever the way that they wear		
Assessment	Location	Fitter	Score	Location	Fitter	Score	Location
Hand and arm movement	Arm-pit, Shoulder, Crotch	P MP F			P MP F		
Does the bottom of the coverall contact your Crotch?		STDNG P-A P-B P-C P-D			STDNG P-A P-B P-C P-D		
How firmly?		No Barely Lght Sng/Tght Painful			No Barely Lght Sng/Tght Painful		
Leg movement (0.62m)	Lower back, Thigh	P MP F			P MP F		
Torso Movement	Neck, lower back, Shoulder	P MP F			P MP F		
Head Movement	Arm-pit, Side, Elbow	P MP F			P MP F		
Overall Subject evaluation on mobility tests							

Safety/Specific Location test		Fitter	Subject Assessment		Fit Ranges (USAF)
Assessment	Landmark/ Posture	Line/Ease	Score	Comments	
Arm Restraint	Direction	1 1.5 2 2.5 3 3.5 4 4.5 5			1 1.5 2 2.5 3 3.5 4 4.5 5
Sleeve length	Ulnar Styloid / Seated			Long Short	-3cm (Short) 1cm to 1cm (Good) 3cm (Long)
Neck and Collar	Suprasternale / Standing			Low High	-2.25cm (High) -0.75 to 2.25cm(Good) 3.75(Low)
Shoulder (Arm-hole)	Acromion / Standing			Low High	-2cm (High) 0 to 2cm (Good) 4cm (Low)
Waist Height (Waist tab)	Omphalion / Standing			Low High	-2.5cm (High) 0.5 to 3.5 (Good) 6.5 (Low)
Leg Length	Ltrl Malleolous / Standing			Long Short	1cm (Short) 5 to 9 cm (Good) 13cm (Long)
Armscye	Axilla / Standing	____, ____		Low/Tght Loose	
Chest	Thelion Level / Standing	____, ____		Loose Tight	15cm (Tight) 21 to 27cm (Good) 33cm (Loose)
Waist	Omphalion Level / Standing	____, ____		Loose Tight	M: 10cm(Tight) 16 to 22cm(Good) 28cm(Loose) F: 4cm(Tight) 10 to 16cm(Good) 22cm (Loose)
Hip	Max Hip level / Standing	____, ____		Loose Tight	M: 4cm(Tight) 10 to 16cm(Good) 22cm (Loose) F: 2cm(Tight) 6 to 10cm(Good) 14cm (Loose)
Crotch	PSIS level / Standing	_____		Loose Tight	7cm (Tight) 11 to 15cm (Good) 19cm (Loose)
Overall Subject evaluation					<Overall Comments>
Photos Front, Side and Back.					

Appendix F. Role and Responsibility of Fit Mapping Team Members

The fit assessment team will participate in the fit test throughout all phases. Determine the data collection and analysis team members early so that they may participate in the project planning from the beginning.

A team generally consists of at least four people representing the following seven positions: *Team Leader, Measurer, Recorder, Evaluator, Fitter, Briefer, and Analyst*. These seven positions discriminate roles. The roles played by individual team members conducting the fit-test may vary depending on the type and number of items to be included in the fit-test. It is possible that one person will perform multiple roles on the team and also possible that many people participate in a single role The assignment of the team role and associated duties is done with the expertise of the individuals in mind. However, these duties need not be rigidly established. It is best if there is some flexibility until after the test plan is evaluated. Time constraints on some portions of the test may dictate the need for extra help in some areas and less in others. However, consistency of measurements is very important in this research and must be kept in mind if roles are changed during the study.

The fit testing team will perform better given a clear understanding of the purpose of the test and the item being tested. It is recommended that the group have a kick-off meeting where the item to be tested is presented and described, and the concept of fit discussed.

F.1.Team Leader

The Team Leader is responsible for making final decisions on the study and ensuring that all aspects of the study are successfully carried out. This person should have a good understanding of the purpose of the test and the analysis methods which will be used. The main duty of this person is to coordinate the work with: 1) the sponsoring organization(s), 2) the test site, 3) organizations conducting the test and, 4) and those providing facilities and subjects.

F.2. Measurer

The Measurer is responsible for landmarking and anthropometric measuring of the subjects. To ensure consistency and accuracy, it is best if the same person is used throughout the test (at least for subjects of the same gender). Slight differences in measurement methods are usually found when different measurers are used. These variations could be enough to make analysis of the results difficult. There should be two measurers, one male and one female - if there are both male and female subjects in the fit test and there are measurements that might be considered sensitive if measured by someone of the opposite sex. In this case, it is efficient to have the measurer and recorder be of opposite sexes and trained for both positions. These two people can then trade roles, depending on the gender of the subject.

F.3. Recorder

The Recorder keeps the anthropometric data records and assists the Measurer by preparing measuring instruments during measurement and checking the orientation and level of measuring tapes and equipment when necessary.

F.4. Fit Evaluator

The Fit Evaluator assesses and records the fit of items. Evaluators need to be experienced or fully trained in each area of fit assessment relevant to the item. It is optimal to have a fit expert, but a novice evaluator can perform this role if properly trained. It is important that the fit criteria are well developed and defined, especially if a novice is making the assessments.

F.5. Fitter

The Fitter is responsible for selecting and tracking the sizes for testing. The Fitter position may not be needed for fit studies involving a small number of items or sizes. This duty can be absorbed by the Evaluator.

F.6. Briefer

The Briefer's responsibilities include greeting the subjects, explaining the purpose of the study, gathering demographic and biographical data, having subjects read and sign a consent form, scheduling, and tracking down subjects who fail to show up or making other such arrangements as needed during data collection. This duty can in some cases be done by the Team Leader. In this study, the Team Leader gave the brief and took care of the schedule.

F.7. Analyst

The Analyst will analyze and interpret the results. This person should be identified early in the test plan development because the data collection methods used can greatly affect the analysis that follows. In this study Fit Evaluator analyzed the data and documented the final report.

Appendix G. Specific Location Assessments

When conducting fit assessment except for mobility tests, there are basically two types of assessment. One is to verify whether each part of the garment is located at or around where it is supposed to be, and the other is to assess whether there is extra room at or around the target location. The first one is called line measurement because it is a measured distance between each design or seam line location and its corresponding body landmark. The other is called ease and most of the time assessed by pinch (tuck).

Specific location assessment is an objective evaluation by a Fit Evaluator. The investigator must measure both the ease amount at a given location and the line location from its corresponding body landmark. Typically, passing scores at a given location are recorded as good, marginal-tight/short, or marginal-loose/long. Failing scores are unacceptable-tight/short, or unacceptable – loose/long. If the fit evaluation is only being performed to determine whether the fit is acceptable or not, an ordinal scale like this would be enough; however, if one needs to make recommendations on how to alter the size or pattern based on the fit evaluation results, *actual measurement values at given locations are required*. For this reason, a key relating a given range of measured values to the ordinal scale is necessary.

G.1. Ease

Ease is the amount of extra fabric in the test garment at the given location beyond that needed to fit the body closely. If the location to be evaluated is on the torso, such as the chest, waist, high hip, or hip, a tuck (or pinch) is measured on both sides. (In the literature, some evaluators measure ease on one side and double it. However, it cannot be guaranteed that the pinched ease amount on one side is equivalent to the other). If the location is on a limb such as upper arm, thigh, or calf, measuring the tuck/pinch on one side is acceptable since the body tissues are not as flexible.

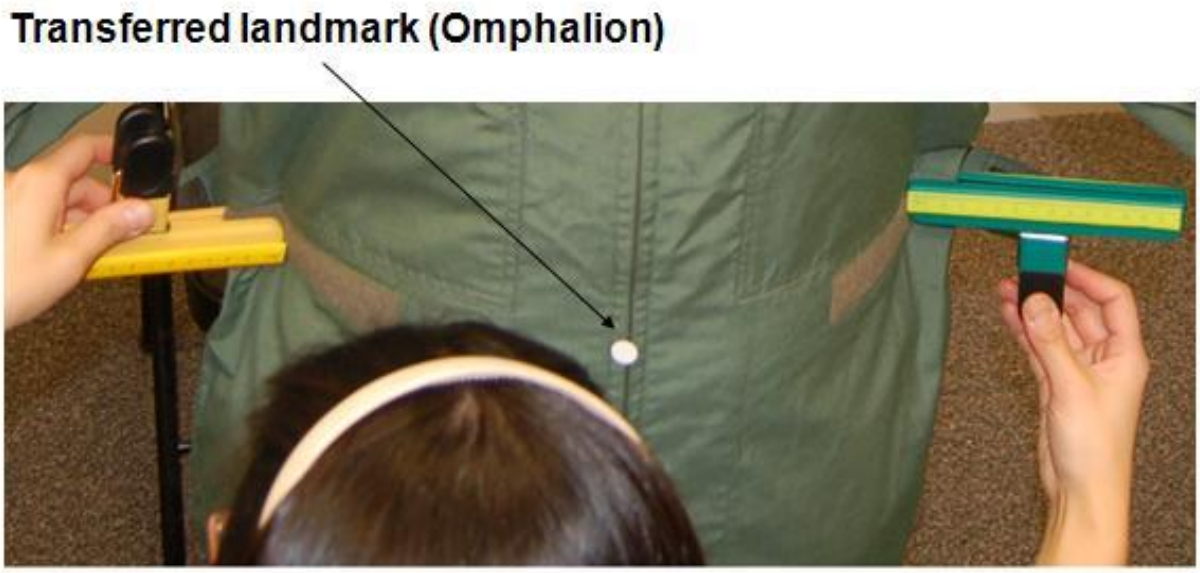


Figure G 1. Ease Example: Measuring Pinch at Waist circ. at Omphalion

Ease Example: Waist circumference

A good fit may be defined as X inches of ease of fabric at the waist level.

- Pinch (tuck) the fabric on both sides at waist level (Figure G 1).
- Measure the flattened fabric on one side and multiply by two.
- Repeat on the other side and sum the two numbers.
- Record the number in the fit evaluation sheet.
- The final sum is the total ease of the test size on the subject at the waist circumference level. Compare the results with the fit criteria.

G.2. Line

Recall that a line measure is the distance of a specific part of the equipment relative to a corresponding body landmark**.** If the location to be evaluated is on the torso such as the arm hole seam location relative to the acromion, or the waist Velcro location relative to the anterior superior iliac spine, palpate the corresponding landmark through the gear. Mark the location of the palpated landmark and then measure the distance from the landmark to the specified part of the equipment. If the location is at the distal part of the limbs-such as the sleeve end relative to the wrist bone or the leg hem relative to the ankle bone - and the test garment covers the landmark location, fold over the hem until it is even with the landmark, and then measure the folded part of the material.

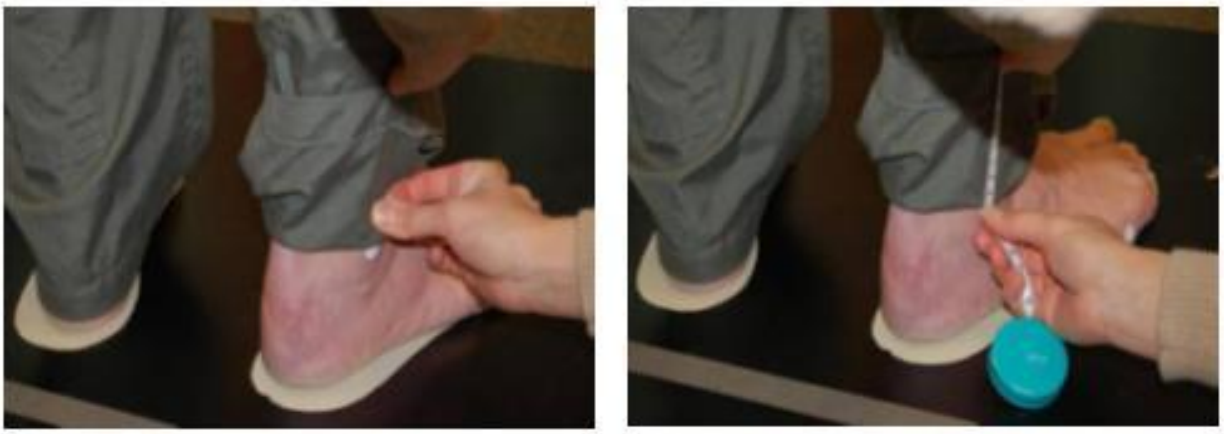


Figure G 2(a-b). Line example: Leg Hem from the Ankle bone.

Line Example: Leg length

If a good fit is defined as having the hem line end between the ankle bone and the floor:

- If necessary, fold over the hem so that the landmark is just visible.
- Measure the distance between the hem line and the ankle bone on each subject. If the hem falls above the ankle, record the value as a negative number. If it falls below the ankle, record it as positive.
- Deviation within some range is appropriate. However, having the hem fall far below ankle bone (dragging the floor) is obviously too long, and if it is falling far above ankle bone it is obviously too short. For this reason, also measure the distance from the ankle landmark to the floor

G.3. Rationale for recording the results as an objective measure.

To ensure consistency across subjects, fit criteria must be developed and translated clearly into a measurable form. Evaluators then follow the procedure in a step by step manner. The critical part is to record the fit test data quantitatively (by the measured value). If the final result for the fit evaluation were only to estimate the accommodation rate (Does a large enough percentage pass?), just rating the fit in an ordinal scale would work. A typical five category scale has the disadvantage of misrepresenting the specific details of fit. A slight failure is indistinguishable from a major failure.

For example, imagine an evaluation in which a number of subjects fail because the leg length of the garment is too long. If the evaluator only records that result via an ordinal scale (e.g. 5-too long = fail), it would be difficult to modify the length of the garment so that it would fit those who failed, while not ignoring or punishing those that passed. In order for fit-mapping results to be used for pattern modification, it is important to associate the ordinal scale with a numeric fit measurement value for each subject in all tested sizes.

Appendix H. Concept of fit for JSF Flight suit (Light Weight Coverall)

H.1. Mobility Tests

1. Range of hand and arm motion : Dynamic and Occupation specific
   - Initial Posture: Standing
   - Task: Raise arm up to the sides and overhead. When raising the arms overhead, first make a "Y" shape with the arms at the 10 and 2 o'clock positions, then make an "I" shape with both arms at 12 o'clock position, and finally bend the arms and place the hands on the top of the head.
   - Pass/Fail
     - Pass: Perform the task without any difficulty
     - Marginal Pass: when the subject makes an extra effort, relative to that subject's performance in the scanning garment, or the task is completed but difficulty is observed
     - Fail: When the task is not completed.

Figure H 1(a-d). Task illustrations for "Range of hand and arm motion"

2. Torso length (will be tested in conjunction with range of hand and arm motion)
   - Aspects: Dynamic, Mobility and comfort
   - Well-fitted: the crotch of the garment should make light contact with body when the arms are raised above the head with no restriction during "Range of hand and arm motion".
   - Assessment: Subject Response and observation
     - Pass (Recorded as "C"): When raising arms to the side, the crotch of the garment may slightly touch the body to the side of genitals. When raising the arms overhead, the crotch may be snug but should not be too restrictive to perform the task.
     - Marginal Pass: (Loose, Recorded as "D") when raising the arms to the side, the garment crotch does not touch the crotch to the side of genitals. When raising the arms overhead, the crotch may lightly touch and it is very easy to perform the task. (Tight, Recorded as "B") Snug fit in the

crotch with minor discomfort and restriction during the raising arm motion.

- Fail: (Loose, Recorded as "E") when raising the arms overhead, the garment crotch does not touch the body. (Tight, Recorded as "A") Discomfort due to tightness at crotch, and it is not possible to complete the task.

3. Range of leg movement : Dynamic, Occupation specific
   - Initial Posture: Standing
   - Task: First, place the right foot on a step 0.62m (or 24.49 inches) above ground while the left foot is on the ground. Repeat the same task with the left foot while the right foot is on the ground.
   - Pass/Fail
     - Pass: Perform the task without any difficulty
     - Marginal Pass: when the subject needed an extra effort, relative to the subject's performance in scanning garments, or the task is completed but difficulty is observed
     - Fail: When the task cannot be completed.

Figure H 2(a-b). Task illustrations for "Range of leg movement"

4. Range of torso movement : Dynamic, Occupation specific
   - Initial Posture: Seated
   - Task: Loosen and fasten the bootlaces while seated. Do this task on both legs - one leg at a time.
   - Pass/Fail
     - Pass: Performs the task without any difficulty
     - Marginal Pass: when the subject needs to make an extra effort, relative to that subject's performance in scanning garments or the task is completed but difficulty is observed

- Fail: When the task cannot be completed or there is excessive tension around the abdomen area.

Figure H 3. Task illustrations for "Range of torso movement"

5. Range of head movement (Rotating): Dynamic, Occupation specific
   - Initial Posture: Seated
   - Task: While seated, look to the rear direction with both hands clasped behind the head (Check 6).
   - Pass/Fail
     - Pass: Perform the task without any difficulty
     - Marginal Pass: when the subject needed an extra effort, relative to the subject's performance in scanning garments, or the task is completed but difficulty is observed
     - Fail: When the task cannot be completed.

Figure H 4(a-b). Task illustrations for "Range of head movement"

6. Arm Restraint system (Webbings & AREL)
   - Aspects: Integration/Compatibility, Safety
   - Subject posture: Standing or seated

- Well-fitted (Webbing): Arm restraint webbings on the Lightweight Coverall is a part on the sleeves to attach Arm Restraint Extension Lines (AREL) by means of a larks head knot threaded through captive rings which are attached to the arm restraint webbings on the sleeves. It should be located between 10 and 11 o'clock (**Error! Reference source not found.**H5).
- Task (AREL): The correct length of Arm Restraint Extension Lines (AREL)'s is such that with the pilots palms placed down on top of each other on the top of his helmet with his elbows facing forwards and moving his elbows outwards to an angle of approximately 60 degrees, the Arm Restraint Extension Lines should become taut. (i.e. under tension without significant limitation to movement)(Figure H 6). If the Arm Restraint Extension Lines do not become taut or the pilot cannot achieve acceptable shoulder movement then a larger or smaller size of Arm Restraint Extension Line shall be tried using the same procedure for fitting.

(*Fit assessment for AREL can be done only if an ejection seat and seat harness system with quick release box are available. Otherwise, only the fit of webbing part will be assessed as shown in Figure H 5)

Line Measure for Webbings: Estimate between 9 o'clock and 12 o'clock.

Figure H 5. Fit evaluation illustrations for "Arm Restraint Webbing"

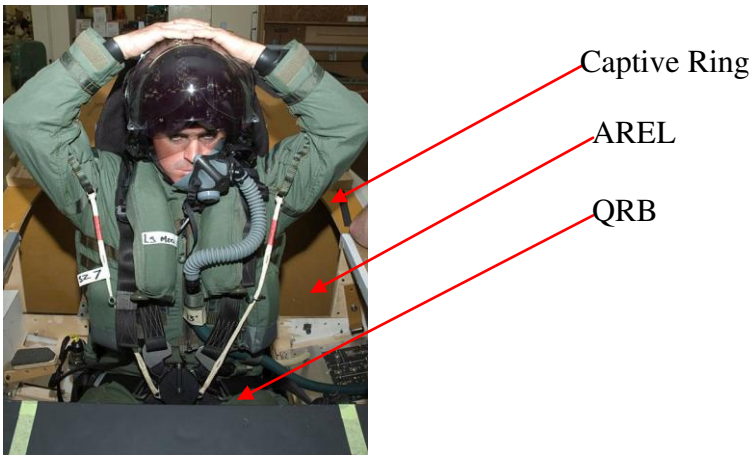


Figure H 6. Fit evaluation illustrations for "AREL"

H.2. Specific Location Test

A ***preliminary test*** is necessary to assign numbers to the pass/fail decision. The preliminary test can be conducted in conjunction with the fit trial if all assessments are recorded as numbers along with subject preference at each assess location during the fit trial.

H.2.1. Line measure

1. Neck and collar
   - Aspects of fit: Static, mobility and comfort
   - Subject posture: Standing
   - Well-fitted: Should be easy to zip up. The zipper should end near Suprasternale.
   - Line measure: The distance between the end of the zipper and Suprasternale.

Figure H 7. Fit evaluation illustrations for "Neck and Collar"

2. Shoulder location
   - Aspects: Static, mobility, comfort and Aesthetic
   - Subject posture: Standing
   - Well-fitted: The upper arm-hole seam should fall around the Acromion point.
   - Line Measure: Distance between the end of shoulder (Arm-hole) seam and the Acromion.

Figure H 8. Fit evaluation illustrations for "Shoulder location"

3. Waist height
    - Aspects: Static, aesthetic
    - Subject posture: Standing
    - Well-fitted: At or around the Omphalion point.
    - Line measure: The distance between the center of the waist band and Omphalion level

Figure H 9. Fit evaluation illustrations for "Waist Height"

4. Sleeve length
    - Aspects: Static, Safety
    - Subject posture: Seated, arms straight between the legs, with hands together.
    - Well-fitted: The edge of the sleeve should end at or around the wrist bone.
    - Line Measure: Distance between the end of sleeve and the Ulnar Styloid point.

Figure H 10. Fit evaluation illustrations for "Sleeve Length"

5. Leg length
    - Aspects: Static, Mobility, Comfort and Aesthetic
    - Subject posture: Standing
    - Well-fitted: Below the ankle bone (Lateral Malleolous). Not above the ankle bone and not dragging the floor.
    - Line Measure: Distance between the hem and the Lateral Malleolous.

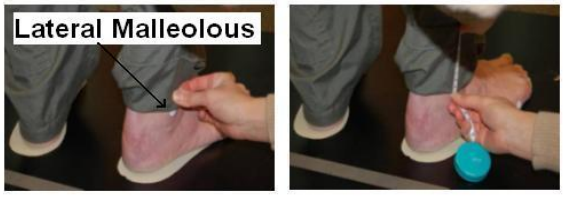


Figure H 11. Fit evaluation illustrations for "Leg Length"

H.2.2. Ease measures

6. Arm Scye
   - Aspects: Static, Mobility, Comfort
   - Subject posture: Standing with the arms raised and together in a Genie position
   - Well-fitted: When the arms are raised slightly, the armhole should not be too high or not too low
   - Ease measure: Pinch extra fabric at the bottom of axilla.

Figure H 12. Fit evaluation illustrations for "Armscye"

7. Chest area
   - Aspects: Static, Comfort and Aesthetic
   - Subject Posture: Standing with the arms raised slightly to the side
   - Well-fitted: While standing, there should be some extra fabric at each side at the fullest part of the chest.
   - Ease measure: Pinch extra fabric at both sides at the chest level.

Figure H 13. Fit evaluation illustrations for "Chest"

8. Waist area
   - Aspects: Static, Comfort, Aesthetic
   - Subject posture: Standing with the arms crossed at the chest
   - Well-fitted: While standing, there should be some extra fabric at each side at Omphalion.
   - Ease measure: Pinch extra fabric at both sides at the Omphalion level, when subjects raise their arms slightly upward.

Figure H 14. Fit evaluation illustrations for "Waist"

9. Hip area
   - Aspects: Static, Comfort and Aesthetic
   - Subject posture: Standing with arms crossed at the chest
   - Well-fitted: While standing, there should be some extra fabric at each side at the fullest part of the hip
   - Ease measure: Pinch extra fabric at both sides at the maximum hip level, when subjects raise their arms slightly to the side

Figure H 15. Fit evaluation illustrations for "Hip"

10. Crotch length
    - Aspects: Static, Mobility and comfort
    - Subject posture: Standing with arms crossed at the chest
    - Well-fitted: While standing, there should be some extra fabric at center back
    - Ease measure: Vertical pinch extra fabric at the center back, when subjects are standing.

Figure H 16. Fit evaluation illustrations for "Crotch Length"

Appendix I. Fit range plots

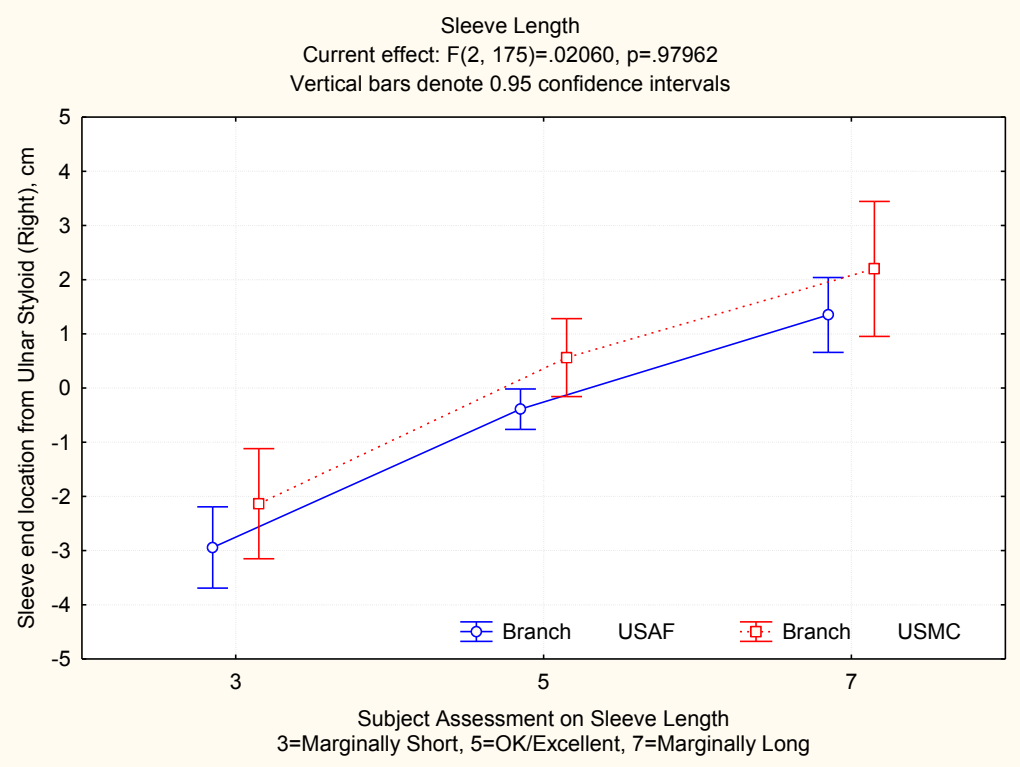
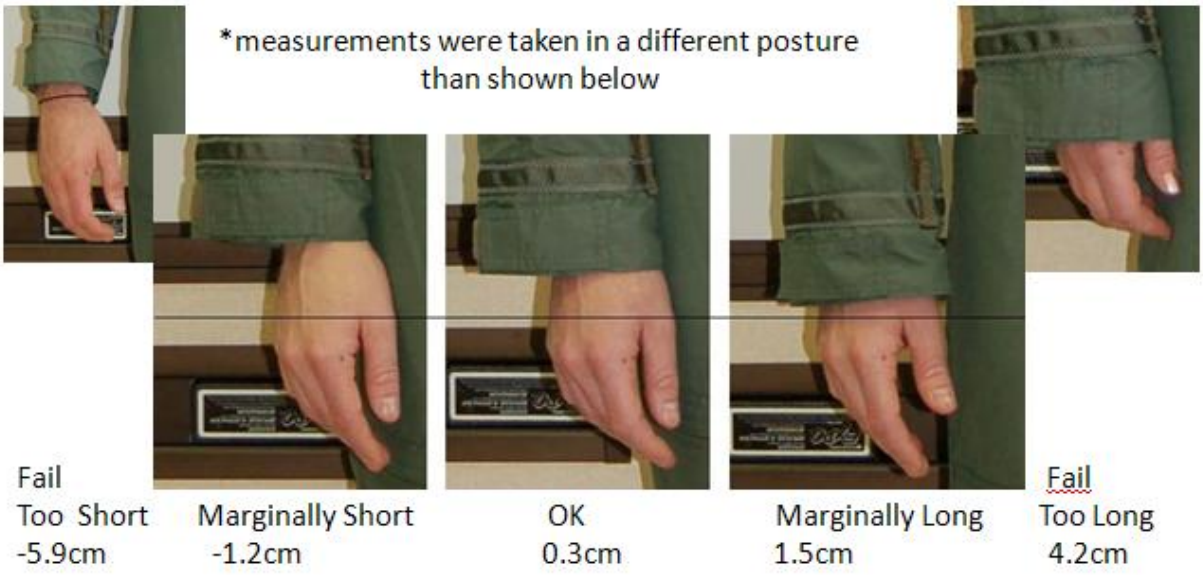


Figure I 1. Fit Criteria 1. Sleeve length



*Refer to Appendix H.2.2. Ease measures, 4. Sleeve length for the measurement posture

Figure I 2. Example of Sleeve fit

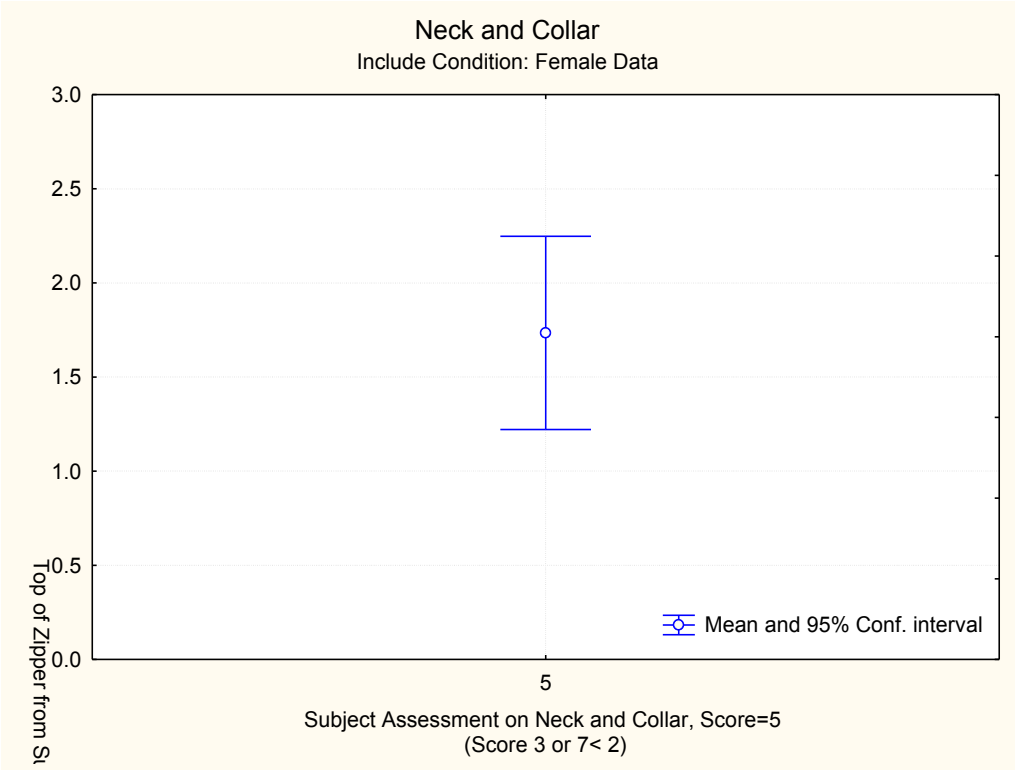


Figure I 3. Fit Criteria 2. Neck and Collar (Gender specific criterion)-Female

*Since no marginal loose or marginally tight values were reported for Females, the OK range for Females was combined with Males to produce one criterion for this location.

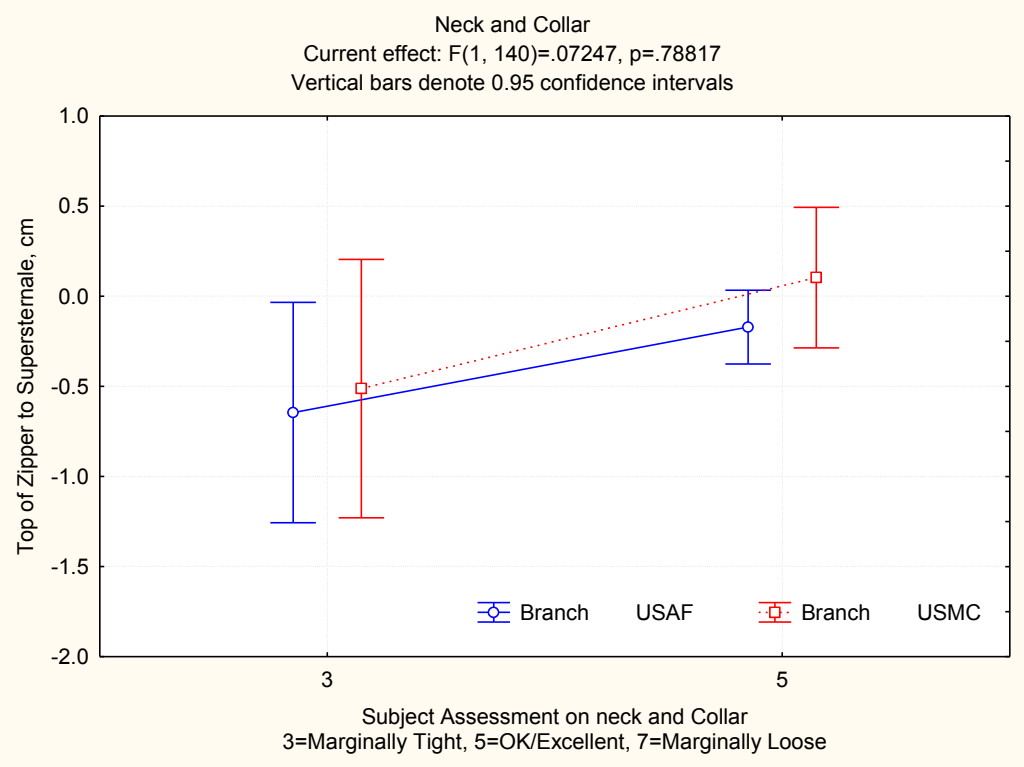


Figure I 4. Fit Criteria 2. Neck and Collar (Gender specific criterion)-Male

Figure I 5. Example of Neck and Collar fit

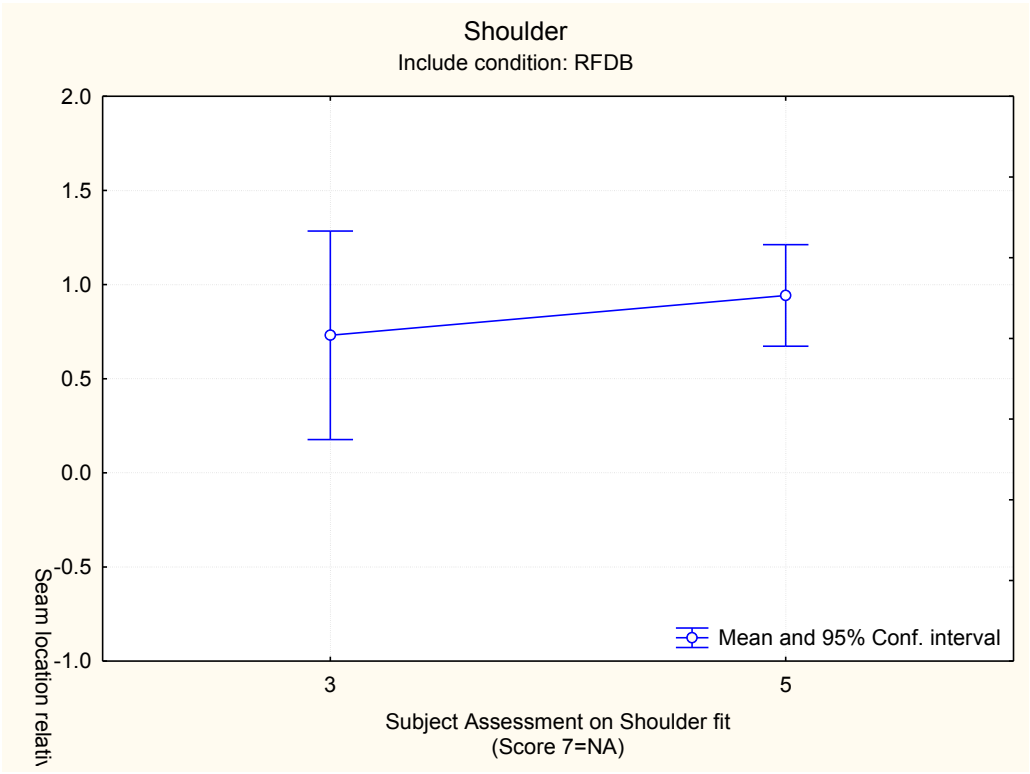


Figure I 6. Fit Criteria 3. Shoulder

Figure I 7. Example of Shoulder fit

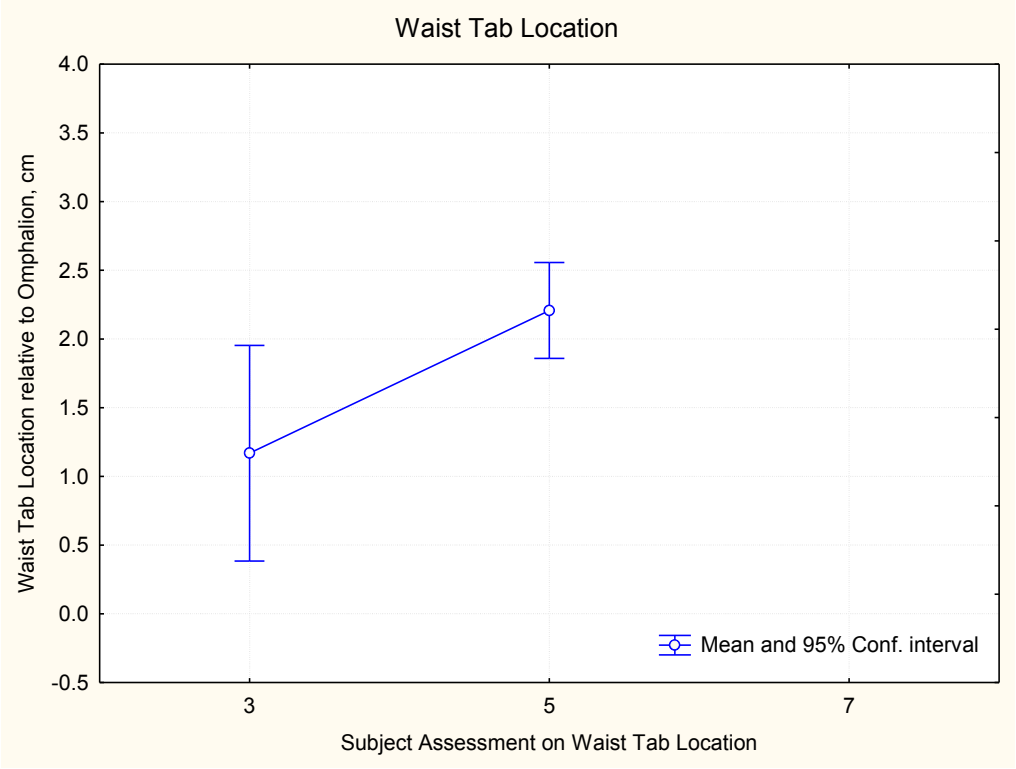


Figure I 8. Fit Criteria 4. Waist Height (Waist Tab location)

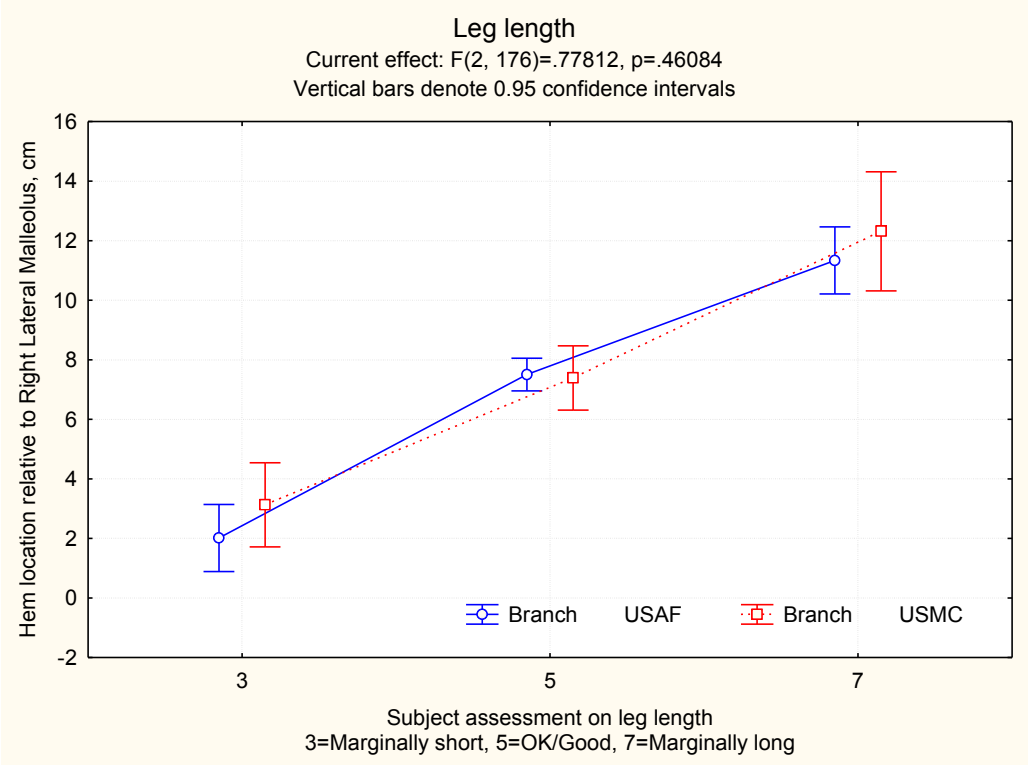


Figure I 9. Fit Criteria 5. Leg Length

Figure I 10. Example of Leg Length fit

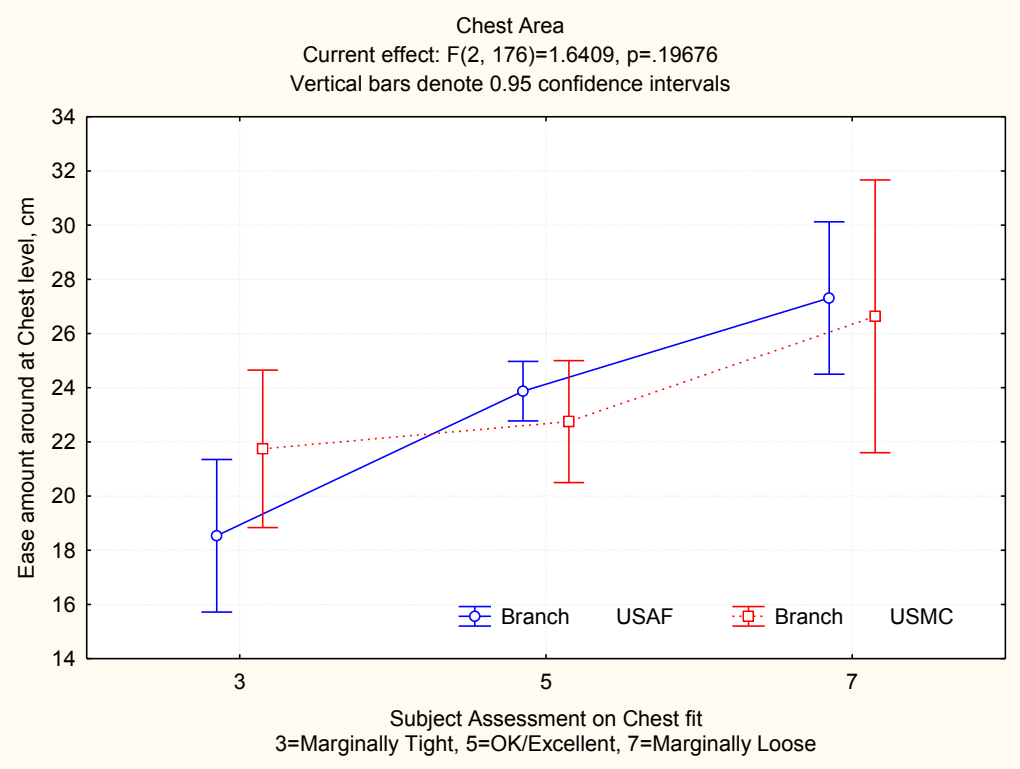


Figure I 11. Fit Criteria 7. Chest

Figure I 12. Example of Chest fit

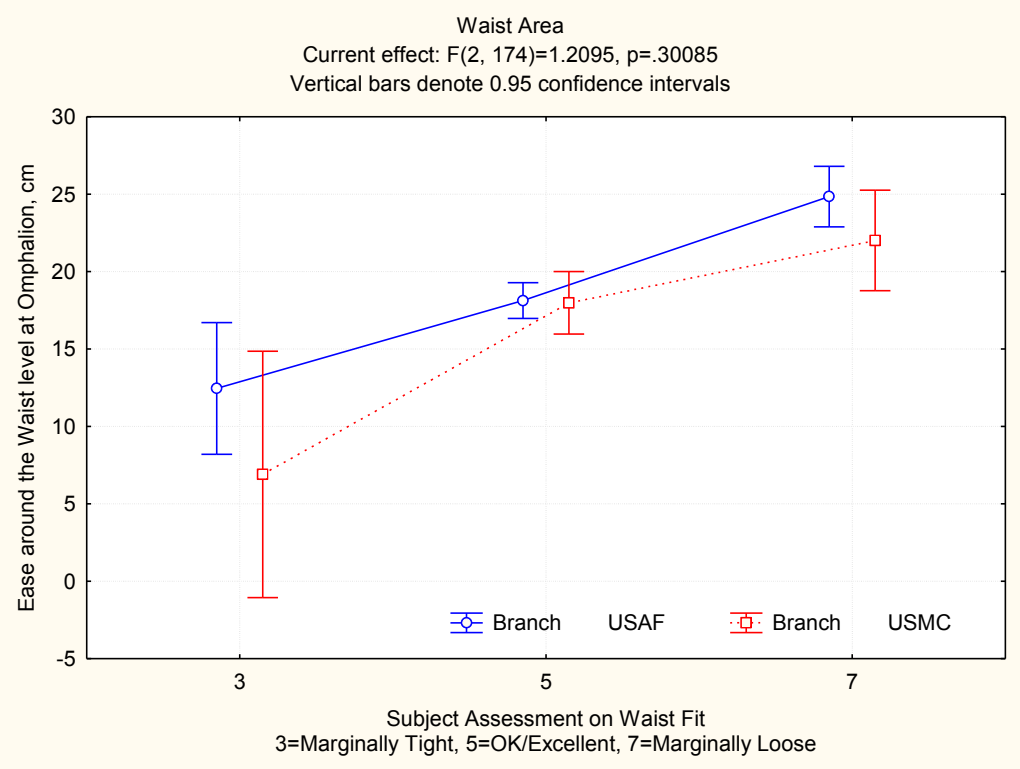


Figure I 13. Fit Criteria 8. Waist Fit (Gender specific criterion) USAF vs USMC

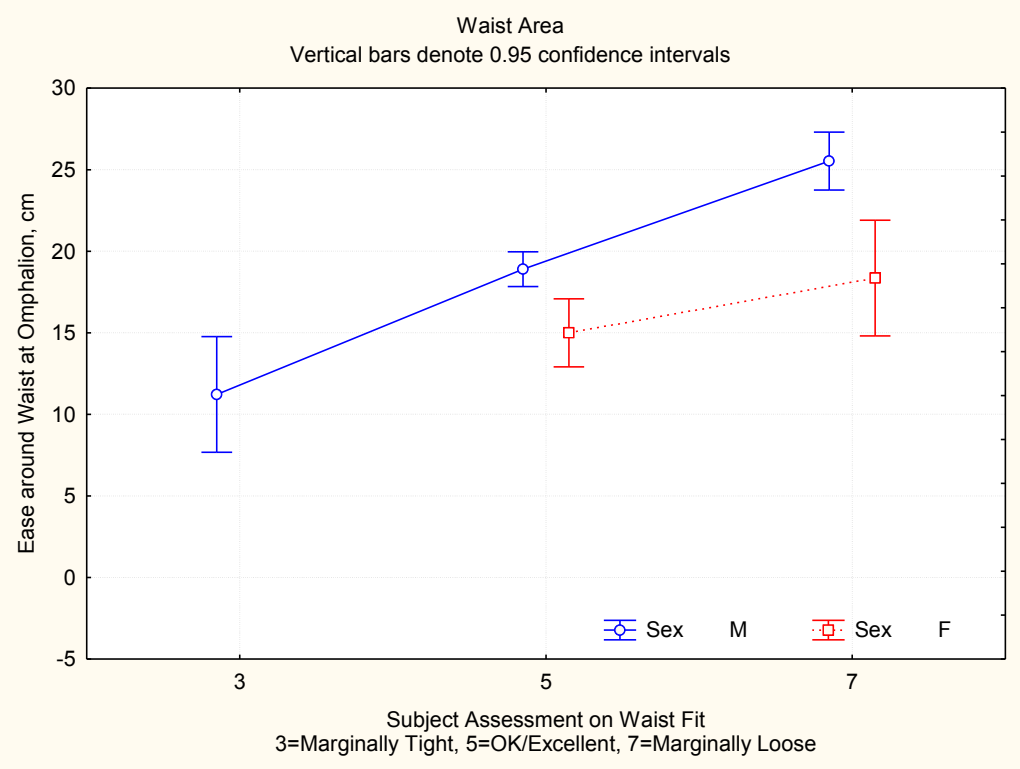


Figure I 14. Fit Criteria 8. Waist Fit (Gender specific criterion) Male vs Female

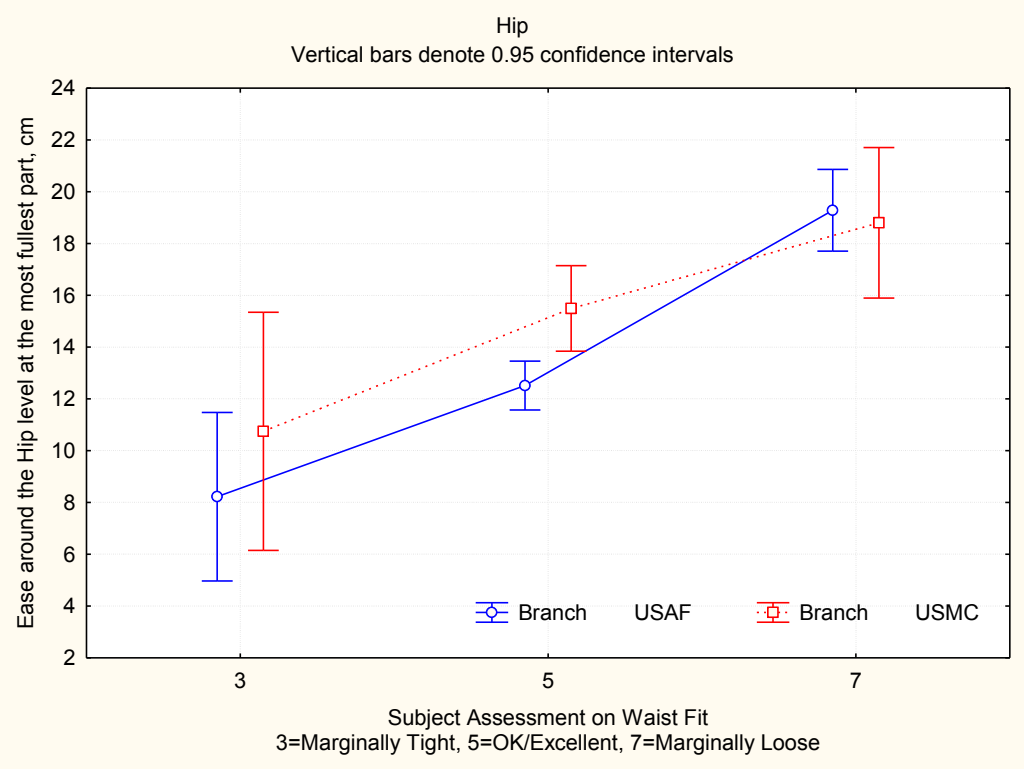


Figure I 15. Fit Criteria 9. Hip Fit (Gender specific criterion) USAF vs USMC

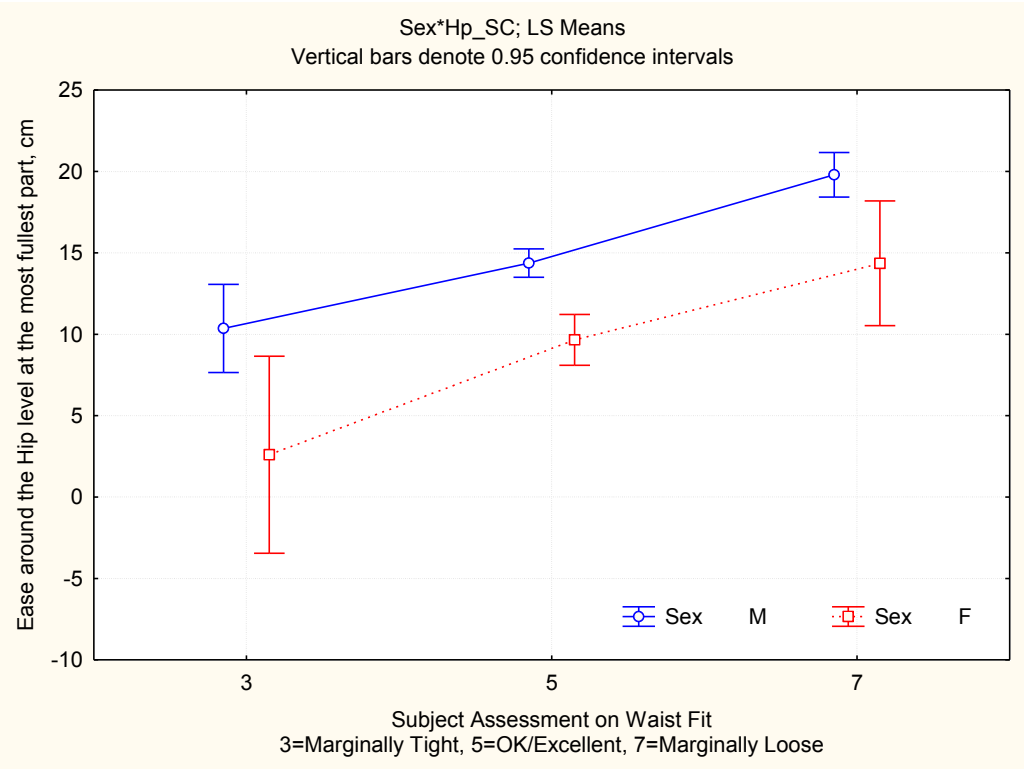


Figure I 16. Fit Criteria 9. Hip Fit (Gender specific criterion) Male vs Female

Figure I 17. Example of Hip fit (Male)

Figure I 18. Example of Hip fit (Female)

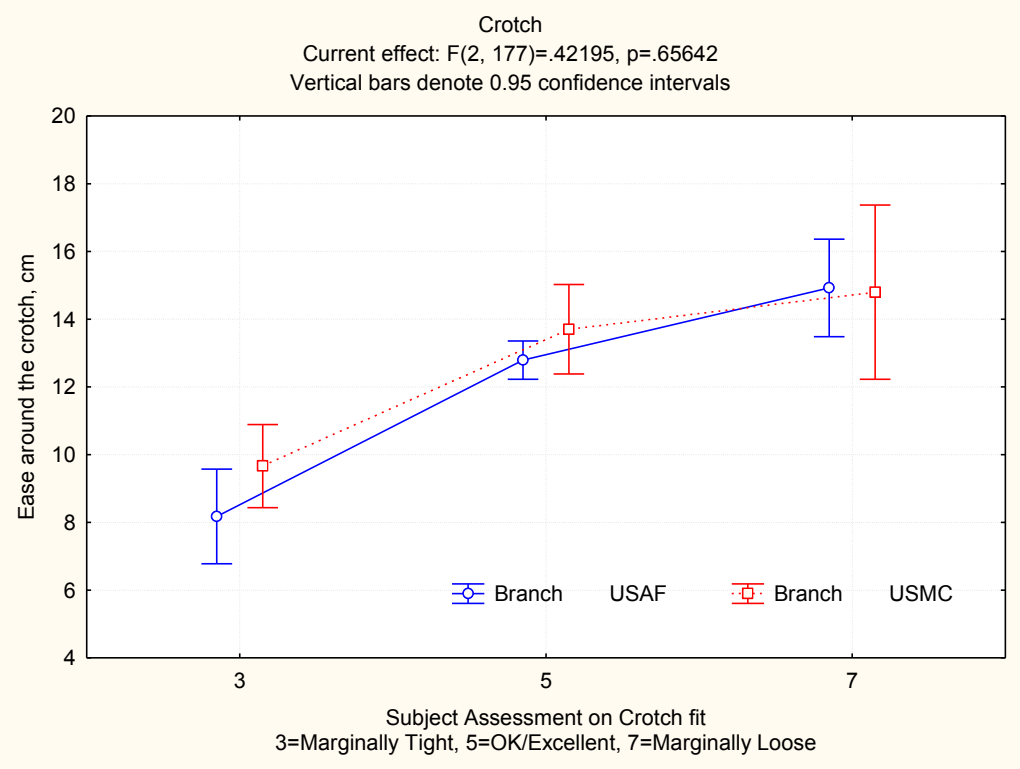


Figure I 19. Fit Criteria 10. Crotch

Appendix J. Accommodation plots (Red-RFDB Predicted, Green-Actual accommodation)

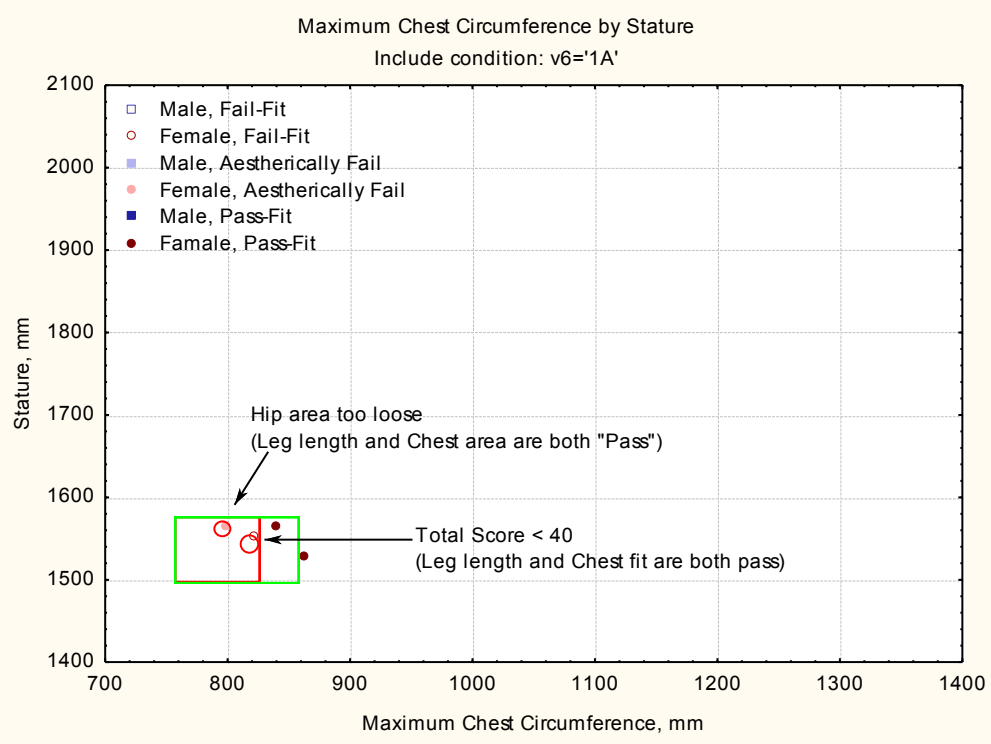


Figure J 1. Size 1A

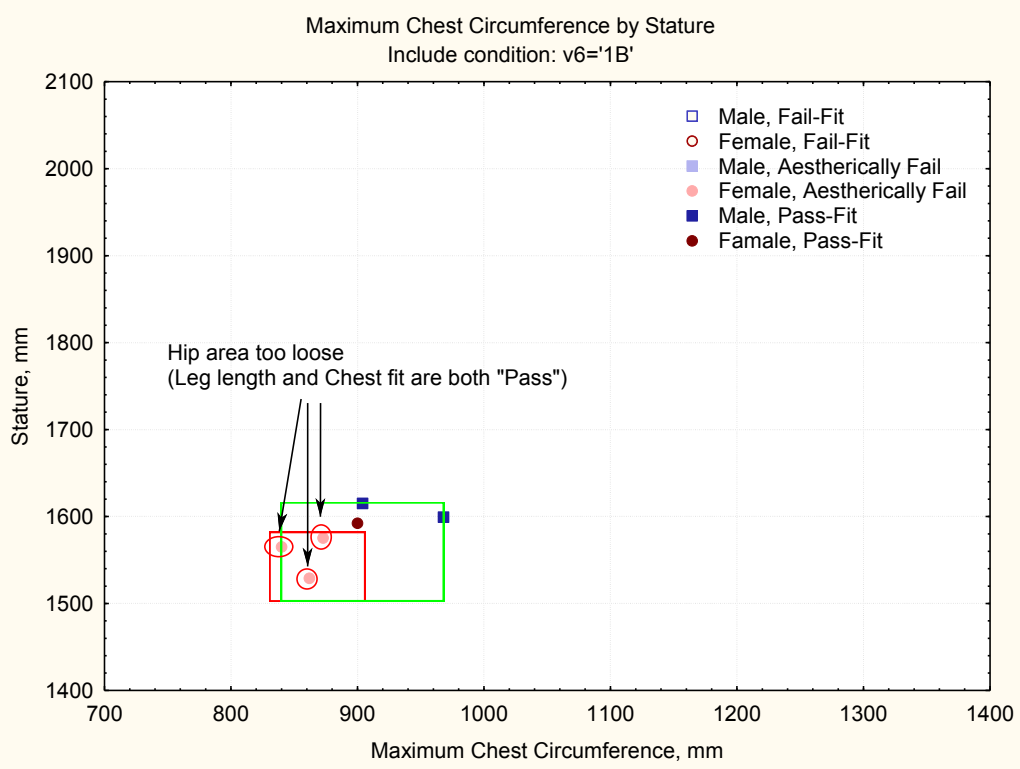


Figure J 2. Size 1B

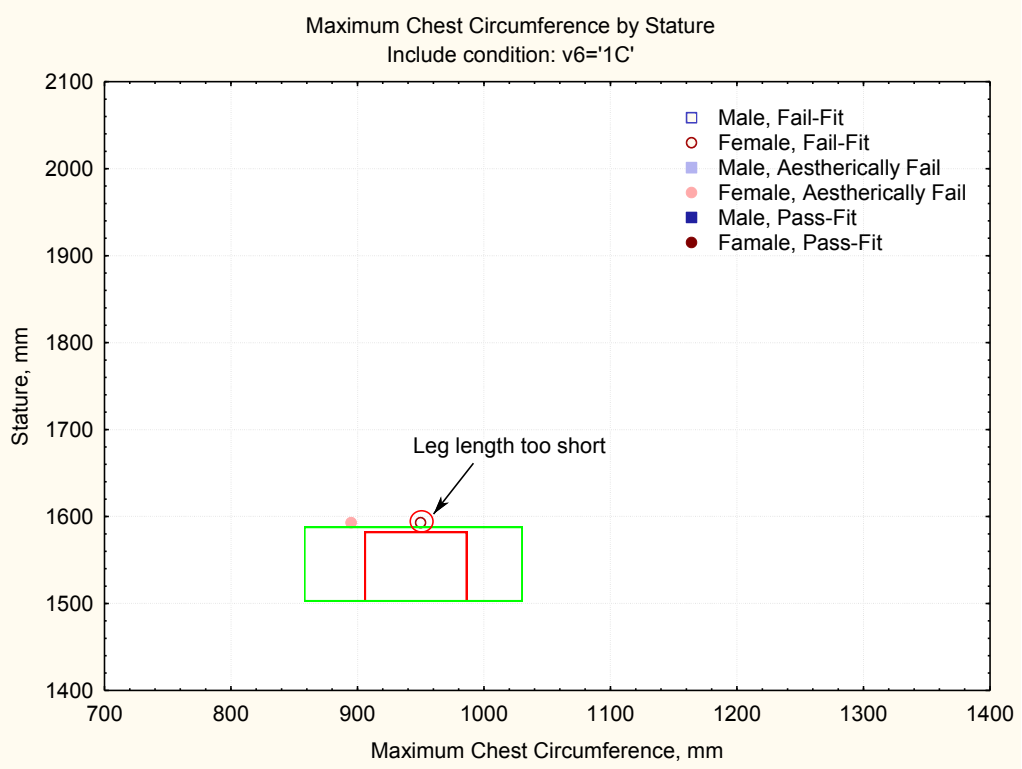


Figure J 3. Size 1C

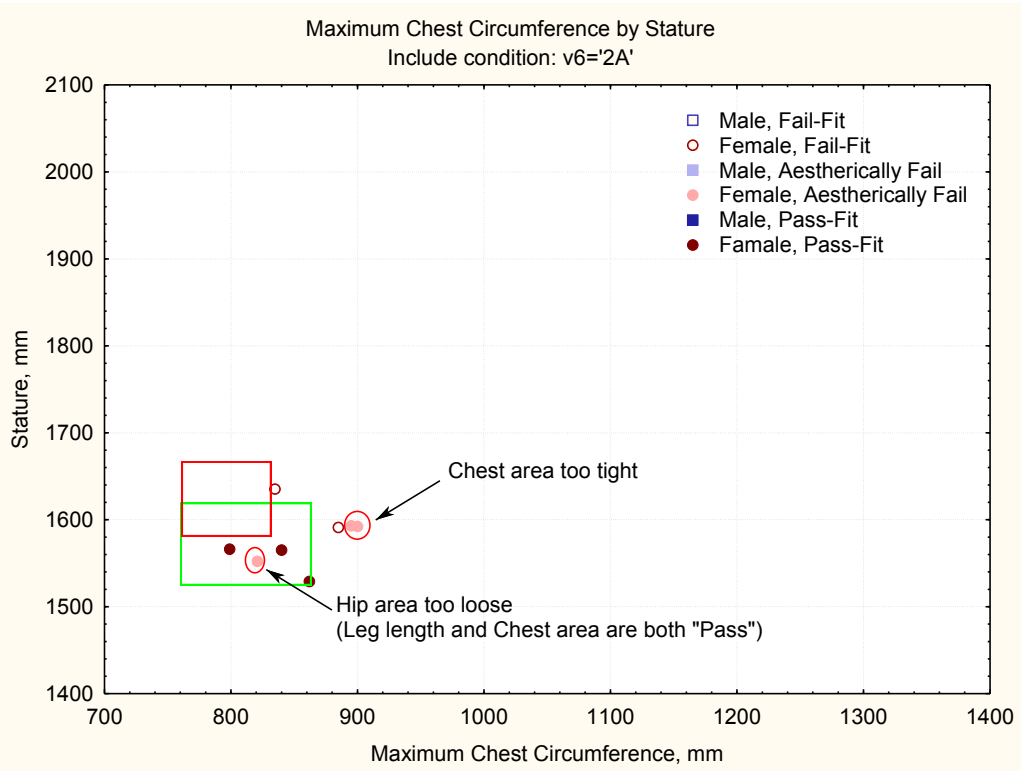


Figure J 4. Size 2A

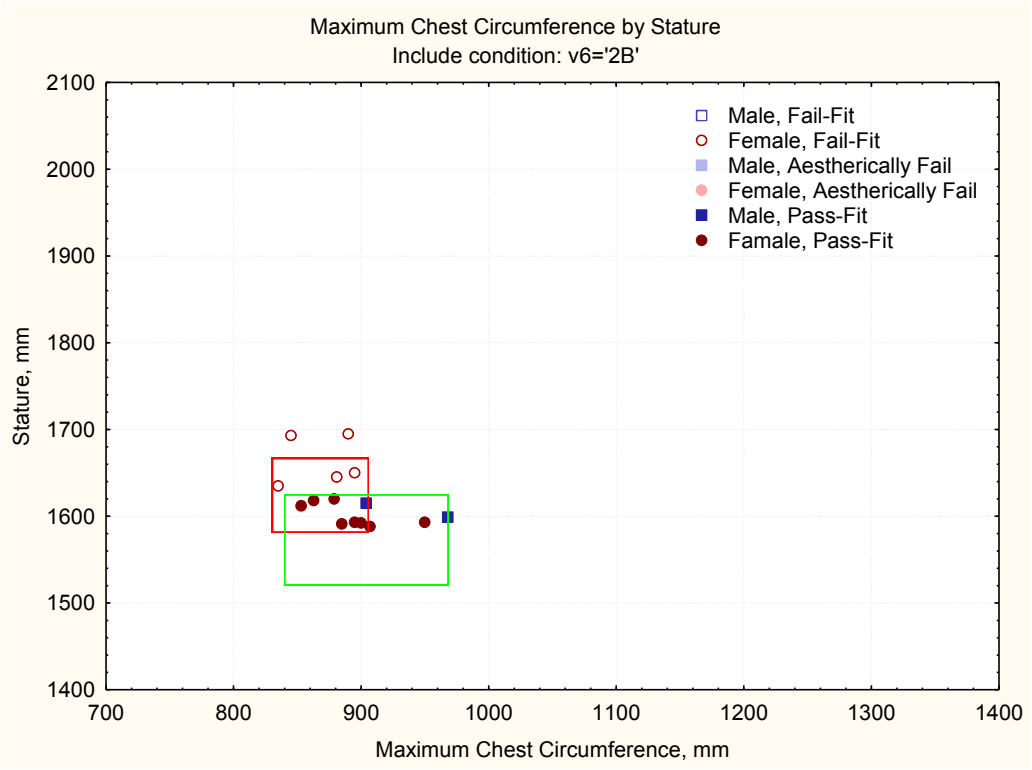


Figure J 5. Size 2B

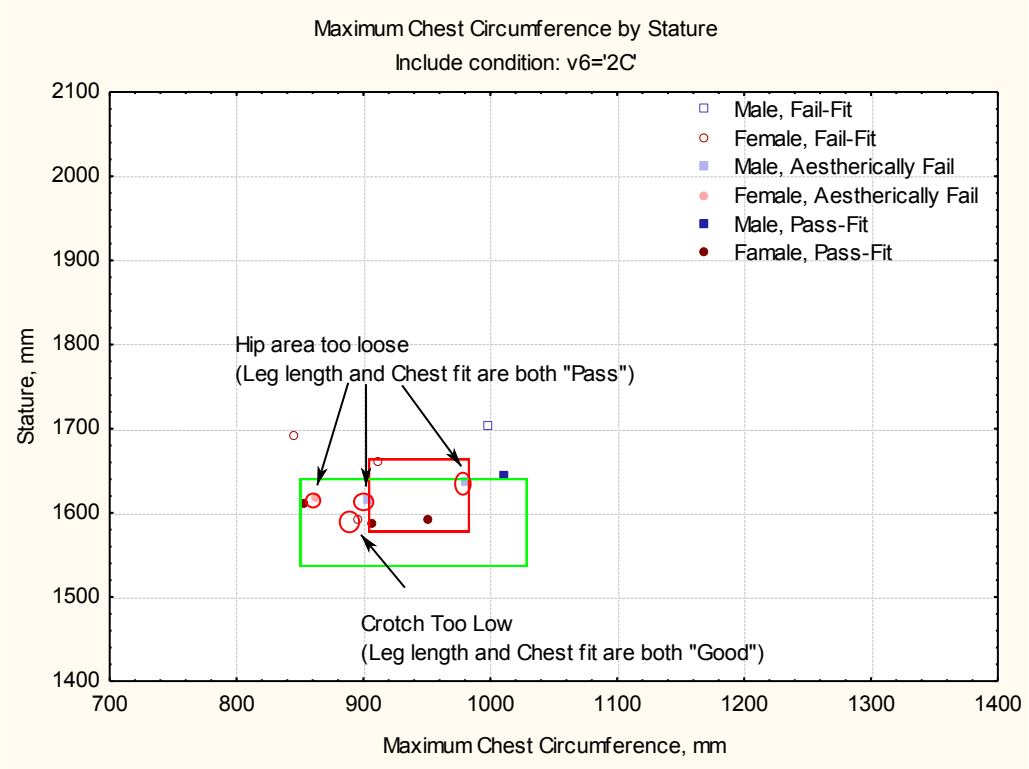


Figure J 6. Size 2C

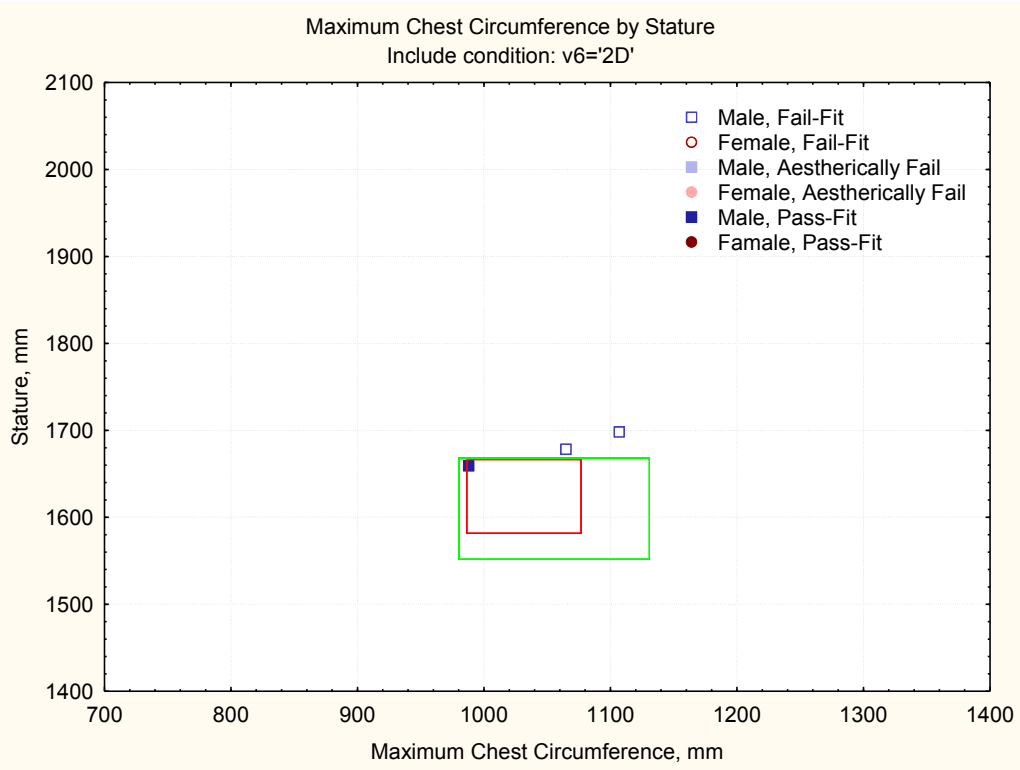


Figure J 7. Size 2D

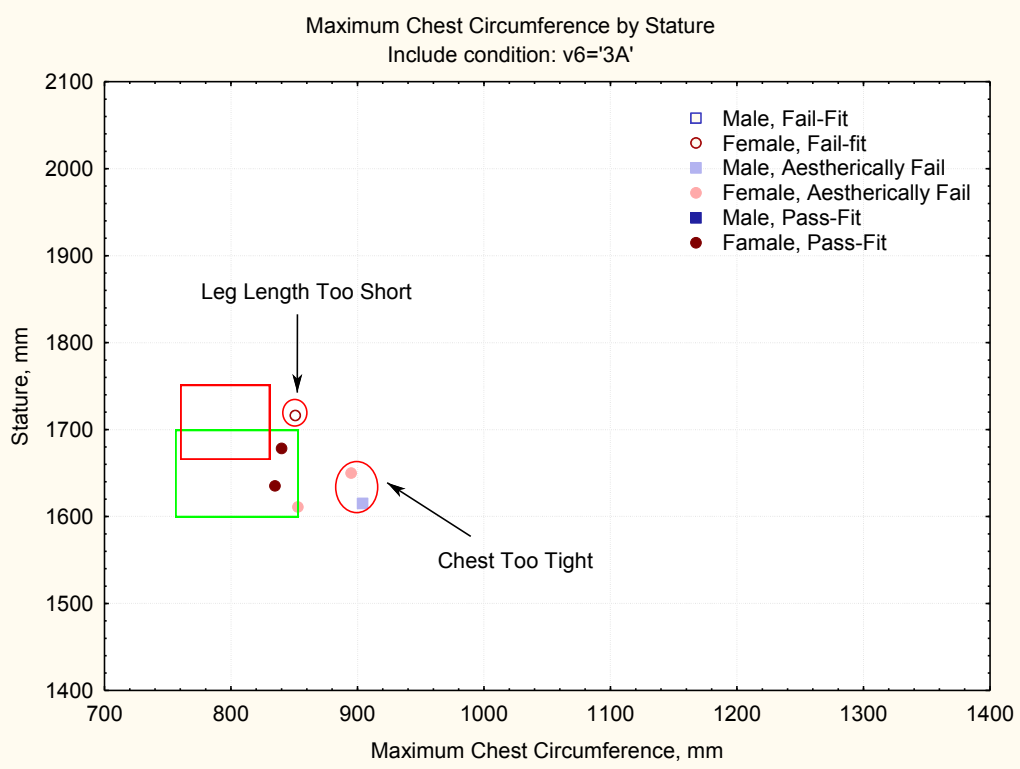


Figure J 8. Size 3A

Figure J 9. Size 3B

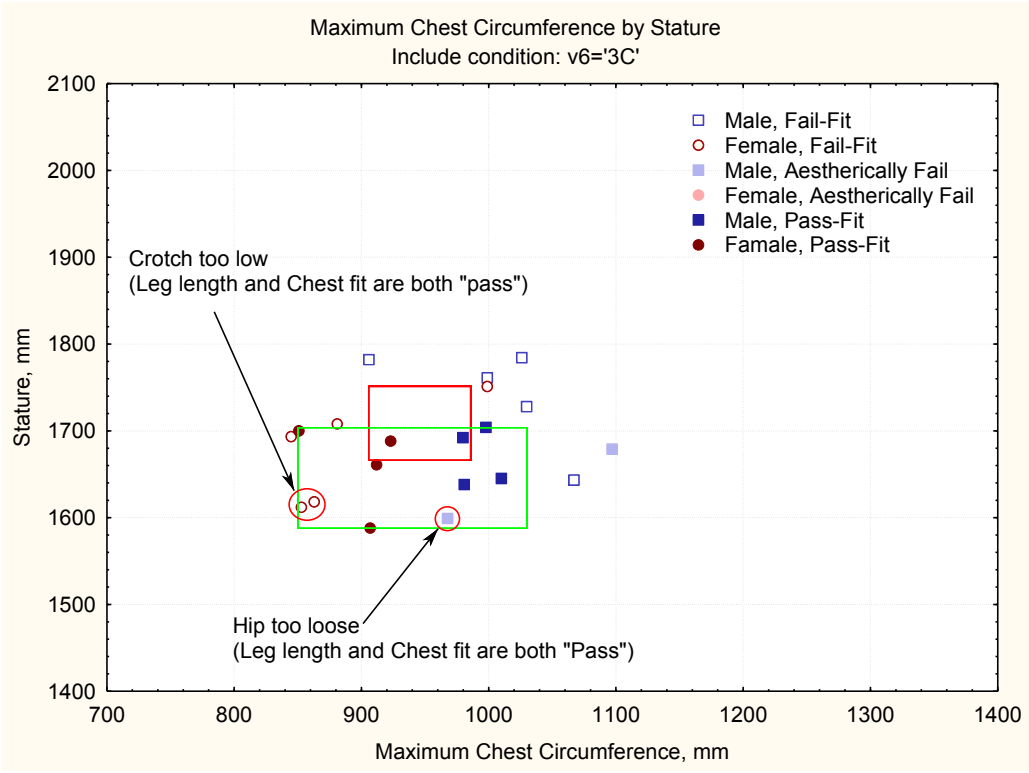


Figure J 10. Size 3C

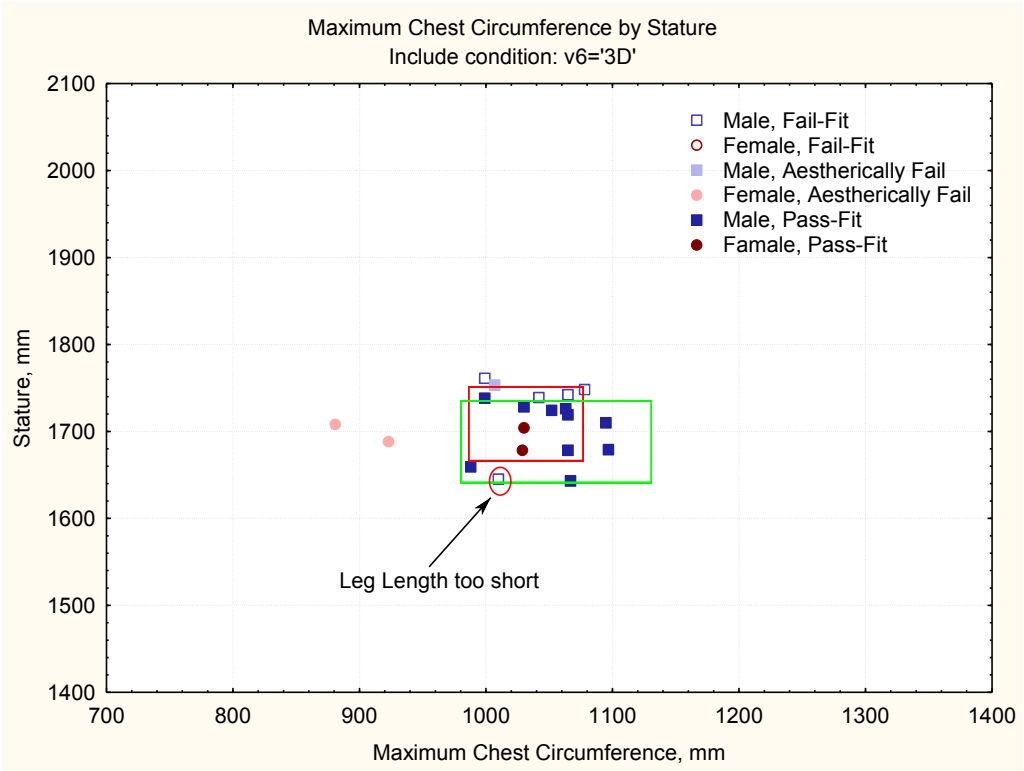


Figure J 11. Size 3D

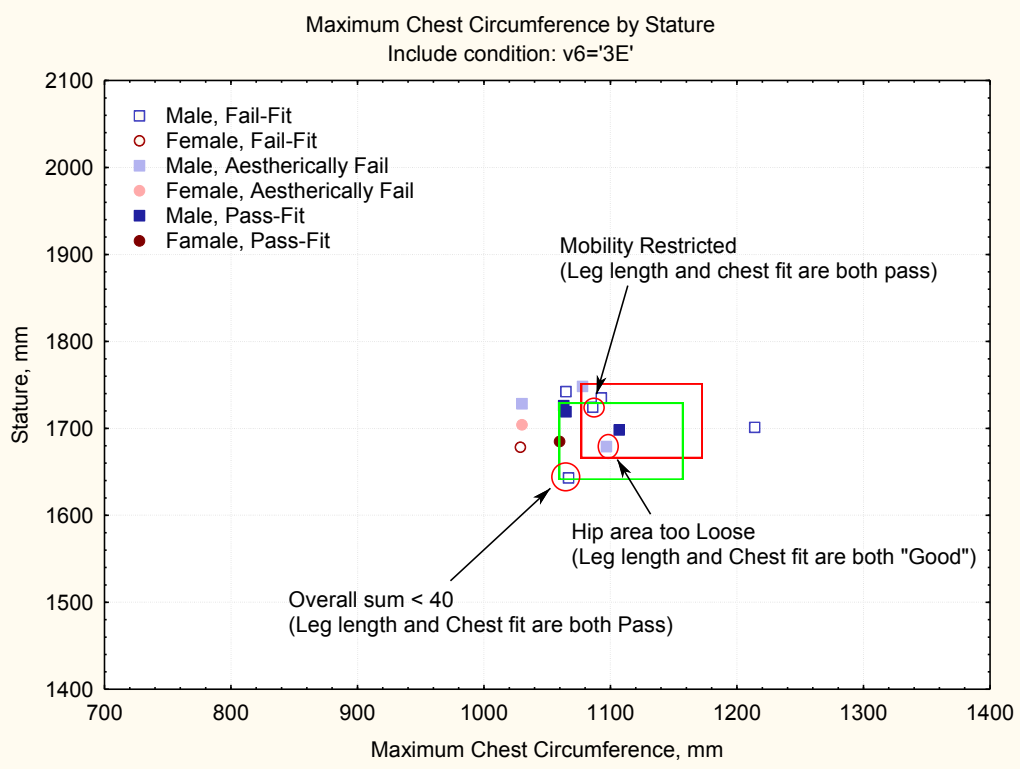


Figure J 12. Size 3E

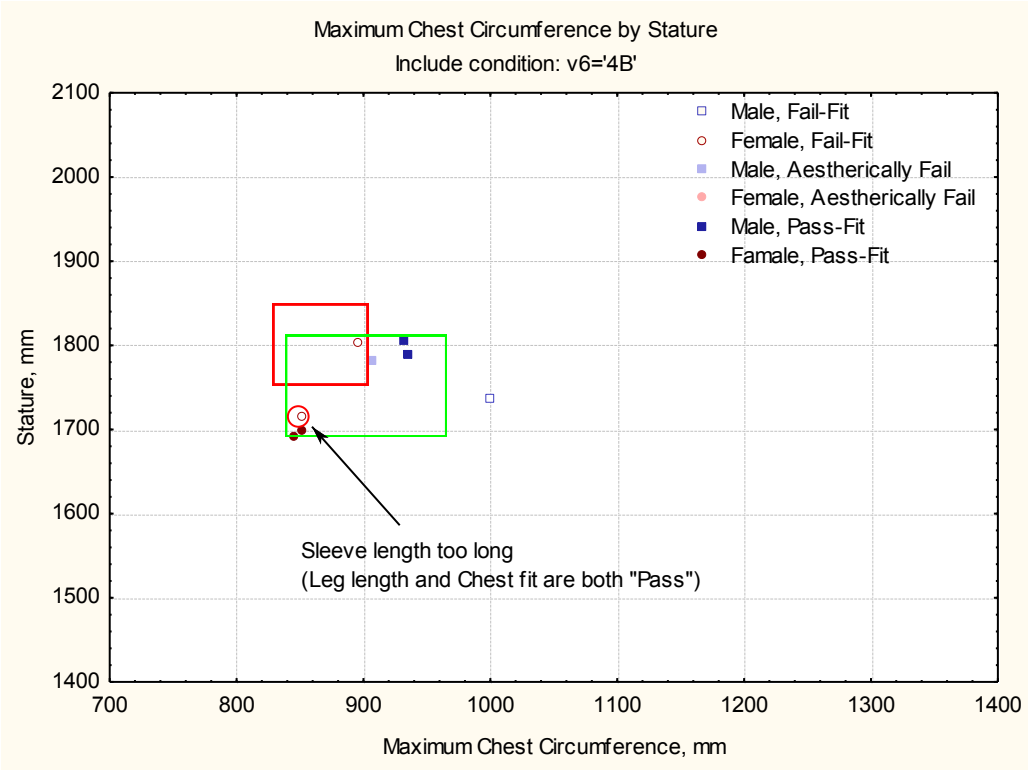


Figure J 13. Size 4B

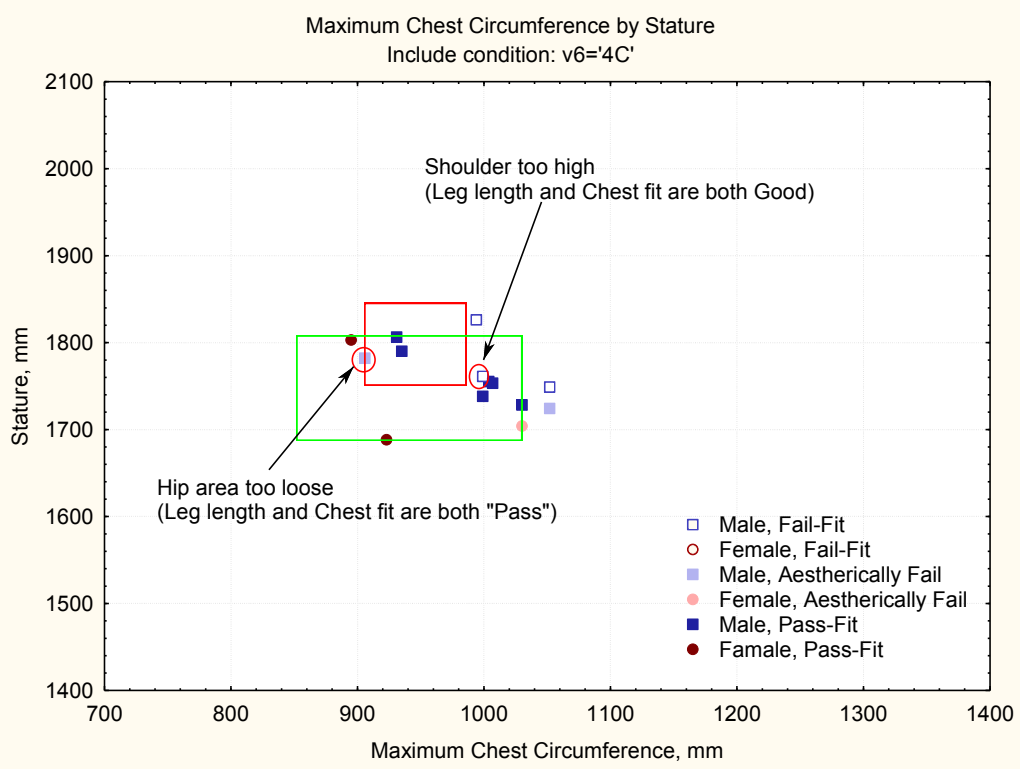


Figure J 14. Size 4C

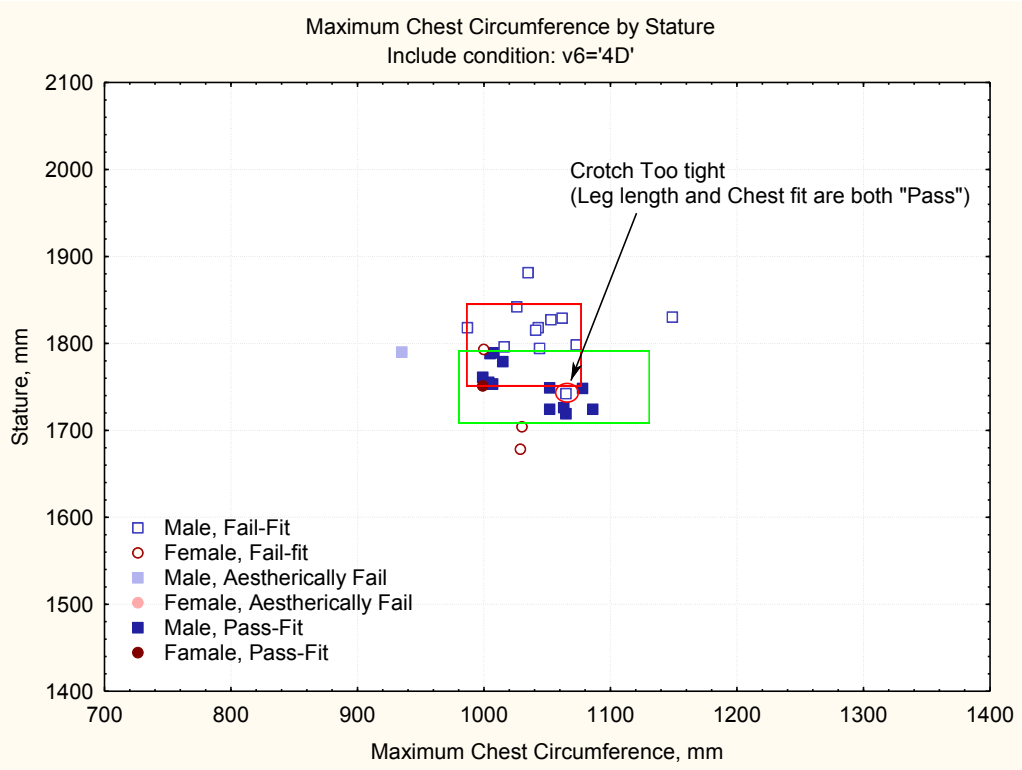


Figure J 15. Size 4D

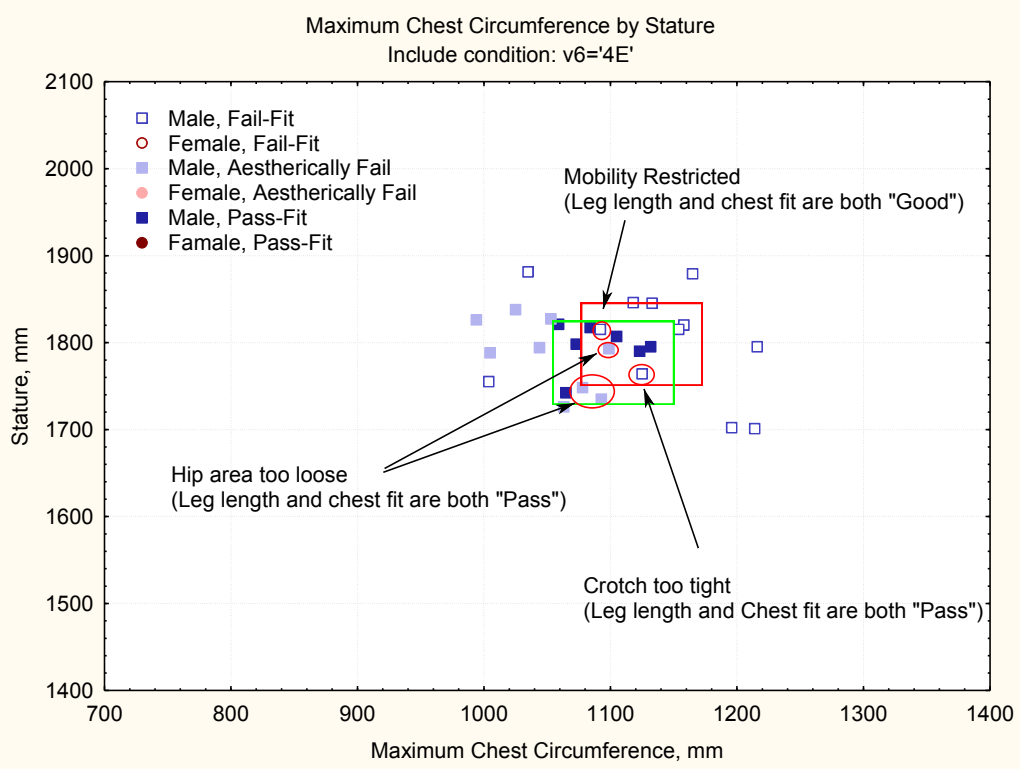


Figure J 16. Size 4E

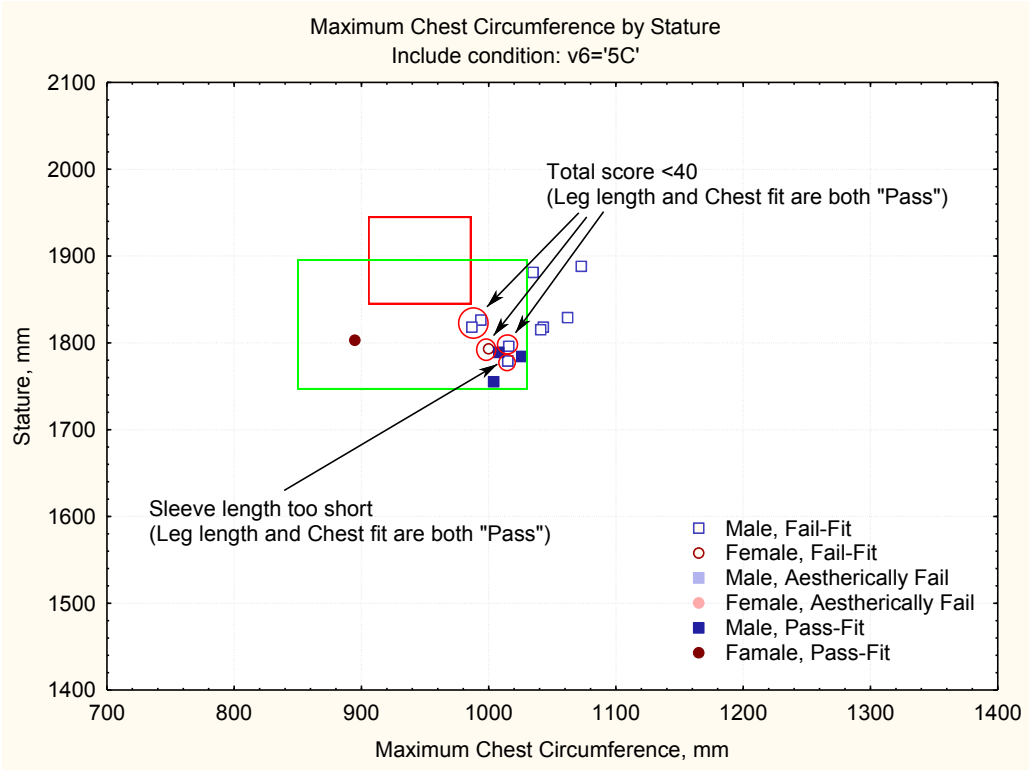


Figure J 17. Size 5C

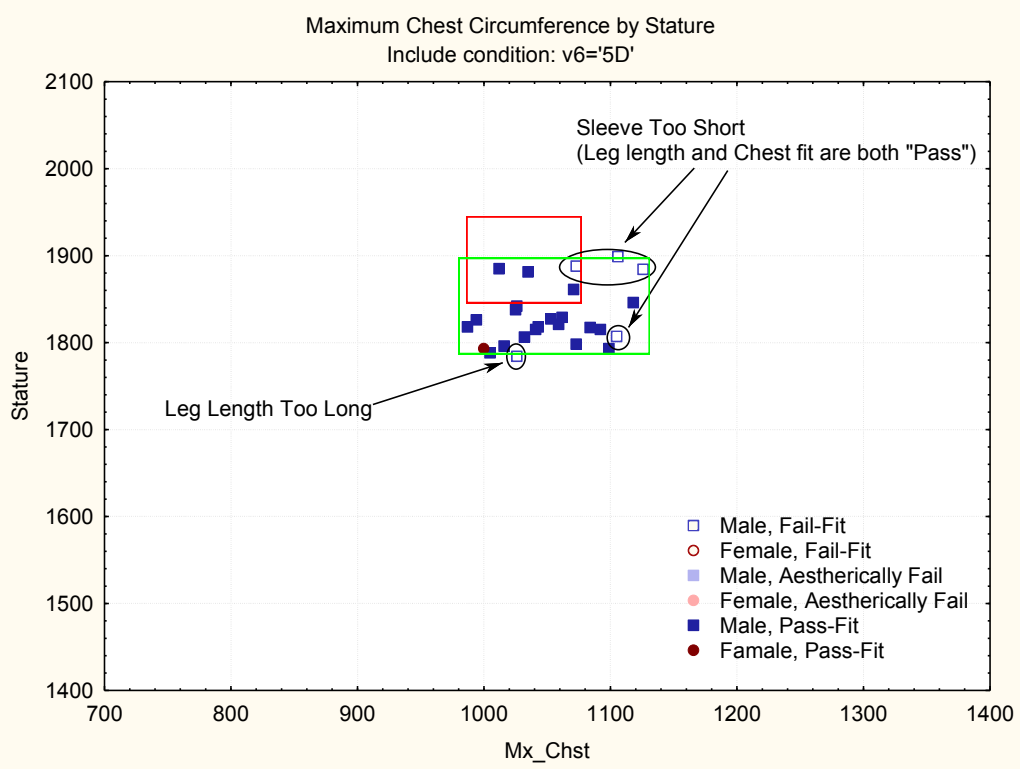


Figure J 18. Size 5D

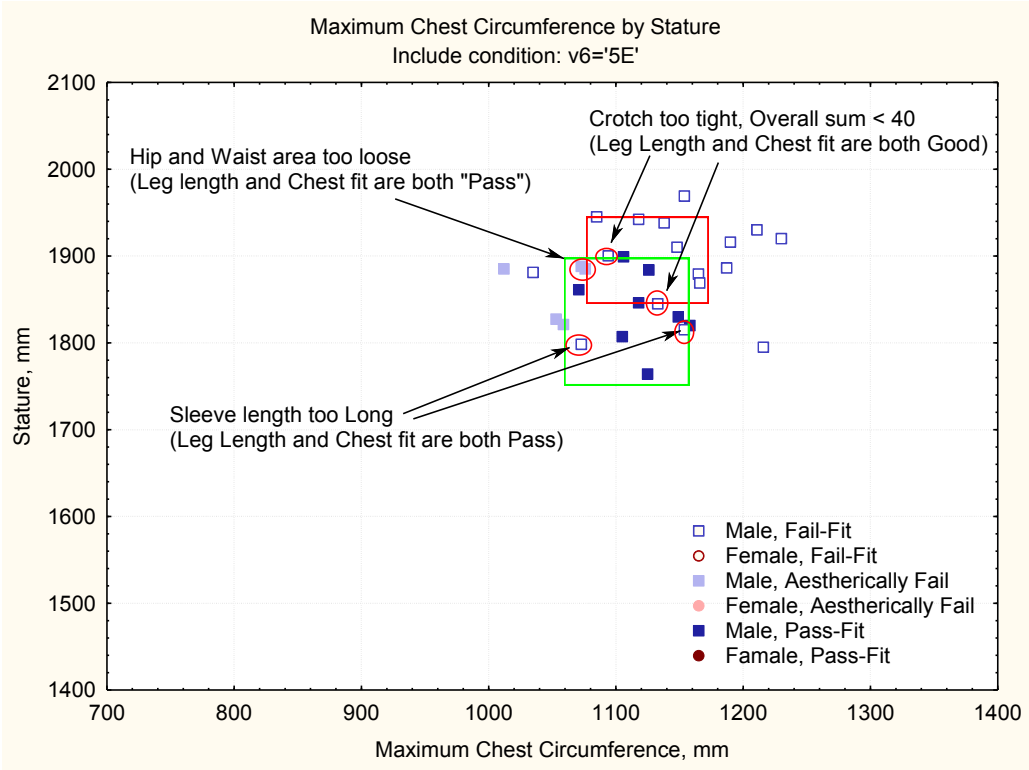


Figure J 19. Size 5E