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PRINCIPAL INVESTIGATOR: LTC James W. Dooley

CONTRACTING ORGANIZATION: Armstrong Laboratory
Brooks AFB, TX 78235

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In high performance aircraft, inadequate G-protective equipment could lead to decreased performance and unsafe flight conditions. The purpose of this project was to provide female aircrew with appropriately designed and fitted G-protective equipment. This project has supported five major efforts: (1) A centrifuge study comparing male and female acceleration tolerances and evaluating a gender-specific anti-G suit modification -- early data analysis (50% completion) indicates female tolerance is at least equivalent to that of males and that the modified CSU-13B/P anti-G suit provides females better protection than the standard suit. (2) Two female F-16 pilots demonstrated improved G-tolerance in the centrifuge after anti-G suit modification -- this modification has been adopted for AF-wide use. (3) An anthropometry evaluation of the potential female aircrew population resulted in an anti-G suit sizing scheme for small females. (4) A proto-type modified anti-G suit for small aircrew was fabricated and fit-tested on three subjects less than 63 inches in stature -- the small suit provided a good fit for all. (5) A protocol was initiated to evaluate a positive pressure breathing apparatus (COMBAT EDGE) relative to male/female G-tolerance; preliminary data indicate a poor female fit for COMBAT EDGE, although there were no reports of excessive discomfort.

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James W. Bobley 29 Aug 95

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Executive Summary

1. The design and sizing of +Gz acceleration protective life support equipment currently used by US Air Force aircrew was based on male anthropometry and physiology. Since the proper design and fit of this equipment is essential for the safety and effectiveness of fighter aircrew, evaluations of equipment function and the development of new equipment sizes or alterations to existing equipment are required for females. To meet this need, the USAF Armstrong Laboratory, Crew Technology Division initiated a multifaceted research and development program to ensure that female aircrew are provided with properly fitting, effective G-protective equipment. The program included the following efforts.

a. Task 1. A centrifuge study comparing male and female acceleration tolerances to an endurance type acceleration profile and evaluating the effectiveness of the Armstrong Laboratory (AL) modification to the CSU-13B/P (Standard) USAF anti-G suit.

b. Task 2. The development and transition of modifications to the standard USAF anti-G suit (CSU-13B/P) which will provide female aircrew with a more comfortable, better performing suit.

c. Task 3. The development of a sizing scheme for the CSU-13B/P anti-G suit and the ATAGS (Advanced Technology Anti-G Suit) that will meet size requirements for nearly 100% of the current female aircrew. Optimally, this effort will provide a sizing scheme for anti-G suits that will fit nearly 100% of the current pilot population and will fit 80% or more of all U.S. females in the pilot eligible age-group population.

d. Task 4. The development of patterns and the fabrication of CSU-13B/P anti-G suits to meet new female sizing requirements.

e. Task 5. Conduct an evaluation of the COMBAT EDGE (COMBined Advanced Technology Enhanced Design G Ensemble) counter pressure garment to determine if new sizes or alteration procedures can be used to improve the fit of the garment on female aircrew.

2. Progress.

a. Task 1. Five male and five female subjects completed the centrifuge study comparing male and female acceleration tolerances. Data from this study plus feedback from USAF female fighter pilots provided adequate information to complete the development of the AL modification to the CSU-13B/P anti-G suit.

b. Task 2. The G-suit modification was certified as safe-to-fly and was promulgated Air Force-wide as a safety supplement to the USAF Technical Manual for the CSU-13B/P anti-G suit

c. Task 3. An anthropometry evaluation of female G-suit fit was conducted by the Human Engineering Division of the Armstrong Laboratory and this information was translated to a G-suit sizing scheme for female aircrew. It was found that one adding one additional G-suit size (Extra small, short) to the current selection would adequately fit nearly 100% of the current USAF aviators and would fit over 80% of the target population. Three additional suit sizes would fit over 90% of the target population.

d. Task 4. Patterns were developed and an extra small, short suit was fabricated. Fit trials were conducted with this suit and it was found to provide an adequate fit for individuals with a stature of 62-65 in. and a weight of 120-135 lbs. The extra-small, short anti-G suit passed the required pressure and leak testing and was made available for centrifuge use.

e. Task 5. A preliminary evaluation of the COMBAT EDGE pressure garment was conducted. Six female subjects using the COMBAT EDGE system were trained to positive pressure breathe at 1 +Gz. The subjects were exposed to breathing pressures up to 60 mmHg. The COMBAT EDGE counter-pressure garment (vest) provided adequate counter-pressure to support the high level pressure breathing and the subjects denied any discomfort or breathing difficulty. Subjectively, the garment provided a poor fit for 4 of the 6 subjects. A protocol to conduct a full scale centrifuge evaluation of the COMBAT EDGE system and ATAGS was developed and approved.

3. Future research and development efforts to support female acceleration tolerance enhancement will include completion of the COMBAT EDGE and ATAGS centrifuge evaluation, the development of gender friendly sizing or alterations for the COMBAT EDGE vest, and the evaluation of female sizing requirements for the ATAGS. These efforts have near-term operational requirements. The COMBAT EDGE system is currently in operational use in USAF F-16 fighter aircraft and will be installed in F-15s during the next year. The ATAGS program was recently approved as a new start Engineering and Manufacturing Development program (6.4) and is expected to become operational in 1997/8.

6. The first nine months of this effort were highly successful. The G-suit modification was fielded and had provided an immediate benefit for female pilots. The gender friendly G-suit sizing scheme was completed and the first prototype suit was fabricated. Centrifuge studies to evaluate female acceleration tolerance are progressing well and evaluations of the COMBAT EDGE system were initiated. Based on the accomplishments of the first nine months of the program, we have every reason to expect a successful conclusion.

FEMALE ACCELERATION TOLERANCE ENHANCEMENT

INTRODUCTION

Women have recently been assigned to high performance fighter aircraft. Currently deployed acceleration protection equipment, anti-G suits and positive-pressure breathing for G protection (PBG), were developed for male flyers. Extensive research and development efforts are needed to ensure that the female aviator is provided with safe and effective G-protective equipment.

A properly fitting anti-G suit has been shown to be critical in providing adequate protection from increased G forces. Departures from optimum fit puts the aviator at increased risk of G-induced Loss of Consciousness (GLOC) resulting from compromised equipment performance and fatigue. A 1992 survey of female pilots revealed that 50% of the sample believed their G-suits were loose in waist and an additional 14% reported discomfort with abdominal bladder inflation. Further, 27% of the females fell below any available G-suit size range for their height and weight.

COMBAT EDGE (COMBined Advanced Technology Enhanced Design G Ensemble) uses pressure breathing during +Gz to increase the pilot's acceleration tolerance. This system applies a high breathing pressure, up to 60 mmHg at 9 +Gz, in the oral-nasal mask. The mask pressure is balanced by a counter-pressure garment covering the chest to allow breathing. This system was found to be highly successful during both centrifuge and field testing. The COMBAT EDGE System was fielded in F-16s during 1992-3 and is being fielded in F-15 in 1995-6. Since the COMBAT EDGE System was only used in fighter aircraft and the development was completed in 1991, the system was sized to fit the male flying population. The pressure balance required between the mask and the counter-pressure garment, the sizing of the counter-pressure garment, the chest area covered by the pressure bladder and the fit of the oral-nasal mask are critical to the proper function to the system. Since COMBAT EDGE improves both safety and performance, it is essential that the system be optimized in terms of fit and function for the female aircrew.

The lack of gender-friendly equipment places female aviators at increased risk and diminishes their ability to fly fight and win. As females are assigned to fighter aircraft in greater numbers, this becomes a significant issue for both women's health and national security.

RESEARCH AND DEVELOPMENT PROGRAMS

Task 1. Male/Female Acceleration Tolerance Comparison/G-Suit Modification Evaluation

BACKGROUND: Previous research to assess the female physiologic response to acceleration has been primarily associated with low G centrifugation (+3 Gz). A notable exception was the study conducted on women's relaxed and straining G-tolerance levels (up to +8 Gz) by Gillingham. This investigation reported no significant difference between men and women in either relaxed or straining G-tolerance during a standard medical evaluation G-profile. However, when the subjects were matched for height, the mean G-tolerance for the females was significantly lower than that of the males. In the Gillingham study, no gender difference was observe for a standard training G profile including a rapid-onset run to +7 Gz for 15 s.

Fisher (1991) conducted a retrospective study to compare the high-G tolerance of men and women. His investigation reported that men had a significantly higher tolerance (time) at the +8 Gz level and a similar, although not significant, trend at +9 Gz. In 1995, Heaps conducted a study evaluating the effect of physical condition and menstrual state on female tolerance to a number of acceleration profiles including a simulated aerial combat maneuver (SACM) acceleration profile. The SACM exposes the subject to alternating acceleration levels (+4.5 Gz for 15s and +7.0 Gz for 15s) with the end point of the profile being subject fatigue. This study included a retrospective evaluation of previous male research subjects exposed to the same profile. In addition to showing no menstrual state effects, the Heaps study showed the time-to-fatigue was not significantly different between male and female subjects.

The Male/Female Tolerance Comparison/G-Suit Modification Evaluation was initiated to evaluate male/female tolerance at higher +Gz levels using a number of acceleration profiles including a SACM profile alternating from +5 Gz for 10s to +9 Gz for 10s. In addition to the gender comparison, the protocol will evaluate the effectiveness of an anti-G suit modification designed to improve fit and performance. To ensure an accurate evaluation of the anti-G suit modification and provide a fair comparison of male/female tolerance, both males and females were fitted with modified CSU-13B/P anti-G suits. In addition, all subjects were paired to ensure that both genders had equivalent centrifuge experience.

RESULTS: Five male and five female subjects have completed the protocol. All five females required the modified G-suit to achieve an optimum fit while the suit modification provided a best fit for two of the male subjects. Mean tolerance time for the SACM profile nearly doubled for the female subjects when they were evaluated using the modified suit (94.7 s with the standard suit vs. 178.9 s with the modified suit). The mean male SACM tolerance time for best fitted suit was 133 s, considerably lower than the female SACM tolerance times.

DISCUSSION: The protocol for this study calls for ten male and ten female subjects; thus, the study is 50% complete. A complete statistical review of the data at this point has not been conducted; however, based on this preliminary review, it does not appear likely that the male tolerance times will exceed the females. On the other hand, the data does strongly indicate that the female tolerances will be significantly improved by the use of the modified suit.

Task 2. CSU-13B/P Anti-G Suit Modification

BACKGROUND: A fit evaluation of the CSU-13B/P anti-G suit showed that the suit did not provide an adequate fit for a large number of female pilots. The suit was generally too large in the waist, and when the female plot was seated in an aircraft cockpit, the suit abdominal bladder tended to ride up over the lower ribs. When the suit was worn in this manner, the inflation of the abdominal bladder compressed the ribs and diaphragm making performance of an adequate anti-G straining maneuver virtually impossible. Centrifuge data from research protocols plus information gathered from two female pilots who were referred to the Armstrong Laboratory for an evaluation of low G-tolerance and improper anti-G suit fit provided adequate background to initiate the development and fielding the gender friendly anti-G suit modification.

TRANSITION: In January 1995, a series of meetings were held with the USAF Life Support Systems Program Office at Kelly AFB, TX. The purpose of these meetings were to explain the anti-G suit modification effort and to develop a plan to conduct field evaluations of the modification. The purposes of the field evaluations were to determine the adequacy of the modification procedures and to ensure that the average USAF Life Support Technician could perform the modification. Field evaluations were conducted at Kelly AFB, TX and Bergstrom AFB, TX. Both evaluations were successfully completed and important input was gained to clarify instructions on how to accomplish the modification.

As an adjunct to the transition process, two female pilots undergoing F-16 training at Luke AFB, AZ were referred to the Armstrong Laboratory, Crew Technology Division, Brooks AFB, TX for low G-tolerance and poor anti-G suit fit. Baseline centrifuge G-tolerance evaluations were conducted with the pilots wearing their anti-G suits as fitted in the field. This evaluation indicated pilots could benefit from the suit modification. One pilot's anti-G suit was modified by lowering the abdominal bladder by 3 in. and a "V" shaped tuck ("dart") was taken at the waist to reduce the circumference. The G-suit for this pilot also required that a fold be taken in the calf area to reduce the circumference. The other pilot required the waist dart and a 2-inch lowering of the abdominal bladder. When G-tolerance evaluations were repeated with the pilots wearing their modified suits, the pilots were able to perform an adequate straining maneuver, both reaching +7 Gz or higher during a rapid onset rate acceleration profile. Based on these successes, a review of the modification procedures and the centrifuge data was conducted by the Human Systems Center, Life Support Systems Program, and the suit modification procedure was given a safe-to-fly certification.

As an additional transition effort, a team of US Navy Life Support Technicians visited Brooks AFB and received training on how to perform the anti-G suit modification. In May 1995, the USAF Life Support Program Office published a Safety Supplement to the CSU-13B/P Technical Order that officially implemented the modification (Appendix A). With the completion of the Navy training and the publication of the USAF Safety Supplement, transition of the gender-friendly anti-G suit modification was completed for all services.

Task 3. Female Sizing Scheme for CSU-13B/P Anti-G Suits

BACKGROUND: Currently all pilots, both male and female, are required to meet the same standards for stature and sitting height, 64-77 in. and 34-40 in., respectively. The aircraft cockpit, ejection seat and the man-mounted life support equipment, including the anti-G suit, are designed to accommodate individuals within these size ranges. Only 40% of U.S. females are taller than 64 in., the height eligibility standard for entry into pilot training in the U.S. Air Force. Air Force aircraft of the future, particularly the F-22 Advanced Tactical Fighter and the JPATS (Joint Primary Aviator Training System), have design requirements that will lower the minimum stature and sitting height requirements and allow a higher percentage of the U.S. female population to compete for pilot positions. The JPATS aircraft design is expected to accommodate a pilot that is approximately 62 in. tall and weighs 95 lbs. (JPATS Case 7). The F-22 design calls for the aircraft to accommodate a pilot that meets the JPATS Case 1 requirement (63 in. tall and approximately 115 lbs). The ATAGS is now projected as a 1997 new start and is expected to meet future size requirements for the small statured pilots; however, as a near term measure, appropriately sized CSU-13B/P suits may be required.

APPROACH: The CSU-13B/P anti-G suit sizing scheme for small statured aircrew was developed in two phases. For the first phase, a sizing study was conducted by the Armstrong Laboratory, Human Engineering Division at Wright-Patterson AFB, OH. This study used a 1988 Survey of Army Women to evaluate the anit- G suit sizing requirements for females smaller than current Air Force Standards. The study provided recommendations for adjustments in anit-G suit leg length and circumference that would allow the CSU-13B/P anti-G suit to be sized for smaller aircrew. The sizing scheme proposed three additional suit sizes to accommodate the smaller female aircrew as defined by JPATS (Appendix B).

The second phase of the CSU-13B/P female sizing effort was conducted by the Armstrong Laboratory, Crew Technology Division, Brooks AFB, TX. The Human Engineering Division analysis was reviewed and compared to an anti-G suit anthropometry analysis that used an older data base (1968 Air Force Women). Information from both data bases were used to establish a two-phase suit sizing scheme. Per the Wright-Patterson analysis, a suit sizing scheme providing three additional sizes was developed to accommodate both JPATS Case 1 and Case 7 sized pilots (Appendix C). To accommodate only the JPATS Case 1 sized pilots, a sizing scheme that used one additional CSU-13B/P suit size was developed (Appendix D).

DISCUSSION: The CSU-13B/P anti-G suit modification effort was highly successful and allowed adjustment of the suit to a wide range of waist and leg circumferences. Thus, the primary concern to design a new suit size became leg length. Females within a stature of 62-65 inches will have an inseam leg length of approximately 25-27 in. The design of the CSU-13B/P anti-G suit with open knee and buttocks areas will allow for a 2-3 in. variation in leg length with no decrement in comfort or safety. The modification for waist/leg circumferences and the allowable leg length range supported the use of a single additional suit size to meet all but the most extreme JPATS size requirements.

Task 4. Prototype Development of Gender-Specific CSU-13B/P Anti-G Suits

METHODS: A prototype CSU-13B/P anti-G suit sized to fit the JPATS pilot was fabricated in the Armstrong Laboratory, Crew Technology Division, Aircrew Life Support Equipment Development Laboratory and was used in a small scale fit study. The prototype suit was given a Laboratory size designation of Extra Small, Short. Three female subjects donned the prototype suit and measurements were taken to determine if the suit provided a proper fit. The subjects' height ranged from 61.75 to 64.5 inches and their weight ranged from 116 to 125 lbs. Measurements to determine suit fit included the distance from the lower rib to the top of the abdominal bladder, the location of the knee relative to the knee hole in the suit and the amount of lacing adjustment required to achieve a proper suit fit. Fit evaluations were conducted with the subjects both standing and seated.

RESULTS: The waist circumferences for the three subjects were nearly identical; however, two of the three subjects required a waist dart to achieve a proper fit for waist circumference. These two subjects had hip circumferences that were more than 10 larger than their waist circumferences. The waist adjustment was the only suit alteration that was required for the subjects to be properly fitted.

DISCUSSION: Based on this small sample, the Extra Small, Short CSU-13B/P anti-G suit appears to have the potential to properly fit the JPATS pilot. The suit will most likely require a minor alteration (V dart) to provide a snugly fitted waist for female pilots who have a hip circumference which is more than 10 inches greater than their waist circumference. Further sizing studies are required to determine the full range of pilots that can be properly fitted in the new suit. The suit was pressure- and leak-tested and is available for centrifuge use. Suit patterns and design specifications will be developed upon completion of the fit and centrifuge testing.

Task 5. Evaluation of the COMBAT EDGE Vest

APPROACH: A centrifuge research protocol to evaluate the comparative performance of males and females using the COMBAT EDGE pressure breathing system for +Gz protection was approved by the USAF Surgeon General's office. This study has two primary objectives: (1) to examine the fit of the COMBAT EDGE vest on female subjects; and (2) to compare the effectiveness of the following equipment configurations to enhance G-tolerance in male and female subjects: (a) modified CSU-13B/P anti-G suit, (b) ATAGS, (c), COMBAT EDGE with the modified CSU-13B/P and (d) ATAGS and COMBAT EDGE. Within the ATAGS and COMBAT EDGE experimental condition, the effectiveness of a custom fit oral-nasal mask will be compared with the standard MBU-20/P COMBAT EDGE mask.

METHODS: Ten male and ten female subjects will be used for the study. The study will be conducted in two phases. In the first phase, the subjects will be fitted with the COMBAT EDGE and ATAGS equipment and are trained in positive pressure breathing (up to 60mmHg breathing pressure) at +1Gz. During the +1 Gz pressure breathing practice, the subjects are monitored for equipment fit, function and comfort. Following the pressure breathing practice, the subjects are exposed to an acceleration regimen consisting of four profiles:

1. Gradual Onset (0.1G/s), subject relaxed, G-protection equipment worn but not pressurized, vision loss end point criteria (100% peripheral vision loss or 50% central vision dim.
2. Gradual Onset, subject relaxed, equipment pressurized, vision loss end-point criteria.
3. Relaxed rapid onset (6.0G/s) series to vision loss criteria, 15s plateaus. Series starting at 1.5-2.0 G less than maximum gradual onset level and increasing at 0.5 G per increment.
4. SACM Profile, subject straining, equipment pressurized. Profile consists of alternating 5.0 - 9.0 G, 10s at each plateau. End-point is subject fatigue or ten +9 Gz peaks.

DISCUSSION: This protocol is a follow-on to the Male/Female Acceleration Tolerance Comparison study; thus, as subjects finish the Male/Female comparison, they start the COMBAT EDGE evaluation. One male subject has completed the COMBAT EDGE protocol, and four female subject are starting centrifuge training. Six female subjects have completed the +1 G positive pressure breathing phase of the study. All wore the small size COMBAT EDGE vest. The vest provided a good fit for two of the female subjects, while the chest and shoulder portions of the vest appeared large for the other four. All six subjects denied any discomfort caused by the vest, and all reported that the vest seemed to provide good breathing support. Several female aerospace physiology officers and flight surgeons have been centrifuge trained using the COMBAT EDGE system. The majority of these students experienced difficulty in achieving a good mask fit; however, all felt that the COMBAT EDGE system provided superior +Gz protection. The students' perception of improved G-protection provides an indication that the vest was functioning as required to support the positive pressure breathing.

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TECHNICAL MANUAL
SAFETY SUPPLEMENT
USE, OPERATION AND MAINTENANCE

ANTI-G CUTAWAY GARMENT

TYPES CSU-13A/P AND CSU-13B/P

(NOMEX)

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15 MAY 1995

1. PURPOSE.

The purpose of this safety supplement is to amend the basic publication.

2. INSTRUCTIONS.

A. Section VI, Alteration of the Garment, Page 6-2A, add Paragraphs 6-12b and 6-12c to read as follows:

b. If the suit can be properly fitted at the hip but the waist remains loose, a vertical dart stitch can be used instead of the "S" shaped tuck procedure described in paragraph 6-12a. The procedures for this alteration are as follow:

(1) Ensure that the suit is properly fitted in accordance with paragraphs 5-3 and 5-4.

(2) If the waist panel laces are taken in all the way (lacer loops are butted up against one another) loosen laces so that they are separated by approximately 1 inch.

NOTE

The vertical dart stitch will originate at the top of the back waist panel and may terminate at either the middle, or at the bottom of the panel. (Figure 6-13 illustrates the dart stitch terminating at the middle of the back waist panel).

(3) The required amount of alteration to the back panel, (Vertical Dart Stitch) shall be accomplished as follows:

(a) Gather any excess material at the top of the back waist panel and mark where the material meets using a non-permanent marker (tailors marker or white chalk).

(b) Determine if there is any excess material at the bottom of the waist panel. If excess material is evident, gather the material at the bottom and mark as per sub-paragraph (a).

(c) If there is no excess material at the bottom of the waist panel, the vertical dart will terminate at the middle of the waist panel (See Figure 6-13).

(4) Remove the center back panel webbing stiffener.

(5) Folding the excess material to the inside, bring both top marks and both bottom marks together.

NOTE

If the remaining back panel stiffeners interfere with such an alteration, the stiffeners may be removed and replaced after the vertical dart stitch has been sewn.

(6) Sew the dart with two rows of stitching, Type 301, 10-12 stitches per inch (thread, MIL-T-43636, Size E or F, Type I or II).

(7) Reattach webbing stiffeners that were removed in accordance with paragraph 6-17.

NOTE

- It may not be possible to replace all three webbing stiffeners after alterating the back panel. A minimum of two back panel webbing stiffeners must be used.
- If top and bottom seam tape were unstitched to remove webbing stiffeners, fold excess material back over itself and resew after attaching webbing stiffeners.

(8) Refit the suit in accordance with paragraphs 5-3 and 5-4.

c. If the top of the abdominal bladder extends over the lower ribs (Paragraph 5-3, WARNING) or if the inflation of the bladder causes discomfort to the lower rib cage, the height of the abdominal bladder can be reduced by the following procedure:

(1) Ensure that the suit is properly fitted in accordance with paragraphs 5-3 and 5-4.

(2) With the aircrew member in a seated position, locate the level of their lowest ribs. Using a tailors chalk, mark in three locations (right, center and left) on the outside of the front abdominal panel the location of the lowest ribs.

CAUTION

Care should be taken to preclude damage to any portion of the bladder system.

(3) Remove the stitching that joins the top of the abdominal bladder case and the front abdominal panel, beginning at the inlet hose and ending one inch before the right bladder tab (See Figure 6-13a). Push the bladder casing out of the way.

(4) Using the markings on the outside of the front abdominal panel as a guide, transfer these markings to the inside of the panel.

NOTE

The minimum distance for this alteration is one inch, and the maximum is two inches. If the markings are less than one (1) inch below the original stitch line that joined the abdominal bladder casing to the front abdominal panel, draw a second set of markings that is at least one (1) inch below the orignal stitch line. If the markings are more than two (2) inches below the original stitch line that joined the abdoninal bladder casing to the front abdominal panel, this alteration can not be used because it requires moving the inlet hose hole. Any aircrew requiring an alteration in excess of two inches is required to contact AL/CFTS, Brooks Air Force Base Tx, DSN 240-3521.

(5) Draw a line, using the markings as a guide, on the inside of the abdominal panel, beginning at the inlet hose hole and ending at the right bladder tab.

(6) Push the bladder down to ensure that the bladder system cannot be damaged. Tack stitch the bladder and casing to the front abdominal panel at the middle bladder tab along the guide line drawn in step (5). Stitch using a Type 301 stitch, 10-12 stitches per inch (thread, MIL-T-43636, Size E of F, Type I or II). This tack stitch is to be used as an alignment aid when resewing the bladder system casing.

(7) Push the bladder down to ensure that the bladder system can not be damaged and sew a double row, using stitch Type 301, 10-12 stitches per inch (thread MIL-T-43636, Size E or F, type I or II) attaching the bladder casing to the front abdominal panel. Use the line drawn in step (5) as a guide. The new stitch line should begin at the inlet hose hole and end at the stitch line 1/2 inch above the right bladder tab.

(8) Three restraining straps will be added to prevent upward movement of the bladder during inflation. The restraining straps will be of Nylon Webbing, Type III, MIL-T-38328, one inch wide by 9 inches long.

(9) Align the webbing straps on the inside of the front abdominal panel so that they are parallel to the webbing stiffeners on the outside of the front abdominal panel. (See Figure 6-13a).

(10) Turn the straps under 3/4 inch at both ends and secure to the inside of the front abdominal panel using a 3/4 inch box and "X" stitch Type 301, 10-12 stitches per inch (thread MIL-T-43636, Size E or F, Type I or II).

(11) The bottom edge of the top box stitch will be horizontally aligned with the top of the back bladder casing. (See Figure 6-13a.)

(12) The top edge of the bottom box stitch will be horizontally aligned with the bottom of the back bladder casing. (See Figure 6-13a.)

(13) The suit must pass a pressure test per paragraph 5-3 following the alteration procedures.

THE END

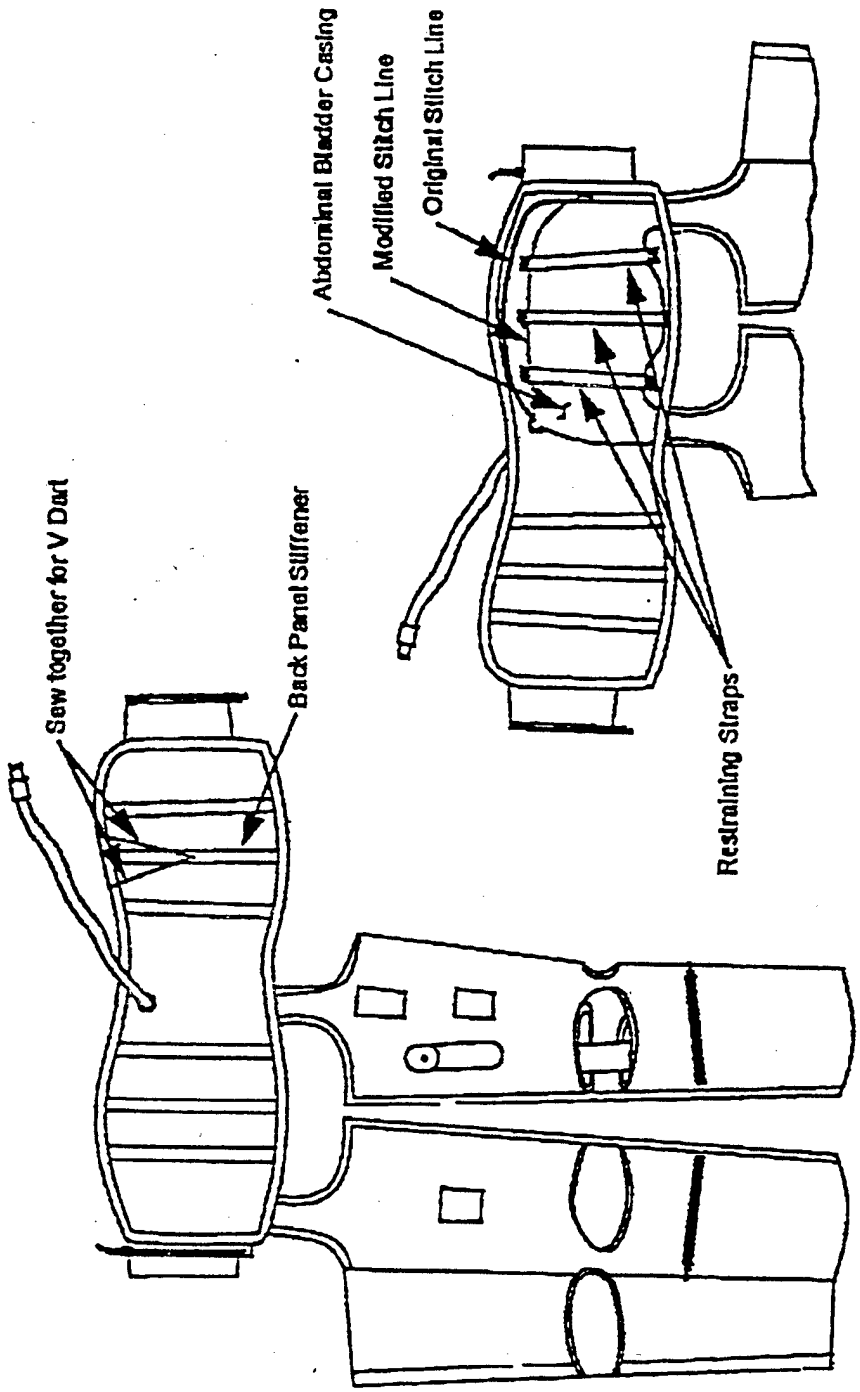

Figure 6-13. Vertcal V-Shaped Dart

Figure 6-13a. Abdominal Bladder Casing

SIZING RECOMMENDATIONS FOR WOMEN'S SIZES FOR THE CSU-13B/P ANTI-G SUIT
3 March 1995
by Kathleen M. Robinette, Sherri Blackwell, and Mary Gross

INTRODUCTION

The approach had the following steps: 1) review previous studies and data for this and the ATAGS suit, as well as the information from the AL modification effort to arrive at a baseline; 2) test the fit of the two sizes women currently use (*small long* and *small regular*) on subjects with selected waist circumference and abdominal height establishing fit cut off points in a size (i.e. the region of good fit), in any areas not clearly defined from the previous studies; 3) compare the fit regions with data on broader populations, including Air Force women samples from 1988-1990, and Army and Navy samples from 1988-89; and 4) integrate this information to estimate the number of sizes and proportioning needed for each new size to effectively fit women. This information would be in the form of changes to existing patterns to create the new sizes. It is anticipated that the patterns only need to be changed in some areas but not others. Initiating changes in this way should make the new patterns cheaper to produce.

Some comparison fit testing of the ATAGS suit sizes 1 and 2 were also added to the second step to enhance our understanding of the fit problems. In other words, some of the nine additional women examined at Wright-Patterson Air Force Base were also examined in the ATAGS suit. Information from researchers at AL/CFB who had conducted centrifuge experiments with females in the CSU-13B/P was also utilized (John Forester and Lloyd Tripp, personal communications).

The recommendation is to add three sizes which are proportioned for women. These three sizes are expressed below as modifications to three existing sizes: the *small regular*, *small long*, and *medium regular* sizes. Of these three sizes, the *small regular* modified size is anticipated to be the most widely needed size. If the program should be limited to producing only one, this one would be the one recommended. It should adequately fit women with hip circumferences 39 inches and below and between 61 and 65 inches in stature. We did not test below 61 inches as this is the smallest stature in the multivariate cases for JPATS and the current minimum stature for pilot training is 64 inches. Approximately 10% of the female population of the United States fall below 61 inches in stature.

One black female who had a stature of 64.8 inches did get a better fit in the size *small long* than in the size *small regular*, even though she would have been given the size *small regular* according to the technical order. A white female with approximately the same stature did not require the extra leg length. Black women tend to have longer legs and shorter torsos than white women on the average; therefore, it is anticipated that the longer leg length of the size *small long* will be needed for many black women as well as other women who are taller than 65 inches, (or approximately the 70th percentile for women.) The size *small long* is essentially the same as the *small regular* except in leg length. The length or height of the abdominal bladder is the same, for example. Therefore, the modification of this size to make it a female proportioned size will be the same as the *small regular* and it will serve as an extra length size. This method of adding a size was demonstrated to be necessary and effective in a previous study of women's sizes (Robinette et. al. 1990).

In this study women were tested up to 39 inches in hip circumference. This appeared to be close to the maximum hip circumference tolerable in the size *small regular*, in other words the subjects near the 39 inch hip level were at the edge of fitting in the small sizes. Previous studies of women in the Wright-Patterson Air Force Base centrifuge with the CSU-13B/P suit indicated that many women require the size *medium regular* (John Forester and Lloyd Tripp, personal communications) to accommodate their larger hips and thighs. A hip circumference of 39 inches is approximately the 65th percentile for women, and it should be expected that approximately 35 % of the population would be better accommodated in a larger size. A plot of the test subjects versus a broader military population as measured in the 1988 Army study (Gordon et. al. 1989) is show in figure 1 below.

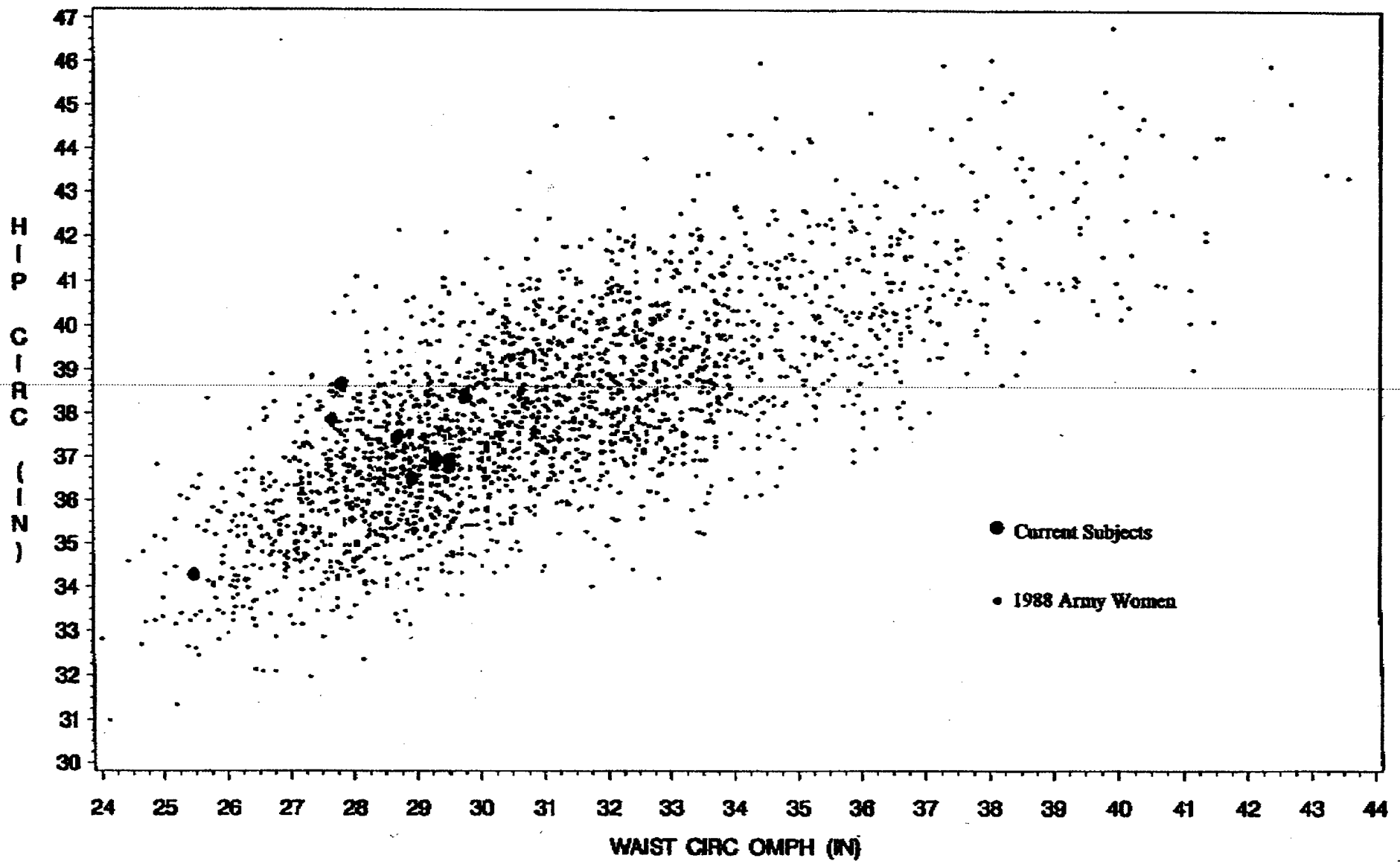

Figure 1. Current test subjects plotted with respect to subjects from the 1988 Survey of Army Women (Gordon et. al. 1989).

This is a plot of the waist circumference at omphalion (navel) versus hip circumference. As can be seen in figure 1, many of the women with hips larger than 39 inches will also have larger waists. Some of these would be able to use a male proportioned size that already exists. Other women who are close the 39 inch area would be able to use a smaller female proportioned size, althought this would not be the ideal solution. However, an estimated 20-25% should be left for which a large size is essential. It is therefore recommended that a female proportioned size *medium regular* be created.

The size *medium regular* has larger circumferences than the size *small regular*, but has approximately the same leg length. It also has an abdominal piece that is 9 1/2 inches long in the front and 10 inches in the back which is 1/2 and 1 inch longer respectively than the size *small regular*. The modifications recommended to this size to create a female proportioned size will be the same as that recommended to the *small regular*. The extra inch in the back piece length may be needed to help fit the larger hip. This new size will add a larger circumference female size to the set, but at the same leg length as the *small regular*. This size should then accommodate the majority of the women between 61 and 65 inches in stature and above 39 inches in hip circumference.

There is one other size which might be considered: a *medium long*. The need for this size is debatable for the following reasons:

1) There will be very few women who are both larger than 39 inches in hip circumference and taller than 65 inches in stature (less than 10% of the population).

2) Of these women, most will be close to the 39 and 65 inch sizes and able to get an acceptable fit in one of the sizes already included.

3) Others will be able to get an acceptable fit in a male proportioned size.

In the end, less than 1 percent of the population may need this size and even that percnetage could probably get another size modified to fit. Therefore, the addition of this size is not recommended at this time. This should be verified with testing of the sizes for women once they are developed.

MODIFICATIONS RECOMMENDED

1) Add a size which is similar to the current size *small regular* with the following exceptions:

a) has a 6 inch abdominal bladder height in the front and a 12 inch abdominal bladder height in the back, with an attachment in the back to the thigh piece much as is currently done in the front. This is equivalent to removing three inches from the current size in the front and adding three inches in the back.

b) has a smaller waist circumference (top of the abdominal piece) by 3 inches. Note the bottom of the abdominal piece should remain the same.

c) has a smaller lower thigh (just above the knee) by 1 inch. Note the upper thigh stays the same.

d) has a smaller calf/lower leg circumference by 1 inch. The entire portion below the knee needs to be reduced in this case.

2) Add a size which is similar to the current size *small long* with the following exceptions:

a) has a 6 inch abdominal bladder height in the front and a 12 inch abdominal bladder height in the back, with an attachment in the back to the thigh piece much as is currently done in the front. This is equivalent to removing three inches from the current size in the front and adding three inches in the back.

b) has a smaller waist circumference (top of the abdominal piece) by 3 inches. Note the bottom of the abdominal piece should remain the same.

c) has a smaller lower thigh (just above the knee) by 1 inch. Note the upper thigh stays the same.

d) has a smaller calf/lower leg circumference by 1 inch. The entire portion below the knee needs to be reduced in this case.

3) Add a size which is similar to the current size *medium regular* with the following exceptions:

a) has a 6-1/2 inch abdominal bladder height in the front and a 13 inch abdominal bladder height in the back, with an attachment in the back to the thigh piece much as is currently done in the front. This is equivalent to removing 3 inches from the current size in the front and adding 3 inches in the back.

b) has a smaller waist circumference (top of the abdominal piece) by 3 inches. Note the bottom of the abdominal piece should remain the same.

c) has a smaller lower thigh (just above the knee) by 1 inch. Note the upper thigh again stays the same.

d) has a smaller calf/lower leg circumference by 1 inch. The entire portion below the knee needs to be reduced in this case.

RATIONALE FOR THE CHANGES

No leg length changes. The leg lengths for the sizes *small regular* and *medium regular* seem to fit a range of female statures from 61 to 65 inches in stature. The size *small long* should fit the taller women without the need for changes.

Bladder height proportioning changes. The biggest problem was with the abdominal bladder. As noted in previous reports, the bladder was situated properly when the subject was standing but slipped upward when she sat down. It was noted that this did not occur with the ATAGS style suit. The shaping of the ATAGS bladder components was examined. From this examination it was determined that the longer back piece attached in back, in conjunction with the shorter front piece, helps to hold the bladder in place. Therefore, this proportioning is recommended for the new CSU-13B/P suit sizes. There is no clear gender related proportioning difference that can be ascribed as the cause for this problem. It is possible that the hip to waist circumference relationship may be a contributing factor which might make this worse for women. However, it is suspected that this is at least one of the accommodation problems for men as well. Previous reports indicate that approximately 30% of the male population do not get a comfortable fit in this region of the suit (Ripley et. al. 1994). We did not test any men and, therefore, can not verify or refute this hypothesis.

Circumference Changes. The remaining problems were with circumferences and are due in part to differences in proportioning between men and women. Previous studies have clearly demonstrated that women have much smaller waists than men, but the same or larger hips and upper thighs. These differences have a large impact on the fit of lower body garments (McConville et. al. 1981, and Robinette 1995). Women also have much smaller lower thighs and calves (Robinette et. al. 1979). Most of the women tested, including the female pilots, had very small hips with respect to the rest of the female military population; yet, they still required the maximum hip and thigh circumferences available in the size *small regular* suit. Similar problems would be anticipated for the similarly proportioned size *medium regular* for the women in the population who have larger hips and thighs.

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DISTRIBUTION OF USAF WOMEN FIT BY THREE NEW CSU-13B/P ANTI-G SUIT SIZES

WEIGHT (LB)

HEIGHT (IN)

	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0	125.0	130.0	135.0	140.0	145.0	150.0	155.0	160.0	165.0	170.0	175.0	180.0	185.0	190.0	195.0	200.0	TOTAL
72.0																			1						1
71.5																									
71.0								1				1													2
70.5									1	1	1		1		2	1									7
70.0								1					2			1		1							5
69.5									2		1	1	5	1	1			1						1	13
69.0									1		2	3	1		1										8
68.5						1	1			3	7	3	4	1	1	1	2	1	1						26
68.0						1	1	1	4	2	6	1	6	4	2	2	1	1		1					33
67.5						1	1	4	3	7	8	5	4	3	6	3	2	1			2		1		51
67.0						2	1	3	8	6	3	11	10	8	4	4	2	2			1				65
66.5					1	1	6	9	6	10	11	14	12	10	2	2			1	2					87
66.0					2	2	6	4	16	16	12	13	10	14	5	5	1		2			1			109
65.5				1	4	4	7	16	13	17	19	12	13	7	4	1	4	2	1		1				126
65.0					1	2	9	13	13	27	17	15	12	6	5	1	1				1				123
64.5				2	3	11	11	12	20	19	19	9	17	7	6	2	1		1		1	1		1	143
64.0				1	7	10	18	21	24	29	15	13	10	4	2	2		1			1				158
63.5				4	8	9	20	28	25	19	13	9	7	1	2	1	1	1							148
63.0			2	5	7	20	23	30	22	19	12	8	2	1	2	1	1						1		156
62.5			1	3	13	11	20	16	22	17	10	4	1	2		2	1	1							124
62.0			2	6	10	18	20	21	21	11	8	5	3		4			1							130
61.5		2	6	5	16	9	19	11	17	10	8	9	1												113
61.0			3	10	14	20	17	13	5	7	5	3		2		1									100
60.5	1	1	1	7	9	7	8	7	8	3	1	2													55
60.0			2	3	6	13	9	8	4	3	2			1				1							52
59.5			2	10	8	6	5	2	4	4	1														42
59.0		1	1	1	1	1	4		2																11
58.5			1	1	2	1	1					1	1												8
58.0			1		1	2	2			1															7
57.5				1																					1
57.0				1																					1
TOTAL	1	4	22	61	113	152	209	221	241	231	181	142	122	72	49	30	17	14	7	3	7	2	2	2	1905

NEW SUIT SIZES

CURRENT SUIT SIZES

AFI 40-502 MAXIMUM ALLOWABLE WEIGHT

DISTRIBUTION OF USAF WOMEN FIT BY ONE NEW CSU-13B/P ANTI-G SUIT SIZE

WEIGHT (LB)

HEIGHT (IN)

	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0	125.0	130.0	135.0	140.0	145.0	150.0	155.0	160.0	165.0	170.0	175.0	180.0	185.0	190.0	195.0	200.0	TOTAL
72.0																			1						1
71.5																									
71.0								1				1													2
70.5									1	1	1		1		2	1									7
70.0								1					2			1		1							5
69.5									2		1	1	5	1	1			1						1	13
69.0									1		2	3	1		1										8
68.5						1	1			3	7	3	4	1	1	1	2	1	1						26
68.0						1	1	1	4	2	6	1	6	4	2	2	1	1		1					33
67.5						1	1	4	3	7	8	5	4	3	6	3	2	1			2		1		51
67.0						2	1	3	8	6	3	11	10	8	4	4	2	2			1				65
66.5					1	1	6	9	6	10	11	14	12	10	2	2			1	2					87
66.0					2	2	6	4	16	16	12	13	10	14	5	5	1		2			1			109
65.5				1	4	4	7	16	13	17	19	12	13	7	4	1	4	2	1		1				126
65.0					1	2	9	13	13	27	17	15	12	5	5	1	1				1				123
64.5				2	3	11	11	12	20	19	19	9	17	7	6	2	1		1		1	1		1	143
64.0				1	7	10	18	21	24	29	15	13	10	4	2	2		1			1				158
63.5				4	8	9	20	28	25	19	13	9	7	1	2	1	1	1							148
63.0			2	5	7	20	23	30	22	19	12	8	2	1	2	1	1						1		156
62.5			1	3	13	11	20	16	22	17	10	4	1	2		2	1	1							124
62.0			2	6	10	18	20	21	21	11	8	5	3		4			1							130
61.5		2	6	5	16	9	19	11	17	10	8	9	1												113
61.0			3	10	14	20	17	13	5	7	5	3		2		1									100
60.5	1	1	1	7	9	7	8	7	8	3	1	2													55
60.0			2	3	6	13	9	8	4	3	2			1				1							52
59.5			2	10	8	6	5	2	4	4	1														42
59.0		1	1	1	1	1	4		2																11
58.5			1	1	2	1	1					1	1												8
58.0			1		1	2	2			1															7
57.5				1																					1
57.0				1																					1
TOTAL	1	4	22	61	113	152	209	221	241	231	181	142	122	72	49	30	17	14	7	3	7	2	2	2	1905

NEW SUIT SIZE

CURRENT SUIT SIZES

AFI 40-502 MAXIMUM ALLOWABLE WEIGHT