SANDIA REPORT

SAND2013-6940
Unlimited Release
Printed August 2013

Analysis to Determine the Maximum Dimensions of Flexible Apertures in Sensored Security Netting Products

Mark Murton, Frank Bouchier, Dale T. vanDongen, Thomas K. Mack, Robert P. Cutler, and Michael P. Ross

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2013-6940
Unlimited Release
Printed August 2013

Analysis to Determine the Maximum Dimensions of Flexible Apertures in Sensored Security Netting Products

Mark Murton, Frank Bouchier, Dale T. vanDongen, Thomas K. Mack, Robert P. Cutler, and Michael P. Ross

DoD Security Systems Engineering, DoD Security System Design and Engineering, Robotic and Security Systems, Active Response & Denial, Security Systems Design & Evaluation
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185

Abstract

Although technological advances provide new capabilities to increase the robustness of security systems, they also potentially introduce new vulnerabilities. New capability sometimes requires new performance requirements. This paper outlines an approach to establishing a key performance requirement for an emerging intrusion detection sensor: the sensored net. Throughout the security industry, the commonly adopted standard for maximum opening size through barriers is a requirement based on square inches—typically 96 square inches. Unlike standard rigid opening, the dimensions of a flexible aperture are not fixed, but variable and conformable. It is demonstrably simple for a human intruder to move through a 96-square-inch opening that is conformable to the human body. The longstanding 96-square-inch requirement itself, though firmly embedded in policy and best practice, lacks a documented empirical basis. This analysis concluded that the traditional 96-square-inch standard for openings is insufficient for flexible openings that are conformable to the human body. Instead, a circumference standard is recommended for these newer types of sensored barriers. The recommended maximum circumference for a flexible opening should be no more than 26 inches, as measured on the inside of the netting material.

CONTENTS

FIGURES

TABLES

NOMENCLATURE

DBT	Design Basis Threat
DCID	Director of Central Intelligence Directive
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
FAR	False Alarm Rate
IDS	Intrusion Detection System
ISO	International Standards Organization
NAR	Nuisance Alarm Rate
NISPOM	National Industrial Security Program Operating Manual
NSRDEC	Natick Soldier Research, Development and Engineering Center
SCIF	Sensitive Compartmented Information Facilities
SD	Standard Deviation
SNL	Sandia National Laboratories
SNM	Special Nuclear Materials
USAF	US Air Force
USMC	US Marine Corps
WAF	US Womens Air Force
XSDS	Expeditionary Swimmer Defense System

1. INTRODUCTION

1.1 Background

The analysis discussed in this report is conducted in support of developing a requirements definition for a sensored flexible barrier technology, such as a net technology. A sensored net could have an application as a component of an intrusion detection system (IDS), either in land or water environments. Figure 1 illustrates the sensored net concept. Various physical security policies and best practices prescribe the maximum allowable size of an unsensored aperture or opening within an IDS. This is usually described in terms of maximum square inches and typically assumes rigid dimensions. The development of sensored flexible netting as a potential IDS concept necessitates reviewing the basic requirement and describing it in terms that include flexible netting applications.

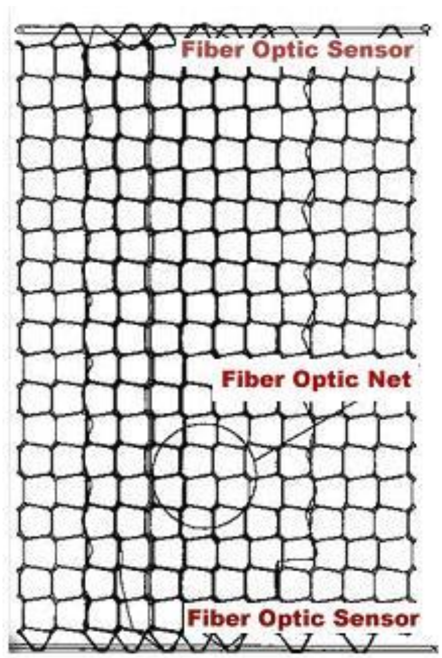


Figure 1. Sensored Net Concept Using Disturbance of Optical Light Paths as the Sensor Mechanism.

2. ANALYSIS

2.1 Analysis Issue

The purpose of this analysis is to determine the maximum dimensions of a sensored conformable opening such that it precludes undetected penetration by a human. The scope of this analysis includes the following:

- Determination of the maximum spacing requirements for openings through the barrier
- Operational testing of the analyzed maximum dimensions
- Identification of other requirements, as appropriate

2.2 Bottom Line

1. This analysis concludes that the traditional 96-square-inch standard for openings is insufficient for flexible openings that are conformable to the human body. Instead, a circumference standard is recommended for these newer types of sensored barriers.
2. The recommended maximum circumference for a flexible opening should be no more than 26 inches, as measured on the inside of the netting material. This is based on statistical analysis of a large US military population sample, with smaller sub-samples that may emulate smaller-framed populations around the world.
3. Recommendations are provided for testing, risk mitigation options, and further research.

2.3 Assumptions and Constraints

2.3.1 Assumptions

1. Intruders can employ small-framed adults, but not small children.
2. One or more insiders have knowledge of the existence of the net sensor.
3. The net sensor will be used in outside environments that are subject to the elements (e.g., water, wind, and wildlife) and require close to zero nuisance alarm rates. Thus, the net will not employ touch, close-proximity, and deformation types of sensors.

2.3.2 Constraints

1. Available anthropometric literature was limited to a few prior surveys.
2. Analysis team did not have time to collect new sets of information on global populations.

2.4 Performance Criteria

The general requirement for intrusion detection sensors across all high-value asset security applications is to achieve a high probability of sensing unauthorized intrusion by humans into a restricted area, along with a low nuisance alarm rate (NAR) and false alarm rate (FAR). To minimize the NAR/FAR for flexible mesh netting, the sensor capability is limited to the actual cutting of the mesh, or extending the mesh to the point where the sensor breaks. Assessment of alarms is beyond the system scope of the sensor net, which performs only the sensing function. However, such a product with zero NAR characteristics can be utilized in underwater applications to provide information to an assessment operator when imaging devices cannot be employed.

2.5 Evaluation Method

The approach to determining the maximum netting opening requirement was as follows:

1. Identify the most relevant body measurements.
2. Sample the human population to determine a range of critical physical characteristics.
3. Determine the largest parameter of that sample (e.g., chest circumference or hip circumference).
4. Define the feasible penetration techniques.
5. Identify the optimal metric to evaluate the effectiveness of a design to defeat feasible penetration techniques by the defined range of threat body proportions.
6. Using that metric, calculate the maximum recommended netting opening.

2.6 The 96-Square-Inch Opening Guideline

There is a longstanding requirement in physical security policy to sensor any opening through a security perimeter that is larger than 96 square inches. For any opening having an inner cross-section larger than 96 square inches and a smallest dimension greater than 6.4 inches, the opening must be protected against entry by installing bars, wire mesh, or other permanent metal barriers that leave no opening greater than 6.4 inches on its shortest side and no opening with an area greater than 96 square inches. References to the 96-square-inch opening standard date back to at least 1960. Examples include:

- *Director of Central Intelligence Directive (DCID) 6/9* is the Manual of Physical Security Standards for Sensitive Compartmented Information Facilities (SCIF) adopted by the Department of Defense (DoD). Section 3.3.4 of this document references the 96-square-inch requirement in regard to physical protection of vents, ducts, and pipes.
- *Department of Homeland Security (DHS) Management Directives System MD# 11030.1* is the Manual of Physical Protection of Facilities and Real Property adopted by DHS. Section VI.A.2 references a 100-square-inch requirement for single openings through perimeter walls.
- *DoD Directive 5210.63* is the directive for Security of Nuclear Reactors and Special Nuclear Materials (SNM). In Enclosure 2, definition E2.1.16.2 references 96 square inches as the maximum allowable opening without protective measures for SNM Vaults.
- *National Industrial Security Program Operating Manual (NISPOM) - Miscellaneous Openings.* This manual states that where ducts, pipes, registers, sewers, and tunnels are of such size and shape as to permit unauthorized entry (in excess of 96 square inches in area and over 6 inches in its smallest dimension), they shall be secured by 18-gauge expanded metal or wire mesh or by rigid metal bars ½ inch in diameter extending across their width, with a maximum space of 6 inches between bars. Rigid metal bars shall be securely fastened at both ends to preclude removal and shall have crossbars to prevent spreading. When wire mesh, expanded metal, or rigid metal bars are used, they must ensure that classified material cannot be removed through the openings with the aid of any type instrument. Expanded metal, wire mesh, or rigid metal bars are not required if an IDS is used as supplemental protection.

The original source and rationale of the 96-square-inch standard could not be found in available documentation. This standard does account for the fact that rectangles of the same circumference but different dimensions could have significantly different areas. A 10-inch by 10-inch square, for example, has a circumference of 40 inches and an area of 100 square inches. However, a 5-inch by 15-inch rectangle has the same circumference, but an area of 75 square inches.

This standard must be applied with consideration not only for the size of the opening, but the depth of the passage through the barrier. Tests have shown that it is easier to pass through a small opening in a thin barrier, such as a piece of plywood, than through a deeper barrier, such as a thick wall or a long section of pipe or ducting. In one test, a subject was able to crawl through a 12-inch by 12-inch by 20-foot-long duct. There are unconfirmed news reports of a prisoner escaping through a 10-inch by 10-inch vent cover. The key feature of rigid openings is that a human intruder cannot make use of all the available area while trying to squeeze through.

Although maximum area is a better metric than dimensions of openings for rigid barriers, it is inadequate for barriers with conformable openings. Unlike a rigid opening, a flexible opening can conform to the body of an intruder, allowing him to make full use of all the interior area of the opening. While a 96-square-inch square has dimensions of 9.797 inches, a circle with the same area has a diameter of 11.06 inches.[1] When such a barrier is shallow, the intruder can maneuver his body laterally on either side of the barrier to increase his ability to slip through an opening. A 96-square-inch circle has a circumference of 34.73 inches. If a significant portion of the human population has a maximum body circumference that is less than 34.73 inches, then the 96-square-inch standard is insufficient. More importantly, to preclude designers of flexible netting barriers of variable degrees of rigidity from falling back on either the dimensions metric or the area metric, a new metric should be established: circumference. As will be seen below, a portion of the human populace does, in fact, have a maximum body circumference that is significantly less than 35 inches.

The field of anthropometry[2] sets standards for the systematic measurement of body proportions. Anthropometry generally supports requirements development for clothing, furniture, or other things with which the human body interacts on a *cooperative* basis. There is no single anthropometric standard of the irreducible minimum dimension of a human body that is attempting to pass through a conformable opening.

Two conclusions result from this: first, the best metric for a barrier with conformable openings is the circumference of the opening; second, given the probable shallowness of the barrier, accurate determination of the maximum allowable circumference is essential. ―Circumference" must be defined—e.g., it must define the perimeter around the usable area, allowing for the thickness of the netting fabric and any bracing devices at the joints of intersecting net segments. It is the actual circumference of the aperture or opening or hole made by the netting strands.

There are factors in addition to a strict circumference that must be considered in evaluating a sensored net. For example, a flexible net is typically made of thin, easily cut material. If every strand is not sensored against cutting and if every horizontal/vertical juncture is not sensored against stretching, then the barrier can be defeated by cutting unsensored segments or stretching

---

[1] Area of a Circle (A); $A = \pi r^2$; circumference of a circle, $C = 2\pi r, or\ \pi * d$

[2] Anthropometry: body measurement research; the study of human body measurements.

the netting aperture. Conversely, design features that reduce the actual usable circumference or area can be considered, such as netting segments that are under tension or braces that prevent stretching. Performance testing of designs can verify their effectiveness.

2.7 Determining the Threat Basis

2.7.1 Intrusion Tactic

The largest parts of the body are the chest and hips. An individual seeking to pass through a constricted opening would seek to minimize his size, especially around the chest and hip area, whichever is larger. It would be difficult to contort the body enough to appreciably change the breadth of the hips. The buttocks, on the other hand, are conformable. The postulated technique below outlines how an intruder might attempt this for the chest area.

1. Increase the size of the opening, if it is possible to do so without triggering an alarm. Possible techniques to accomplish this might be to slide apart the devices that brace the junctures of netting segments. Alternatively, the netting fabric, if significantly thick, might be shaved back to just short of the woven sensor to reduce the inner thickness and increase the available area.

   NOTE: There would be significant adversary risk entailed in this later technique.

2. Slide one arm through the opening and rotate the other arm so that the maximum circumference of the body required to pass through is little more than the maximum circumference of the chest itself.
3. Pull through the remainder of the body.

2.7.2 Performance Testing

The team was limited in its ability to do live tests; nevertheless, the following photos illustrate the key intrusion techniques and measurements outlined in this analysis.

The first test evaluated a prototype sensored net designed to a requirement for openings no larger than the 96-square-inch standard. The actual test article had an aperture with a circumference of about 35.75 inches and an area about 90 square inches. The thickness of the netting cable and nodes binding the cables together is not part of the aperture, but forms the boundary of the aperture. The test objective was to evaluate whether the traditional 96-square-inch standard was appropriate in this application. In a performance test of the prototype netting, conducted at Sandia National Laboratories, the subject was able to push through the netting in less than 30 seconds[3] without cutting the mesh. Figure 2 illustrates the test.

[3] Test conducted on 21 Nov 2011 at SNL Exterior Sensor Testbed. Principal Investigator was Tom Mack, tkmack@sandia.gov.

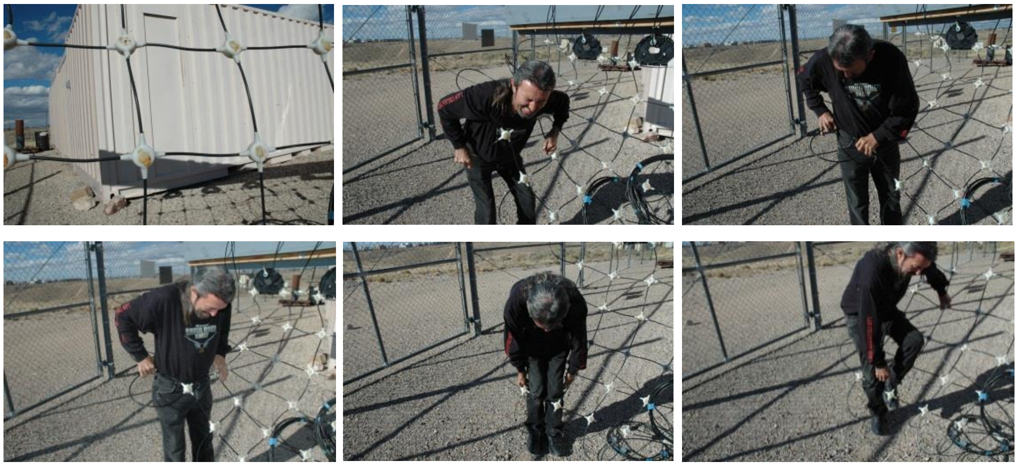


Figure 2. Defeat of a 90-Square-Inch Conformable Square Opening.

A second test was conducted using an opening defined primarily by its circumference. The test article was a 27-inch length of rope that was ¼-inch in diameter. The actual inner circumference was thus 26.5 inches with a usable area of 55.883 square inches. The photos below show the difficulty of attempting to defeat this barrier. In this test, the subject was unable to get either his upper torso or his hips through the opening. To penetrate a sensored mesh with such small openings, cutting of the mesh would be necessary, which could activate the sensors embedded within.

Figure 3. Penetration Attempt Objective System.

2.7.2.1 Additional Testing Recommendations

With any sensored netting system, there are additional areas of concern beyond the configuration of the netting openings. First among these would be the connections between the netting and its support structure. Figure 4 shows an example of net application. These connections must also conform to the specified circumference requirement and be designed in such a way that they cannot be slid, stretched, or bypassed without triggering the sensor.

Figure 4. Netting Support Structure Connections.

A second focus of design evaluation should be the connectors between netting strands that limit the size of the netting opening (Figure 5). If these can be slid on either axis, effectively enlarging the aperture without causing alarm or otherwise defeated, this would constitute a vulnerability.

A third prototype testing objective should be to determine how much the netting sensor can be stretched without triggering an alarm (Figure 6). Again, any significant stretching to achieve a larger circumference that does not trigger an alarm could be a vulnerability. One recommended method to test this would be to use a solid sphere (or a cylinder lengthwise) of known solid circumference and push it through the netting opening. This would subject the length of the sensor to pressure of roughly equal force and provide a good conservative estimate of susceptibility to stretching. Where environmental conditions such as temperature or water conditions might impact performance, testing should be done under realistic conditions.

Figure 5. Netting Connectors.

Figure 6. Stretching a Netting Sensor.

2.7.3 Threat Physical Characteristics

2.7.3.1 Anthropometric Data

The intent of the traditional 96-square-inch standard is to prevent undetected intrusion into a secure area by a person. But what size person is being addressed? Human proportions vary widely.

To establish the range of proportions of a human intruder, available anthropometric surveys were reviewed. The US Army Natick Soldier Research, Development and Engineering Center (NSRDEC[4]) maintains a large database of anthropometric data for American military personnel. The US Marine Corps (USMC) has adapted this large population to USMC populations with essentially equivalent results. Reference [1] contains the results of several anthropometric surveys that measured 203 specific body characteristics of US military personnel (men and women) primarily from World War II to 1988. In aggregate, over 73,000 personnel were measured across all surveys.

There are some important limitations to the data available for this analysis.

- First, DOD-HDBK-743A [1] data is limited to US military personnel and should not be considered particularly representative of the global human population. There is increasing international cooperation in the field of anthropometry, notably the establishment of a common standard by the International Standards Organization (ISO), in ISO 15535:2006, *General requirements for establishing anthropometric databases* [2]. There is an effort to establish an international database, the World Engineering Anthropometry Resource.[5] In the absence of a larger data sample, the team elected to approximate the data of other populations with smaller dimensions, such as East Asians, and by using the data for female population samples in DOD-HDBK-743A [1].
- Second, it should be noted that the normal purpose of anthropometric data is to support ergonomic engineering of clothing, furniture, tools, and equipment. Human proportions are measured as they normally are, not how they might be conformed to squeeze through an opening. The human skeletal structure is less conformable. There are some anthropometric measurements that can approximate this, but—as seen in the comments in Table 1 below—most of these contain a conformable component (i.e., the hip or buttocks circumference measurement).
- Third, the minimum circumference values provided in the report may represent an additional degree of conservatism since people have been growing taller and heavier since 1988. There is evidence that this trend may apply to Asian countries as well, though it has been most widely evaluated in the US. For example, Air Midwest Flight 5481 crashed in 2003 because it was overloaded and out of balance, due to the use of outdated passenger weight estimates. All 19 passengers and two pilots on board died in the crash. Afterward, it was determined the actual weight of an average passenger was more than 20 pounds greater than estimated at the time of the flight.[6]

---

[4] http://nsrdec.natick.army.mil/ANSURII/

[5] http://wear.io.tudelft.nl/publications

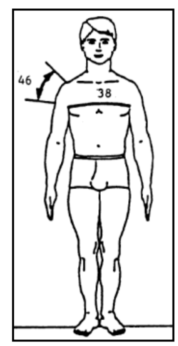
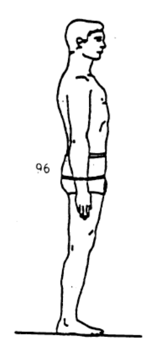
[6] http://en.wikipedia.org/wiki/Air_Midwest_Flight_5481 and http://www.care2.com/causes/getting-bigger-all-the-time-why-humans-are-taller-and-healthier-than-ever.html

2.7.3.2 Anthropometric Measurements

Given the intrusion tactic discussed above, shoulder width was ruled out as a suitable metric. Chest circumference is closer to an irreducible minimum, but the data is less informative for female subjects, given the specification of the measurement. On the other hand, chest circumference below the bust may be less a limiting factor than hip circumference. But here again, while hip breadth might be irreducible, hip circumference also includes the highly conformable buttocks.

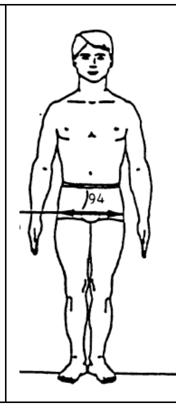
Of the 203 anthropometric dimensions cataloged in DOD-HDBK-743A [1], two measurements were chosen as they included the largest and least conformable aspects of the human body. Due to the conformable, flexible nature of a sensored net barrier, the anthropometric measures chosen for evaluation were chest or bust circumference and hip or buttocks circumference. Chest circumference statistics are included for information. These measurements are listed in Table 1 below, as they are numerically listed in DOD-HDBK-743A [1].

Table 1. Relevant Anthropometric Measurements.

38. Chest/Bust Circumference — the circumference of the torso measured at the level of the nipples. *COMMENT: the comment for measurement #96 below applies here, especially for females.*	
42. Chest Circumference below Bust — the circumference of the torso measured below the cups of the bra. *COMMENT: this measurement seemed to be the least conformable measurement.*	
96. Hip (Buttock) Circumference, Standing — the circumference of the hips, at the level of the maximum posterior protrusion of the buttocks, measured with the subject standing. *COMMENT: this circumference for a standing person will vary for a horizontal person. Additionally, the buttocks are highly conformable. This measurement does not completely address the threat tactic.*	

94. Hip Breadth, Standing — the maximum breadth across the hips, measured with the subject standing.

COMMENT: this is a largely non-conformable physical proportion. Using this metric, however, requires extrapolation to derive a credible circumference estimate.



2.7.4 Chest/Bust Circumference

The team chose the sample that had the smallest mean chest/bust circumference (All Female Series, #12–16). The reason for this conservative approach derives from the fact that the requirement is to stop a single individual. The Design Basis Threat (DBT) might include several individuals, but speculation about how many would have to penetrate the netting undetected to perform follow-on tasks inside the restricted area is site-specific and cannot be generalized. While it might be difficult to assemble a team of small adversaries, the ability to find at least one individual that can support follow-on tasks inside the restricted area is a reasonable threat assumption.

Relevant data samples from DOD MIL-HDBK 743A for this analysis included the following:

- Sample #12, US Army Women (1988); sample size (n) = 2208
- Sample #13, US Army Women (1977); n = 1331
- Sample #14, US Air Force (USAF) Women (1968); n = 1905
- Sample #15, Women in the Air Force (WAF) (US) Trainees (1952); n = 834
- Sample #16, US Army Women (1946); n = 8118

Additional data were analyzed for Vietnamese military personnel (Table 2). These were primarily South Vietnamese, but some critical measurements were made of men from North Vietnam [3]. The sample size included only military men (column A). The weighted average mean chest circumference (column B) among these personnel was 81.09 cm with a range of means from 80.6 cm to 81.1 cm. Differences between military personnel by region were minor; the mean chest circumference of North Vietnamese men was 80.0 cm, while that of personnel from the South was 81.2 cm. One limitation of this sample, of course, is that it did not include Vietnamese females.

Table 2. Anthropometric Survey, Vietnamese Military Population.

	A	B	C	D	E
	N	Mean	S.D.	-3σ (cm)	-3σ (in)
Army	1225	81.1	4.2	68.5	26.97
Navy	299	80.6	4.2	68	26.77
Marine	301	81.6	4.2	69	27.17
Air Force	302	81	4.7	66.9	26.34
Totals	2127	81.09	4.28	68.25	26.87

NOTE: Green and red shading indicate the high and low end of each range for each column. The highest standard deviation is highlighted in red. Column E indicates standard deviation (SD or sigma σ).

Table 3 reflects that American military women, in aggregate, had a 27% smaller chest circumference than the male series. That relationship might not hold for ethnic Vietnamese, however. Moreover, surveys of other Asian populations, while not directly comparable (as they did not measure chest circumference) showed, for example, only a 7–9% difference in chest breadth between males and females in a survey of Taiwanese, Chinese, and Japanese populations. These had a large sample size of around 11,000 each. [4]

- Sample #17, Vietnam military service males (1964); n = 2127
- Data from all sixteen population series in DOD-HDBK-743A, plus the Vietnam military sample (17), were examined to see if a larger sample size would yield significantly different results. These samples combined to a total of 68,157 individuals. The weighted average mean chest/bust circumference of these 16 population series were calculated both separately for the male and female population series, and for the combined series as a whole. The results in Table 3. reveal a range of variation among the means of these various populations of 9% or about three inches. This validated the choice of population series #15 from DOD-HDBK-743A as balancing the need for a conservative approach with the need to be representative.

Table 3. Chest/Bust Mean Circumference.

Chest/Bust Circumference					
DOD-HDBK-743A, Table 38a	Pop. (n)	Mean (cm)	-2σ (inches)	-3σ (inches)	SD
USAF WAF Trainees (Series 15)	850	85.59	29.64	27.61	5.15
All Male Series (1-11)	53,748	93.98	32.10	29.64	6.23
All Female Series + Viet Military (12-16)	14,409	88.01	29.13	26.38	7.01
All Male and Female Series (1-17)	68,157	92.93	31.55	29.03	6.40
Vietnam military service males (Series 17)	2,127	81.09	28.55	26.87	4.28

The mean chest/bust circumference of this sample was 88.01 cm, with an SD of 7.01. Values at three standard deviations from the mean are included to capture 99.73% of the population. For this sample, this yielded a minimum chest circumference of 26.38 inches. Because the chest/bust measurement contains a conformable element, this measurement was not considered definitive for security application.

2.7.5 Chest Circumference below Bust

The chest circumference measurement obviously contains a conformable component, the bust. To get around this, another metric was selected, Chest Circumference Below Bust (

). The sample size is smaller for these measurements (16,184).

Table 4. Chest Circumference below Bust.

Chest Circumference below Bust						
DOD-HDBK-743A, Table 42a	**Pop. (n)**	**Mean (cm)**	**-2σ (inches)**	**-3σ (inches)**	**SD**
USAF WAF Trainees (Series 15)	850	75.11	25.88	24.03	4.69
All Male Series (1)	1,774	92.61	31.31	28.74	6.54
All Female Series (12-16)	14,410	76.50	26.06	24.02	5.16
All Male & Female Series (1, 12-16)	16,184	78.27	25.99	23.57	6.13

The smallest measurement from this sample is the All Male and Female series (1, 12-16), which yields a minimum circumference of 23.57 inches at 3σ. The SD is fairly high for this sample, indicating the data is spread farther from the mean. This measurement was 2.81 inches smaller than the chest circumference for the same sample in Table 3.

2.7.6 Hip/Buttock Circumference

Normally, hip circumference is larger than chest circumference, which is reflected in **Error! eference source not found.**. For female samples, the hips/buttocks were 7.41 inches larger in circumference than the chest below bust. For the single male population sample (#1), the difference was 2.27 inches. Recall that we are not including US military female data only to model female intruders as such, but to approximate somewhat smaller-proportioned intruders from other populations around the world, in the absence of data.

Table 5. Hip/Buttock Circumference.

Hip/Buttock Circumference					
DOD-HDBK-743A, Table 96a	**Pop. (n)**	**Mean (cm)**	**-2σ (inches)**	**-3σ (inches)**	**SD**
USAF WAF Trainees (Series 15)	850	93.73	31.86	29.34	6.40
All Male Series (1-11)	53,748	94.23	32.48	30.16	5.87
All Female Series (12-16)	14,409	95.32	32.44	29.89	6.47
All Male & Female Series (1-16)	68,157	94.46	32.46	30.10	6.00

3. TOWARD A WORKABLE PERFORMANCE REQUIREMENT

For currently available population samples, the hip/buttock circumference is the largest dimension. The most important question with respect to this measurement is how much of this nominal circumference measurement is conformable? Clearly the buttocks are and, moreover, the measurement taken of a standing subject yields the maximum circumference for this measurement. Through a thin barrier, the hip/buttock circumference could be squeezed to a value significantly less than the anthropometric measurement, but how much less? In one limited scope performance test at Sandia,[7] a person was able to squeeze through an opening that was three inches less than the subject's nominal hip/buttock circumference.

Commercial manufacturers of hip-supported backpacks offer some limited insights into what size aperture is required to prevent unwanted slippage (Figure 7 and

Figure 8). A survey of three manufacturers, Arc'teryx, Ultralight Adventure Equipment, and Osprey show a sizing requirement of 26–30 inches maximum circumference for the extra-small sizes. Two of the three manufacturers specified a less than 28-inch circumference. This is 1–3 inches less than the smallest hip/buttock circumference measurement in Table 5 and in accordance with the variation seen in the limited test mentioned above.

Figure 7. Arc'teryx Hip-Belt Pack Sizing Guide.[8]

---

[7] Demonstration performed in February 2012. Principal Investigator was Michael Ross, mpross@sandia.gov.

[8] http://www.arcteryx.com/pack-fit.aspx?EN; http://www.ula-equipment.com/circuit.asp; http://www.ospreypacks.com/en/web/sizing_and_fitting

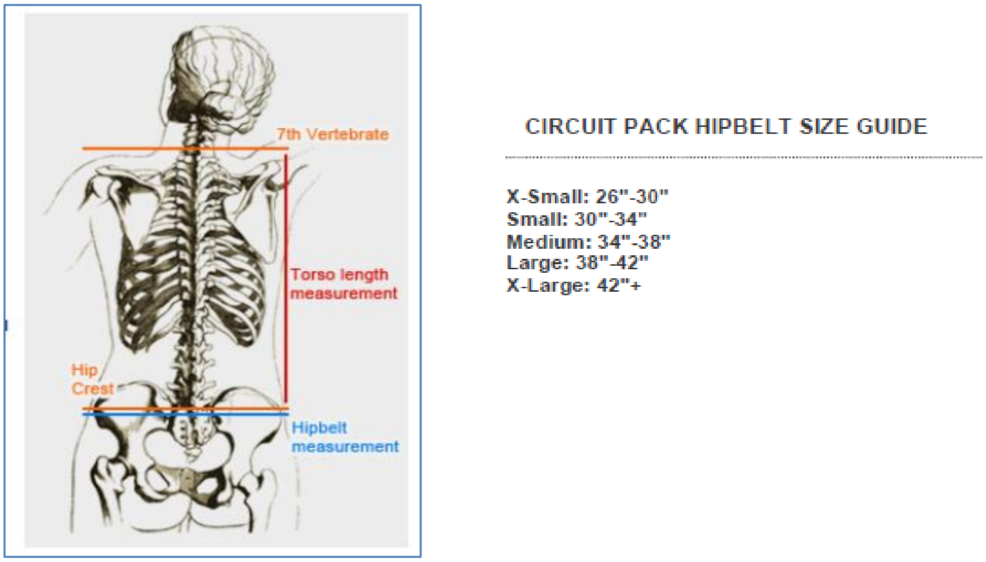


Figure 8. Ultralight Adventure Equipment Hip-Pack Sizing Guide.

3.1 Recommended Requirement

Based on the population survey outlined above, the following requirement is recommended:

REQUIREMENT: Sensored flexible netting must not permit an opening of more than **26 inches/66 cm** in circumference before alarming. This includes not only the netting itself, but its connections to upper/lower and left/right support structures.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Summary

New technology can open up new territory for performance and for attendant requirements. The emergence of flexible sensored barrier technology pushes performance and vulnerability into an area where the 40-year-old 96-square-inch standard does not apply. This analysis advocates a new standard for these types of sensors stated in terms of circumference rather than area.

To determine what that circumference should be, the problem was bounded by using available anthropometric data. In analyzing this data, several considerations argued for a conservative estimate.

1. This is the best data currently available, but it is not a perfect fit for actions involving a deliberate attempt to minimize body dimensions to defeat a sensor. Anthropometric measurements are not taken with that contingency in mind.
2. The relevant measurements include conformable components—chest/bust and buttocks. The preponderance of data is limited to adult US military personnel, which is a sample not necessarily representative of the global population. This limitation was addressed somewhat by addressing a few adult Asian population samples, though they lacked some statistical information and did not include the two most important measurements.
3. A flexible barrier design may entail some risk of stretching, despite mitigating design features.

The team determined that 26 inches was a sufficiently small circumference. This conservative estimate was determined by the following:

1. Assessing the chest/below-bust measurement and the hip/buttock measurement out to three standard deviations, and selection of the worst-case population for each measurement:
   - The worst-case circumference for chest/below-bust circumference was 23.57 inches. The smallest hip-buttock circumference from Table 3 is 29.34 inches at 3σ from the mean. Recall that this sample, though only 1.25% of the total US military sample, emulates smaller-framed populations among the global human population.
2. Estimating the range of reduction in the hip/buttock circumference where it is squeezed through an opening:
   - This limited testing and a market survey of sizing requirements that address this concern yielded a range of 1–3 inches.

4.2 Risk Management Options

4.2.1 Risk Identification

Any security design involves some level of mission risk. It is important to know the sources of risk in determining the design requirements for a flexible netting sensor. Below is a partial list:

- The risk that an adversary will attempt an attack on a given facility

- The risk that an adversary would seek to defeat this particular sensor, among all of his available alternatives
    - **CAUTION**: this must be evaluated with the endstate physical protection system in view. If the endstate physical protection system is very robust, the difficult but effective penetration becomes a more attractive adversary option.
- The conditional risk that, having decided to defeat the net sensor, the adversary can find an intruder small enough in the relevant body dimensions to make the attempt
- The risk of failure of the physical protection system if this sensor is defeated
- The consequences of system failure of the physical protection system

4.2.2 Risk Mitigation

If the risk cannot be accepted, it can be mitigated through design, conduct of operations, or other measures. Engineering out some of the inherent flexibility of a net sensor—such as putting it under tension—could offer some tradeoffs in circumference. The design would have to be verified in performance testing. Adding additional complementary sensors is another option.

5. REFERENCES

1 DOD-HDBK-743A, *Military Handbook Anthropometry of U.S. Military Personnel.* 13 February 1991.

2 International Standard ISO 15535:2010. *General requirements for establishing anthropometric databases*.

3 Defense Technical Information Center (DTIC) No. AD 457939. *Anthropometric Survey of the Armed Forces of the Republic of Vietnam*. Washington, DC: Advanced Research Projects Agency. White, R.M., 1964.

4 Applied Ergonomics, Vol. 35, Issue 2, Technical Note. *The Comparisons of Anthropometric characteristics among Four Peoples in East Asia.* Lin, Y., Wang, M.J., Wang, E.M., March 2004.

5 Defense Technical Information Center (DTIC) No. AD 759949. *Anthropometry of the Latin-American Armed Forces* (Report No. USATTC 7209002). Fort Clayton, Canal Zone: US Army Tropics Test Center. Dobbins, D.A. & Kindick, C.M., 1972.

6 Director of Central Intelligence Directive (DCID) 6/9. *Physical Security Standards for Sensitive Compartmented Information Facilities.* 18 November 2002.

7 Department of Homeland Security Management Directives System MD# 11030.1, *Physical Protection of Facilities and Real Property*, 21 April 2003.

8 Department of Defense Directive 5210.63, *Security of Nuclear Reactors and Special Nuclear Materials*, 06 April 1990.

9 National Industrial Security Program Operating Manual (NISPOM) - Miscellaneous Openings, February 2006.

10 Defense Technical Information Center (DTIC) No. AD 728822. *Anthropometry Survey of the Imperial Iranian Armed Forces: Phase III – Technical Summary.* United States Army Natick Laboratories, Natick, Mass. Kennedy, S.J. & White, R.M., May 1971.

6. APPENDIX A: APPLICATION OF SENSORED NETTING APERTURE ANALYSIS TO XSDS PRODUCT

Expeditionary Swimmer Defense System (XSDS) is a sensored net product being developed by Sound and Sea Technology, Inc. The size of net is defined by cable-center-to-cable-center measurements around each aperture or opening. A 10-inch by 10-inch aperture product has an actual aperture circumference of 35.75 inches, accounting for the cable radius and the bulk of the nodes (including node arms) that hold the cables fixed at the cross points. The cable diameter used in the calculation is 0.358 inch. AutoCAD® is the product used to calculate the actual aperture opening. Following the same calculation process, a 9-inch by 9-inch and 8-inch by 8-inch aperture product has actual aperture circumferences of 31.75 inches and 27.75 inches, respectively. See the three examples illustrated in Figure A-1.

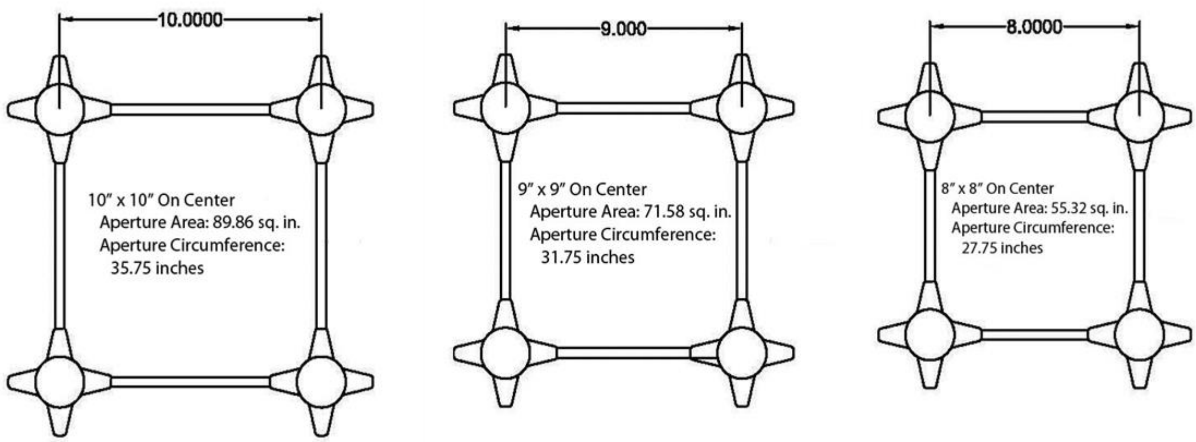


Figure A-1. Examples of XSDS Configurations with Actual Aperture Dimensions.

Applying the recommendation from the sensored netting aperture analysis, the XSDS product would need to have an aperture defined as 7.5 inches by 7.5 inches, as this would give a nominal aperture circumference of 25.75 inches. The product would then need to be tested to ensure that the aperture cannot be made larger than 26 inches without alarming. It should be noted that if the bulk of all four nodes protruding into the aperture were removed by cutting or grinding, the actual aperture size would increase to as much as 28.57 inches. To account for the possible removal of bulk from the nodes, the XSDS product would need to have an aperture defined as 7 inches by 7 inches, thus giving a nominal aperture circumference of 23.75 inches, but with room to expand to 26.57 inches if the node bulk were removed from all four nodes. Based on known product construction, it is highly unlikely that the aperture could be expanded beyond 26.57 inches without producing a sensor alarm. It should be noted that the more bulk that is attempted to be removed, the higher the probability that the product would alarm. Also, the more bulk that is successively removed, the higher the alarm probability as an intruder struggles through the aperture.

There is no doubt that a complete net hanging vertically would present a potential intruder with more difficulty; however, there is no evidence to suggest that the probability to slip through an aperture in this type of configuration without alarm decreases for a selected aperture size. The same can be said for a net made of an increased rigidity. However, there is a point at which a net is no longer conformable by the hands of a potential intruder as rigidity increases. Present versions of the XSDS product are considered easily conformable. A recent documented demonstration[9] showed that an adult person could slip through a flexible 30-inch loop made of a 1/8-inch plastic-coated steel cable, but could not slip through a 29-inch loop of the same construction. It also showed the person slipping through an 8.5-inch by 8.5-inch XSDS product that has an aperture circumference of 29.75 inches with the same level of effort as the 30-inch flexible loop. See sequential scenes from the demonstration in Figures A-2 and A-3.

Figure A-2. Sequence Showing the Slipping of a 30-inch Loop from Head to Toe.

[9] Demonstration performed in February 2012. Principal Investigator was Michael Ross, mpross@sandia.gov

Figure A-3. Sequence Showing the Slipping of an 8.5-inch by 8.5-inch XSDS Aperture (29.75-inch circumference) from Head to Toe.

DISTRIBUTION:

1	MS1002	Dave Corbett, 6500 (electronic)
1	MS1002	Randy J. Peterson, 6510 (electronic)
1	MS1006	Gerry Lipka, 6513 (electronic)
1	MS1006	Frank Bouchier, 6513 (electronic)
1	MS1006	Dale T. vanDongen, 6513 (electronic)
1	MS0781	Jennifer E. Nelson, 6520 (electronic)
1	MS0780	Mark Murton, 6521 (electronic)
1	MS0781	Charlie Richardson, 6525 (electronic)
1	MS0781	Michael P. Ross, 6525 (electronic)
1	MS1002	Philip Heermann, 6530 (electronic)
1	MS1125	Jamieson Deuel, 6532 (electronic)
1	MS1125	Thomas K. Mack, 6532 (electronic)
1	MS0783	Chad Monthan, 6615 (electronic)
1	MS0783	Robert P. Cutler, 6615 (electronic)
1	MS0899	Technical Library, 9536 (electronic)
1	MS0762	Safeguards Library, 9536 (electronic)
1	MS9018	Central Technical Files, 8944 (electronic)
1	MS0899	Technical Library, 9536 (electronic copy)

Sandia National Laboratories