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Evaluation of Selected Navy Equipment for the Women-Aboard-Ship Program

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National Engineering Laboratory
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U.S. Department of the Navy
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Abstract

A study of the human factors aspects of five selected items of Navy equipment, namely, oxygen breathing apparatus, safety harness, emergency escape scuttle, life rails, and rotary observation windows, has been undertaken to ensure that the smaller size and lesser strength of females would not be a deterrent to the use of the equipment by women. The study involved a review of the applicable specifications for each item of equipment, a survey and enumeration of male and female anthropometric data, and a linking of engineering and anthropometric data. Each item has been assigned to a hazard category.

Of the five items evaluated, two appear to pose significant problems when used by women. Fit and high deceleration forces were the major concerns for the safety harness while operating force requirements were critical for the escape scuttle. In addition, there were also some difficulties for some women in the use of the oxygen breathing apparatus.

1.0 INTRODUCTION

In the Fall of 1978, the U.S. Navy began the task of assigning women to sea-duty on non-combatant ships other than hospital or transport ships. While the presence of women on Navy ships is not expected to alter normal operations, there are design features of ships and shipboard equipment which may require modification for use by females. The most obvious, of course, involve considerations of sleeping quarters, and similar ship features. In addition, though, equipment and systems may require modification if they are to be used extensively by women.

Most naval shipboard safety and emergency escape equipment currently in use was designed for the 5th to 95th percentile male with respect to height, weight, and physical strength. Approximately 25 percent of the female population is smaller, lighter, and weaker than the 5th percentile male. In view of these differences, the adequacy of critical equipment should be reassessed as during an emergency, survival could depend upon the ability of women to operate the equipment successfully.

The Naval Ship Engineering Center (NAVSEC) was given the task of assessing the impact upon systems and equipment if the crews of non-combatant ships were staffed from 20 to 50 percent by women. NAVSEC identified an initial group of five items of equipment which might not perform adequately when operated by females. These items included: oxygen breathing apparatus (OBA)--type A4, safety harness, emergency escape scuttles, life rails and lifelines, and rotary observation windows. A study of the human factors aspects of this equipment was then undertaken to ensure that no serious problems would arise through female use. This study involved--

- direct observation of the equipment use aboard ship;
- review of applicable engineering specifications and blueprints for each item of equipment;
- survey and enumeration of both male and female anthropometric data; and
- linking of engineering and anthropometric data.

The goal of this investigation was the identification of any potential safety or performance problems. Results of the study are presented in this report.

2.0 ANTHROPOMETRIC/BIOMECHANICAL DIFFERENCES BETWEEN MALES AND FEMALES

Two of the major areas of difference between present day male crewmembers and female crewmembers are body dimensions (anthropometry) and body action (biomechanics). Body dimensions are critical to sizing of personal equipment, operating equipment, access and mobility space and work space. Body action is critical to all of these requirements and, in addition, to force application in a wide variety of tasks and general activities. Therefore, the gap between the lower percentile female anthropometric and biomechanical dimensions and the dimensions of the 5th percentile male crewmembers is a critical research area for adaptation of women crewmembers to an environment designed for a male crew. Details of current anthropometric/biomechanical data capabilities are presented in Appendix A. References to selected works which deal with the subject are also included.

Presented in Table 1 are some comparative anthropometric data on selected dimensions from male and female populations. These represent the best approximations available for those populations from which male and female Navy crewmembers may be obtained. The dimensions given were primarily selected as body configuration and strength characteristics which could be considered as descriptors of male and female similarities and differences which might be encountered in decisions regarding utilization of female crewmembers aboard Navy ships. The procedure used in selecting this data is explained in detail in Appendix B. Additional anthropometric data, relevant to each of the selected pieces of equipment, is presented in Table 2.

The usual caveat for this kind of data applies where the population from which the data are obtained may not be representative of Navy male and female crewmembers. Also, the data are descriptive of people, not task performance requirements. It is to be expected that the data will be

TABLE 1. Anthropometric and Biomechanical Dimensions for Males and Females*

Dimensions	Population	5th % ile	50th % ile	95th % ile	% Overlap**	Remarks
Weight (Kg)	U.S. Army F	46.63	59.58	74.52	52	All body measurements are in bra and panties or under-shorts and bare foot, unless otherwise stated.
Ibid	U.S. Army M	57.35	70.95	91.65		
Stature (cm)	U.S. Army F	152.6	162.7	174.1	38	Floor to top of head
Ibid	U.S. Army M	163.7	174.4	185.6		
Sitting Height (cm)	U.S. Army F	79.01	83.17	90.32	37	Sitting surface to top of head
Ibid	U.S. Army M	84.54	90.75	96.68		
Bust Depth (cm)	U.S. Army F	19.60	22.74	26.81	95	Tip of bra to back of torso (F).
Chest Depth (cm)	U.S. Army M	20.19	23.02	26.70		Nipple to back of torso (M). Note that bra design and fit and, posture may be important sources of variance in this dimension for women.
Shoulder Breadth (cm)	U.S. Army F	38.41	42.01	45.66	49	Maximum breadth across shoulder at bulges of deltoid muscles in upper arm
Ibid	U.S. Army M	41.46	45.23	49.77		
Hip Breadth (cm)	U.S. Army F	32.33	35.25	39.54	63	Maximum horizontal breadth of hips
Ibid	U.S. Army M	30.16	33.05	36.72		
Waist Height (cm)	U.S. Army F	93.21	101.18	110.31	64	Floor to natural waist level (F).
Ibid	U.S. Army M	97.46	106.35	115.16		Floor to upper edge (iliac crest) (M) of hip bone. Measurement may favor a higher waist line for women due to female soft tissue distribution.
Hip Circumference (cm)	U.S. Army F	85.89	95.28	106.1		
Ibid	U.S. Army M	85.12	93.58	105.5		
Upper Thigh Circumference (cm)	U.S. Army F	49.35	56.90	64.52		
Ibid	U.S. Army M	48.07	55.10	63.86		
Waist Front Length (cm)	U.S. Army F	32.78	36.52	41.36	--	Surface difference from waist to anterior (front) neck - torso junction.
(not available for male population)	U.S. Army M	- N O T	A V A I L	A B L E -		
Vertical Trunk Circumference (cm)	U.S. Army F	142.2	155.5	166.1	51	Tape passing through the crotch, over the buttock and shoulder, and the tip of the bra (F).
Ibid	U.S. Army M	150.6	163.3	178.6		Same as for (F) except that tape is not over a bra tip (M). Note that tape follows contour of male front body much more closely than it does the female front body.
Waist Back Length (cm)	U.S. Army F	36.71	40.73	45.49	49	Surface distance from cervical point to waist
Ibid	U.S. Army M	39.52	44.90	50.83		
Hand Length (cm)	U.S. Army F	16.06	17.38	19.04	39	Wrist crease to tip of middle finger.
Ibid	U.S. Army M	17.51	19.00	20.66		
Hand Circumference (cm)	U.S. Army F	17.05	18.43	19.87	11	Around metacarpal-phalangeal joints (knuckles and excluding thumb).
Ibid	U.S. Army M	19.83	21.56	23.56		
Hand Breadth (cm)	U.S. Army F	7.18	7.82	8.46	22	Across palm at distal and metacarpal bones (knuckle level).
Ibid	U.S. Army M	8.12	8.88	9.74		
Functional Reach (cm)	U.S. Army F	64.02	71.08	78.99	22	Subject standing against wall, measured from wall to tip of thumb along horizontal arm line U.S.A.F. Mean Stature is 162.10cm. However, R for stature - thumbtip reach is only .646.
Ibid	U.S. Army M	74.90	82.45	90.92		
Standing Vertical Grip Reach (cm)	High School F (17.5-19.0 yrs.)	188.4	196.4	205.6	27 (based on minimum and maximum)	Floor to thumb tip of grip. Mean stature, F 163.0cm Mean stature, M 176.5cm R for stature - vertical grip reach is .915 F - .911 M for these samples.
Ibid	High School M (17.5-19.0 yrs.)	206.0	213.8	228.9		
Bent Torso Height (cm)	U.S. Army F	112.7	126.3	130.6	Insufficient Data	Floor to top of head in stooped position (F,M). F clothed, M may be clothed.
Ibid	U.S.A.F. M	117.6	122.1	150.0		
Kneeling Height - Upright (cm)	U.S. Army F	114.5	122.92	130.3	Insufficient Data	Floor to top of head, on knees with torso erect, F clothed, M may be clothed.
Ibid	U.S.A.F. M	122.4	129.54	138.2		
Grip Strength (N)	College, F	197	258 (mean)	320	Insufficient Data	Smedley hand dynamometer, 1N(ewton)=0.2248 lbf
Ibid	College, M	352	494 (mean)	636		
Maximum Acceptable Weight Lift, (kg)	Indus. Workers, F	(10 th % ile) 13	15	(90th %tile) 21	Insufficient Data	Two hand repetitive lift of tote box 34.3 x 48.3 x 14.0 cm loaded with lead shot, floor to knuckle height
Ibid	Indus. Workers, M	(10th % ile) 17	25	(90th %tile) 29		
Maximum reasonable weight, carry (kg)	30-44 yrs. F	9.57	16.00	22.43	Insufficient Data	Two hand carry of box loaded by subject to an acceptable weight for the subject
Ibid	30-44 yrs. M	11.60	21.50	31.40		
Forward Push, both hands (N)	College, F	118	234 (mean)	343	Insufficient Data	Reaction force provided by floor and foot rest 1N(ewton)=0.2248 lbf
Ibid	College, M	381	623 (mean)	866		

*See Appendix B for references and selection criteria.
**See Tilton, J.W. The Measurement of Overlapping J. Educ. Psychol., 1937 Vol. 24, p. 656-662.

Table 2. SPECIFICATIONS AND RELEVANT ANTHROPOMETRIC DATA FOR SELECTED EQUIPMENT

Equipment	Applicable Specifications	Product Parameters	Design Requirements	Relevant Anthropometric Measurements* Dimension (cm)	Sex	5th %ile	50th %ile	95th %ile	Comments
Oxygen Breathing Apparatus (OBA)	NAVSEA 5-5600-AA-[illegible]-00-01 Type A4	Single Size, Adjustable Fit, Harness							Fit may be poor but still tolerable.
				Waist Front Length (cm)	F M	32.78 Not Available	36.52	41.36	
				Waist Back Length (cm)	F M	36.71 39.52	40.73 44.90	45.40 50.83	
				Bust circumference Chest circumference (cm)	 M	78.35 84.10	87.88 93.05	98.99 105.86	Bust size should be non-critical
		Single Size, Adjustable Fit, Face Mask		Head circumference (cm)	F M	52.34 53.52	54.86 56.08	57.74 58.82	Head size differences are non-critical
				Bitragion Breadth (cm)	F M	12.08 12.58	12.98 13.49	13.85 14.94	
				Menton to Vertex (cm)	F M	19.27 20.47	20.84 22.19	22.58 23.86	*Naval aviators
		Weight	Sample weight 9 kg	Shoulder load tolerance (kg)		Not Available			
Safety Harness	MIL-H-24460	Single Size, Adjustable Fit for Extremes of Dress	Fit users between 63 to 113 kg	Weight (kg)	F M	46.43 57.35	59.58 70.95	74.52 91.65	All measurements based on nude/minimum dress body.
			Fit users between 152 to 193 cm	Stature (cm)	F M	156.6 163.7	162.7 174.4	17[illegible].1 185.4	Increments must be added to account for various types of clothing
				Arm Scye circumference** (cm)	F M	33.81 39.60	37.37 44.31	41.68 50.2?	
				Chest circumference scye** (cm)	F M	77.54 84.10	85.28 93.05	94.33 105.9	
				Waist circumference (cm)	F M	61.13 69.66	70.05 78.87	77.53 95.94	
				Hip circumference (cm)	F M	85.89 85.12	95.28 93.58	106.09 105.53	Two of the few dimensions where the female is larger than the male.
				Upper thigh circumference (cm)	F M	49.35 48.07	56.90 55.10	64.52 63.86	
				Vertical trunk circumference (cm)	F M	142.2 150.6	153.7 163.8	166.1 178.6	Measured differently for females & males
				Mid-shoulder height, setting (cm)	F M	 57.13	 62.38	 67.63	
				Shoulder breath (cm)	F M	38.41 41.46	42.01 45.23	45.66 49.77	Shorter female shoulder breadth might contribute to harness strap slippage
		Don-Doff, under extreme of dress	Manipulatable by gloved person with fit adjustments in frontal plane.	Reach envelopes, left & right arms, frontal plane.					Non-critical
				Grip Strength (N) gloved	F M		Not available 351		Non-critical
				Bare	F M	258	325 469	387	
				Dexterity/Tactility, gloved	M M	Gloved: reduced to 65% Pressure Glove: reduced to 35%			
Energy Absorber Device	MIL-H-24460	Deceleration Device	Activates at 1800N ±10% to decelerate a 135 kg mass with a force no greater than 3100N	G-load, stress tolerances					Major differences between sexes are in contact of gravity and weight distributions. No special problems anticipated.
Scuttles and Hatches	General Specifications for Ships of the U.S. Navy	38cm x 58cm manholes throughout ship	Free passage, Emergency escape must be quick-opening and easily operated in a standard mode of operation	Size data similar to safety harness					No special female problems.
		38cm x 46cm minimum		Strength data (N)					
	MIL-STD-1472B	46cm dia. in transverse floors		Standing 2-handed pull 38 cm level	F	312	543	814	Average force over 3-second interval not peak force.
		69cm width for main fore and aft passageways		Standing 2-handed pull 50 cm level	M	288	566	814	1N(ewton) = 0.2248 lbf
				Maximal static upward pull forces exerted on a horizontal bar (British study)	College Students F M	 712 1205	 961 1630	 1210 2060	Maximum strength can be significantly effected by many variables, such as motivation, training, or age. In addition max. strength whether static (isometric) or dynamics, are entirely dependent on how the force is exerted & measured. Hence correlations between strengths are low.
					Factory Workers F M	 529 1120	 314 1610	 1100 2110	
				Vertical Push Upwards (N)	F M	— —	135 232	— —	1N(ewton) = 0.2248 lbf
Rotary observation windows	General Specifications for ships of the U.S. Navy	Height of center line above deck	165 cm height above deck	Eye height (cm)	F M	142.7 152.1	151.4 (mean) 162.7 (mean)	160.1 173.3	May require attending platform for 5th percentile females.

pertinent to a wide range of operational requirements onboard ship but many tasks will probably call for physical configurations and capabilities not mentioned herein. Finally, some dimensions are not exactly equivalent for both men and women even though they may involve the same body or performance areas. Chest measurements are an obvious example.

Comparison of body measurements between the sexes (Table 1) reveals the obvious. The male is generally larger than the female, although there is a considerable amount of overlap. In only two dimensions, namely hip breadth and circumference and thigh circumference. are females consistently larger than the male. By interpolating between anthropometric data, it is noted that for most dimensions approximately 20 to 25 percent of all females have measurements falling outside the range of measurements for the 5th through the 95th percentile male. Examination of the head measurement data of Table 2 indicates that there are only very small differences between the male and the female, with the female face being somewhat smaller. However, these small variations in facial size and shape may be critical in achieving a good facemask fit.

Studies comparing the strengths of males and females indicate that the female's strength is from 50 to 80 percent that of the male, depending on the strength measured (see Figure 1) [1]. Under normal conditions, most task requirements are well below the maximum strength potentials of both male and female, so that sex differences are not critical. However, some stress conditions of long-term duration may produce performance degradations to the point where maximum strength potentials are below task requirements. This relationship is best illustrated by considering the case of force exertion over time. As shown by fictitious example in Table 3, although the performance decrement from one minute to one hour is proportionally the same (50%) for both sexes, a female's performance after one hour would be unacceptable for tasks requiring forces greater than 26 newtons. Therefore, a task that can just be sustained for one hour by a male would obviously have to be terminated in less than one hour by a female.

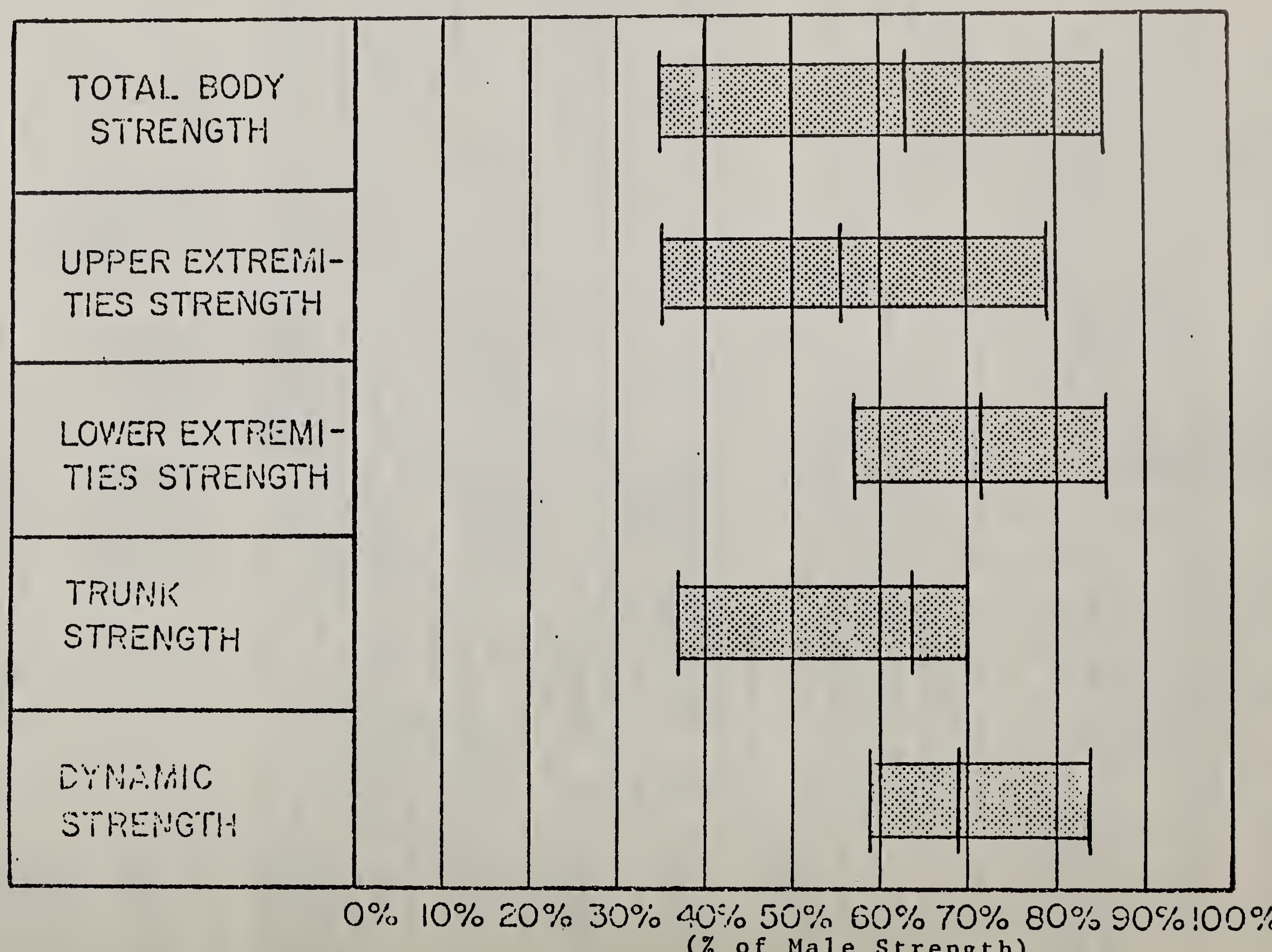

Figure 1. Range and Mean Percentage Differences in Muscle Strength Characteristics Between Women and Men [9]

Table 3. Example of Isometric Force Exerted Over Time

	Sustained for 1 Min	Sustained for 1 Hr
Men	80 N	40 N
Women	52 N	26 N

Unfortunately there is a scarcity of dynamic strength data for females. This type of information is currently being developed by Robertson [2].

3.0 AN ERGONOMIC EVALUATION OF THE SELECTED EQUIPMENT

Based on a visual inspection and a review of specifications and operating characteristics of the selected equipment, possible problem areas were identified. These areas, presented in Table 4, were later considered in greater depth in order to determine whether anthropometric/biomechanical differences between males and females might cause significant problems for female personnel or ship safety.

Table 4. Possible Problem Areas

Equipment	Possible Problem Area
Oxygen Breathing Apparatus	Fit of breast plate, face piece Weight and bulk of apparatus
Safety Harness	Fit Operation of Energy Absorber Device
Escape Scuttle	Physical Capabilities (strength required to operate)
Life Rails, Stanchions, Life Lines	Differences in bulk, weight, and weight distribution of personnel
Rotary Observation Window	Distance from floor to windows Viewing area

While it is recognized that problems in these areas may also be experienced by male personnel, the equipment was analyzed in terms of "special" problems which might affect females more severely, particularly those 20 to 25 percent females having physical characeristics falling outside the range of the 5th through 95th percentile male.

Four hazard categories, presented in Table 5, were developed as criteria for evaluating the performance of safety items. These criteria were applied in the evaluation of the five pieces of equipment for use by females.

Table 5. Hazard Categories for Navy Equipment

Category #1--items that will pose a serious threat to personnel safety, impair mission performance, or cause damage to essential equipment or systems.

Category #2--items that are likely to result in a deterioration in successful performance or a marked increase in personnel stress. The level of performance degradation under this category is not intolerable, but does represent a compromise of effectiveness and efficiency over a measurable span of time.

Category #3--items that do not perform satisfactorily when used as intended, but which can be modified by the user to perform adequately. These devices have characteristics which permit the user to adapt them, adjust them, or use a supplementary device for successful operation. The penalty for such modification may be excessive stress or fatigue for the user. The items could permit proper use and satisfactory performance with slight design modification.

Category #4--items that present no apparent consequence as a result of operation by female users.

In the remainder of this section, the significance of each aforementioned possible problem area is assessed for the selected equipment. The equipment is then categorized using the preceding criteria.

3.1 Oxygen Breathing Apparatus (OBA)

Problems with the OBA, which might be experienced by female users, include 1) poor fit and 2) reduced freedom of movement and fatigue/poor performance due to the bulk and weight of the apparatus. While these problems also exist for male personnel they may tend to affect female performance more severely.

3.1.1 Fit of OBA

Body harness/breastplate: The OBA body harness is adjustable and allows the OBA to be worn high or low, and tight or loose on the chest. As such, the OBA should accommodate virtually all female personnel. Unfortunately, in some cases, the fit obtained will be less than acceptable--particularly, for smaller, lighter females. The shorter trunk length of these personnel can result in OBA interference with the facepiece or the upper front thighs while bending, climbing or changing oxygen canisters, and should therefore be of concern.

The problem of OBA fit becomes apparent upon consideration of the relevant anthropometric data and OBA dimensions. Anthropometric data presented in Table 2 indicates that the waist front length for females ranges from about 33 to 41 cm. Comparable data for males is not available, but measurements presented in Table 2 indicate that the waist back length for males is about 3 to 5 cm greater than for females. Waist front lengths for males might similarly be 3 to 5 cm greater than for females or about 38 to 46 cm. In contrast to waist front length, the length of the OBA when worn is about 43 cm. Comparison of waist front and OBA lengths indicates an overlap of as much as 10 cm--between the upper legs and the OBA, and the OBA and the shoulders--for female users, versus an overlap of 5 cm for male users. The effects of this additional 5 cm overlap for females on body movement and job performance are not expected to be significant but should be further investigated.

Face Piece: The OBA face piece headband straps are adjustable and do not appear to present any problem with female use. Face piece sealing, however, may not be satisfactory with some female facial contours. Naval Air Systems Command has found that some women aviators require a face mask with a laminar seal (Type ABA) in order to achieve complete sealing [3]. Discussions with Mine Safety Appliances Co. (MSA) [4], manufacturer of the OBA, indicate that a similar sealing problem with the OBA face piece is possible in some cases, but the problem is not of immediate concern.

3.1.2 Bulk and Weight of OBA

The weight of the OBA is approximately 9 kg (20 lbm). A search of the literature failed to yield data relevant to the weight of equipment worn by individuals. However. female back-packers normally carry 20 to 30 kg in a back-pack configuration. Since the OBA is worn in front the OBA's weight per se should not be critical to female performance. In conjunction with a poorly fitting body harness, however, the net effect could have a significant impact on female performance--such as passing through a scuttle or fighting a fire for an extended period of time.

3.1.3 OBA--as a Unit

Due to size and strength differences, females may experience performance decrements below an acceptable level during OBA use. The OBA should therefore be considered as a Category #2 problem. The rationale for placing the whole OBA unit in Category #2 is that the interaction of weight, interference, other accouterments, and hostile environment may result in performance below some tolerable level. On the other hand, the male having the same performance decrements may still perform above the same tolerable level.

3.2 Safety Harness

The safety harness under consideration is of the parachute harness type. It is adjustable to provide fit over outer garments and other accouterments such as a life jacket. Possible problems which may result with female use of the device include poor harness fit and faulty operation of the accompanying energy absorber device.

3.2.1 Fit of Safety Harness

The harness requires a good fit around the upper thighs and hips, which are intended to absorb most of the deceleration energy. Less critical are the shoulder straps which distribute the deceleration energy over the chest; however, the possible distribution of the deceleration energy over the female bust is of some concern.

As specified in MIL-H-24460, the safety harness shall fit users between 63 and 113 kg (140 and 250 lbm) in weight and between 152 and 193 cm (5 ft and 6 ft 4 in) in height. Inspection of Table 2 indicates that a harness meeting this specification might fail to fit half of all female personnel because their weight falls outside the specified range.

A sample safety harness was test fitted on two females. These persons represented low and high percentile weight and medium to high percentile height for female populations. Poor fit--due to excessive shoulder strap length--was obtained in both cases, i.e. the shoulder strap could not be tightened enough to give a snug fit. A shorter shoulder-to-waist distance for females was identified as a factor contributing to this poor fit. Apparently, the combination of shorter waist front and waist back lengths for some females (see section 3.1.1) results in a required strap length shorter than attainable by adjusting the harness.

Since women participate in sky-diving, parachute jumping, and other aerial acrobatics, the question arose as to whether female's parachute harnesses are different from the males. Information from the National Parachute Test Range at El Centro, California, indicated that size (weight and height) was (somewhat) more important than sex. Apparently, in order to accommodate the wide range of height and weight of personnel, the Air Force uses 12 harness sizes [5]. An additional safety harness size might also be required to accommodate females in the Navy program.

Another concern with the safety harness involves shoulder straps slipping off the shoulder. This could present a safety problem if the straps were riding the periphery of the shoulders at the time of a fall. Two factors would tend to increase shoulder strap slippage for females: 1) the shoulder straps might fit on the outside edge of the bosom and 2) female shoulder breadth is about 3 cm smaller than males.

Modification of existing safety harnesses to reduce shoulder strap slippage might involve the addition of a snap-on crosspiece between the two chest straps to reduce the possibility of straps slipping off shoulders. Addition of the crosspiece would increase the safety of male users as well as female users. Safety harness redesign efforts, if required, should consider 1) including such a crosspiece and 2) increasing the range of shoulder and waist strap adjustment to compensate for small framed personnel and personnel with greater waist to shoulder measurements.

3.2.2 Operation of Energy Absorber Device

The requirement for the energy absorbing device is that it activates at 1800 N ± 10% (400 lbf ± 10%). Also, it should decelerate a 135 kg (300 lbm) mass with a force no greater than 3100 N (700 lbf), without producing an elongation of more than 61 cm (2 ft). A 135 kg simulated human torso is used in a free-fall drop-test to check that the device meets specifications. It should be noted that this test is not sufficient for evaluating the effect of deceleration on personnel safety since it checks force levels and not g-loadings.

It is possible that a light female, under some fall conditions, would fail to activate the energy absorbing device because of low forces, yet still be subjected to high enough g-loadings to cause serious injuries. A full explanation of the rationale for g-load testing to simulate lightweight personnel (63 kg (140 lbm) or less) is rather lengthy; the reader is referred to "A Study of Personal Fall-Safety Equipment." [6] It is strongly recommended that the energy absorbing device be investigated further to insure that lightweight personnel would not be subjected to intolerable g-loadings. Satisfactory operation can be insured by testing the absorber with a light mass as well as the presently used heavier mass.

Because of questions regarding safety harness fit, shoulder strap slippage, and energy absorber operation, the safety harness appears to pose significant safety problems for female users. Until more definitive data, and perhaps results of actual use tests are obtained, the safety harness should be considered a Category 1 item.

3.3 Escape Scuttle

Several different size scuttles are currently being used on Navy ships. These range in size from 46 cm (18 in) diameter scuttles used on older ships, to 64 cm (25 in) diameter spring-balanced units. Most common are 53 cm (21 in) diameter scuttles, which are used on new ships. These 53 cm units, designed so that the maximum upward force required for operation does not exceed 220 N (50 lbf), appear to pose the most significant problems with regard to operation by females.

The major problem with escape scuttles appears to be the force required to operate them. Two processes are involved in scuttle operation: turning a wheel to unlock the scuttle, and forcibly lifting or pushing the scuttle open. Of concern here is whether females, generally weaker than males, would be physically capable of performing these tasks.

Locking/Unlocking Scuttles: The force required to lock and unlock escape scuttles is generally dependent on (1) the degree of tightening either required for sealing or previously used respectively, (2) dirt/corrosion buildup on locking mechanism components, and (3) scuttle alignment/sealing problems. Although force requirements for locking/unlocking are not specified as scuttle design requirements, maintenance procedures aimed at assuring satisfactory scuttle operation are specified. However, the force requirements for scuttle operation can still be excessive in some cases, and beyond the physical capabilities of some males as well as females.

In order to adequately assess problems pertaining to scuttle operation, an analysis or survey of operating force requirements should first be undertaken. Once the range of forces required to open the scuttle has been established for scuttles, then it should be verified that female recruits can meet these requirements. This requires measurement of the strength, torque, and force needed for scuttle operation, as well as verification that females can meet these requirements.

Lifting/Pushing Scuttles Open: In evaluating problems with female use of scuttles, the two different modes of scuttle operation must be considered--operation from above deck involving lifting strength, and operation from below deck involving pushing strength.

Comparison of upward pull strength data presented in Table 2, with scuttle lifting force requirements (220 N) suggests that when scuttles are activated from above, the force requirements appear to be within the capacity of the 5th percentile female. However, actuating access/exit openings from below may prove to be an especial problem for females. As shown in Figure 1, for example, the static strength in the upper extremities of women was found to be roughly 55 percent that of men while for the lower extremities it was found to be about 72 percent of that of men. Women's trunk strength was found to be 64 percent of that of men [1]. These findings indicate that the female is at a more severe disadvantage vis-a-vis the male when she is required to use arm/shoulder muscles--especially if the arms must be used above the head. What limited vertical upward push data exists (see Table 2) indicates that average female strength, 135 N, is significantly less than that required to push th 53 cm scuttle (220 N) open. Male strength, 232 N. is only barely sufficient. These figures, while appearing to be low, indicate that the scuttle is indeed more of a problem for females than for males.

In summary, when actuated from above deck, scuttles do not appear to present any special problems for female personnel. However, when operated from below, females might lack the upper body strength required to open the scuttle. For this reason, the scuttle is considered a Category 1 problem.

In addition to the problem of force requirements for scuttle operation, there appears to be potential safety related problems due to inadequate footholds and lighting in the scuttle shaft. The addition of an extra foothold on the opposite side of the ladder would allow a person to support both feet, and thus increase stability while trying to open the scuttle. Use of lighted, fluorescent, or raised markings on the scuttle might also increase ease of operation. An examination of relevant Navy accident records should bear out any real problems.

3.4 Life Rails and Life Lines

Inspection of human factors data presented in Table 1 indicates that women are only slightly smaller than men in body width and depth measurements. Also, a female's center of mass would tend to be at a lower vertical elevation than a male's due to shorter female height and greater weight concentration at midbody level. These factors combined would tend to reduce the likelihood of females falling between or over life rails, perhaps making this even less of a problem than for males. As life rails and life lines do not present significantly greater danger for women than that currently experienced by men, these items are considered to fall into Category 4.

3.5 Rotary Observation Windows

The primary visual problems that might arise for the Women-Aboard-Ship program are mainly related to differences in female height. One such problem involves the use of rotary observation windows by short personnel.

The specifications for rotary observation windows require that the center line of the window be 1.64 m above deck. At this height. the lower edge of a typical 33 cm diameter spinning window would be about 1.47 m above the deck. Examination of the eye height data of Table 2 reveals that roughly one-fourth of all females will require a stool or other stable and sturdy platform to bring their eye level with the window's center line. Because the range of male heights is so great, wooden platforms and stools have already been provided on the bridges of many ships to overcome this problem as it relates to windows. These same devices should compensate for male-female height differences in most cases and additional platforms can be provided for shorter females. Because the eye height problem is easily solved using techniques presently in use, windows and other such devices would appear to be noncritical for the Women-Aboard-Ship program. They are therefore considered to be Category 3 items. A consideration of greater ranges in height should be made when positioning apertures in new ship design.

4.0 SUMMARY AND CONCLUSION

Five selected items of Navy equipment have been evaluated with regard to operation by female personnel, particularly, those females with physical attributes falling outside the range of the 5th through 95th percentile males. These items were categorized in terms of the hazards they may present to ship and personnel safety when operated by female personnel. A summary of the hazard classifications for the selected equipment is presented in Table 6.

Table 6. Hazard Classifications for the Selected Equipment

Equipment	Category Number 1	2	3	4
Oxygen Breathing Apparatus (OBA)		X		
Safety Harness	X			
Escape Scuttles	X			
Life Rails and Life Lines				X
Rotary Observation Windows			X	

Of the five items evaluated, two are considered to pose significant personnel or ship safety problems related to female operation; these are the safety harness and the emergency escape scuttle. With the safety harness, problems with fit, shoulder strap slippage, and high deceleration forces for lighter personnel appear likely. For the scuttle, the force required to open it from below is expected to be greater than the upper body (arm) strength of many females (the strength in the upper extremities of females is about 55 percent that of males). Accordingly, both pieces of equipment are classified as Category 1 items.

Use of the oxygen breathing apparatus (OBA) by female personnel is also of concern as interaction of possible problems cited in this study--OBA weight, poor face piece/OBA fit, and fatigue--may result in unacceptable performance. Hence, the OBA is considered a Category 2 item.

Performance of two remaining items--life rails and life lines, and rotary observation windows--appears to be sex neutral. No female related problems with life rails and life lines have been identified, and eye height associated problems (for short personnel) with rotary windows are easily solved by adding platforms to stand on. These devices are therefore considered Category 4 and Category 3 items respectively. Specific problems with each piece of

Table 7 - PROBLEM IDENTIFICATION/EVALUATION

Equipment	Female Users	Cause/Reason	Undesirable Result	Possible Action
1. Safety Harness	Improper Fit - Harness too large or small	Differences in physical dimensions of female (height, waist, etc.)	Poorly distributed deceleration forces. Possible injuries to user in an interrupted fall.	Verify that harness fits 5th 5-95th percentile Navy form. Revise specs. if necessary.
	Slipping off shoulder	Outward shifting of straps at shoulders - due to strap interference with bust and smaller shoulder breadth	User's upper torso slips out of harness. Poorly distributed deceleration forces in an interupted fall - possible injuries to user.	Investigate problem further. If necessary, modify existing harnesses, revise specs.
Energy Absorber Device	Does not actuate for lighter personnel	Momentum of lighter user may not be great enough to bring absorber device into action.	High deceleration forces - possible injuries to user.	Revise specs to include a deceleration test which uses a light test mass as well as the presently used heavy mass.
2. Scuttles and Hatches	Difficulty in operating	Large force required to open some scuttles due to dirt & corrosion buildup, misalignment and other factors.	Impeding of shipboard traffic - potential hazard situation.	Investigate the problem further. If necessary, prescribe new specs. maintenance procedures or modifications.
	*Falls while operating or passing through scuttle	Scuttle is awkward means of passage.	Injuries to Personnel.	Place a foothold on the opposite side of passage way from the ladder.
	*Fumbling to operate scuttle	Insufficient lighting.	Impeding of shipboard traffic - potential hazard situation.	Improve lighting in passageways. Add florescent reflective arrows to indicate direction to open/close or raised arrows since scuttle is in darkness.
3. Oxygen Breathing Apparatus (OBA)	Improper fit - OBA does not compensate for difference in body contours	Anthropametric differences between male and females.		
	Weight - OBA may exceed weight carrying capacity for some females	Weight carrying capacity for females is somewhat less than for males.	Potential degradation in performance of duties - possible hazard situation.	Investigate potential problems further. Determine whether adding OBA to female chest causes 1) movement problem - 2) too much bulk, which reduces ability to use fire-fighting equipment. If necessary, modify OBA or limit users.
	Bulk of OBA	Fit of OBA on females may reduce ability to pass through scuttles.		
4. Windows	Eye height/window height	Difference in height between males and females.	Addition equipment (platforms, stools) required to perform duties.	Utilize platforms and stools where necessary. Consider wider range of height in future designs.
5. Life rails and Life Lines	*Falling over or between rails	Differences in body thickness, height, weight distribution between males and females.	Injuries to personnel.	Determine whether a problem actually exists.

*Potential problems for male users also.

equipment and recommended Navy action are summarized in Table 7.

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APPENDIX A

Anthropometric and Biomechanical Data Capabilities

While much of the data required to assess the significance of anthropometric and biomechanical differences between male and potential female crewmembers will need to be collected, the Consumer Ergonomics and Information Group (CEIG) at NBS has a large collection of this type of data readily available as a result of the Standard Ergnomics Reference Data System (SERDS) project activity. This data collection is summarized in the References Section of this Appendix. The general applicability of each reference is further summarized for nine types of areas of measurement and whether the data is from male or female populations. It should also be noted that in addition to the data from the sources cited in the References there are a great deal of anthropometric and biomechanical data available in miscellaneous textbooks and other sources which are either in the CEIG library or in the possession of the CEIG staff.

The data sources cited in the References Section of this Appendix and summarized in Table A1 are probably representative of the published state-of-the-art in anthropometry and biomechanics in that they are most available for General Anthropometry and Push-Pull and least available for the rather ill-defined area of human torque application. The citation of only one source for Reach Envelope is not as restrictive as it appears since most general anthropometry references include simple reach data and Kennedy and Kennedy (14) is not only an up to date reference but also includes reference to and discussion of reach envelope data from other sources, e.g. Dempster, Garrett, and previous work by Kennedy. The lack of data on Position Anthropometry and Joint Movement is not too restrictive in practice since available data are basic and any other data required beyond such basic mesurements should probably be derived from a study of the performance required for a specific task. The Lift and Carry data are largely contained in Kramer and Meguire (15). This study is recent and contains an extensive data presentation from other lifting and carrying studies. Torque data are not represented for women in Table A1, although some torque data are probably available from miscellaneous sources in the CEIG literature collection. However, it should be noted that application of torque by some controls, e.g. a hand wheel, is actually push-pull action from the biomechanical standpoint. Hand grip strength is not shown in Table A1 or cited in the References, although, again, such data are available in references in the CEIG miscellaneous collection. However relatively few tasks are performed by hand grip force alone. Although it may be critical for some types of force applications, especially for biomechanical torque through the length of the arm. there is not reference to a category such as "manual dexterity." This is because "manual dexterity" is very difficult to demonstrate as a general characteristic. Furthermore, dexterity tests, such as the Minnesota Rate of Manipulation Test, do not appear to predict performance in manual test beyond the training period, although wrist and finger dexterity may be a factor in differences in job output between two workers with long experience on a manual task.

The basic caveat to the use of data from the sources cited in the References is that anthropometric and biomechanical data are precisely valid only for the populations from which they are obtained and in terms of the methods used to obtain them. This caveat is especially applicable in the women-at-sea project since many of the factors which will influence the characteristics of the women crewmember population cannot be presently evaluated. For example, some characteristics may be influenced by whether or not sea duty is voluntary for women and, if so, on what basis. These considerations do not prohibit the use of available anthropometric and biomechanical data in defining problems associated with the utilization of women crewmembers in solving these problems. They do, however, emphasize the need for professional judgment in the selection, application, and updating of these data. A more serious restriction on the applicability of available anthropometric and biomechanical data in the women-at-sea program is that little or none of such data have been derived on moving platforms, such as may be a critical task performance factor in a ship at sea. This is an especially critical factor for biomechanical data.

Table A1

Summary of References* by Type of Measurement and Sex Applicability

Type of Measurement	Male	Female
General Anthropometry	A2, A13, A17, A20, A22, A23	A3, A4, A5, A8, A19, A20, A22, A24
Hand Anthropometry	A6, A11, A12 **	A10 **
Head Anthropometry	A1 **	**
Position Anthropometry	A21	A4
Reach Envelope	A14	A14
Joint Measurement	A7	A7
Lift and carry	A9, A15	A15
Push-Pull	A16, A21	A4, A16, A18
Torque	A12	

* From References, this appendix.

**Also included in most of General Anthropometry references.

A1. Alexander, M. and Laubach, L.L., Anthropometry of the Human Ear. (A programmatic study of USAF flight personnel). AMRL-TR-67-203, 1968. 500 male, mean age 28.32. 15 measurements.

A2. Body measurements for the sizing of apparel for young men (students). NBS Voluntary Product Standard PS 45-71. Recognized size categories, size designations, and body measurements for the sizing of apparel for young men. 26 measurements.

A3. Body measurements for the sizing of women's patterns and apparel. NBS voluntary Product Standard PS 42-70, 1971. Standard classifications, size designations and body measurements for sizing of women's ready to wear apparel. 44 measurements.

A4. Churchhill, E. et al. Anthropometry of Women of the U.S. Army 1977, Report No. 2 Univariate Statistics, Report No. 3 Bivariate Frequency Tables, Natick, MA. TR-77/024, 1977, 1, 331 + 200-300 Females, 17-60 yrs, 142 Anthropometric and 9 Static Strength Measurements.

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A17. Martin, J.I. et al. Anthropometry of law enforcement officers, NELC/TD 442, 1975. 3000 males, 18-65 years, 23 measurements.

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A19. Snow, C.C. et al. Anthropometry of airline stewardesses FAA-AM-75-2, 1975. 423 stewardess-trainees. 72 measurements.

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APPENDIX B

Anthropometric and Biomechanical Dimensions of Male and Female Populations

The procedure used in the collection of the anthropometric and biomechanical data presented in Tables 2 and 3 was 1) to select populations which were credibly similar to a reasonably expected male and female Navy crewmember population, 2) to select anthropometric and biomechanical dimensions which could economically describe the physical characteristics of these populations, and 3) to select a data format which would adequately present this description.

The populations selected were primarily Army males and females (Ref B1 and B10) for the anthropometric dimensions and a more diverse set of populations (Ref. B7, B9, B3, B3a, B3b, and B4) for the biomechanical dimensions. The biomechanical populations are more diverse than the anthropometric populations for reasons of data availability.

The dimensions were selected on the basis of three criteria: 1) the sample areas which are basic to the physical description of people in a task performance situation; 2) the availability of both male and female measurements (an exception to this is Waist Front Length for females for which there was no male equivalent dimension available), and 3) they represented a mix of both general and specific measurements. The latter criterion, for example, yielded height and weight, which are highly correlated with a relatively large number of other dimensions, and bust depth, which (in women) is highly correlated with relatively few other dimensions. While, as noted above, none of the dimensions were specifically selected for task criticality, there was a general consideration of functional relevance to shipboard operations which served to exclude head and foot dimensions from the brief list feasible for this report. Also, there was no attempt to select dimensions on the basis of male-female differences as such, although, as will be seen from Table 3, such differences do emerge.

The data presentation format for Table 3 lists the dimensions for which data were obtained, the population from which the data were derived, the 5th, 50th, and 95th percentiles of the data (in most cases), the relative overlap of the ranges of male and female distributions, and explanatory remarks on what the data represent.

In most cases the dimensions are identical in terminology for both men and women, the outstanding exception being the dimensional terminology of Bust Depth for females and Chest Depth for males. This is a rather important distinction which will be discussed below.

The data presentation of 5th, 50th, and 95th percentile (or 10th percentile, mean, and 90th percentile) shows selected points of each distribution but does not bring out the complete picture of dimensional data. This incompleteness is especially critical for arm reach dimensions. The only adequate way to evaluate arm reach dimensions for operational functions is to examine the arm reach envelope. Since such data cannot be presented in a brief form, the reader is referred to Kennedy, K.W., Reach Capability of Men and Women: A Three Dimensional Analysis. AMRL-TR-77-50, 1978, for an updated presentation of this material.

The data in Table 3 are in the generally expected direction of lower values for females than males, although this difference tends to be somewhat more pronounced for the force application dimensions than for the strictly anthropometric dimensions. Based on average dimensional overlap values there tends to be more commonality of the male-female dimension range for "tissue-based," female dimensions, although the hand dimensions are not entirely consistent with this tendency. Similarity of male-female dimensions is most pronounced for Bust Depth and Chest Depth. It is probable that the female breast compensates for the smaller female rib cage to produce this dimensional similarity. It should be noted that the brassiere produces a chest/bust depth configuration that is not entirely anatomical. However, the female Bust Depth dimension, as shown in Table 3, is a valid design consideration for equipment and access.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A study of the human factors aspects of five selected items of Navy equipment, namely, oxygen breathing apparatus, safety harness, emergency escape scuttle, life rails, and rotary observation windows, has been undertaken to ensure that the smaller size and lesser strength of females would not be a deterrent to the use of the equipment by women. The study involved a review of the applicable specifications for each item of equipment, a survey and enumeration of male and female anthropometric data, and a linking of engineering and anthropometric data. Each item has been assigned to a hazard category.

Of the five items evaluated, two appear to pose significant problems when used by women. Fit and high deceleration forces were the major concerns for the safety harness while operating force requirements were critical for the escape scuttle. In addition, there were also some difficulties for some women in the use of the oxygen breathing apparatus.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Anthropometry, equipment evaluation, escape scuttles, female, oxygen breathing apparatus, performance, safety evaluation, safety harness, safety hazards.

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