NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL REPORT

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U.S. NAVY FLIGHT DECK HEARING PROTECTION USE TRENDS: SURVEY RESULTS

by

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18 May 2006

DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
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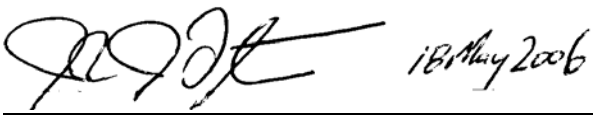

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14. ABSTRACT

Hearing loss claims have risen steadily in the U.S. Department of Veterans Affairs across all military services for decades. The U.S. Navy, with U.S. Air Force and industry partners, is working to improve hearing protection and speech intelligibility for aircraft carrier flight deck crews who work up to 16 hr per day in 130-150 dBA tactical jet aircraft noise. Currently, flight deck crews are required to wear double hearing protection: earplugs and earmuffs (in a cranial helmet). Previous studies indicated this double hearing protection provides approximately 30 dB of noise attenuation when earplugs are inserted correctly and the cranial/earmuffs are well-fit and in good condition. To assess hearing protection practices and estimate noise attenuation levels for active duty flight deck crews, Naval Air Systems Command surveyed 301 U.S. Navy Atlantic and Pacific Fleet flight deck personnel from four aircraft carriers and two amphibious assault ships. The survey included a detailed assessment of cranial helmet fit and maintenance condition; earplug use and insertion depth; anthropometric head size measures; and personal/historical data. This survey identified numerous technological and hearing conservation policy changes to improve hearing protection for flight deck crews. Based on these findings, the U.S. Navy is improving procedural documentation for flight deck hearing protection fit, use, and maintenance, as well as developing and fielding enhanced hearing protection technology in joint efforts with the U.S. Air Force.

15. SUBJECT TERMS

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SUMMARY

Hearing loss claims have risen steadily in the U.S. Department of Veterans Affairs across all military services for decades. The U.S. Navy, with U.S. Air Force and industry partners, is working to improve hearing protection and speech intelligibility for aircraft carrier flight deck crews who work up to 16 hr per day in 130-150 dBA tactical jet aircraft noise. Currently, flight deck crews are required to wear double hearing protection: earplugs and earmuffs (in a cranial helmet). Previous studies indicated this double hearing protection provides approximately 30 dB of noise attenuation when earplugs are inserted correctly and the cranial/earmuffs are well-fit and in good condition. To assess hearing protection practices and estimate noise attenuation levels for active duty flight deck crews, Naval Air Systems Command surveyed 301 U.S. Navy Atlantic and Pacific Fleet flight deck personnel from four aircraft carriers and two amphibious assault ships. The survey included a detailed assessment of cranial helmet fit and maintenance condition (e.g., earmuff headband tension, earcup foam and cushion integrity); earplug use and insertion depth; anthropometric head size measures; and personal/historical data. Data analysis showed that 79% of surveyed flight deck personnel ears received an estimated 0-6 dB of noise attenuation from either shallow earplug insertion depths or never wearing earplugs (47% reported never wearing earplugs). For subjects who reported they sometimes or always wore earplugs (14% reported always wearing earplugs), only 7% inserted the earplugs deeply enough in both ears to achieve the maximum expected noise attenuation of 22 dB in both ears. Worn without earplugs, the cranial helmet with earmuffs has been reported to provide approximately 21 dB of noise attenuation when correctly fit, worn, and maintained. All survey subjects reported wearing a cranial helmet with earmuffs, but 75% of subjects were issued a questionable size (most wore the largest of four sizes available), and 41% of earcup cushions and foam inserts were deteriorated, hard, creased, or missing. This survey identified numerous technological and hearing conservation policy changes to improve hearing protection for flight deck crews. Based on these findings, the U.S. Navy is improving procedural documentation for flight deck hearing protection fit, use, and maintenance, as well as developing and fielding enhanced hearing protection technology in joint efforts with the U.S. Air Force.

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INTRODUCTION

BACKGROUND

U.S. Department of Defense occupational safety and health instructions set 85 dBA as the safe noise exposure limit for an 8-hr time-weighted average (TWA); and for every 3 dB increase in noise level, the safe exposure time limit is cut in half (reference 1). U.S. Navy instructions state that, when noise levels exceed 104 dBA, double hearing protection (earplugs and earmuffs) shall be worn, and when noise exposures exceed an 8-hr TWA of 84 dBA, administrative controls like crew rotation are to be implemented, in addition to wearing double hearing protection (references 2 through 5).

U.S. MILITARY JET AIRCRAFT NOISE LEVELS

U.S. Navy, Marine Corps, and Air Force high-performance jet aircraft produce 130-150 dB noise. Figure 1 compares legacy military jet noise and estimated noise produced by the next-generation F-35 Joint Strike Fighter. On an aircraft carrier, each catapult launch exposes flight deck crews to approximately 20-30 sec of aircraft noise with engines at maximum power. Launch duration is defined as the time from when the engine is first runup past 25% of maximum power until the aircraft clears the end of the flight deck. When an aircraft is recovered (a cable arrested landing), pilots are required to push the throttle to maximum power again and to prepare to take off in the event they miss the arresting cables. A recovery takes approximately 3 sec. The recovery duration is defined as the time from when the aircraft first passes the end of the deck until the engine setting is less than 25% of maximum power. In a 24-hr period, a typical busy day for a flight deck crewperson is approximately 60 launches and 60 recoveries on an aircraft carrier (reference 6).

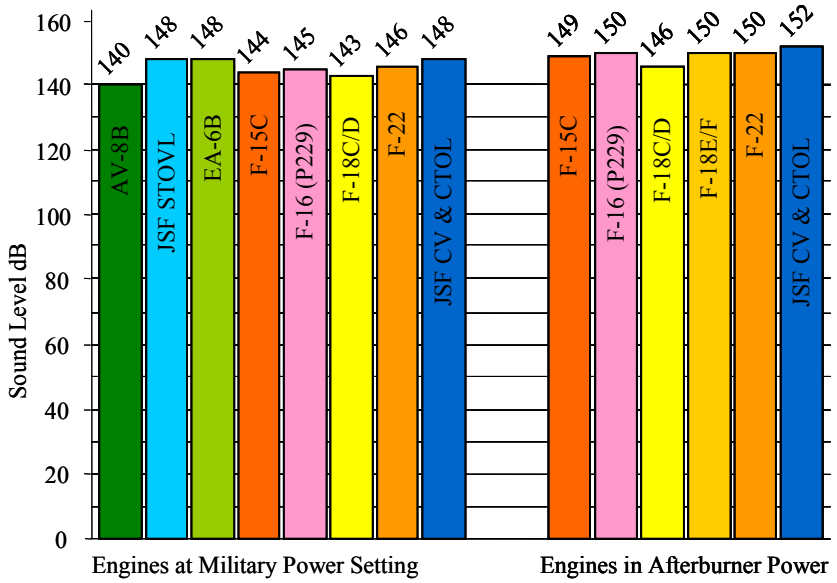

Figure 1: U.S. Military Jet Aircraft Near-Field Noise
Levels Measured Approximately 50 ft Radius and 135 deg Off Nose/Centerline (Reference 6)

HEARING PROTECTION ON U.S. NAVY FLIGHT DECKS

Earplugs Commonly Used on U.S. Navy Flight Decks

Three commonly used earplugs on U.S. Navy flight decks are the Aearo E·A·R Classic™ foam earplug, the V-51R Single-Flange earplug, and the Triple-Flange earplug (see figure 2).[1] The E·A·R Classic™ is a one-size-fits-most expanding foam earplug that needs to be fully inserted in the ear canal to achieve maximum noise attenuation performance (reference 7). The V-51R Single-Flange earplug and the Triple-Flange earplug are available in sizes; both must be initially fit by medically trained personnel and then fit correctly again for each use by the trained wearer to achieve maximum noise attenuation.

Figure 2: Earplugs Commonly Used by U.S. Navy Flight Decks Personnel;
Aearo E·A·R Classic™, V-51R Single-Flange, Triple-Flange

U.S. Navy Flight Deck Crewman Helmet with Earmuffs

The U.S. Navy Flight Deck Crewman Sound Attenuating Helmet Assembly is commonly called "the cranial" (see figure 3, left insert). The cranial is worn to protect against head injuries and high intensity noise on U.S. Navy flight decks and in some aircraft.

HGU-24 and 25/P

The HGU-24/P cranial includes a sound-powered microphone and headset assembly for communication, while the HGU-25(V)2/P cranial does not include communications capability (reference 8). The HGU-24/P and HGU-25/P cranials are available in four sizes (6¾, 7, 7¼, and 7½).

Radio Cranial

The Radio Cranial (also known as the Hydra Helmet) is another communications helmet approved for use (see figure 3, right insert). The Radio Cranial is one size to fit all.

[1] Since April 2003, the Defense Supply Center is congressionally mandated to provide Sound Guard foam earplugs when universal fit foam earplugs are ordered. New Dynamics, the manufacturer, is a sheltered workshop activity. During the time period of this survey, E·A·R Classic earplugs were still the most prevalent earplug in use. Sound Guard earplugs fit and perform similarly to E·A·R Classic earplugs.

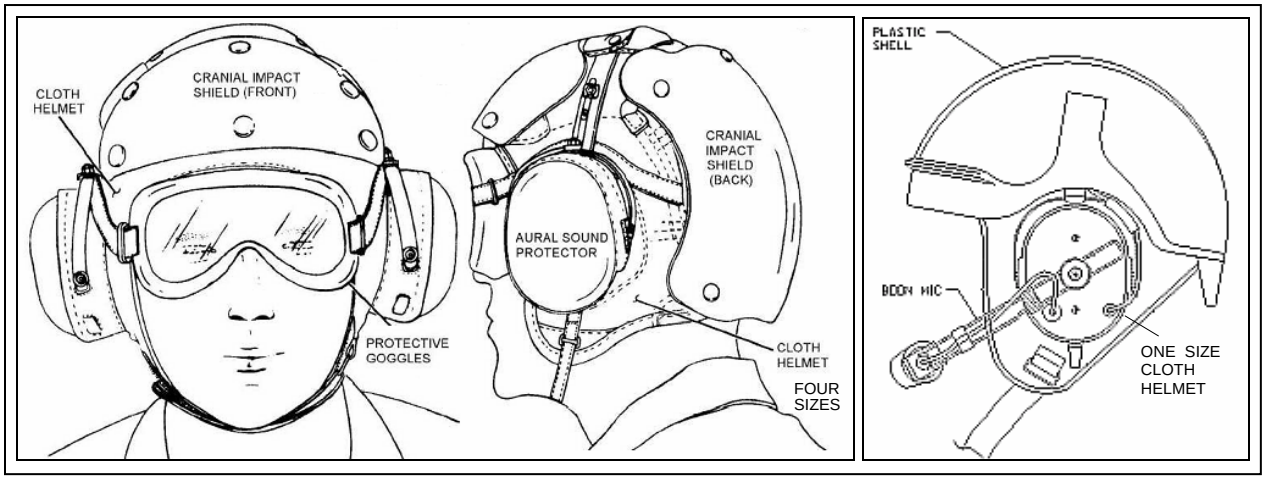

Figure 3: Flight Deck Crewman Sound Attenuating Helmets -
HGU-25(V)2/P and Radio Cranial (respectively)

Earmuffs (see figure 4) are tethered in the cranial to provide noise attenuation. The left and right earcups include standard earcup cushion seals that consist of foam inside a polyurethane skin. The purpose of the earcup cushion seal is to create an acoustic seal between the earcup and the user's head. The inside of each earcup is lined with 0.5-in. polyurethane foam to dampen noise inside the earcup (reference 9).

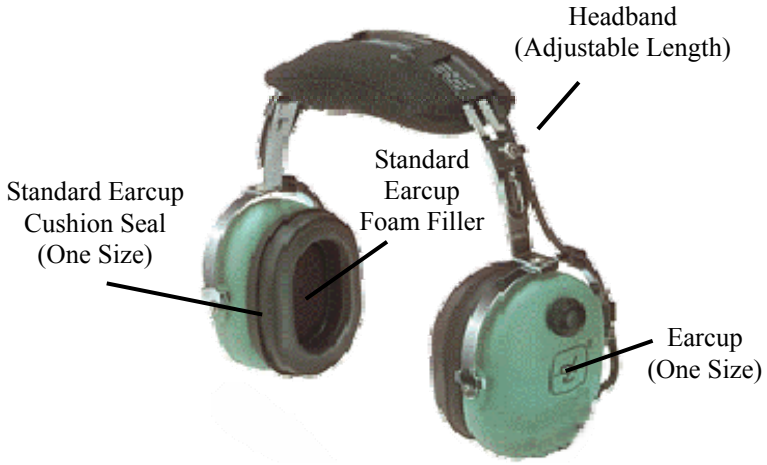

Figure 4: Sound Aural Protection (Earmuffs)

U.S. NAVY FLIGHT DECK CREW DAILY HAZARDOUS NOISE EXPOSURE

Figure 5 is a diagram of flight deck personnel locations as they ready an aircraft for catapult launch. Just prior to launch, the Plane Captain (green diamond) and forward Final Checker (blue star) move to the Foul Line; however, the aft two Final Checkers (orange triangles) remain as shown. Figure 6 provides a photograph of deck personnel at work around launching aircraft. Crews working at side-by-side catapults are often exposed to the noise of adjacent aircraft, as well as the aircraft they are launching. Figure 7 shows noise propagation contour lines for an

F-18C jet aircraft. Similar noise contours are generated by other conventional takeoff and landing aircraft. Vertical takeoff and landing aircraft like the AV-8B Harrier produce noise contours that are generally more omni-directional. It is important to note that a number of flight deck personnel routinely work within the marked "noise hazard" area (reference 6).

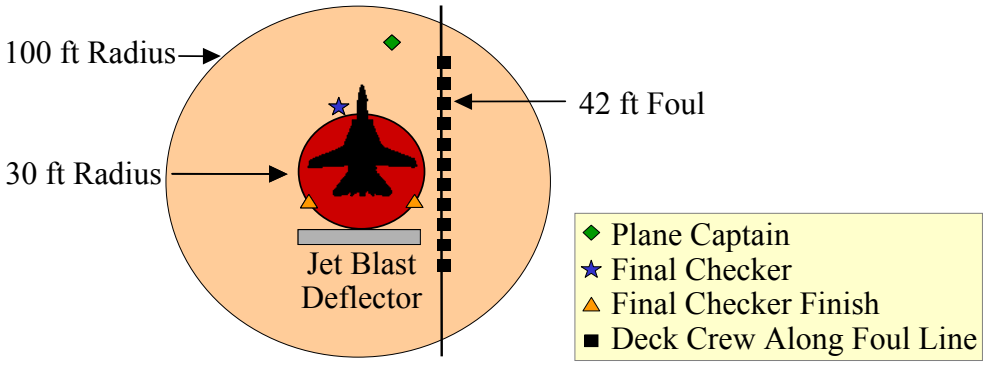

Figure 5: U.S. Navy Flight Deck Personnel Location During Aircraft Catapult Launch

Figure 6: Photographs of Deck Crews at Work in Close Proximity to Jet Noise

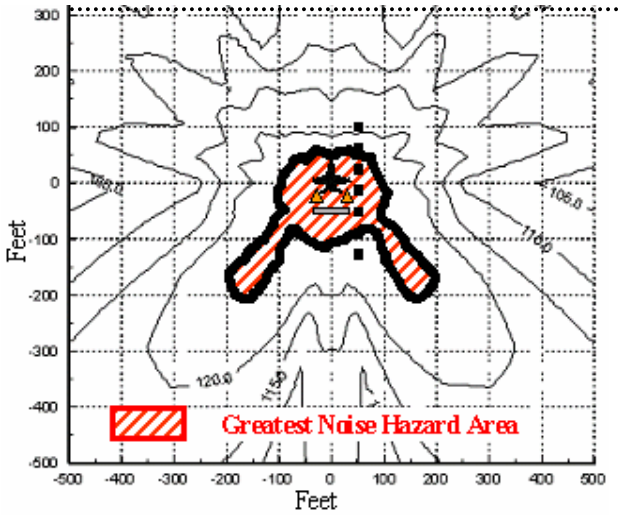

Figure 7: F-18C Noise Contours and Hazard Area

Aircraft personnel work long shifts (10-16 hr per day) in close proximity to high-level engine noise. If worn correctly, current double hearing protection of earplugs and earmuffs provides approximately 30 dB of noise attenuation protection (references 10 and 11). It has long been known that earplugs and earmuffs worn together offer greater protection than either item individually, but less than the sum of protection of the two devices (references 10, 11, and 12). Double hearing protection commonly used by U.S. Navy flight deck crews provides adequate noise attenuation in jet noise environments (130-150 dB) when worn correctly and when total daily noise exposures limit crews to an 8-hr TWA of 85 dBA or less. For example, a 30 dB sound protector would allow the wearer less than 5 min total daily exposure in a 135 dB noise field (reference 1). A Final Checker would exceed the safe daily noise exposure limit with just one or two high-performance jet aircraft launches. Additionally, after long flight deck duty days in jet aircraft noise, there are few, if any, quiet spaces below 84 dBA for flight deck crews' hearing to recover (reference 13). The most prevalent U.S. Department of Veterans Affairs disability claim is hearing loss. For all military departments combined, hearing loss claims totalled over $786M in 2005, over $7.5B since 1977, and the trend is upward (reference 14). These costs only include disability compensation payments for hearing loss and do not include the compensation for tinnitus (ringing in the ears) or the added cost of treatment, audiograms, hearing aides, retraining, etc. The U.S. military total costs associated with hearing loss have been estimated at $2-3B per year (reference 13). The U.S. Navy and Marine Corps portion of these compensation costs is approximately 25-30% (reference 14).

PURPOSE

The purpose of this survey was to estimate noise attenuation provided by helmets, earmuffs, and earplugs as used by U.S. Navy flight deck crews and to check the level of compliance with hearing conservation instructions. This survey was one part of a larger effort to determine both

non-material (e.g., training, enforcement, crew rotation) and material (e.g., technological, pharmacological) intervention routes to improve hearing protection for U.S. Navy (reference 15) and U.S. Air Force aviation personnel.

METHODS

GENERAL

A core data collection team comprised of experienced life support equipment developers and anthropometrists collected survey data by questionnaire interview, inspection, and anthropometric measures. The survey (appendix A) included queries of personnel demographics (e.g., age, gender, rank, etc.), the type of hearing protection worn, and how hearing protection was selected, worn, and maintained. The survey protocol was approved by a U.S. Navy human-use review board and included gathering Informed Consent from each survey participant (reference 16). The goal was to survey at least 300 personnel across six ships: two aircraft carriers per U.S. Second (Atlantic) and Third (Pacific) Fleets and an amphibious assault ship from each fleet as well, i.e., three ships per coast.

SUBJECT SELECTION

The survey was not to interfere with normal duties; therefore, subjects were not selected for discriminating variables like rank, duty station, age, gender, race, or anthropometric dimensions (e.g., head circumference). Rather, subjects volunteered or were ordered by superiors to participate (the survey included a question on reason for the participation). U.S. Navy Bureau of Naval Personnel data were used to assure the subject population was representative of actual flight deck personnel distributions for gender and military rank.

ANTHROPOMETRY

Three common head dimensions were measured on each subject using spreading calipers and measuring tapes: bi-temple breadth, head breadth, and head circumference.

EARPLUG USE AND INSERTION DEPTH

For this survey, subjects who reported that they were earplug users were asked to insert Aearo E·A·R Classic™ expanding yellow foam earplugs in both their ears. After waiting several minutes for the earplugs to fully expand, the earplugs were marked around their circumference at the opening of the ear canal. Earplugs were removed, allowed to expand fully, and then left and right earplug insertion depths were measured as the distance from the inserted earplug tip to the ink marking. Subject's left and right earplug insertions depths were analyzed separately, i.e., they were not averaged together.

CRANIAL HELMET SIZE, FIT, AND MAINTENANCE

The following was recorded to assess overall cranial helmet fit for each subject: size of cranial worn, earcup position over left and right ears, chinstrap length, suitability of cranial helmet position on the head and relative to the brow ridge (glabella). Each cranial was also inspected, particularly for the condition of the earcup cushions and earcup foam inserts.

HEADBAND CLAMPING FORCE

Each subject's cranial headband force was measured as a practical way to estimate earmuff headband condition and ability to press the earcups tightly to the head. Headband clamping force was measured using an Inspec Laboratories, Ltd. (Salford, UK) tension rig (see figure 8) and following ANSI S12.6 methods (set 145 mm bitragion breadth and 130 mm head height) (reference 17).

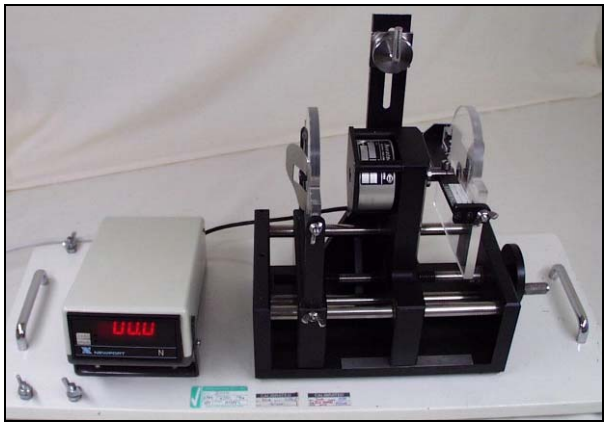

Figure 8: Inspec Laboratories, Ltd. Rig to Measure Earmuff Headband Clamping Force

HAIR AND HELMET FIT

Subject hair type was recorded (i.e., thick/thin, coarse/fine, curly/straight, close-cut/bald). Several measures were taken on females with long hair to estimate the girth added by tied-up hair under the cranial helmet: (1) head circumference under hair buns/braids, (2) head circumference including hair buns/braids at what appeared to be the greatest hair volume, and (3) distance up or down from the head circumference path, at what appeared to be the greatest hair volume.

EYEGLASS TEMPLES

The style of eyeglasses worn by subjects was noted. The distance from the side of the head to the outer surface of the eyeglass temples where they passed under the earcups was estimated by subtracting bi-temple breadth from eyeglasses bi-temple breadth and dividing by two. Temple height under the earcup cushion was also measured using calipers. Figure 9 provides a diagram of eyeglass temple measurements.

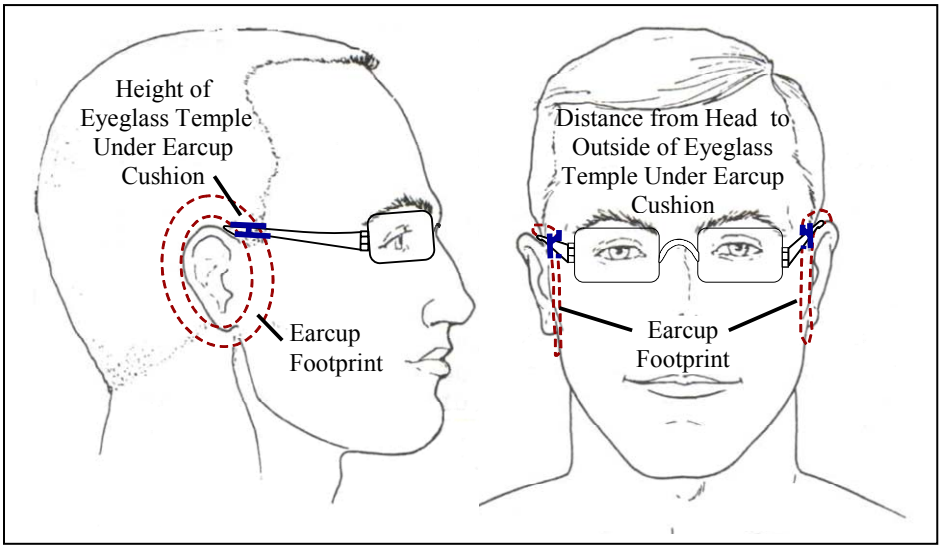

Figure 9: Eyeglass Temple Dimensions Under Earcup Cushion

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RESULTS AND DISCUSSION

GENERAL

Over 300 U.S. Navy flight deck personnel were interviewed and measured from six Atlantic and Pacific Fleet aircraft carrier and amphibious ship flight decks to assess how well hearing protection devices were used, fit, and maintained. This survey identified numerous ways to improve hearing conservation policy, policy implementation, and hearing protection designs.

SUBJECTS

A total of 301 subjects (34 female, 267 male) were measured and interviewed in this survey. Tables 1-5 provide descriptive statistics for subject age, flight deck experience, job type/ location, rank, and ship type.

Table 1: Subjects' Age and Flight Deck Experience

Subjects	Mean	Median	SD	Min	Max
Age (yr)	24	22	5	18	42
Flight Deck Experience (mo.)	34	24	37	1	204

Table 2: Subjects by Job Type (Shirt Color)

(Appendix B provides typical jobs associated with specific shirt colors worn on U.S. Navy flight decks)

Shirt Color	N	Percent
Red	37	12.3
Blue	81	26.9
Green	47	15.6
Yellow	63	20.9
Brown	6	2.0
Purple	52	17.3
White	15	5.0

Table 3: Subjects by Job Location

Job Location	N	Percent
Checker/Shooter	11	3.7
Jet Blast Deflector	3	1.0
Catapults	28	9.3
Arresting Gear	5	1.7
Fire Crew	30	10.0
Safety	6	2.0
Chocks & Chains	61	20.3
Tractor	14	4.7
Plane Captain	5	1.7
Aircraft Director	57	18.9
Fuel	52	17.3
Other	29	9.6

Table 4: Subjects by Rank

Rank	N	Percent
E1	3	1.0
E2	19	6.3
E3	152	50.5
E4	74	24.6
E5	26	8.6
E6	20	6.6
E7	4	1.3
O3	3	1.0

Table 5: Subject by Ship Type and Fleet

Ship Type	Location	N	Percent
LHA/LHD*	Atlantic	63	20.9
LHA/LHD	Pacific	53	17.6
CVN*	Atlantic	61	20.3
CVN	Pacific	53	17.6
CVN	Pacific	55	18.3
CVN	Pacific	16	5.3
* CVN – Aircraft Carrier * LHA/LHD – Amphibious Assault Ship			

Subjects represented the typical flight deck population distribution for rank and gender (according to unpublished data acquired for this survey from the U.S. Navy Bureau of Naval Personnel statistics). Additionally, 63% of the subjects reported spending at least 11 hr on the flight deck during a typical shift; 29% reported durations between 6 and 10 hr per day.

ANTHROPOMETRY

Head breadth and head circumference were collected on 285 subjects. These data were compared to head anthropometry data collected in 2002 on 747 U.S. Navy aircrew and flight deck crew personnel (reference 18). Survey subjects were similar (could find no statistically significant difference) for head breadth and circumference to those measured in the referenced study. Figure 10 and table 6 report the similarities between the two data sets.

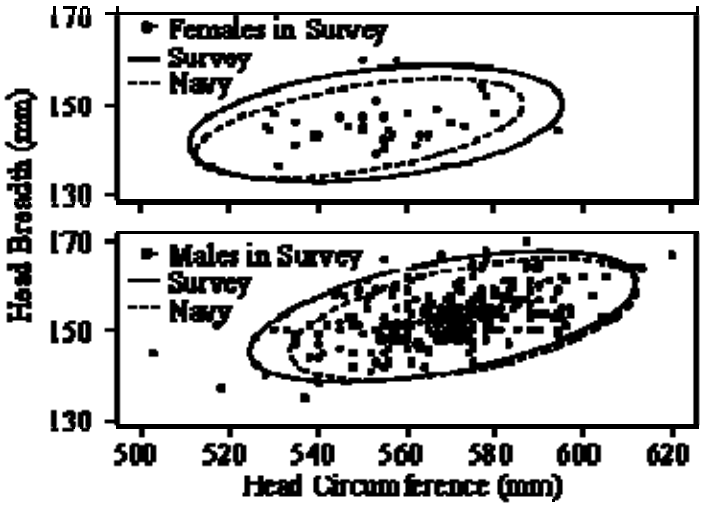


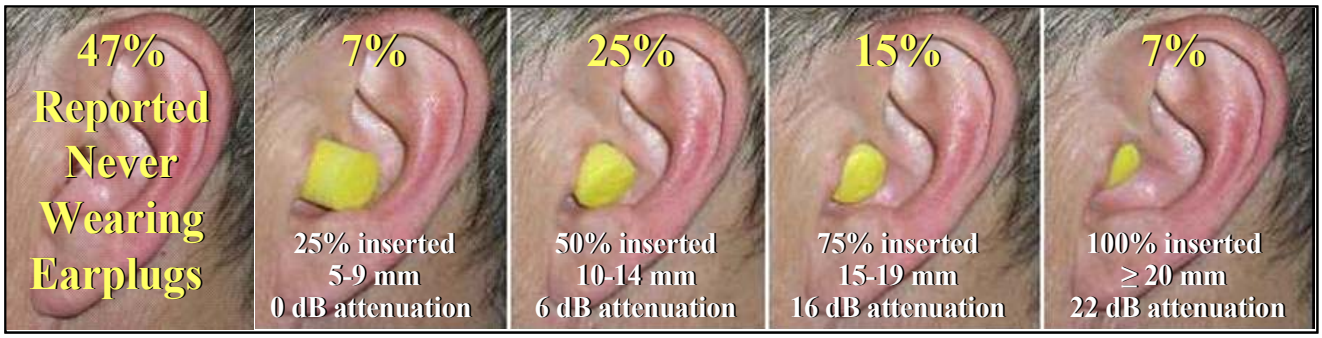
Figure 10: Estimated 95th Percentile Regions for Head Size by Gender:
Compares Navy Anthro Survey and This Survey

Table 6: Head Size by Gender: Navy Anthro Survey and This Survey

Gender	Data	Measure	N	Values in mm				
				Mean	Med	Min	Max	SD
Female	Anthro Survey	Breadth	220	144.5	144	132	158	4.6
		Circumference	220	549.4	548	514	593	15.1
	This Survey	Breadth	34	145.6	145	136	160	5.4
		Circumference	34	553.1	554	515	594	17.2
Male	Anthro Survey	Breadth	521	152.4	152	132	170	5.6
		Circumference	521	573.2	572	523	618	16.0
	This Survey	Breadth	251	153.1	153	135	170	6.1
		Circumference	251	568.4	570	503	620	17.8

EARPLUG USE AND INSERTION DEPTH

The most significant finding of this survey was that 79% of the ears of flight deck personnel interviewed received an estimated 0-6 dB of noise attenuation from either shallow earplug insertion depths or never wearing earplugs (47% self-reported never wearing earplugs). Only 14% reported always wearing earplugs beneath their cranials, i.e., 14% reported wearing the required double hearing protection. Further, of those who reported sometimes or always wearing earplugs, few inserted the earplugs deeply enough to benefit fully. Figure 11 shows how noise attenuation provided by an expanding foam earplug is directly proportional to its insertion depth (reference 12). Figure 11 also shows the percentage of earplugs inserted to each depth. For example, only 7% inserted the earplugs deeply enough to achieve 22 dB noise attenuation in both ears.



Noise Reduction Ratings from Air Force Research Laboratory earplug insertion depth study using American National Standard S12.6-1997 (R2002) Methods for Measuring the Real-Ear Attenuation of Hearing Protectors, Method A (Experimenter Supervised / Verbally Coach), mean minus two standard deviations.

Figure 11: Earplug Insertion Depth, Related Noise Attenuation,
Percentage of Earplugs at Each Depth

Table 7 provides earplug insertion depth summary statistics. No significant difference could be found between left and right earplug insertion depth, suggesting handedness is not a factor, i.e., right handedness predominates yet right earplug insertion was not deeper than left. Some 85% of subjects' left and right earplugs were ≤2 mm different for insertion depth (8 mm was the maximum difference between left and right earplug insertion depth). No correlation could be found between having similar left/right earplug insertion depths and achieving an optimum earplug insertion depth of ≥20 mm. For example, one subject had a 10 mm left earplug insertion and a 12 mm right earplug insertion; the insertion depths were within 2 mm of each other, yet both were shallow and only achieved an estimated 6 dB attenuation.

Table 7: Descriptive Statistics for Earplug Depth
(Left and Right Earplugs Accounted Separately)

Earplug Insertion	Mean	Med	SD	Min	Max
Earplug Depth (mm)	13.6	13	3.9	7	22

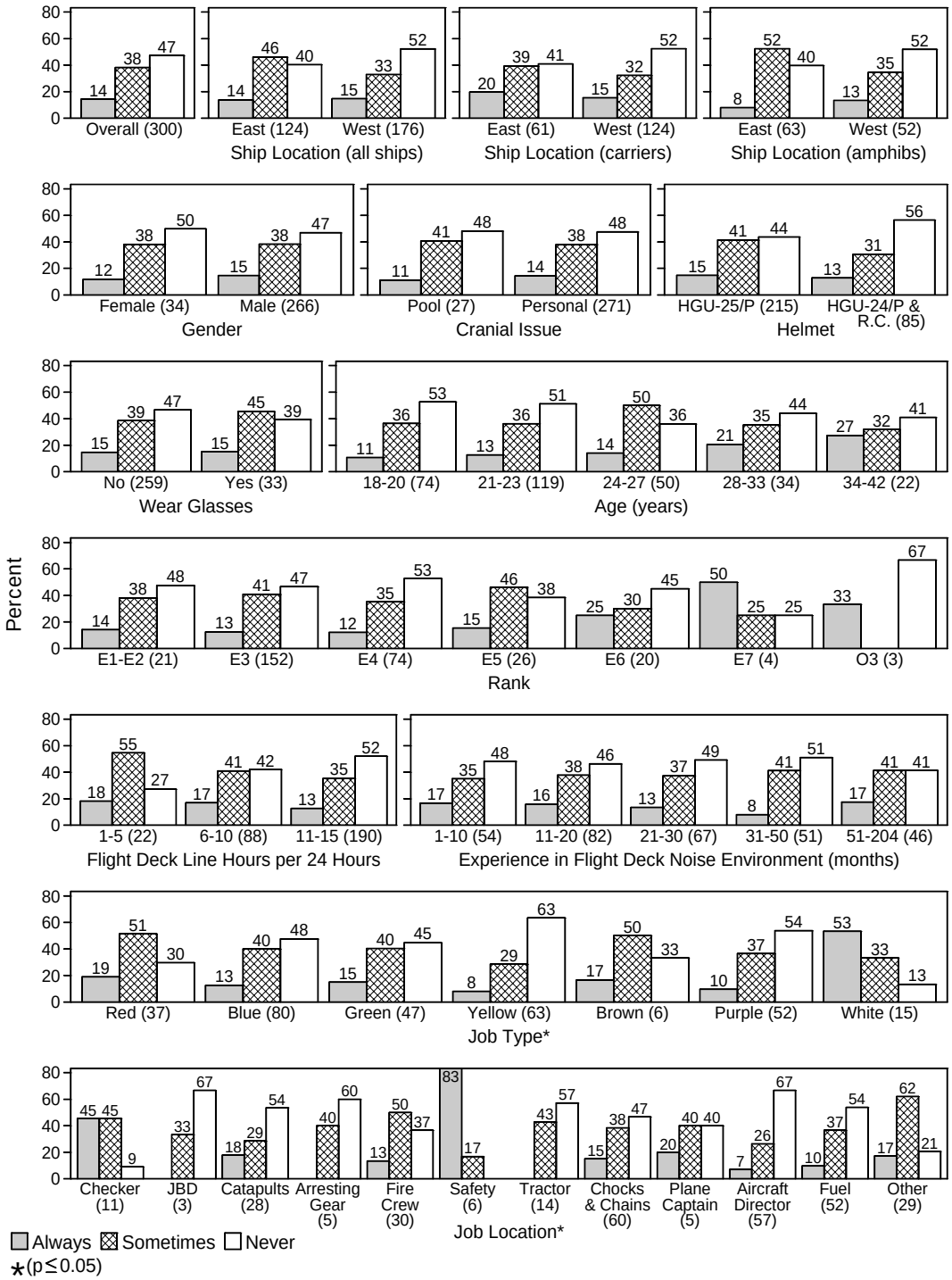
Of the subjects who reported wearing earplugs at least sometimes, 75% reported wearing E·A·R Classic™ earplugs; 75% reported they replaced their earplugs daily, while 24% reported replacing them when they appeared soiled. Table 8 ranks earplug use by both job type and job location. These data indicate personnel in some of the most hazardous jet engine noise locations, such as Aircraft Directors and Jet Blast Deflector personnel, were least likely to wear earplugs.

Table 8: Earplug Usage by Job Type and Job Location

Job Type	Job Location	N	Wears Earplugs			
			Always	Sometimes	Never	Percent Never
Green	Safety	1	1	0	0	0.0
Yellow	Catapults	1	1	0	0	0.0
White	Safety	5	4	1	0	0.0
Red	Other	8	3	5	0	0.0
Green	Checker	3	1	2	0	0.0
Blue	Fire Crew	1	0	1	0	0.0
Brown	Other	1	0	1	0	0.0
Yellow	Tractor	1	0	1	0	0.0
White	Checker	8	4	3	1	12.5
Green	Other	8	1	6	1	12.5
Blue	Other	6	1	3	2	33.3
Red	Fire Crew	29	4	14	11	37.9
Brown	Plane Captain	5	1	2	2	40.0
Blue	Chocks & Chains	60	9	23	28	46.7
White	Other	2	0	1	1	50.0
Yellow	Other	4	0	2	2	50.0
Purple	Fuel	52	5	19	28	53.8
Green	Catapults	27	4	8	15	55.6
Green	Arresting Gear	5	0	2	3	60.0
Blue	Tractor	13	0	5	8	61.5
Yellow	Aircraft Director	57	4	15	38	66.7
Green	Jet Blast Deflector	3	0	1	2	66.7
Total		300*	43	115	142	47.3
* Does not total 301 because one subject did not report earplug use.						

Figure 12 shows earplug use habits across various subject groupings: ship type, ship location, gender, cranial helmet issuing, age, rank, daily time on the flight deck, overall flight deck experience, job type, and location. Chi-square testing determined whether the frequency of those who always, sometimes, or never used earplugs varied significantly between these groups. No significant differences were found between subjects, fleets, or ship types for hearing protection use, fit confirmation, and maintenance. The only significant differences found ($p \leq 0.05$) between these groups were for job type and job location. For job type, White Shirts used earplugs more

often than others (appendix B provides typical jobs associated with specific shirt colors worn on U.S. Navy flight decks). For job location, Safety and Final Checker personnel used earplugs more often than others.



Indicates that the frequency of earplug use varied significantly among the levels for that group. Parentheses include number of deck crew surveyed for that group.

Figure 12: Percentage of Earplug Use for Various Subject Groupings

CRANIAL HELMET SIZE, FIT, AND MAINTENANCE

The cranial/earmuffs, worn without earplugs, have been reported to provide approximately 21 dB of noise attenuation (reference 10) when correctly fit, worn, and maintained. It has been reported since the 1950s that air (acoustic) leaks between earcups and wearers' heads can reduce noise attenuation 3-15 dB across a broad range of frequencies, predominantly in the lower frequencies (references 12 and 19). The following criteria are important to maximize cranial/earmuff noise attenuation; these were assessed in the survey and findings are reported below:

a. Sized correctly.
b. Adjusted to fit comfortably and to ensure earcup-to-head seal is not disrupted by items such as thick hair, eyeglasses, caps, ear warmers, etc.
c. Well maintained so earcup cushions and earcup foam inserts are soft and pliable.
d. Headband clamping force falls in the range of 6-21 N (references 20, 21, and 22).

CRANIAL SIZES ISSUED AND FIT OBSERVATIONS

Subjects wore one of three cranial helmet types: the HGU-24/P (sound powered), HGU-25(V)2/P, or the Radio Cranial (see figure 3 above). Table 9 lists the distribution of the cranials inspected in this survey.

Table 9: Distribution of Cranial Types Inspected

Cranial Helmet Type	N	Percent
HGU-24/P (sound powered)	17	5.6
HGU-25(V)2/P	216	71.8
Radio Cranial	68	22.6

Of the four cranial cloth sizes, 70% of the subjects were issued the largest (size 7½); 68% did not know cranials came in sizes or what size they should wear; and 67% took whatever size they were issued. Most ships stocked only the two largest sized cranials (sizes 7¼ and 7½). According to a common hat size chart (table 10), 75% were issued a questionable size of cranial, e.g., 13% of subjects issued the largest cranial size (7½) may have been better fit in the smallest cranial size (6¾). Figure 13 shows crewmember in issued cranial (largest size, 7½). Fit trials indicated the smalled cranial size would have fit best.

Figure 13: Crewmember Wearing Issued Cranial (Too Large)

Table 10: Common Hat Size Chart
Used to Estimate Correct Cranial Size

Head Size (Head Circumference)		
in.	cm	Hat Size
21	53	6⅝
21½	54	6¾
21⅝	55	6⅞
22⅛	56	7
22½	57	7⅛
23	58	7¼
23⅜	59	7⅜
23¾	60	7½
24	61	7⅝
24½	62	7¾
25	63	7⅞

Despite these possible cranial size issues, the survey team reported that 90% of all gear fit well, according to appearance and fit checks. For example, inspection of the earcup cushion seal around the ears indicated that 73% had both ears inside the earcup cushions, indicating a good earcup fit. The other 27% had at least one earlobe trapped under the bottom of the earcup cushion, possibly causing an acoustic leak and degraded attenuation (references 12 and 19). Chinstrap length was rated as good for 94% of the subjects (the chinstrap may have been too long for 4% and too short for 2%). Cranial position in the fore - aft direction was measured from the brow (glabella) to the leading edge of the cloth liner (table 11 provides summary statistics). These cranial position data do not correspond to existing fit instructions; they provide a relative indicator of earmuff and headband fore - aft rotation on the head and around the ears. For 9% of subjects, the cranial appeared to sit too high on the head, while 1% appeared to sit too far back, forward, or low on the head.

Table 11: Distance from Brow to Cranial Cloth Front Edge

Cranial Placement on Head	Mean	Med	SD	Min	Max
Brow to Cloth Distance (mm)	40.4	39.0	18.4	0.0	104.0

CRANIAL MAINTENANCE

The survey team determined that approximately 41% of the earcup cushions and/or earcup foam inserts were in unsatisfactory condition, despite 73% reporting they inspected or looked over their cranials at least daily. Figure 14 shows a cranial with poor earcup cushions and missing earcup foam inserts. Another 15% reported they never inspected their cranials. Some 9% reported that they had to share or "hot swap" cranials throughout daily missions. These shared gear tended to be the most soiled and least maintained. Noise attenuation is likely reduced in poorly maintained cranials with deteriorated, flat, hard, and missing earcup cushions and earcup foam (reference 12).

Figure 14: Survey Subject's Cranial in Poor Condition
(Note Hard-Creased Earcup Cushions, Missing Earcup Foam Inserts, and Dirty Cloth)

HEADBAND CLAMPING FORCE

Headband clamping force has been linked to wearer comfort and to noise attenuation. Previous research indicated that new headbands generally provide 6-21 N of clamping force, but that 17 N approximates the upper limit for comfort when wearing traditional earmuff designs (references 12, 20, 21, and 22). Comfort relates to pressure (headband force per earcup seal contact area); however, higher headband clamping forces are thought to reduce acoustic leaks between the earcup seal and the wearer's head (references 12 and 19 through 23). As headband clamping force commonly reduces with routine use, age, and active headband stretching by wearers (reference 12), this survey included clamping force measurements on all cranials/earmuffs. Table 12 provides clamping force data collected on earmuffs while in the cranials. These clamping forces are consistent with previously reported headband forces and indicate that these headbands may not have been age-fatigued or excessively spread open to loosen them.

Table 12: Cranial Headband Clamping Force

Cranial Headband Clamping	Mean	Med	SD	Min	Max
Tension (Force in N)	15.3	15.5	2.9	6.5	23.2

The cranial was reported to be comfortable enough to wear at least 10 hr at a time by 30% of the subjects. However, 55% reported that, after a few hours of wearing the cranial, they felt major discomfort. Another 15% reported that the cranial caused severe discomfort within a few hours of donning (the subject with the maximum clamping force (23.2 N) reported immediate, severe discomfort).

EFFECT OF HAIR AND OTHER ITEMS ON FIT

Many personnel who had to share cranials wore a bandana or skullcap under their cranial as a hygiene barrier. Others reported that they wore items like bandanas to absorb sweat in hot weather and winter caps and ear warmers to keep warm in cold weather. These barriers generally passed under the earcup cushions (see figure 15), and while attenuation was not measured in this survey, air (acoustic) leaks can reduce earcup attenuation (references 12 and 19).

Figure 15: Survey Subjects Wearing Personal Items Under Earcup Seals
(Note Placement of Bandana, Eyeglasses, and Winter Hat)

Males are not permitted to have long hair in the U.S. Navy; however, even short hair can disrupt the earcup sealing to the head. For this reason, subject hair type was recorded (i.e., thick/thin, coarse/fine, curly/straight, close-cut/bald). The survey team did not note that any hair type correlated to a cranial fit issue. Female subjects who had long hair and wore it tied up added an average of 2 cm to head circumference measures. Tied up hair, hair type, length, or style was not reported to impact cranial fit for female subjects. This may be due to the largest size cranials being issued and these sizes being large enough to accommodate the added hair mass and bulk and/or the hair buns passing inferior to the bottom edge of the cranial and fitting in the nape of the neck.

EYEGLASS TEMPLES

Eyeglass temples passing between the earcup cushion and the wearer's head creates a noise leak pathway that has been linked to a 3-7 dB reduction in noise attenuation (references 12 and 19 through 23). Eyeglasses use was reported by 11% of the subjects: 72% wore standard type frames, 21% cable-type, and 7% wore some other type. Table 13 provides the three eyeglass-related measurements (described in Methods). Figure 16 shows a subject with eyeglasses temple worn under earcup cushion.

Table 13: Descriptive Statistics for Measures Taken on Eyeglass Wearers

At Intersection with Earcup Footprint	Mean	Med	SD	Min	Max
Temple Breadth (mm)	140.8	140.0	6.7	127.0	156.0
Eyeglass Breadth (mm)	150.4	150.0	6.8	140.0	167.0
Eyeglass Temple Height (mm)	3.3	3.0	1.4	1.5	8.0

Figure 16: Eyeglasses Temple Worn Under Earcup Cushion

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CONCLUSIONS

Of the 301 survey subjects, no significant differences were found between Atlantic and Pacific fleets or ship types for hearing protection use, fit confirmation, and maintenance. The most significant finding of this survey was that 79% of the ears of flight deck personnel interviewed received an estimated 0-6 dB of noise attenuation from either shallow earplug insertion depths or never wearing earplugs. (Left and right ear data were analyzed independently: not averaged per person.) Some 47% self-reported never wearing earplugs while just 14% reported always wearing earplugs with their cranials (which is the required double hearing protection). Further, of those who reported sometimes or always wearing earplugs, only 7% inserted the earplugs deeply enough to achieve the estimated 22 dB noise attenuation in both ears.

The only significant differences found ($p \leq 0.05$) between subjects were for job type and job location. These data indicated personnel in some of the most hazardous jet engine noise locations, such as Aircraft Directors and Jet Blast Deflector personnel, were least likely to wear earplugs. White Shirts, like Safety Observers and Medical personnel, used earplugs more often than others.

The cranial and earmuffs have been reported to provide approximately 21 dB of noise attenuation (reference 10) when worn without earplugs, fit correctly, and maintained. This survey found that 75% of subjects may not have had a well-fit cranial helmet and that 41% of the earmuffs needed new earcup cushions and/or foam inserts. This survey also identified numerous items worn under earcup cushions that may have led to acoustic leaks and reduced noise attenuation (references 12 and 19 through 23), items such as caps, ear warmers, and eyeglasses. However, earmuff headband clamping forces were within normal expected ranges (6-23 N).

U.S. Navy flight deck noise levels (up to 150 dB) and personnel exposure durations (most over 11 hr per day, 7 days a week) are among the worst in the world. The double hearing protection available to flight deck crews can provide approximately 30 dB of noise attenuation (references 10, 11, and 12); however, this survey identified numerous practices that likely reduce this level noise attenuation.

RECOMMENDATIONS

Analysis of the data collected in this survey identified technological and non-technological (e.g., training, enforcement) ways to improve hearing protection for U.S. Navy flight deck personnel. Based on these survey findings, the following is recommended:

a. Improve helmet, earmuff, and earplug noise attenuation performance to extend the daily safe noise exposure time limit.
b. Advance attenuation technology for high, repeatable performance.
c. Make helmet/earmuffs personal issue equipment, i.e., do not share hearing protectors.
d. Instruct users how to select the best size and to correctly wear and maintain helmets, earcups, and earplugs.
e. Design earplugs that encourage the use of earplugs and correct earplug insertion.
f. Set, distribute, and enforce consistent hearing conservation procedures.
g. Make hearing protection part of the uniform.
h. Associate cost/penalty for not complying.
i. Issue Surgeon General policy statement to all Ship Commanding Officers that Hearing Conservation Instructions must be enforced.

Recommend that areas for additional research include the following:

a. Investigate why personnel are not wearing double protection – i.e., not wearing earplugs.
b. Determine effective level for supervisory control for hearing protection.
c. Investigate the effects on attenuation of hair, caps, eyeglasses, etc., under earcups and helmets.
d. Measure/track effect of new hearing protection technologies and policies.
e. Survey U.S. Air Force flight line personnel hearing protection use.

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APPENDIX A
SUBJECT SURVEY QUESTIONNAIRE

Data Collector _____

Ship _____

Time of day (24 hr, e.g. 1500) _____

Date (mm/dd/yy)_____

Subject Name _____

Gender ☐ Male or ☐ Female

Age ____ years

Date of Birth (circle month) Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

(fill in day and year) ____ day in the year 19 ____ ____

1. **Division / Squadron** _____

2. **Rate / Rank:**
   - ☐ E1
   - ☐ E2
   - ☐ E-3
   - ☐ E-4
   - ☐ E-5
   - ☐ E-6
   - ☐ E-7
   - ☐ E-8
   - ☐ E-9
   - ☐ O1
   - ☐ O2
   - ☐ O3
   - ☐ O4

   PHOTO #s / Descriptions

3. **Time of experience in flight deck/line noise environment:** _____Years _____ Months

4. **Job Type:**
   - ☐ Red shirt
   - ☐ Blue shirt
   - ☐ Green shirt
   - ☐ Yellow shirt
   - ☐ Brown shirt
   - ☐ Purple shirt
   - ☐ White shirt

5. **Job location:**
   - ☐ Checker/trouble shooter
   - ☐ JBD
   - ☐ Catapults
   - ☐ Arresting gear (flight deck/engine room)
   - ☐ Fire Crew
   - ☐ Safety
   - ☐ Chocks and chains
   - ☐ Tractor
   - ☐ Plane captain
   - ☐ Aircraft Director
   - ☐ Fuel
   - ☐ Other _____

6. **How many hours per 24-hour period are you normally in the flight deck/line noise environment?**
   - ☐ 0-5 hours
   - ☐ 6-10 hours
   - ☐ 10-15 hours

7. **Which ONE best describes why you are participating?**
   - ☐ A higher-ranking person ordered me to

   OR, I want to participate on my own
   - ☐ To help improve hearing protection technology
   - ☐ To be with friends who are participating
   - ☐ To receive an incentive (like zappers)
   - ☐ Because I have problems with my hearing protection equipment and thought you could help me

   OR,
   - ☐ None of these

8. **Helmet model:**
   - ☐ HGU-24/P (sound powered)
   - ☐ HGU-25(V)2/P
   - ☐ Radio Cranial

9. **General cranial assembly fit observations (ALL that apply):**
   - ☐ Appears to seal well around the ear. Subject concurs.
   - ☐ Too high (helmet appears higher than normal)
   - ☐ Too low (earcups forced lowered than ears)
   - ☐ Too far forward (below glabella)
   - ☐ Too far back (hairline shows in front)
   - ☐ Loose cloth (can see large gaps, fabric folds)
   - ☐ Tight cloth (can see strained seams)

10. **Chin strap length:**
    - ☐ Length is OK
    - ☐ Length too short (velcro can't clasp adequately)
    - ☐ Length is too long (too loose to touch under chin)

11. **Earlobe**

    Left ☐ Under earcup cushion ☐ Inside earcup

    Right ☐ Under earcup cushion ☐ Inside earcup

REMOVE CRANIAL

12. **Describe your cranial/earcup comfort:**
    - ☐ Comfortable (can wear >10 hours)
    - ☐ Minor discomfort (can wear a few hours before major discomfort)
    - ☐ Major discomfort (can wear a few hours before severe discomfort)
    - ☐ Severe discomfort (requires effort to maintain wear)

13. **Hair type (mark all that apply):**
    - ☐ Thick ☐ Thin
    - ☐ Coarse ☐ Fine
    - ☐ Curly ☐ Straight
    - ☐ Close cut ☐ Bald/Shaven

14. **Earcup seal condition (mark ONE only):**
    - ☐ Missing
    - ☐ Bad (deteriorated, flat, hard)
    - ☐ Good (if good, ask if "new")
    - ☐ New (how new?) _____

15. **Earcup foam condition (mark ONE only):**
    - ☐ Missing
    - ☐ Bad (deteriorated, too small, torn)
    - ☐ Good (if looks good, ask if it's "new")
    - ☐ New (how new) _____

16. How often do you inspect/maintain your:
    - ☐ Earmuffs _____
    - ☐ Ear cushions_____
    - ☐ Earcup foam _____
    - ☐ Cloth helmet_____
    - ☐ Not routinely/never performed

17. How did you obtain your cranial?
    - ☐ Pool Issue (grab-n-go)
    - ☐ Personal Issue (pool assigned for cruise duration))
    - ☐ Personal Issue (keep cruise to cruise / or while in squadron)
    - ☐ Other_____

18. What size cranial should you wear?
    - ☐ 6 ¾
    - ☐ 7
    - ☐ 7 ¼
    - ☐ 7 ½
    - ☐ Don't know

19. How did you select your cranial size?
    - ☐ By hat size
    - ☐ Whatever was available
    - ☐ Did not know cranials were sized
    - ☐ Tried various sizes, picked best
    - ☐ Other_____

20. Cranial size worn:
    - ☐ 6 ¾
    - ☐ 7
    - ☐ 7 ¼
    - ☐ 7 ½
    - ☐ Label inaccessible
    - ☐ Label missing

EARPLUGS

21. How often do you normally wear earplugs on the flight deck?
    - ☐ Always
    - ☐ Most of the time/when available
    - ☐ Half the time
    - ☐ Occasionally
    - ☐ Never

22. Earplugs worn (If subject does not come in with earplugs from the deck, mark NO, earplugs not worn)
    - ☐ No
    - ☐ Yes

23. Earplug condition (If subject does not come in with earplugs from the deck, slash through Q, mark N/A)
    - ☐ Very Poor
    - ☐ Poor
    - ☐ Good
    - ☐ New
    - ☐ Length of use _____

24. Earplug type normally worn:
    - ☐ Yellow foam
    - ☐ Blue foam
    - ☐ White foam
    - ☐ Triple flange Size/Color_____
    - ☐ Single flange Size/Color_____
    - ☐ E.A.R. Superfit 30/33
    - ☐ Other _____

25. How often replaced?
    - ☐ Daily
    - ☐ Weekly
    - ☐ When soiled/worn out

MEASUREMENTS

26. Do you wear glasses?
    - ☐ No
    - ☐ Yes

    Temple style:
    - ☐ Standard
    - ☐ Cable
    - ☐ Bayonet/Blade
    - ☐ Skull
    - ☐ Other _____

27. Glasses stem measurements forward of the ear where the earcup would seal

    Subject Bi-temple breadth_____mm

    Glasses Bi-temple breadth_____mm

    Stem height in same _____ mm

28. Glabella to cranial distance (top of brow to edge of cranial cloth, centerline): _____mm

29. Cranial configuration earcup pressure: _____N

HAIR IN BUN, TIED UP, OR BRAIDED

30. Hair circumference at head circumference path

    _____mm

    If fattest part of bun occurs above or below the head circumference pathway and is normally under the cranial cloth, measure head + bun circ at greatest point and note where this occurs, e.g. 10 mm below head circ line)

    Head + bun circ _____mm

    Circle one [above / below] head circ path_____mm

ALL

31. Head Circumference _____mm
    (If hair is tied up and in the way, ask to participant to let hair down to get accurate head circumference)

32. Head Breadth_____ mm

33. Earplug depth: Left _____mm

    Right_____mm

APPENDIX B
SHIRT COLORS ON U.S. NAVY AIRCRAFT CARRIERS
http://www.chinfo.navy.mil/navpalib/ships/carriers/rainbow.html

Blue
Plane Handlers
Aircraft Elevator Operators
Tractor Drivers
Messengers and Phone Talkers

Red
Ordnancemen
Crash and Salvage Crews
Explosive Ordnance Disposal

Brown
Air Wing Plane Captains
Air Wing Line Leading Petty Officers

Yellow
Aircraft Handling Officers
Catapult and Arresting Gear Officers
Plane Directors

White
Air Wing Quality Control Personnel
Squadron Plane Inspectors
Landing Signal Officer
Air Transfer Officers
Liquid Oxygen Crews
Safety Observers
Medical Personnel

Green
Catapult and Arresting Gear Crews
Air Wing Maintenance Personnel
Cargo-handling Personnel
Ground Support Equipment Troubleshooters
Hook Runners
Photographer's Mates
Helicopter Landing Signal Enlisted Personnel

Purple
Aviation Fuels

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USAARL (Ahroon), Aircrew Protection Division (2)
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USACHPPM (MCHB-TS-CHC, Ohlin) (2)
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