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**Noise Attenuation Performance Assessment of the Joint Helmet Mounted
Cueing System (JHMCS)**

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1.0 SUMMARY

Modern military flight helmets are used not only for pilot protection, but also for increased mission effectiveness⁵. The HGU-55/P and HGU-68/P flight helmets have been meeting the needs of the United States Air Force and the United States Navy pilots respectively for years. In recent years, the Joint Helmet Mounted Cueing System (JHMCS) flight helmet has been developed and introduced into the aircrew community to enhance the pilot's targeting performance. Louder conditions and missed radio calls have recently been reported by users of the HGU-55 A/P JHMCS helmet (compared to legacy helmets). The objective of this study was to determine what noise attenuation differences, if any, are present when comparing the JHMCS helmet configuration to legacy helmet configurations. Overall the JHMCS helmet attenuation, with and without the Combined Advanced Technology Enhanced Design G Ensemble (COMBAT EDGE), is not significantly different from the legacy helmets. Microphone-In-Real Ear (MIRE) tests and in-flight analysis data confirm these findings. Earphone elements were tested and frequency response differences were found between elements. Recent improved designs or improved magnetic materials will need to be evaluated to determine if frequency response variation has been reduced. The results from the Real Ear Attenuation at Threshold (REAT) earcup attenuation testing (mean octave band data, Noise Reduction Ratings (NRR), and C-A results) determined the new Oregon Aero (OA) Triangle L/O to be the best performer in the JHMCS. The new earcup is currently being evaluated in-flight by F-15, F-16, and F/A-18 pilots to confirm these findings and to ensure user acceptability and comfort. The new OA triangle L/O will also need to be authorized for future use in the JHMCS. Proper helmet and earcup fit continue to be highly emphasized to units for the highest attenuation performance.

2.0 BACKGROUND

2.1 *Flight Helmet*

The JHMCS enhances aircrew's targeting performance with good overall system accuracy, faster target acquisition, and less exposure time. The JHMCS's Helmet Display Unit (HDU) provides visor-projected symbols and alpha-numeric data allowing aircrew to view flight-critical information without using the aircraft's Head-Up or Head-Down Displays, while visually targeting weapons and sensors at high off-boresight angles. The JHMCS provides the warfighter with a first-look, first-shot capability that allow eyes out of the cockpit targeting within the visual range arena. The JHMCS is deployed operationally on F-15, F-16, and F/A-18 aircraft.

Prior to the development of the JHMCS helmet; aircrew used HGU-55/P or HGU-68/P flight helmets (Figure 1). The HGU-55/P is worn by pilots in the United States Air Force (USAF) and the HGU-68/P is worn by the pilots in the United States Navy (USN). The JHMCS shell (HGU-55A/P) is a modified HGU-55 type helmet. This shell provides the mounting platform for the HDU, protects the pilot from high impact and wind loads during ejection and egress, and provides noise attenuation and communication. The modified shell is a lightweight configuration constructed of aramid and carbon fiber.

There is increased material in the facial cheek area for helmet strengthening, a cutout in the top front of the helmet for the installation of the Universal Connector (providing electrical interface for the HDU), and a modified nape to accommodate the Upper Helmet Vehicle Interface (HVI) cable entrance⁵. The helmet is common for the USAF and USN JHMCS users although the USN no longer uses the COMBAT EDGE helmet bladder and therefore has a small hole in the nape where the COMBAT EDGE hose is no longer routed. This hole is hypothesized to be a potential source of noise intrusion into the USN JHMCS helmet.



Figure 1. Flight helmets: a. HGU-55/P b. HGU-68/P c. JHMCS d. JHMCS with COMBAT EDGE e. JHMCS without COMBAT EDGE

2.2 Earphone Element

Earphone elements (also known as speakers) provide voice communication and aural warnings within high-noise conditions, at either ground-level or altitude. The earphone elements are wired into the earcup and then installed into the flight helmet together. The H-143/AIC (Figure 2) and H-87 B/U earphone elements are manufactured by multiple vendors to include: Telex, Electro-Voice, Sonetronics, Acousticom, Astrocom, and Roanwell. The earphone elements evaluated came from the above mentioned suppliers and varied in overall weight, material, relative sensitivity, and frequency response with manufacturer. Additionally, the age of each earphone element varied (determined from the manufacturer's date code).

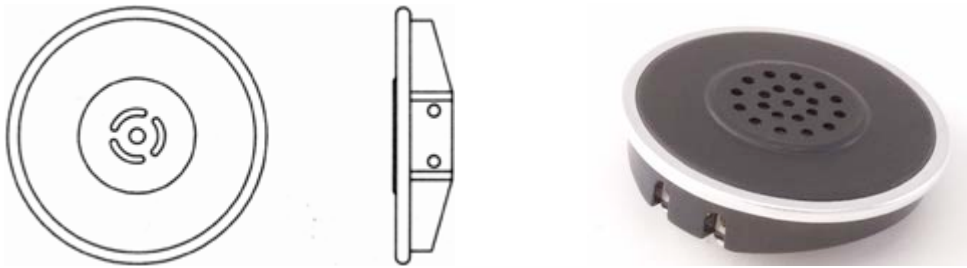
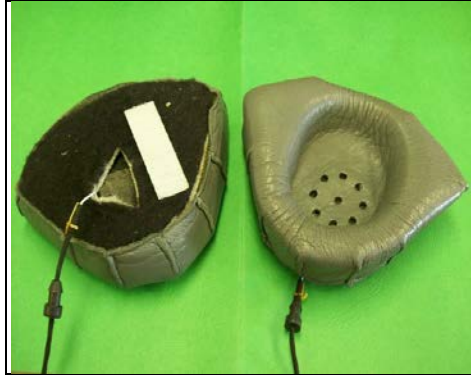


Figure 2: H-143/AIC Earphone Element

2.3 Earcup

The use of earcups in the flight helmet enhances noise attenuation and speech intelligibility. Earcups can vary in size, shape, and material depending on the manufacturer. Earcups improve impact safety and eliminates pain to the ear while improving noise attenuation. Two manufacturers, Gentex and OA, have developed multiple earcups that are currently in operational use. Gentex produces a Grey Triangle, Oval (H-154/AIC Standard USAF earcup), and a Black Triangle (HGU-68/P Standard Cup). This USN configuration incorporates a plastic earcup inserted inside the earcup material. Oregon Aero produces the Oval and Triangle (with and without a vinyl insert they call Barium [a play on the word “barrier” and no relation to the element barium]), (Figure 3) and a new Triangle earcup. The OA Oval without the vinyl insert is JHMCS standard equipment. The difference between the old and the new OA Triangle is the shape of the ear hole. The old shape is oval (Figure 3e) while the new shape is a triangle (Figure 3g). The larger triangular ear hole was developed to make a better seal against the head when inside the helmet; the new triangular earcup will be called the Triangle L/O (large opening). All the earcups vary in size and shape but also in noise attenuation. Noise attenuation will vary with the size of the acoustic leak, earcup size, and material choices.



a.



b.



c.



d.



e.



f.



g.

Figure 3. Examples of Earcups a. Gentex Grey Triangle b. H-154/AIC c. Gentex Black Triangle d. OA Oval e. OA Triangle f. OA Vinyl Insert g. OA Triangle L/O

3.0 FIELD REPORTS/DEFICIENCIES

Aircrews operating with the JHMCS helmet during flight have reported louder conditions when compared to legacy helmets (HGU-55/P and HGU-68/P). The poor audio levels have caused some pilots to miss radio calls. This decrease in received speech energy is a flight safety concern. Additionally, a USN unit has submitted a Hazard Report citing short-term hearing loss while permanent hearing damage is possible. Specific Air National Guard (ANG) pilots have refused to fly with JHMCS due to signal and noise issues. Pilots are attempting to compensate by using non-standard or unauthorized earcup configurations.

3.1 Objective

This study was conducted to provide objective measurements of both the earphone elements and the helmet/earcup attenuation to determine if any differences in performance among operational equipment are present. In addition to the objective measurements done in the lab, in-flight noise data was collected from F-15 pilots to determine if any differences were present, at specific conditions, between helmet shells. The results may determine if the JHMCS is significantly louder when compared to the legacy helmets.

4.0 METHODS

4.1 Test Facility

Sound attenuation testing was conducted at the Air Force Research Laboratory's (AFRL) Battlespace Acoustics Branch's Hearing Protection Performance Facility, located at Wright-Patterson Air Force Base, Ohio. In-flight noise data was collected at the Naval Air Station Joint Reserve Base of New Orleans with the Louisiana Air National Guard (LAANG), 159th Fighter Wing's 122nd Fighter Squadron,

4.2 Test Procedure

Test procedures were used to obtain objective measurements from the earphone elements and the helmet/earcup. Free-field sensitivity and frequency response tests were performed on all earphone elements. Two different American National Standard Institute (ANSI) methods were used to measure the passive attenuation of the helmet/earcup combination. Passive attenuation was measured using ANSI S12.42-1995⁴: American National Standard Microphone in Real Ear (MIRE) and ANSI S12.6-1997³: American National Standards Methods for measuring the Real Ear Attenuation (REAT) of Hearing Protectors. In-flight interior acoustics data was captured in F-15 aircrafts to compare the JHMCS helmet to that of the standard HGU-55/P helmet.

4.2.1 Earphone Elements

All measurements were conducted in the AFRL Battlespace Acoustics Branch's anechoic chamber. The facility has a low frequency cut-off for the anechoic space of 150 Hz with a minimum sound field of less than 40 dB(A). The facility uses a suspended wire floor and hard mounts for positioning measuring equipment. Table 1 lists the specific instrumentation used in this testing.

Table 1. Specific instrumentation used in earphone element data collection

NOUN	Model / Item Number	Purpose
Spectrum Analyzer	Model # HP 3665A	Used as noise source and data processing
Computer System control	DELL	Used for Data collection and analyzer
National Instruments Software	NI	Used to perform data collection
Artificial Ear	Brüel & Kjær type 4153	Used for ear muff type collection
Circuit Board Hold Fixture	n/a	Used to hold speakers for open air testing
Microphone, Free Field	Brüel & Kjær 4191	Used for open air data collection
Microphone, Pressure Field	G.R.A.S. type 40AG	Use for muff type testing
Pre-Amp & Cable assembly	Brüel & Kjær 2669	Used in conjunction with microphones
Microphone Power Supply	Brüel & Kjær 2804	Used to provide power to polarized microphones
Oscilloscope, TEX analyzer	Model # 2205	Used to evaluate signal prior to spectrum
Digital Volt Meter analyzer	Model # 8842A	Used to evaluate signal prior to spectrum
BNC Cables	n/a	Used for audio data transfer

The free-field sensitivity and frequency response of the earphone elements was measured using an HP spectrum analyzer (Model # HP 3665A). A calibrated laboratory microphone at a distance of 6" from the earphone element (Figure 4) measured the acoustic output when the element was stimulated with a fixed amplitude signal from the spectrum analyzer. The signal presented was a sine wave with a log frequency sweep from 100 Hz to 10 kHz. The output of the microphone was compared to the input to the earphone element and the sensitivity and frequency response was computed.

The in-situ sensitivity and frequency response were measured using the same HP spectrum analyzer (used in the free-field sensitivity tests). The earphone elements were installed in a USAF earcup (H-154/AIC) with earcushion (Figure 5) and placed on a Bruel & Kjaer artificial ear with a flat plate coupler (Figure 6). The artificial ear included a calibrated laboratory microphone. The signal presented to the earphone element was a sine wave with a log frequency sweep from 100 Hz to 10 kHz. The output of the microphone was compared to the input to the earphone element and the sensitivity and frequency response was computed.

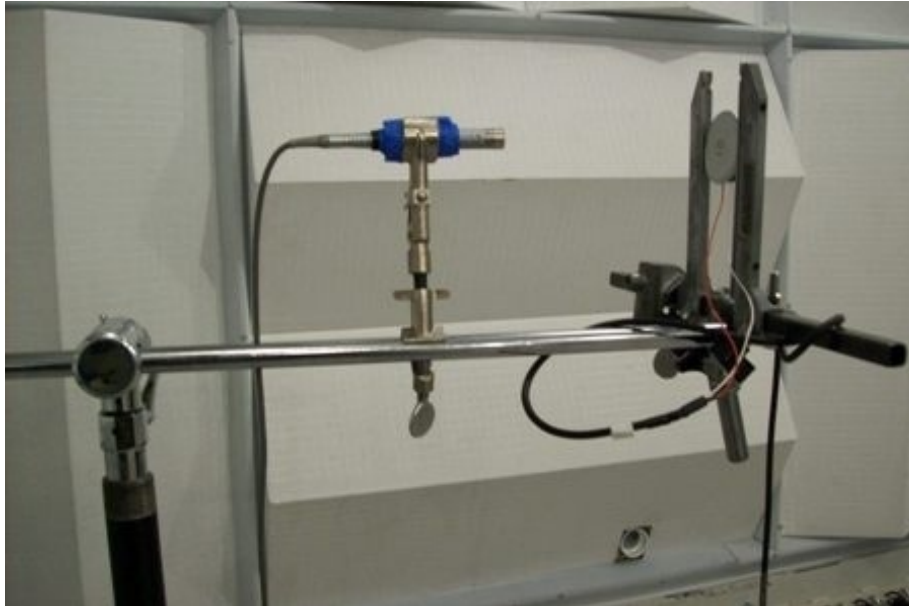


Figure 4. Free-field sensitivity and frequency response measurement setup



Figure 5. Earphone elements installed in a H-154/AIC earcup with ear cushion

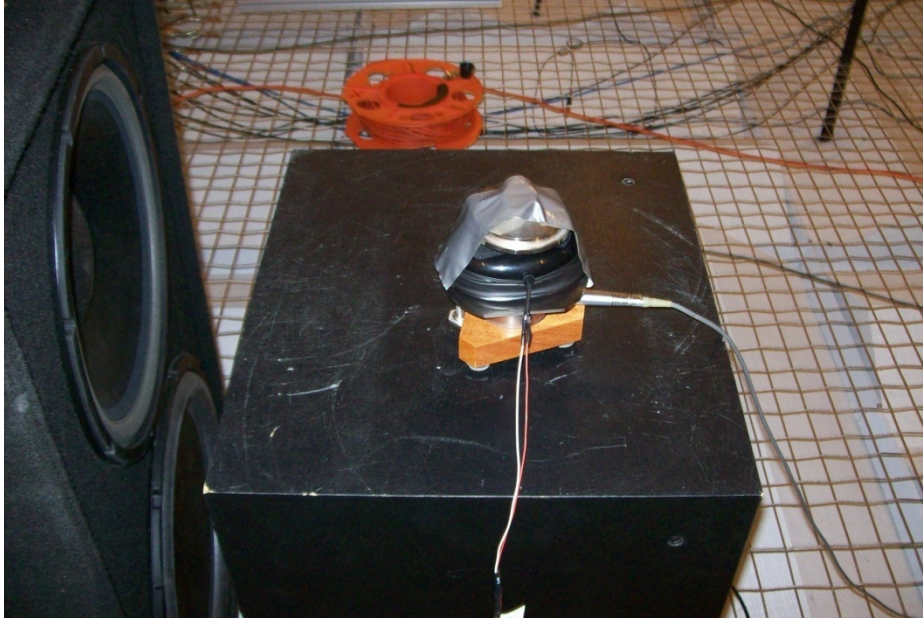


Figure 6. H-154/AIC earcup with ear cushion placed on a Bruel & Kjaer artificial ear with a flat plate coupler

4.2.2 Helmet/Earcup Attenuation

All mask and helmet equipment was fitted properly by a certified fitter, a USAF Life Support Technician. The subjects were fitted with one of four helmets: JHMCS with and without COMBAT EDGE, HGU-55/P, and HGU-68/P. For each test the subject also wore a MBU-20/P mask, valve, hose, visor in the down position, standard H-143/AIC speaker, and an OA ZetaLiner® helmet fitting pad. The subject would also wear one of eight earcups: the Gentex Grey Triangle, Black Triangle, and Oval earcup; the OA Oval and Triangle (with and without vinyl inserts); and the new OA Triangle L/O earcup. A negative pressure check was conducted to ensure proper fit. The test subjects became familiar with the helmet fit and feel to obtain the maximum amount of hearing protection from the helmet/earcup combination. Each subject self donned the helmet and was assisted with the donning of the mask. The hearing protector was visually checked by the Test Conductor and the certified fitter prior to the start of each trial to ensure proper fit and placement.

4.2.2.1 Microphone in Real Ear Testing

The initial attenuation test was conducted in the MIRE facility. Twenty-six helmet/earcup combination configurations were tested by the MIRE specification (Table 2) to measure insertion loss (attenuation). Ten subjects completed each trial, Figure 7a. The MIRE portion of testing provided hearing protection performance results for the legacy and JHMCS systems for comparison to the performance specification. MIRE is an empirical test conducted in a high-noise level diffuse sound field chamber. Each subject wore pre-formed earplugs which is a safety precaution and not an actual factor in the test. A miniature microphone was placed at the opening of each ear canal to monitor/record the sound intensity presented to the subject. The miniature microphones were Knowles, model BT-1759. The microphones were secured so that they did not change position

with the fitting and refitting of the helmet. The sensing surface of the microphone was oriented parallel to the plane of the ear canal opening and directed away from the center of the subject's head. There were three wires from the microphone, two of the wires were AWG 28 and the third wire was AWG 34. These wires were run between the ear seal and the subject's head with negligible acoustic leak.

Broadband noise was presented through speakers (Figure 7b) at a level of 105 dB SPL (pink noise) and the noise spectrum at each ear was recorded as a 32 second linear average by a spectrum analyzer. The test was repeated with the same noise spectrum. This constituted one run. The MIRE facility was in compliance with ANSI S-12.42-1995⁴.

Three open ear and three occluded ear (open before each occluded) measurements were made with ten subjects. The hearing protection device was removed and refitted before each occluded ear measurement. The open ear and occluded ear measurement data was used to calculate the insertion loss of the hearing protection device. Data was analyzed by using an MS Excel™ macro, which automatically generated a report and graph that depicted passive attenuation values in both data point and graph format from 63 Hz to 10 KHz. The report also included average, A-weighted, and linear attenuation data points.

Table 2. MIRE test matrix with helmet and earcup combination configurations

Earcup	Helmet			
	JHMCS with COMBAT EDGE	JHMCS without COMBAT EDGE	HGU-55/P	HGU-68/P
Gentex Grey Triangle	X	X	X	X
Gentex Oval – H-154/AIC (55/P Standard Cup)	X		X	X
Gentex Black Triangle (68/P Standard Cup)	X	X		
Oregon Aero Oval	X	X	X	X
Oregon Aero Triangle	X	X	X	X
Oregon Aero Oval with Vinyl Insert	X	X	X	X
Oregon Aero Triangle with Vinyl Insert	X	X	X	X
Oregon Aero Triangle L/O	X			



Figure 7. a. MIRE test subject b. MIRE test facility with speakers behind test subject

Table 3. NIOSH recommended exposure limit (REL) for occupational noise exposure²

Sound Level (dBA)	Time (minutes)	Sound Level (dBA)	Time (minutes)	Sound Level (dBA)	Time (minutes)
Over 115	Forbidden	103	7.5	90	151
115	0.5	102	9.5	89	190
114	0.6	101	12	88	240
113	0.7	100	15	87	302
112	0.9	99	19	86	381
111	1.2	98	24	85	480
110	1.5	97	30	84	605
109	1.9	96	38	83**	762
108	2.4	95	48	82**	960
107	3.0	94	60	81**	1210
106	3.8	93	76	80**	24 Hours
105	4.7	92	95	Below 80	No limit
104	6.0	91	120		

* The A-weighted sound level is used to assess hearing damage risk due to noise exposure; for engineering noise control, other measures are required. The limiting duration of exposure at any noise level equal to or less than 115 dBA can also be determined from the following equation:

$$Time, T(\text{min}) = 480 \times 2^{(85 - L_A)/3}$$

where, L_A = A-weighted sound level.

** Exposures of more than 12 hours should be followed by periods of equal length in quiet (less than 72 dBA).

4.2.2.2 Real-Ear Attenuation Testing

The second part of the test was conducted in the REAT facility to measure passive hearing protector performance. The chamber, its current instrumentation, and measurement procedures were in accordance with the requirements of ANSI standard S12.6-1997³ (Method A, experimenter-supervised fitting). Five configurations were tested by the REAT specification. Ten subjects were tested wearing the JHMCS flight helmet with COMBAT EDGE and 5 previously selected earcups based on MIRE testing results: OA Oval and Triangle (without vinyl inserts), the new OA Triangle L/O, and the Gentex Black Triangle (USN) and Oval (H-154/AIC). Subjects were placed in a low-noise room and took a special hearing test (REAT) in which the sounds were delivered through calibrated speakers in the room (instead of through headphones like conventional hearing tests). The test was administered with and without the devices under study to determine the relative octave-band noise attenuation values of the device combinations using a Békésy threshold tracking task. The thresholds are measured two times for the unoccluded condition and two times for the occluded condition. The thresholds are averaged in accordance with the standard to determine a measure attenuation value. The data from all subjects in each test condition are also averaged to determine mean and sample standard deviation values. The mean minus two standard deviation values are used in hearing conservation programs for military personnel in the field. In this way, about 97.7% of the users will achieve the specified or greater attenuation.



Figure 8. Male subject in REAT facility

4.2.3 In-Flight Noise Data

4.2.3.1 Noise Collection Device

The recording of the noise levels was accomplished by equipping F-15 pilots with an M-Audio pocket digital recorder (Micro-track 96-24) with Compact Flash Drive (CFD) memory (Figure 9) and Sound Professionals SP-TFB-2 Miniature Binaural Microphones with the Sound Professionals SP-SPSB-1 Slim-line microphone power supply (Figure 10). AFRL 711 HPW/RHCB has combined technologies from the commercial audio world to provide digital sampling of in-flight noise. Sound Professionals binaural microphones were placed to record both internal and external sounds. One microphone was attached to the outside of the helmet on the back. The other microphone was placed in the entrance of the left ear canal. The placement of the internal microphone was done in such a manner as to not interfere with insert plugs (and therefore alter sound attenuation). The recorder was set to wave file format which provides more than two hours of constant recording time. The microtrack 96/24 hold button was turned on and the recorder was placed in a breast pocket of the flight suit with the cabling and power supply for the microphone placed in the other breast pocket. If the flight time exceeded the record time the recorder would close the file and terminate the record function without human intervention. The M-Audio pocket recorder has been EM/RFI certified for AF fixed wing aircraft¹.



Figure 9. The M-Audio pocket digital recorder and Battery Power Supply



Figure 10. The Sound Professional Microphone

4.2.3.2 Procedures

For equipment configurations requiring personnel to wear miniature recorders, the recorder and microphones were connected in the Life Support shop prior to stepping to the flight line. A 60 second National Institute of Standards and Technology (NIST) traceable acoustic calibration tone from a Brüel & Kjær 4231 Acoustics calibrator was recorded through each microphone (94 dB @ 1.0 kHz). At the aircraft, following the aircraft pre-flight inspection, the flight crew was fitted with the recorder systems. The recorder and microphone power supply was worn in the flight suit breast pocket. After entering the aircraft the microphones were secured. One microphone was placed over the concha of the left ear inside the helmet/earcup (see Figure 2 above) while the second microphone was secured to the outside of the helmet with electrical tape.

Noise Levels were collected during twelve separate flights. Six pilots flew two different sorties each; one with a JHMCS and one with the HGU-55/P flight helmet. The aircraft and earcup configuration would remain constant throughout the data collection. The H-154/AIC was used as it was authorized for both helmets. Flights were at “worst case” conditions as identified by the LAANG, Table 4.

Table 4. Flight conditions at specified altitude and airspeed

Altitude (Ft)	Airspeed (KIAS – Knots Indicated Airspeed)		
5,000	400	500	550
10,000	400	500	550
20,000	450		

The conditions were identified on the recordings by the pilot stating the airspeed and altitude. The left microphone (under the earcup) recorded the narration. Since both audio channels on the recorder share the identical time stamp the helmet surface (right microphone) data can be correlated with the key flight events narrated on the other channel.

5.0 RESULTS

5.1 Earphone Elements

A total of 63 earphone elements were tested in the AFRL Battlespace Acoustics Branch’s small anechoic chamber. The earphone elements were a mix of both H-143/AIC and H-87 B/U and manufactured by one of the following: Sonetronics, Electro-Voice, Roanwell, Acousticom, or Astrocom. The average mass of the earphone was 27.11 g (ranging from 19.45 g to 42.86 g).

Free-field sensitivity and frequency response was measured on 27 H-143/AIC and 36 H-87 B/U earphone elements. The free-field frequency responses for the H-143 are graphed in Figure 11 where a maximum frequency difference of 46 dB is found across the frequency range. Each color on the graph represents an earphone element. Figure 12 is a graph of the H-143 frequency response on an artificial ear in earcup. A maximum difference of 36 dB was found when comparing earphones across all frequencies. The 36 H-87 B/U earphone elements had similar comparisons for free-field and artificial ear

frequency responses in Figures 13 and 14 with maximum frequency differences of 47 and 35 dB respectively.

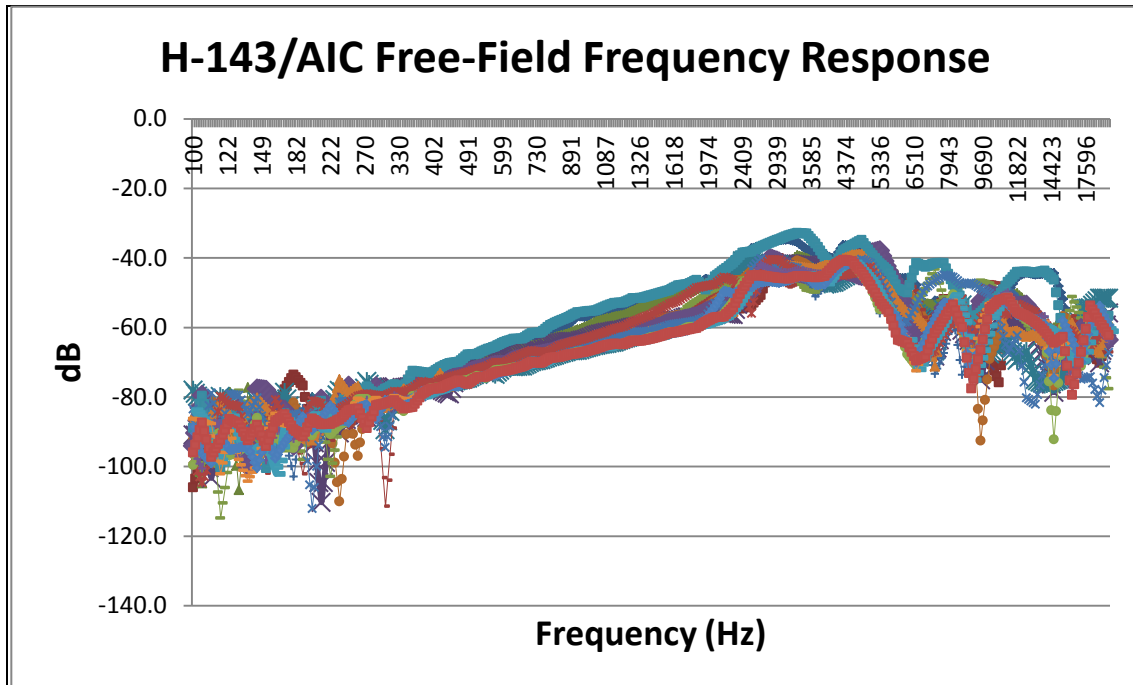


Figure 11. H-143/AIC Free Field Frequency Response

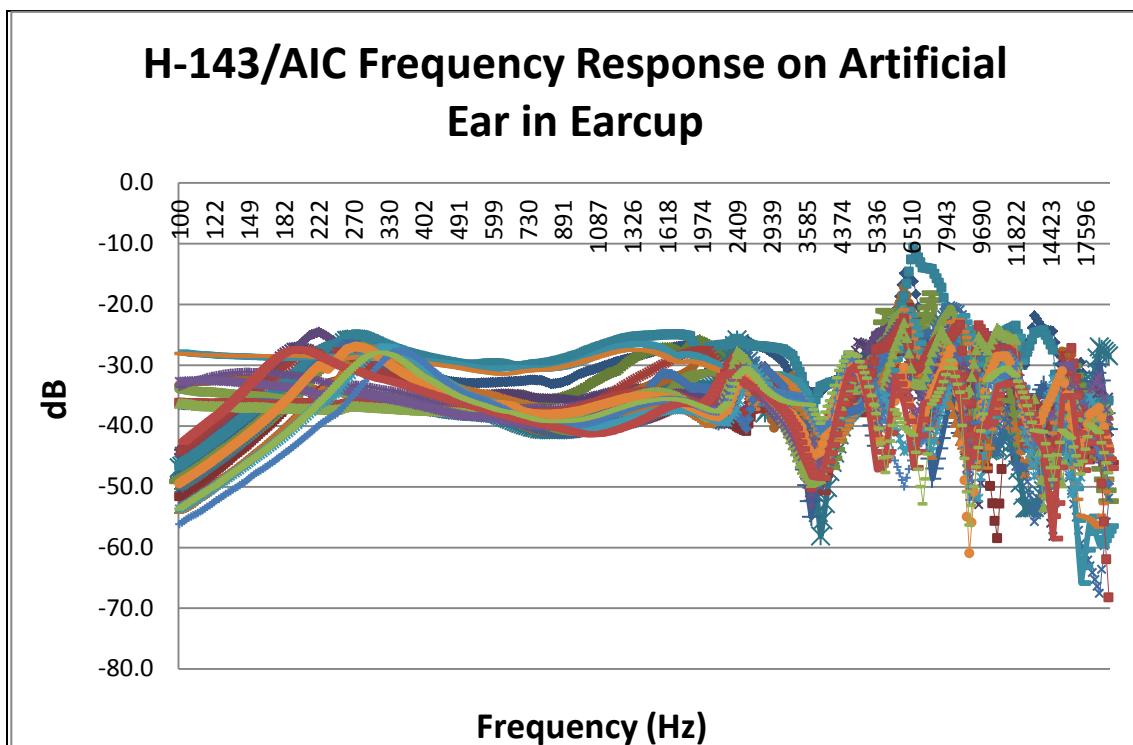


Figure 12. H-143/AIC Frequency Response on Artificial Ear in Earcup

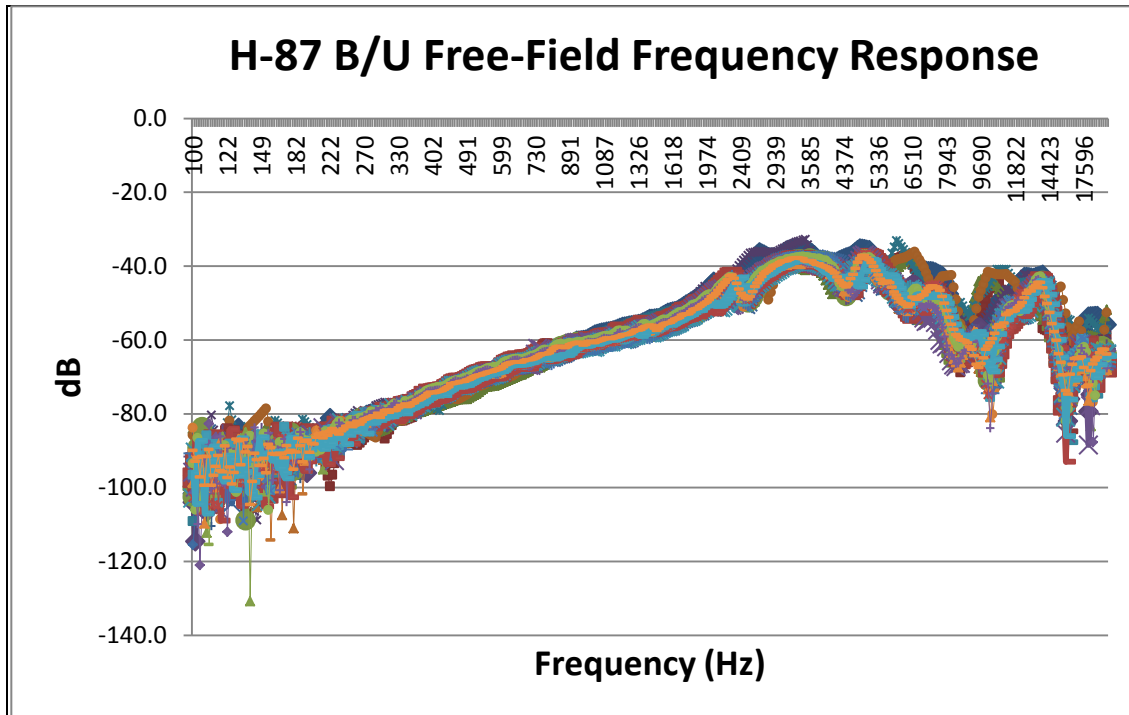


Figure 13. H-87 B/U Free Field Frequency Response

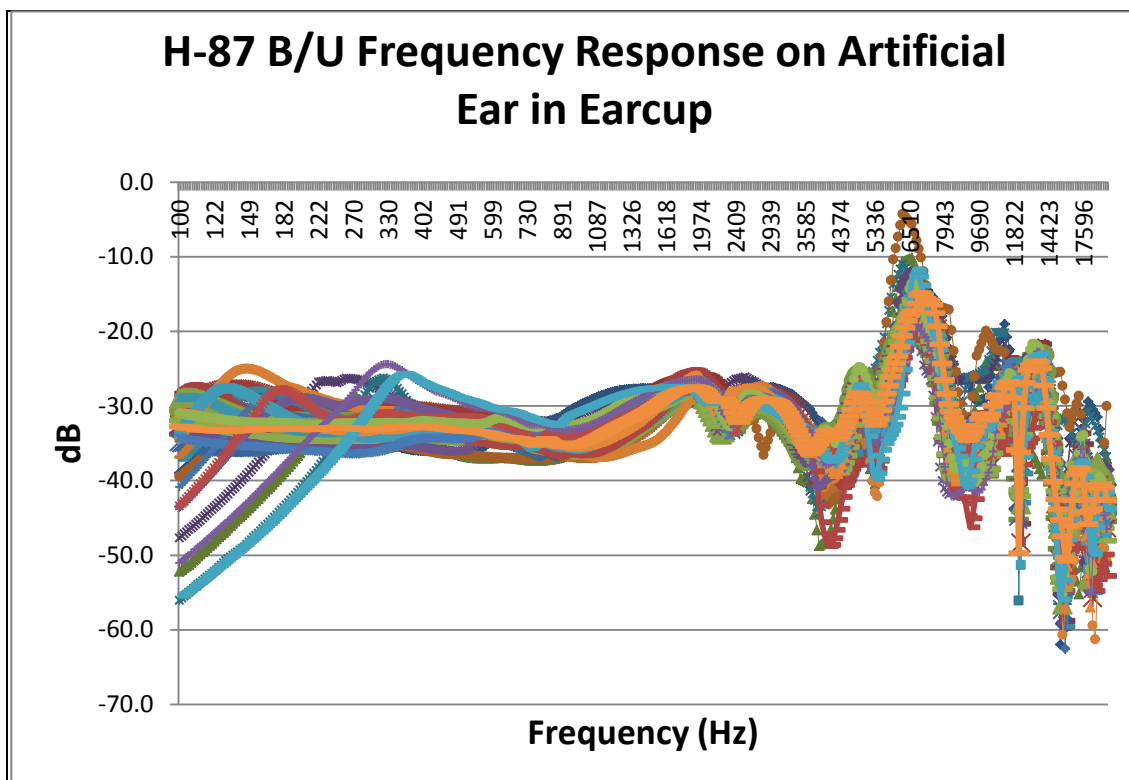


Figure 14. H-87 B/U Frequency Response on Artificial Ear in Earcup

An additional analysis was performed comparing the earphone elements by manufacturer for the H-143/AIC and H-87 B/U separately. Again, differences were found among elements at varying frequencies manufactured by the same company. The maximum variations found are listed in Table 5.

Table 5. Maximum Differences found among earphone elements of the same manufacturer for H-143 and H-87 elements

Manufacturer and Earphone Element Type	Maximum Difference (dB)	
	Free-Field	Artificial Ear
Sonetronics (H-143)	10	10
Roanwell (H-143)	20	15
Acousticom (H-143)	20	20
ElectroVoice (H-143)	25	20
Sontronics (H-87)	30	15
Electro Voice (H-87)	*	15

*Earphone element comparison was very similar, no maximum difference results

5.2 Helmet/Earcup Attenuation

Ten subjects (5 male, 5 female) were able to complete the 26 MIRE and 5 REAT tests. All subjects had hearing and threshold levels within the normal hearing range, i.e. less than or equal to 20 dB hearing level (HL). Subjects were tested for normal middle ear function and given a visual otoscopic examination. The subjects ranged in age from 19 to 23 years old with a mean age of 22 years. Average head width was 13.4 cm, ranging from 12.7 to 14.0 cm, and the average head length was 12.8 cm, ranging from 11.7 to 14.0 cm.

5.2.1 MIRE Testing

MIRE test results found the JHMCS helmet attenuation was comparable to legacy helmet attenuations for all earcup combinations. Attenuation differences ranged from 2-5 dB at varying frequencies for all helmet comparisons. An increase or decrease of 3dB will change the allowable exposure time by a factor of 2 when following the time-intensity trading relationship of 3dB per doubling. Figure 15a is the helmet attenuation comparing the JHMCS with COMBAT EDGE and the 55/P helmet in combination with the H-154/AIC earcup and Figure 15b is the helmet attenuation comparing the JHMCS without COMBAT EDGE and the 68/P helmet in combination with the Gentex Grey Triangle earcup.

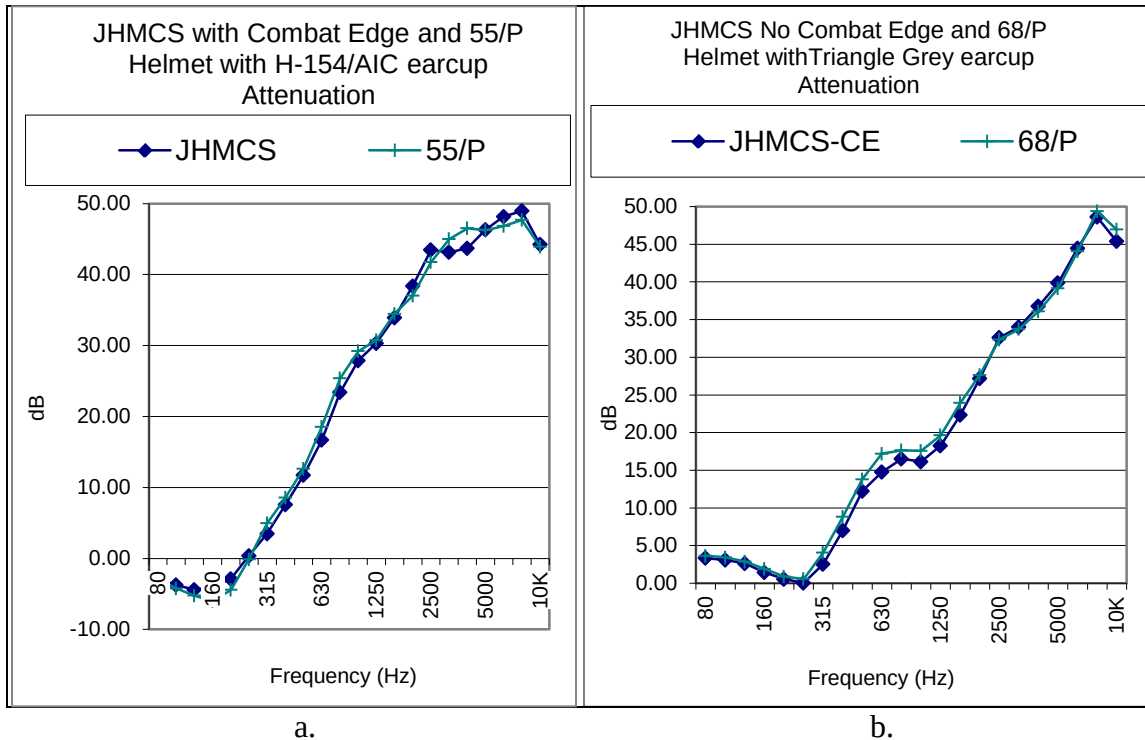


Figure 15. MIRE test results comparing the a.) JHMCS with COMBAT EDGE to the HGU-55/P and the b.) JHMCS without COMBAT EDGE to the HGU-68/P helmet

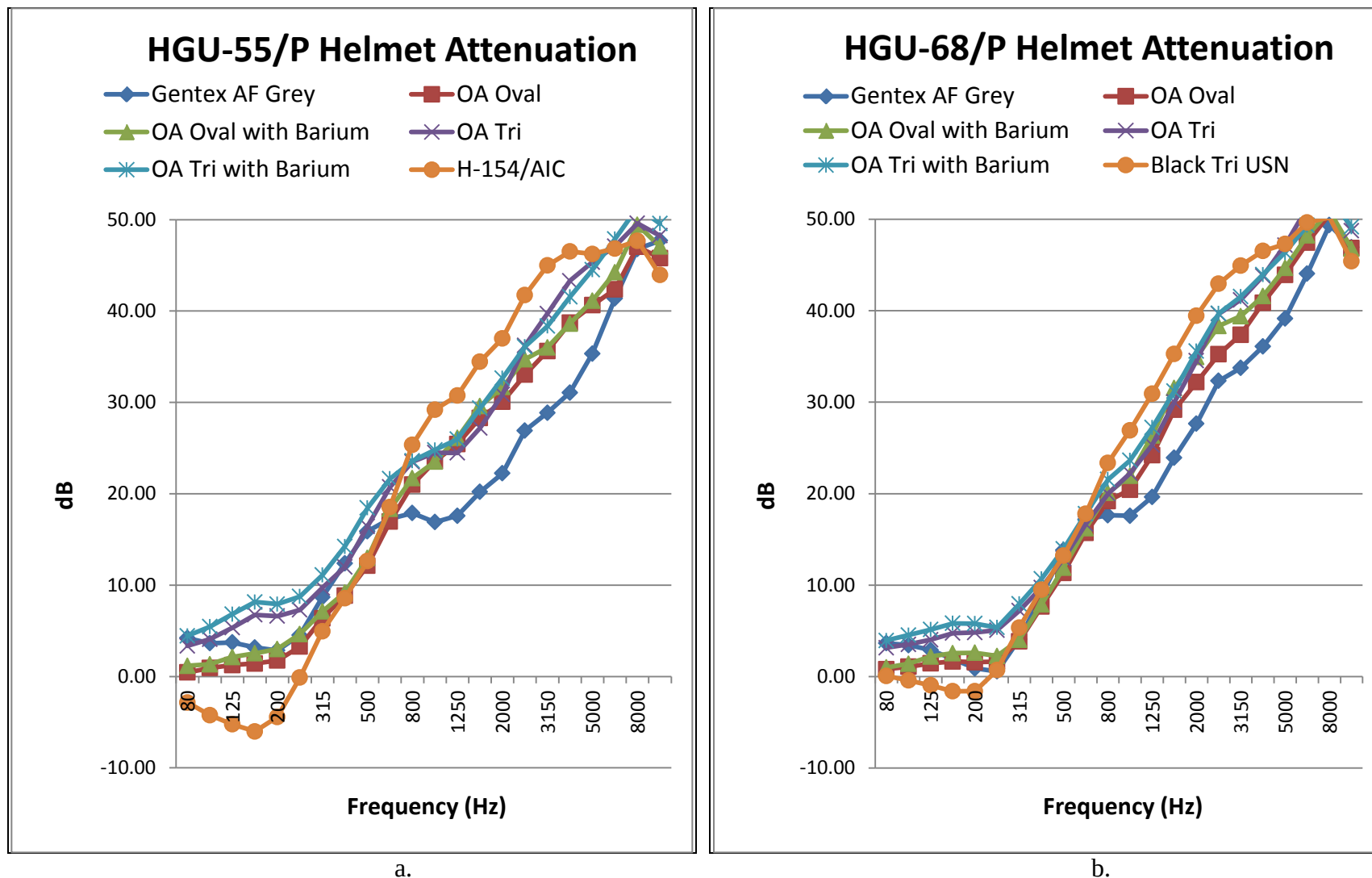
A two-part statistical analysis was performed for the MIRE tests. Part one of the analysis held the earcups fixed while comparing the helmets using a paired t-test. The helmets were compared at seven different frequencies: 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. 42 paired t-tests were performed (7 frequencies and 6 helmet comparisons) for each earcup (except the H-154/AIC, that was tested in all helmets except the JHMCS without COMBAT EDGE (-CE), and the Black Triangle (USN) that was tested in the 68/P and both JHMCS helmets). The data analyzed was left ear only. Paired t-test results are listed in Table 6 where only the red highlighted p-values are statistically significant ($\alpha=0.05$). Part two of the statistical analysis held the helmet fixed while comparing earcups using a paired t-test (Tables 7-8). The same seven frequencies were analyzed from left ear data only. 105 paired t-tests were performed (7 frequencies and 15 earcup comparisons) for each helmet except the JHMCS which had 196 paired t-tests (7 frequencies and 28 earcup comparisons).

Table 6. MIRE statistical analysis – part 1 (paired t-test for fixed earcups)

	55/P – 68/P	55/P - JHMCS	55/P – JHMCS-CE	68/P - JHMCS	68/P - JHMCS-CE	JHMCS – JHMCS-CE
Gen Grey						
125	0.432	0.294	0.931	0.126	0.354	0.305
250	0.022	0.085	0.012	0.087	0.533	0.015
500	0.615	0.312	0.063	0.596	0.126	0.481
1000	0.449	0.423	0.399	0.785	0.669	0.787
2000	0.217	0.447	0.141	0.787	0.955	0.823
4000	0.435	0.948	0.142	0.440	0.411	0.249
8000	0.256	0.332	0.501	0.984	0.789	0.820
OA Oval						
125	0.229	0.826	0.793	0.191		0.918
250	0.030	0.944	0.090	0.067	0.417	0.154
500	0.808	0.069	0.014	0.394	0.003	0.035
1000	0.051	0.002	0.001	0.406	0.005	0.043
2000	0.404	0.295	0.230	0.055	0.039	0.873
4000	0.448	0.066	0.322	0.010	0.055	0.104
8000	0.019	0.600	0.237	0.169	0.384	0.426
OA Oval wB						
125	0.131	0.936	0.230	0.082	0.025	0.245
250	0.029	0.810	0.053	0.010	0.097	0.101
500	0.433	0.016	0.001	0.041	0.001	0.134
1000	0.061	0.463	0.020	0.080	0.648	0.035
2000	0.059	0.232	0.665	0.794	0.382	0.365
4000	0.419	0.477	0.465	0.916	0.890	0.972
8000	0.644	0.061	0.079	0.444	0.400	0.872
OA Tri						
125	0.131	0.552	0.316	0.199	0.166	0.518
250	0.062	0.598	0.066	0.091	0.429	0.109
500	0.004	0.421	0.022	0.326	0.384	0.015
1000	0.107	0.420	0.066	0.373	0.894	0.397
2000	0.101	0.528	0.605	0.474	0.094	0.251
4000	0.653	0.207	0.380	0.022	0.104	0.623
8000	0.000	0.184	0.075	0.294	0.068	0.976
OA Tri wB						
125	0.052	0.850	0.465	0.010	0.034	0.249
250	0.003	0.425	0.025	0.003	0.066	0.191
500	0.008	0.035	0.001	0.282	0.878	0.019
1000	0.337	0.331	0.376	0.803	0.770	0.989
2000	0.143	0.978	0.917	0.112	0.122	0.885
4000	0.580	0.769	0.836	0.465	0.405	0.942
8000	0.484	0.886	0.671	0.377	0.169	0.777
H – 154/AIC					Black Tri	
125	0.161	0.050		0.352		0.002
250	0.701	0.125		0.306		0.663
500	0.600	0.400		0.994		0.679
1000	0.291	0.589		0.007		0.079
2000	0.708	0.074		0.309		0.067
4000	0.335	0.172		0.721		0.253
8000	0.187	0.002		0.408		0.869

Table 7. MIRE statistical analysis – part 2 (paired t-test for fixed helmets (HGU-55/P and HGU-68/P))

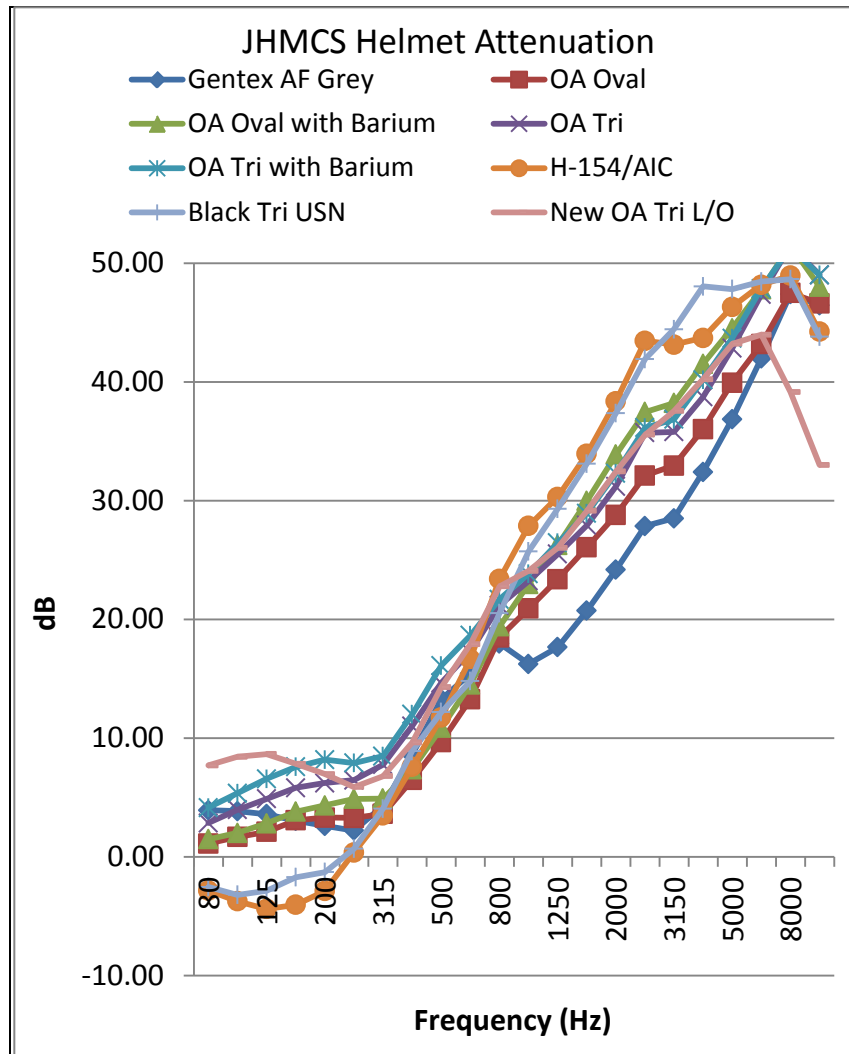
	Gen Grey - OA Oval	Gen Grey - OA Oval wB	Gen Grey - OA Tri	Gen Grey - OA Tri wB	Gen Grey – H- 154/AIC	OA Oval – OA Oval wB	OA Oval – OA Tri wB	OA Oval – OA Tri wB	OA Oval - H- 154/AIC	OA Oval wB - OA Tri	OA Oval wB - OA Tri wB	OA Oval wB – H- 154/AIC	OA Tri – OA Tri wB	OA Tri - H- 154/AIC	OA Tri wB – H- 154/AIC
55/P															
125	0.465	0.511	0.018	0.000	0.000	0.760	0.005	0.003	0.000	0.001	0.001	0.000	0.394	0.000	0.000
250	0.925	0.676	0.023	0.000	0.006	0.591	0.008	0.001	0.006	0.006	0.006	0.012	0.213	0.000	0.000
500	0.059	0.149	0.643	0.016	0.030	0.566	0.007	0.000	0.555	0.033	0.000	0.734	0.054	0.010	0.000
1000	0.000	0.003	0.001	0.001	0.000	0.491	0.400	0.942	0.038	0.791	0.689	0.021	0.783	0.011	0.077
2000	0.014	0.010	0.014	0.006	0.000	0.999	0.711	0.790	0.037	0.794	0.804	0.052	0.536	0.021	0.135
4000	0.063	0.135	0.021	0.000	0.001	0.766	0.391	0.528	0.038	0.333	0.436	0.005	0.858	0.100	0.055
8000	0.461	0.431	0.405	0.142	0.315	0.037	0.211	0.036	0.813	0.984	0.143	0.053	0.283	0.111	0.008
68/P															
125	0.044	0.016	0.080	0.002	0.035	0.427	0.008	0.000	0.120	0.006	0.000	0.067	0.084	0.016	0.002
250	0.377	0.078	0.008	0.002	0.754	0.583	0.025	0.018	0.813	0.004	0.008	0.562	0.999	0.039	0.016
500	0.181	0.142	0.573	0.951	0.534	0.508	0.317	0.044	0.458	0.433	0.088	0.578	0.426	0.883	0.484
1000	0.003	0.009	0.009	0.000	0.000	0.464	0.983	0.253	0.009	0.447	0.068	0.005	0.264	0.015	0.030
2000	0.001	0.001	0.002	0.002	0.005	0.489	0.819	0.066	0.088	0.502	0.466	0.207	0.244	0.142	0.568
4000	0.003	0.088	0.004	0.012	0.005	0.887	0.146	0.356	0.089	0.410	0.489	0.051	0.881	0.397	0.317
8000	0.376	0.862	0.001	0.025	0.831	0.654	0.072	0.266	0.304	0.105	0.230	0.716	0.547	0.006	0.029



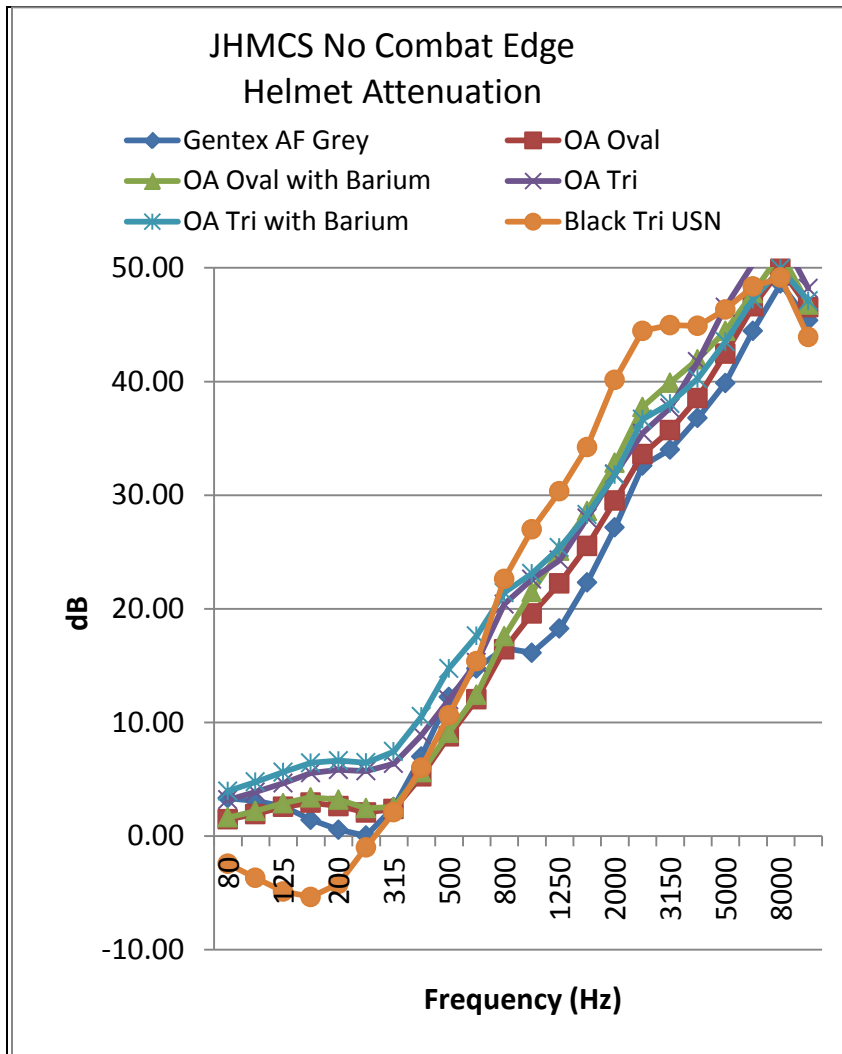
a. b.
Figure 16. Helmet Attenuation for a. HGU-55/P and b. HGU-68/P flight helmets for all earcups tested

Table 8. MIRE statistical analysis – part 2 (paired t-test for fixed helmets (JHMCS with and without COMBAT EDGE))

	Gen Grey – OA Oval	Gen Grey – OA Oval wB	Gen Grey – OA Tri	Gen Grey – OA Tri wB	Gen Grey – H-154/AIC	Gen Grey – Black Tri	Gen Grey – New OA Tri L/O	OA Oval – OA Oval wB	OA Oval – OA Tri	OA Oval – OA Tri wB	OA Oval – H-154/AIC	OA Oval – Black Tri	OA Oval – New OA Tri L/O	OA Oval wB – OA Tri
JHMCS														
125	0.043	0.184	0.021	0.000	0.000	0.000	0.000	0.569	0.000	0.000	0.000	0.000	0.000	0.016
250	0.043	0.010	0.000	0.000	0.990	0.000	0.001	0.476	0.001	0.014	0.146	0.000	0.028	0.190
500	0.099	0.040	0.335	0.113	0.960	0.041	0.755	0.598	0.000	0.001	0.000	0.651	0.005	0.001
1000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.021	0.068	0.009	0.000	0.174	0.001	0.849
2000	0.221	0.007	0.033	0.046	0.000	0.006	0.004	0.014	0.122	0.085	0.000	0.060	0.023	0.368
4000	0.711	0.044	0.110	0.035	0.000	0.000	0.032	0.036	0.195	0.043	0.000	0.000	0.057	0.496
8000	0.496	0.278	0.086	0.181	0.616	0.558	0.000	0.052	0.125	0.090	0.107	0.626	0.000	0.977
	OA Oval wB – OA Tri wB	OA Oval wB – H-154/AIC	OA Oval wB – Black Tri	OA Oval wB – New OA Tri L/O	OA Tri – OA Tri wB	OA Tri – H-154/AIC	OA Tri – Black Tri	OA Tri – New OA Tri L/O	OA Tri wB – H-154/AIC	OA Tri wB – Black Tri	OA Tri wB – New OA Tri L/O	H-154/AIC – Black Tri	H-154/AIC – New OA Tri L/O	Black Tri – New OA Tri L/O
JHMCS-CE														
125	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.005	0.744	0.000	0.000
250	0.002	0.057	0.000	0.236	0.269	0.001	0.000	0.543	0.000	0.000	0.128	0.009	0.000	0.000
500	0.001	0.011	0.919	0.001	0.452	0.051	0.001	0.283	0.011	0.001	0.166	0.005	0.509	0.002
1000	0.862	0.000	0.987	0.010	0.911	0.002	0.815	0.021	0.000	0.877	0.020	0.006	0.016	0.037
2000	0.432	0.009	0.710	0.446	0.925	0.002	0.205	0.525	0.000	0.272	0.678	0.084	0.004	0.534
4000	0.853	0.088	0.032	0.906	0.406	0.037	0.003	0.422	0.142	0.024	0.899	0.103	0.162	0.021
8000	0.876	0.072	0.015	0.000	0.829	0.336	0.068	0.000	0.409	0.026	0.000	0.045	0.000	0.000



a.



b.

Figure 17. Helmet Attenuation for a. JHMCS and b. JHMCS no COMBAT EDGE flight helmets for all earcups tested

5.2.2 REAT Testing

Figures 16-17 presents the four helmets separately with each tested earcup. From these REAT results, five earcups were chosen for further MIRE testing in the JHMCS helmet with COMBAT EDGE only: OA Oval and Triangle, the Gentex Black Triangle (USN) and Oval (H-154/AIC), and the new OA Triangle L/O. The JHMCS was compared at seven different frequencies: 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. The mean data for the 10 subjects are shown in Figure 18. The new OA triangle L/O performed the best in the JHMCS helmet with COMBAT EDGE while the H-154/AIC was the worst performer overall at most frequencies. 70 one-sample t-tests were performed (7 frequencies and 10 earcup comparisons, Table 9).

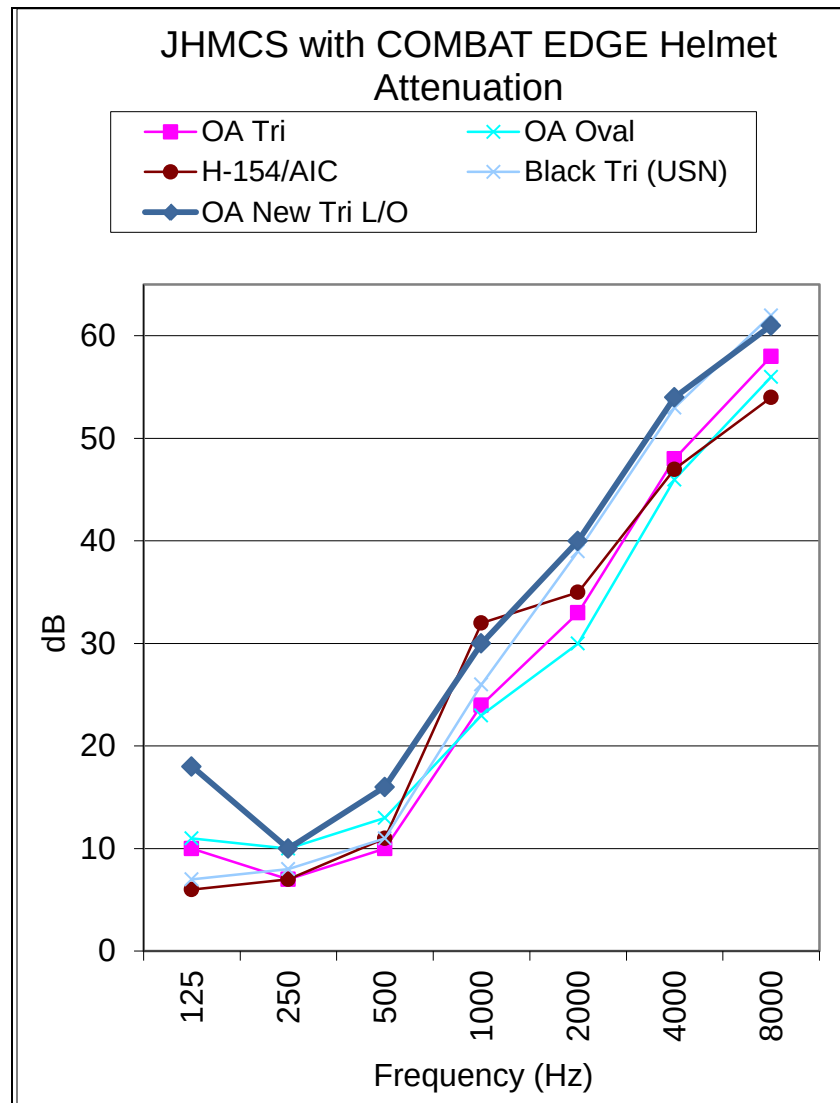


Figure 18. REAT test results for the JHMCS with COMBAT EDGE helmet comparing five different earcups

Table 9. REAT statistical analysis

	OA Oval – OA Tri	OA Oval – H-154/AIC	OA Oval – Black Tri	OA Oval – New OA Tri L/O	OA Tri – H-154/AIC
Freq (Hz)					
125	0.869	0.012	0.109	0.025	0.001
250	0.193	0.795	0.721	0.153	0.100
500	0.106	0.552	0.396	0.001	0.099
1000	0.449	0.000	0.078	0.001	0.000
2000	0.065	0.065	0.002	0.005	0.013
4000	0.453	0.677	0.131	0.011	0.645
8000	0.281	0.032	0.017	0.078	0.335

	OA Tri – Black Tri	OA Tri – New OA Tri L/O	H-154/AIC – Black Tri	H-154/AIC – New OA Tri L/O	Black Tri – New OA Tri L/O
Freq (Hz)					
125	0.033	0.012	0.519	0.000	0.002
250	0.165	0.830	0.851	0.273	0.312
500	0.315	0.018	0.791	0.003	0.032
1000	0.015	0.002	0.001	0.266	0.058
2000	0.000	0.005	0.049	0.021	0.806
4000	0.024	0.021	0.072	0.017	0.446
8000	0.005	0.015	0.002	0.007	0.678

REAT test results also produce mean octave band data, C-A (USAF test method), and Noise Reduction Rate (NRR) data. The mean octave band data is listed in Table 10 and Table 11 presents the C-A (1 and 2 SD) results for both the 1 to 3 dB and 4 to 7 dB band (band most typical of cockpit noise). The C-A method is a single number reduction value that takes into account the spectral content of the noise and the attenuation of the hearing protection in response to that noise. The C-A is significantly more accurate than the NRR and is only exceeded in accuracy by the long Octave Band Method. The new OA Triangle L/O produced the best result for 5 of the 7 frequencies when comparing the mean octave band data and the best results for the C-A Air Force Test Method. Similar results were found when comparing the NRR data.

Table 10. JHMCS results for the mean octave band data per earcup

Mean Octave Band Data							
	Frequency (Hz)						
Earcup	125	250	500	1000	2000	4000	8000
OA Oval	6	7	11	32	35	47	54
OA Triangle	10	7	10	24	33	48	58
New OA Triangle L/O	11	10	13	23	30	46	56
H-154/AIC	18	10	16	30	40	54	61
Black Triangle (USN)	7	8	11	26	39	53	62

Table 11. JHMCS results for C-A Air Force Test Method per earcup

C-A (USAF) – (1 SD/2 SD)		
Earcup	C-A Band	
	1-3 dB	4-7 dB
OA Oval	12/9	8/4
OA Triangle	14/10	10/6
New OA Triangle L/O	15/10	11/6
H-154/AIC	13/10	9/6
Black Triangle (USN)	13/9	9/5

5.3 *In-Flight Noise Data*

A total of six LAANG F-15 pilots flew two separate flights each using a JHMCS flight helmet for one flight and a HGU-55/P for the other flight. The pilot's were instructed to fly 7 specific flight conditions/test points at airspeeds ranging from 400 to 550 Knots Indicated Airspeed (KIAS) and altitude ranging from 5,000 to 20,000 feet. The flight conditions were spoken aloud in order for the time of the condition to later be extracted in the analysis. Each flight had an external microphone and an internal microphone to collect the noise on the outside of the helmet and the inside of the earcup respectively.

The collected in-flight noise levels were saved as a file (.wav format). The flight conditions were identified per flight and the time histories were recorded. A total of 9 different flight conditions were collected and numbered in Table 12. The stereo .wav files were then converted into two separate mono .wav files using Adobe Audition 2.0 (external and internal). A batch analyzer was used to conduct a frequency analysis for each of the .wav files. The data was reported in decibels (dB) on a second by second basis for frequencies ranging from 10 Hz to 16 kHz. An acoustic summary program was then used to locate the time intervals within each flight that the test conditions were completed. The overall dB level for each test condition was calculated using an average of the dB levels across all frequencies. To capture each test condition more accurately, a time interval of five seconds before and after each data point was used in the calculation. A calibration tone recorded before each flight served as a reference point to determine the actual dB levels in each respective flight.

Table 12. Flight conditions collected from F-15 pilots

Flight Condition	Altitude (ft)	Airspeed (KIAS)
1	5,000	400
2	5,000	450
3	5,000	500
4	5,000	550
5	10,000	400
6	10,000	450
7	10,000	500
8	10,000	550
9	20,000	450

The noise levels were analyzed using MATLAB[®] to compare the internal noise levels of the helmet and the external noise levels of the helmet. Flight Conditions 1 and 5 were not included due to the small number of pilots who collected at these conditions. First, a comparison of the mean external microphone data (ext) of the HGU-55A/P (JHMCS) to the mean ext of the HGU-55/P for all conditions was made to ensure that a true comparison could be made between helmets. The results were very similar across the frequency span. The mean data was graphed with the error bars (calculated +/- 1 standard deviation) added to the charts per condition, Figure 19. The same analysis was performed for the internal microphone data (int), Figure 20.

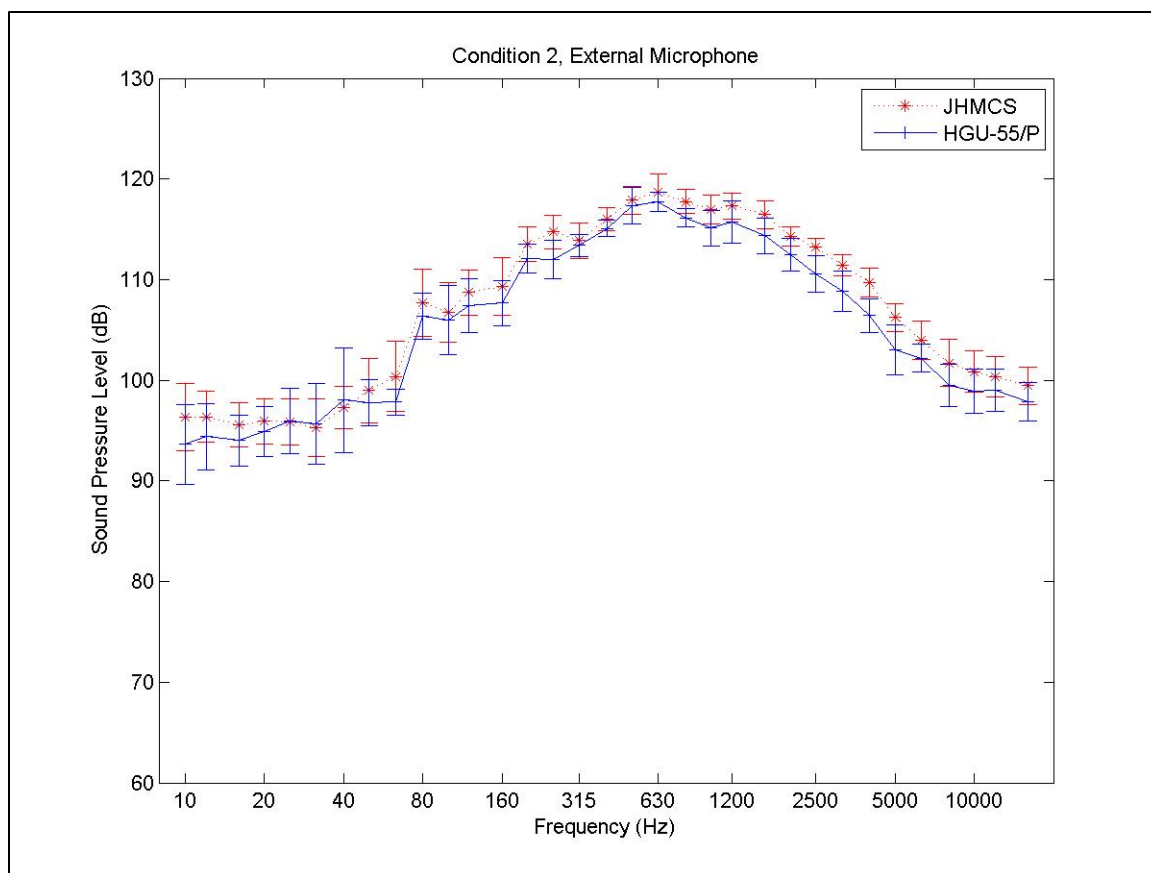


Figure 19. Mean external microphone data for the JHMCS and HGU-55/P during flight condition 2 (450 KIAS, 5,000 ft)

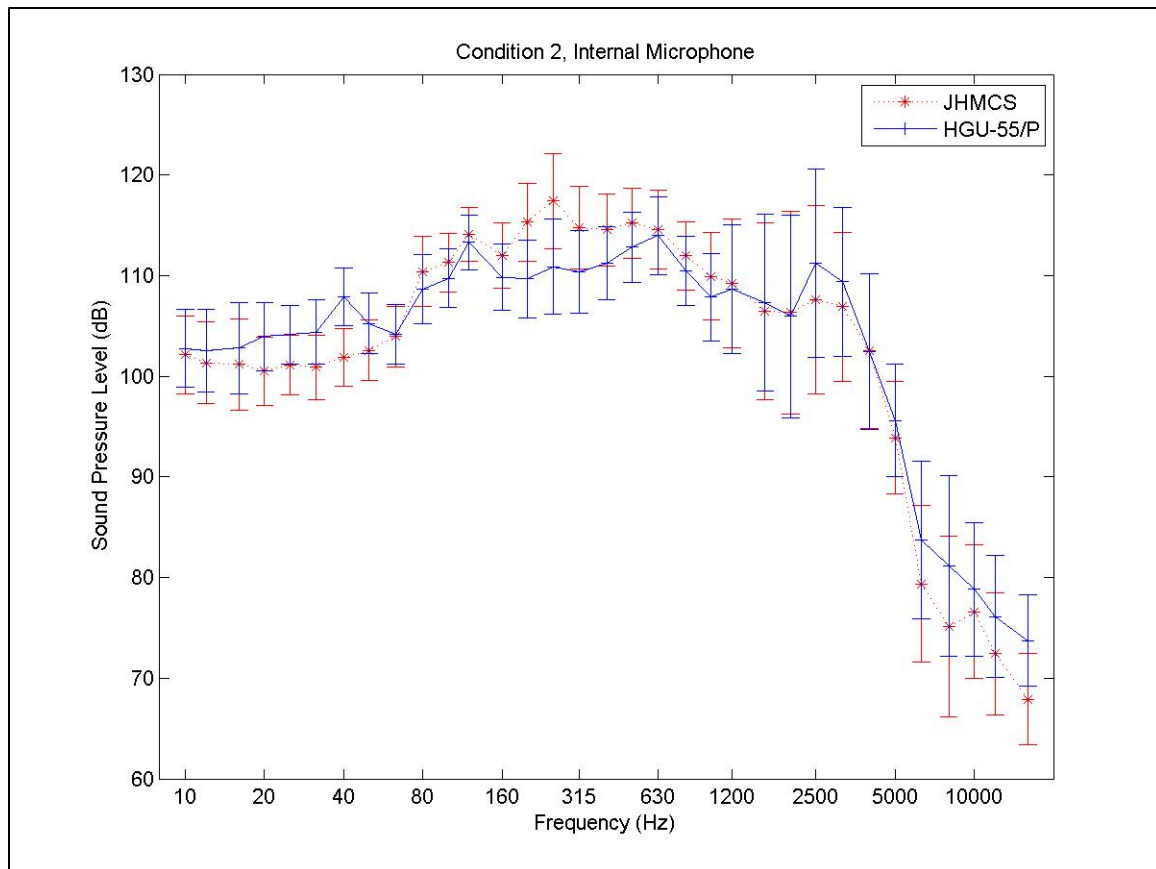


Figure 20. Mean internal microphone data for the JHMCS and HGU-55/P during flight condition 2 (450 KIAS, 5,000 ft)

The helmet attenuation was determined by subtracting the mean (int) Sound Pressure Levels (SPL) from the mean (ext) SPL. The error bars were calculated by subtracting the mean $\pm$ 1SD (int) from the mean $\pm$ 1SD (ext). Figure 21 shows similar helmet attenuation effectiveness for both the JHMCS and the HGU-55/P flight helmets. A dB difference of 3 or more is used as a rule of thumb to indicate a significant difference. A delta was calculated between the ext JHMCS and the ext HGU-55/P for all conditions. This offset was then applied to the helmet attenuation analysis, Figure 22. From this figure, the JHMCS performed equally well to the HGU-55/P if not better during the specified flight conditions.

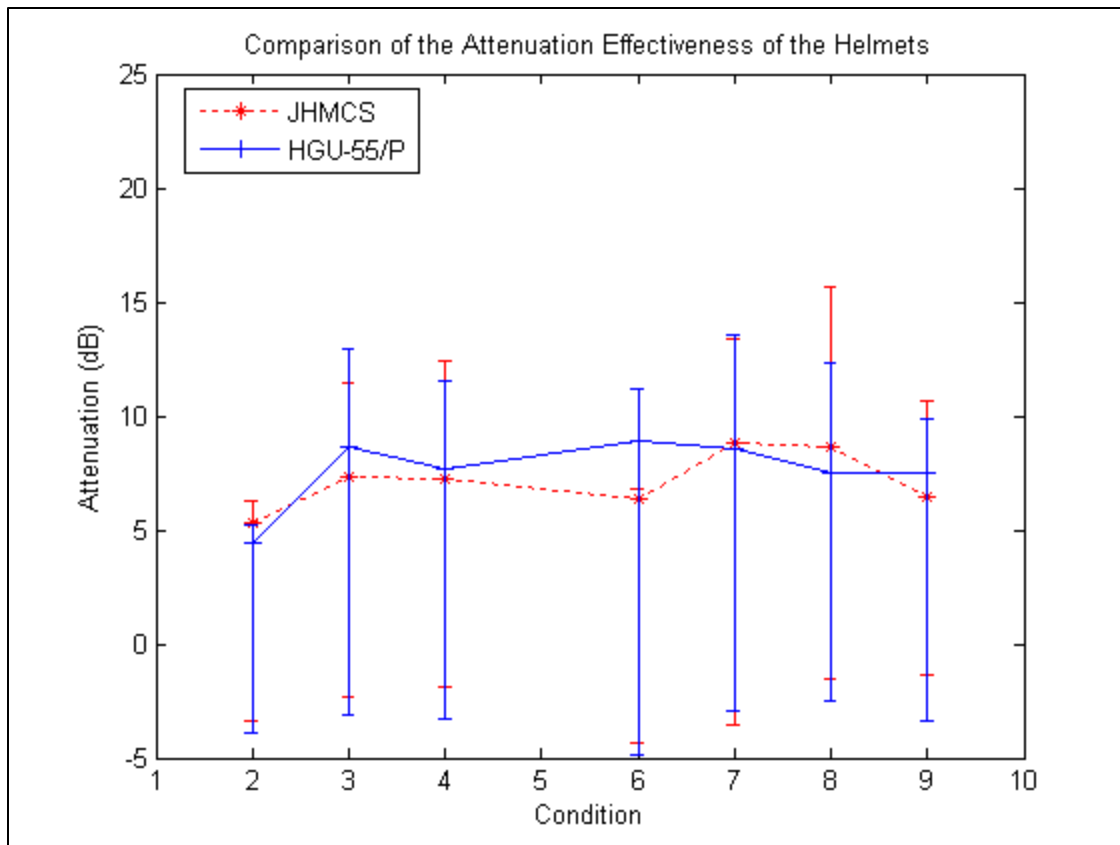


Figure 21. Helmet attenuation effectiveness for the JHMCS and HGU-55/P during specified flight conditions

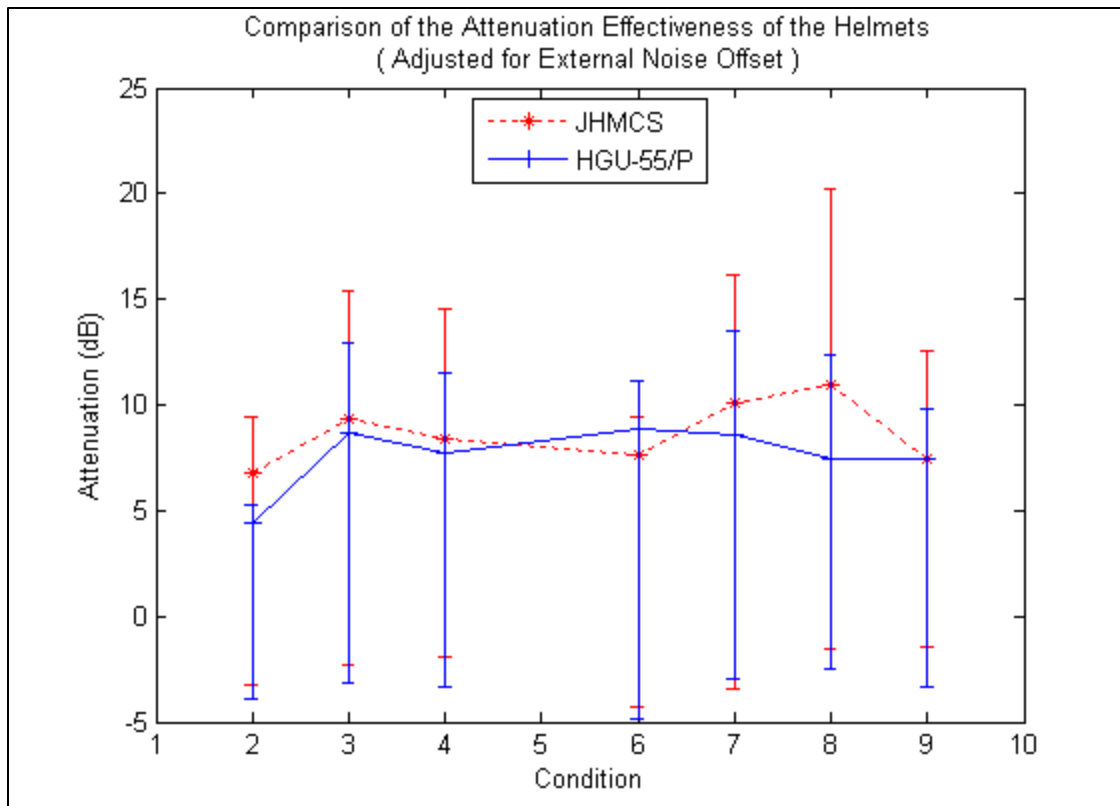


Figure 22. Adjusted helmet attenuation effectiveness for the JHMCS and HGU-55/P during specified flight conditions

6.0 DISCUSSION

6.1 Earphone Element

The free-field sensitivity and frequency response of the H-143/AIC and H-87 B/U earphone elements allowed for a comparison of operational earphones. Comparing the type of element revealed large differences in response at varying frequencies, up to 47 dB. Then comparing each manufacturer of that element separately, smaller differences were found, up to 30 dB. The large differences mean that the earphone elements are not producing a consistent frequency response; one element may attenuate more or less when compared to another element from the same manufacturer.

6.2 Helmet/Earcup Attenuation

MIRE results found attenuation differences that ranged from 2-5 dB at varying frequencies for all helmet/earcup comparisons. Therefore the JHMCS helmet attenuation is comparable to that of the legacy helmets. The JHMCS with COMBAT EDGE is not significantly different than the HGU-55/P helmet and the JHMCS without COMBAT EDGE is not significantly different than the HGU-68/P helmet. The type of helmet is not a factor when investigating the JHMCS noise issue. However, there were significant differences in earcup performances. The Gentex Grey Triangle performed the worst in the legacy helmets at 800 Hz and above while the Gentex Black Triangle (USN) performed the worst at 80 to 300 Hz and the best at 700 to 4000 Hz in the legacy helmets. When comparing earcups in the JHMCS, the Gentex Oval (H-154/AIC) performed the

worst from 80 to 300 Hz and the best from 800 to 2500 Hz. From these results, further testing was done in the REAT facility on the OA Oval and Triangle, the new OA Triangle L/O, the Gentex Black Triangle (USN) and the Gentex Oval (H-154/AIC) with the JHMCS helmet only. The new OA Triangle L/O was found to be the best attenuation performer based on the REAT results (mean octave band, C-A test method, and NRR).

6.3 In-Flight Noise Data

The in-flight data analysis collected from the LAANG F-15 pilots determined that the helmet shell attenuation of the JHMCS equally performed with, if not outperformed, the HGU-55/P shell attenuation during the specified flight conditions.

7.0 CONCLUSION

Overall the JHMCS helmet attenuation, with and without COMBAT EDGE, is not significantly different from the legacy helmets. The MIRE and in-flight attenuation analysis both confirm these findings. As for the helmet configurations including earphone elements and earcups, some significant differences were found. The earphone element testing found large differences between elements. A further evaluation of the elements will be needed before determining which earphone element is best in the JHMCS. Improved designs, magnetic materials, or manufacturing processes will need to be tested to determine if frequency response variation has been reduced. The REAT earcup attenuation testing determined the new OA Triangle L/O to be the best performer in the JHMCS with higher mean octave band attenuation data, NRR, and C-A results. This new earcup is currently being evaluated in-flight by F-15, F-16, and F/A-18 pilots to help confirm these findings and to ensure user acceptability and comfort. The earcup will also need to be authorized for future use in the JHMCS. Proper helmet and earcup fit continue to be highly emphasized to units for the highest attenuation performance.

8.0 REFERENCES

1. ACC Approval List, EMI Certification Letter, page 16.
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5. N78-NTSP-A-50-0103/D, NAVY Training System Plan for the Joint Helmet Mounted Cueing System, May 2002.