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USAARL REPORT NO. 81-3

VIBRATION IN A HELMET MOUNTED SIGHT (HMS) USING MECHANICAL LINKAGE

By

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BIODYNAMICS RESEARCH DIVISION

March 1981

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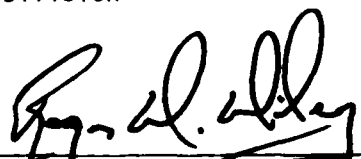
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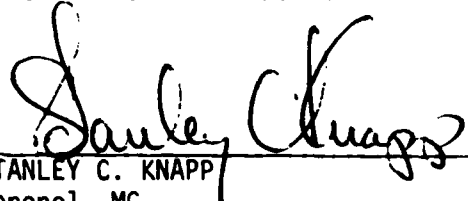
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20. ABSTRACT

The purpose of this experiment was to determine the extent to which aircraft vibration was coupled to a crewman's flight helmet by the mechanical linkage of a helmet mounted sight (Fire Control Subsystem, Helmet Directed, XM128). Two variations of the SPH-4 flight helmet were tested: 1. SPH-4 with standard web suspension, 2. SPH-4 with a form-fit foam liner suspension. The system was tested in the front seat of an AH-1S "Cobra" helicopter. Five (5) flight conditions were used in the experiment: 1. hover, 2. 40kn, 3. 80kn, 4. 120kn, 5. standard left turn. Two conditions of the helmet mounted control linkage were tested: 1. connected, 2. disconnected. A triaxial accelerometer was mounted on top of the flight helmet to measure vibration. The data were analyzed using a fast Fourier transform analyzer and a desk-top computer. The following observations were made: 1. Both helmets vibrate more with the sight attached. 2. The response to the sight coupled vibration of the standard SPH-4 differed from that of the form-fit SPH-4. 3. The form-fit SPH-4 helmet vibrated more in a narrow band centered at about 30Hz. 4. The standard SPH-4 helmet vibrated more over a wide band of frequencies above 30Hz. Based on a review of published literature with respect to known or probable physiological problems related to the effects of vibration, we concluded that the significant increase in vibration of the helmet caused by the mechanical sight linkage may be expected to degrade pilot/gunner visual performance and hearing acuity, and increase fatigue rate to some extent. Insufficient data is currently available to predict the magnitude of performance degradation which could result from increases in helmet vibration.

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PREFACE

The specialized talents and dedicated efforts of many technicians and administrative personnel went to complete this study. The authors appreciate their efforts.

Appendixes A through D, the detailed data analyses procedures and the graphic presentations of the vibration spectra, were printed under separate cover. Titles of the four appendixes are:

Appendix A. Table of Identification Numbers and File Number for Vibration Data Processed onto 5 1/2" Diskettes and Digital Cassette Tape

Appendix B. Data Analysis and Control Software

Appendix C. Helmet Acceleration Spectra

Appendix D. Difference in Helmet Acceleration Spectra

These appendixes are available upon request from:

Commander
U.S. Army Aeromedical Research Laboratory
ATTN: Scientific Information Center
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Ft. Rucker, AL 36362

Human subjects participated in these studies after giving their free and informed volunteer consent. Investigators adhered to AR 725 and USAAMRDC Reg 70-25 on Use of Volunteers in Research.

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INTRODUCTION

This report was written to document our findings, that a mechanical helmet mounted sight (HMS) linkage significantly increased helmet vibration during flight in an AH-1S Cobra. The report was specifically requested by Commander, Frankfort Arsenal (DA, SARFA-FCW-W, 11549Z Aug 76, TWX), and is a complete analysis of the data provided to them in a preliminary report (TRADOC, ATMAS-CBT Jul 76).

A visually coupled system (VCS) is a closed loop control technique by which a mechanical system (e.g. gun, missile, rocket launcher) tracks a target by following the visual tracking movements of the operator (Verona, Johnson, Jones, 1979). See Figure 1. Such a system, the "Fire Control Subsystem, Helmet Directed, XM128" (DA TM, 1975), is used in the S Model AH-1 Cobra attack helicopter.
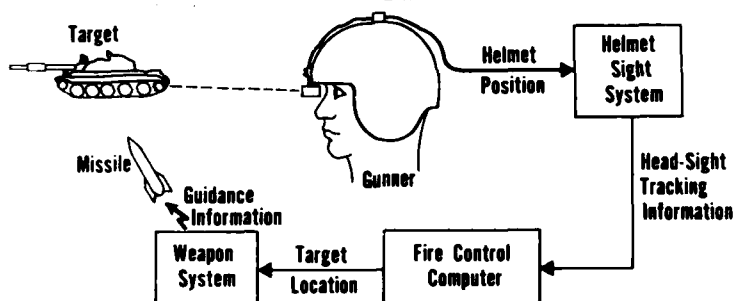
FIGURE 1. A visually coupled system (VCS).

Two methods are available for providing head tracking information to the fire control computer: contact or non-contact. In a contact system a mechanical linkage connects the helmet to the airframe (reference) and detects relative position of the helmet by measuring perturbations of the mechanical linkage, Figure 2. In the non-contact system, helmet position is measured by electro-optical, electromagnetic or other transducers which sense perturbation in a well defined reference field within the aircraft. The non-contact sensing systems have the advantage of not physically coupling the head of the operator to the airframe. The mechanical systems are less complex and less expensive. The cost and technical complexity of non-contact systems are known. The physiological effects of connecting the head to the airframe by a mechanical system are unknown. The purpose of this paper is to provide information on the possible physiological hazards and performance decrements which may be induced in the HMS user by aircraft vibration transmitted through a mechanical

sight linkage. By providing this data, we aid the designer of helmet mounted sight systems by giving him an idea of the physiological cost of using a mechanically linked system. He may then balance the physiological cost of a system against the expense of a non-contact system. Consideration of this information along with other factors will enable him to select the most efficient and effective system.
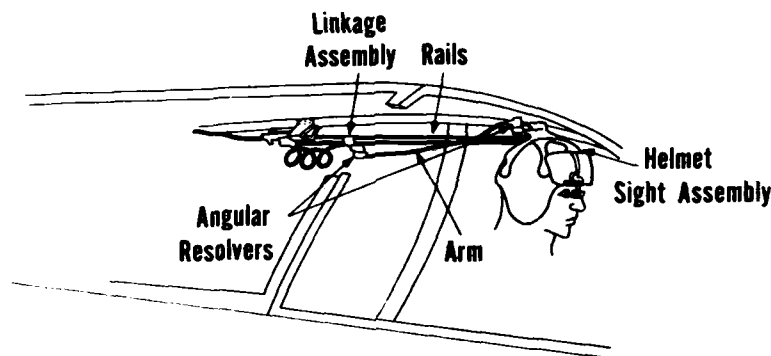
FIGURE 2. Mechanical linkage.

The purpose of this experiment was to determine the extent to which aircraft vibration was coupled to the helmet by the mechanical linkage of the Fire Control Subsystem, Helmet Directed, XM128. We addressed two specific questions:

a. Does the mechanical sight linkage increase vibration at the head of the operator?

b. Is there a difference in helmet vibration level between sling suspension (SPH-4) and form-fit helmet?

We answered these questions by recording vibration of each helmet, during flight in an AH-1S aircraft under a variety of flight conditions, with HMS connected and disconnected. The resulting data were converted to spectra and total root mean square average accelerations were calculated. Values of acceleration for the connected and disconnected sight conditions were then compared. Results showed that the vibration at the helmet was always greater with the sight linkage connected.

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MATERIALS

In the AH-1S, a mechanical system (DA 1975) is used to acquire head track-
ing information from the gunner. The system (Figure 2) consists of a helmet
sight assembly which is fastened to the SPH-4 flight helmet, and a linkage as-
sembly which connects the helmet to the aircraft and allows for head movement.
Head sighting angle is measured by resolvers at the articulation points of the
linkage assembly.

The data collection system is shown in Figure 3.
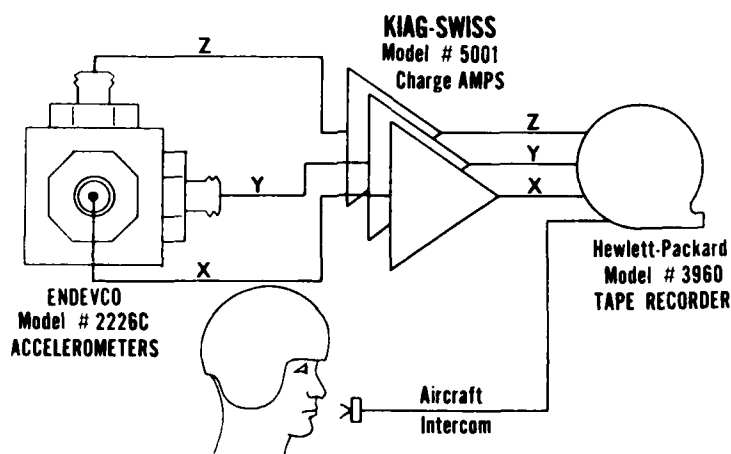
FIGURE 3. The data collection system.

The SPH-4 helmet used in the study is shown on the head of the volunteer
in Figure 4. The black block at the apex of the helmet (A) is the attachment
point for the linkage assembly of the system. The white block (B) is a 1/2"
cube of aluminum to which three Endevco^{TM*} Model 226C accelerometers are
attached. The mounting plate (C) of the helmet sight assembly and the sight
reticle (D) are also shown. Low noise coaxial cables connect the accelerometers
to the charge amplifiers (not shown).

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* All registered Trade Marks are defined in the Appendix.

FIGURE 4.   Exterior of the SPH-4 Helmet.

        A.   Linkage attachment point
        B.   Accelerometer block
        C.   Sight mounting plate
        D.   Sight reticle

The Endevco^{TM} Model 2226C piezoelectric accelerometers were chosen for their small size and low mass. The frequency response of the accelerometers was ± 5% (1 dB) from 3 Hz to 6 KHz. The total weight of the test fixture (3 accelerometers plus the aluminum block) was 47.1 g. Mounting detail is shown in Figure 5. Accelerometers were affixed to the aluminum block and the block to the sight connector using cyano acrylate cement. The model 5001 KIAG-SWISS^{TM} charge amplifier used to condition the output of each accelerometer has a frequency response of .16 Hz to 100 KHz ± 3 dB. The Hewlett-Packard^{TM} Model 3960 tape recorder with which we recorded our data has a passband of DC 1250 Hz ± 3 dB at the selected tape speed of 3 3/4 ips. Thus the overall frequency response of the system was 3 Hz to 1250 Hz limited by the accelerometer at the low end of the spectrum and by the tape recorder at the upper end.
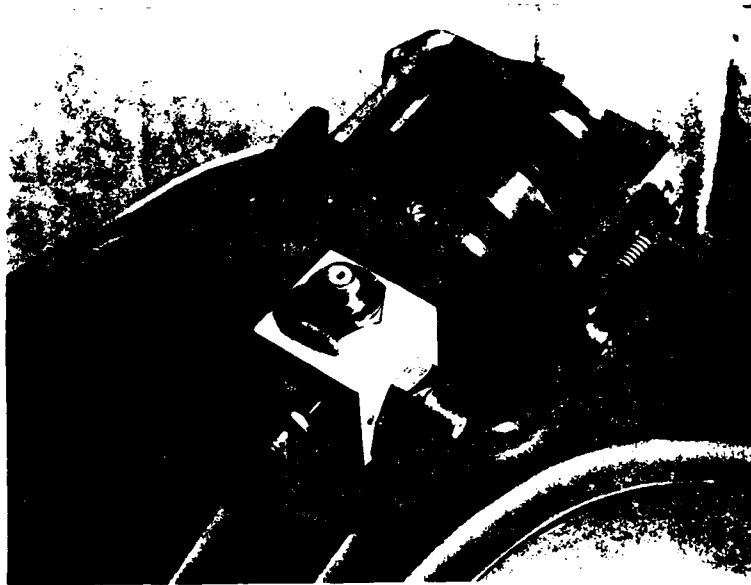
FIGURE 5. Mounting detail of accelerometers.

The data analysis system is shown in Figure 7, p. 12.

The parameter list for the Nicolet 660^{TM} spectrum analyzer is shown in Table 1, p. 10.

Spectral data was stored by the 160C^{TM} data recorder on 5 1/2" standard diskettes. File identification numbers for the spectral data stored on diskettes are listed in Appendix A (available upon request). The recorded spectral data were further reduced using a Hewlett-Packard 9824S^{TM} computer. Software to perform the analysis and to control the 160C^{TM} on the IEEE-488* bus is documented in Appendix B (available upon request). The program for extracting data from the 160C^{TM} was written by Nicolet Scientific Corp. The programs for performing analysis functions were written by the authors.

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* IEEE-488 bus is an interface system defined by IEEE Standard Digital Interface for Programmable Instrumentation, 1978, New York: Institute for Electrical and Electronic Engineers.

TABLE 1

PARAMETER SETTING FOR NICOLET 660^{TM} SPECTRUM ANALYZER

PARAMETER	SETTING
MODE	1K CH A-B FFT
FUNCTION	RMS SPECTRUM
AVERAGE	SUM (N = 128)
CHANNEL A INPUT	1.0 VOLTS
	AC COUPLED (-3 dB @ 0.5 Hz)
	NORMAL MODE
CHANNEL B INPUT	1.0 VOLTS
	AC COUPLED (-3 dB @ 0.5 Hz)
	NORMAL MODE
CAPTURE CONTROL	CONTINUOUS (HANNING WINDOW)
FREQUENCY RANGE	2000 Hz (.2 SEC WINDOW)

METHODS

DATA COLLECTION

Triaxial linear accelerations were measured at the apex of the gunner's helmet. Orientation of the measurement axis is shown in Figure 6.

SIDE VIEW **FRONT VIEW**
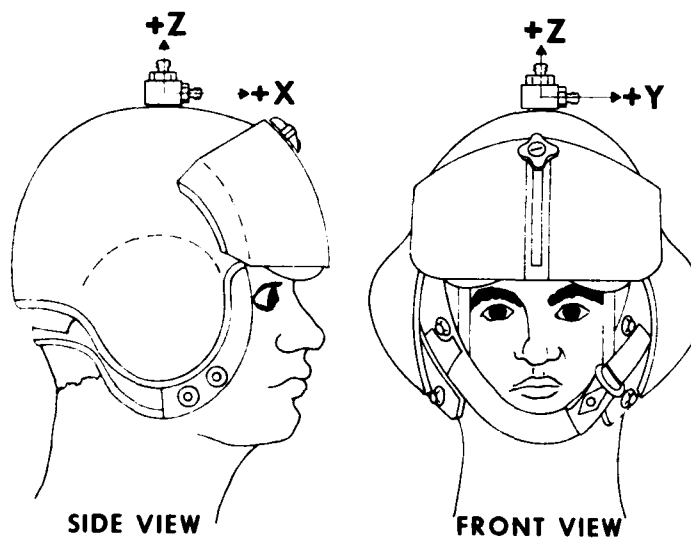
FIGURE 6. Orientation of measurement axes
for helmet accelerometer.

Two helmet configurations were evaluated, standard sling suspension SPH-4 aviator helmet and a modified SPH-4 helmet with a form-fit polyurethane foam liner. A volunteer subject was seated in the front (gunner) seat of an AH-1S aircraft. For the first flight the subject was fitted with an SPH-4 medium sized flight helmet modified by addition of a form-fitted, leather-covered, polyurethane foam liner in place of the standard sling suspension. The volunteer started the recording of vibration data and made verbal annotations of flight conditions during the recording. Approximately 120 seconds of data were collected in each of five flight conditions: Hover (50 ft), 40 kn, 80 kn, 120 kn and standard left turn. During the first half of the 120 second data block the gunner linkage assembly was connected to the helmet. During the last half of the data record the assembly was disconnected from the helmet. For the second flight the volunteer replaced the form-fit SPH-4 with a standard SPH-4

flight helmet having a sling suspension. The data collection sequence
was repeated with this second helmet.

DATA ANALYSIS

Analog acceleration data from the inflight recording were transformed
using Fourier analysis. The analysis system is shown in Figure 7. This
analysis yielded a function of frequency and amplitude for each block of
data. From this transformed data we obtained information on the dynamic
behavior of each helmet system.
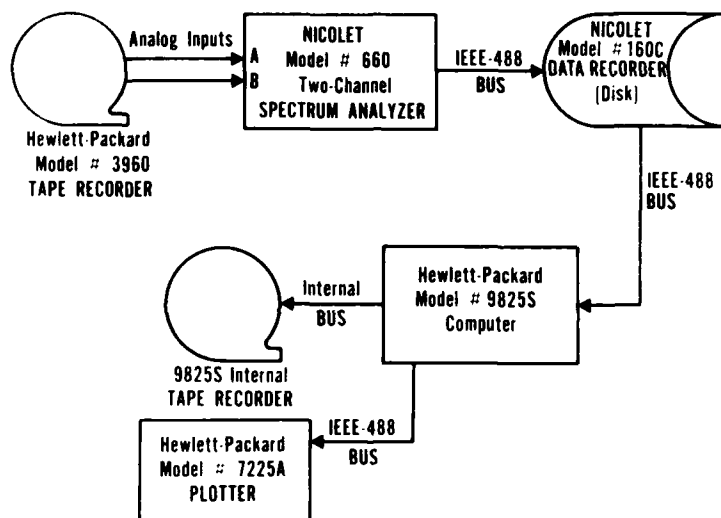
FIGURE 7. Data analysis system.

Since the Nicolet 660^{TM} used to perform the fast Fourier transform
had two analysis channels, acceleration channels Z and X were analyzed
first followed by channels Z and Y. We used redundancy of the Z acceler-
ation data as a check on the reproducability of the data between analyses.

The analysis bandwidth selected was 0.5 to 2000 Hz. This bandwidth
was chosen in order to have sufficient resolution (5.0 Hz) and sufficient
range to measure vibration in the lower audio range. The length of the
data window at this bandwith is 0.2 seconds. Since the amount of clean
data on each flight condition and helmet-sight condition was about 30 seconds,
128 samples (windows) were transformed and the Fourier coefficients arith-
metically averaged. Thus, approximately 26 seconds of raw data were analyzed

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to produce each Fourier transform. The Fourier coefficients which make up
the transformed data were scaled by the Nicolet 660[TM] to compensate for the
hanning window used to truncate the analog data and to compensate for the
effective noise bandwidth of the analysis. The ordinate of the spectra
presented in this report represents root-mean-square (RMS) average accelera-
tion in units of m/s^2. After processing, the raw Fourier coefficients and
the compensation data were stored on 5½ inch floppy disketts using a Nicolet
160C[TM] data recorder.

Difference functions were calculated from the stored data for each of
the flight conditions. Difference functions, A[F], are result of point
by point substraction of the disconnected sight spectrum from the connected
sight spectrum.

$$A[F] = A_c[F] - A_d[F] \qquad\qquad (1)$$

$A_c[F]$ is the magnitude of vibration acceleration as a function of fre-

quency with the sight connected to the helmet.

$A_d[F]$ is the magnitude of vibration acceleration as a function of fre-

quency with the sight disconnected.

RESULTS

A total root mean square (RMS) helmet acceleration for each condition
is presented in Table 2, p.14. The resultant RMS acceleration is the vector
magnitude of the RMS acceleration for each of the three (X, Y, Z) orthogonal
linear accelerometer axes. It is expressed quantitatively as A_T in equation
2.

$$A_T = (A_x^2 + A_y^2 + A_z^2)^{\frac{1}{2}} \qquad\qquad (2)$$

where A_x is the RMS average (over time) of the vibration acceleration in the

X axis; A_y, for the Y axis; and A_z, for the Z axis.

Typical example vibration spectra for the form-fit and standard SPH-4 hel-
met are shown in Figure 8. Also shown in Figure 8 are the vibration spectra
for connected versus disconnected condition of the helmet sight.

The X, Y, and Z axes exhibited similar trends in response to the helmet-
sight variables. A complete set of vibration spectra is presented as Appendix C
(available upon request).

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TABLE 2

HELMET VIBRATION LEVELS (ROOT MEAN SQUARE AVERAGE, M/S^2) FOR EACH CONDITION EVALUATED

HELMET	SIGHT CONDITION	AXIS	FLIGHT PROFILE				
			HOVER 50 FT	40 KN	80 KN	120 KN	LEFT TURN
STD SPH-4	CONNECTED	X	.75466	.85209	1.76160	1.6411	1.58976
		Y	.44230	.61447	1.21277	1.42111	1.76677
		Z	.76511	.79482	1.71849	1.64996	1.90948
		RESULTANT	1.16	1.32	2.74	2.73	3.05
STD SPH-4	DISCONNECTED	X	.37520	.29734	.35943	.46822	.44839
		Y	.17778	.16719	.17695	.23235	.25591
		Z	.28439	.31921	.35118	.46783	.42373
		RESULTANT	0.50	0.47	0.53	0.70	0.67
FORM FIT	CONNECTED	X	.48323	1.4478	.88968	1.69056	2.30703
		Y	.44955	1.04494	.79133	1.17285	1.91915
		Z	.56322	1.19556	.82938	1.39338	1.78555
		RESULTANT	0.87	2.15	1.45	2.48	3.49
FORM FIT	DISCONNECTED	X	.35470	.35916	.36969	.41699	.39302
		Y	.29448	.32260	.27315	.34842	.39435
		Z	.37996	.44937	.38890	.58295	.56643
		RESULTANT	0.60	0.66	0.60	0.80	0.79

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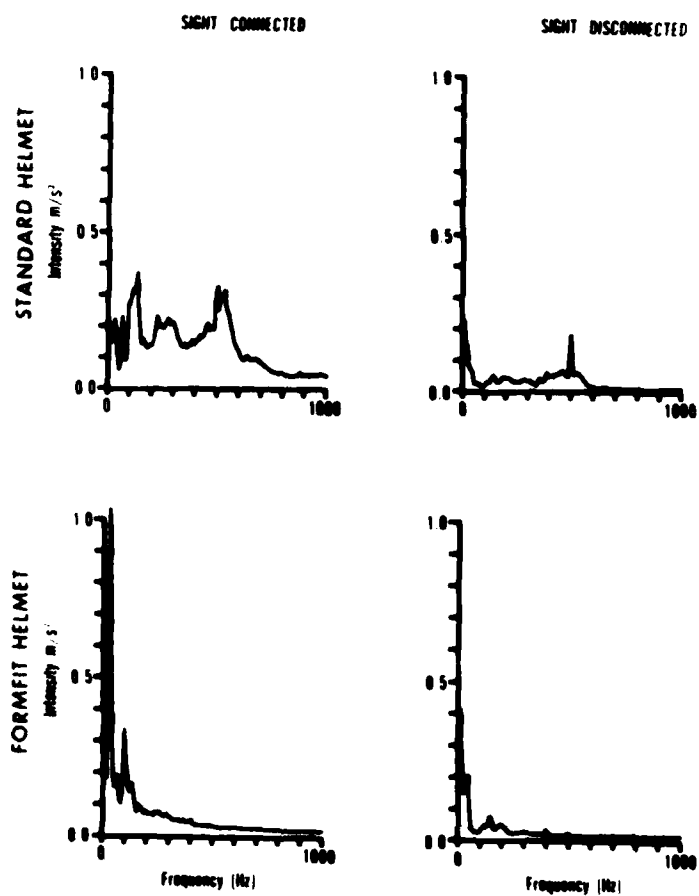
FIGURE 8.   Sample Helmet Acceleration Spectra

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DISCUSSION

The first question we must answer is whether the connected sight condition caused more helmet vibration than the non-connected condition. Table 2 shows that for every case the helmet with sight connected experienced more vibration than the helmet without sight connected (Table 2 p. 14). The magnitude of the difference is shown (in percent) in Table 3.

TABLE 3

INCREASE IN HELMET VIBRATION WITH THE HELMET SIGHT CONNECTED
(SHOWN IN PERCENT)

	FLIGHT PROFILE				
HELMET TYPE	HOVER	40 kn	80 kn	120 kn	LEFT TURN
SPH-4	132%	181%	417%	290%	355%
FORM-FIT	45	226	142	210	342

The second question we have to address is which helmet was "better" for use with the HMS system. There are significant differences in the responses of the two different helmet types to the sight induced vibration. In order to evaluate these we calculated and plotted the point for point differences between the spectra for each helmet with and without the sight connected. Two of these difference graphs are presented in Figure 9 and 10 for the standard SPH-4 and form-fit SPH-4 helmets respectively. A complete set of difference graphs is included for all test conditions in Appendix D (available upon request).

Note that in the case of the standard SPH-4 helmet the total vibration was spread over a wide band with the peak value of acceleration being 0.4 m/s^2 at a frequency of approximately 130 Hz. The form-fit helmet experienced vibrations which had a narrower but higher peak at a lower frequency: 0.8 m/s^2 at 30 Hz. The amplitudes of the primary peaks change depending upon flight profile. The shape of the spectra and the frequencies of the primary peaks remain approximately the same. Thus, the standard SPH-4 helmet experienced increased vibrations over a broad band of frequencies. The form-fit SPH-4 helmet experienced increased accelerations in a much narrower band in the vicinity of 30 Hz.

STANDARD HELMET

Difference in Intensity m/s²

0

1000

Frequency, Hz

-1

FIGURE 9. Sample Standard Helmet Difference Spectra

FORMFIT HELMET

Difference in Intensity m/s²

0

1000

Frequency, Hz

-1

FIGURE 10. Sample Form-fit Helmet Difference Spectra

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In summary our observations are:

1. Both helmets vibrate more with the sight attached.

2. The response to the sight coupled vibration of the standard SPH-4 differed from that of the form-fit SPH-4.

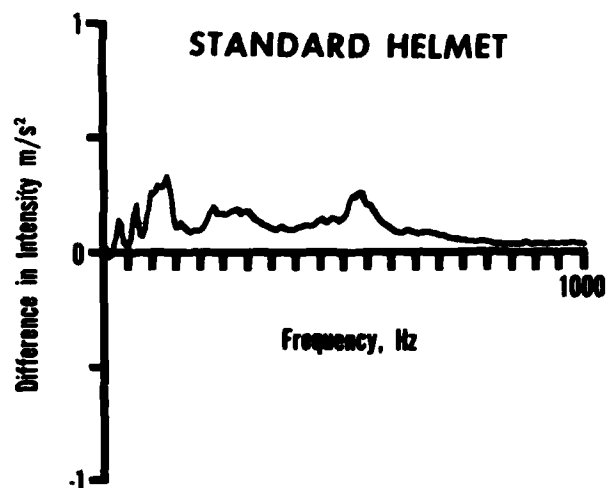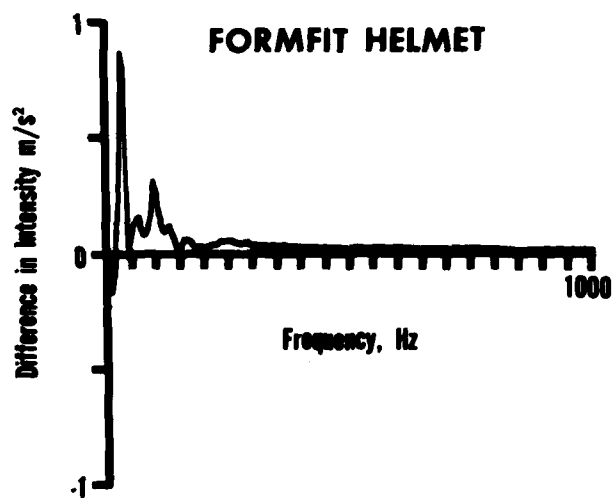3. The form-fit SPH-4 helmet vibrated more in a narrow band centered at about 30 Hz.

4. The standard SPH-4 helmet vibrated more over a wide band of frequencies above 30 Hz.

Interpretation of the results of this experiment must be somewhat limited due to the paucity of data collected. To do a complete biodynamics evaluation of the head and helmet vibration question would have required a much larger instrumentation package. Under ideal circumstances we might have measured head, aircraft and helmet accelerations as well as neck muscle stress data on several subjects. However, available equipment, aircraft space, power limitations and funding restricted us to a maximum of four data channels, hence the single triaxial helmet accelerometer. Aircraft availability limited the number of subjects to one.

Recognizing these limitations, we give the following explanation of the results leaving empirical verification for a time when a full-scale evaluation can be performed. The fact that both helmets experienced substantial increases in vibration when the linkage assembly was connected suggests several physiological consequences. The increase in vibration will result in increased exposure of the head to vibration. The effects of the increase may be twofold. First, Okada (1971) and Kile* have shown a synergistic link between vibration and acoustic noise in producing hearing loss. Furthermore, a large body of research documented by Griffin and Lewis (1978) and Guignard (1972) indicates that vibration can cause decrements in visual performance. Additionally, work by Homma (1972) and Marsden (1969) indicate a correlation between vibration and muscle stimulation. This has been corroborated in this laboratory by Johnson (1978). Thus, increased vibration of the head may be expected to result in a visual acuity decrement, a possible increased risk of hearing damage, and an increase in muscular stress in the neck.

The second question which we ask after enumerating the probable effects of increased vibration is: Which helmet, SPH-4 or form-fit, minimizes the adverse effect of vibration? We really have insufficient

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* Kile, J.E., Wurzbach, W.F. 1979. Temporary threshold shifts induced by vibration stimulation. Unpublished paper from Kile, Department of Speech, University of Wisconsin, Oshkosh, Wisconsin.

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data to answer that question. We will limit our discussion to differences in helmet dynamics and to guidance for future studies. Each helmet had the same outer shell but differed in mechanism for coupling the shell to the head. The standard SPH-4 helmet has a sling (cloth strap) suspension which joins the shell loosely to the head. The straps have considerable elasticity and allow more relative movement of the head within the shell than is allowed by the form-fit helmet. The form-fit helmet, as the name implies, is foamed in place on the head of the individual using a polyurethane foam. This creates a liner which closely conforms to the contours of the head of the individual. The foam is characterized by low elasticity and allows little relative motion of the head and shell.

The head is more tightly coupled to the shell in the form-fit helmet than in the sling suspension helmet. Therefore, we would expect the dynamic mass of the head helmet system to be greater for the form-fit helmet than for the standard sling suspension helmet. The higher the dynamic mass of an object, the lower acceleration one would measure for a given input force. If we make the assumption that the sight bar delivers a constant vibratory force to the helmet then it follows that the more loosely the shell is coupled to the head (lower dynamic mass) the higher will be the measured acceleration at the helmet. This assumption could explain the increase in broad band acceleration measured in the SPH-4 but not found in the form-fit helmet.

Rigidity of the coupling of the helmet and head will affect the wearer of the helmet in two ways. The more rigid the coupling is, the greater the vibration transmitted to the head will be. Secondly, if the helmet is loosely coupled relative motion between the head (eye) and the helmet mounted sight is increased. In the first case, physiological problems are maximized. In the second case, visual tracking ability may be impaired.

The large peak near 30 Hz in the vibration difference data from the form-fit helmet (Figure 10) is puzzling. This may be a result of the interaction between seat transmitted vibration and sight transmitted vibration. Laing (1974) showed that the transmissibility of vibration to the pilot in the AH-1 gunner's seat is near 1.0 for vibratory stimuli of 30 Hz. Furthermore, there is significant vibration in the 30 Hz range in an AH-1 aircraft (Laing 1974). Thus it is reasonable to assume that the head of the volunteer may have been experiencing 30 Hz vibration at the time this data was collected. It is unlikely that this 30 Hz peak is an artifact. The reason for the pronounced increase in 30 Hz vibration with the form-fit helmet but not with the standard helmet is not found in the data which we collected. Additional data to include head and body vibration as well as helmet vibration is needed to ascertain the cause for the difference in the helmet vibration characteristics.

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CONCLUSIONS

The mechanical linkage of helmet to airframe by a helmet mounted sight system significantly increased vibration levels measured at the apex of the helmet. The magnitude of the increase in the range was 45% to 417%. The increase in vibration due to sight connection was experienced by both a standard SPH-4 flight helmet (sling suspension) and by a modified SPH-4 helmet having a form-fitted polyurethane foam liner. The standard SPH-4 helmet experienced increased vibration in a broad spectrum above 30 Hz (nominal). The form-fit SPH-4 helmet experienced increased vibration with a pronounced peak at 30 Hz (nominal) and less higher frequency vibration than the standard SPH-4.

The significant increase in vibration of the helmet caused by the mechanical sight linkage may be expected to degrade pilot/gunner visual performance to some extent. Detrimental effects on fatigue rate and hearing due to vibration may also occur. Insufficient data is currently available to predict the magnitude of performance degradation which could result from increases in helmet vibration.

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APPENDIX

REGISTERED TRADE MARKS

Endevco Model 2226C accelerometer, Division of Becton, Dickinson & Co., Rancho
Viejo Rd, San Juan Capistrano, CA 92675.

Hewlett-Packard, 1501, Page Mill Road, Palo Alto, CA 94304.

Model 3960 tape recorder
Model 9825S desktop computer
Model 7225A plotter

KIAG Swiss, Model 5001 change amplifier, Kistler Instrumente AG, CH 8408,
Winterthur, Switzerland.

Nicolet Scientific Corporation, 245 Livingston Street, Northvale, NJ 07647.

Model 660 fast Fourier transform analyzer
Model 160C data recorder

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Moffett Field, CA 94035 (1)

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 Research and Engineering
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 Medical and Life Sciences
Washington, DC 20301 (1)

Sixth United States Army
ATTN: SMA
Presidio of San Francisco,
 California 94129 (1)

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 of the Health Sciences
4301 Jones Bridge Road
Bethesda, MD 20014 (1)

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Forest Glen Section, Bldg 156
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US Army Missile R&D Command
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US Army Yuma Proving Ground
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US Army Aviation Engineering
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 Range
Technical Library Division
White Sands Missile Range
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