Correlation of HGU-56/P Aircrew Helmet Fitting with Head Anthropometric Measurements

By

James E. Bruckart
Kevin T. Mason
Samuel G. Shannon
Biodynamics Research Divison

and

William E. McLean
Sensory Research Division

and

Steven P. Pacquette
Harold G. Moody
Natick Research, Development, and Engineering Center

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Reviewed:

JOHN V. BARSON
LTC, MC, SFS
Director, Biodynamics
Research Division

ROGER W. WILEY, O.D., Ph.D.
Chairman, Scientific
Review Committee

Released for publication:

DAVID H. KARNEY
Colonel, MC, SFS
Commanding

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The U.S. Army is developing an Aircrew Integrated Helmet System to replace the current flight helmets. The HGU-56/P flight helmet is proposed in six sizes with a new fitting method based on a nonstandard measure of the aviator head length.

Standard anthropometric head measurements and the Gentex Corporation fitting method for the HGU-56/P flight helmet are evaluated to determine the applicability of the fitting method and distribution of helmet sizes required to fit the U.S. Army aviator population.

Two hundred forty-two volunteer aviators had standard anthropometric measurements of their heads. Each was fitted with an HGU-56/P flight helmet in their recommended size, and a helmet one size larger and one size smaller than recommended. ANVIS compatibility with each helmet was tested for a subset of the subjects.

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Only one subject did not receive an acceptable fit with any of the six helmet sizes. The recommended helmet size was acceptable for 84 percent of the subjects. One size larger was acceptable for 86 percent of the subjects, and a size smaller for 38 percent. None of the subjects exceeded the available length or width in the largest helmet. Overall, 86 percent of the wearers could obtain full field-of-view with ANVIS while wearing the helmet. If users choose to wear their preferred rather than recommended helmet size, more larger size helmets will be required.

The basic fitting method was easily applied and effective. Primarily, this resulted from excess width in the helmet shells for most subjects with a specific head length. Ninety-three percent of the subjects could be accommodated with an acceptable fit if only three of the proposed sizes of the helmet are available.

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Introduction

The United States Army is developing an Aircrew Integrated Helmet System to replace the current SPH-4 and SPH-4B flight helmets worn by U.S. Army helicopter pilots. This new helmet will include the latest materials and advanced design features to protect the wearer during an aircraft mishap and provide a stable platform for head-mounted devices.

The Gentex Corporation (Gentex) is fabricating the HGU-56/P (Head Gear Unit, Model 56, Personal) as the Aircrew Integrated Helmet System. The HGU-56/P is currently manufactured in six different sizes, using four different helmet shells, to fit the broad range of U.S. Army pilots. The manufacturer directs that the helmet size is found by measuring the length of the head with a designated procedure. (Department of the Army, 1992). Gentex and the U.S. Army are currently testing the HGU-56/P in pre-production technical and user tests.

In this study, standard anthropometric head measurements and the Gentex modified head length measurement were obtained for 242 volunteer aviator subjects at Fort Rucker, Alabama. Helmet fit and acceptance were evaluated for each subject in their recommended HGU-56/P helmet size and in helmets one size larger and one size smaller when applicable. A subset of the subjects was evaluated to learn if they could wear night vision goggles (NVGs) with each helmet.

The goals of the study were to assess the applicability of the Gentex sizing method, develop a sizing method based on standard anthropometric measures, and to determine the distribution of helmet sizes required by a representative group of aviators. A sizing method based on standard anthropometric measures will be discussed in a follow-on report.

Background

Military significance

The aircrew helmet protects the wearer from head injury during an aircraft mishap, ballistic eye injury, and hearing loss. It also serves as a platform for oxygen delivery, communication, vision enhancement, weapon sighting, and laser protection devices. The modern aircrew helmet requires a precise fit to provide optimum performance and comfort.

Earlier aircrew helmet programs encountered fitting problems in the post-production phase. These problems were caused by increased complexity of helmet-mounted devices, outdated aviator head anthropometric data, changes in helmet design, and reduced fitting tolerances. This resulted in operational limitation for some aviators using the helmet and launched a post-production

development program to produce helmet modifications and additional helmet sizes (Sippo et al., 1988). The Army can save post-production development and modification costs if problems with sizing and fitting the HGU-56/P are identified and solved before helmet production.

Helmet design and fitting

The human engineering challenge in helmet sizing and fit is to design a product that fits the three-dimensional relationships found in head and face morphology. This challenge is coupled with the complex distribution of head and face shapes within the population. Anthropometrists have noted problems when helmet designs rely on percentile models or single linear measurements (Robinette and McConville, 1981; Sippo, Licina, and Noehl, 1991). Natick Laboratory completed a broad anthropometric study of U.S. Army aircrew in 1988. The study includes 48 direct and derived measures of the head and face (Donelson and Gordon, 1991).

In the past, Army aircrew helmets were issued in one or two sizes. Recent studies have recommended from five to nine helmet sizes to fit the wide range of head sizes found in aviator populations (Sippo and Belyavin, 1988; Sippo Licina, and Noel, 1991; Natick-STRNC-YBA, 1991).

Gentex uses a custom measurement procedure to decide the correct helmet size among the six available sizes proposed for the HGU-56/P. This method does not account for non-linear variation between the head length and other head dimensions (Natick-STRNC-YBA, 1992). In addition, the distribution of helmet sizes depends on a weighted mean of head measurements from two anthropometric databases. This grouping may not represent the true aviator population, particularly in the largest and smallest head sizes. (Natick-STRNC-YBA, 1991).

Methods

Subjects

Two hundred and forty-two volunteer subjects were enrolled in the study. These included pilots from the Warrant Officer Career College, instructor pilots, student pilots, and an operational aviation unit at Fort Rucker, Alabama. All of the subjects were required to have experience wearing a flight helmet in military aviation service and were appraised of the objectives of the study. Each subject's birth date, gender, and racial/ethic group were recorded as prescribed by the Measurer's Handbook (Clauser et al., 1988).

Anthropometric measurements

Each subject had body weight in stocking feet and duty uniform, to the nearest one-tenth pound, and standing height in stocking feet, to the nearest millimeter, measured. A single anthropometrist measured the head length, head breadth, head circumference, bitragion coronal arc, and vertical distance from the tragion to top of the head for all the subjects. Measurements were made to the nearest millimeter using the methods prescribed by the Measurer's Handbook (Clauser et al., 1988). An Army flight surgeon, using the method prescribed in the Operator's and Aviation Unit Maintenance Manual for the HGU-56/P (Department of the Army, 1992), measured the head length, herein called the "modified" head length, to the nearest tenth of an inch. The modified head length is the distance from the forehead reference point (a point in the middle of the forehead, 1.5 inches above a line between the pupils) to a block placed vertically behind the upright head.

Helmet fitting

In accordance with the Gentex fitting procedure, all subjects were assigned a "recommended" helmet size based on their modified head length as shown in Table 1. The helmet was fit to the head using the basic fitting procedure from the Operator's and Aviation Unit Maintenance Manual for the HGU-56/P (Department of the Army, 1992). The subject was asked to judge the overall comfort and security of the fit as "acceptable" or "unacceptable" and the response was recorded on a data sheet. In addition, the number and location of fitting pads were noted. Most subjects wore the helmet for five minutes, but several subjects decided a particular helmet fit was unacceptable after wearing the helmet for a shorter period. A limitation of this study is the short duration available for each subject to wear the helmet. Subjects with experience wearing flight helmets were selected to improve the reliability of the subjective assessment of comfort and security with the short duration of actual helmet wear.

Table 1.
Gentex correct helmet size based on modified head length.

Helmet size	Maximum head length (inches)
-2	<7.11
0	7.11-7.40
2	7.41-7.70
4	7.71-8.00
6	8.01-8.30
8	>8.30

Since there were no additional prototype liners available, if the helmet was unacceptable because it was "too tight," custom-fitting of the thermoplastic liner was not attempted. After wearing the "recommended" size helmet, subjects were fit in the next larger and smaller helmet size following the same procedures.

ANVIS compatibility test

Each HGU-56/P test helmet was fitted with a centrally-positioned ANVIS visor mount. A subset of the subjects had ANVIS compatibility tests on each helmet with an "acceptable" fit (n=694). ANVIS NVGs were placed on the helmet, tilt adjusted to the middle position, and fore/aft adjustment placed in the aft position. Using the circular green image provided by the NVG with attenuating translucent lens covers in normal room illumination, the subject adjusted the interpupillary distance and vertical height adjustment to obtain ANVIS compatibility. The subject adjusted the fore-aft adjustment forward only if the lenses touched the eyelashes. ANVIS compatibility was "acceptable" when the wearer could align the optical axis of the NVGs with his/her visual axis and obtain a full field-of-view with the NVG. The NVG adjustment was "unacceptable" if the subject could not obtain a full field-of-view or align the optical axis with the NVG. When the ANVIS was properly adjusted, the eye clearance, measured from the apex of the cornea of the eye to the NVG, and vertical adjustment of the NVG mount were measured. The results of eye clearance, vertical adjustment, and head tilt measurements will be reported in a separate report.

Results

Subjects

The subject group included 15 enlisted soldiers, 142 warrant officers, 79 commissioned officers, and 6 Department of the Army civilians in the distribution presented in Figure 1. All of the subjects were rated pilots or student pilots except 16 aircrew members from the operational aviation unit and the U.S. Army Aeromedical Research Laboratory. The average age of the subject group was 28.8 years with the age distribution presented in Figure 2. Table 2 shows the racial/ethnic groups represented by the subjects.

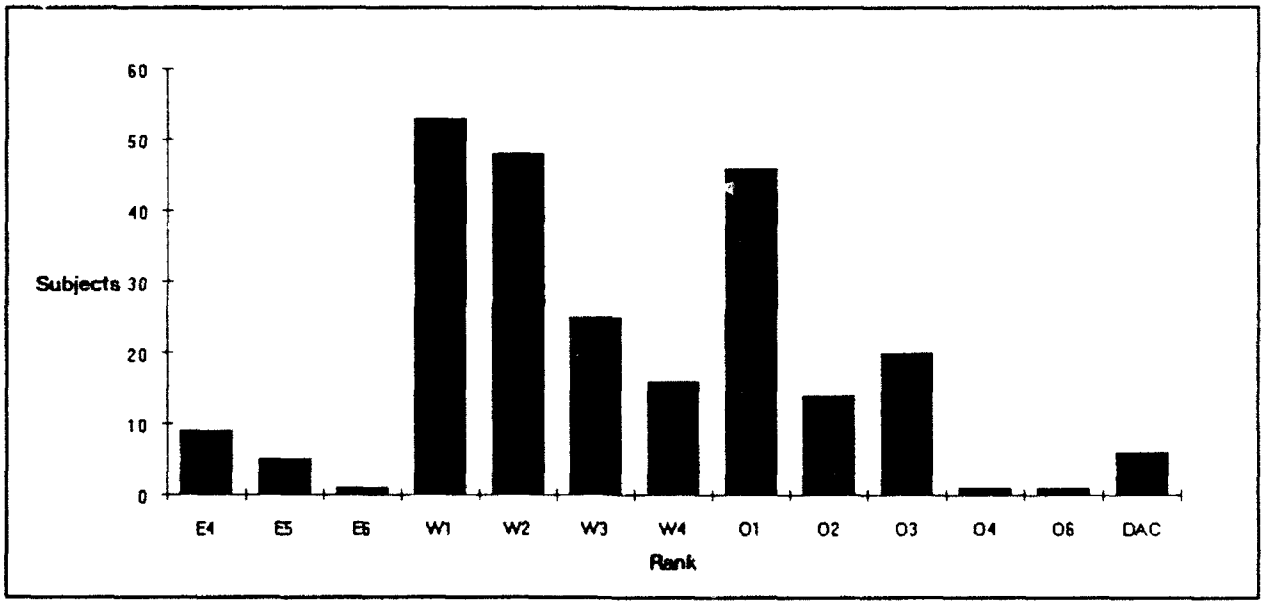

Figure 1. Distribution of subjects by rank.

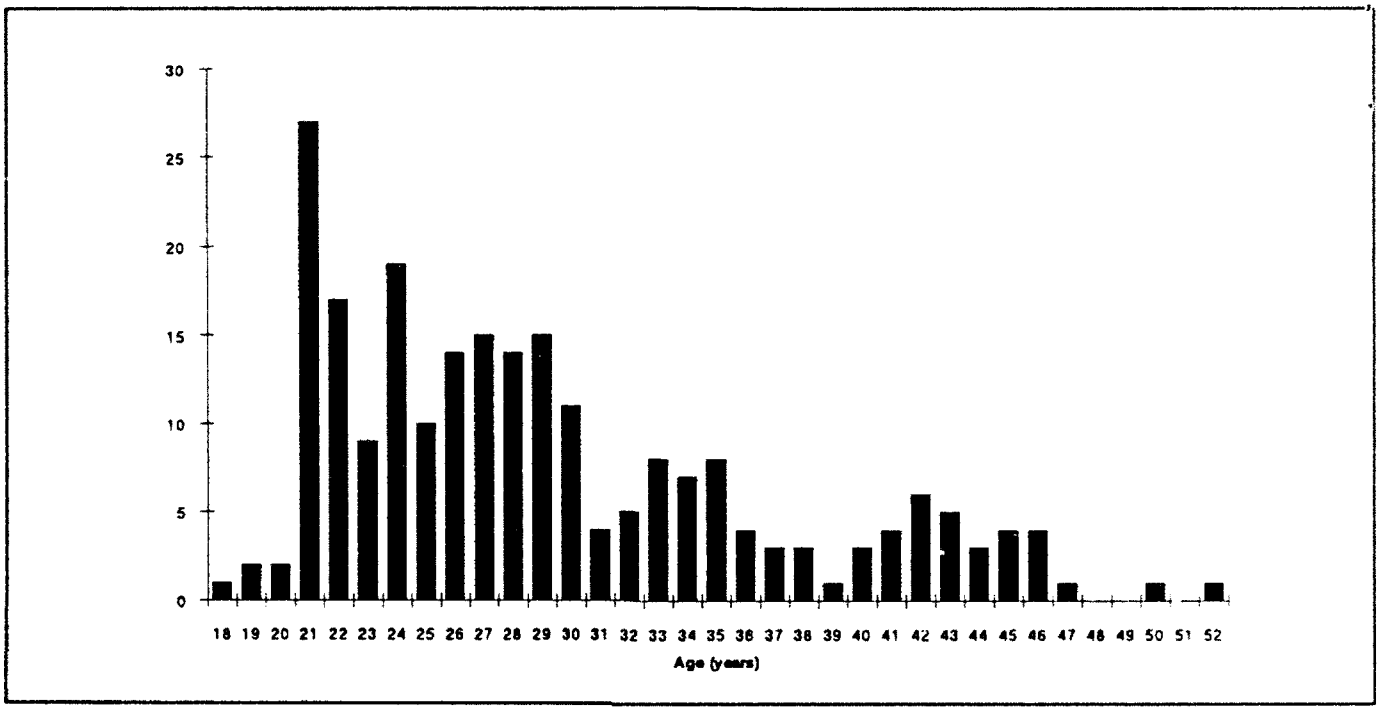

Figure 2. Distribution of subjects by age.

Table 2.

Distribution of subjects by racial/ethnic group.

Racial/ethnic group	Number	Percent
White, not Hispanic	219	90.5
Black, not Hispanic	11	4.5
Hispanic	6	2.5
asian Pacific	4	1.6
American Indian	1	0.4
Other	1	0.4

Anthropometric measurements

Tables 3 through 10 present the mean, standard deviation, maximum, minimum, and calculated percentile measures for the body weight, height, head length, head breadth, head circumference, bitragion coronal arc, tragion to top-of-head, and modified head length measurements. The measures from this study are compared with the 1988 Natick Anthropometric Survey Pilot group where equivalent measures were available.

Table 3.

Comparison of body weight (lbs).

	1992 helmet study		1988 pilot study	
	Female N=10	Male N=231	Female N=334	Male N=487
Mean	143.8	181.2	144.12	175.93
SD	13.5	23.1	18.79	21.19
Min	127.6	137.0	102.08	125.18
Max	172.8	277.3	212.74	249.92
1st %	127.6	139.4	105.23	132.48
5th %	127.8	148.6	115.81	143.70
50th %	144.6	178.6	142.43	174.44
95th %	164.0	224.2	177.61	213.77
99th %	171.0	248.6	196.20	228.21

Table 4.

Comparison of height/stature (cm).

	1992 Helmet study		1988 Pilot study	
	Female N=10	Male N=231	Female N=334	Male N=487
Mean	163.0	177.4	168.02	177.10
SD	4.6	6.7	4.52	6.47
Min	156.8	161.9	156.20	157.90
Max	172.7	197.3	187.00	194.10
1st %	156.9	163.8	157.29	161.85
5th %	157.3	166.3	161.17	166.33
50th %	163.0	176.9	167.64	177.11
95th %	169.9	189.3	175.95	187.75
99th %	172.1	194.2	178.80	191.44

Table 5.

Comparison of head length (cm).

	1992 Helmet study		1988 Pilot study	
	Female N=10	Male N=231	Female N=334	Male N=487
Mean	19.50	19.89	18.82	19.89
SD	0.66	0.64	0.64	0.64
Min	18.20	17.20	16.50	17.70
Max	20.60	21.80	20.50	21.90
1st %	18.25	18.30	17.15	18.27
5th %	18.43	18.80	17.68	18.83
50th %	19.50	19.90	18.86	19.90
95th %	20.15	20.70	19.79	20.94
99th %	20.51	21.17	20.22	21.34

Table 6.

Comparison of head breadth (cm).

	1992 Helmet study		1988 Pilot study	
	Female N=10	Male N=231	Female N=334	Male N=487
Mean	14.54	15.19	14.51	15.33
SD	.34	.57	0.48	0.53
Min	17.70	13.70	12.90	14.00
Max	15.00	18.40	16.70	17.10
1st %	13.76	14.03	13.32	14.19
5th %	14.02	14.30	13.78	14.52
50th %	14.60	15.20	14.49	15.30
95th %	14.91	16.10	15.30	16.27
99th %	14.98	16.57	15.63	16.74

Table 7.

Comparison of head circumference (cm).

	1992 Helmet study		1988 Pilot study	
	Female N=10	Male N=231	Female N=334	Male N=487
Mean	55.71	57.56	54.79	57.06
SD	1.60	1.44	1.33	1.36
Min	53.70	54.10	50.50	53.60
Max	59.50	62.20	58.70	60.60
1st %	53.75	54.26	51.15	54.10
5th %	53.97	55.25	52.51	54.81
50th %	55.45	57.60	54.83	57.08
95th %	58.20	59.95	56.84	59.30
99th %	59.24	60.50	57.45	60.24

Table 8.

Comparison of bitragion coronal arc (cm).

	1992 Helmet study		1988 Pilot study	
	Female N=10	Male N=231	Female N=334	Male N=487
Mean	34.38	35.42	33.77	35.30
SD	0.79	1.24	1.24	1.25
Min	33.20	32.10	30.60	31.90
Max	35.6	38.70	38.00	39.80
1st %	33.22	32.60	30.85	32.50
5th %	33.29	33.20	31.76	33.27
50th %	34.55	35.50	33.72	35.28
95th %	35.56	37.46	37.37	37.37
99th %	35.59	38.44	38.26	38.26

Table 9.

Distribution of tragion to top-of-head measure (cm).

	1992 Helmet study	
	Female N=10	Male N=231
Mean	13.30	13.10
SD	0.74	0.67
Min	12.30	11.10
Max	14.90	15.00
1st %	12.31	11.53
5th %	12.35	11.95
50th %	13.30	13.20
95th %	14.41	14.10
99th %	14.80	14.57

Table 10.

Distribution of modified head length (in).

	1992 Helmet study	
	Female N=10	Male N=231
Mean	7.62	7.81
SD	0.34	0.28
Min	7.20	6.90
Max	8.30	8.40
1st %	7.21	7.20
5th %	7.25	7.36
50th %	7.55	7.80
95th %	8.17	8.20
99th %	8.27	8.40

Helmet fitting

Among the 241 subjects enrolled in the study, 696 helmet fitting trials were completed. Each subject was tested with three helmets: a helmet of the recommended size, one size smaller (downsize), and one size larger (upsize). Overall, 68% of the fitting trials resulted in an "acceptable" fit. The recommended size helmet resulted in an acceptable fit for 84% of the subjects. Only 38% of the helmets were judged acceptable when they were one size smaller than the subject's recommended size (downsize). If the helmet was one size larger than the recommended size, 86% of the subjects judged the fit acceptable. A summary of the number of subjects tested in each helmet and fit test results for each helmet are presented in Table 11. This table shows the helmet tested in the first column and the recommended helmet size for the subject wearing the helmet in column two. For example, a subject with the size 2 as his recommended size will be "downsize" when wearing the size 0 helmet. Since size -2 is the smallest size helmet, none of the subjects' recommended size could be smaller than -2 so there are no "upsize" subjects for this helmet. Likewise, there are no subjects "downsized" to the largest helmet (size 8).

Table 11.

Summary of helmets and subject acceptance.

Helmet	Subject Recommended size	Number of trials	Proportion "Acceptable"
	0 (downsize)	21	.43
Size -2	-2 (recommended)	2	1.00
	Not applicable	**	**
	+2 (downsize)	72	0.21
Size 0	0 (recommended)	25	0.68
	-2 (upsize)	2	1.00
	+4 (downsize)	81	0.36
Size 2	+2 (recommended)	79	0.81
	0 (upsize)	23	0.83
	+6 (downsize)	43	0.46
Size 4	+4 (recommended)	86	0.90
	+2 (upsize)	79	0.92
	+8 (downsize)	8	0.38
Size 6	+6 (recommended)	43	0.86
	+4 (upsize)	83	0.80
	Not applicable	**	**
Size 8	+8 (recommended)	7	1.00
	+6 (upsize)	42	0.90
	Downsize	225	0.34
Overall	Recommended	242	0.84
	Upsize	229	0.86

ANVIS compatibility tests

Among the 241 subjects enrolled in the study, 333 ANVIS compatibility tests were completed. Each subject was tested only with a helmet that provided an acceptable fit. This helmet could be a helmet of the recommended size, one size smaller (downsize), or one size larger (upsize). Overall, 86% of the ANVIS compatibility trials resulted in an "acceptable" ANVIS position. The recommended size helmet resulted in ANVIS compatibility among 91% of the subjects with an acceptable helmet fit. The downsize (smaller) helmet resulted in 96% compatibility. If the helmet was one size larger than the recommended size, 79% of the subjects could obtain acceptable ANVIS positioning. A summary of the number of subjects tested in each helmet and ANVIS compatibility test results for each helmet are presented in table 12. Additional findings from the ANVIS mount measurements and recommendations for the ANVIS mount will be presented in a follow-on report.

Table 12.

Results of ANVIS compatibility tests among subjects with an "acceptable" helmet fit.

Helmet	Subject Recommended size	Number of trials	Proportion "Acceptable"
	0 (downsize)	7	1.00
Size -2	-2 (recommended)	2	1.00
	Not applicable	**	**
	+2 (downsize)	10	0.90
Size 0	0 (recommended)	13	1.00
	-2 (upsize)	2	1.00
	+4 (downsize)	18	0.94
Size 2	+2 (recommended)	41	0.88
	0 (upsize)	14	0.76
	+6 (downsize)	12	1.00
Size 4	+4 (recommended)	55	0.93
	+2 (upsize)	45	0.78
	+8 (downsize)	4	1.00
Size 6	+6 (recommended)	25	0.84
	+4 (upsize)	50	0.75
	Not applicable	**	**
Size 8	+8 (recommended)	6	1.00
	+6 (Upsize)	29	0.72
	Downsize	51	0.96
Overall	Recommended	142	0.91
	Upsize	140	0.79

Discussion

Subjects

The distribution of subjects enrolled in the study typifies the U.S. Army aviator population and the 1988 Natick study group. In most of the measures the study population is similar to the Natick 1988 population. Most important is the similarity in head length among the two populations. This is emphasized because head length is the most important dimension used in choosing the initial size of the HGU-56/P flight helmet with the recommended procedure.

The mean weight of male subjects is higher than the 1988 Natick group. Some of the difference may be attributed to our subjects wearing a uniform rather than only nylon shorts for the

Natick subjects. On data analysis, the specific data on one subject was not included.

Helmet fitting

The recommended procedure for fitting the HGU-56/P flight helmet uses the modified head length measured in tenths of an inch from the forehead reference point. Carpenter squares obtained for this study were marked in 1/8" and 1/16" increments. The measure from the ruler had to be converted to tenths of an inch to obtain the recommended helmet size. The helmet size chart should show 1/8 and 1/16 inch increments as well as metric equivalents to simplify the process of selecting the recommended helmet size.

Only one subject could not obtain an acceptable fit, for the short period of wear, in either the recommended or an adjacent size helmet. This suggests that the HGU-56/P will fit most of the aviators in the U.S. Army. None of our subject's head dimensions exceeded the available width or length in the largest helmet size. A limitation of this study is the short period available for each subject to judge the acceptability of the fit. However, if "hot spots" develop in longer duration wear then custom fitting procedures, such as heat treatment of the thermoplastic liner, might regain the acceptability of the helmet fit.

The distribution of helmet sizes required to fit the subject population with their recommended helmet size and preferred helmet size is shown in Table 13. Many wearers of the HGU-56/P could be fit in more than one helmet size. When asked which helmet size each wearer preferred, 5% said the helmet smaller than their recommended size, 41% responded with the recommended size, and 54% preferred a size larger than their recommended size. In this study, 84% of the subjects fit in the recommended helmet size while 86% fit in a helmet one size larger. If subjects wear their preferred helmet size (instead of the recommended size), more large helmets will be required.

Table 13.

Percentage of each helmet size required.

Helmet size	Recommended size	Preferred size
-2	0.8 %	0.6 %
0	10.3 %	9.8 %
2	32.6 %	19.0 %
4	35.5 %	40.5 %
6	17.8 %	20.2 %
8	2.9 %	9.8 %

Most subjects required earcup pads to obtain an earcup seal while wearing the HGU-56/P. We found that an average of 0.4 earcup pads were required on each side with the downsize helmet, 0.9 pads each side with the recommended size, and 1.7 earcup pads each side in the upsize helmet.

Inadequate length was the most common reason for an unacceptable helmet fit. This was most frequently seen in helmets smaller than the recommended size and was described by the wearer as tightness in the headband area at the forehead. Most wearers had sufficient width in all sizes of the helmet. Head length is effective in selecting helmet size in the HGU-56/P because it detects the smallest helmet an individual is likely to tolerate. This would not be true in a helmet where inadequate width or height limits the acceptable fit. Subject head length versus width and the interior dimensions of each helmet size are plotted in Figure 3.

Individual heads vary in several dimensions, including length, width, and height. Recent helmet fitting studies have recommended several shell shapes and sizes to fit various combinations of head shapes and sizes. The HGU-56/P conforms to different head shapes in a unique way. First, each size of the HGU-56/P is wider than most subjects for a given head length. Narrow heads are constrained in the helmet with earcup pads. Different head lengths are accommodated by six helmet sizes (four shell sizes) and an adjustable nape plate assembly. Differences in head height are accommodated by fore/aft tilt of the helmet. The helmet is tilted to position the front edge of the helmet at the helmet reference point. This places the eye at the proper position for the ANVIS night vision goggle mount on the helmet. The disadvantage of this fitting method is that it provides excess width in the shell for most wearers. Technical and user tests of the helmet should compare stability with a narrow and wide helmet on the same individual and focus on whether the wider helmet permits more movement when turning the head.

Figure 3 shows that there is little difference in inside dimensions among several helmet sizes. In fact, the size -2 is wider than the larger size 0 and size 2. If the nape plate and earcup pads adapt to excess length and width without compromising stability or retention, most wearers could be fit in fewer sizes of the HGU-56/P. Specifically, if the size -2, 0, and 6 helmets were not available, at least 93% of the subjects could still have been fit with an "acceptable" helmet given the basic fitting procedures used in this study. A wider size 2 helmet would accommodate most of the remaining wearers.

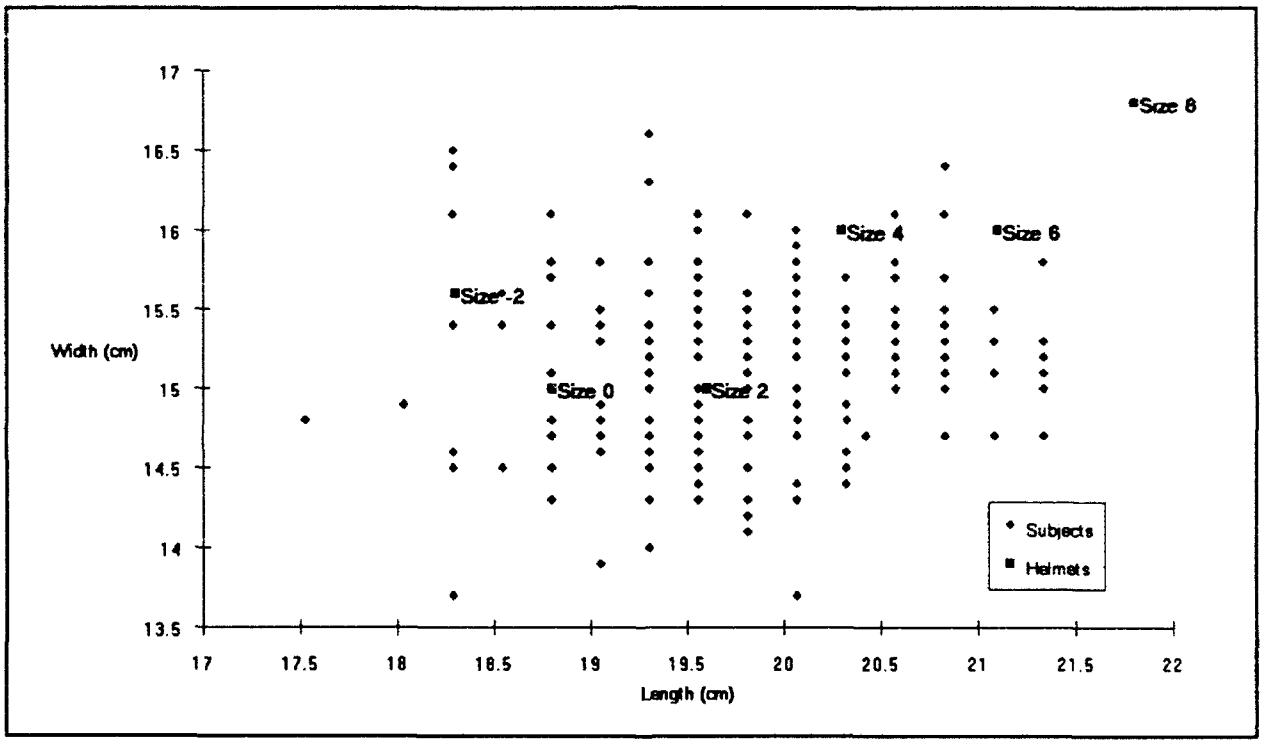

Figure 3. Plot of subject head length vs. breadth (width) and interior dimensions (cm) of each helmet size.

Conclusions

Among 242 subjects fitted with the HGU-56/P flight helmet, only one could not obtain an "acceptable" fit with the six sizes available. None of our subjects exceeded the available length or width in the largest helmet. Most of the wearers could obtain full field-of-view and optical alignment of night vision goggles with the recommended helmet.

The distribution of sizes required for a typical aviator population depends on the fitting method. The distribution of sizes is presented in Table 13. If users choose to wear their preferred size, more larger helmets will be required.

The basic fitting method was easily applied and will permit initial fitting of most aviators with the flight helmet. The table of recommended helmet sizes should include 1/8", 1/16", and metric equivalents.

The HGU-56/P has adequate width in most sizes for almost all wearers at a given head length. Most wearers will use at least one earcup pad to obtain an earcup seal. Technical and user tests of the helmet should look for rotation of the helmet with head turning. There are only small differences between sizes in several of the helmets. Most of the subjects from this study would be accommodated if only the size 2, 4, and 8 helmets were available.

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