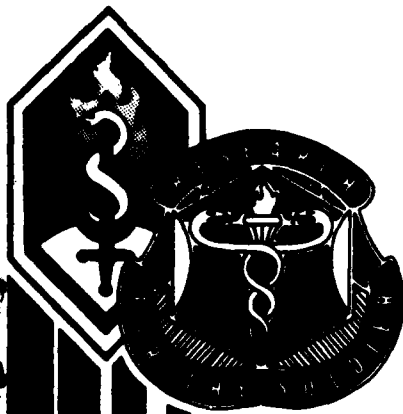MICROCOPY RESOLUTION TEST CHART
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USAARL REPORT NO. 86-11

IMPROVED DESIGN CRITERIA FOR CRASH HELMETS

By
R. Fred Rolsten
J. Haley, Jr.

BIODYNAMICS RESEARCH DIVISION

May 1986

USAARL

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18.   Portions of this presentation are included in USAARL Report No. 85-5, Dynamics of Head Protection (Impact Protective Comparison of the SPH-4 Flight Helmet to a Commercial Motorcycle Helmet, by R. Fred Rolston and J. L. Haley, Jr. July 1985.

20.   A commercial motorcycle helmet was impact evaluated. The motorcycle helmet's impact protection is compared to that of the SPH-4, the standard Army aviator's helmet. Drop tests, ranging from 0.91- to 2.44-meters, were used for the helmet testing by means of a helmet/headform free-fall device. The two examples of the helmet were subjected to 16 drop tests. Two of these drop tests resulted in a high level of transmitted force and acceleration which focuses on the inadequate thickness of the motorcycle helmet liner. The helmets did not provide adequate protection to prevent concussion or serious injury at all energy levels greater than produced at a 1-meter drop height. The tested helmets could be changed to provide adequate protection by doubling the thickness of the liner.

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Introduction

Based on government motorcycle test standards in this country and abroad, your head may sustain a transmitted deceleration of up to 400 g as a result of impacting pavement from a six-foot fall. Various studies since 1962 have shown that g levels above 150 will result in various degrees of injury. Levels about 250 g could be fatal based on the studies of knockout boxing impacts; thus, it is imperative that helmet design/test criteria be revised.

It is well within industry capability to construct improved impact protective helmets; however, the compressive foam must be reduced in density and increased in thickness and the test impact surface must be changed to a flat rather than a sharp corner surface.

This report illustrates the performance of two foreign motorcycle helmets and shows the improvement possible by reducing foam density and increasing its thickness.

Method

The commercial motorcycle helmet shown in Figure 1, was impact evaluated. The shell was a solid integral-white plastic of 4.2 mm thickness at the crown, with a thickness of 3.5 mm in the hatband region. The polystyrene energy-absorbing liner of 12 mm thickness was located about 3 cm above the ear canal at the sides and about 2 cm below the occipital bone at the rear. Retention of the helmet was accomplished by the chin strap, which was yoke-mounted to the shell. The yoke mount is preferable to a single swivel mount to the shell because rotation either forward or rearward is more difficult.

Procedure

The impact tests were conducted on a drop tower conforming to or exceeding American Standards Association (ASA) Z90.1-1971 standards; the impact test device is shown in Figure 2. The rigid base plate exceeds Z90.1 requirements by an order of magnitude; i.e., it weighs over 1800 kg. This mass insures that the headform acceleration is as accurate as is feasible at high acceleration levels. The helmeted headform was impacted primarily on a flat surface, but three impacts were conducted on the standard Z90.1 (4.8 cm radius hemisphere) impact surface to provide comparative data. The helmets were placed on a medium size (3.76 kg) cast magnesium headform with one accelerometer mounted near the center of gravity as shown in Figure 2. The magnesium headform was attached to a lightweight cage and the cage was guided vertically on two steel cables. The headform,

helmet, and cage were elevated up the vertical cables to a selected drop height for each impact test. The weight of the headform and cage was 11.0 lb (5.0 kg) while the weight of the helmet was 2.9 lb (1.3 kg) for a total drop weight of 13.9 lb (6.3 kg).
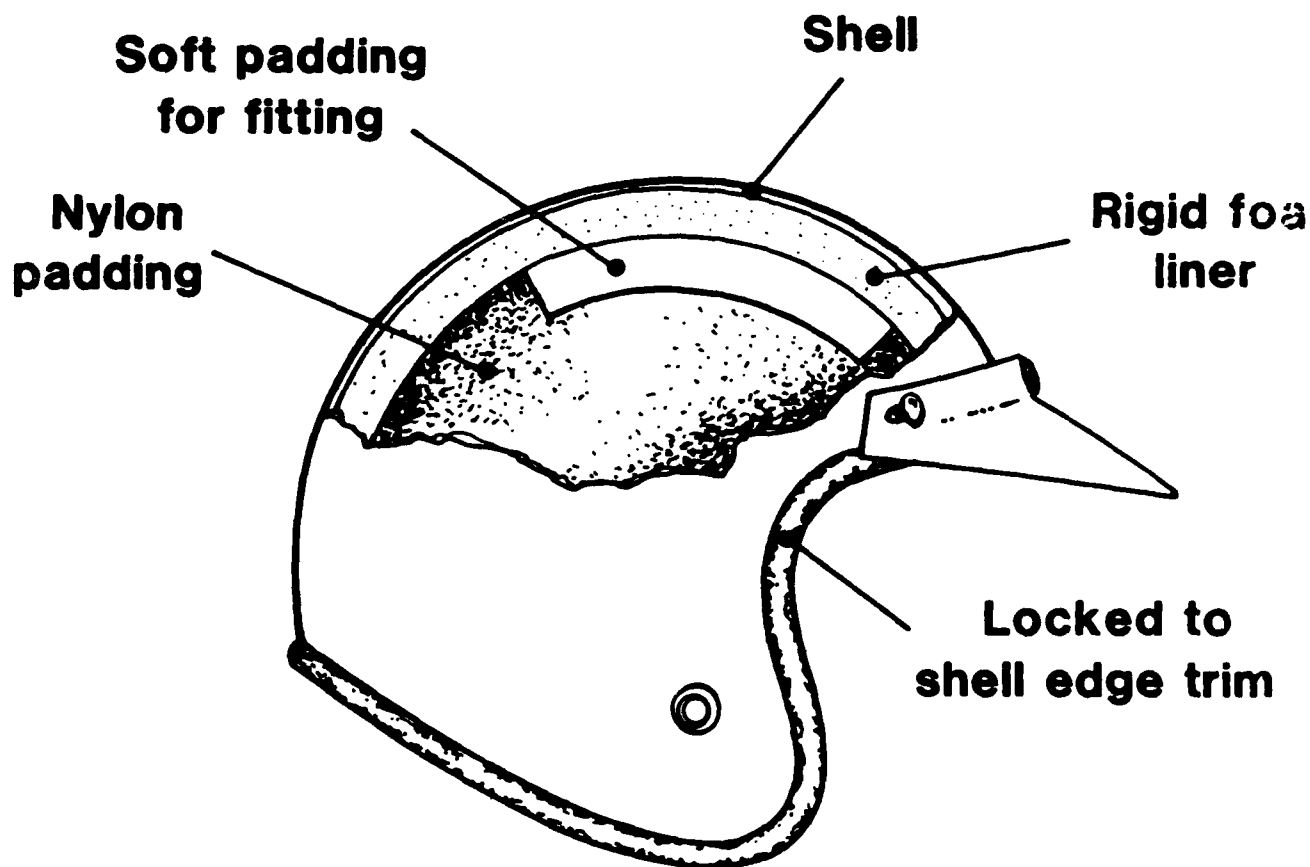
Figure 1. Cutaway view of the motorcycle test helmet.

A uni-axial accelerometer was positioned near the headform's center-of-mass, and its signal was amplified by a signal conditioner. Three piezoelectric load washers (Kistler type 9021) were positioned beneath the force plate shown in Figure 2. The accelerometer and force plate transducer were displayed on an oscilloscope and also read from peak voltage meters.

The test sequence and impact locations for the motorcycle helmet are shown in Table 1. The drop sequence is shown by test number in the table. The drop height was varied from 0.91- to 2.44-m.

Figure 2. Helmet/headform free-fall test device.

Table 1. Peak G, transmitted force, and rebound velocity measured in 16 helmet-headform impacts.

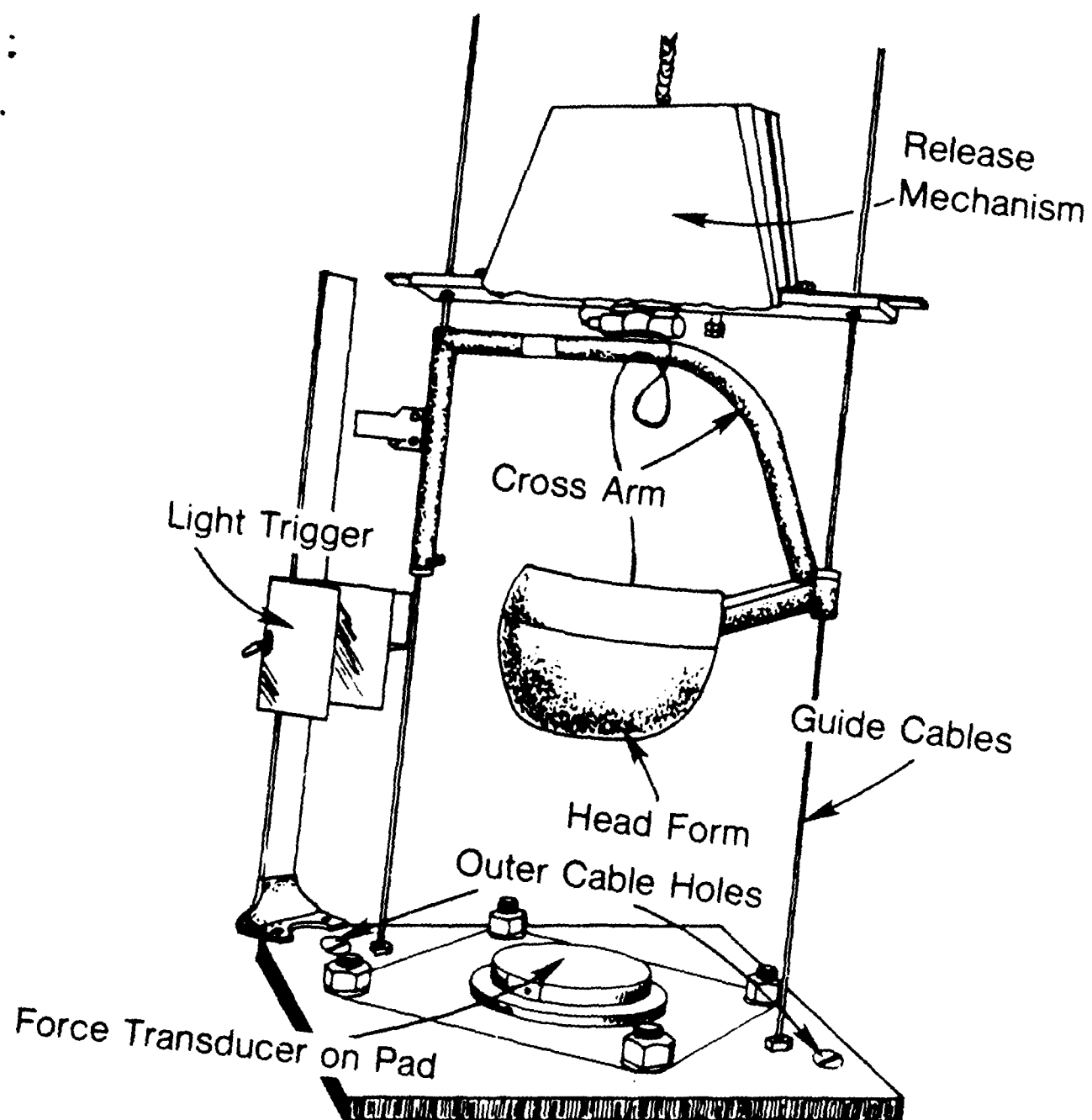| HELMET NO.	DROP NO.	DROP LOCATION	IMPACT SURFACE	OFFSET(a) DIST. (cm)	DROP(b) HEIGHT (meters)	MEASURED(c) FORCE (NEWTONS)	DECELERATION			PULSE DURATION (millisec)	REBOUND VELOCITY (m/sec)
							Calc.(d) PEAK (G)	MEASURED PEAK (G)	Calc.(e) Avg. (G)		
1	10A	R FRT	FLAT	2.5	1.47	12,090	244	249	92.5	8.0	.58
1	13B	R SIDE	FLAT	2.5	1.47	13,890	279	258	105.9	7.7	.82
1	14C	R REAR	FLAT	2.2	1.47	14,810	298	287	113.7	6.6	.64
1	22D	L FRT	FLAT	2.1	2.44	19,620	394	402	117.4	8.0	.73
1	23E	L SIDE	FLAT	2.5	2.44	18,740	377	350	135.8	7.6	.98
1	24F	L REAR	FLAT	2.1	2.44	30,030	604	576	154.4	6.0	.67
1	25G	CTR FRT	FLAT	1.9	2.13	22,300	448	430	135.0	6.6	.82
1	26H	CTR REAR	FLAT	2.5	2.13	19,620	394	382	147.6	6.7	1.1
2	11A	R FRT	4.8cm rad. Hemisphere	1.4	1.47	16,850	339	353	132.4	5.4	.52
2	12B	R SIDE	"	2.7	1.47	10,170	204	196	82.2	10.0	.70
2	16C	R REAR	"	3.3	1.47	17,090	344	330	90.8	7.7	.58
2	17D	L FRT	FLAT	2.4	0.91	9,410	189	195	79.0	7.8	.61
2	18E	L SIDE	FLAT	2.5	0.91	10,070	202	174	83.5	7.6	.61
2	19F	L REAR	FLAT	2.1	0.91	10,470	211	176	83.9	7.2	.55
2	20H	REAR CTR	FLAT	2.1	1.22	13,930	280	252	108.8	6.3	.64
2	21G	FRT CTR	FLAT	2.5	1.22	13,270	267	237	98.2	7.5	.79

(a) Distance from shell outer surface to the metal headform
(b) Vertical distance from the impact surface to helmet's point of contact
(c) Reaction force in load cell at the impact surface

(d) This value is calculated as follows: $G = \frac{f \times 10^3}{9.81 \times m}$ where f = Transmitted force in Newtons and m = mass of headform and guide cage of 5070 grams

(e) This value is calculated as follows: $G_{avg} = \frac{\text{area under (accel x time) trace}}{\text{total pulse duration}} = \frac{\Delta V}{t}$

Front of Helmet

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Results and discussion

The two motorcycle-type helmets were subjected to 16 impact tests. The location of impact, energy of impact (drop height and total drop mass), impact surface, transmitted force, and acceleration to the headform are presented in Table 1. The centroid of all impact points was at least 6 cm above the lower edge of the foam liner. The effect of increased drop height and concomitant impact energy from 0.91 to 1.47 m is shown in the plot of acceleration vs. time in Figure 3. The difference between a flat surface and a 4.8 cm radiused surface for equal impact energy (1.47 m drop height) also is shown in Figure 3. It should be observed that the acceleration value obtained for eight (Nos. 10, 13, 14, 17, 18, 19, 20, and 21) impact tests at three different drop heights (0.91-, 1.22-, and 1.47 m) are consistent. This indicates uniform quality of the helmets as well as good instrumentation. The significant variation of the traces in the 4.8-cm radius drops shown in Figure 3 probably are caused by friction between the guide cables and the headform guide cage. This type of problem is more likely to occur when impacting the radiused surface than when impacting a flat surface due to the lateral movement of the headform and guide cage, as the helmet tends to "slip or slide" down the side of the radiused surface. The effect of increasing the drop height to 2.13- and to 2.44-m is shown in Figure 4. At the 2.13-m drop height, the two traces nearly are identical. At the 2.44-m drop height, the three traces differ as evidenced from comparison of the 580 peak g on run 24 F (left rear) and the 350 peak g on run 23 E (left side). This large difference in peak g response most likely is caused by the "bottoming out" of the foam liner in run 24 F due to the small volume of foam compressed. A difference of only 1 mm in crush distance can result in a significantly large change in the peak acceleration level. It is possible that the friction prevented drops 22 D and 23 E from being greater than shown in Figure 4.

Peak headform deceleration vs. drop height is shown in Figure 5 and can be compared to the derived WSU tolerance curve (Haley et al. 1966); the effect of various energy levels is shown. The derived curve reveals (with three exceptions) that all experimental impacts on these helmets resulted in injurious g values.

The 1975 Snell Foundation Helmet Specification calls for the helmet to permit transmission of a peak acceleration of 300 g or less when dropped from a height of 3.3 m (10.83 ft). From Figure 5, it can be seen that 9 out of the 16 experimental drops (Nos. 10, 12, 13, 14, 17, 18, 19, 20, and 21) would have passed the Snell Specification while the experimental runs designated Nos. 11, 16, 22, 23, 24, 25, and 26 would not have passed.

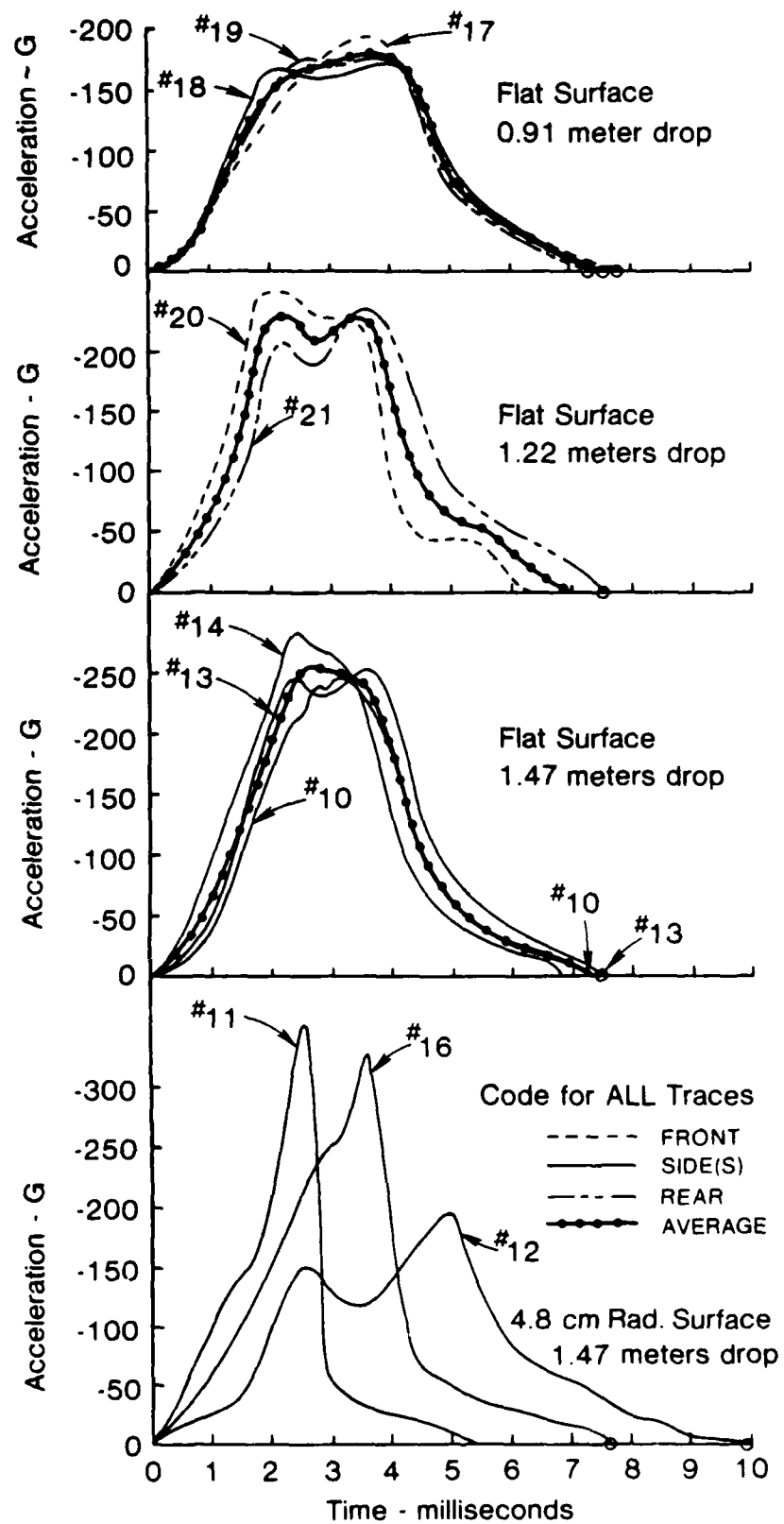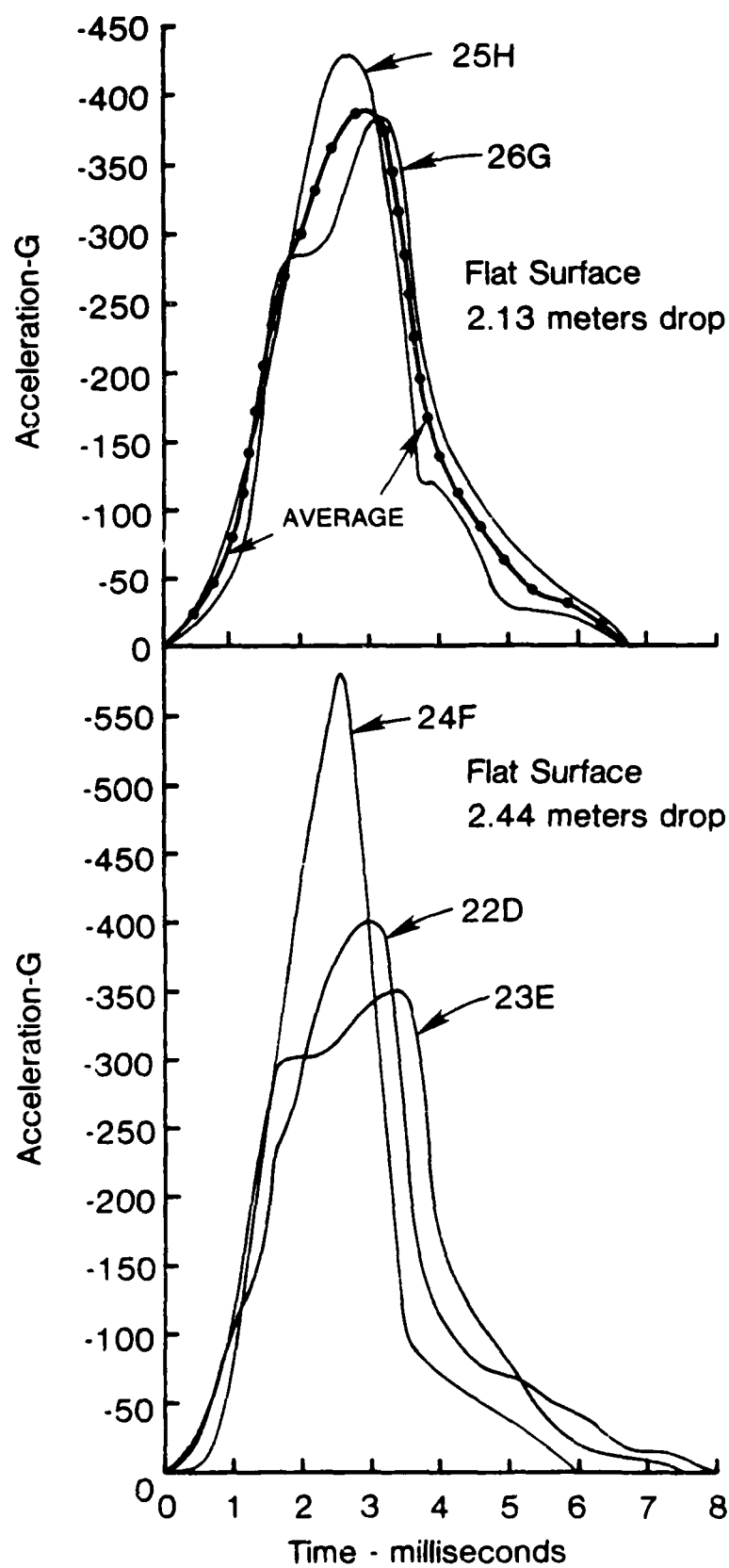Figure 3. Variation of transmitted accelerations for three drop heights.

Figure 4. Variation of transmitted accelerations for two drop heights.

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MOTORCYCLE HELMET
IMPACT IDENTITY SURFACE

o Helmet No. 1 - Flat Impactor
□ Helmet No. 2 - Flat Impactor
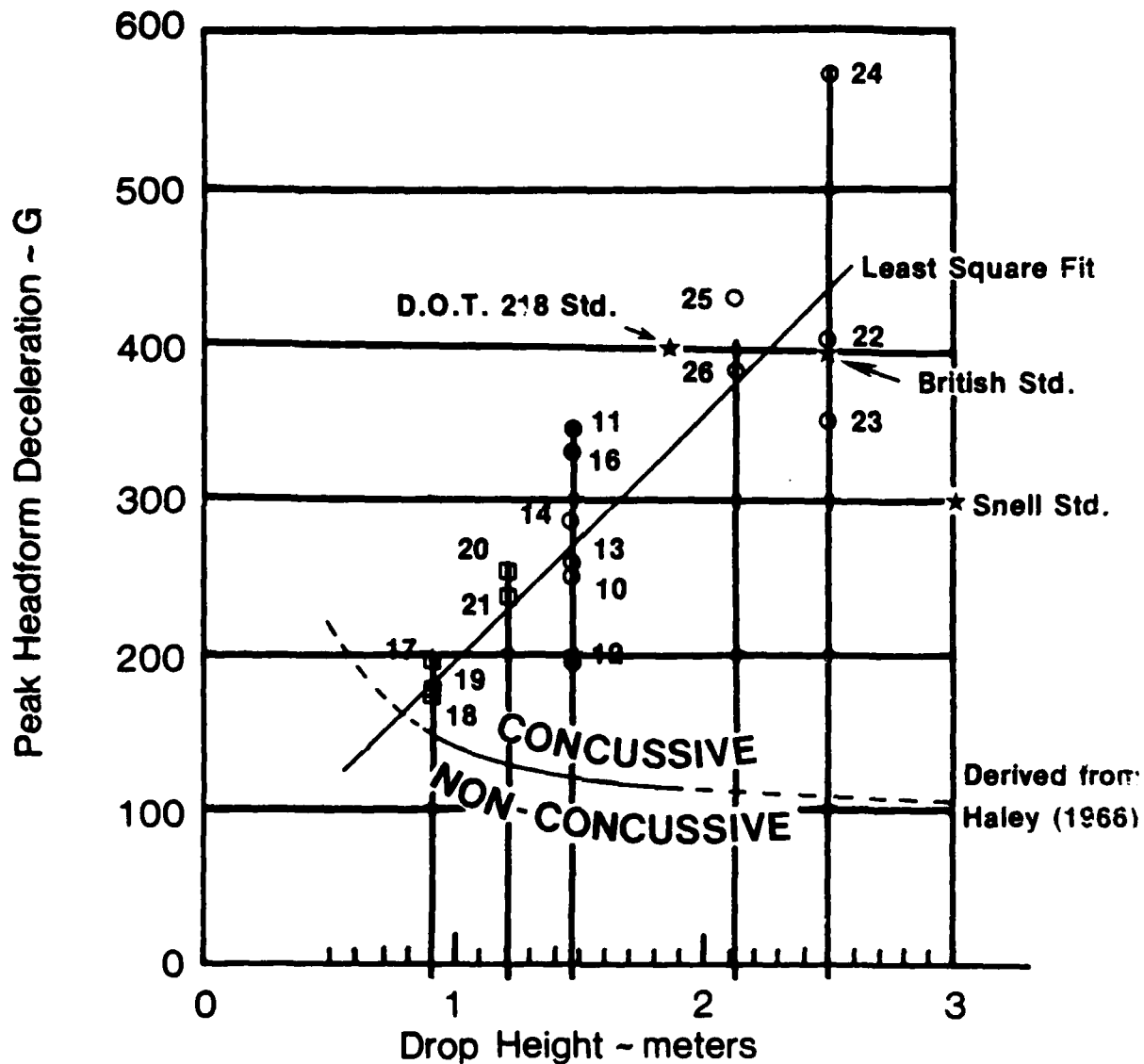● Helmet No. 2 - 4.8 cm Rad. Hemisphere Impactor

Figure 5. Peak headform deceleration vs. drop height compared to derived Wayne State University tolerance curve.

The British Standard requires that a motorcycle helmet not cause a peak headform force of greater than 4,400 lb (19,580 N) when a 5 kg headform mass is dropped from a height of 2.5 m (8.20 ft). From Table 1, it can be seen that experimental drops 24 and 25 resulted in a transmitted force of 30,000 N (6,673 lb) and 22,300 N (4,955 lb), respectively, and would have failed the requirements of the British (2001) Standard, as well as the US Department of Transportation (DOT) 218 Standard and the 1975 Snell Foundation Standard.

The fact that two of the impacts resulted in such a high level of transmitted force and acceleration focuses attention on the inadequate liner provided in the helmet. The liner should be no less than twice the thickness provided; i.e., the liner should be no less than 25 mm in order to lower the transmitted force to tolerable levels for all impacts greater than 1 m in drop height.

Since it may be expected that motorcyclists may fall or be thrown from heights of 1.6 m up to 3.0 m, it is clear that riders could receive various degrees of head injury while wearing the helmet. These energy values are within the limits of 3.3 m (Snell 1975) and 1.8 m (DOT 218) for energy; however, both these standards permit transmitted acceleration to the head which is far in excess of the values recommended (Gurdjian 1962 and Haley et al., 1966, 1983).

Compendium of US Army SPH-4 flight helmet testing

For comparative purposes, the transmitted deceleration of the standard US Army Flight Helmet (Figure 6), the Sound Protective Helmet No. 4 (SPH-4), for 3- through 6-ft drops is summarized in Figure 7. The thickness and density of the SPH-4 helmet was varied as shown in Figure 7 to determine the effect on transmitted peak g. It should be noted that the SPH-4 contains a polystyrene foam liner along with an energy-absorbing web suspension so that one would expect the helmet to yield lower peak g values, especially in the apex region than do other helmets with equal foam thickness.

Note in Figure 7 that doubling the thickness of the polystyrene foam liner of the SPH-4 can result in headform peak g values of only 140 g at a drop height of 6 ft. This would increase the weight by only one-tenth (0.1) lb. Such dramatic improvement clearly points the way to improved helmet design.
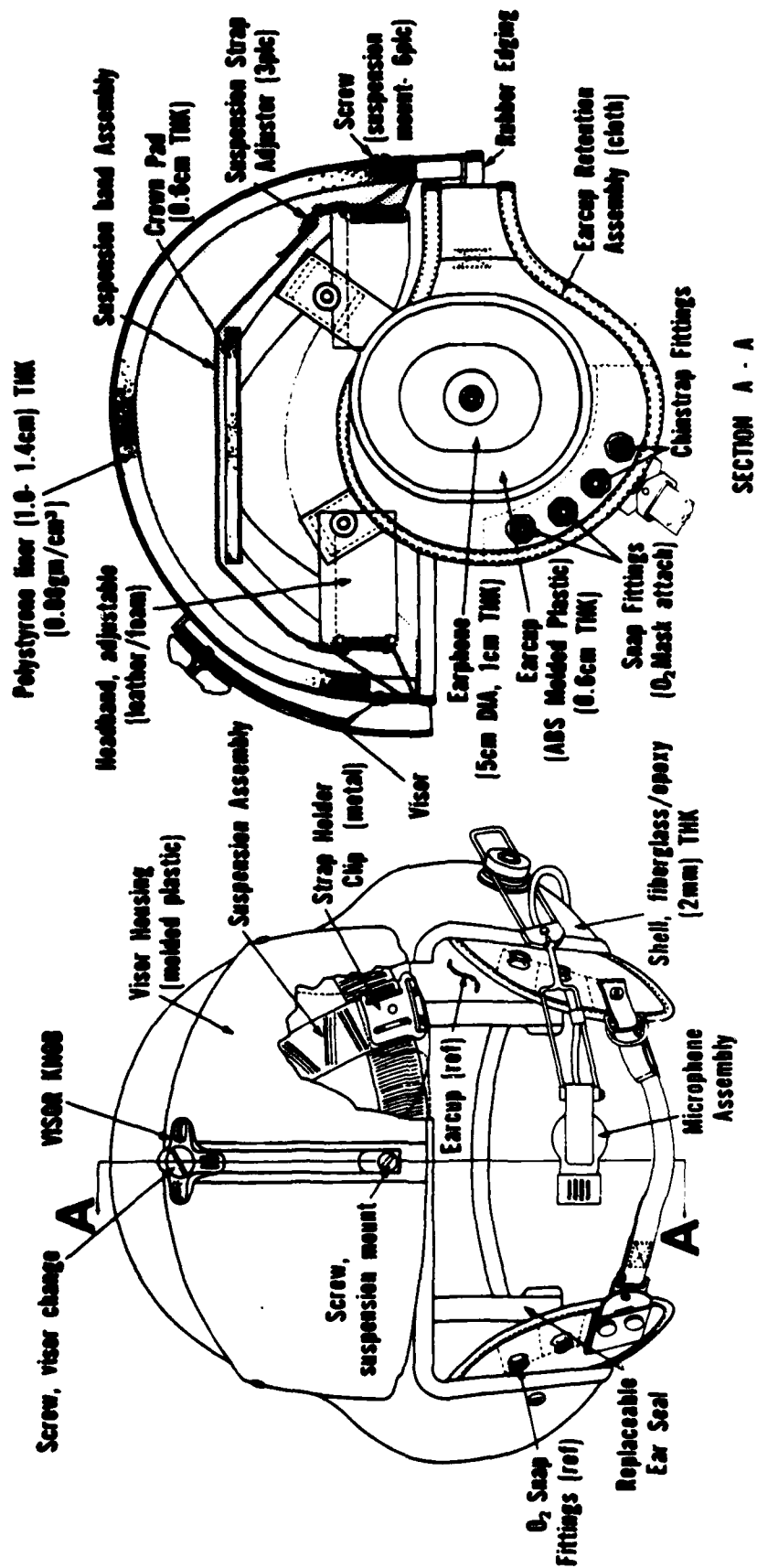
Figure 6. US Army aviator helmet—the SPH-4.
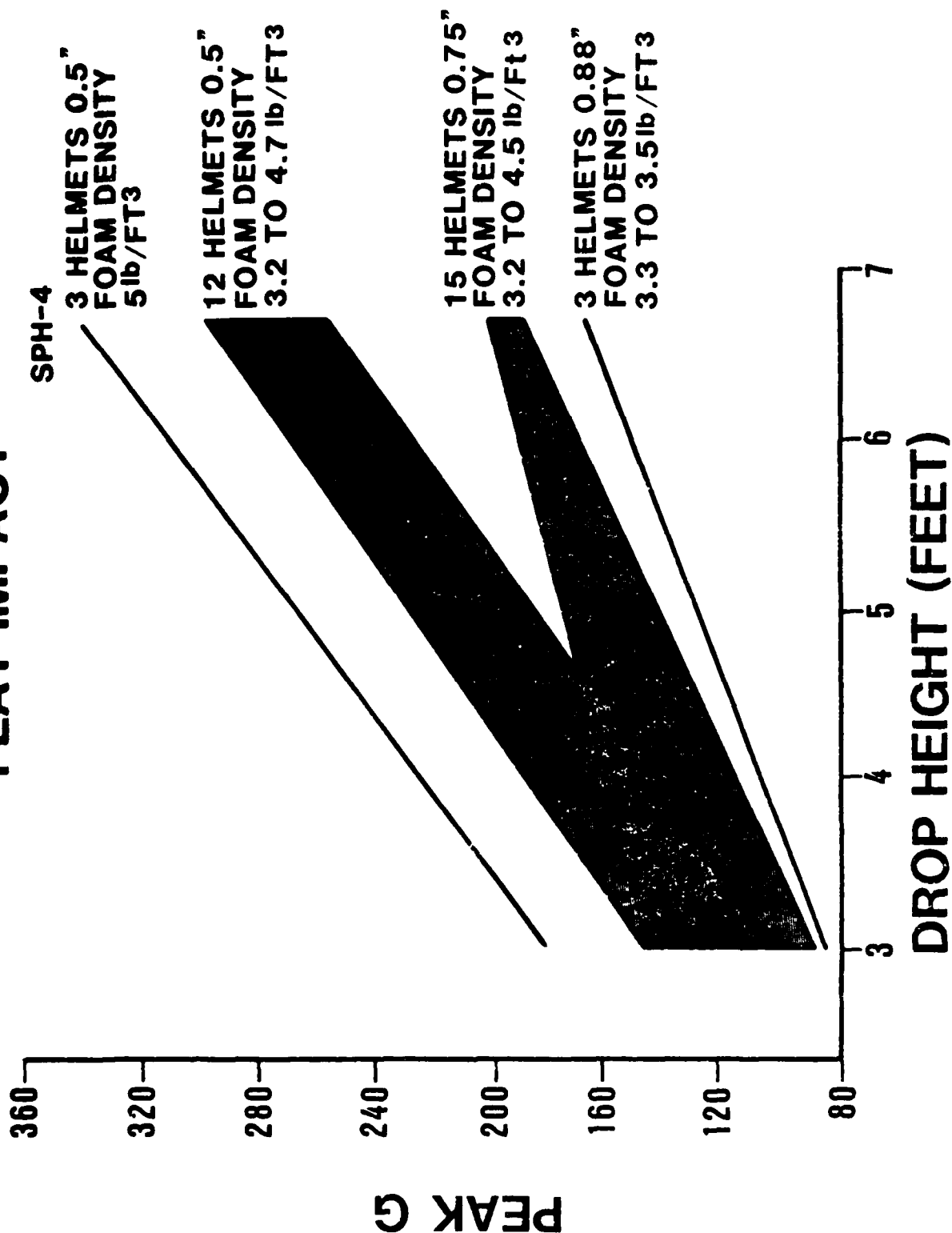
Figure 7. Transmitted deceleration of standard US Army aviator helmet (SPH-4).

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Conclusions

1. The motorcycle helmets tested did not provide adequate force attenuation to prevent concussion and/or more serious injury at all energy levels greater that a 1-m drop height.

2. Existing helmet standards permit the production of helmets which provide less protection than is possible, practical, and feasible.

3. The motorcycle helmets tested could be changed to provide more adequate protection by the doubling of the liner thickness to approximately 2.5 cm.

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                                             Netherlands Army Liaison Office
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RAF Staff, British Embassy   Fort Rucker, AL   36362
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Canadian Society of Aviation Medicine   Fort Rucker, AL   36362
c/o Academy of Medicine, Toronto
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Commanding Officer
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