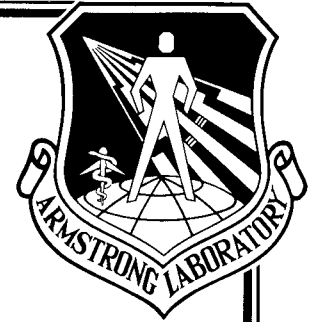


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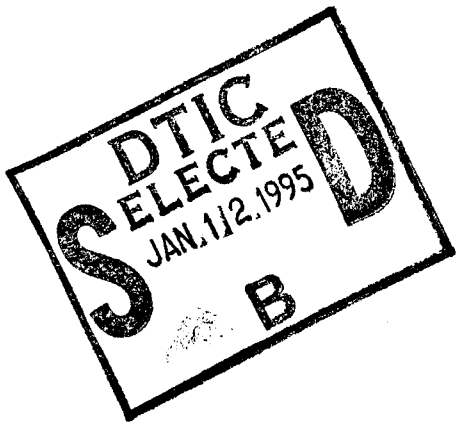
HELMET IMPACT TESTS:  
ANR EARCUP STRUCTURAL INTEGRITY AND THE  
EFFECT OF THE ANR EARCUP SYSTEM ON HELMET  
ENERGY ATTENUATION

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FOR THE COMMANDER



THOMAS J. MOORE, Chief  
Biodynamics and Biocommunications Division  
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**13. ABSTRACT (Maximum 200 words)**

An experimental effort was conducted to measure the structural integrity of the ANR earcup during helmet impact, and to measure whether th ANR earcup affects the energy attenuation properties of the helmet system during helmet impact. Helmet testing was completed using the Crew Systems Directorate's Helmet Drop Facility in which a helmeted headform experiences a guided freefall onto a rigid steel anvil to produce a dynamic impact at 35 ft-lbs energy transfer. Standard earcups and the ANR earcups were compared in helmet impacts using the HGU-53/P and HGU-55/P helmets. The earcups were equal in their performance in that they did not have a negative effect on the energy attenuation properties of the helmet systems. The standard earcup's structural integrity was not compromised during the impacts; however, the ANR earcups sustained structural damage to their outer shell and their gel filled ear cushion.

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PREFACE

An experimental effort was conducted to measure the structural integrity of the ANR earcup system, and to measure the effects the ANR earcup system would have on the helmet's energy attenuation properties and pilot safety during helmet impact. The tests were conducted for the Life Support Systems Program Office by the Escape and Impact Protection Branch of the Armstrong Laboratory.

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## INTRODUCTION

In order to ensure maximum safety and protection for Air Force pilots, any change or addition to standard flight helmets often will necessitate additional helmet testing to ensure compliance with USAF helmet design requirements. For example, modified ANSI Z-90 standard is used to evaluate the structural characteristics (impact energy attenuation, impact penetration resistance) of the HGU-53/P helmet. Any modification to the helmet would potentially require re-evaluation.

Recently, the USAF has been pushing for the addition of the ANR earcup system to the HGU-55/P and HGU-53/P flight helmets. The ANR earcup is a modification to the standard helmet system and therefore it was required to evaluate the following:

- 1) Does the new earcup system affect the helmet's energy attenuation properties?
- 2) Will the ANR system impinge on the pilot's ear region after a side impact on the helmet?
- 3) Will the ANR system structurally withstand a side impact on the helmet?

## METHODS

The impact testing (energy attenuation) of the flight helmets in this program was completed using the AL/CFBE Helmet Drop Facility (HDF) located in Bldg 824. The facility, when used for impact testing, is composed of a small, vertical displacement carriage to which a low resonant magnesium alloy headform is mounted. The facility can also be used to test the penetration resistance of helmet shells in which case the headform is rigidly mounted at the base of the carriage. The carriage and helmeted headform are allowed to undergo a guided freefall onto a rigid hemispherical steel anvil 1.9 inches in radius to produce a dynamic impact. Testing was conducted such that the anvil would impart 35 ft-lbs of energy to the helmet at the point of impact. The HDF with the HGU-26/P helmet mounted on the headform is shown in Figure 1.

This test program was conducted using four separate helmets. They were a HGU-2/P, one HGU-55/P, and two HGU-53/P helmets. The HGU-2/P and one of the HGU-53/P helmets were fitted with standard earcups. The remaining helmets were fitted with the ANR system. The test matrix is shown in Table 1.

TABLE 1. HELMET/ANR TEST MATRIX

TEST #	CELL	HELMET	ORIENTATION	EARCUP	DROP HEIGHT
1	A	HGU-2/P	Right Side	Standard	28.4"
2	B	HGU-2/P	Left Side	Standard	28.4"
3	C	HGU-2/P	Right Side	Standard	28.4"
4	D	HGU-55/P(1)	Right Side	ANR	30.29"
5	E	HGU-55/P(1)	Left Side	ANR	30.29"
Deleted	F	HGU-55/P(2)	Right Side	Standard	28" +
Deleted	G	HGU-55/P(2)	Left Side	Standard	28" +
6	H	HGU-53/P(1)	Right Side	ANR	31.00"
7	I	HGU-53/P(1)	Left Side	ANR	31.00"
8	J	HGU-53/P(2)	Left Side	Standard	32.35"
9	K	HGU-53/P(2)	Right Side	Standard	32.35"
10	L	HGU-53/P(2)	Right/Top	Standard	46.21"

Test cells A, B, and C were pre-test drops used to determine the facility friction factor during guided freefall (the test carriage is guided on steel cables).

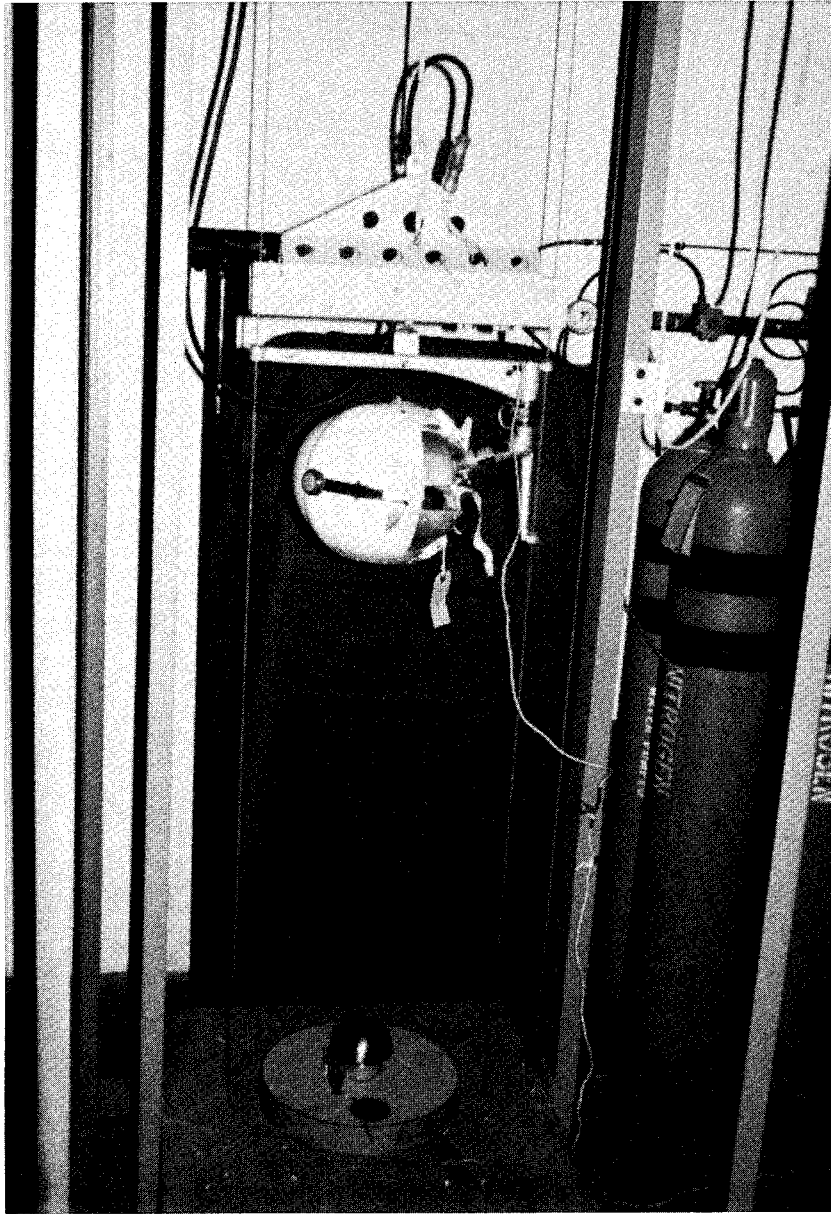


FIGURE 1. AL/CFBE HELMET DROP FACILITY

This was found by comparing actual freefall time to the theoretical freefall time. Theoretical freefall was calculated using the following equation:

$$t_{\text{f}} = ((2*h)/a)^{0.5}$$

where  $t_{\text{f}}$  is the theoretical freefall,  $h$  is the estimated initial drop height (calculated from  $h = E/w$  where  $E$  is required energy at impact and  $w$  is weight of carriage and helmet), and  $a$  is the acceleration due to gravity ( $32.2 \text{ ft/s}^2$ ). Knowing the required initial energy was 35 ft-lbs and the HGU-2/P helmet and carriage weight was  $w = 14.78 \text{ lbs}$ , the initial height was found to be  $h = 28.42 \text{ in}$ , and the corresponding theoretical free fall time was found to be  $t_{\text{f}} = 0.3957 \text{ sec}$ . From these two values, the facility friction factor was found to be  $f = 0.0305$  using the following equation:

$$f = (t_{\text{af}} - t_{\text{f}})/t_{\text{f}}$$

Since this value could be affected by temperature and humidity, all tests were completed on the same day the factor was determined. For each test in the matrix, the helmet with liner and earcups were fitted onto the rigid headform such that the area of helmet impact (side over each earcup) was positioned directly over impact anvil. The helmet was secured to the headform by its retention system (nape and chin straps) to prevent movement during freefall. The drop height for each test was determined using the following equation:

$$D_{\text{h}} = [(I_{\text{c}}/w) + f*(I_{\text{c}}/w)]$$

where  $D_{\text{h}}$  is the drop height,  $I_{\text{c}}$  is the impact energy,  $w$  is the total weight at freefall (carriage and helmet), and  $f$  is the facility friction factor. The helmet/carriage assembly was raised to the proper height for each test and then the carriage was released from an electronically activated solenoid and allowed to freefall. For tests 1 through 9, the impact energy was 35 ft-lbs as stated before, but for test 10, the energy was increased to 50 ft-lbs to determine the structural integrity of the 53/P helmet to an impact at a point approximately halfway between the earcup and the top. This was done at the request of the Life Support SPO.

Data collection was simple and consisted of: (1) a time trace of the acceleration of the headform using a single axis accelerometer mounted at the approximate center-of-gravity, (2) a time trace of the load imparted to the headform using a flat load cell (10k pound max) mounted under the impact anvil, and (3) the trigger signal used to operate the solenoid release. Test requirements for the data consisted of analyzing the acceleration waveforms and comparing them to the modified ANSI Z-90 helmet

impact standards which state the following: acceleration of the test headform shall not exceed 400 Gs, nor shall it exceed 200 Gs for 3 milliseconds or more, and nor shall it exceed 150 Gs for 6 milliseconds or more. Additional helmet evaluation consisted of observation of the structural integrity of the ANR earcups and comparing them to the standard earcups. All tests were documented using a KODAK high-speed video system running at approximately 500 frames per second.

## RESULTS

All test data was collected at 10K samples per second and filtered at 1K Hz. Test cells F and G were not conducted per instructions from Life Support SPO. For each test, a plot was constructed for the acceleration and the load time histories with the time referenced to the start of helmet free-fall. These plots can be found in Figures 2 through 21. From these plots, the peak acceleration, peak load, and Z-90 acceleration time requirements could be obtained. This information is summarized below.

TABLE 2. HELMET IMPACT DATA SUMMARY

TEST #	TIME OVER G (MS)			PEAK ACCELERATION (G)	PEAK LOAD (LBS)
	400 G	200 G	150 G		
1	0	0	1.2	173	2205
2	0	0	0.5	161	2080
3	0	0	1.2	193	2467
4	0	0	0	88	1278
5	0	0	0	93	1271
6	0	0	0	117	1457
7	0	0	0	129	1739
8	0	0	0	116	1459
9	0	0	0	112	1381
10	0	0.8	1.2	286	3530

As shown in Table 2, the energy attenuation properties of the helmet systems with both the standard and ANR earcups satisfied the Z-90 criteria with little problem. Even the last test at a 50 ft-lb impact energy using the HGU-53/P helmet and standard earcup had no problem meeting the criteria.

The structural integrity of the ANR earcup system can be demonstrated in Figures 22 through 26. The figures document that in the HGU-55/P helmet, the earcups show little deformation after impact other than slight cracks on the back of each earcup shell as shown by Figures 22 and 23. Figures 24 and 26 show that in the HGU-53/P helmet, the ANR shell received major structural damage after impact. Figure 25 also shows where the gel filled earpad ruptured after impact. The standard earcups in either the 55/P or 53/P helmet did not sustain structural damage (shell or earpad) after impact.

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

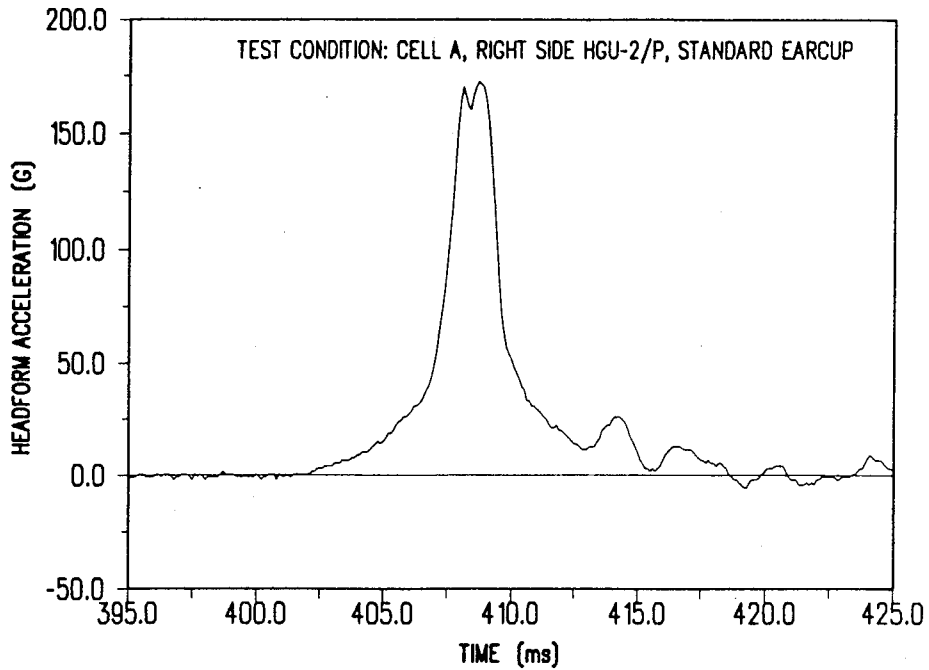


FIGURE 2. HEADFORM ACCELERATION: HGU-2/P IN CELL A

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

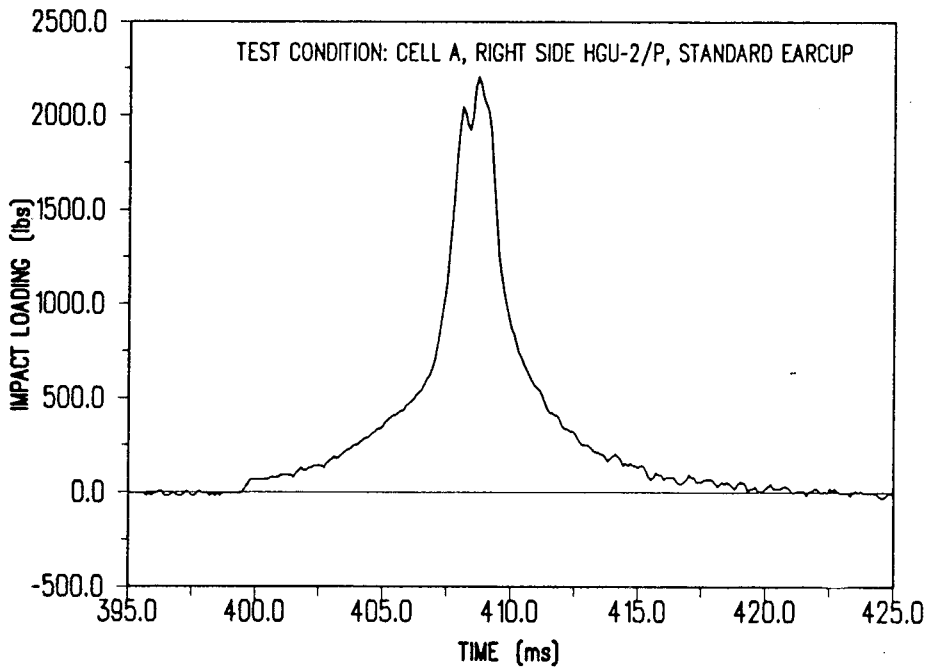


FIGURE 3. IMPACT LOADING: HGU-2/P IN CELL A

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

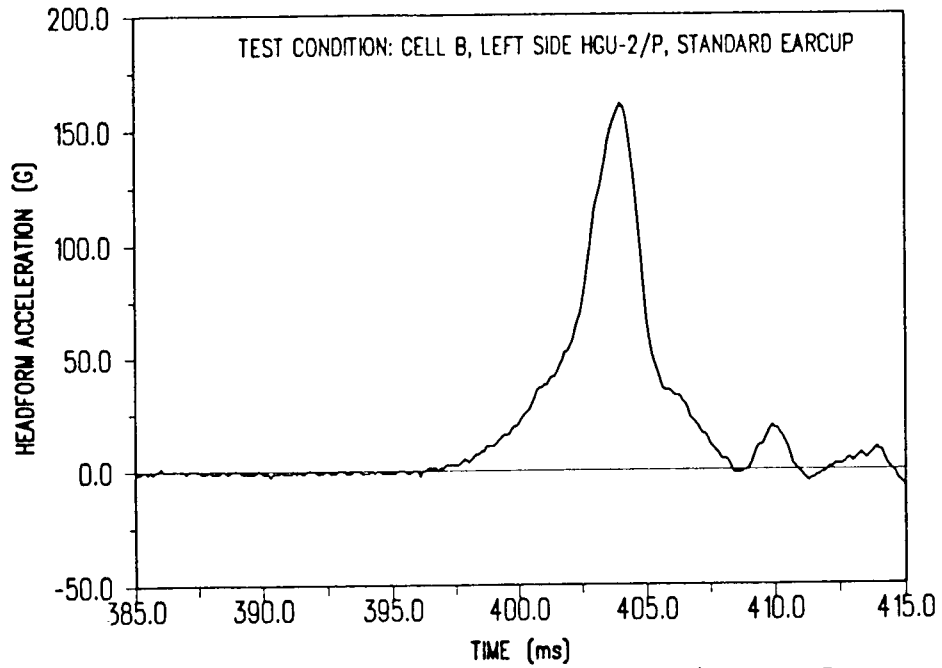


FIGURE 4. HEADFORM ACCELERATION: HGU-2/P IN CELL B

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

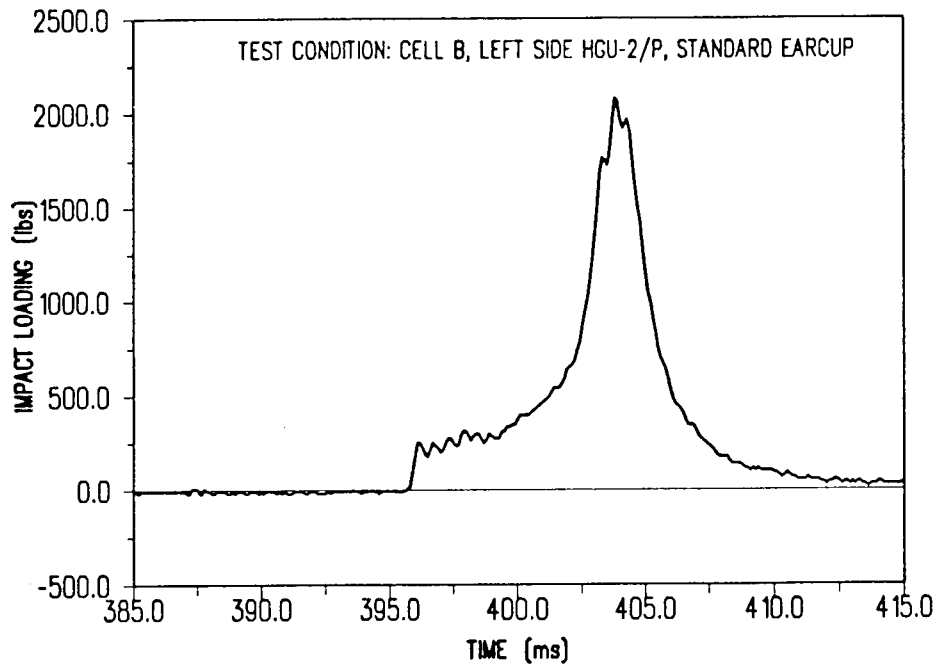


FIGURE 5. IMPACT LOADING: HGU-2/P IN CELL B



HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

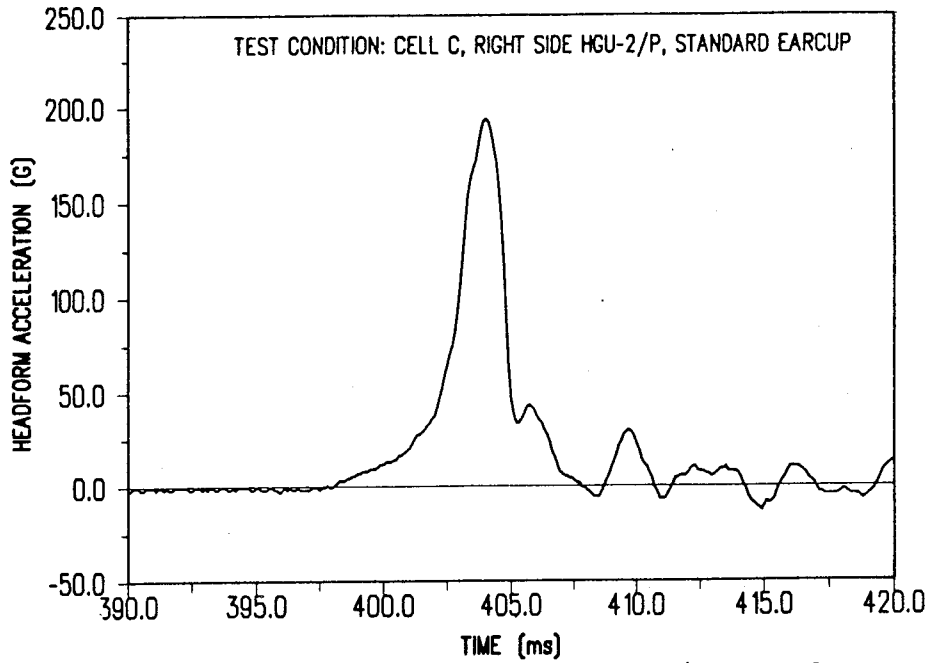


FIGURE 6. HEADFORM ACCELERATION: HGU-2/P IN CELL C

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

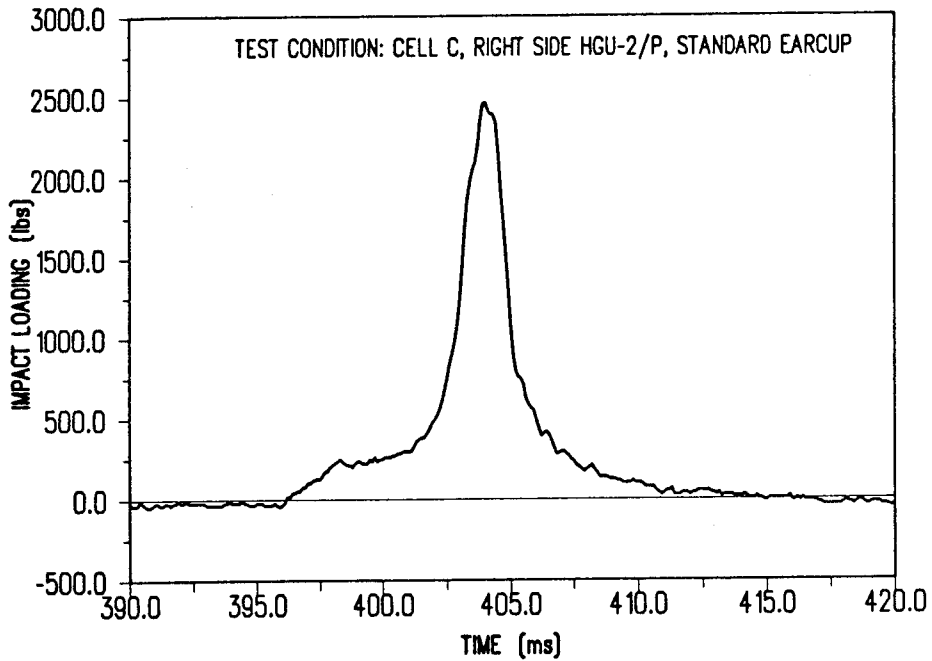


FIGURE 7. IMPACT LOADING: HGU-2/P IN CELL C

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

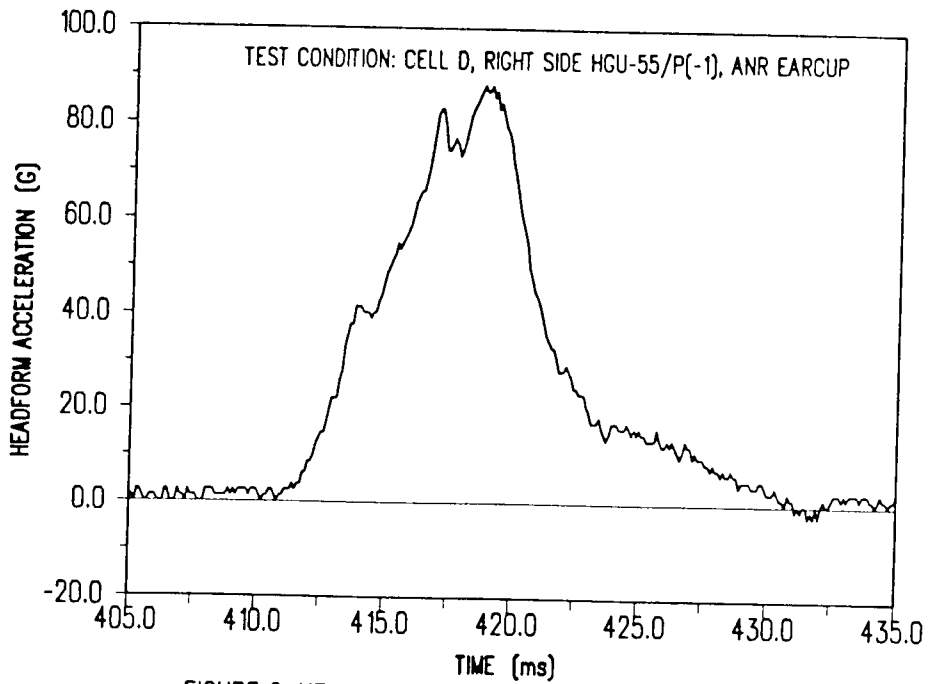


FIGURE 8. HEADFORM ACCFLERATION:HGU-55/P IN CELL D

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

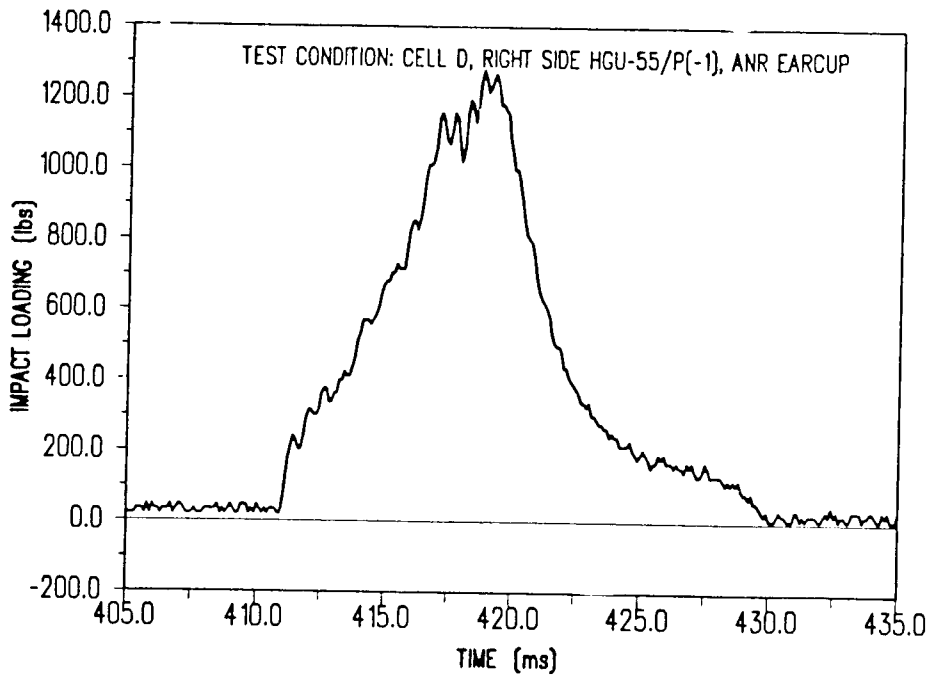


FIGURE 9. IMPACT LOADING: HGU-55/P IN CELL D

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

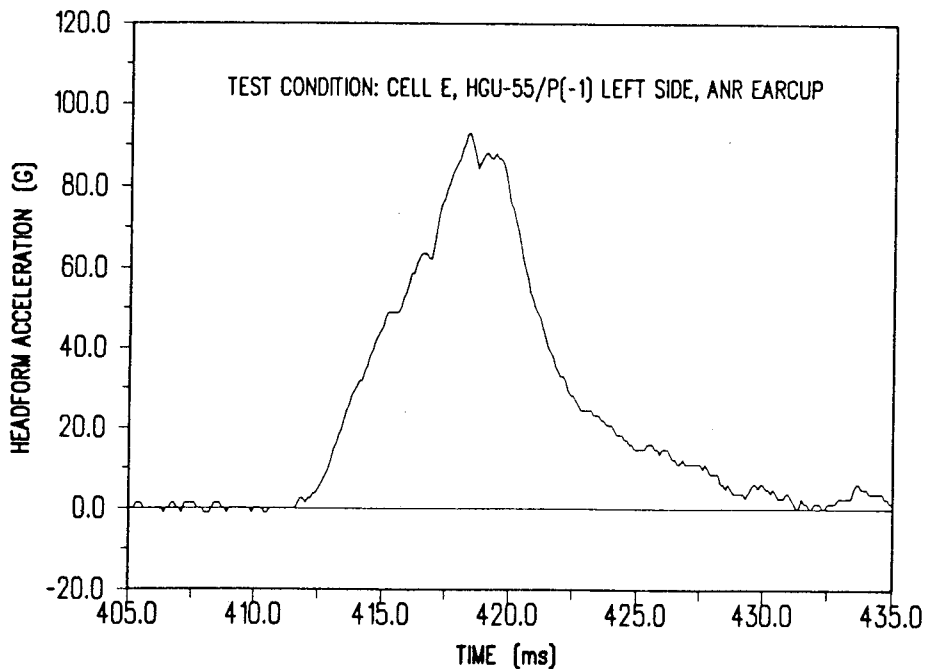


FIGURE 10. HEADFORM ACCELERATION: HGU-55/P, CELL E

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

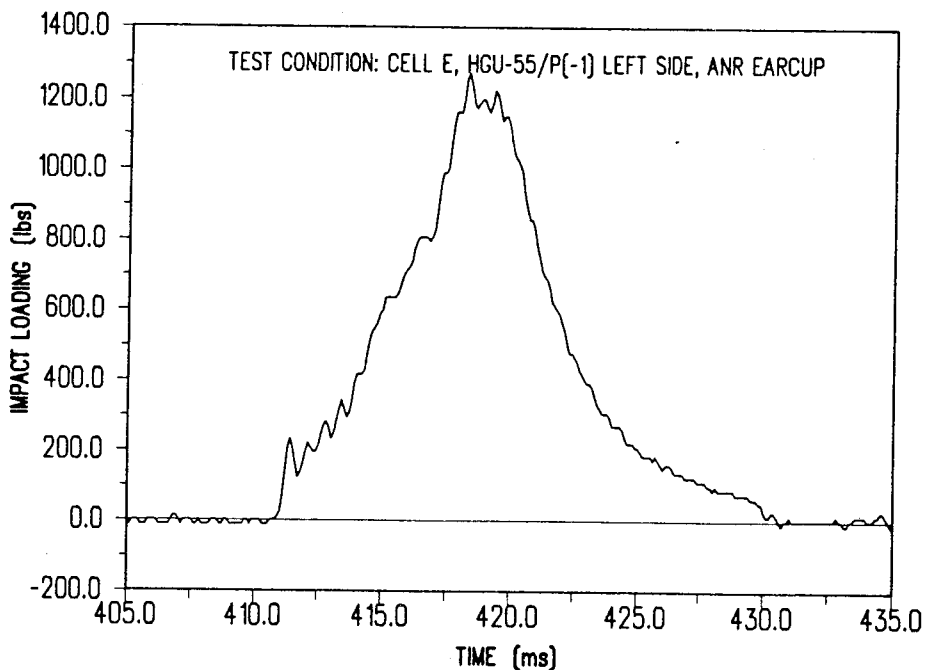


FIGURE 11. IMPACT LOADING: HGU-55/P IN CELL E

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

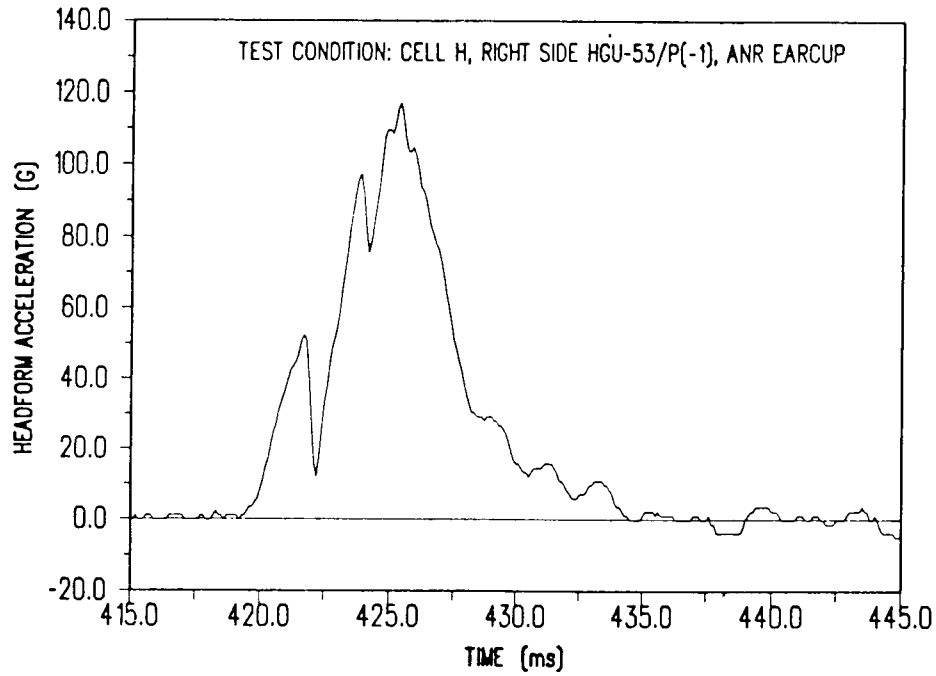


FIGURE 12. HEADFORM ACCELERATION: HGU-53/P, CELL H

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=355FT-LB

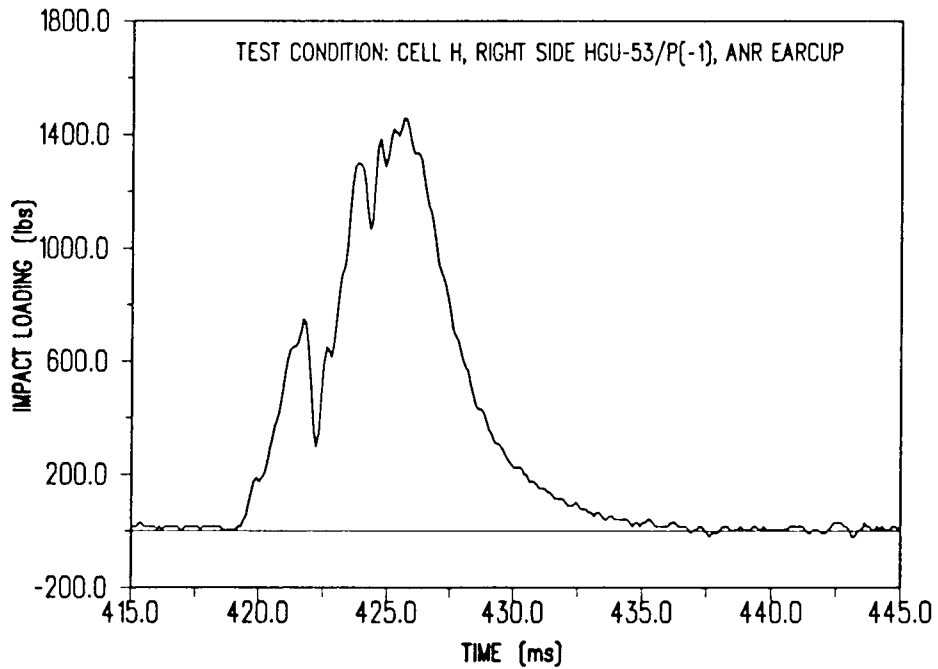


FIGURE 13. IMPACT LOADING: HGU-53/P IN CELL H

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

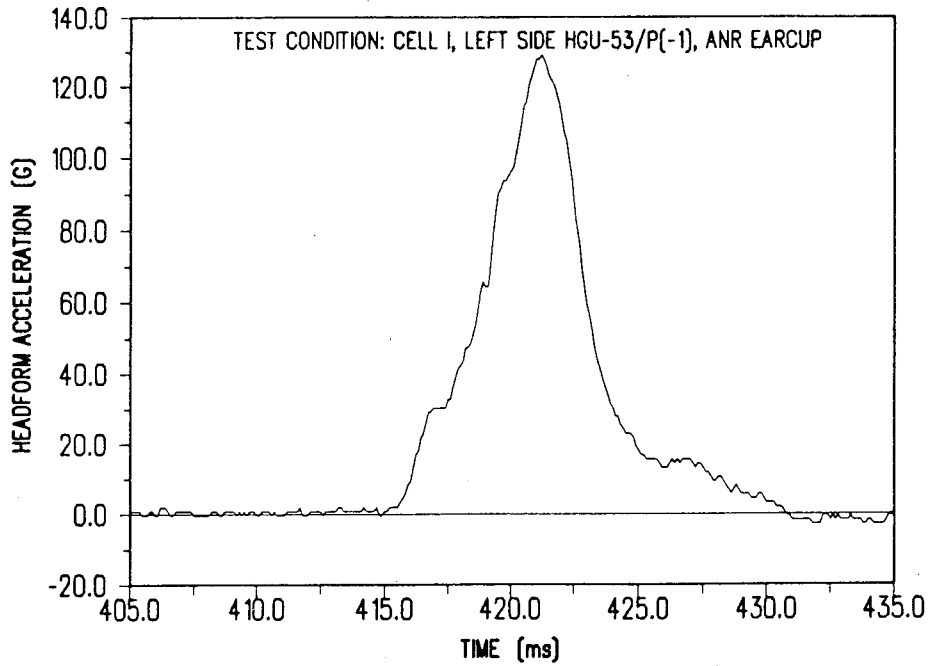


FIGURE 14. HEADFORM ACCELERATION: HGU-53/P, CELL I

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

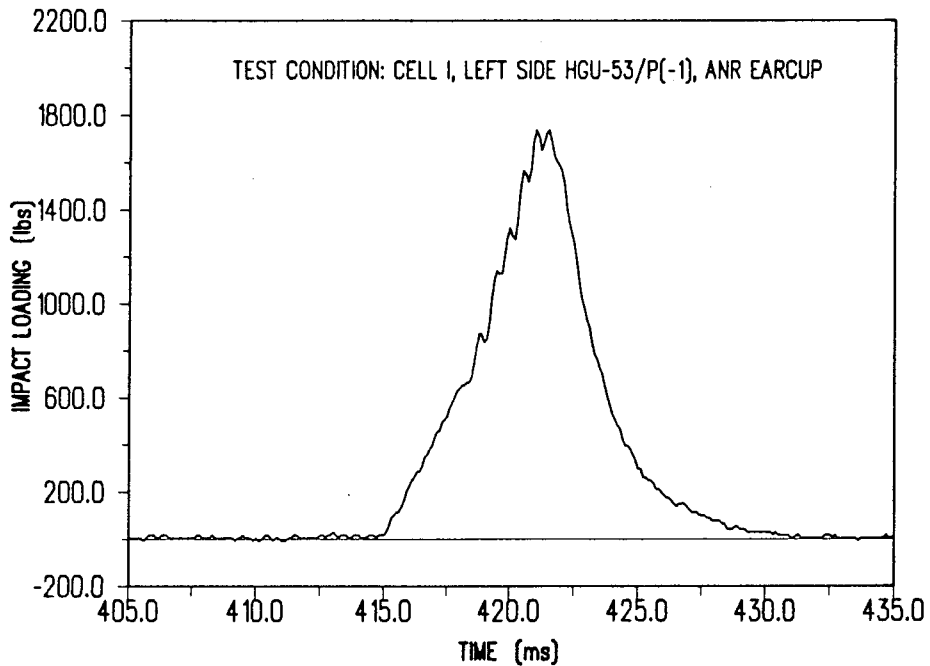


FIGURE 15. IMPACT LOADING: HGU-53/P IN CELL I

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

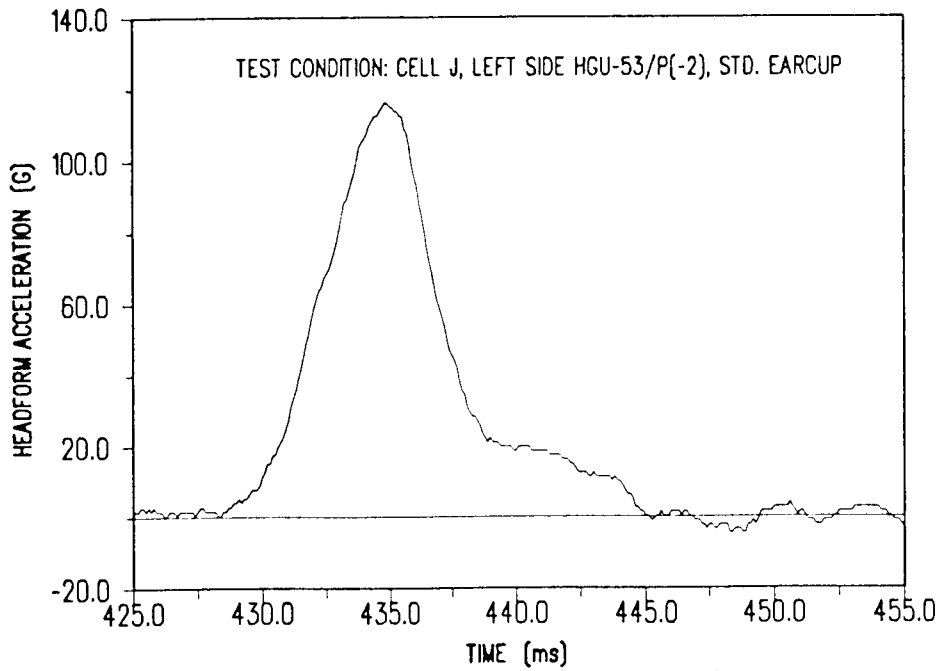


FIGURE 16. HEADFORM ACCELERATION:HGU-53/P, CELL J

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

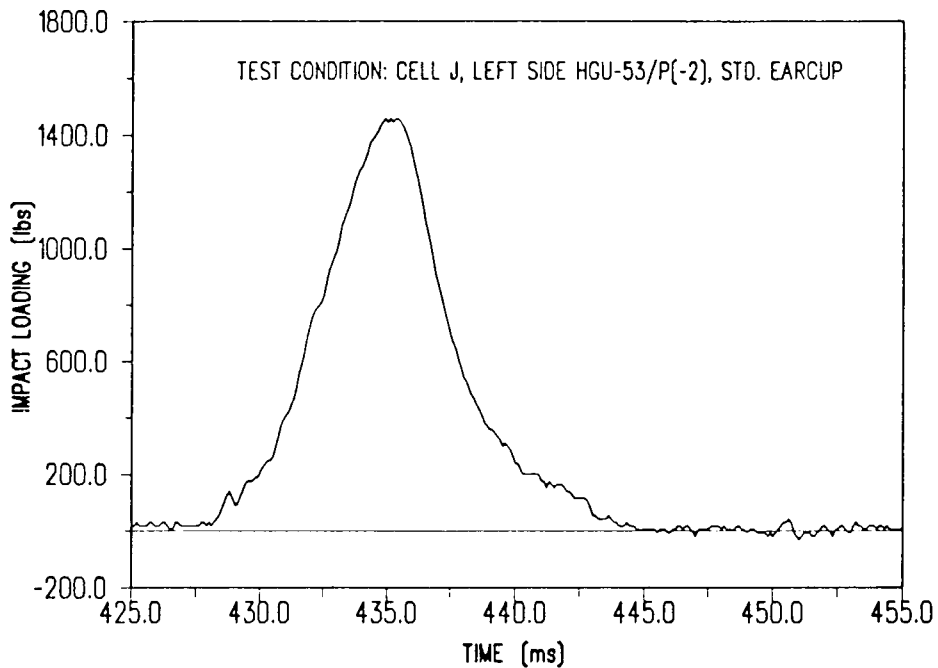


FIGURE 17. IMPACT LOADING: HGU-53/P IN CELL J

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

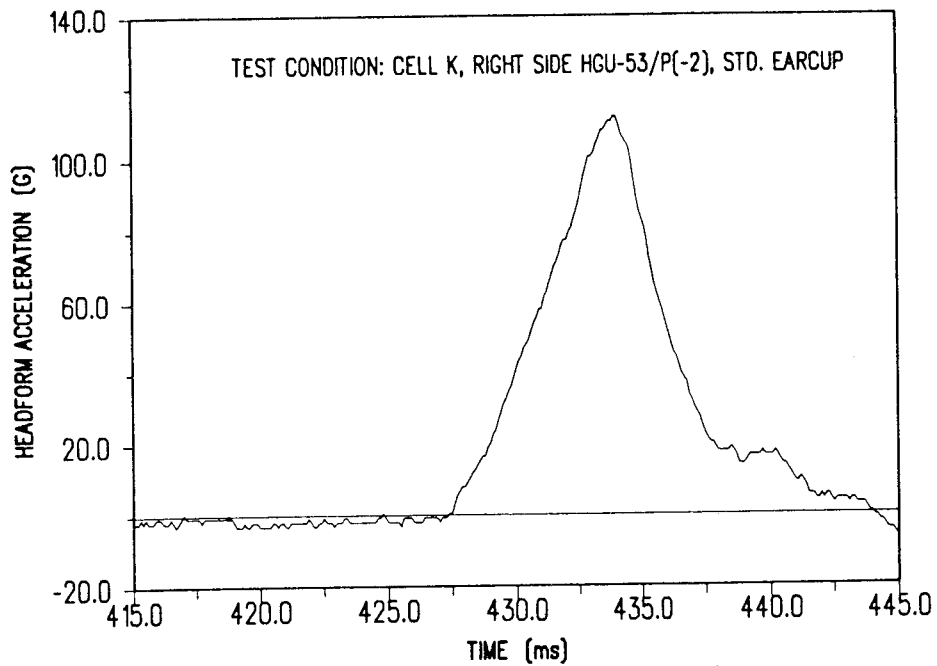


FIGURE 18. HEADFORM ACCELERATION: HGU-53/P, CELL K

HELMET/ANR IMPACT TEST AT ENERGY TRANSFER=35 FT-LB

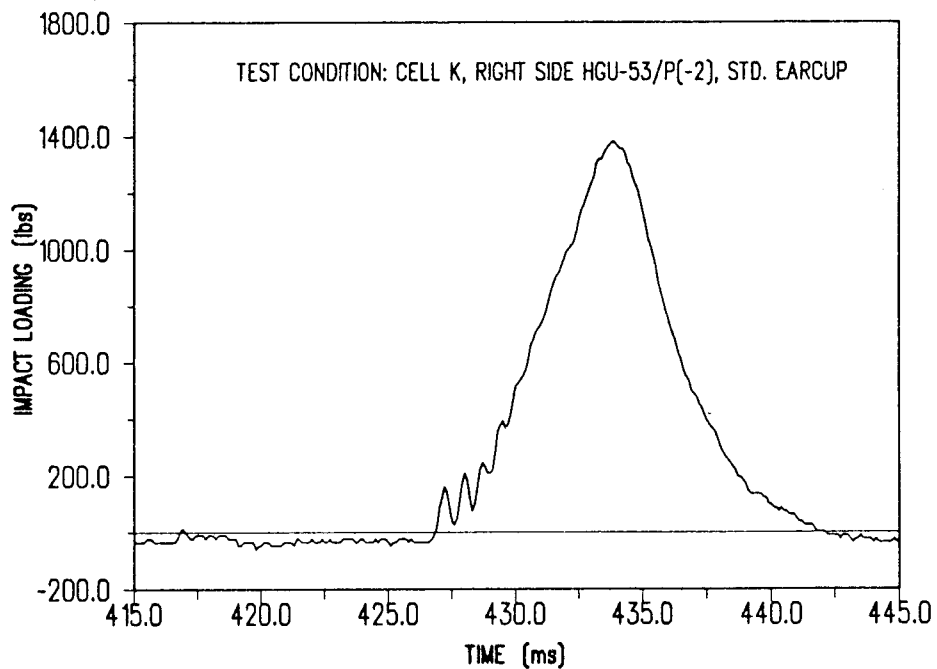


FIGURE 19. IMPACT LOADING: HGU-53/P IN CELL K

HELMET STRUCTURAL TEST AT IMPACT ENERGY=50 FT-LB

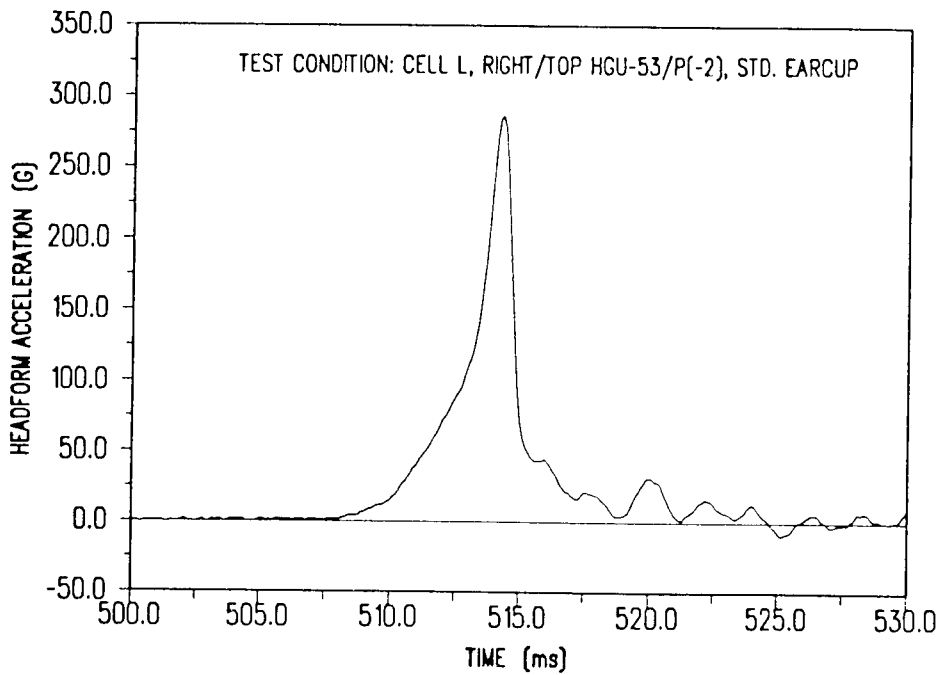


FIGURE 20. STRUCTURAL TEST HEADFORM ACCEL.: CELL L

HELMET STRUCTURAL TEST AT IMPACT ENERGY=50 FT-LB

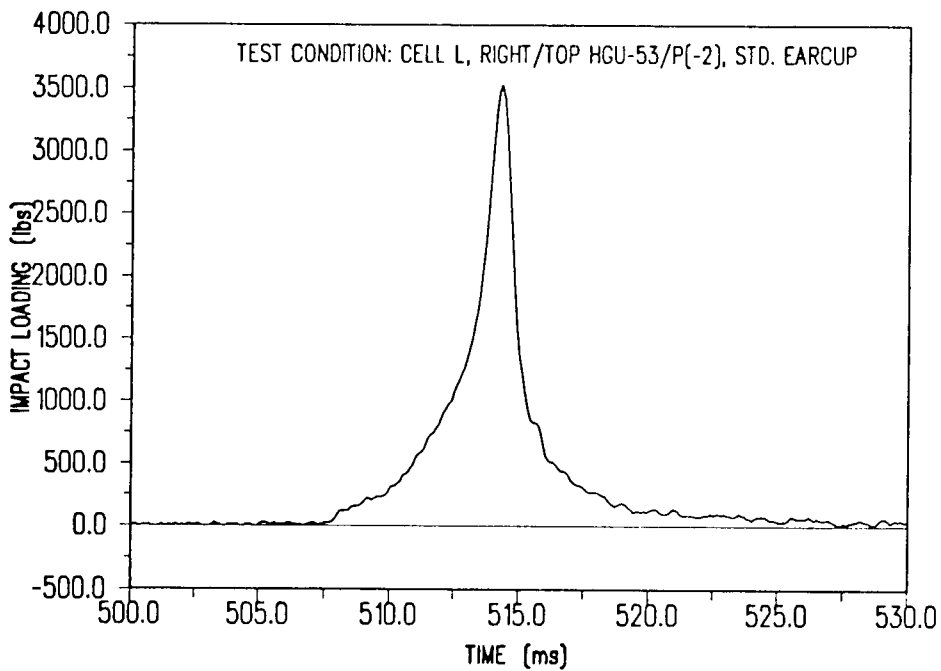


FIGURE 21. STRUCTURAL TEST IMPACT LOADING: CELL L



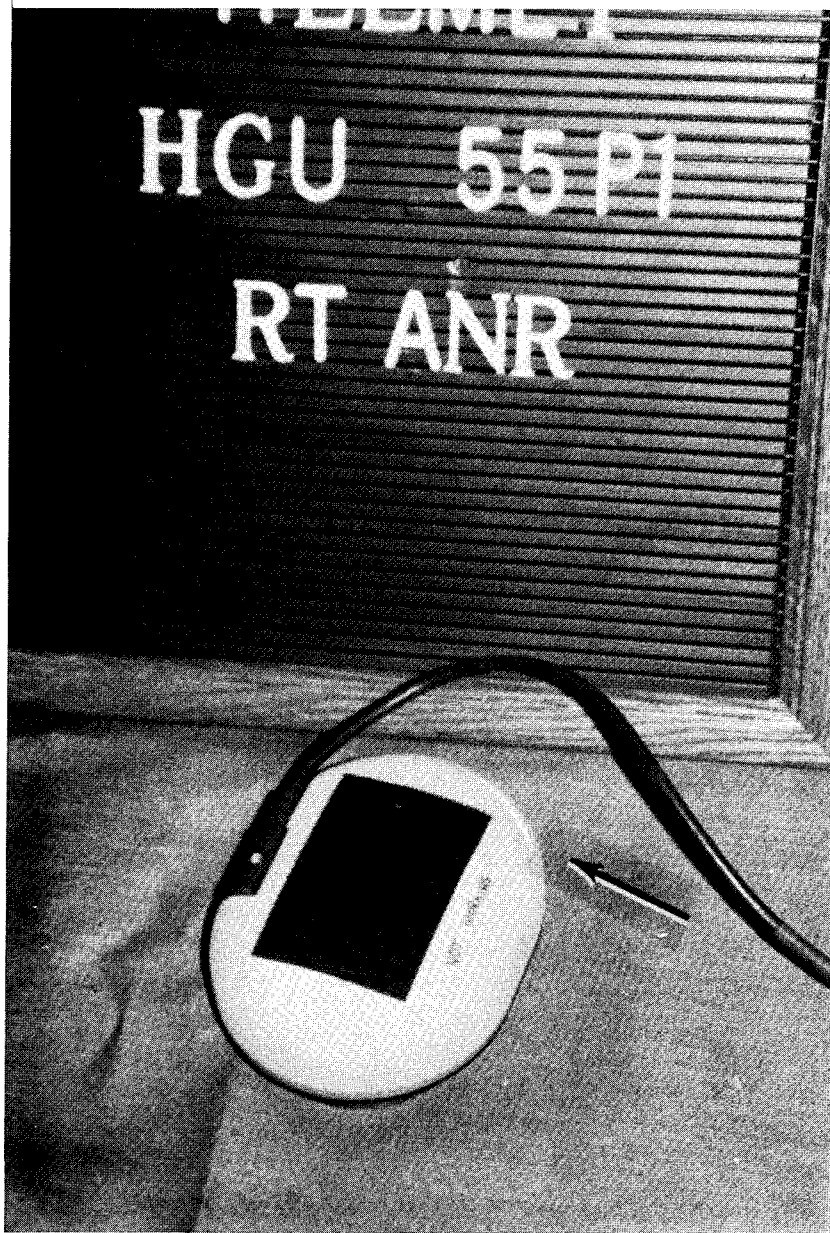




FIGURE 23. ANR EARCUP DAMAGE AFTER TEST #5

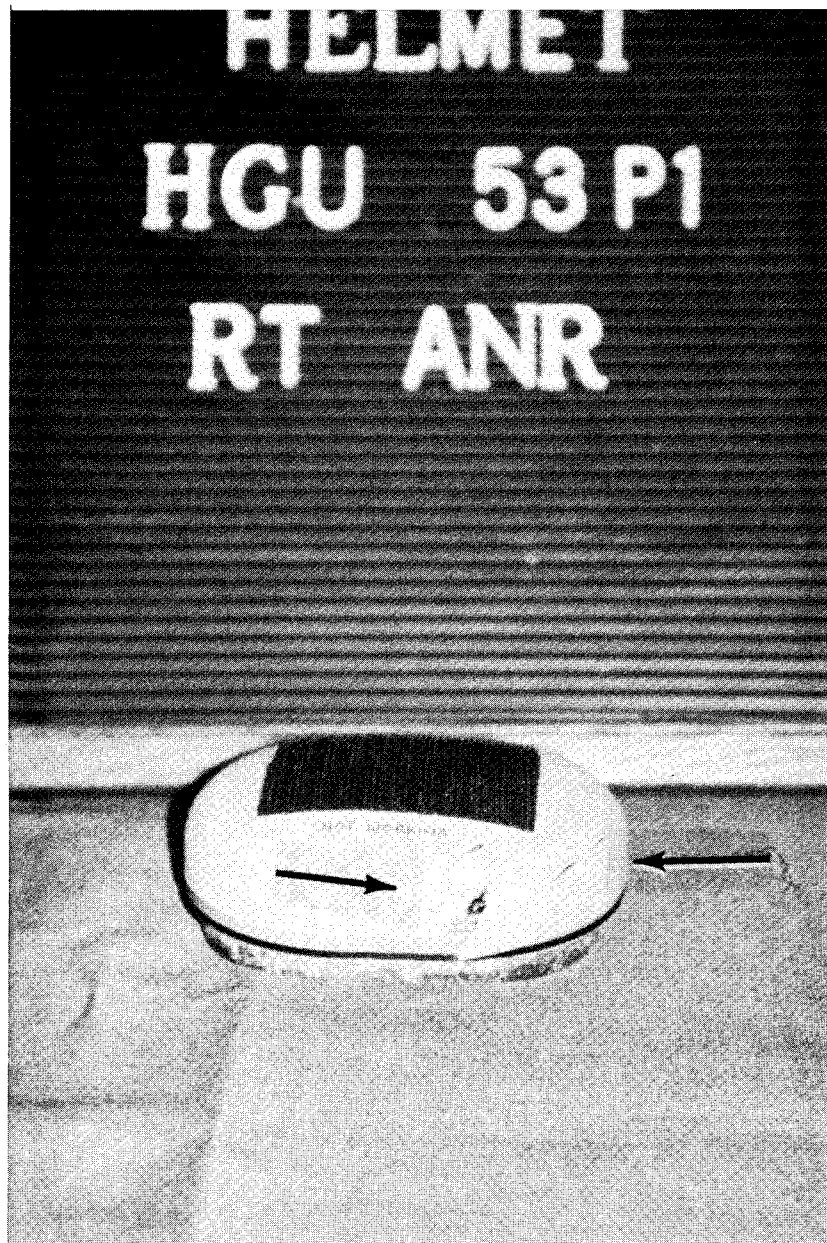


FIGURE 24. ANR EARCUP DAMAGE AFTER TEST #6

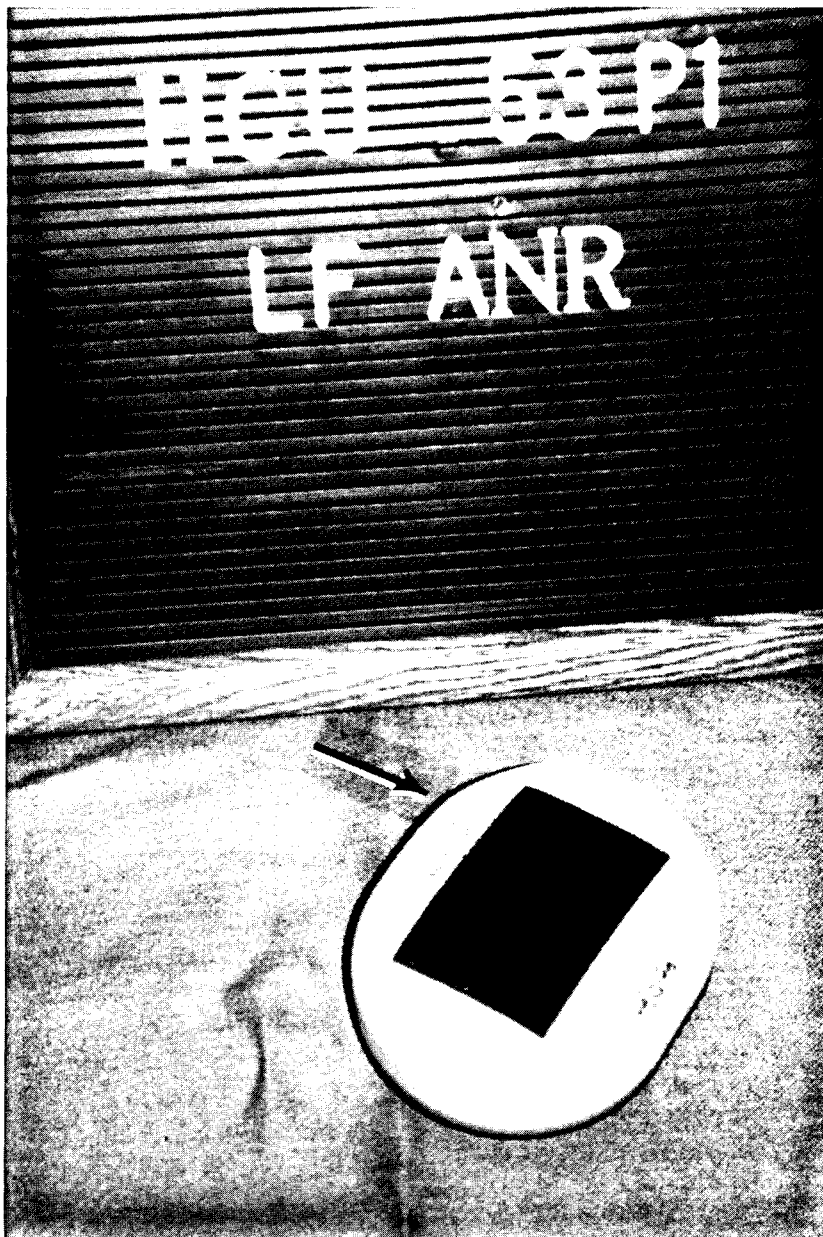


FIGURE 25. ANR EARCUP DAMAGE AFTER TEST #7

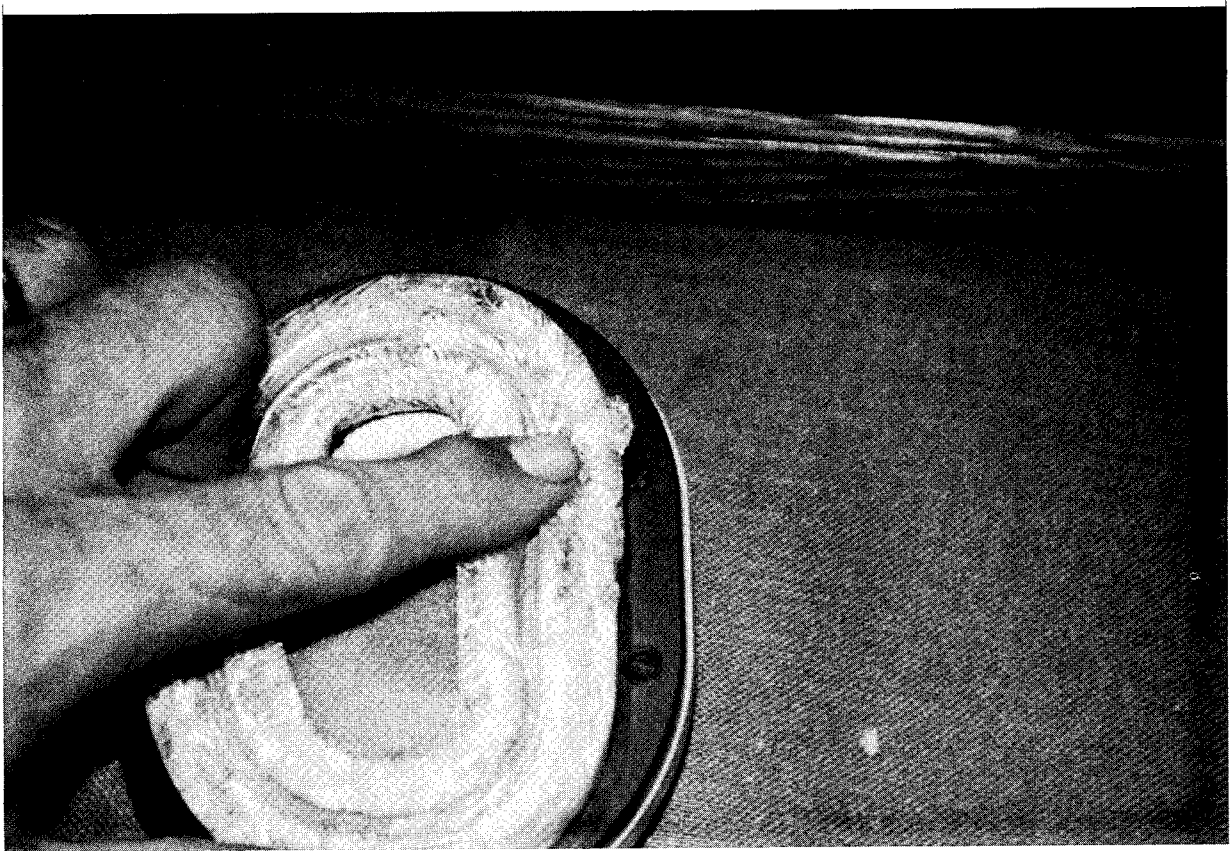


FIGURE 26. DAMAGE TO GEL-FILLED EARPAP AFTER TEST #7

Figure 27 shows the point of impact for the final test conducted at the 50 ft-lb impact energy level. The HGU-53/P helmet showed no visible damage to the outer shell, but the inner styrofoam liner beneath the point of impact was damaged as shown in Figure 28. This is the function of the liner (energy absorption) and was considered a positive test result.



FIGURE 27. POINT OF IMPACT FOR 50 FT-LB IMPACT ENERGY TEST

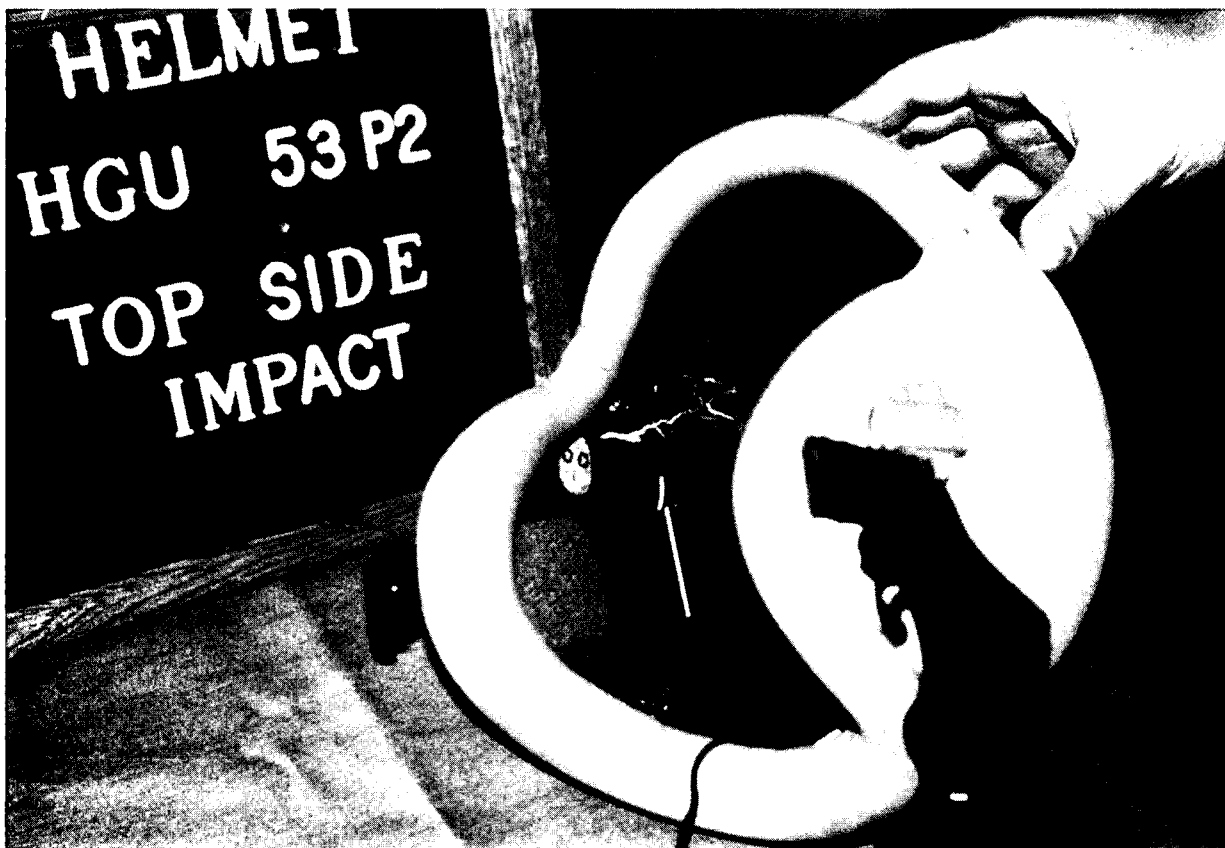


FIGURE 28. DAMAGE TO LINER OF 53/P HELMET AFTER 50 FT-LB IMPACT ENERGY TEST



## CONCLUSIONS

Tests were conducted on a helmet drop facility to compare standard earmuffs and the ANR earmuffs in two areas: effect on helmet impact energy attenuation, and earmuff structural integrity. The earmuffs performed equally well in their ability to affect the energy attenuation properties of the helmet system when subjected to an impact of 35 ft-lbs. The standard earmuff's structural integrity was much better than the ANR earmuffs as the standard earmuffs displayed no damage during impact, but each ANR earmuff sustained some damage to its outer shell during impact. A possible explanation for this could be that the standard earmuff has a low density foam cushion that forms to the ear, while the ANR earmuff has a high density gel cushion that would not absorb the short-time duration energy from the impact as well as the low density foam. The results would be that the energy transmitted through the helmet shell during impact would be partially absorbed by the outer shell of the ANR earmuff instead of the cushion, resulting in structural failure of the earmuff shell.

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