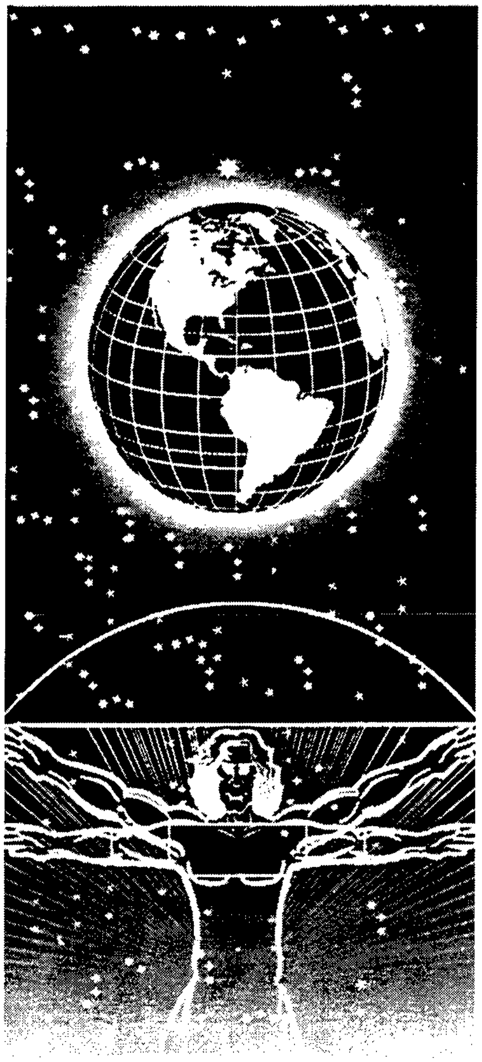
AL/CF-SR-1997-0008



UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Vertical Impact Tests of the X-31 Helmet-Mounted Visual and Audio Display (HMVAD) System

Chris E. Perry

October 1993

Interim Report for the Period June 1993 through October 1993

Crew Systems Directorate
Biodynamics and
Biocommunications Division
Wright-Patterson AFB OH
45433-7901

Approved for public release; distribution is unlimited.

NOTICES

Please do not request copies of this report from the Armstrong Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield VA 22161

Federal Government agencies registered with Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
8725 John J. Kingman Rd., Ste 0944
Ft Belvoir VA 22060-6218

TECHNICAL REVIEW AND APPROVAL

AL/CF-SR-1997-0008

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

Thomas J. Moore

THOMAS J. MOORE, Chief
Biodynamics and Biocommunications Division
Armstrong Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1993

3. REPORT TYPE AND DATES COVERED
Final Report June 1993 to October 1993

4. TITLE AND SUBTITLE
Vertical Impact Tests of the X-31 Helmet-Mounted Visual and Audio Display (HMVAD) System

5. FUNDING NUMBERS
PE - 62202F
PR - 7231
TA - 723124
WU- 72312401

6. AUTHOR(S)
Chris E. Perry

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Crew Systems Directorate
Biodynamics and Biocommunications Division
Human Systems Center
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7901

8. PERFORMING ORGANIZATION REPORT NUMBER
AL/CF-SR-1997-0008

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ASC/SMYC
BLDG 28
2145 Monahan Way
Wright-Patterson AFB Oh 45433-7017

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

An experimental effort was conducted to measure the biodynamic response of an ADAM subjected to a simulated SJU-5 ejection pulse while wearing the X-31 HMVAD system. The test results will be used to evaluate the injury potential of this particular helmet system if worn by an aircrew member during an ejection. The tests were conducted for the Armstrong Laboratory/Wright Laboratory Joint Cockpit Office by the Escape and Impact Protection Branch of the Armstrong Laboratory.

14. SUBJECT TERMS
Ejection, Escape, Manikin, SJU-5, X-31
Biodynamic Response, Impact Response

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT
UNCLASSIFIED

20. LIMITATION OF ABSTRACT
UNL

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

THIS PAGE INTENTIONALLY LEFT BLANK

PREFACE

An experimental effort was conducted to measure the biodynamic response of an ADAM subjected to a simulated SJU-5 ejection pulse while wearing the X-31 HMVAD system. The test results will be used to evaluate the injury potential of this particular helmet system if worn by an aircrew member during an ejection. The tests were conducted for the Armstrong Laboratory/Wright Laboratory Joint Cockpit Office by the Escape and Impact Protection Branch of the Armstrong Laboratory.

Special thanks to Eureka Matsunaga and Sam Sanchez from Rockwell International, Trevor Bushell from GEC Avionics, and Rick Borsch from NASA for their guidance and assistance during the test program. Also, thanks to DynCorp for their cooperation and professional response in preparing the test facility and assisting during the tests.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

INTRODUCTION

The X-31 Test Program is a joint International Test Organization (ITO) and USAF research effort investigating the use of a combined helmet-mounted display and 3-D audio system (HMVAD) to improve pilot workload and mission effectiveness with the X-31 aircraft. The helmet system is a variation of the GEC Avionics Interim-Night Integrated and Head Tracking System (I-NIGHTS) helmet system using only a helmet mounted display and no enhanced night vision system. The X-31 aircraft, built jointly by Rockwell International and Deutsche Aerospace with funding from both the U.S. and German governments, was developed primarily for research of technology to improve aircraft in-flight agility. The X-31 aircraft uses a variable thrust-vector nozzle at the engine exhaust which is interfaced with the aircraft's flight control surfaces. This gives the X-31 superior maneuverability compared to conventional aircraft.

The X-31 Test Program will be conducting a flight test evaluation of the special X-31 helmet with the HMVAD system for use during the aircraft's enhanced flight maneuvers. The X-31 flight test aircraft will be using a Martin Baker SJU-5 ejection seat. A potential increase in the risk of neck injury during emergency escape exists with this helmet due to: (1) the increased weight and altered center-of-gravity of the helmet when compared to conventional flight helmets; (2) the moderately high ejection seat acceleration; and (3) the "head forward" position of the pilot's head relative to the seatback plane. NASA Flight Research Facility at Edwards AFB CA has flight release authority for the X-31 aircraft; however, NASA requires assistance in order to flight certify the X-31 helmet. Therefore, a study was initiated to assist in the flight certification of the X-31 helmet by evaluating the risk of neck injury during the catapult phase of ejection.

This report documents the research conducted by the Escape and Impact Protection Branch of the Armstrong Laboratory (AL/CFBE) to evaluate the biodynamic response of the X-31 helmet in a simulation of the SJU-5 ejection acceleration environment to determine the risk of injury.

METHODS

To evaluate the potential increase in the risk of injury of an aircrew member wearing the X-31 helmet during the catapult phase of ejection, a series of vertical impact tests were conducted on AL's vertical deceleration tower (VDT) test facility using a large, instrumented Advanced Dynamic Anthropomorphic Manikin (ADAM). The VDT functions to simulate the catapult phase of an ejection by generating a positive z-axis (inferior to superior) impact acceleration pulse using a hydraulic decelerator. A test seat and restraint system are mounted to a carriage which moves on vertical guide rails. The carriage and test subject are hoisted to a pre-determined height and then allowed to free-fall. A contoured plunger mounted on the bottom of the carriage is guided into a cylindrical reservoir filled with water. The force generated by the plunger displacing the water produces a vertical deceleration profile. The VDT impact profile (magnitude of impact and acceleration rise time) is controlled by the height of the drop carriage and the shape of the plunger. The VDT is shown in Figure 1.

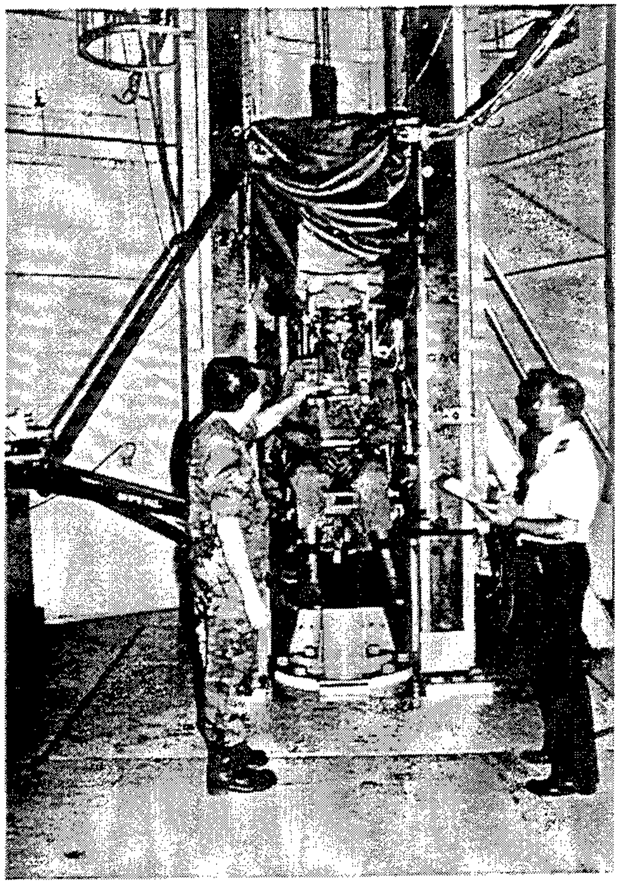


Figure 1. Vertical Deceleration Tower (VDT)

The VDT test seat was configured to mock the Martin Baker seat with the seatback angle positioned 5 degrees forward of vertical, and the headrest positioned 2 inches forward of the seatback plane. A short duration, +Gz impact pulse provided by the VDT was configured to produce a 15G peak pulse in 60 milliseconds and was considered a good approximation of the SJU-5 ejection seat acceleration (Figure 2). Some tests were also conducted at a 0 degree seatback angle, and with the headrest at 0.5 inch and 0 inch forward of the plane of the seatback. Tests were also conducted with and without the 3-D audio system in the helmet. See Table 1 for a complete list of the test conditions. No tests were conducted in Cells F, G, and I due to time constraints.

ADAM was restrained in the VDT carriage seat with the X-31 parachute harness. The harness was interfaced with a Y-yoke behind ADAM's neck to allow measurement of the forces generated by forward displacement of the upper torso. ADAM was restrained in the seat with a standard lap belt configuration also instrumented to measure attatchment point forces. Figures 3 through 7 show ADAM's pre-test positions, and the various seatback and headrest positions.

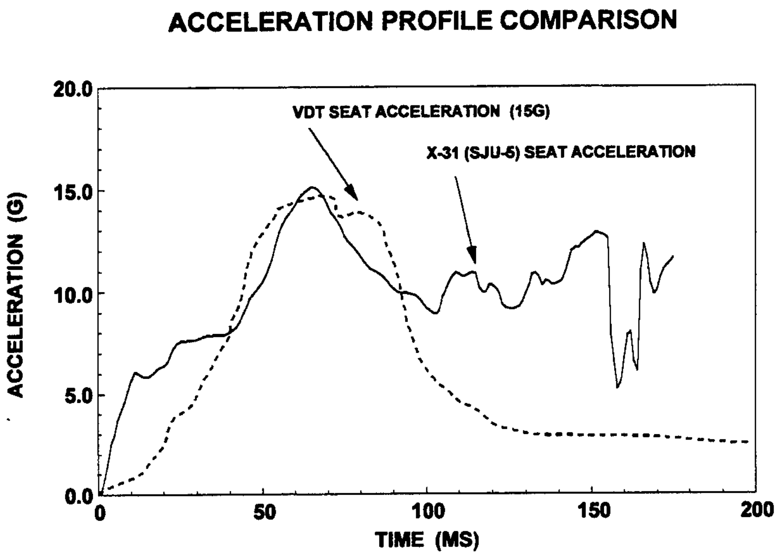


Figure 2. SJU-5 Ejection Seat and VDT Seat Acceleration Profiles

Table 1. Test Matrix for VDT Impact Tests with the X-31 Helmet

TEST CELL	# TESTS	SEATBACK ANGLE	HEADREST POSITION	HELMET SYSTEM
A	3	+5°	+ 2 in.	HGU-55/P
B	3	+5°	+ 2 in.	X-31 w/3-D
C	1	+5°	+ 2 in.	X-31 wo/3-D
D	2	+5°	+ 0.5 in.	HGU-55/P
E	3	+5°	+ 0.5 in.	X-31 w/3-D
F	0	+5°	+ 0.5 in.	X-31 wo/3-D
G	0	0°	0 in.	HGU-55/P
H	1	0°	0 in.	X-31 w/3-D
I	0	0°	0 in.	X-31 wo/3-D

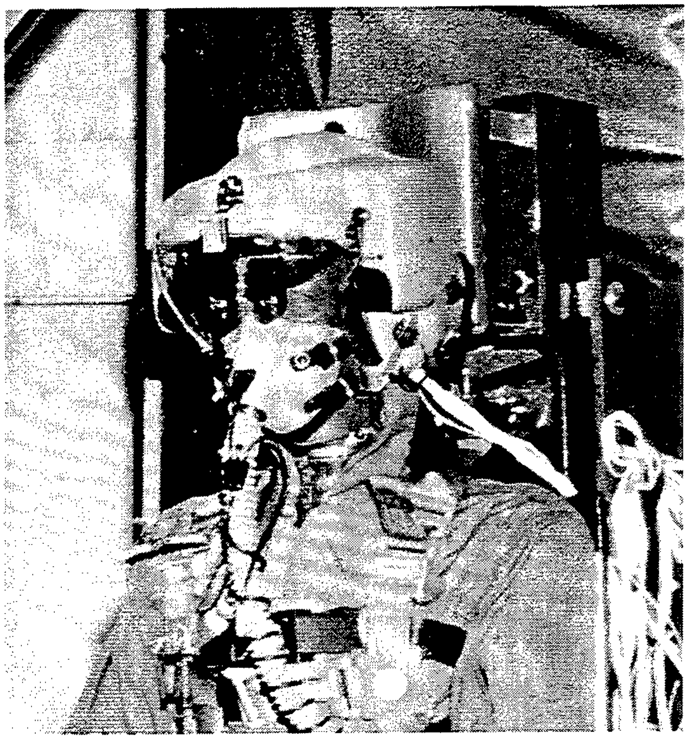


Figure 3. Close-up View of X-31 Helmet on ADAM Manikin

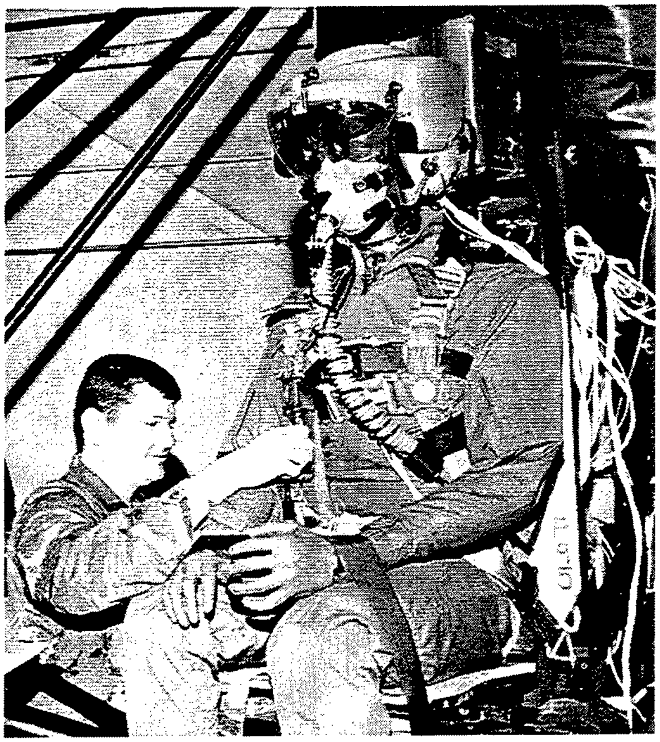


Figure 4. Off-axis View of VDT Test Set-up Showing Manikin Pre-test Position

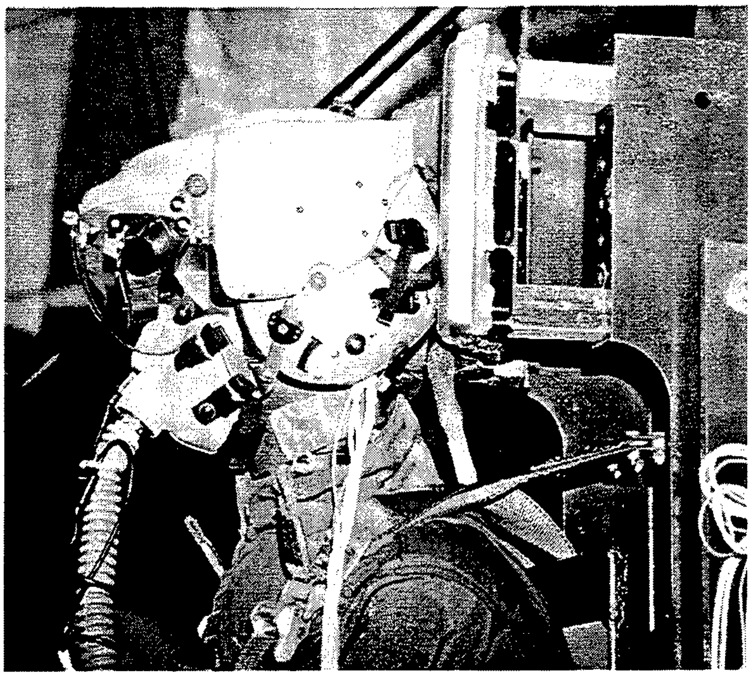


Figure 5. Test Set-up with Seatback at +5° and Headrest at +2 inch

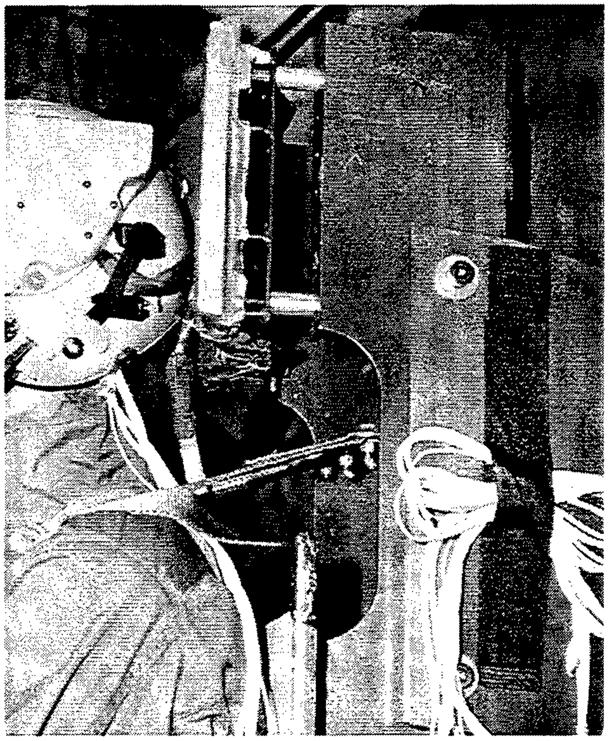


Figure 6. Test Set-up with Seatback at +5° and Headrest at +0.5 inch

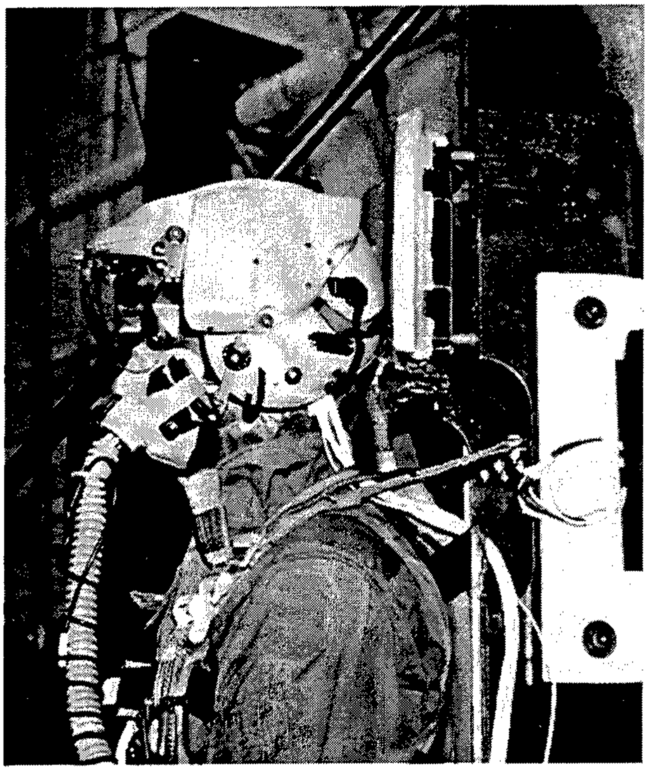


Figure 7. Test Set-up with Seatback at 0° and Headrest at 0 inch

ADAM was instrumented with linear accelerometers and angular rate sensors to collect linear head and chest accelerations and angular head and chest velocities. ADAM's neck was instrumented with a six-axis load cell to measure neck loads and torques in three axes. The compression loads (z-axis) and the shear loads (x-axis) collected by ADAM are a good estimate of the loads that may be experienced by a human subject; however, to optimize the estimate of human M_y neck torque, the following regression equation was used:

$$T_H = 699.2 + \left[\left(-355.5 * Hwt \right) + \left(44.3 * Hwt^2 \right) \right] + \left(1.796 * T_M \right)$$

where T_H is the estimated human M_y torque, Hwt is the helmet weight, and T_M is the M_y torque measured by the ADAM manikin.

Acceleration and velocity of the drop carriage, ADAM accelerations and loads, and force measurements in the seat and the restraint system were collected by a data acquisition system mounted on the VDT carriage. The tests were documented by an onboard Kodak high-speed video system which captured, in detail, the movement of ADAM in the seat during the carriage free-fall and during impact.

RESULTS

The specific objective of the tests was to evaluate the biodynamic response of the ADAM head and neck to impact when the head was encumbered by the X-31 helmet system. The evaluation included analysis of the helmet's inertial properties and the loads generated in the neck during impact. A summary of the inertial properties is shown in Table 2. The weight of the helmets includes an MBU-12/P oxygen mask and approximately 3 inches of hose. The center of gravity data include the ADAM headform and are relative to the anatomical coordinate system. A summary of the impact data along with the estimated human torque is shown in Table 3.

The X-31 helmet is a heavy helmet at 6.3 lb with a mask, and 6.8 lb including the 3-D audio earcups. Its weight is similar to the I-NIGHTS night vision and visual display helmet (6.7 lb); however, this weight is almost twice the baseline HGU-55/P helmet (3.4 lb). The center-of-gravity (Cg) of the X-31 helmet is much improved over the I-NIGHTS helmet because it has decreased the x-axis component by approximately 0.3 inch. Relative to the Interim Head/Neck Criteria, the helmet is heavier than that recommended by the criteria (maximum of 5 lb), but the Cg for both systems (with and without the 3-D audio earcups) is toward the center of the criteria box. The Interim Head/Neck Criteria outlines inertial property limits for head-mounted systems for the catapult phase of ejection.

Table 2. Head and Helmet Inertial Properties

HEADFORM AND HELMET IDENTIFICATION	HELMET SYSTEM WEIGHT (lb)	ADAM HEADFORM & HELMET WEIGHT (lb)	CENTER OF GRAVITY (in.)
Large Human Head		9.70	-0.28, 0.00, 1.32
Large ADAM Head		8.93	-0.32, -0.03, 1.01
ADAM + HGU-55/P	3.24	12.17	-0.15, -0.01, 0.99
ADAM + GEC I-NIGHTS	6.35	15.28	0.32, 0.00, 1.31
ADAM + X-31 Helmet with Standard Earcups	6.24	15.17	-0.07, 0.10, 1.30
ADAM + X-31 Helmet with 3-D Audio Earcups	6.79	15.72	-0.07, -0.03, 1.19

Table 3. VDT Impact Data Summary

TEST CELL	ADAM Z-AXIS NECK LOAD (lb)	ADAM X-AXIS NECK LOAD (lb)	ADAM M_y NECK TORQUE (in-lb)	HUMAN M_y NECK TORQUE (in-lb)
A	282 ± 4	124 ± 14	309 ± 20	551
B	386 ± 21	152 ± 10	426 ± 14	1093
C	390	139	349	832
D	308	114	306	546
E	414 ± 13	126 ± 5	380 ± 6	1010
F	—	—	—	—
G*	*346 ±8*	*95 ±8*	*214 ±11*	*380*
H	413	76	287	725
I	—	—	—	—

* *Note: Test data in Cell G are from previous test program.*

Figure 8 provides a brief overview of the center-of-gravity results along with the criteria box which represents the limits for the Cg location. For a frame of reference for the graph, the graph's origin is located at the tragion (ear notch) with the positive z-axis directed toward the top of the head, and the positive x-axis toward the eyes.

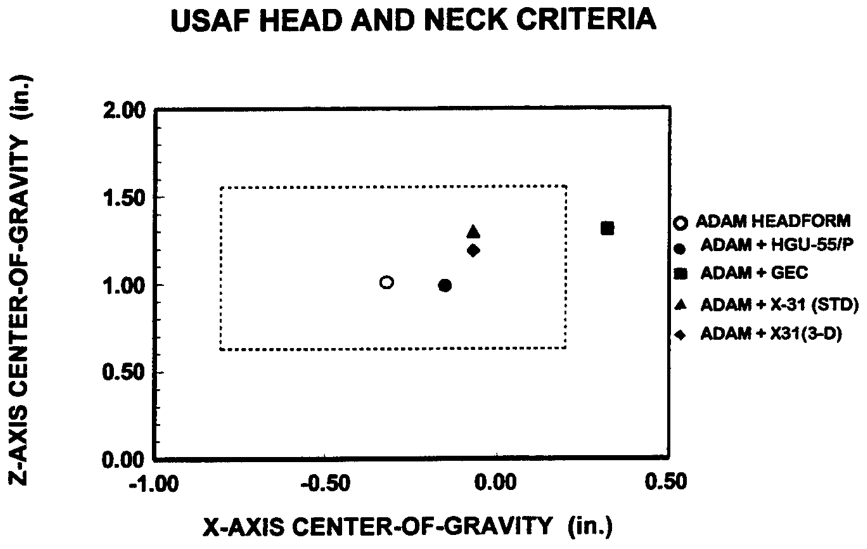


Figure 8. ADAM/Helmet Center-of-Gravity Relative to Interim Criteria

When compared to the HGU-55/P baseline helmet, the X-31 helmet with and without the 3-D audio system generated greater compression loads (z-axis), shear loads (x-axis) and torques (M_y) with the seatback at +5 degrees and the headrest at +2.0 inches. When the headrest was repositioned at +0.5 inch, the X-31 helmet with the 3-D audio (helmet without 3-D audio was not tested) still generated greater loads than the baseline helmet; however, the compression loads were slightly greater, and the torques slightly less than those at the +2.0 inch headrest position. This was due to the fact that at +2.0 inch, the more forward position induces more head rotation and less compression, but at +0.5 inch, the position generates greater compression loads but slightly lower torques. In both cases however, the estimated human torques with the baseline helmet were approximately half those of the X-31 helmets (approximately 550 in-lb. as compared to approximately 1050 in-lb.). When the VDT seat was reconfigured to 0 degrees seatback angle and 0.0 inch headrest position (approximation of an ACES II seat), the estimated human neck torque decreased further, but at the same time the z-axis compression loads increased. Again, this is due to the decrease in the head forward position. In all cases, the x-axis shear loads did not appreciably change.

A comparative type analysis was conducted between the X-31 helmet and the baseline helmet, and between the X-31 helmet, the GEC I-NIGHTS helmet, and a set of maximum load criteria. The GEC I-NIGHTS helmet was used in the comparison because of its similarity to the X-31 helmet, and because it successfully completed flight certification for the AFTI/F-16 flight test program (an ACES II ejection seat was used for the AFTI/F-16). All helmet data were compared to maximum load criteria as defined by Mertz and Patrick. The load criteria as referenced to the occipital condyle (head/neck attachment point) are as follows: (1) maximum neck compression, z-axis = 400 lb, (2) maximum neck shear load, x-axis = 450 lb, and (3) maximum neck torque, M_y = 1700 in-lb. These data were derived from cadaver tests conducted by Mertz and Patrick and represent an estimate of the tolerable load at the occipital condyle beyond which bone fracture or ligament damage would occur.

In a 15G test conducted with the GEC I-NIGHTS helmet at 0 degree seatback angle and 0 inch headrest position, the helmet on an ADAM generated approximate loads as follows: neck compression = 489 lb, neck shear = 96 lb, and an estimated human neck torque of 688 in-lb. When compared to the data in test cells G and H, the GEC I-NIGHTS helmet is very similar to the X-31 helmet with the 3-D audio earcups, and both generated data greater than the baseline helmet. The compression loads for the X-31 and the I-NIGHTS helmets are greater than the estimated maximum load (400 lb). When the seatback and headrest are adjusted forward (Cells A, B, C), the X-31 helmet generates similar compression loads but approximately 40% greater torques when compared to its values at 0 degree seatback and 0 inch headrest position. When compared to the baseline helmet in Cell A, the compression load is 30% higher and the estimated human torque is 100% higher. The compression load for the X-31 helmet is very close to the maximum limit. The estimated human torque in all the cells is less than the maximum of 1700 in-lb; however, the X-31 helmet in the Martin Baker configuration generates torques (1093 in-lb) approximately 40% greater than the I-

NIGHTS helmet in an ACES II configuration. Even though this is less than 1700 in-lb maximum, severe soft tissue damage may begin to occur in this range. This is supported by the fact that in a current AL/CFBE study with varying helmet weight, there is presently an 8% minor injury rate to the neck and upper thoracic spine with helmet weights greater than 6 lb which produced estimated neck torques of between 500 and 700 in-lb. Below 6 lb, there have been no reported injuries.

CONCLUSION

The X-31 helmet is a heavy helmet (6.8 lb) with a Cg that is close to the Cg of the unencumbered head. The Martin Baker SJU-5 ejection seat positions the body such that the spine is 5 degrees forward of the impact acceleration vector, and the head is approximately 2 inches forward of the seatback plane. Due to this positioning, the helmet induced compression loads equal to the maximum acceptable, and torques that are below the maximum but that are twice that produced by the HGU-55/P. These torques could produce severe soft tissue damage, and have a high potential of producing neck strains.

BIBLIOGRAPHY

1. Brinkley, J.W. and Schaffer J.T. Dynamic Simulation Techniques for the Design of Escape Systems: Current Applications and Future Air Force Requirements. AFAMRL-TR-71-29, 1971.

2. Melvin, J.W. Human Neck Injury Tolerance. Society of Automotive Engineers (SAE 790136), 1979.

3. Mertz, H.J. and Patrick, L.M. Strength and Response of the Human Neck. Proceedings of the Fifteenth Stapp Car Crash Conference, Society of Automotive Engineers 710855, 1971.

4. Perry, C.E. Evaluation of the Effects of Visually Coupled Systems on the Biodynamic Response to Simulated Ejection Accelerations. AL/CF-TR-1993-0159.

5. Weiss, M.S. and Lustick, L.S. Guidelines for Safe Human Exposure to Impact Acceleration. Naval Biodynamics Laboratory Research Report No. NBDL86R006, 1986.