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BODY DISPLACEMENT MEASURED DURING SUSTAINED +GZ, -GZ, and ±GY ACCELERATION USING A STEREOSCOPIC PHOTOGRAPHIC SYSTEM

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NOTICES

TECHNICAL REVIEW AND APPROVAL

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

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 COMMANDER

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Pilot performance may be adversely affected by G-induced body displacement. Controls may be difficult to reach and activate. The use of a head-up-display may be rendered ineffective by excessive head movement. Also, measurement of body displacement can be useful in evaluating restraint systems. A technique has been devised to quantify body displacement during acceleration studies conducted on the Dynamic Environment Simulator (DES), a three axis centrifuge A stereoscopic photographic system consisting of two motorized 35 mm SLR cameras, a microprocessor controller, and displays were used. Reference marks defining the DES cab in 3 dimensions (3-D) and targets on the subject are recorded photographically. The film strips were then processed on an x-y plotter to digitize the target information. From these data, calculations were performed to compute the 3-D coordinates of the points of interest. Data collected when using the stereoscopic photographic systems are presented on eye and shoulder displacements during various acceleration and restraint conditions. Eye displacements of 3.95 cm at +4.0 Gz, 4.79 cm at -1.0 Gz, and 10.16 cm at 2 Gy are reported. Improving the

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restraint system by adding lateral shoulder supports reduced the eye displacement at 2 Gy to 3.96 cm (61%). The average lateral restraining force exerted on the shoulder pads at 2 Gy was 55.8 Kg (123 lbs).

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PREFACE AND ACKNOWLEDGMENTS

This report documents an in-house experiment conducted on the Dynamic Environment Simulator (DES) at the Acceleration Effects Branch, Biodynamics and Bioengineering Division, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The effort was conducted under work unit 72313501 in cooperation with AAMRL/HEG. The photographic system described in the report was developed under contract by the University of Dayton Research Institute, Dayton, Ohio. The authors extend their appreciation to Diana Coddington and Vanessa Deer for typing the manuscript and to Van Thai for his assistance with the mathematical equations and computer solutions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Pilots of high performance aircraft require a wide variety of body restraint conditions. During most flight conditions the crewmembers desire a high level of mobility in order to activate controls, reach switches, and check rear vision. During some flight environments, however, such as buffet, outside loops, or out-of-control conditions a high level of restraint is necessary. Pilot performance may be degraded by involuntary G-induced body displacement in the cockpit. The forces generated by these types of flight maneuvers may significantly decrease the pilot's ability to control the aircraft or even initiate ejection procedures. Pilots have reported contacting the canopy during -Gz maneuvers (4). Centrifuge studies with human subjects using typical military restraints have been conducted and measurements of 3.8 cm displacement off the seat pan (4) and 12 cm of helmet rise at -2.0 Gz have been documented (5). The measurement of displacement can be a useful quantitative tool in evaluating restraint systems. The use of a head-up-display (HUD) may be rendered ineffective by lateral or vertical head motion of greater than 12.7 cm. A data base relating head and eye positions to acceleration levels would be helpful to cockpit designers. This report describes a photographic system that has been used to measure body displacement on the Dynamic Environment Simulator (DES), a three axis man-rated centrifuge located at Wright-Patterson AFB, OH. Data from various acceleration environments are also presented.

METHODS

Photographic System

A stereoscopic photographic system consisting of two motorized 35 mm single lens reflex (SLR) cameras, two light emitting diode (LED) digital display units, three accelerometers, and a microprocessor controller was used. The cameras (Canon A-1 with 50 mm lens) were mounted in the DES cab in the horizontal plane with a separation angle of approximately 90°. The field of view of each camera included the subject's head, upper torso, and a digital display unit containing X,Y, and Z accelerometer values, film frame counter, date, and subject's name. Reference targets were installed to define the geometry of the DES cab. A minimum of eight targets was used, three of which were required to be in the field of view of both cameras. Also, targets to track body displacement were placed on the subjects. Typical target placements included the shoulders and helmet. The eyes were also used as targets. A subject in the DES cab and reference targets are shown in Figure 1. Figure 2 presents a block diagram and picture of the photographic system. The system can be operated in either an automatic or manual mode. In the automatic mode the microprocessor is programmed to activate the cameras with each acceleration level change of ±0.5 Gx, 0.5 Gy, or 1.0 Gz. The cameras may also be operated manually by personnel in the monitoring room. ASA 400 color slide film was used in this application. The light level in the DES cab was sufficient so that no additional flash lighting was required. The exposed film was processed and left in strip form.

Digitizer

Each target location was manually measured using an X,Y filmstrip digitizer. This unit consists of a 35 mm projector, 50.8 x 50.8 cm rear projection screen, movable X,Y cursor, keyboard, and a paper tape punch unit. As each frame is projected onto the viewing screen, the movable cursor is positioned over each reference target and points of interest on the subject. The vertical (X) and horizontal (Y) coordinates of each location are then punched on eight channel, one inch paper tape. The subject number, date, film frame number, and X,Y, and Z acceleration levels were entered via the keyboard. After the filmstrip data have been encoded onto paper tape, it is transferred to a 9-track magnetic tape for computer processing. An analysis program reads the horizontal and vertical coordinates and computes the 3-D coordinates (X,Y,Z) of the points of interest. Measurement errors with the systems were found to be less than 3%.

RESULTS

Filmstrips have been taken to provide body displacement data during several experiments conducted on the DES. The primary objectives of those experiments were to measure performance or physiological parameters and are reported separately by others. The displacement measurements quantified by the photographic system are documented in this report.

Experimental setup 1 consisted of a modified Stencel aircraft seat with adjustable lap belt and double shoulder straps (4.4 cm wide). The seat back angle (SBA) was 30° from the vertical. Experiments using this setup are reported by Frazier (1), Guthrie (2), Popplow (6), Repperger (7), and Van Patten (9). Results from this setup are reported in Table I.

TABLE I - DISPLACEMENT DATA COMPILED BY GUTHRIE (2)

	Displacement (cm)		
G	Eye	Helmet	N
-1 Gz	4.79	5.84	12
+1 Gz	0	0	12
+2 Gz	2.43	2.85	12
+3 Gz	2.04	2.67	12
+4 Gz	3.04	3.43	12
+5 Gz	3.43	3.87	12
-2 Gy	7.16	9.19	6
-1 Gy	3.48	4.83	12
+1 Gy	4.87	6.12	12
+2 Gy	6.61	8.45	6

Restraining forces during +Gy acceleration have been measured by instrumenting the left shoulder pad support with a load cell (1). Additional data were subsequently collected by also installing an instrumented head support (Fig. 3). The data are presented in Table II.

TABLE II - LATERAL FORCES (KILOGRAMS)

Gy	Gz	Shoulder Pad (kg) Mean ± s.d.	Helmet Pad (kg)	N
1.0	0	28.6 ± 9.0	--	8
1.5	1.0	37.6 ± 8.6	--	8
1.5	2.0	30.4 ± 9.0	--	8
2.0	1.0	55.8 ± 12.7	--	8
2.0	2.0	47.2 ± 14.5	--	8
2.5	1.0	66.2 ± 18.1	--	8
2.5	2.0	60.4 ± 11.8	--	8
1.5	1.0	33.0	9.0	4
1.5	3.0	28.5	7.0	4
1.5	5.0	27.8	8.1	4
2.0	1.0	44.8	12.1	4
2.0	5.0	32.6	11.4	4

Experimental setup 2 consisted of a rebuilt ACES II seat, SBA of 30°, lap belt, and PCU-15/P torso harness with the inertia reel locked (Figure 4). Additional lateral support was provided by shoulder pads during half of the runs. The shoulder pads were 10 cm x 15.2 cm and were individually adjusted for each subject to provide lateral support at the upper humerus. They were padded with high density foam rubber (1.9 cm thick). The performance and physiological results are reported by Stewart (8). The displacement data are reported in Table III.

TABLE III - DISPLACEMENT DATA IN THE ACES II SEAT

	Mean Displacement (cm) ± Standard Deviation			
	Standard Restraint		Shoulder Pads	
	Eye	Shoulder	Eye	Shoulder
2 Gy	10.16 ±3.55	9.05 ±2.29	3.96 ±1.96	4.08 ±0.40
4 Gz	3.95 ±2.30	1.70 ±0.77	----	----

Displacements at Gy are in the lateral axis and in the vertical axis for Gz.

DISCUSSION

+Gz Acceleration

The acceleration environment most commonly encountered by the aircrew member is in the +Gz direction. In our experiments the highest G levels were attained and the least eye displacement occurred during +Gz. The seat provides good support in this direction. Compression of the seat pan cushion and subject's spinal column and torso would constitute components contributing to eye displacement during +Gz. During these studies the subjects were instructed and able to maintain an upright posture. It is possible, however, during high Gz maneuvers for a crewmember to become slumped over and unable to regain an upright position until the G force is decreased. The initial slumping could occur voluntarily or be induced by factors such as asymmetrical helmet loading or off-axis G force components.

The data by Guthrie (2) records an average eye displacement of 3.43 cm at 5 Gz (Table 1 & Figure 5). At 2.0 Gz, 70% of that displacement was reached, perhaps as the initial compression of the torso and seat cushion occurred. Vertical helmet displacement was always greater than eye displacement. The average difference was 0.47 cm, with little additional change occurring between 2.0 and 5.0 Gz. The data compare favorably with Kennedy (3) who reported up to 5.5 cm of eye displacement at 6.0 Gz. That study attributed 17% of the eye displacement to head pitch down and 83% to the slump of the subject.

-Gz Acceleration

The lap belt and shoulder harness restrains the crewmember against -Gz forces. The displacement is greater in this direction than in +Gz. Strap material, attachment geometry, tightness of adjustment, area of support, and other factors affect -Gz restraint. Our data were taken only at -1.0 Gz and resulted in an average upward vertical displacement of the eye of 4.79 cm. Lorch (5), using seven different restraint harness configurations, reported a displacement (helmet) range of 5 to 12 cm at -2.0 Gz. Leupp (4) reported buttock displacement off the seat pan of 3.6 cm at -2.0 Gz with human subjects. Off-seat displacement of 3.7 cm at -2.0 Gz and 6.4 cm at -5.0 Gz were also reported by Leupp when a 95 percentile manikin was used.

Gy Acceleration

Most aircraft are not capable of generating significant Gy (lateral) accelerations. Consequently, restraint systems are not designed to provide good lateral support. Mean eye displacement of 10.16 cm was recorded at 2.0 Gy (Table III). This is nearing the exit pupil of the typical HUD (12.7 cm). It was our observation that the subjects exposed to Gy acceleration experienced not only a lateral displacement but also bending of the torso or head-neck and rotation (primarily of the head). The data are for total sideward displacement and do not differentiate between displacement, bending, and rotation. Improving the standard restraint system by adding shoulder pad supports reduced, at the 2 Gy level, mean eye displacement from 10.16 to 3.96 cm (61%) and shoulder displacement from 9.05 to 4.08 cm (55%). Increasing the Gz component decreased the force measured with an instrumented shoulder pad (Table II & Fig. 6) and probably reduced sideward displacement. It was the consensus of our subjects that the standard restraint system was inadequate above 1.5 Gy. Some of our subjects at 2.0 Gy experienced lateral head rotation estimated between 20° and 45°. This high degree of rotation in combination with the helmet and mask profile could obscure the viewing of some forward mounted cockpit instruments and be outside the viewing envelope of a HUD.

CONCLUSIONS

The stereoscopic photographic system was used on the DES to measure eye displacement during a variety of acceleration environments. Eye displacements of 3.95 cm have been measured at +4.0 Gz, 4.79 cm at -1.0 Gz, and 10.16 cm at 2.0 Gy. The system, once installed, is easy to use and non-invasive to the subject. The disadvantage of the system is that large amounts of data are time consuming to reduce. Our current plans are to replace the photographic system with a sonic digitizer system that will provide real time displacement data.

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CAMERA 1 CAMERA 2

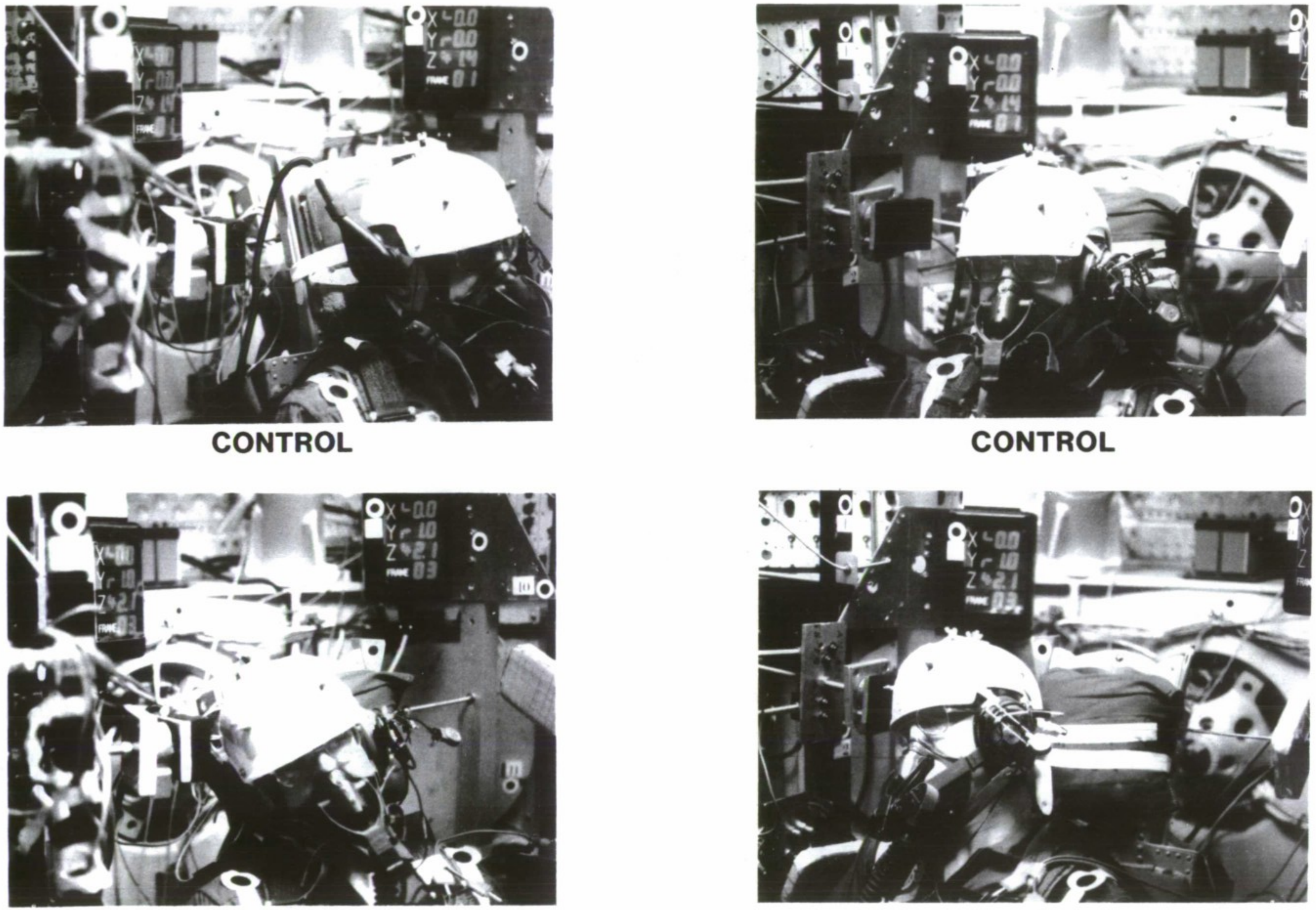
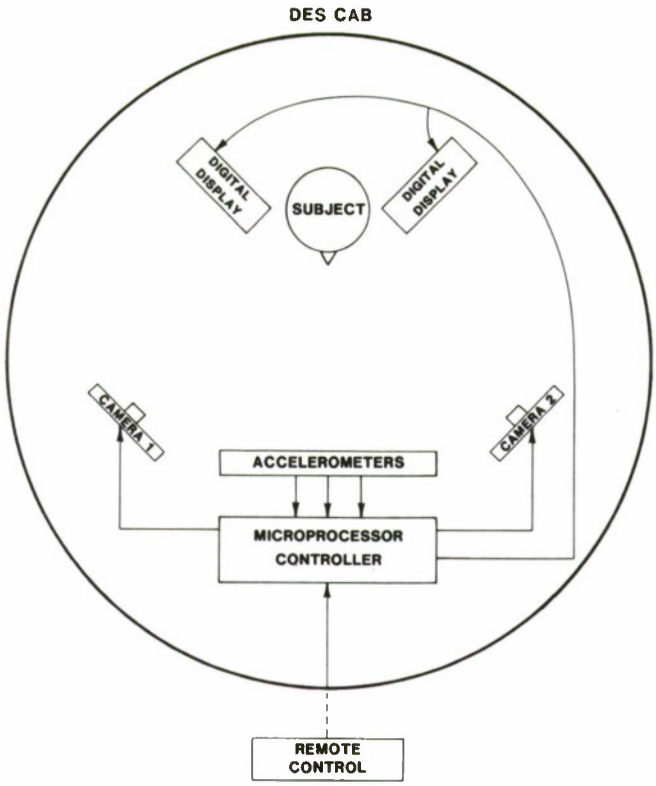
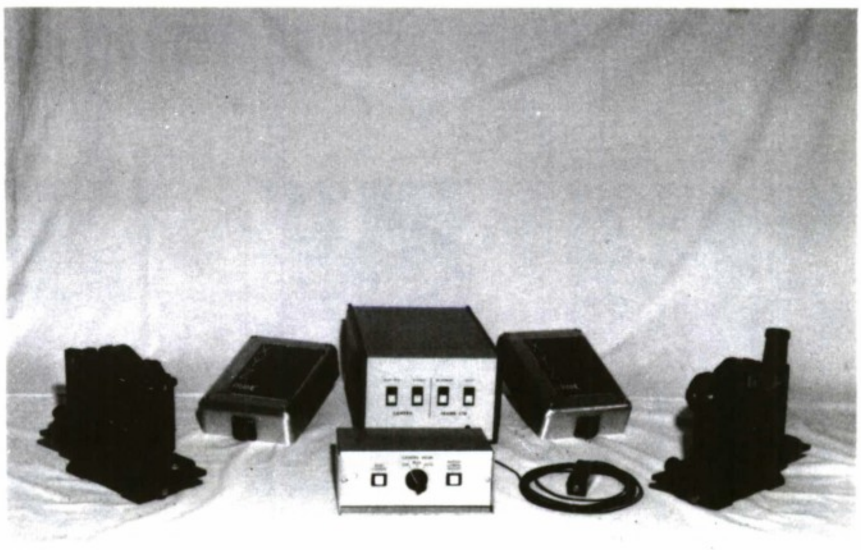


Figure 1. Photos taken by the Stereoscopic Photographic System of a subject on the DES at - Gy.





CAMERAS, CONTROLS, & DISPLAYS

Figure 2. Stereoscopic Photographic System.

Figure 3. Stencel Seat with Instrumented Shoulder Pad and Head Supports to measure +Gy restraining forces.

Figure 4. Subject at −2 Gy in the ACES II Seat.

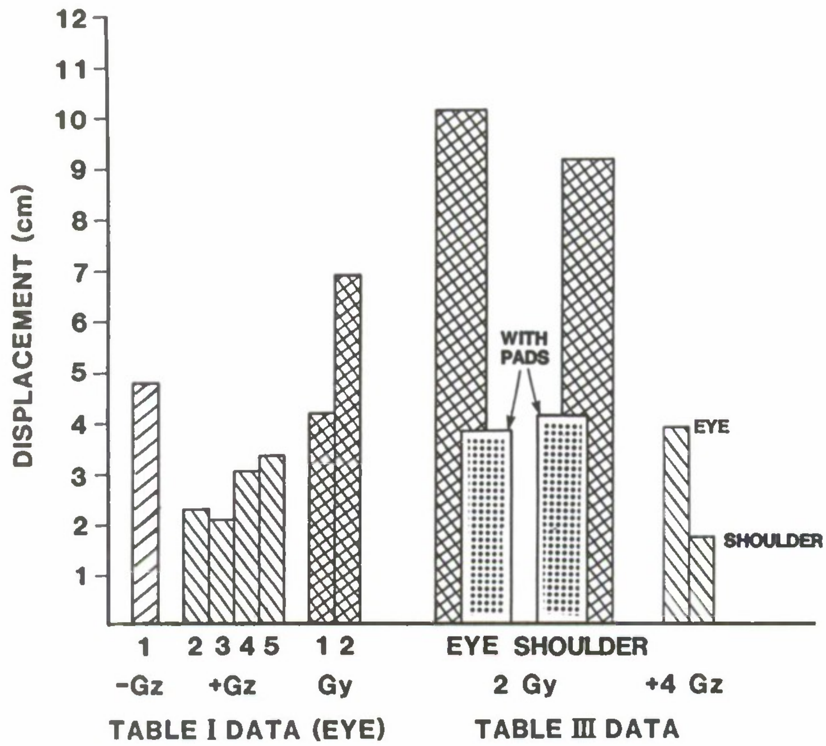


Figure 5. Displacements at various conditions.

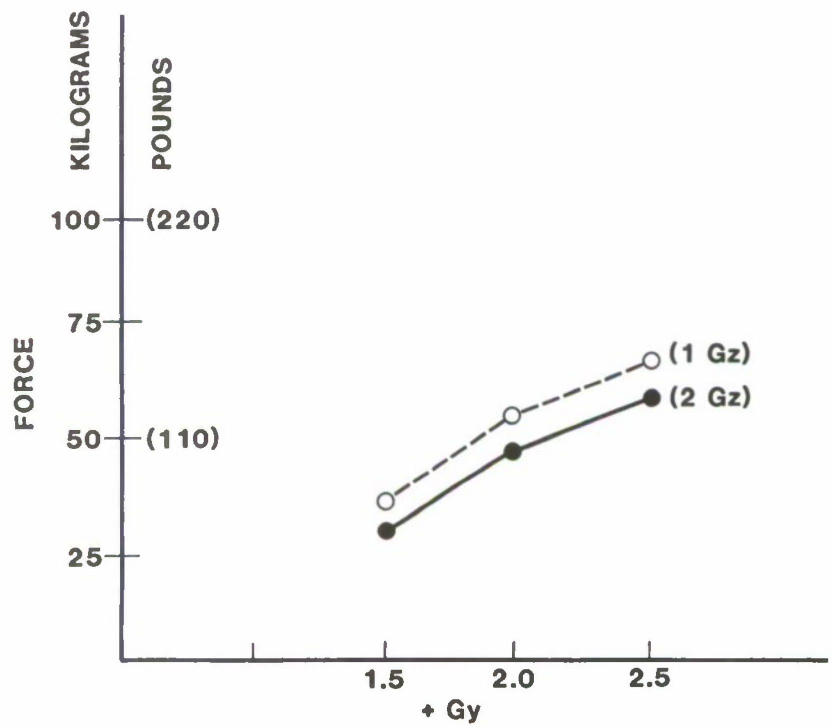


Figure 6. Left shoulder pad forces measured during sustained lateral G (TABLE II).

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