VOLUME 35
NUMBER 12
DECEMBER 1964

Aerospace Medicine

FORMERLY THE JOURNAL OF AVIATION MEDICINE
FOUNDED BY LOUIS H. BAUER, M.D.
Official Publication of the Aerospace Medical Association

Space Cabin Landing Impact Vector Effects on Human Physiology

COLONEL JOHN P. STAPP, USAF, MC, and MAJOR ELLIS R. TAYLOR, USAF, MC

ABSTRACT

Fifty-eight human volunteers in 146 experiments endured impact forces simulating space cabin landing impacts following parachute descent. Impact forces were experienced in 16 body positions in combination of pitch and yaw, and seven configurations of onset (1,000, 1,500 and 2,000 G/sec.), magnitude (10, 15, 20 and 25 G) and durations (60 to 130 milliseconds).

The volunteer subject sat in a seat mounted in three sets of gimbals providing fixation by 10 degree increments in yaw (0° to 360°), pitch (0° to 180°) and roll (0° to 180°), on a sled suspended by 4 slippers between cylindrical rails of 1.524 meters gauge, 36.6 meters in length.

A pneumatic piston propelled the sled through a 13.0 meter stroke to predetermined velocities ranging from 6.1 to 13.7 meters per second, letting the sled coast 23.5 meters to impact on a piston-and-cylinder water inertia brake to penetrations of 43 to 83 centimeters before stopping.

A trailing cable from the sled to recorders in a blockhouse near the track transmitted electrocardiograph, pneumograph, haemo-barograph, electroencephalograph, biceps tendon reflex, handgrip dynamometer, and tri-axial accelerometer data before, during and after impact. Stomach X-rays to indicate gastric motility were taken before and after exposure to impact. During impact 2,000 frames per second motion pictures were taken from overhead, and from right and left profile positions to record body displacements.

All body positions and impact configurations were within voluntary tolerance limits except the forward facing 45° reclining position at 25.4 G measured on the sled with onset of 1,000 G per second and 60 millisecond duration, in which compression of soft tissues around the 6th, 7th, 8th thoracic vertebrae caused pain and stiffness for 60 days.

Bradycardia immediately post impact was triggered by headward impact vectors resulting in hydraulic pressure stimulation of carotid sinuses, dropping heart rate by as much as 90 beats per minute for 10-30 seconds.

Gastric motility changes related to pitch or yaw angles of 40° or more from the line of motion. No significant changes in blood or urine were recorded.

Head fixation, automatic retraction of harness before impact, and energy attenuation to keep impact force below 20 G magnitudes and above 60 millisecond pulse duration are recommended.

The animals used in this study were handled in accordance with the "Principles of Laboratory Animal Care" established by the National Society of Medical Research.

THE 148 EXPERIMENTS reported here were performed at Holloman Air Force Base, New Mexico, between 13 May and 7 November 1963, under a contract with the Crew Systems Division of the National Aeronautics and Space Administration to investigate human tolerance to impacts resulting from probable descent velocities and angles of impingement anticipated for Apollo capsule landings. A total of 146 experiments were accomplished with 58 human volunteers, and 2 with anesthetized black bears to find persistent injury limits in the body orientation in which human subjects were vulnerable.

Tolerance of human volunteers to deceleration of a rocket propelled sled on rails from aircraft crash velocity of 70 meters per second to 30 or less meters per second in 5.5 to 11.0 meters of mechanical friction brakes during 130 to 350 milliseconds was investigated by Stapp.[21, 22] Maximum exposure in the forward facing seated position to 46.2 G at 493 G per second during 228 milliseconds, produced bilateral superficial venular retinal hemorrhages and mild physiological shock; more severe shock without hemorrhages occurred with exposure to 38.6 G at 1360 G per second onset during 130 milliseconds. In the backward facing seated position tolerance was not exceeded with 36 G at 1000 G per second onset in 160 milliseconds. In either orientation, shock manifested by drop in blood pressure, decrease in pulse rate, shallow, rapid respiration and pallor occurred on exposure to more than 30 G, above 1000 G per second with recuperation time of about five minutes. The primary factor relating to shock signs in these experiments was rate of onset of impact.

Beeding,[2] reports severe shock and repeated syncope, with myalgia requiring 5 days hospitalization following exposure to 40 G at 2139 G per second during deceleration from 14.78 meters per second to a stop in less than 30 centimeters and in 40 milliseconds, sustained in the backward facing seated position. Adverse physiological reaction correlates with diminishing onset and duration of impact in the magnitude of 40 G. Evident voluntary tolerance limits for backward facing seated and bottom forward supine seated subjects in Beeding's experiments occurred for exposures ranging between 25 to 40 G at onsets of 1034 to 2139 G per second for duration of 23.8 to 40.4 milliseconds. Stopping distances were 75 centimeters or less from velocities below 15 meters per second. An earlier version of the sled and water inertia brake described under "Apparatus and Methods" in this report was used by Beeding.

Lombard, *et al.*[14] report voluntary tolerance to hammer blows against the back of the helmet protected head up to 36 G, which resulted in persistent, severe headaches.

Swearingen,[24] using himself as a subject in standing

TABLE I. HUMAN SUBJECT DATA

Subject	Age	Height (Cms)	Weight (Kgs)	Sitting Height (Cms)	Total Runs	Runs This Series No.
BNS	32	181.61	72.58	91.69	28	1399
DAP	30	175.26	74.84	90.93	9	1400
SJR	42	172.72	70.76	——	10	1403
RCJ	27	182.25	91.63	95.25	12	1441
RDM	23	167.64	76.66	87.63	6	1443
EPV	26	187.96	92.99	96.52	11	1475
CDE	25	170.18	82.56	89.92	12	1409, 1487
CEW	20	179.07	72.58	93.73	13	1499
YBF	24	172.72	94.80	90.42	2	1512
EMF	32	176.53	81.65	90.17	11	1477, 1534
RMB	30	179.07	75.75	88.90	6	1461, 1537
WHS	30	182.25	85.73	88.90	6	1473, 1549
JCM	22	177.80	74.84	88.14	3	1505, 1554
JCT	29	177.80	76.66	90.17	23	1442, 1559
MDH	21	177.80	76.20	91.19	16	1420, 1462, 1564
JTB	30	177.80	79.83	89.66	7	1470, 1565
BLC	32	182.88	81.65	95.00	12	1406, 1472, 1571
GAG	25	177.80	79.83	91.95	11	1488, 1572
CWH	23	182.88	68.95	93.47	3	1507, 1580
RJG	24	172.72	61.69	92.71	22	1551, 1585
RWD	26	167.64	74.84	90.68	16	1516, 1552, 1586
JWE	20	180.34	67.59	93.47	8	1465, 1541, 1588
LMS	22	179.07	68.95	90.42	1	1624
CRM	32	179.07	76.21	91.19	1	1625
RJB	30	177.80	81.19	90.93	8	1398, 1440, 1532, 1626
GTB	25	190.50	80.74	94.49	10	1417, 1489, 1566, 1627
DSB	25	180.34	73.48	89.66	31	1457, 1504, 1544, 1632
GVA	25	170.18	53.98	88.65	1	1633
WCC	26	170.18	88.00	87.12	14	1410, 1467, 1502, 1581, 1634
JDT	30	180.34	74.84	95.76	1	1635
DAC	28	177.80	71.22	92.71	1	1637
ERS	23	175.26	75.30	90.93	4	1511, 1573, 1638
BDN	22	175.26	62.60	91.19	1	1639
TSG	39	180.34	80.29	——	4	1531, 1640
TWM	26	173.99	72.58	90.68	8	1408, 1456, 1501, 1545, 1583, 1641
GWC	19	172.72	80.29	——	4	1506, 1579, 1644
WHT	22	172.72	72.19	90.42	17	1460, 1593, 1645
FJC	23	179.07	78.93	91.19	13	1478, 1535, 1587, 1646
CGO	27	182.88	73.94	95.00	1	1647
RJS	20	180.34	59.88	90.93	16	1438, 1540, 1591
KDH	31	185.42	94.80	92.20	15	1471, 1542, 1592
CAR	21	177.80	73.48	91.69	17	1436, 1484, 1548, 1594
JHS	41	176.53	66.68	84.33	14	1404, 1485, 1550, 1596
JLP	20	179.07	76.66	89.92	3	1515, 1597
SM	21	167.64	58.51	84.58	14	1466, 1536, 1598
WG	35	165.10	60.78	84.07	16	1463, 1539, 1599
WG	38	175.26	77.11	89.15	5	1401, 1608
TKC	19	180.34	69.85	94.23	4	1514, 1555, 1609
JOE	23	181.61	83.01	91.19	3	1560, 1610
GAR	25	185.42	92.99	92.71	12	1405, 1468, 1567, 1611
WLB	23	184.15	68.04	96.27	17	1490, 1547, 1613
JPW	30	182.88	81.19	91.95	16	1419, 1476, 1614, 1561
WMC	18	172.72	52.16	88.65	4	1510, 1556, 1615
DMA	27	167.64	59.42	83.31	4	1500, 1562, 1616
SHB	26	170.18	53.07	84.58	15	1411, 1437, 1517, 1619
GOS	22	167.64	66.68	86.61	4	1509, 1557, 1620
JMP	21	180.34	63.50	90.68	10	1435, 1482, 1578, 1621
JRB	22	177.80	54.89	89.15	8	1418, 1483, 1574, 1622

drop tests with knees stiffened, from heights of less than 1.5 meters, sustained lumbar intervertebral injury which became chronic.

Holcomb,[9, 10, 11, 12] reported a third thoracic vertebral fracture from simultaneous flexion and compression by transverse and axial vectors of impact resulting from drop testing an escape capsule off the back of a moving truck onto hard ground, with forces exceeding 43 G at 1200 G per second during 50 milliseconds.

The Mercury Capsule was drop tested by Headley, *et al.*[8] to evaluate the webbing restraints, the energy absorbing polyurethane couch liner, and to develop the crushable aluminum honeycomb couch support strucure. Energy attenuation of four or five fold to less than 20 G measured on the human volunteer was achieved.

Weis, *et al.*[33] exposed 20 different volunteer subjects in 75 experiments to six different impact configurations in seven different body orientations of pitch and yaw, by means of an omnidirectional carriage in a vertical drop tower decelerating with a water inertia-piston and cylinder brake. Drop velocities at brake entry ranged from 4.82 to 8.47 meters/sec., peak G from 13.5 to 26.6, onset from 386 to 1380 G/sec., and durations from 56 to 75 milliseconds. The positions varied by 45° increments in pitch and yaw. Mercury helmet and Dacron restrainst were identical with those supplied by NASA for the series of experiments in this report. Neither the subjective reports nor clinical findings indicated that tolerance end point had been reached in Weis' series. Four instances of minimal transient electrocardiogram changes were noted, including one bradycardia dropping from 116 to 36 beats per minute and return within ten seconds post-impact, and three instances of premature ventricular contractions.

Taylor, *et al.*[25, 26, 27, 28, 29, 30, 31, 32] in a long series of human and bear and chimpanzee exposures to impact, using the same apparatus described for the experiments of this report, observed relative bradycardia in subjects exposed to more than 25 peak G in various body orientations, and on the abolishment of this vagus reflex response by atropine injected subcutaneously before exposure to impact. In subjects exposed to more than 25 peak G at more than 1000 G/sec., Taylor reported thrombocytopenia with 30 per cent or more decrease in blood platelet count following impact.

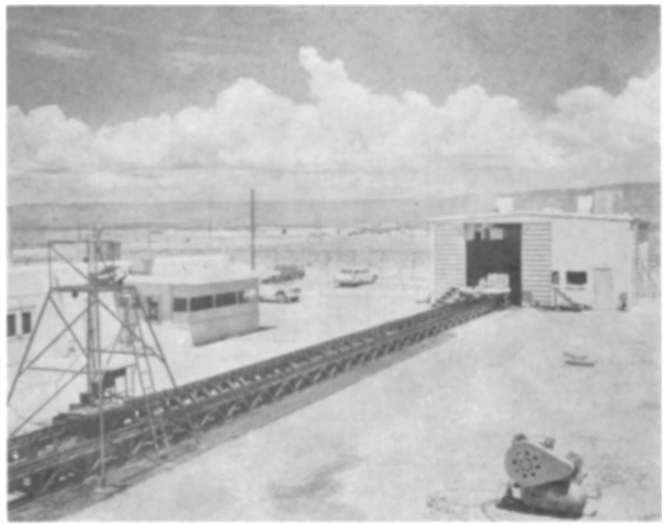

Fig. 1. The Daisy decelerator. This view shows the facility from the midpoint of the track towards the breech end. The airgun accelerator is housed in the building to the right. The tower to the left of the picture provides a firm stand for high speed overhead cameras, and is located over the waterbrake number 1, here mounted at the track midpoint. Instrumentat on and fire control buildings are in the background.

Fig. 2. Omni-directional sled. Horizonal ring, 3.05 meters in diameter, with bolt holes for 10° increments of yaw positioning of cradle, suspended between gimbals providing for 10° increments of positioning in roll; contained between gimbals in the cradle is the seat, locked in pitch position 45°, tipped back from vertical, or 0° pitch. Trailing cable in lower right corner of picture links sled instrumentation to recording station in upper right.

APPARATUS AND METHODS

The Daisy Decelerator consists of an omnidirectional test sled sliding on two horizontal rails, which is propelled by a pneumatically powered piston having a 13.0 meter stroke to predetermined velocities between 2 and 47.0 meters per second; thereafter coasting into a water inertia brake, providing stopping distances of 5 to 125 centimeters. The brake consists of cylindrical probe 138 centimeters long and 15.24 centimeters in diameter extending horizontally forward from the front structure of the sled, which enters a corresponding cylinder, retaining water behind a frangible plastic disk. The probe compresses the water and sled motion is retarded by inertia of the water compressed out of holes through the block to the cylinder. The 135 sets of holes through the upper half of the block to the cylinder can be occluded or choked to modulate deceleration. Impact configuration depends on sled velocity, brake pattern and orientation of the subject. The sled suspends the seat containing the subject within three pairs of concentric gimbals at right angles to each other, permitting orientation of the seat in any radius of a hemisphere determined by 10° increments of pitch, roll and yaw in which respective gimbals could be locked.

Subjects:—The 58 volunteer human subjects ranged in age from 18 to 42 years, in weight from 52.16 to 94.80 kilograms, and in height from 165.10 to 190.50

centimeters and were representative of astronaut somatotype percentile range of distribution. Thorough psychological, psychiatric and clinical examinations were given to select the fit, who were then indoctrinated on a portable, rubber-elastic powered decelerator set at about 15 G deceleration peak. (See Table I).

PROCEDURES

The subject reported without breakfast for physical examination and clinical laboratory tests one hour preceding the experiment. These included oral temperature, pulse, respiration, blood pressure, auscultation, body weight, and significant observations. Blood and urine standard morphology and chemistry were done, including blood platelet counts and a few acid phosphatase blood levels; all tests were repeated post run and 24 hours after exposure. In addition, electrocardiogram, electroencephalogram, biceps reflex time, individual hand grip and two-handed pull on a strain gauge dynamometer and pre- and post-run X-rays of gastric motility, using 100 cc's of barium suspension to visualize it, were recorded before and after impact. Following exposure to impact, the subject returned to the examining room for clinical, laboratory and physical examinations.

Prior to exposing human subjects, a test run of each experimental impact configuration was accomplished on a 95th percentile size-weight anthropomorphic dummy. Seated in the sled seat, the dummy was restrained with same 2,000 kilogram tensile strength 5 cm. width dacron webbing harness used for human experiments (Fig. 3). Shoulder straps converged at the chest belt buckle, diverging to the attachment points of the seat belt. Other straps passed over each mid-thigh and over the ankles at the foot rests. A triaxial accelerometer mounted on the chest of the dummy, and one mounted on the seat back recorded via trailing cable leads to oscillographs and tape recorders in the blockhouse.

Fig. 3. Helmet and Restraints. Subject in firing position, wearing Mercury helmet attached to neck ring on Nylon vest, anchored to strap passing under the crotch. Apollo Dacron webbing restraint harness with shoulder straps, chest belt, seat belt, thigh straps, ankle straps and hand holds. Between feet and at right, instrumentation leads to trailing cable.

Duplicate runs with human subjects were made for each impact configuration. In addition to the Apollo harness restraints, they wore the Mercury project helmet on a neck ring attached to a nylon vest, held by a strap passing through the crotch. The helmet, weighing 2 kilos, was not restrained. A rubber bite block was held between the teeth to protect them during impact. Adhesive tape was applied over the elbows and chin to prevent abrasions in some body orientations during impact. The check list of preparations and the count down for each run were recorded on sound tape.

At countdown zero, the pneumatic catapult accelerated the sled 13.11 meters to predetermined velocity, allowing it to coast on the oiled cylindrical rails for 21.03 meters, where impact with the water inertia brake decelerated the sled and occupant, recorded by two thousand frame per second motion picture cameras from overhead, right and left profile positions. Physiological and accelerometer electronic recordings were continuous during sled motion.

Animal Experiments:—Two black bears of 60.00 kilograms were anesthetized for exposure to impact forces higher than those resulting in injuries to a human volunteer in the forward facing position reclining 45° from vertical. Skeletal X-rays were taken under anesthesia two weeks prior to exposure. On the morning of the experiment, anesthesia, induced with nitrous oxide and maintained with 500 milligrams of sodium pentothal intravenously per hour, was administered to implant accelerometers surgically to the skull, sternum and just below the crest of the right ilium and continued until completion of the experiment. Vital signs and electrocardiograph were recorded. The human model Apollo restraint harness was used for bear experiments, although the absence of clavicles in the bear permitted the shoulders to roll under the straps. Autopsy was performed two weeks after exposure on the first bear, which sustained survivable internal injuries.

Physical Measurements:—Simultaneous recordings on an Ampex Model CP 100 tape recorder for immediate playback following a test run, and on Oscillograph traces of greater speed and sensitivity, suitable for computer analysis, were made of velocity and acceleration measurements. These included Berkeley Counter time-displacement data for beginning and end of pneumatic piston stroke accelerating the sled, at water brake entry and at 5 cm. intervals during deceleration; and acceleration traces from the X-axis accelerometer on the sled frame and triaxial accelerometer clusters on the subject's sternum and on the seat back. Statham strain gauge accelerometers of ± 50 G range and 300 cps frequency response were used. Sled onboard measurements and trackside recordings of sled passage were compared by plotting the first integral of the sled X-axis accelerometer trace and Berkeley Counter velocity data points against distance of waterbrake penetration for each run (Fig. 6). These graphs also correlate displacement and elapsed time for impact events registered on accelerometer traces and 2,000 frame per second overhead and profile motion pictures. The impact configuration and body position combinations of the the test program are shown in Table II. The results are tabulated in Table III. Graphs of typical G vector summations for each position are shown in Figs. 10, 11, 12, and 13, shown at the end of this report.

Physiological Data:—Biceps tendon reflex measurements and electroencephalograms were of insufficient reliability due to artifacts. Plethysmograms of respiration were significant for rate only. Blood and urine microscopic and chemical findings of samples before, one hour after, and 24 hours after impact exposure were within normal limits, allowing for heat stress of desert summer morning temperatures between 8 o'clock and 12 o'clock of 32 to 42 degrees C. No significant changes in blood platelet counts, within limits of accuracy, correlating with deceleration effects were found at these impact parameters, such as were reported for more severe exposures by Taylor.[32] On the basis that ability to exit from a capsule quickly after emergency landing would be impaired by loss of strength and coordination of the upper extremities, hand dynamometer measurements were recorded before and after exposure to sled impact during the last sixty experiments of the series. No large or consistent changes were noted for either hand, although more severe exposures to impact in a longer series might produce valuable data. Twenty-six pairs of subjects were directed to, in one case, tense all muscles; in the other, relax as completely as posssible just prior to impact. There was no check on involuntary non-compliance in this small series. No consistent subjective report or physiological reactions were recorded, although in some lateral yaw positions, tensing neck muscles appeared in 2,000 frame per second motion pictures to help hold the head against the headrest. Fifty-five electrocardiograms showed significant bradycardia (more than 10 beats per minute decrease) within 15 seconds after impact of more than 15 G, out of a total of 144 recorded. Those body positions favoring a headward vector component of impact and consequent hydrostatic pressure pulse in the carotid arteries correlated with lower thresholds and larger values for drop in heart rate, and conversely, positions with footward vector causing drop in carotid hydrostatic pressure resulted in no bradycardia at Peak G of 50 per cent higher than threshold for observed effect. (Positions 4, 6, 7, 11, 12, 13, 14 and 15). Maximum drop in heart rate following impact occurred in positions 9 and 10, with the semi-supine subjects seated facing backward. This suggests a vagus reflex to carotid sinus stimulation, reported by Taylor[27]; he abolished the reflex by premedication with atropine. No correlation of subjective complaints or injury thresholds with occurrence of bradycardia was evident in the 55 cases reported here.

Gastric motility changes between one X-ray before

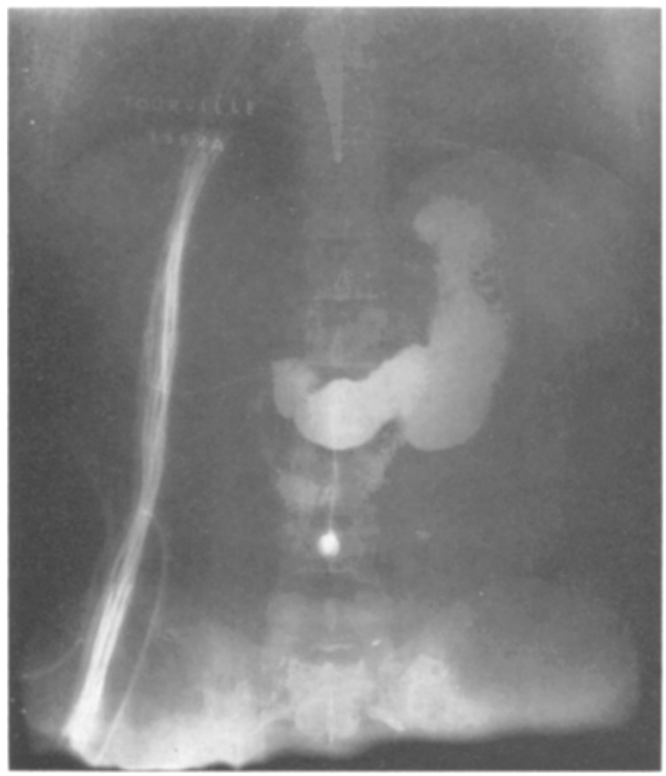

Fig. 4. Roentgenogram of human subject's stomach just before exposure to impact 100 cc. of barium suspension ingested. Standing peristaltic contraction at fundus.

TABLE II.

Configurations						Plan of Test Positions and Configurations								
Duration Milliseconds:						125	80	75	100	100	145	125	145	145
Velocity Meters per Second:						7.6	7.6	7.6	9.15	9.15	13.7	13.7	13.7	13.7
Peak G:						10.0	15.0	20.0	20.0	20.0	15.0	20.0	20.0	20.0
Onset, G per Second:						1,000	1,000	1,000	1,000	1,500	1,000	1,000	1,500	2,000
Positions														
No.	Pitch	Yaw	No.	Pitch	Yaw	1	1	1	1	1	9	9	9	9
1	315°	0°	9	45°	180°	2	2	2		2	10	10	10	10
2	335°	330°	10	35°	210°	3	3	3	3	3	11	11	11	11
3	5°	320°	11	5°	220°	4	4	4	4	4	12		12	12
4	35°	330°	12	335°	210°	5	5	5	5	5	13		13	13
5	45°	0°	13	315°	180°	6	6	6	6	6	14		14	14
6	35°	30°	14	335°	150°	7	7	7	7	7	15	15	15	
7	5°	40°	15	5°	140°	8	8	8	8	8	16	16	16	16
8	335°	30°	16	35°	150°	10								
						16								

TABLE III RESULTS POSITION NO. 1 (0-215-0)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) *Base*	*Immed*	Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
26-6	1462	MDH	160	5.49	9.8	800.15	610	136	108	80	135	+10	......	......	Neg
26-6	1463	WG	147	6.40	13.7	870.01	820	166	87	70	75	-10	......	......	B+, R 3 min.
27-6	1465	JWR	163	7.53	10.5	776.34	770	128	128	81	91	+ 5	......	......	Neg
27-6	1466	SM	170	7.93	12.2	785.82	820	143	112	80	107	+ 7	......	......	Neg
18-7	1516	RWD	122	6.92	13.2	1035.84	769	676	91	103	138	+ 6	Same	......	P+, R 23 hrs.
18-7	1517	SBB	109	7.71	17.2	1014.25	910	770	76	80	141	-79	Incr.	Yes	P2+, B2+, F2+, R 24 hrs.
29-7	1544	DSB	92	7.74	21.9	1718.55	1290	500	69	123	150	-44	Unsat.	......	Neg
29-7	1545	TWM	100	7.22	19.3	1488.26	1020	400	72	152	157	+ 5	Same	......	Neg
1-8	1561	JPW	120	9.48	24.6	2187.07	980	361	107	80	102	-36	......	......	P+, R 14 days
1-8	1562	DNA	100	9.88	26.3	1634.37	1050	514	82	85	140	-50	Unsat.	......	F+, R 5 min.
14-8	1593	WHT	103	9.36	21.3	1632.84	1390	500	101	105	175	-15	Incr.	No	Neg
14-8	1594	CAR	114	9.70	23.0	1794.44	1430	480	85	100	170	-20	Decr.	Yes	P2+, R 6 min.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 2 (0-335-330)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) *Base*	*Immed*	Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
30.6	1484	CAR	219	5.33	6.0	462.67	250	565	169	125	165	+10	......	......	Neg
30-6	1485	JHS	209	6.52	8.3	602.38	390	721	180	110	139	+ 8	......	......	Neg
17-7	1509	GOS	110	7.50	17.3	1302.65	715	690	80	125	147	+ 3	......	......	P2+, R 12 hrs.
17-7	1510	WMC	117	7.47	15.6	891.60	833	769	77	88	138	-44	......	......	P+, R 7 min.
24-7	1536	SM	110	7.29	19.0	1215.19	910	326	80	76	122	-37	?	......	Neg
24-7	1537	RMB	102	7.62	20.0	1605.74	1000	515	68	75	119	-15	Same	......	Neg
8-8	1578	JMP	114	9.06	21.0	1419.31	1360	828	84	80	138	+ 2	......	No	P+, R 5 min.
8-8	1579	GWC	120	8.87	20.0	1705.54	1330	380	89	56	126	- 6	Unsat.	No	P+, R 3 min.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 3 (0-005-320)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) *Base*	*Immed*	Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
1-7	1487	CDR	150	7.19	9.2	801.24	530	159	114	65	107	+27	......	......	Neg
1-7	1488	GAG	153	7.10	9.8	844.60	730	123	122	93	104	+21	......	......	Neg
15-7	1501	TWM	123	7.35	14.9	1162.49	667	662	82	73	153	+ 5	......	......	Neg
15-7	1502	WCC	120	7.25	14.8	1275.52	625	598	84	80	90	- 9	......	......	Neg
23-7	1531	TSG	110	7.44	17.5	1492.75	880	1050	80	80	120	+ 5	?	......	P2+, R 24 hrs.
23-7	1532	RJB	106	7.38	17.0	1426.57	920	835	75	95	144	+ 9	Decr.	......	P+, R 7 hrs.
30-7	1549	WHS	109	7.10	18.0	1624.80	900	345	82	88	134	+ 2	Decr.	Yes	P2+, R 5 min.
30-7	1550	JHS	107	7.56	18.0	1322.70	1160	400	77	96	136	+ 5	Same	Yes	P2+, R 5 min.
31-7	1556	WMC	98	9.48	24.6	1450.61	1050	587	75	74	134	-44	Unsat.	Yes	P+, R 3 hrs.
31-7	1557	GOS	101	9.75	25.6	1962.46	1030	526	79	60	145	-18	Incr.	No	P2+, R 24 hrs.
15-8	1596	JHS	111	9.48	22.0	1566.73	1360	357	84	70	140	-30	......	No	P+, R 30 min.
15-8	1597	JLP	112	9.57	22.5	1826.87	1370	370	83	95	140	-65	......	Yes	P+, R 4 min.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 4 (0-35-330)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) *Base*	*Immed*	Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
29-6	1475	EWV	150	7.19	10.5	1024.00	500	167	115	71	104	+11	......	......	Neg
29-6	1476	JPW	144	7.56	11.5	991.12	680	145	126	58	82	+12	......	......	Neg
16-7	1506	GWC	116	7.77	15.8	1318.71	835	741	78	81	100	+14	......	......	Neg
16-7	1507	CWH	111	7.56	17.9	1347.83	898	832	75	90	127	+23	......	......	Neg
24-7	1534	HNF	104	7.71	20.0	1723.68	1020	417	76	112	110	+15	Incr.	......	Neg
24-7	1535	FJC	106	7.53	19.5	1547.91	1000	406	76	75	145	+15	Decr.	Yes	Neg
2-8	1564	MDH	92	9.60	25.0	2018.52	1020	423	72	88	122	-26	......	Yes	P3+, R 3 min.
2-8	1565	JTB	119	9.33	24.0	2024.87	980	351	99	87	141	- 5	......	......	P2+, R 48 hrs.
13-8	1585	PJG	126	8.84	18.5	1225.17	1200	299	99	117	123	- 8	Same	No	P3+, B3+, F+, R
13-8	1586	RWD	130	9.30	20.5	1627.29	1340	279	104	92	138	-15	......	Yes	P3+, R 36 hrs.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 5 (0-45-0)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
26-6	1460	WHT	180	5.46	8.5	655.45	630	200	140	90	125	+ 5	......	......	Neg
26-6	1461	RMB	170	6.13	11.5	912.87	790	250	128	80	90	+20	......	......	Neg
27-6	1467	WCC	120	7.71	10.2	943.85	890	244	101	99	100	+19	......	......	Neg
27-6	1468	CAR	152	7.65	11.6	1131.28	940	200	118	75	112	- 9	......	......	Neg
18-7	1514	TKC	98	8.08	17.4	1318.07	1000	1173	68	112	127	+ 4	Incr.	.....	P+, R 6 min.
18-7	1515	JLP	110	7.62	15.7	1274.75	930	740	78	95	147	- 3	......	......	P+, R 3 min.
30-7	1547	WLB	94	7.41	19.3	1400.72	1080	463	92	84	127	-14	Incr.	......	P+, B+, R 10 min.
30-7	1548	CAR	105	7.19	18.0	1428.84	970	478	78	104	134	+ 7	Same	No	P+, R 6 hrs.
1-8	1559	JCT	120	9.57	25.0	2029.86	960	792	97	85	126	-68	Decr.	No	P3+, B3+, F+, R 60 days
1-8	1560	JOE	120	7.80	17.3	1490.98	640	351	100	110	136	-17	Incr.	No	P2+, R 72 hrs.
14-8	1591	RJS	130	9.21	21.0	1352.64	1440	320	104	85	150	0	......	No	P2+, B+, R 12 hrs.
14-8	1592	KDH	130	9.02	19.5	1937.10	1230	318	104	105	150	0	?	Yes	P+, R 2 min.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 6 (0-35-30)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
29-6	1477	HNF	160	7.62	11.6	999.73	690	185	130	104	103	+ 6	......	......	Neg
29-6	1478	FJC	170	7.53	11.2	889.06	630	208	140	110	136	+11	......	......	Neg
16-7	1504	DSB	80	7.80	17.7	1421.08	1000	870	73	80	130	-10	......	.....	Neg
16-7	1505	JCM	86	7.77	16.7	1295.35	1000	1008	79	110	140	+14	......	. ....	B+, R 2 min.
25-7	1541	JWR	105	7.50	20.0	1460.59	1030	425	73	79	115	-24	......	......	P+, R 3 min.
25-7	1542	KDH	93	8.02	23.0	2253.49	1330	442	69	105	134	+10	Same	...	P2+, B2+, R 5 min.
2-8	1566	GTB	117	9.39	23.5	2078.62	930	697	72	109	144	- 3	......	......	P2+, B2+, R 72 hrs.
2-8	1567	GAR	112	9.57	24.5	2367.11	1000	732	90	68	102	-14	......	......	P+, R 72 hrs.
13-8	1587	FJC	130	8.75	18.5	1493.71	1220	238	102	100	145	+10	Same	No	P+, R 5 min.
13-8	1588	JWR	115	9.33	21.9	1579.49	1450	320	95	64	115	-13	Decr.	Yes	P+, R 6 min.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 7 (0-5-40)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
1-7	1489	GTB	150	7.41	10.0	893.59	670	176	126	102	125	+ 8	......	......	Neg
1-7	1490	WLB	140	7.74	12.4	911.19	690	186	112	115	135	+19	......	......	Neg
15-7	1499	CEN	113	7.29	14.2	1094.99	800	645	83	104	150	- 3	......	......	P+, R 2 min.
15-7	1500	DNA	116	7.35	14.8	933.15	870	760	86	69	107	+11	......	......	Neg
30-7	1551	PJG	105	7.04	17.3	1161.40	870	435	77	67	104	- 8	Unsat.	......	P+, R 24 hrs.
30-7	1552	RWD	93	7.77	23.0	1815.31	1280	549	70	97	136	- 2	Same	......	P+, R 5 min.
31-7	1554	JCM	107	9.39	23.5	1865.43	920	770	87	87	125	-16	..	Yes	Neg
31-7	1555	TKC	106	9.54	23.5	1705.54	1030	910	86	90	150	-15	Decr.	.. ...	P+, R 36 hrs.
15-8	1598	SM	112	9.11	20.9	1317.75	1370	346	85	80	130	+ 2	......	No	P+, R 12 hrs.
15-8	1599	WG	130	9.42	22.0	1437.01	1330	371	103	80	85	-18	......	Yes	P+, R 10 min.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 8 (0-335-30)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
30-6	1482	JNP	131	7.22	9.7	686.39	700	153	121	...	...	....	......	......	Neg
30-6	1483	JRB	163	6.49	8.0	493.52	490	134	133	78	165	+12	......	......	P+, R 5 min.
17-7	1511	ERS	107	7.29	15.9	1413.60	870	835	78	85	109	+ 6	......	.....	P+, R 6 min.
17-7	1512	YSF	111	7.65	18.7	1857.63	910	770	71	78	103	- 1	......	......	F+, R 15 min.
25-7	1539	WG	95	7.68	21.0	1314.53	1100	445	70	75	95	-38	Same	......	P+, B+, R 5 min.
25-7	1540	RJS	104	7.44	19.5	1282.55	1020	380	76	95	160	-20	?	......	P+, R 24 hrs.
6-8	1571	BLC	117	9.08	21.0	1809.86	790	870	97	88	120	-18	......	......	Neg
6-8	1572	GAG	105	8.93	22.5	1898.32	860	400	85	80	90	-10	......	......	Neg
6-8	1573	ERS	100	8.93	22.5	2041.20	890	465	75	100	117	-24	......	......	Neg
6-8	1574	JRB	104	9.36	24.5	1466.94	960	450	82	152	160	-13	......	......	P+, R 12 hrs.
7-8	1580	CWH	120	8.96	20.5	1506.41	1310	301	90	102	138	-49	......	No	P+, F+, R 12 hrs.
7-8	1581	WCC	130	9.54	24.7	2229.58	1600	362	102	73	112	-32	......	Yes	P+, R 12 hrs.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 9 (0-45-180)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Heart Rate Pre-run (beats/min) Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
15-5	1408	TWM	170	13.35	16.5	1272.35	910	400	154	83	87	-27	......	......	P+, R 3 min.
15-5	1409	CDR	150	13.23	16.5	1459.46	835	417	140	75	100	-25	......	......	Neg
24-6	1456	TWM	140	13.20	19.6	1511.40	900	572	130	107	138	-75	......	......	B+, R 3 min.
24-6	1457	DSB	140	13.44	21.2	1702.09	940	589	124	65	130	-50	......	......	B+, R 3 min.
19-8	1608	WG	160	13.41	19.0	1551.31	1450	154	148	110	144	-91	Same	Yes	B+, R 3 min.
19-8	1609	TKC	150	13.56	19.6	1458.05	1460	175	139	100	150	-70	Incr.	No	P+, R 3 min.
28-8	1646	FJC	180	13.96	22.5	1877.90	2110	133	160	105	150	-48	Decr.	Yes	P+, B+, R 5 min.
28-8	1647	CGO	200	13.90	21.7	1702.86	1960	147	177	105	130	-77	......	No	P2+, B+, R 12 hrs.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 10 (0-35-210)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Heart Rate Pre-run (beats/min) Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
14-5	1405	GAR	150	12.68	15.0	1428.84	770	400	138	80	100	-50	......	......	P+, R 24 hrs.
14-5	1406	BLC	160	13.05	16.0	1415.23	936	400	144	130	150	-40	......	......	Neg
13-6	1442	JCT	111	13.47	21.0	1666.98	910	895	105	104	140	-30	......	......	P+, B+, R 3 min.
13-6	1443	RDM	112	13.26	21.0	1705.08	850	995	108	93	130	-50	......	......	P+, R 3 min.
28-6	1472	BLC	140	7.56	11.0	972.97	790	166	115	100	126	+10	......	......	Neg
28-6	1473	WHS	150	7.56	10.5	938.27	770	190	123	100	134	+13	......	......	Neg
20-8	1613	WLB	150	13.99	19.3	1400.72	1530	179	148	96	140	-65	Decr.	Yes	B+, F+, R 10 min.
20-8	1614	JPW	164	13.63	19.5	1218.14	1530	152	140	100	110	-46	Same	No	P+, R 3 min.
27-8	1639	BDN	140	13.87	23.5	1577.62	2120	190	118	82	150	-63	Same	Yes	P+, B2+, R 3 hrs.
27-8	1640	TSG	200	13.59	16.7	1416.55	1140	170	180	75	120	- 8	Same	No	P2+, B2+

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITION NO. 11 (0-5-220)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Heart Rate Pre-run (beats/min) Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
13-5	1400	DAP	140	13.35	16.8	1333.58	1000	378	127	85	130	0	......	Neg	Neg
13-5	1401	WG	135	13.26	16.5	1309.77	920	378	121	120	135	+ 5	......	Neg	P+, R 3 min.
12-6	1437	SBB	120	13.29	21.4	1310.45	955	665	110	90	140	-15	......	Neg	Neg
12-6	1438	RJS	140	13.11	20.8	1481.28	948	745	125	100	160	+12	......	Neg	Neg
21-8	1619	SBB	150	13.81	19.3	1111.82	1450	178	130	75	130	0	Decr.	Yes	Neg
21-8	1620	GOS	160	14.69	22.0	1566.73	1880	197	137	120	...	....	Decr.	No	Neg

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 12 (0-335-210)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Heart Rate Pre-run (beats/min) Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
17-5	1419	JPW	150	12.92	14.8	1048.72	900	320	140	95	100	+ 5	......	......	P+, R 3 min.
17-5	1420	NDH	174	13.14	15.3	1249.21	780	384	152	90	140	0	......	......	P+, R 3 min.
22-8	1624	LMS	170	13.69	19.2	1410.88	1430	149	150	75	175	0	Same	......	Neg
22-8	1625	CRM	160	13.87	19.8	1598.67	1310	154	137	65	120	+10	Same	Yes	P+, R 24 hrs.
26-8	1634	WCC	192	13.50	20.0	1850.69	1970	165	170	78	124	- 4	Unsat.	....	Neg
26-8	1635	JDT	197	13.96	21.9	1738.42	1860	183	176	120	180	-13	......	......	P+, R 3 hrs.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 13 (0-315-180)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) Base	Heart Rate Pre-run (beats/min) Immed	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
15-5	1410	WCC	170	13.14	15.8	1361.71	910	770	150	90	120	0	......	......	Neg
15-5	1411	SBB	170	13.23	16.0	979.78	910	314	155	80	140	+10	......	Yes	P+, B+, R 24 min.
19-8	1610	JOE	168	13.56	19.0	1663.35	1390	144	192	118	140	-15	Same	No	Neg
19-8	1611	GAR	165	13.75	21.0	2076.58	1530	145	155	80	94	+ 4	?	Yes	Neg
28-8	1644	GWC	190	13.50	20.0	1696.46	1970	171	170	105	150	-48	Decr.	No	Neg
28-8	1645	WHT	197	13.96	21.9	1678.82	1860	168	172	100	170	0	Same	No	Neg

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 14 (0-335-150)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) *Base*	*Immed*	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
17-5	1417	GTB	155	13.08	15.0	1326.78	1000	347	145	90	125	+ 5	......	......	Neg
17-5	1418	JRB	170	13.02	15.0	918.54	1000	400	146	115	160	+10	......	......	Neg
22-8	1626	RJS	168	13.78	20.4	1748.90	1500	149	148	85	150	+10	Same	......	Neg
22-8	1627	GTS	170	13.90	21.7	1850.51	1530	151	158	118	150	0	Same	Yes	B+, R 1 min.
26-8	1632	DSB	164	13.50	20.0	1560.38	1970	143	140	115	160	- 5	......	......	P+, R 5 min.
26-8	1633	GVA	200	13.87	21.9	1281.47	1860	139	178	85	120	- 3	Same	......	P+, R 1 min.

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 15 (0-5-140)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) *Base*	*Immed*	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
13-5	1398	RJB	130	13.53	16.3	1390.01	940	420	118	90	No	Firing	......	......	Neg
13-5	1399	BNS	150	13.66	16.8	1340.84	960	445	140	90	100	- 3	......	......	Neg
12-6	1435	JNP	138	13.47	21.0	1485.99	925	955	121	85	130	+10	......	......	Neg
12-6	1436	CAR	140	13.38	21.0	1619.35	1040	900	120	135	160	0	......	......	Neg
21-8	1621	JNP	160	13.78	20.4	1388.02	1500	146	149	70	132	+10	Same	Yes	Neg
21-8	1622	JRB	159	13.90	21.7	1289.45	1530	142	151	120	157	- 7	Decr.	No	Neg

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

TABLE III RESULTS POSITON NO. 16 (0-35-150)

Date (1963)	Run No.	Name	T_2 (sec)	Av Meters per sec	Peak G	F = MA Kilograms	Onset G per sec	Decay G per sec	T_1 (sec)	Heart Rate Pre-run (beats/min) *Base*	*Immed*	Heart Rate Post Impact (beats/min)	Gastric Motility X-rays	Muscles Tensed	Subjective Reactions
14-5	1403	SJR	170	13.35	16.5	1242.41	830	485	156	85	125	-67	......	......	P2+, B+, R 24 hrs.
14-5	1404	JHS	180	13.20	16.0	1161.22	800	475	178	110	120	+20	......	......	Neg
13-6	1440	RJB	124	13.11	20.0	1678.32	820	832	100	110	150	-10	......	......	P+, R 3 min.
13-6	1441	RCJ	121	13.20	20.2	1942.50	860	870	107	100	130	-90	......	......	P+, R 1 min.
28-6	1470	JTB	170	7.74	11.4	930.79	760	182	140	84	85	+10	......	......	Neg
28-6	1471	KDH	170	7.74	11.0	1087.73	680	207	136	85	115	+12	......	......	Neg
20-8	1615	WLB	170	13.81	21.2	1202.04	1520	148	156	85	155	-50	?	Yes	P+, R 3 min.
20-8	1616	JPW	190	13.84	21.5	1375.09	1510	164	166	105	140	-65	Same	No	Neg
20-8	1637	DAC	194	13.90	21.0	1590.78	2000	196	170	...	...	...	Same	Yes	B+, R 1 min.
27-8	1638	ERS	190	13.99	22.3	1982.60	2130	189	166	110	150	-40	Same	No	Neg

Subjective Reactions: Pain = P; Breathing Difficulty = B; Faintness = F; Mild = +; Moderate = 2+; Severe = 3+; Recuperation = R, and time to recuperate.

and another after impact, with 100 cc of barium suspension in the stomach, were observed for 58 acceptable pairs of X-rays out of 65 taken in the last 82 human experiments of this series. Thirty pairs showed no significant changes. Body positions with yaw and pitch angles of less than 30° did not result in significant gastric motility changes (Positions 2, 8, 12, 14, and 16), even at more than 24 Peak G impacts. A complete absence of peristaltic contractions and tight constriction of the pylorus after impact occurred in one subject in position 5 (See Figs. 4 & 5), following exposure to more than 30 G peaks of compression and flexion forward simultaneously (See Graph, Fig. 6). Painful soft tissue injuries at the 6th, 7th, 8th thoracic spinal levels persistent for 60 days were sustained by this subject. There was no correlation with subjective and physiological findings in any other case where gastric motility change occurred.

There were no subjective complaints of significant pain, breathing difficulty, faintness or delay in recuperation beyond 12 hours for positions 7, 11, 13, 14, and 15. Positions 7, 11, and 15 are in 5° pitch, essentially upright, and at 40° yaw to right or left; position 13 is backward facing, bowing 45° from vertical, with vectors compressing the subject against the back and bottom of the seat.

The small number of cases and single still X-ray photographs instead of fluoroscopic motion pictures limits the value of these observations. Gastric motility changes were evident in 23 subjects, as follows:

NUMBER OF CASES

Position	Increased Motility	Decreased Motility
1	1	1
3	1	2
4	1	1
5	3	1
6	1	1
7		1
9	1	1
10		1
13		1
15		1

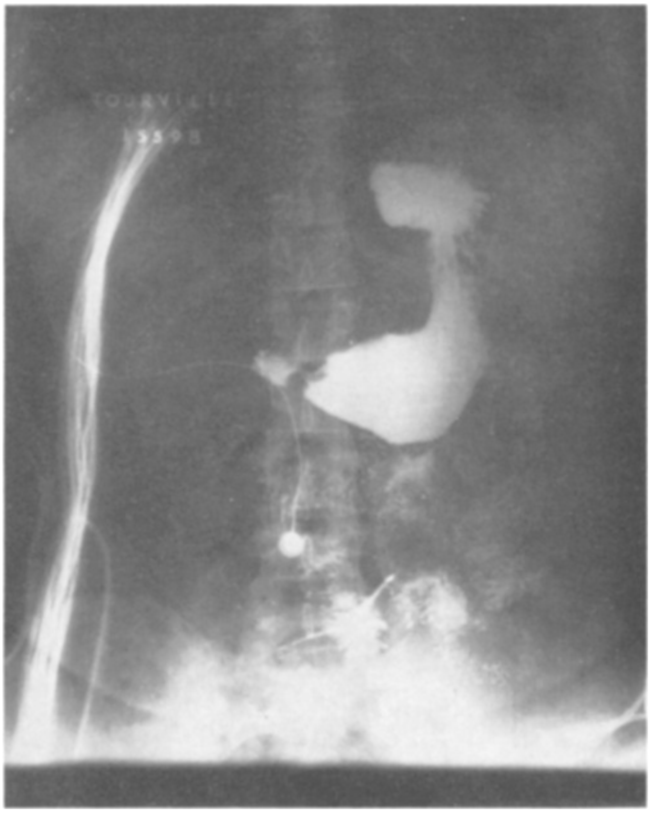

Fig. 5. Roentgenogram of human subject's stomach just after 25.0 G impact. Note cardiac and pyloric spasm, absence of peristalic waves.

In general, gastric motility was altered in subject orientations of 40° or more yaw or pitch angles with respect to forward or backward facing seated positions, which would result in large angular displacements of the stomach during impact. This agrees with the findings of Lombard[15] for relation of body position to impact survival in guinea pigs. Lombard reports highest injury thresholds for guinea pigs, in the aft facing and sideward upright positions.

Significant subjective complaints following impact were reported in other positions as follows:

Some instances of slow recuperation related to neck pain in positions where the unrestrained head with helmet was abducted and rotated abruptly. Positions 9 through 16 were exposed to longer duration deceleration from velocities of 13.7 meters per second into 85 centimeters of waterbrake penetration. Even at 2,000 G per second onset, these impacts of about 145 millisecond duration were more tolerable than the 75 to 100 millisecond duration impacts from 7.6 meters per second into 42 centimeters of waterbrake, as evidenced by the distribution of subjective complaints —17 individuals in lower duration group versus 5 in the 145 millisecond duration group. In the 146 human experiments, voluntary tolerance was exceeded once, in position 5, in which the subject is reclined 45° from vertical, seated facing forward. The accelerometer traces (Fig. 6), show an amplified rebound, indicative of slack in the webbing restraint harness. This is corroborated by displacements shown in 2,000 frame per second motion pictures. Compression and forward flexion are followed by enhanced rebound. Excruciating

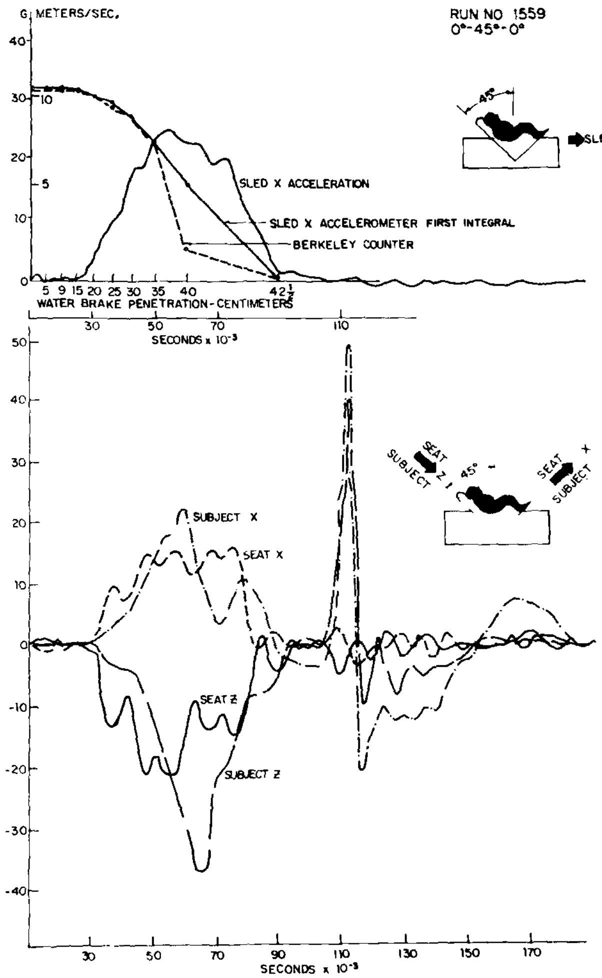

Fig. 6. Accelerometer traces.

NUMBER OF CASES

Position	Recuperation in 12 hours or Over	Moderate to Severe Pain	Breathing Difficulty	Faintness
1	3	2	1	1
2	1	1		
3	2	4		
4	2	2		
5	3	2	1	
6	2	2	2	
8	4			
9	1	1		
10	2	1	2	
12	1			
16	1	1		

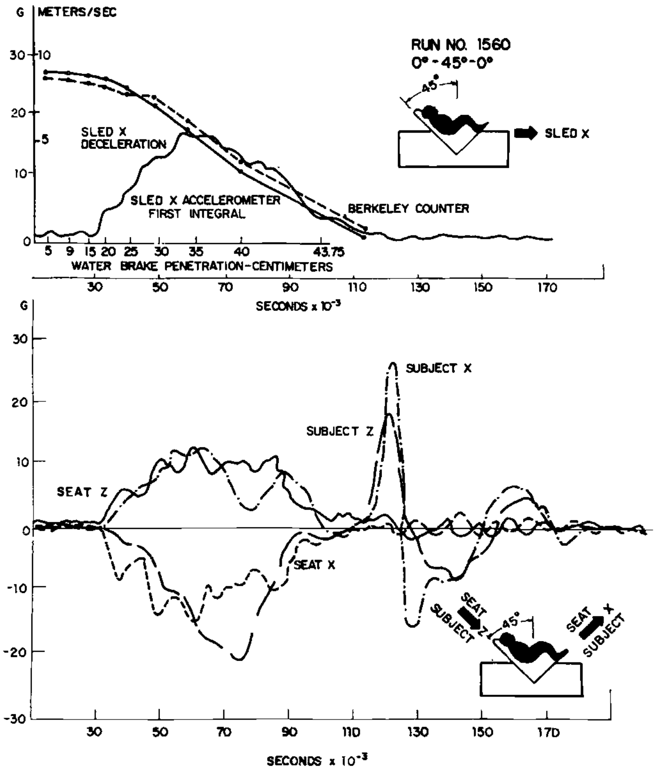

Fig. 7. Accelerometer traces.

lower thoracic back pain resulted. A second subject in the same position at slightly lower velocity with well tightened restraint underwent less and slower displacements with only fleeting back pain and no persisting injury from the impact and moderate rebound. (Fig. 7).

Having found a limit for safe experimentation with human subjects in position 5, reclining at 45° from vertical, seated facing forward, anesthetized black bear subjects were used in two experiments in this position to determine impact configuration causing definitive injury. In the first of these, waterbrake entry velocity was 16.31 meters per second, penetration distance was 40.46 centimeters, onset was in excess of 10,000 G per second to 83 G peak in the sled X-axis, for a duration of less than 70 milliseconds (See Fig. 7). Post run radiographs revealed a fracture of the spinous process of the fifth lumbar vertebra and partial fracture of the body of the sixth lumbar vertebra. No other lesions were evident.

The subject was awake within 6 hours, and was walking with no impairment, 24 hours after exposure. Stiffness, but no pain was evidenced by the subject's movement.

The subject was sacrificed with a combination of formaldehyde perfusion and exsanguination 14 days following his having been subjected to 80 G's on the Daisy Decelerator. It is probable, since he was fully mobile following the fracture and in view of the fact that he exhibited no evidence of constipation or anuria, that there was no severe impairment or lesion produced in the spinal cord as a result of the fracture of L-6. The interval of 14 days following the experiment was allowed in order to study histologically, the degree, if any, of demyelonization accumulating in the spinal cord, as well as to demonstrate the musculo-skeletal and other lesions produced by this experiment.

Pathological Diagnoses:

1. *Musculo-skeletal:* Linear fracture of the 6th lumbar vertebral body and spinous process in the stages or organization and callus formation.
2. *Splenic:* (1) Acute, focal, capsular and parenchymal laceration, hemorrhage, fibrous tissue organization and hemorrhage; (2) Acute congestion.
3. *Hepatic:* (1) Multiple, acute, focal, subcapsular,

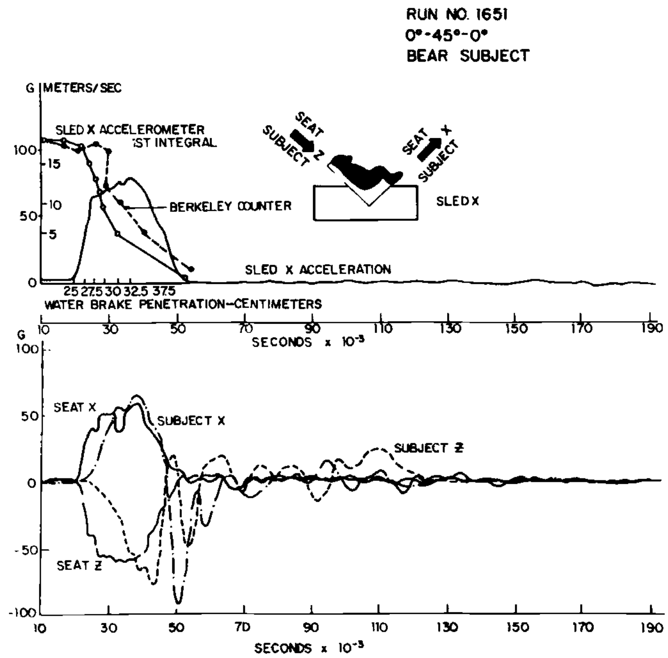

Fig. 8. Accelerometer traces.

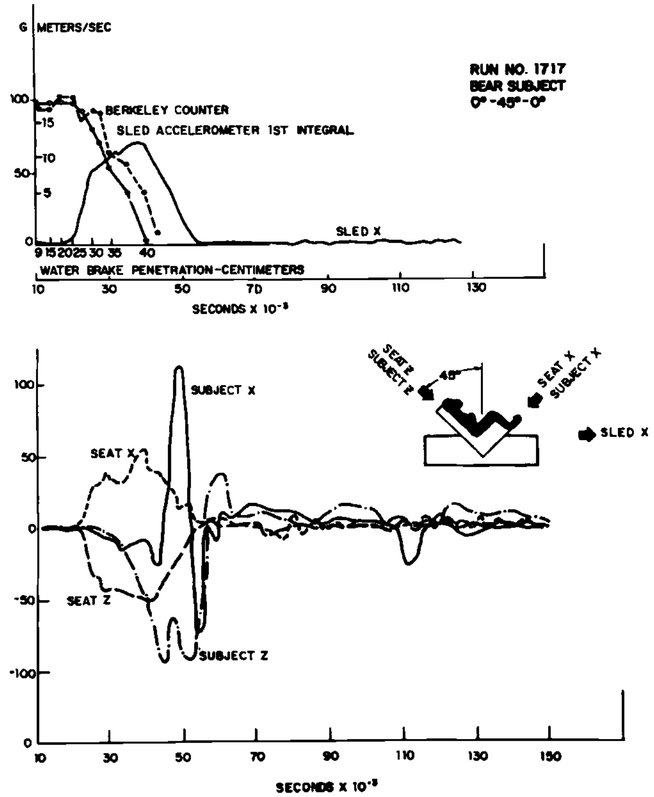

Fig. 9. Accelerometer traces.

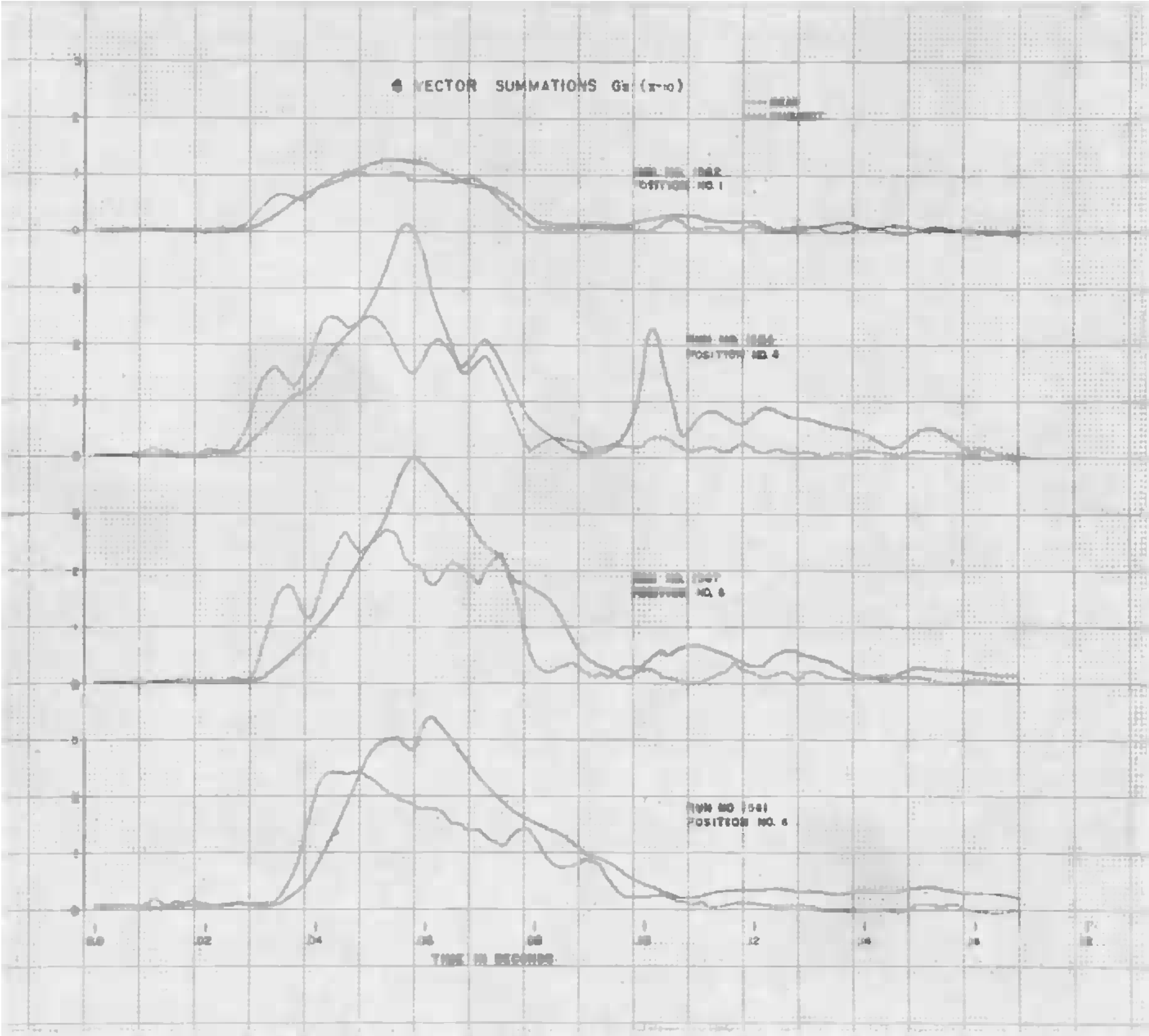

Fig. 10. Position graph.

ligamental, capsular, and superficial lobular parenchymal lacerations and hemorrhage; (2) Focal, acute, subcapsular, lobular hepatitis, cellular necrosis (minimal), and infarction (minimal); (3) Diffuse, cloudy swelling.

4. *Pulmonary:* (1) Focal, acute emphysema (minimal) of the following areas: (a) subpleural, (b) parabronchial, (c) parabronchilar, (d) paravascular; (2) Focal alveolar hemorrhage, inflammation, and erythrophagocytosis.

The 2,000 frame per second motion pictures of the impact taken from overhead and right and left sides of the waterbrake show extreme forward flexion of the bear's torso, followed by rebound. The bear's knees are bent and its feet are on the seat, so that the fulcrum of flexion was in the lumbar region. The three areas of contusion and subcapsular hemorrhage of the spleen correspond to impingement of lower rib margins against that organ, and against the liver, where infarcts were found.

A second experiment with an anesthetized black bear was accomplished with waterbrake entry at 15.03 meters per second, into the same waterbrake pattern. The sled X-axis accelerometer recorded 73 Peak G at more than 10,000 G per second. Following recovery from anesthesia, the bear had no signs of trauma and therefore no autopy was done. Only 10 G peak deceleration and of 1.28 meters per second brake entry velocity increment made the difference between intact survival and definite injury, including a spinal fracture, in the two bear subjects. (Fig. 9)

DISCUSSION

The impact velocities included in the human experiments of this series ranged from 6.10 meters per second, corresponding to that of a 2.13 meter free fall; to 13.72 meters per second, equivalent to that of a 9.75 meter free fall. Average terminal free fall velocity of 53.65 meters per second is attained in 146.91 meters to sea level.[20] Personal parachute descent velocities vary with canopy size and load weight, ranging between 6.10 and 7.62 meters per second near sea level. The 13.7 meters per second estimated for descent rate of the Apollo Capsule with a damaged parachute is in the range for inflicting injury on impacting hard ground with the body in a vulnerable orientation. Holcomb reported a fracture of the third thoracic vertebra of a human volunteer exposed to combined flexion-compression at 43 G and 1200 G/sec. in an escape capsule drop test.[12] Voluntary tolerance limits were not exceeded in 15 of the 16 body orientations in which 58 human subjects sustained 146 exposures to impact at velocities from 7.6 to 13.7 meters per second, decelerating in 40 to 85 centimeters, at 6.0 to 26.3 G, onset 250 to 2130 G per second and duration of 68 to 192 milliseconds measured in the X-axis of the sled. (Fig. 9).

Position 5, in which the subject faces forward in a seat reclining 45° from vertical, proved injurious to one subject at waterbrake entry velocity of 6.50 meters per second and within tolerance for another subject at 6.97 meters per second into the same brake configuration. In this position the force vectors are at right angles, one flexing the spine, the other simultaneously compressing it. Loose webbing restraints contributed to an amplified elastic rebound synchronous with the subject's whole body resonance response. The triaxial accelerometer traces (Fig. 6), shows rise time of 25 milliseconds, or 1/4th of 10 cycles per second, inciting a dynamic response of 37 G in compression, rebounding to 50 G extension of the spine. The second subject sustained less impact at lower onset with tighter restraints and was not injured, although brake entry velocities differed by less than .5 meter per second. Even more striking was the difference in effects on the two bears in the same position, at higher impact forces, resulting from a difference of entry velocity of 1.28 meters per second (See Figs. 8 and 9). Some means of pre-tensing harness restraints to take up slack prior to impact would improve protection for the spinal column by damping and containing resonant response.

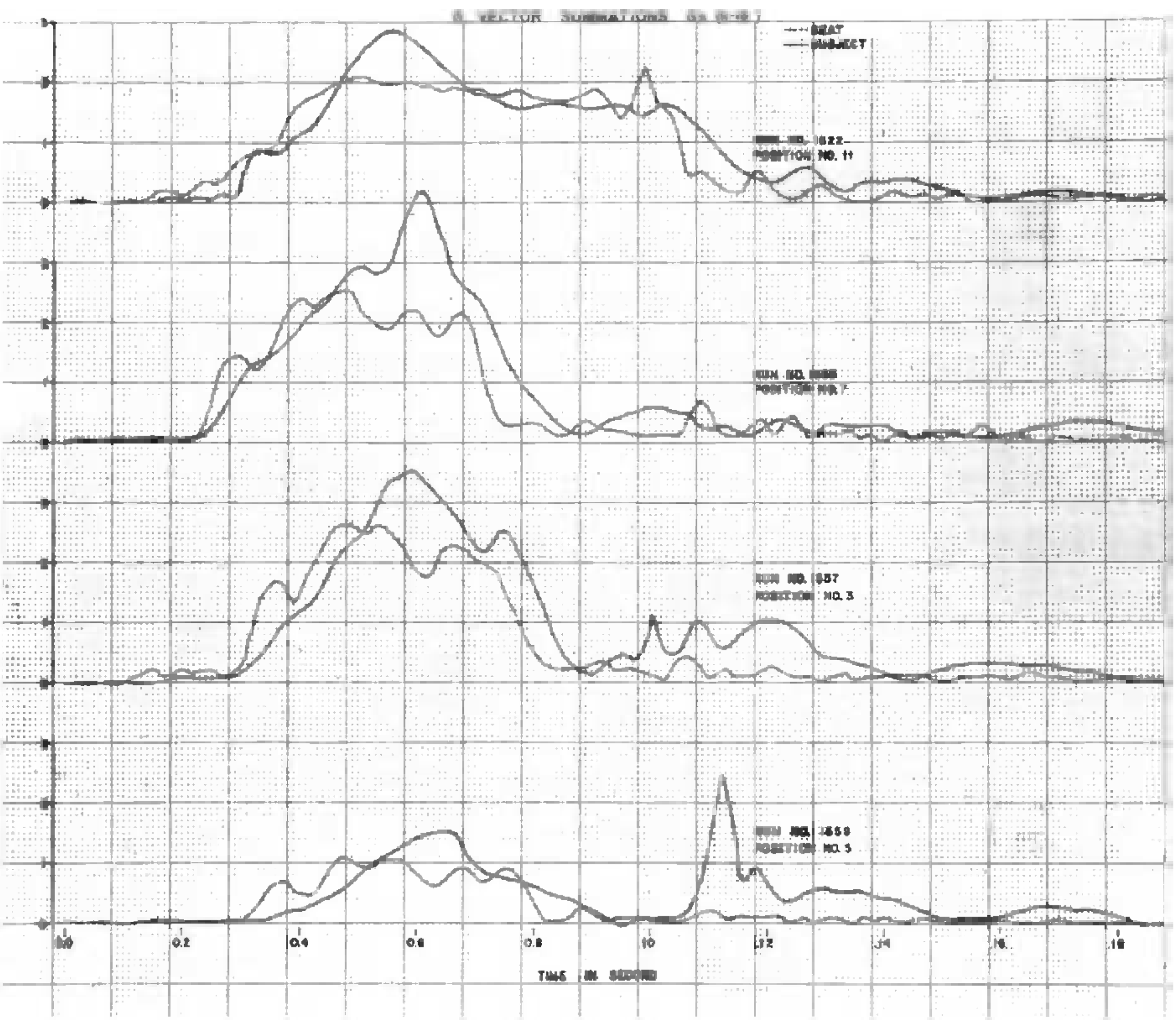

Fig. 11. Position graph.

Head restraint could limit forward flexion in this position, and arm rest support could offset some of the compression vector loading the spine. Energy attenuation to less than 20 G at 1000 G per second would keep the subject below injury threshold for all positions explored in these experiments.

The occurrence of bradycardia as a carotid sinus reflex response incited by headward acceleration vectors exceeding 15 G and absence of significant heart rate change even at 24 G of forward vector has no significance with respect to injury vulnerability, but demonstrates a physiological response to impact.

Gastric motility changes correlate with angular displacement of the stomach by impact forces, and possibly with autonomic shock response to severe impact. Persistent loss of gastric motility following traumatic impact could have diagnostic significance. Changes of gastric motility did not correlate with the occurrence of bradycardia in this series of exposures to impact. Both phenomena were observed in the presence of normal blood and urine chemistry and morphology. Neurological responses to impact could not be discriminated in the electroencephalogram and biceps tendon reflex data because of artifacts.

The protective effect of prolonging duration of impact with resultant damping of whole body resonance response is bourne out by subjective response data. Five individuals reported significant adverse effects even at 2,000 G per second onset where impact pulse duration was 145 or more milliseconds, whereas 17 were adversely affected by 1,000 G per second or less onset at 68 to 100 milliseconds duration. Seat orientations in which relative motion between occupant and seat during impact is minimized, enhance tolerance. Those positions in which the head was compressed into the headrest avoiding flailing and jerking the neck and

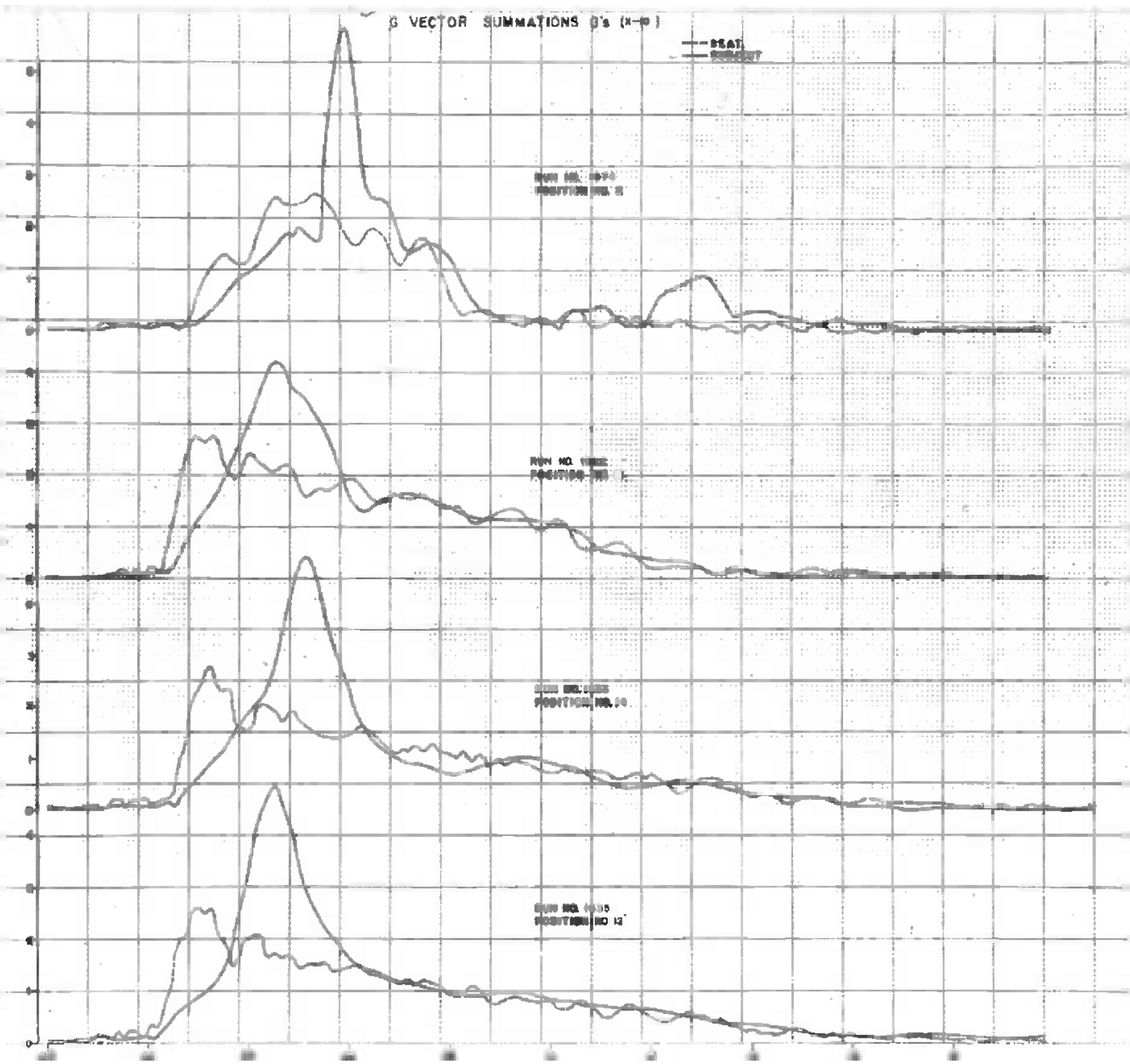

Fig. 12. Position graph.

arms. In this regard, the most favorable position was backward facing, bowing 45° from vertical, the opposite of position 5 in which human and animal subjects were injured. The equal vectors at right angles compressed all body areas in contact with the seat uniformly, with no relative displacement between seat and anatomy. The seat and not the webbing harness restrained the subject, providing optimum support and protection. This corresponds to the ideal landing position of the Apollo Capsule, bottom parallel to the ground surface, for which it is designed. (See Figs. 10, 11, 12, and 13 at the end of this report).

CONCLUSIONS

1. Absence of persistent or severe subjective complaints in 119 of the 146 human experiments, vital signs recorded within normal limits except for innocu-

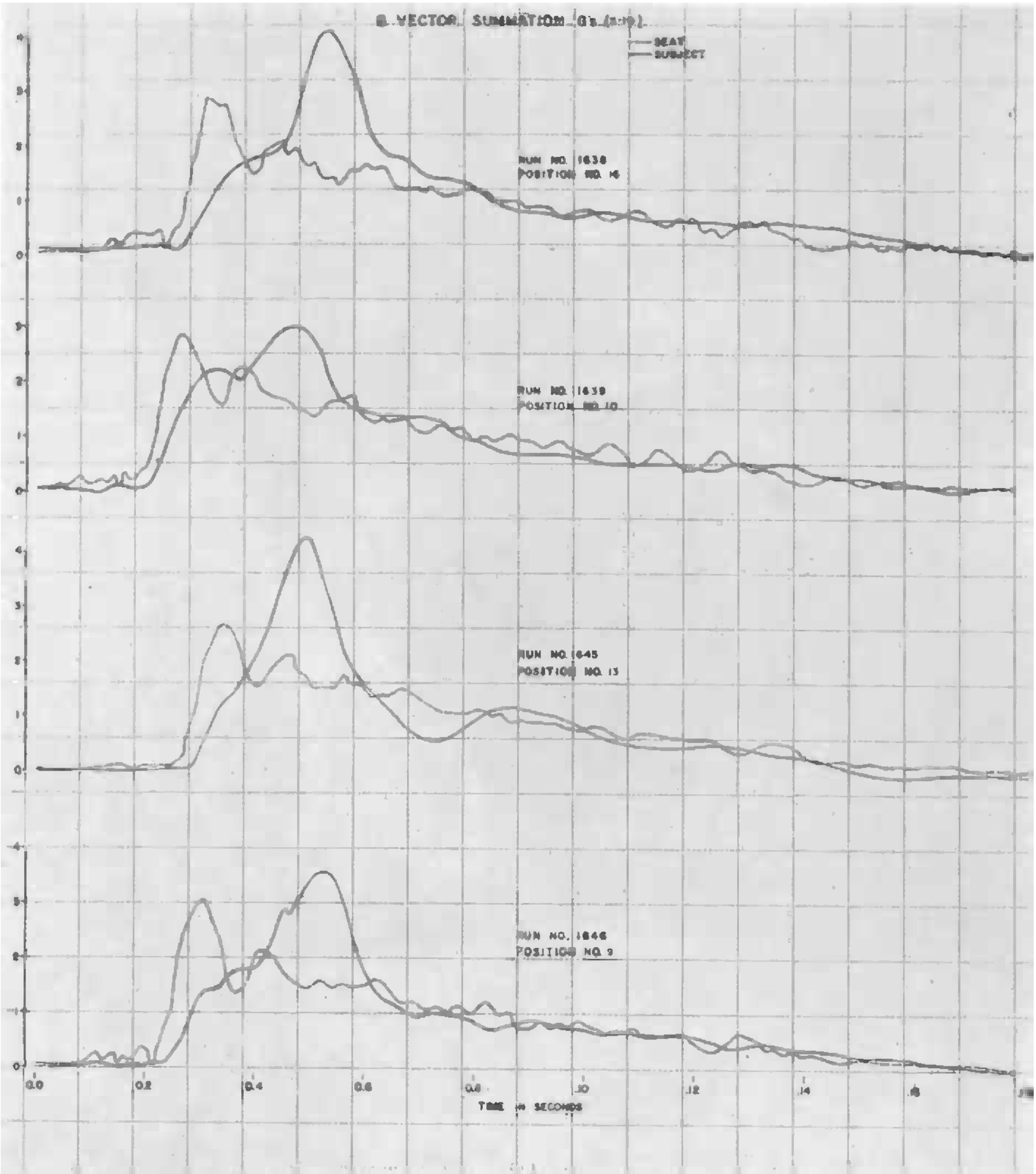

Fig. 13. Position graph.

ous transient changes, and uniformly normal and negative blood and urine measurements are evidences that whole body impacts of 6 to 26.3 G, 250 to 2130 G/sec. and 68 to 192 milliseconds duration, measured on the sled, were within tolerance limits for human volunteer subjects with the exception noted in conclusion 2.

2. A forward facing subject tipped back 45° in pitch sustained simultaneous compression and hyperflexion of the trunk by force vectors at right angles which produced persistent soft tissue injury in the 6th, 7th, and 8th thoracic area, from impact of 25.0 G at 960 G per second in 97.0 milliseconds; loose restraints contributed to whole body resonance amplification of impact.

3. At 83 Peak G at 10,000 G/sec. in the 45° backward pitch forward facing position, a black bear sustained a 6th lumbar vertebra fracture and recuperable internal injuries.

4. A carotid sinus reflex bradycardia of less than 30 seconds duration results from headward force vectors of whole body single impact exceeding 15 G magnitude, which probably triggers the carotid sinus by an abrupt rise in hydraulic pressure. The reflex did not occur with impacts exceeding 24 G in which no headward force vector was produced.

5. Gastric motility changes related to severity of whole body single impact and to angular force moments exceeding 40°, displacing the stomach in pitch or in yaw.

6. Use of head restraint, impact attenuation and mechanical retraction of harness restraint to prevent slack and relative body motion are recommended.

REFERENCES

1. Beeding, E. L., Jr., and Mosely, J. D.: Human tolerance to ultra high G forces. *Aerospace Med.*, 31:210, 1960.
2. Beeding, E. L., Jr.: Human forward facing impact tolerances. *Aerospace Med.*, 32:241, 1961.
3. Chandler, Richard F.: Determination of Equivalent Natural Frequency Indicated by Accelerometers Mounted Over the Sternum During Human Impact in the G_x Direction. Project No. 7850, Task No. 785001, Technical Documentary Report No. ARL-TDR-62-29, 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico, December 1962.
4. Clarke, Neville P.: Biodynamic response to supersonic ejection. *Aerospace Med.*, 34:1089, 1963.
5. DeHaven, H.: Mechanical analysis of survivable accidents in falls from heights of 50 to 150 feet. *War Med.*, 2:586-596, July 1942.
6. Evans, F. G., Lissner, H. R., and Patrick, L. M.: Acceleration induced strains in the intact vertebral column. *J. Applied Physiol.*, 17:405, 1962.
7. Freeman, Howard E., Boyce, William C., and Gell, C. F.: Investigation of a Personnel Restraint System for Advanced Manned Flight Vehicles. Tech. Doc. Rep. AMRL TDR 62-128, December 1962.
8. Headley, Robert N., Capt., USAF, MC, *et al.*: Human Factors Responses During Ground Impact. WADD TR 60-590, November 1960.
9. Holcomb, Galen A., and Huheey, M., *et al.*: Investigations to Determine Human Tolerance to Short Duration Accelerations. Stanley Aviation Corp. Report No. 1217, November 1960.
10. Holcomb, Galen A.: B-58 Capsule Drop Tests to Determine Load Factors Produced in Various Soils. Stanley Aviation Report No. 1318, June 1961.
11. Holcomb, Galen A.: Impact studies of the United States Aerospace Industry. I. Impact acceleration stress, National Academy of Sciences. *National Research Council Publication*, 977:83, 1962.
12. Holcomb, Galen A., and Huheey, Marilyn: A minimal compression fracture of T-3 as a result of impact. Impact acceleration stress. *National Research Council Publication*, 977:191, 1962.
13. Laurell, Lars, and Nachemson, Alf: Some factors influencing spinal injuries in seat ejected pilots. *Aerospace Med.*, 34:726, 1963.
14. Lombard, C. F., *et al.*: Voluntary tolerance of the human to impact acceleration on the head. *J. Aviation Med.*, 22:17, 1951.
15. Lombard, C. F., Close, Perry, Thiede, F. C., and Larmie, F.: Impact tolerance of guinea pigs related to orientation and containment. *Aerospace Med.*, 35:1, 1964.
16. Mosely, J. D., and Cook, James E.: Visceral displacement in black bears subjected to abrupt deceleration. *Aerospace Med.*, 31:1, 1960.
17. Perey, Olof: Biomechanical problems of the human spine. Impact acceleration stress. National Academy of Sciences. *National Research Council Publication*, 977:25, 1962.
18. Peterson, R. L.: An Investigation of the Abrupt Acceleration Properties of the Prototype Net Crew Support-Restraint System. Tech. Memorandum No. FDFR-TM-63-25. October 1963.
19. Snyder, R. G.: A Case of Survival of Extreme Vertical Impact in Seated Position. C.A.R.I. Report 62-19, Fed. Av. Agency, Oklahoma City, Okla., 1962.
20. Snyder, Richard G., Ph.D.: Human tolerance to extreme impacts in free-fall. *Aerospace Med.*, 34:695, 1963.
21. Stapp, J. P.: Human Exposures to Linear Acceleration. I. Preliminary Survey of Aft Facing Seated Position. AF Tech. Report 5915, 1959.
22. Stapp, J. P.: Human Exposures to Linear Acceleration. II. The Forward Facing Position and Development of a Crash Harness. WADC TR 5915, 1951.
23. Stapp, J. P., and Blunt, W. C.: Effects of mechanical force on living tissue. III. A compressed air catapult for high impact forces. *J. Av. Med.*, 28:281, 1957.
24. Swearingen, J. J., McFadden, E. B., Garner, J. D., Blethrow, J. G.: Human voluntary tolerance of vertical impact. *Aerospace Med.*, 31:989, 1960.
25. Taylor, Ellis R., and Rhein, Leroy W.: Physiologic Effects of Abrupt Deceleration: I. Relative Bradycardia (March 1962). Presented at the 33rd Annual Meeting of the Aerospace Medical Association, Atlantic City, N. J., 9-12 April 1962.
26. Taylor, Ellis R., and Rhein, Leroy W.: A Comparison of Methods of Impact Experimentation Control. Project 7850, Task 78501, Technical Documentary Report No. ARL-TDR-62-19, 6571st Aeromedical Research Laboratory, AMD, (AFSC), Holloman AFB, N. M., August 1962.
27. Taylor, Ellis R., Rhein, Leroy W., and Beers, George R.: Effect of Atropine Upon the Relative Bradycardia Associated with Impact. Project 7850, Task 785001, Technical Documentary Report No. ARL-TDR-62-13, 6571st Aeromedical Research Laboratory, AMD, (AFSC), Holloman AFB, N. M., Aug. 1962.
28. Taylor, Ellis, Rhein, Leroy W., and Ferguson, James F. III: The Effects of Impact Upon the Patellar and Other Deep Tendon Reflexes. Project 7850, Task 785001, Technical Documentary Report No. ARL-TDR-62-18), 6571st Aeromedical Research Laboratory, AMD, (AFSC), Holloman AFB, N. M., Aug. 1962.
29. Taylor, Ellis R., and Chandler, Richard F.: A Simple Reflex Sensor; A Description and Trial Use. Project 7850, Task 785001, Technical Documentary Report No. ARL-TDR-62-23, 6571st Aeromedical Research Laboratory, AMD, (AFSC), Holloman AFB, N. M., September 1962.

30. Taylor, Ellis R.: Problems and Techniques of Human Sled Subject Selection. Technical Documentary Report No. ARL-TDR-63-5. Presented at 6th Stapp Automotive Car Crash Conference, Holloman AFB, N. M., 7-9 November 1962.
31. Taylor, Ellis R., and Rhein, Leroy W.: The Nature of Reflex Briskness. ARL-TDR-62-27, 6571st Aeromedical Research Laboratory, AMD, (AFSC), Holloman AFB, N. M., Project 7850, Task 785001, December 1962.
32. Taylor, Ellis R.: Thrombocytopenia Following Abrupt Deceleration. ARL-TDR-62-30, 6571st Aeromedical Research Laboratory, AMD, (AFSC), Holloman AFB, N. M., Project 7850, Task 785001. December 1962.
33. Weis, Edmund B., Jr., Clarke, Neville P., and Brinkley, James W.: Human response to several impact acceleration orientations and patterns. *Aerospace Med.*, 34:1122, 1963.