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Effect of Initial Position on the Human Head and Neck Response to +Y Impact Acceleration

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Abstract

The response of the human head and neck to impact acceleration has been previously reported for the -X (chest to back) and +Y (right to left) directions. Wide ranges of sled peak acceleration, rate of onset of acceleration and duration of acceleration have been investigated and reported. A major mechanical effect on the dynamic response due to initial position for the -X direction has been reported. The purpose of this study is to report the initial position effect on the human head and neck response for +Y direction experiments.

Four initial positions of the head relative to the first thoracic vertebral body (T_1) have been investigated over a range of sled acceleration peaks from 2 to 7G. The data from six young adult male volunteers representative of a wide range of anthropometry will be presented. There are 18 experiments for each volunteer for a total of 108 experiments.

The effect of initial position on the resulting head angular and linear acceleration, velocity and displacement will be presented. A comparison of the initial position effect for -X and +Y direction experiments will be made. The ability to

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model the initial position effect will be discussed.

PURPOSE

The Naval Aerospace Medical Research Laboratory Detachment (NAMRLD) New Orleans, Louisiana, is conducting a continuing program to determine the dynamic response of volunteer subjects to impact acceleration (1,2,3,4,5,6).* The effect of initial condition on the dynamic response for -X acceleration experiments has been previously reported (1). The specific purpose of this paper is to present the effect of initial head and neck orientation on the dynamic response for +Y acceleration experiments and to compare these results with the study for the -X data base. In addition, the implications that initial position has on modeling +Y head and neck response will also be discussed.

METHODOLOGY

SLED ACCELERATION PROFILES - A Bendix HYGE® pneumatically driven .3048m diameter accelerator was used to accelerate an approximately 1.2m by 3.7m sled of 1,669 kg mass which was rail mounted on 12 Delrin AF® pucks. The acceleration stroke is limited to 1.52m and sled mounted brakes were not used. The effective drag is about .2G and the sled was allowed to coast to a stop. Total rail length is 213m. The subject was restrained in a nominally upright position by shoulder straps, a lap belt and an inverted V pelvic strap tied to the lap belt. A loose safety belt around the chest was also employed. The thrust vector of the sled was nominally directed from the right to the left shoulder and the subject was positioned snugly against a lightly padded wooden board used to limit the upper torso motion (Figures 1 through 4). The sled pulse duration was controlled so that the end stroke velocity was approximately constant and independent of G level.

The pertinent sled parameters for each run in each of the four initial conditions are shown in Figures 5 through 8. The averages and standard deviations at each G level within the initial conditions are shown in the same figures. Peak Sled Acceleration (PSA) is the maximum absolute value of the measured sled acceleration profile. Rate of onset (ROO) is defined

*Numbers in parentheses designate References at end of paper.

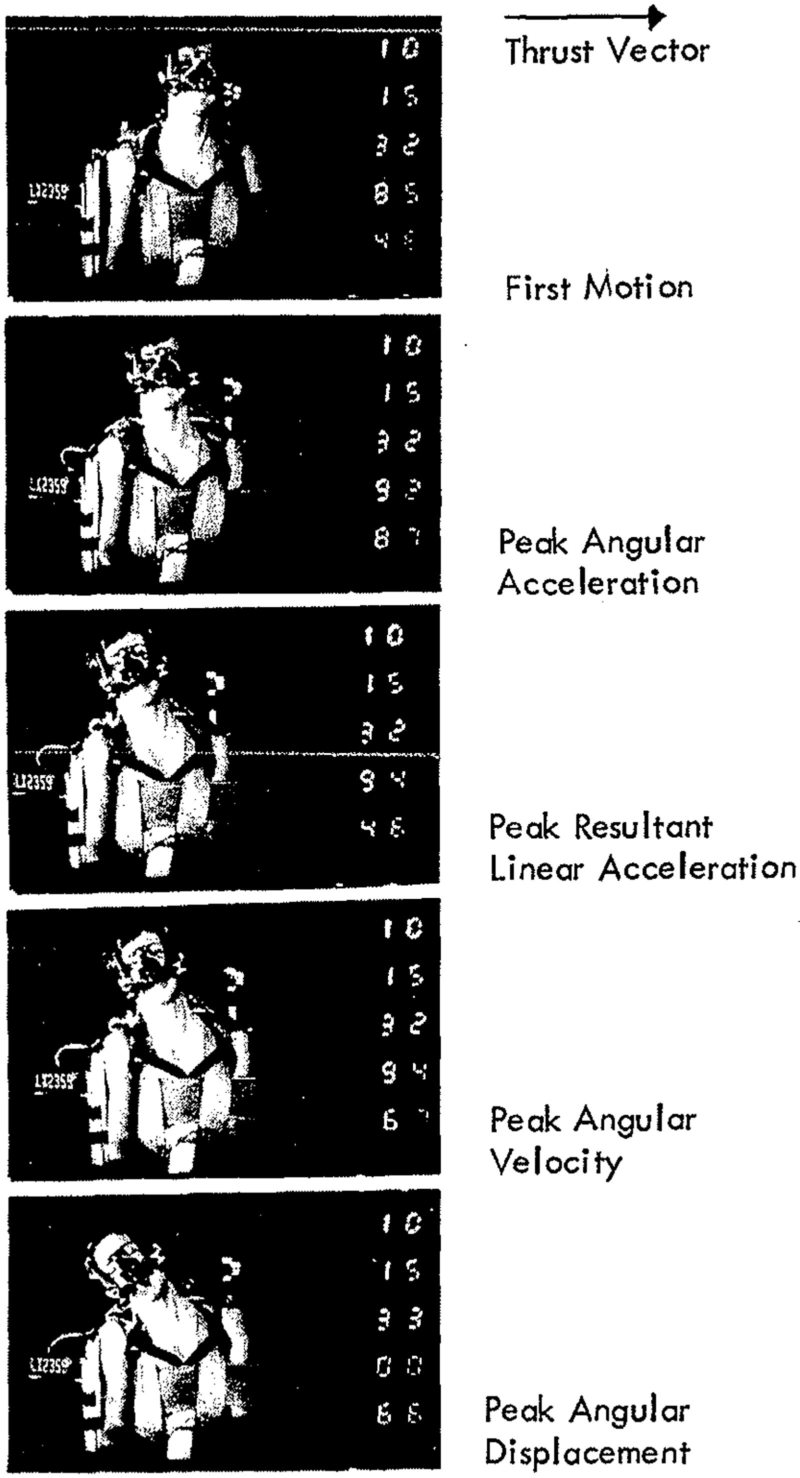


Fig. 1 - Photographs of a subject at critical events in run profile - NUCU (5G)

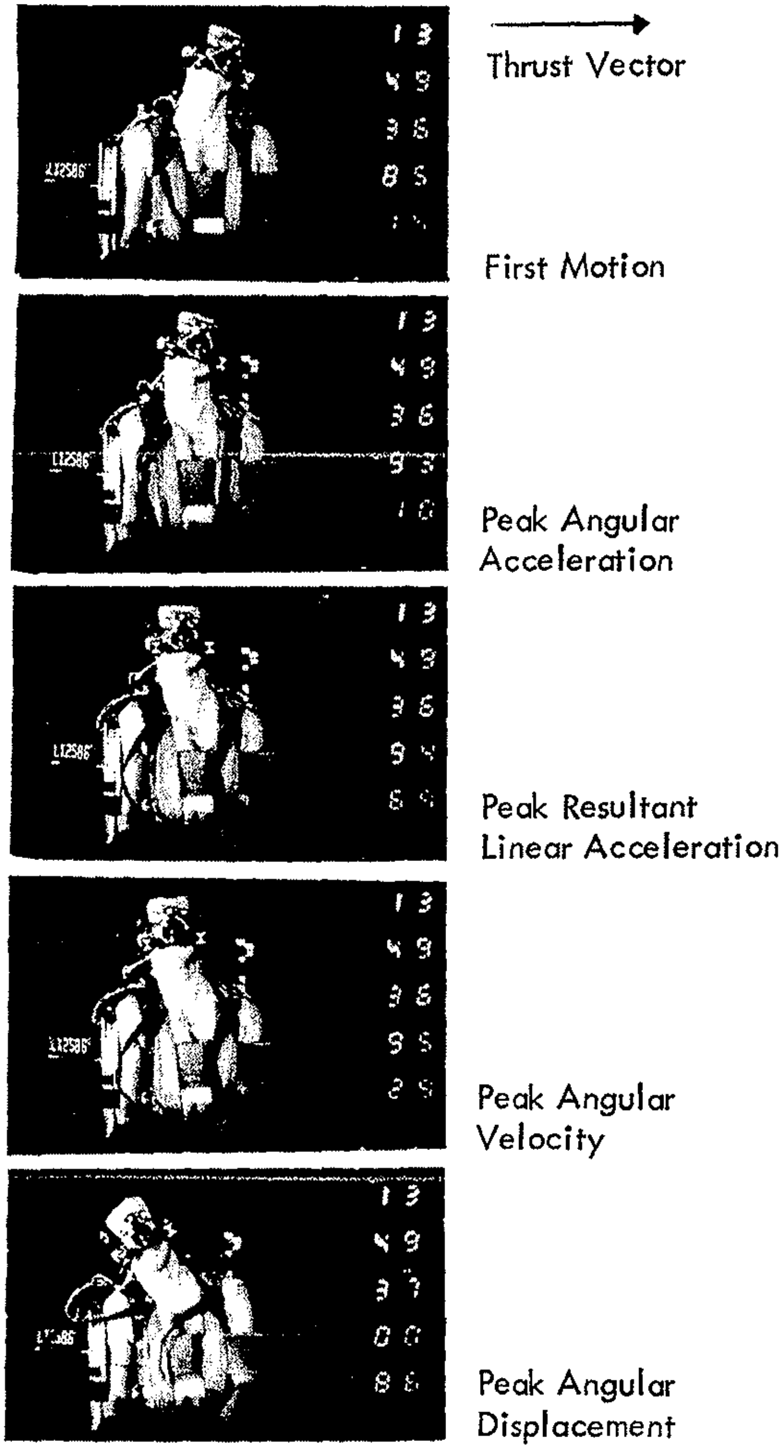


Fig. 2 - Photographs of a subject at critical events in run profile - HTLT (5G)

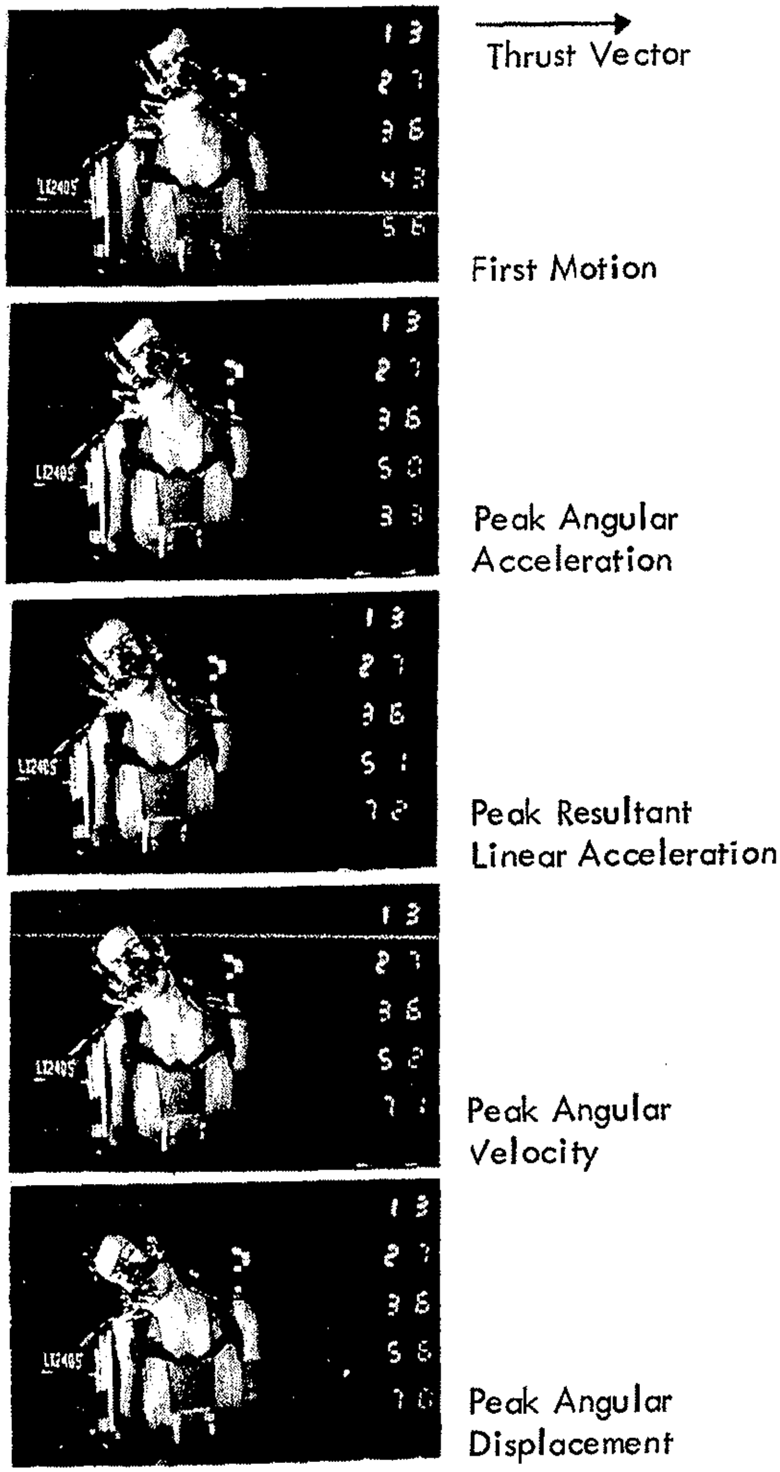
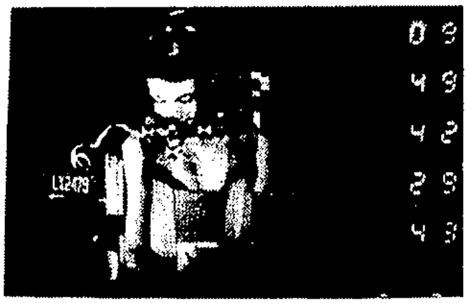


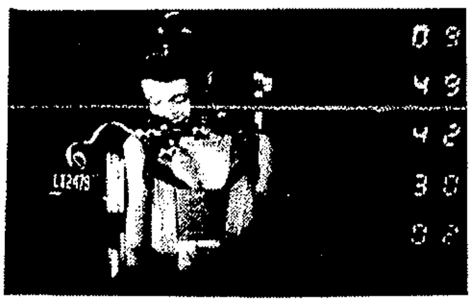
Fig. 3 - Photographs of a subject at critical events in run profile - HTRT (5G)

Thurst Vector

First Motion
(Site I and Site 2)

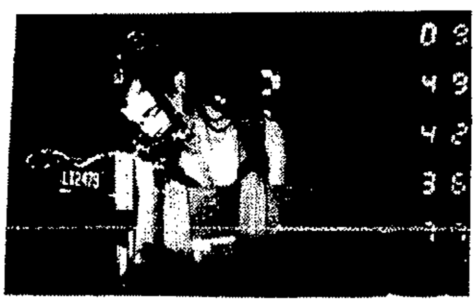


Peak Angular
Acceleration



Peak Resultant
Linear Acceleration

Peak Angular
Velocity



Peak Angular
Displacement

Fig. 4 - Photographs of a subject at critical events in run profile - HDWN (5G)

NECK UP CHIN UP
(NUCU)

RUN NUMBER	SUBJECT ID	PSA M/S/S	ROO M/S/S/S	DURATION SEC	END ST V M/SEC	NECK LEN METERS	EULER 1 DEG	EULER 2 DEG	EULER 3 DEG	NECK ROLL DEG	NECK PITCH DEG	AVG RANGLE DEG	SIGMA RANGLE DEG
LX1619	H075	20.1	1256.	.120	3.11	.110	-.7	-15.9	-2.7	-3.3	4.3	-42.300	9.500
LX1625	H075	29.7	2066.	.143	5.52	.149	-.4	-10.1	-7.0	-3.0	11.8	-35.900	2.400
LX1535	H075	48.2	3505.	.107	6.46	.143	1.8	-6.3	-5.8	.9	6.3	-34.100	4.600
LX1627	H075	50.6	3236.	.102	6.58	.152	-9.6	-17.5	-4.1	-23.7	16.5	-39.600	3.500
LX1548	H075	59.9	6468.	.090	6.43	.188	5.6	-1.2	-6.0	-2.7	19.4	-32.700	2.100
LX1921	H075	71.1	5663.	.078	6.46	.123	-6.2	-11.4	.2	-13.0	18.7	-34.200	3.000
					MEAN	.144	-1.6	-10.4	-4.2	-7.5	12.9	-36.467	4.183
					SIGMA	.025	5.0	5.5	2.4	0.4	5.9	3.393	2.511
LX1767	H078	22.4	1681.	.130	4.11	.155	-2.3	-10.8	-4.3	-7.4	10.8	-38.400	10.800
LX1780	H078	30.2	2318.	.148	5.71	.145	-4.5	-12.1	-5.2	-3.3	7.4	-33.200	6.700
LX1824	H079	50.0	3697.	.101	6.53	.150	-5.7	-9.0	-8.8	-10.1	14.6	-29.900	5.200
LX1912	H078	59.7	3705.	.090	6.48	.141	-6.1	-11.4	-10.6	-8.7	15.8	-27 200	2.200
LX1925	H078	68.8	5986.	.082	6.46	.139	-7.2	-2.0	-7.2	-9.5	20.4	-26.500	1.400
					MEAN	.146	-5.2	-9.1	-7.2	-7.8	13.8	-31.040	5.260
					SIGMA	.006	1.7	3.7	2.3	2.4	4.4	4.370	3.377
LX1756	H091	22.2	1948.	.130	4.07	.148	-.3	-17.7	-2.4	-18.3	3.6	-44.300	7.600
LX1779	H091	30.5	2306.	.146	5.62	.150	.5	-16.0	-2.8	-13.0	1.5	-35.900	7.500
LX1796	H091	49.8	3760.	.106	6.5[illegible]	.144	-.4	-15.2	-.7	-15.6	4.9	-34.700	2.500
LX1855	H091	58.0	3468.	.090	[illegible]	.140	-.3	-18.4	-4.8	-16.9	8.3	-34.000	2.100
LX1927	H091	69.0	5890.	.081	6.38	.151	-3.0	-18.1	-.5	-21.6	10.2	-38.900	3.500
					MEAN	.147	-.7	-17.1	-2.2	-17.1	5.7	-37.560	4.640
					SIGMA	.004	1.2	1.3	1.6	2.8	3.2	3.764	2.420
LX1777	H083	22.5	1342.	.140	4.26	.090	.3	.0	-2.0	-3.8	-.0	-37.200	10.400
LX1785	H083	29.9	1905.	.147	5.58	.101	2.9	-2.9	.7	.8	-2.5	-35.600	11.500
LX1831	H093	49.3	3235.	.105	6.50	.087	.8	-.4	-2.4	-9.9	9.6	-31.300	10.400
LX2341	H033	48.0	4715.	.108	6.42	.113	-.8	4.0	1.1	-10.5	10.3	-41.600	8.000
LX1950	H093	57.1	3935.	.090	6.22	.098	.7	1.5	.5	-4.9	1.1	-28.900	8.100
LX1928	H083	69.2	5830.	.081	6.45	.101	-.6	1.6	-1.6	-.8	-.8	-30.600	8.900
					MEAN	.098	.5	.6	-.6	-4.8	2.9	-34.200	9.550
					SIGMA	.008	1.2	2.1	1.4	4.2	5.1	4.381	1.302
LX1836	H084	21.8	1036	.141	4.11	.129	.4	-14.4	-2.8	-2.7	9.0	-37.400	3.900
LX1690	H084	30.3	1377	.140	5.50	.125	2.9	-18.7	1.6	-8.3	9.1	-33.000	1.300
LX2317	H084	49.4	4853.	.101	6.59	.160	.7	-17.0	-5.4	-2.3	11.7	-28.400	9.000
LX2359	H084	50.7	5111.	.101	6.65	.138	-2.1	-17.2	-.3	-10.3	11.2	-29.300	12.300
LX2332	H084	60.4	5766.	.092	6.50	.150	-1.1	-17.8	-3.8	-8.1	7.6	-28.500	11.200
LX2344	H084	65.9	6435.	.080	5.98	.148	1.3	-13.9	-2.6	-7.1	9.3	-29.700	7.500
					MEAN	.142	.3	-16.5	-2.2	-6.4	9.6	-31.050	7.533
					SIGMA	.012	1.6	1.8	2.3	3.0	1.4	3.228	3.881
LX1839	H094	21.5	1122.	.143	4.07	.147	1.5	-10.6	1.2	-2.4	1.8	-37.900	8.700
LX1876	H094	30.0	1102.	.135	5.47	.175	-2.8	4.3	-4.0	.3	7.0	-37.000	6.500
LX2312	H094	49.4	5057.	.101	6.53	.156	-2.4	-18.2	-4.1	-.7	11.1	-32.500	11.500
LX2354	H094	50.1	4899.	.104	6.58	.178	-.6	-10.7	-3.5	2.0	9.2	-31.000	17.600
LX2327	H094	60.8	5718.	.091	6.47	.151	-4.0	-14.2	-3.5	-.8	9.8	-29.200	19.000
LX2337	H094	70.4	7762.	.079	6.27	.164	-3.3	-13.6	-2.3	1.4	7.5	-31.400	8.100
					MEAN	.162	-1.9	-10.5	-2.7	-.1	7.7	-33.167	11.900
					SIGMA	.012	1.9	7.1	1.8	1.5	3.0	3.191	4.777
MEAN FOR 2G		21.7	1397.	.134	3.95								
SIGMA FOR 2G		.8	320.	.008	.38								
MEAN FOR 3G		30.1	1846.	.143	5.57								
SIGMA FOR 3G		.3	458.	.005	.08								
MEAN FOR 5G		49.5	4203.	.104	6.54								
SIGMA FOR 5G		.9	743.	.003	.06								
MEAN FOR 6G		59.3	4843.	.090	6.39								
SIGMA FOR 6G		1.3	1174.	.001	.11								
MEAN FOR 7G		69.1	6259.	.080	6.33								
SIGMA FOR 7G		1 6	713.	.001	.17								

Fig. 5 - Summary of sled profile and initial condition parameters for each run (NUCU)

HEAD TILTED LEFT
(HTLT)

RUN NUMBER	SUBJECT ID	PSA M/S/S	ROO M/S/S/S	DURATION SEC	END ST V M/SEC	NECK LEN METERS	EULER 1 DEG	EULER 2 DEG	EULER 3 DEG	NECK ROLL DEG	NECK PITCH DEG	AVG RANGLE DEG	SIGMA RANGLE DEG
LX2512	H075	21.9	1237.	.132	4.06	.140	-22.1	-26.0	-5.1	-15.5	8.2	-37.800	4.400
LX2544	H075	30.6	2141.	.134	5.52	.138	-39.1	-16.0	-6.8	-35.6	11.4	-42.000	5.400
LX2575	H075	50.7	5511.	.101	6.51	.153	-31.4	-16.2	.2	-24.8	10.3	-39.400	7.800
LX2629	H075	59.3	6508.	.093	6.32	.154	-33.6	-25.3	1.1	-25.4	9.3	-38.900	7.800
LX2669	H075	70.4	6948.	.079	6.29	.136	-28.7	-27.1	6.1	-27.0	3.4	-41.200	6.800
					MEAN	.144	-31.0	-22.1	-.9	-25.7	8.5	-39.960	6.440
					SIGMA	.008	5.6	4.9	4.6	6.4	2.8	1.533	1.347
LX2515	H078	22.1	1007.	.130	4.13	.147	-16.2	.6	-3.5	-15.6	20.3	-37.000	8.000
LX2540	H078	29.8	2045.	.142	5.49	.171	-19.4	-3.4	-3.9	-21.9	19.2	-30.600	4.900
LX2577	H078	50.2	5710.	.101	6.44	.163	-25.0	2.7	3.5	-24.9	15.2	-32.200	7.600
LX2703	H078	50.1	5068.	.102	6.43	.181	-25.3	8.9	5.0	-30.1	20.8	-35.500	10.200
LX2592	H078	60.0	5671.	.093	6.41	.166	-21.7	-3.1	2.3	-24.6	16.4	-29.200	4.700
LX2673	H078	69.5	6525.	.079	6.25	.170	-18.3	4.4	9.4	-20.3	14.6	-30.300	5.100
					MEAN	.166	-21.0	1.7	2.1	-22.9	17.7	-32.457	6.750
					SIGMA	.010	3.4	4.3	4.7	4.5	2.5	2.848	2.022
LX2501	H081	21.3	1165.	.131	4.01	.155	-29.3	-10.5	-3.8	-36.2	14.1	-30.000	15.500
LX2546	H081	29.8	2946.	.134	5.41	.161	-33.9	-9.7	.5	-40.7	12.4	-15.200	19.000
LX2596	H081	49.3	5990.	.101	6.27	.173	-24.0	-13.9	6.1	-35.9	8.1	-31.400	2.900
LX2622	H081	60.6	6324.	.089	6.29	.149	-26.3	-14.3	2.4	-32.4	13.5	-23.700	9.200
LX2674	H081	69.6	6574.	.078	6.18	.174	-25.0	-12.2	-2.5	-33.9	7.6	-32.100	6.600
					MEAN	.162	-27.7	-12.1	.5	-35.8	11.1	-27.660	10.640
					SIGMA	.010	3.6	1.8	3.5	2.8	2.7	6.302	5.862
LX2516	H083	21.9	1223.	.134	4.09	.114	-29.2	-.9	-.9	-27.6	12.1	-43.400	13.500
LX2537	H083	30.3	2359.	.136	5.48	.117	-25.9	.4	3.9	-32.7	6.5	-36.100	12.200
LX2595	H083	50.2	6006.	.101	6.42	.116	-30.0	-7.4	1.3	-34.0	8.8	-44.000	10.500
LX2621	H083	60.7	6245.	.091	6.37	.109	-31.6	-2.3	-1.7	-33.9	2.1	-40.800	14.900
					MEAN	.114	-29.2	-2.5	.7	-32.1	7.4	-41.075	12.775
					SIGMA	.003	2.1	3.0	2.2	2.6	3.6	3.114	1.624
LX2517	H084	22.3	1324.	.130	4.11	.147	-20.4	-22.0	-3.9	-13.0	11.5	-25.000	16.200
LX2531	H084	30.1	1687.	.139	5.53	.146	-23.5	-23.5	2.6	-22.7	13.2	-35.800	5.700
LX2586	H084	50.4	6175.	.101	6.46	.151	-21.4	-20.0	4.4	-20.0	10.0	-33.500	10.300
LX2624	H084	60.7	6454.	.090	6.39	.135	-21.3	-25.3	4.1	-15.8	7.2	-26.700	11.000
LX2677	H084	70.6	6577.	.078	6.30	.162	-24.8	-20.9	6.7	-15.9	9.1	-27.800	8.800
					MEAN	.148	-22.3	-22.3	2.8	-17.5	10.2	-29.760	10.400
					SIGMA	.008	1.6	1.9	3.6	3.4	2.0	4.155	3.425
LX2505	H094	21.8	1055.	.129	4.05	.161	-32.4	-14.8	-2.5	-12.8	9.9	-35.500	2.300
LX2524	H094	29.9	1531.	.136	5.49	.139	-35.7	-16.9	-5.8	-16.3	11.1	-34.200	4.300
LX2599	H094	49.6	6021.	.101	6.34	.144	-31.6	-11.9	-2.0	-19.7	11.8	-36.100	5.100
LX2694	H094	70.7	6140.	.079	6.28	.163	-36.6	-13.0	1.8	-19.7	11.8	-36.800	1.500
					MEAN	.152	-34.1	-14.1	-2.1	-17.1	11.2	-35.650	3.300
					SIGMA	.010	2.1	1.9	2.7	2.8	.8	.955	1.456
MEAN FOR 2G		21.9	1169.	.131	4.07								
SIGMA FOR 2G		.3	108.	.002	.26								
MEAN FOR 3G		30.1	2118.	.137	5.49								
SIGMA FOR 3G		.3	462.	.003	.18								
MEAN FOR 5G		50.1	5797.	.101	6.41								
SIGMA FOR 5G		.4	348.	.000	.17								
MEAN FOR 6G		60.3	6240.	.091	6.36								
SIGMA FOR 6G		.5	299.	.002	.21								
MEAN FOR 7G		70.2	6553.	.079	6.26								
SIGMA FOR 7G		.5	256.	.000	.19								

Fig. 6 - Summary of sled profile and initial condition parameters for each run (HTLT)

HEAD TILTED RIGHT
(HTRT)

RUN NUMBER	SUBJECT ID	PSA M/S/S	ROO M/S/S/S	DURATION SEC	END ST V M/SEC	NECK LEN METERS	EULER 1 DEG	EULER 2 DEG	EULER 3 DEG	NECK ROLL DEG	NECK PITCH DEG	AVG RANGLE DEG	SIGMA RANGLE DEG
LX2376	H075	29.5	1321.	.142	5.46	.142	34.2	-23.1	-3.5	18.2	13.8	-45.800	3.000
LX2397	H075	50.1	4613.	.100	6.54	.141	41.6	-1.6	-14.7	23.2	18.1	-27.700	5.600
LX2421	H075	69.7	6422.	.078	6.19	.153	24.7	-4.6	2.4	10.1	14.3	-35.300	4.900
					MEAN	.145	33.5	-9.8	-5.3	17.1	15.4	-36.267	4.500
					SIGMA	.005	6.9	9.5	7.1	5.4	1.9	7.421	1.098
LX2378	H078	29.4	1401.	.143	5.42	.166	24.1	-8.9	-11.0	18.1	19.9	-38.700	5.800
LX2400	H078	49.3	4469.	.099	6.53	.166	30.8	-5.6	-4.0	21.2	20.3	-30.200	2.900
LX2423	H078	69.9	6360.	.079	6.26	.174	23.4	-2.4	-8.5	12.2	24.9	-26.000	7.000
					MEAN	.169	26.1	-5.6	-7.8	17.2	21.7	-31.633	5.233
					SIGMA	.004	3.3	2.7	2.9	3.7	2.3	5.283	1.721
LX2379	H081	29.2	1257.	.141	5.40	.122	34.5	-20.7	-10.2	7.1	14.3	-43.100	4.400
LX2408	H081	49.8	4774.	.099	6.40	.132	38.6	-18.6	-2.5	9.0	11.3	-45.800	6.200
LX2441	H081	69.0	6138.	.079	6.15	.123	40.0	-12.1	3.4	11.2	15.1	-44.900	8.500
					MEAN	.126	37.7	-17.1	-3.1	9.1	13.6	-44.600	6.367
					SIGMA	.004	2.3	3.7	5.6	1.7	1.6	1.123	1.678
LX2384	H083	30.5	1599.	.143	5.62	.091	32.5	-2.4	-.6	24.9	5.8	-34.600	5.600
LX2409	H083	49.9	4964.	.100	6.49	.096	30.7	3.7	-.8	20.9	10.2	-34.600	6.200
LX2438	H083	69.1	6105.	.079	6.23	.096	23.8	-3.6	5.3	16.2	14.9	-42.300	7.900
					MEAN	.094	29.0	-.8	1.3	20.7	10.3	-37.167	6.567
					SIGMA	.002	3.7	3.2	2.8	3.6	3.7	3.630	.974
LX2385	H084	30.6	1986.	.141	5.64	.158	20.1	-13.6	-3.0	2.5	12.3	-34.000	3.400
LX2405	H084	51.2	4468.	.097	6.56	.139	25.2	-11.6	.5	9.4	11.1	-31.700	4.500
LX2437	H084	69.7	6249.	.079	6.27	.136	29.4	-11.0	-1.3	10.5	15.4	-32.800	6.200
					MEAN	.144	24.9	-12.1	-1.3	7.5	12.9	-32.833	4.700
					SIGMA	.010	3.8	1.1	1.4	3.5	1.8	.939	1.152
LX2392	H094	30.4	1656.	.140	5.58	.145	29.2	-10.3	3.3	17.2	21.0	-10.100	23.000
LX2416	H094	50.5	4804.	.099	6.59	.148	27.4	-14.0	2.3	14.1	12.5	-28.400	7.200
LX2722	H094	50.4	5293.	.101	6.43	.131	31.6	-24.1	6.3	13.3	12.3	-35.600	3.200
LX2430	H094	70.1	6081.	.078	6.24	.131	35.0	-18.0	3.2	16.0	11.6	-33.600	1.700
					MEAN	.139	30.8	-16.6	3.8	15.1	14.4	-26.925	8.775
					SIGMA	.008	2.8	5.1	1.5	1.6	3.9	10.063	8.455
MEAN FOR 3G		29.9	1537.	.142	5.52								
SIGMA FOR 3G		.6	246.	.001	.18								
MEAN FOR 5G		50.2	4769.	.099	6.51								
SIGMA FOR 5G		.6	272.	.001	.17								
MEAN FOR 7G		69.6	6226.	.079	6.22								
SIGMA FOR 7G		.4	129.	.000	.17								

Fig. 7 - Summary of sled profile and initial condition parameters for each run (HTRT)

HEAD DOWN (HDWN)

RUN NUMBER	SUBJECT ID	PSA M/S/S	ROO M/S/S/S	DURATION SEC	END ST V M/SEC	NECK LEN METERS	EULER 1 DEG	EULER 2 DEG	EULER 3 DEG	NECK ROLL DEG	NECK PITCH DEG	AVG RANGLE DEG	SIGMA RANGLE DEG
LX2463	H075	31.1	3541.	.133	5.55	.144	1.9	50.4	-2.6	-13.2	56.5	-13.700	21.200
LX2470	H075	47.6	4276.	.099	6.31	.139	-3.8	51.3	7.4	-21.2	60.4	-10.000	23.500
LX2712	H075	49.9	4703.	.100	6.35	.140	-.9	23.9	-1.1	-12.1	33.2	-28.200	8.700
LX2495	H075	59.6	5729.	.091	6.38	.140	-5.4	21.0	5.2	-15.5	35.6	-19.200	22.400
					MEAN	.141	-2.0	36.6	2.2	-15.5	46.4	-17.775	18.950
					SIGMA	.002	2.8	14.2	4.2	3.5	12.2	6.851	5.973
LX2460	H078	30.6	3972.	.142	5.53	.169	1.1	58.0	-5.0	-1.9	57.6	-30.300	5.700
LX2474	H078	50.4	4900.	.100	6.61	.170	-1.2	47.2	-2.5	-9.1	49.5	-24.300	1.700
LX2497	H078	59.6	5632.	.092	6.39	.177	-.8	38.1	-1.1	-7.2	42.6	-20.100	13.200
					MEAN	.172	-.3	47.8	-2.9	-6.1	49.9	-24.900	6.867
					SIGMA	.004	1.0	8.1	1.6	3.1	6.1	4.186	4.767
LX2534	H081	30.1	2201.	.134	5.44	.149	6.5	40.6	-8.7	-25.2	55.7	6.700	27.000
LX2580	H081	50.4	5892.	.101	6.41	.118	-9.6	15.8	-2.3	-45.6	42.4	-12.800	21.900
LX2711	H081	49.5	4795.	.101	6.29	.153	-1.1	20.2	2.1	-27.5	36.2	-8.900	27.800
LX2633	H081	59.5	6168.	.092	6.28	.161	4.7	22.0	3.9	-16.2	31.5	-17.300	21.700
					MEAN	.145	.1	24.6	-1.3	-28.6	41.4	-8.075	24.600
					SIGMA	.016	6.3	9.5	4.9	10.7	9.1	9.033	2.815
LX2466	H083	31.3	3417.	.135	5.60	.109	6.4	55.1	-5.4	-3.8	59.0	-27.900	4.400
LX2478	H083	50.4	4900.	.100	6.64	.114	8.1	56.8	-5.4	-6.7	66.8	-21.600	2.000
LX2710	H083	50.1	4789.	.100	6.41	.119	-1.0	42.8	.6	-10.5	41.7	-26.800	6.500
					MEAN	.114	4.5	51.6	-3.4	-7.0	55.8	-25.433	4.300
					SIGMA	.004	4.0	6.2	2.8	2.8	10.5	2.748	1.838
LX2459	H084	30.4	2963.	.142	5.55	.147	1.9	30.8	-7.8	-4.5	32.5	-25.300	10.500
LX2479	H084	51.0	4841.	.101	6.69	.165	1.2	37.8	-4.9	-9.2	41.0	-25.300	9.900
					MEAN	.156	1.5	34.3	-6.3	-6.8	36.8	-25.300	10.200
					SIGMA	.009	.4	3.5	1.5	2.3	4.3	.000	.300
LX2450	H094	31.5	3079.	.134	5.64	.137	10.2	64.6	-10.4	2.8	66.9	6.300	33.600
LX2487	H094	50.2	4782.	.103	6.56	.144	2.7	51.9	.2	8.1	55.0	-1.100	33.900
					MEAN	.140	6.4	58.2	-5.1	5.5	60.9	2.600	33.750
					SIGMA	.004	3.8	6.4	5.3	2.6	6.0	3.700	.150
MEAN FOR 3G		30.8	3045.	.137	5.55								
SIGMA FOR 3G		.5	429.	.004	.13								
MEAN FOR 5G		49.9	4875.	.101	6.47								
SIGMA FOR 5G		.9	401.	.001	.17								
MEAN FOR 6G		59.6	5843.	.092	6.35								
SIGMA FOR 6G		.0	233.	.000	.20								

Fig. 8 - Summary of sled profile and initial condition parameters for each run (HDWN)

as the slope on the rising portion of the acceleration profile between 20 and 50 percent of peak sled acceleration and duration is defined as the time spent above 75 percent of peak sled acceleration. End stroke velocity (END STV) is the maximum sled velocity determined from integration of the sled profile and for a given G level correlates with duration. Figure 9 shows the sled acceleration profiles for each condition defined by onset and duration averaged over subjects at 5G. The sled profiles are controlled very closely and the comparison at other G levels would be similar.

As can be seen in Figures 5 through 8 the sled profile parameters are controlled very accurately across initial conditions and subjects. The rate of onset increases with G level from 1,000m/sec^3 at 2G to 7,000m/sec^3 at 7G peak sled acceleration. The duration is relatively long decreasing with increasing G level in order to keep the end stroke velocity near constant at slightly greater than 6m/sec.

EXPERIMENTAL MEASUREMENTS - The dynamic parameters of interest presented in this paper have been derived from measurements using six piezoresistive accelerometers mounted on a T-shaped plate at the mouth and six accelerometers mounted on a T-plate at the spinous process of T_1. The configuration of the accelerometers on the T-plate and the error propagations associated with this method for determining linear displacement, velocity, acceleration and angular orientation, angular velocity and angular acceleration components of a rigid body have been described previously (7). The cinephotographic system (8) was used to obtain the initial conditions of the head and T_1 in this study. The head and T_1 instrumentation mount and attached phototargets were each acquired by two of three cameras.

In order to compare subjects at similar points in the anatomy, a definition of a head anatomical coordinate system and a T_1 anatomical coordinate system is required (1,9). These anthropometric coordinate systems are related to the instrumentation coordinate systems by three dimensional X-ray anthropometry for each subject (10).

The basic reference frame for the entire series of experiments is fixed to the laboratory. This is established by first defining a sled coordinate system, in which the origin is a benchmark permanently machined into the sled structure. The +X axis is parallel but in the opposite direction to the thrust vector of the accelerator (Figure 10). The +Z axis is parallel to gravity and positive upward and the +Y axis is established so that the XYZ axes form an orthogonal right hand triad. All coordinate systems

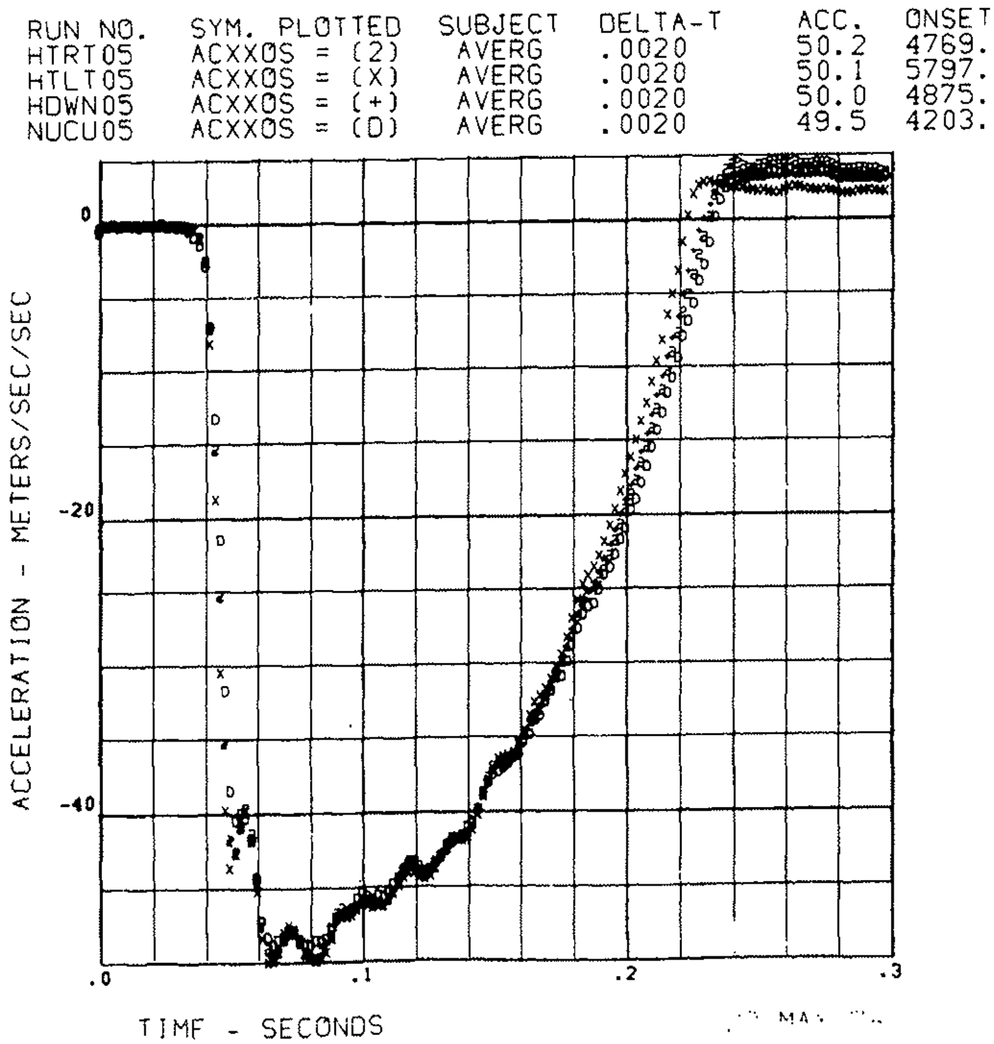


Fig. 9 - Comparison of average sled profile for each initial condition (5G)

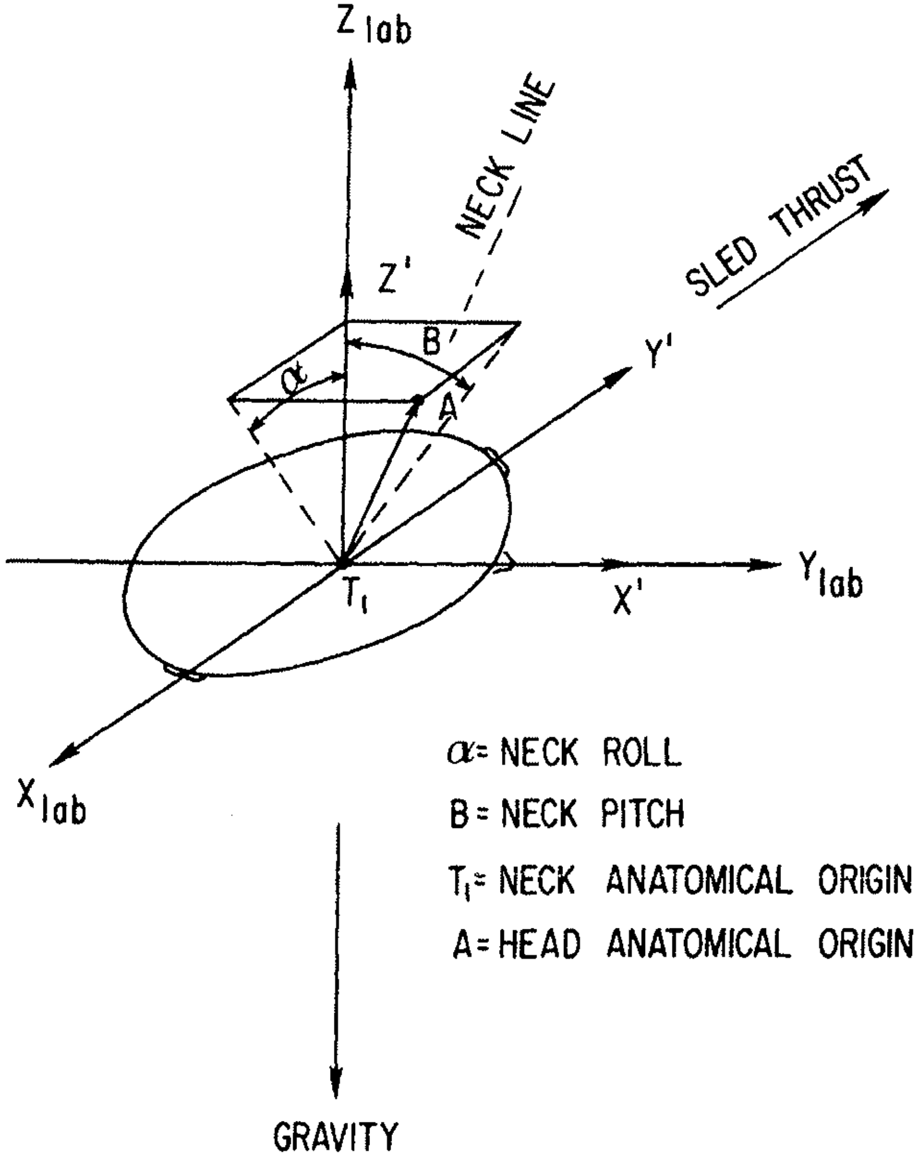


Fig. 10 - Head and neck orientation

used in this study are right handed where X,Y and Z axes are taken in that order. The sled acceleration is in the -X laboratory direction. The orientation of the subject on the sled for these +Y experiments is so that the sled acceleration is in the +Y anatomical direction.

The dependent variables presented in this report are named and defined as follows:

QHOOXS - Resultant Angular Acceleration - is the magnitude of the head angular acceleration relative to the laboratory coordinate system. The component of angular acceleration about the anatomical Y axis is not significant for these +Y acceleration runs.

RHOOXS - Resultant Angular Velocity - is the magnitude of the head angular velocity relative to the laboratory coordinate system. The component of angular velocity about the anatomical Y axis (pitch) is not significant for these +Y impact acceleration runs.

AAOXOS - Resultant Linear Acceleration - is the magnitude of the head linear acceleration at the origin of the head anatomical coordinate system relative to the laboratory reference coordinate system.

ANXXOS - Horizontal Acceleration at T_1 - is the acceleration component of the T_1 anatomical coordinate system origin relative to the laboratory reference coordinate system along the +X axis of the laboratory reference coordinate system.

ACXXOS - Sled Acceleration - is the acceleration of the sled along the X component of the laboratory coordinate system. The laboratory Y and Z components of acceleration are negligible. All of the recorded data are relative to a zero time established as 40 milliseconds prior to sled first motion as determined from the sled acceleration profile.

RANGLE - Direction of Angular Velocity Vector - is defined as the arc tangent of the component of head angular velocity about the head anatomical Z axis (yaw) divided by the head angular velocity about the head anatomical X axis (roll). The component of head angular velocity about the head anatomical Y axis is not significant for these +Y impact runs.

The average and standard deviation in this variable has been calculated in a time window where the resultant angular velocity was greater than 0.2 of the peak resultant angular velocity. The calculation was terminated at a time greater than the time of occurrence of the maximum resultant angular velocity if either the angular velocity component about the anatomical X axis (roll) was less than 0.15 or the resultant angular acceleration was less than 0.2 of the maximum resultant angular velocity. Average RANGLE and its deviation were thus calculated only in a region where the angular velocity components were significant.

If the RANGLE angle were constant it would indicate that the rotation was taking place about an axis fixed in the head anatomy or laboratory. The standard deviation in the RANGLE angle is therefore a measure of the departure from this fixed axis rotation model.

The time on all plots is relative to a time (data processing time zero - DPTZ) established as 40 milliseconds prior to first motion of the sled. First motion of the sled is determined by the best straight line fit to the rising portion of the sled acceleration profile between 20 and 50 percent of peak sled acceleration. The extrapolation of this line to its intercept with the time axis establishes the time of first motion.

INITIAL CONDITIONS - For all +Y runs the subject is seated upright in a chair so that the sled thrust vector is nominally in the direction from the right to the left shoulder, and the gravity vector is downward from the head through the subject's seat. Therefore, the initial nominal orientation of the head anatomical and the T_1 anatomical coordinate system is such that the anatomical +X is nearly along the laboratory +Y and the anatomical +Y is parallel with the laboratory -X as shown in Figure 10. The initial conditions of the neck link and the head are defined relative to a coordinate system with the Y' axis directed along the sled thrust vector, the Z' axis directed upward in the opposite direction to the gravity vector, and the X' axis directed so that X', Y', Z' form a right hand orthogonal coordinate system. This coordinate system and its orientation relative to the laboratory coordinate system and the nominal head anatomical coordinate system are shown in Figure 10. The neck link is defined by the location of the origin of the head anatomical coordinate system relative to the origin of the coordinate system for the first thoracic vertebral body (T_1). The neck link is defined by a length (NECK LEN) and two angles as shown in Figure 10. The initial orientation of the head anatomical coordinate system is defined by three Euler angles. Assuming that the head anatomical X,Y,Z coordinate system is aligned with the X', Y', Z' system in Figure 10, then Euler 1 is a rotation about the head anatomical X axis (roll), Euler 2 is a rotation about the carried head Y anatomical axis (pitch), and Euler 3 is a rotation about the carried head Z anatomical axis (yaw).

The four initial conditions investigated in this study are shown in Figures 1 through 4. The Neck Up/Chin Up (NUCU) initial condition (1) is the canonical configuration in which the subject is usually run. The other three initial conditions are variations from the normal run configuration. Each initial condition has been produced by having the subject bend his head and neck in a specified direction as far as comfortably possible. As far as possible, the bending of the head and neck were in concert with no attempt to control the head independent of the neck. Reproducibility for each initial condition was obtained by the use of a phototarget template on a TV monitor established for each subject on his first run in that initial condition. On subsequent runs, the subject was asked to align the phototargets as seen on the TV monitor with the template. This was done for all initial conditions except during the head down condition, at which time the TV monitor was not in the subject's visual field.

The definition and approximate characterization of each of the four initial conditions of this study are described in the following paragraph:

1. Neck Up/Chin Up (NUCU). In this initial condition the neck was nearly vertical or pitched slightly forward and the plane determined by the auditory meatuses and orbital ridges of the eyes was near horizontal.

2. Head Tilted Left (HTLT). The subject sitting in the NUCU position bends his head and neck toward the left shoulder as far as comfortably possible.

3. Head Tilted Right (HTRT). The subject sitting in the NUCU position bends his head and neck toward the right shoulder as far as comfortably possible.

4. Head Down (HDWN). The subject sitting in the NUCU position bends his head and neck forward as far as comfortably possible.

The significant descriptors for the initial conditions HTLT and HTRT are Euler 1 (roll) in Figures 6 and 7 respectively. The average value of Euler 1 for these conditions is approximately +30 and -30 degrees for the HTRT and HTLT initial conditions respectively. If one calculates the angle the neck link projected into the XZ laboratory plane makes with the Z axis (neck roll), it is found to be approximately equal to the head roll (Euler 1) for most runs. This justifies that the head and neck do move in concert and that the neck link orientation in the head anatomy does not change appreciably.

The significant angle for the HDWN condition is Euler 2 (head pitch). As shown in Figure 8, and the average angle of Euler 2 for the HDWN condition is approximately +42 degrees. In some subjects the angle decreases at the higher G levels to avoid the possibility of a chin strike on the right shoulder. Once again, if one calculates the angle that the neck link projected into the laboratory YZ plane makes with the laboratory Z axis (neck pitch angle), it is found to be approximately equal to the head pitch angle (Euler 2). The selection of these particular angles to represent the neck link configuration was made to facilitate direct comparison with angles defining head orientation.

EXPERIMENTAL DESIGN - Six human volunteer subjects covering a wide range of anthropometric parameters (Figure 11) were each exposed to +Y sled acceleration profiles at nominal peak sled accelerations of 2,3,5,6 and 7G. Each subject was run in four distinct initial conditions defined by the orientation of the head anatomy and the neck link, relative to the thrust vector of the sled. The thrust vector was perpendicular to gravity. A photograph of a subject in each of the four initial condition configurations is shown in the uppermost picture of Figures 1 through 4. The direction of the sled thrust vector is shown on these same photographs and is nominally directed from the right to left shoulder of the subject. The time of center of shutter opening of the Milliken cameras is shown to the right on each frame in hours, minutes and seconds to one tenth of a millisecond.

The results presented in this paper encompass a total of 100 separate +Y experiments including duplications at the 5G level for each of the initial conditions. More specifically, two of the four initial conditions (NUCU, HTLT) were investigated for each subject at the 2G level. All four initial conditions (NUCU, HTLT, HTRT and HDWN) were studied at 3 and 5G. Three initial conditions (NUCU, HTLT and HDWN) were investigated at 6G, and three initial conditions (NUCU, HTLT and HTRT) were investigated at 7G. The assignment of the initial condition at each G level was determined by the response of the subject to the HDWN condition. Subjects who nearly struck their chin against the right shoulder or right shoulder restraint at 5G were not run at 6G and no subjects were run in this HDWN condition at 7G. Sled acceleration profile parameters and the initial condition for each subject and for each run are listed by run number and subject number, Figures 5 through 8.

Subject	Age at time of measurement	Stature Cm	Stature Inches	Stature Percentile	Weight Kg	Weight Lbs	Weight Percentile	Sitting Height Cm	Sitting Height Inches	Sitting Height Percentile
H075	22	164.50	64.8	1st %	65.5	144	8th %	86.10	33.9	3rd %
H078	22	187.30	73.8	94th %	76.8	169	46th %	97.40	38.4	95th %
H081	20	191.40	75.4	99th %	108.4	239	99th %	95.80	37.7	88th %
H083	21	180.00	70.9	65th %	75.7	167	41st %	92.40	36.4	53rd %
H084	18	167.60	66.0	4th %	61.2	135	2nd %	89.00	35.0	18th %
H094	20	182.30	71.8	77th %	78.9	174	56th %	95.70	37.7	87th %

Percentiles are relative to "Anthropometry of Naval Aviators - 1964," by Edmund C. Gifford, Joseph R. Provost, and John Lazo. U.S. Naval Air Engineering Center, Philadelphia, Pennsylvania. NAEC-ACEL-533, 8 October 1965.

Fig. 11 - Selected anthropometry of volunteer subjects (11)

ANALYTICAL METHODS - This study is directed toward the evaluation of the average effects of initial conditions over subjects. The data from the subjects were pooled to obtain average profiles of parameters of interest as well as for purposes of subsequent regression analysis on peak values of interest. The average profile for each variable of interest was calculated for each experimental initial condition and comparison plots of these average profiles are shown for a peak sled acceleration level of 5G in Figures 12 through 15. The 5G level was selected because it was the highest G level for which all four initial conditions were investigated. The comparison of other G levels has been calculated and would have indicated similar results.

The average profile for each condition has been obtained by averaging across subjects using the time of first motion as determined from the sled profile to align the profiles of the subjects. The variations in time at which peak values of head and T_1 response measurements occured were small enough across subjects so that the average profiles were an excellent summary of the replications.

The standard deviation across subjects and within subject was evaluated in a time window from 60 to 220 milliseconds for each of the plotted average profiles and is presented in Figure 16.

In this study, the effects of initial conditions on head peak angular acceleration, head peak angular velocity, head peak resultant linear acceleration and peak horizontal acceleration at T_1 were of particular interest.

For each variable of interest, the peaks were read manually from the time profile for that variable. The first positive major peak was used for the parameters of head angular acceleration, angular velocity, and resultant linear acceleration. These peaks were ordinarily found to be the largest for these runs with the exception that the second peak in the head angular acceleration profile was often larger than the first peak for the HTRT initial condition.

An unambiguous first peak was found to be more difficult to define for the horizontal linear acceleration at T_1. The first peak was always negative and was usually followed by a relatively sharp decrease in magnitude followed by a series of lesser peaks. The first peak was selected as the peak value as long as the decrease subsequent to it was of sufficient magnitude. However, if the decrease was minor and the continuing part of the curve fit in well with its antecedent the second peak was selected.

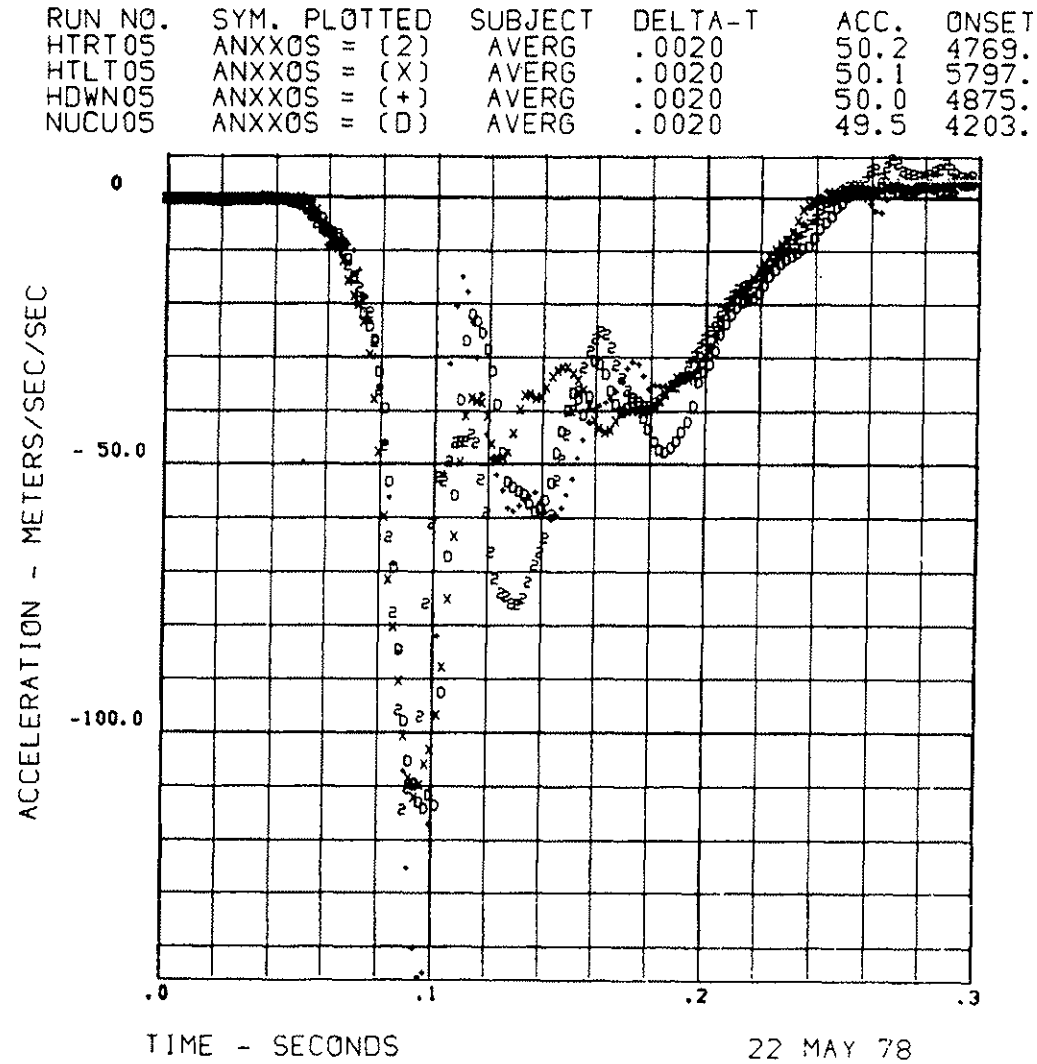


Fig. 12 - Comparison of average horizontal acceleration a
T_1 for each initial condition (5G)

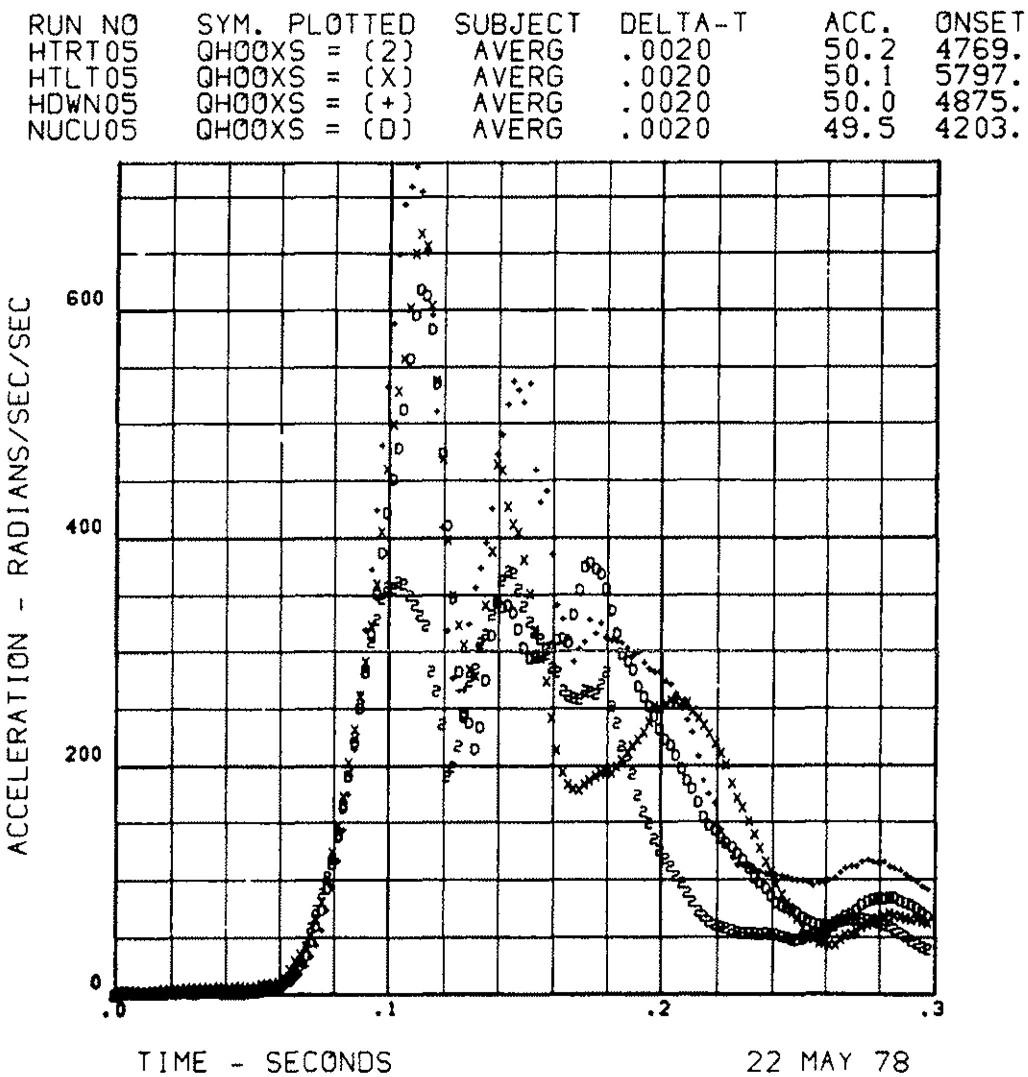


Fig. 13 - Comparison of average resultant angular acceleration for each initial condition (5G)

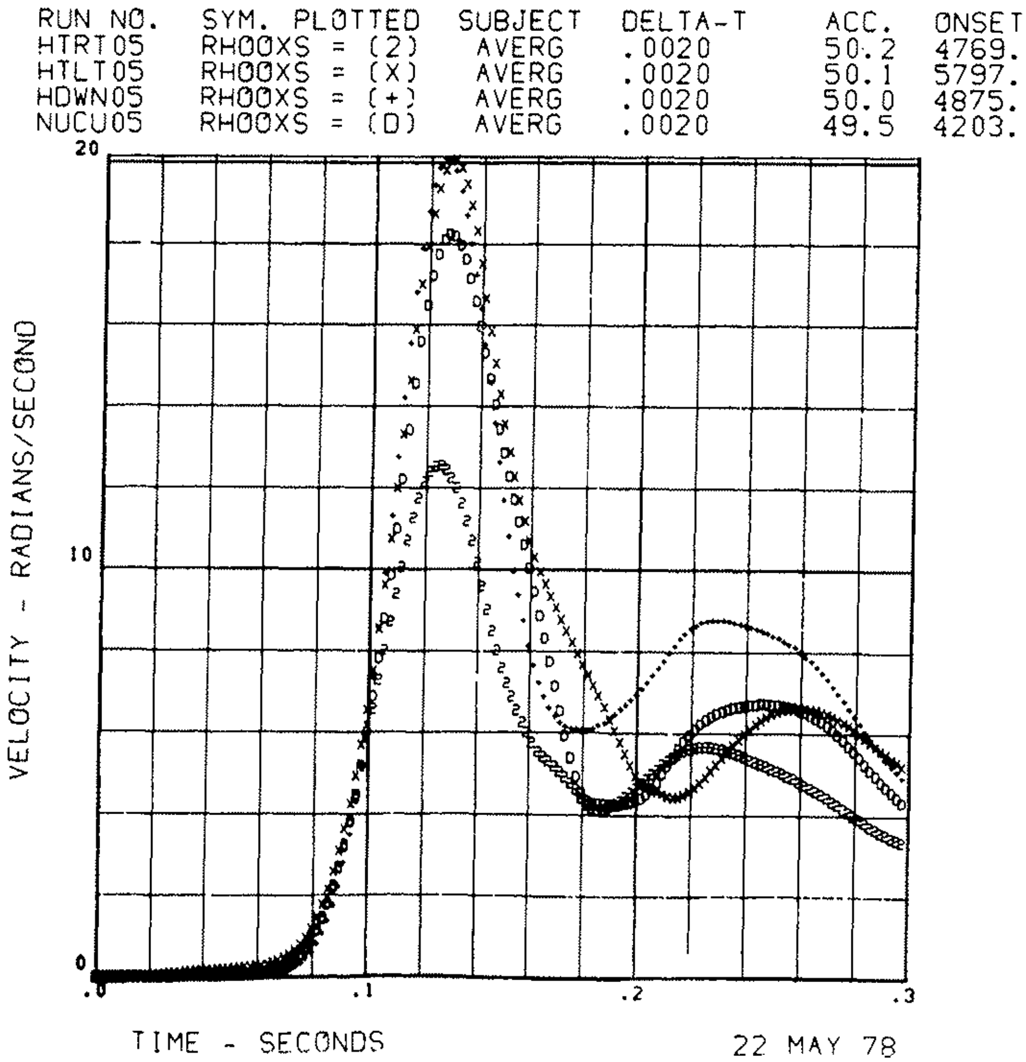


Fig. 14 - Comparison of average resultant angular velocity for each initial condition (5G)

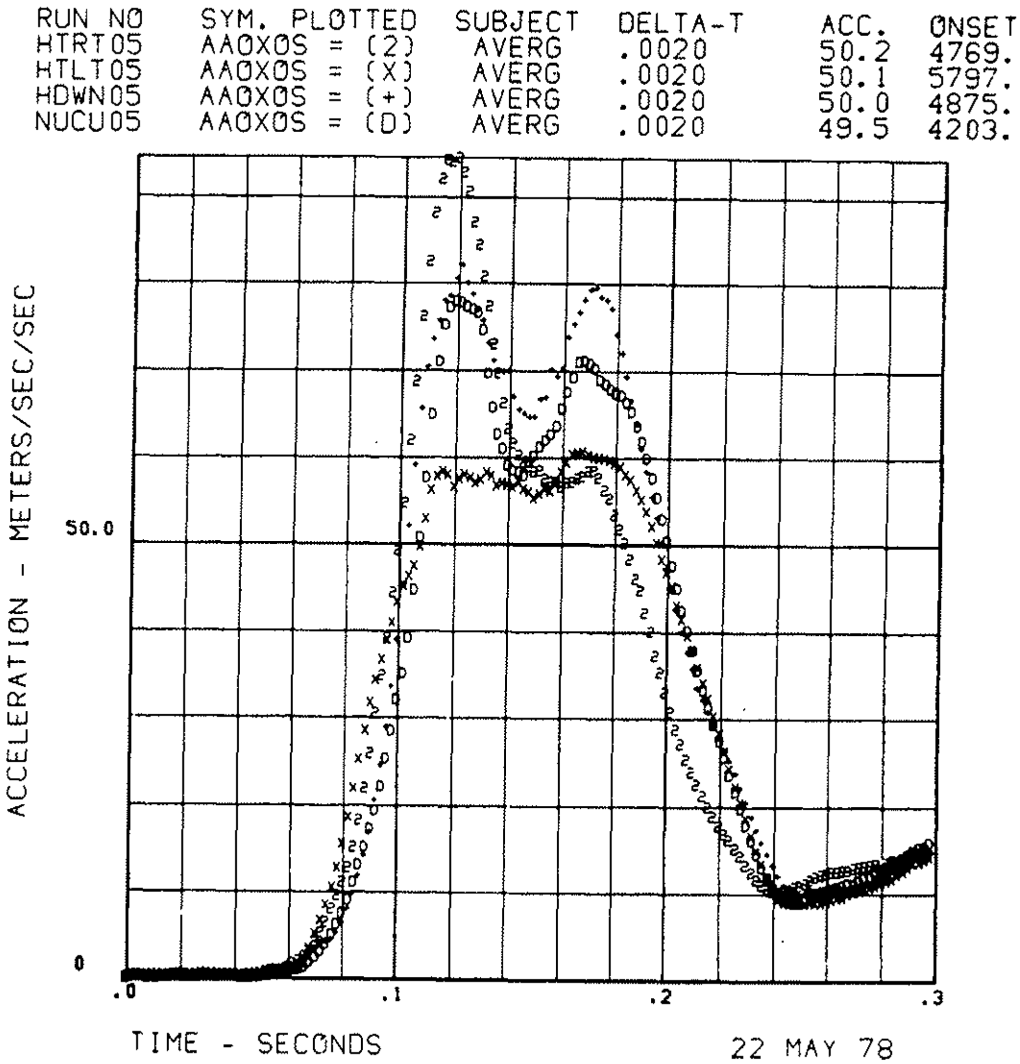


Fig. 15 - Comparison of resultant linear acceleration of head anatomical origin for each initial condition (5G)

INIT COND / VAR.	NUCU		HTLT		HTRT		HDWN		
ANXXOS	12.1	m/sec^2	13.0		12.1		10.9		3G
QHOOXS	75.1	rad/sec^2	57.1		42.8		73.2		
RHOOXS	2.3	rad/sec	1.9		1.4		2.0		
AAOXOS	6.0	m/sec^2	4.3		5.8		4.6		
		within subj.		within subj.		within subj.		within subj.	
ANXXOS	23.8	12.6	13.6	8.1	25.3	17.0	19.4	13.5	5G
QHOOXS	105.3	56.0	95.3	75.5	101.9	39.0	115.4	92.0	
RHOOXS	2.1	0.88	2.5	1.0	2.1	0.6	2.1	1.2	
AAOXOS	9.4	5.5	9.0	2.8	9.6	5.0	7.6	5.2	
ANXXOS	34.0				32.5		32.5		7G
QHOOXS	182.2				180.6		135.2		
RHOOXS	2.4				2.6		2.7		
AAOXOS	13.2				14.6		12.4		

Fig. 16 - Deviation on profile parameter from average profile for each initial condition (3, 5 and 7G)

The peak values for the variables of interest are compared for the four initial conditions for each subject at the 3,5 and 7G levels in Figures 17 through 19. These peak values, together with the peak values at 2 and 6G, were regressed on combinations of sets of the following variables.

1. Peak sled acceleration or peak linear horizontal acceleration at T_1
2. Euler 1 (head roll angle)
3. Euler 2 (head pitch angle)
4. Neck roll angle
5. Neck pitch angle

A stepwise multiple linear regression was used in which independent variables were eliminated from the regression on the basis of an F test if found not to be significant at the five percent level.

RESULTS

Figures 1 through 4 show photographs of a subject at the times of critical events in the dynamic response profile for each of the initial conditions investigated in this study. The NUCU initial condition is shown in Figure 1. The conditions shown in Figures 2 through 4 should be compared to NUCU, Figure 1. The uppermost photograph for each initial condition is just prior to first motion of the sled and illustrates the configuration of the head and neck for that condition. The thrust vector direction is from the right to the left shoulder and is indicated in each figure. The events depicted in each figure are in chronological order and are as follows:

a. The time of first motion of the sled.
b. The time at which the peak resultant angular acceleration of the head occurs.
c. The time at which the peak resultant linear acceleration of the head anatomical origin occurs.
d. The time at which the peak resultant angular velocity of of the head occurs.
e. The time at which the maximum angular displacement of the head occurs.

Observation of these figures indicates that these critical events in the dynamic response to +Y acceleration occur at greatly different head and neck orientation for the different initial conditions. This is particularly evident for the HTLT initial condition. The average times of occurrence of these events are

G LEVEL

3

RUN	SUBJECT	INIT COND	PEAK SLED ACC	PK ACC AT TI	TIME TO PK ACC AT TI	PK RES HEAD ANG ACC	TIME TO PK HEAD ANG ACC	PK RES HEAD ANG VEL	TIME TO PK HEAD ANG VEL	PK RES HEAD LIN ACC	TIME TO PEAK LIN ACC
			M/S/S	M/S/S	SEC	RAD/S/S	SEC	RAD/SEC	SEC	M/S/S	SEC
1625	75	NUCU	29.7	-67.4	.117	400.0	.131	12.66	.148	56.9	.145
2544	75	HTLT	30.6	-72.7	.111	383.0	.130	12.65	.141	47.8	.132
2376	75	HTRT	29.5	-53.8	.110	179.0	.115	6.98	.136	49.6	.133
2463	75	HDWN	31.1	-60.3	.104	409.0	.115	12.80	.132	47.2	.129
1780	78	NUCU	30.2	-54.8	.114	314.0	.122	10.47	.139	45.0	.154
2540	78	HTLT	29.8	-55.4	.103	340.0	.117	9.72	.136	46.0	.175
2378	78	HTRT	29.4	-52.7	.106	230.0	.116	7.82	.135	37.7	.134
2460	78	HDWN	30.6	-46.6	.090	309.0	.111	10.61	.129	48.0	.180
1779	81	NUCU	30.5	-98.2	.114	401.0	.131	12.81	.151	52.7	.137
2546	81	HTLT	29.8	-102.0	.104	330.0	.116	13.26	.144	32.0	.110
2379	81	HTRT	29.2	-57.5	.134	137.0	.118	5.36	.143	56.7	.138
2534	81	HDWN	30.1	-105.0	.109	462.0	.129	14.13	.148	52.1	.138
1785	83	NUCU	29.9	-91.7	.114	439.0	.129	13.66	.149	58.0	.142
2537	83	HTLT	30.3	-98.1	.116	388.0	.121	10.70	.139	46.9	.144
2384	83	HTRT	30.5	-90.7	.111	233.0	.119	8.98	.145	60.2	.138
2466	83	HDWN	31.3	-84.1	.102	413.0	.111	11.91	.132	47.4	.131
1880	84	NUCU	30.3	-57.2	.106	295.0	.120	9.40	.138	48.0	.140
2531	84	HTLT	30.1	-53.9	.110	273.0	.119	9.82	.134	41.9	.138
2385	84	HTRT	30.6	-70.3	.096	232.0	.107	8.15	.126	58.3	.133
2459	84	HDWN	30.4	-60.0	.099	242.0	.102	9.42	.125	48.4	.133
1876	94	NUCU	30.0	-91.0	.135	560.0	.153	17.22	.172	66.6	.157
2524	94	HTLT	29.9	-80.5	.115	354.0	.128	11.81	.152	33.0	.160
2392	94	HTRT	30.4	-99.1	.121	165.0	.115	9.14	.158	53.2	.139
2450	94	HDWN	31.5	-71.8	.111	382.0	.124	13.54	.143	43.0	.143
	AVG	NUCU	30.1	-76.7	.117	401.5	.131	12.70	.149	54.5	.146
	DEV		.3	17.5	.009	87.1	.011	2.49	.011	7.1	.007
	AVG	HTLT	30.1	-77.1	.110	344.7	.122	11.33	.141	41.3	.143
	DEV		.3	18.7	.005	38.3	.005	1.35	.006	6.5	.021
	AVG	HTRT	29.9	-70.7	.113	196.0	.115	7.74	.140	52.6	.136
	DEV		.6	18.2	.012	37.8	.004	1.29	.010	7.5	.003
	AVG	HDWN	30.8	-71.3	.102	369.5	.115	12.07	.135	47.7	.142
	DEV		.5	19.0	.007	73.1	.009	1.64	.008	2.7	.017

Fig. 17 - Summary of peak values for each variable and each initial condition by subject (3G)

G LEVEL

5

RUN	SUBJECT	INIT COND	PEAK SLED ACC	PK ACC AT T1	TIME TO PK ACC AT T1	PK RES HEAD ANG ACC	TIME TO PK HEAD ANG ACC	PK RES HEAD ANG VEL	TIME TO PK HEAD ANG VEL	PK RES HEAD LIN ACC	TIME TO PEAK LIN ACC
			M/S/S	M/S/S	SEC	RAD/S/S	SEC	RAD/SEC	SEC	M/S/S	SEC
1635	75	NUCU	48.2	-117.0	.102	604.0	.113	18.44	.129	89.2	.119
1827	75	NUCU	50.6	-122.0	.104	614.0	.110	18.05	.127	83.2	.124
2575	75	HTLT	50.7	-118.0	.106	594.0	.111	17.69	.125	64.3	.112
2397	75	HTRT	50.1	-101.0	.102	422.0	.115	13.01	.126	102.0	.118
2470	75	HDWN	47.6	-127.0	.092	695.0	.108	19.43	.122	71.5	.117
2712	75	HDWN	49.9	-137.0	.097	1110.0	.112	26.57	.128	102.0	.102
1824	78	NUCU	50.0	-91.3	.100	668.0	.115	17.99	.129	80.6	.132
2703	78	HTLT	50.1	-105.0	.092	695.0	.112	18.35	.129	65.2	.140
2577	78	HTLT	50.2	-126.0	.093	844.0	.115	23.61	.133	79.8	.143
2400	78	HTRT	49.3	-70.1	.104	366.0	.098	11.12	.116	76.4	.125
2474	78	HDWN	50.4	-80.7	.092	617.0	.110	18.34	.125	76.9	.130
1796	81	NUCU	49.8	-252.0	.098	941.0	.114	22.24	.134	88.9	.117
2596	81	HTLT	49.3	-148.0	.093	770.0	.114	20.97	.130	65.6	.130
2408	81	HTRT	49.8	-236.0	.093	534.0	.114	12.90	.123	112.0	.116
2580	81	HDWN	50.4	-291.0	.095	830.0	.114	22.85	.133	91.1	.123
2711	81	HDWN	49.5	-188.0	.097	526.0	.115	17.53	.132	87.3	.124
1831	83	NUCU	49.3	-227.0	.102	772.0	.111	19.52	.130	86.5	.127
2341	83	NUCU	48.0	-141.0	.091	498.0	.097	16.48	.125	65.3	.116
2565	83	HTLT	50.2	-120.0	.093	577.0	.106	19.70	.124	55.9	.117
2409	83	HTRT	49.9	-166.0	.097	518.0	.099	13.64	.116	86.8	.128
2478	83	HDWN	50.4	-188.0	.098	840.0	.106	20.16	.122	83.3	.121
2710	83	HDWN	50.1	-135.0	.100	827.0	.106	19.83	.122	94.7	.122
2317	84	NUCU	49.4	-106.0	.087	587.0	.101	17.47	.118	69.5	.115
2359	84	NUCU	50.7	-116.0	.092	600.0	.106	17.72	.123	70.3	.121
2586	84	HTLT	50.4	-101.0	.089	677.0	.102	16.90	.124	67.7	.117
2405	84	HTRT	51.2	-104.0	.094	403.0	.099	13.73	.123	92.7	.114
2479	84	HDWN	51.0	-126.0	.095	705.0	.110	19.49	.125	82.6	.117
2312	94	NUCU	49.4	-156.0	.091	896.0	.117	20.89	.132	105.0	.122
2354	94	NUCU	50.1	-139.0	.098	719.0	.115	19.69	.133	83.0	.117
2599	94	HTLT	49.8	-157.0	.100	835.0	.113	25.34	.135	64.4	.137
2416	94	HTRT	50.5	-123.0	.107	362.0	.114	14.93	.139	91.7	.120
2722	94	HTRT	50.4	-111.0	.101	396.0	.113	15.50	.139	117.0	.121
2487	94	HDWN	50.2	-139.0	.099	717.0	.110	21.96	.132	74.8	.130
	AVG	NUCU	49.5	-146.7	.096	689.9	.110	18.85	.128	82.0	.121
	DEV		.9	49.9	.006	135.0	.006	1.65	.005	11.0	.005
	AVG	HTLT	50.1	-125.0	.095	711.7	.110	20.65	.129	66.1	.128
	DEV		.4	19.3	.005	101.4	.004	2.64	.004	6.6	.012
	AVG	HTRT	50.2	-130.2	.100	431.6	.107	13.55	.126	96.9	.120
	DEV		.6	50.8	.005	62.0	.008	1.33	.009	13.2	.005
	AVG	HDWN	49.9	-156.9	.096	763.0	.110	20.68	.127	84.9	.121
	DEV		.9	56.5	.003	157.2	.003	2.59	.004	9.3	.008

Fig. 18 - Summary of peak values for each variable and each initial condition by subject (5G)

G LEVEL

7

RUN	SUBJECT	INIT COND	PEAK SLED ACC	PK ACC AT T1	TIME TO PK ACC AT T1	PK RES HEAD ANG ACC	TIME TO PK HEAD ANG ACC	PK RES HEAD ANG VEL	TIME TO PK HEAD ANG VEL	PK RES HEAD LIN ACC	TIME TO PEAK LIN ACC
			M/S/S	M/S/S	SEC	RAD/S/S	SEC	RAD/SEC	SEC	M/S/S	SEC
1921	75	NUCU	71.1	-147.0	.086	1114.0	.104	27.07	.118	140.0	.108
2669	75	HTLT	70.4	-154.0	.089	1146.0	.104	26.98	.119	111.0	.110
2421	75	HTRT	69.7	-131.0	.090	547.0	.096	18.71	.115	130.0	.108
1926	78	NUCU	68.8	-129.0	.093	979.0	.105	23.75	.117	139.0	.120
2673	78	HTLT	69.5	-195.0	.088	996.0	.109	30.17	.124	105.0	.129
2423	78	HTRT	69.9	-175.0	.096	704.0	.103	18.75	.115	127.0	.113
1927	81	NUCU	69.0	-407.0	.090	1614.0	.104	31.45	.120	142.0	.110
2674	81	HTLT	69.6	-393.0	.094	1698.0	.111	34.54	.126	123.0	.128
2441	81	HTRT	69.0	-185.0	.082	703.0	.105	16.17	.112	148.0	.107
1928	83	NUCU	69.2	-288.0	.088	1111.0	.100	24.34	.116	139.0	.113
2438	83	HTRT	69.1	-155.0	.086	569.0	.098	20.59	.119	118.0	.111
2677	84	HTLT	70.6	-219.0	.092	1127.0	.099	29.40	.120	103.0	.119
2437	84	HTRT	69.7	-144.0	.094	636.0	.101	18.78	.119	140.0	.108
2337	94	NUCU	70.4	-279.0	.093	1546.0	.108	28.01	.120	127.0	.110
2694	94	HTLT	70.7	-184.0	.085	1130.0	.109	31.63	.124	85.0	.129
2430	94	HTRT	70.1	-303.0	.096	742.0	.112	18.31	.131	187.0	.113
	AVG	NUCU	69.7	-250.0	.090	1272.8	.104	26.92	.118	137.4	.112
	DEV		.9	102.2	.003	256.4	.003	2.77	.002	5.3	.004
	AVG	HTLT	70.2	-229.0	.090	1219.4	.106	30.54	.123	105.4	.123
	DEV		.5	84.6	.003	245.3	.004	2.50	.003	12.4	.008
	AVG	HTRT	69.6	-182.2	.091	650.2	.102	18.55	.118	141.7	.110
	DEV		.4	57.0	.005	72.5	.005	1.29	.006	22.4	.002

Fig. 19 - Summary of peak values for each variable and each initial condition by subject (7G)

shown in Figures 17 through 19 for each initial condition for 3, 5 and 7G respectively. Although the orientation of the head and neck at the time of these critical events is different, the times from first motion are approximately the same for all conditions except the HTRT initial condition. The events occur somewhat earlier for the HTRT initial condition. Subsequently, it will be shown that the dynamic response is greatly different only for this HTRT initial condition where the initial displacement of the head and neck is in the direction of the induced motion.

Comparison of the average response profile for the four initial conditions at the 5G level for the variables horizontal acceleration at T_1, resultant head angular acceleration, resultant angular velocity and resulting head linear acceleration at the head anatomical origin are shown in Figures 12 through 15 respectively. The average for each condition was calculated across all subjects using first motion of the sled to align the individual subject profiles. The 5G level was selected because it was representative of the results at other G levels and it was the highest G level at which all the initial conditions were investigated.

It can be observed from these comparison curves that there is a general similarity in shape for each of these variables independent of initial condition. The most dramatic difference is the relatively low magnitude angular acceleration and velocity of the HTRT condition relative to all other conditions (Figures 13 and 14). This was true for the comparison of average profiles for all G levels investigated in this study and also true for initial conditions compared for each subject.

One exception to the general similarity of the average profiles occur in the peak resultant head angular acceleration (Figure 13) for the HTRT initial condition. For this condition the second peak in the profile (deceleration peak) is much higher relative to the first peak than for the other initial conditions. On individual runs this peak was often higher than the first peak for this initial condition. This increased second peak (deceleration peak) is consistent with the relatively attenuated, narrow angular velocity profile for this initial condition (Figure 14). In contrast to the head angular acceleration and velocity, the resultant linear acceleration at the head anatomical origin (Figure 15) is usually greatest for HTRT condition and lowest for the HTLT condition. This is true for comparisons of averages across subjects as well as on individual subjects at all G levels.

The standard deviation evaluated across subjects from the average profiles presented in Figures 12 through 15 are shown for each initial condition at the 3, 5 and 7G levels in Figure 16. As mentioned previously, these standard deviations were evaluated in a time window between 60 to 220 milliseconds where the significant portion of the dynamic response occurs. The variability is appreciable and can be seen to increase with G level. At the 5G level, a number of duplicate runs were made on several subjects. Subjects 75, 83, 84 and 94 had duplicate runs in the NUCU condition, whereas subject 75, 81 and 83 had duplicate runs in the HDWN condition. Subject 78 and 94 had duplicate runs in the HTLT and HTRT conditions respectively. For comparisons, the standard deviation corresponding to within subject variability is also presented for each initial condition at 5G. It should be noted that within subject variability is significantly less than among subject variability.

This result is not suprising since in these +Y experiments with the transmission of forces from the sled through the slightly padded wood board to the right shoulder one would expect a subject dependent response at T_1. The variability between subjects is not so much a profile shape change as it is a magnitude and time shift change due to the response at T_1.

In Figures 17 through 19, the peak values of the linear horizontal acceleration at T_1, the resultant head angular acceleration and angular velocity, the resultant head linear acceleration at the head anatomical origin are compared for each initial condition for each subject at the 3, 5 and 7G level respectively. The times of occurrence of these peak values are also compared in these same figures.

At the bottom of Figures 17 through 19, the average peak values across subjects and the standard deviations are given for each initial condition. Comparison of average peak values from these figures with the peaks of the average profiles shows the average profile peak values to be somewhat smaller. This is to be expected as the average profile peaks are attenuated because the peak values for each subject in the average do not occur at the same time. This is particularly noticeable in the higher bandwidth profiles such as peak horizontal acceleration at T_1 and peak resultant angular acceleration. Although the average peak values of Figures 17 through 19 are greater than the peaks on the average profiles, both qualitatively indicate the similar result that the peak resultant head angular acceleration and angular velocity are drastically reduced for the HTRT initial condition. As with the average profiles, Figures 17 through 19 indicate that the resultant linear acceleration at the head anatomical origin is in general greatest for the HTRT condition and least for the HTLT condition. The same conclusions are reached when comparing the initial conditions for each subject. It is interesting to point out that a similar result was obtained in the study of initial condition with the -X experiments (1). The initial condition (neck forward/head down) where the head and neck were initially displaced in the direction of induced motion had much lower angular accelerations and velocities.

The data in Figures 17 through 19 augmented with similar data at the 2 and 6G levels were used in a stepwise multiple regression to quantify the effect of initial head and neck orientation on the peak values of interest. The results of the stepwise multiple regression for the peak resultant head angular acceleration and velocity, and the peak linear resultant acceleration at the head anatomical origin are presented in Figure 20. A dash in a particular coefficient column indicates that a particular independent variable was not considered in the regression whereas a notation of "INSIGN" indicates that regression on that variable was not found significant at the five percent level. The units for each coefficient are the units of the dependent variable divided by the units of the independent variable. The column labeled "condition" specified what G levels and initial conditions were pooled in the regression analysis. Figure 20a, b and c are for all initial conditions pooled, all except HTLT and all except HTRT respectively.

Observations of Figure 20a where all the initial conditions are pooled, indicate that a positive Euler 1 angle (head roll to right) reduces the angular acceleration by 9.7 rad/sec^2 per degree and the angular velocity by 0.22 rad/sec per degree. Neck roll to the right, on the other hand, increases the angular acceleration and angular velocity by 8.4 rad/sec^2 per degree and 0.18 rad/sec per degree respectively. Hence head tilted to the right relative to the neck magnifies the decrease in angular acceleration and angular velocity. The linear acceleration at the head anatomical origin increases with neck roll to the right (0.73m/sec^2 per degree). The head angular acceleration and velocity also increase with increased neck pitch angle (2.74 rad/sec^2 per degree and 0.073 rad/sec per degree respectively). The horizontal acceleration at T_1 decreases with head roll to the right and increases with neck roll to the right.

Of course, the coefficients in Figure 20 imply just the opposite effect for head and neck rolled to the left. The average

Coeff. / Dep. Variable	Const. Units of Dep. Var	PSA m/sec^2	ANXXOS m/sec^2	Euler 1 Deg.	Neck Roll Deg.	Euler 2 Deg.	Neck Pitch Deg.	St'd Dev. Units of Dep. Var.	Condition
QHOOXS rad/sec^2	112.0	--	-3.84	-9.70	+8.4	Insign.	2.74	169.0	All G levels NUCU, HTLT, HTRT, HDWN
RHOOXS rad/sec	7.38	--	-0.072	-0.22	0.18	Insign.	0.073	3.85	"
AAOXOS m/sec^2	41.1	--	-0.33	Insign.	0.73	Insign.	Insign.	20.7	"
ANXXOS m/sec^2	50.7	-3.51	--	-1.68	2.84	Insign.	Insign.	53.7	"

Figure 20a

QHOOXS	211.0	--	-3.55	-14.02	10.11	Insign.	2.30	160.0	All G levels NUCU, HTRT, HDWN
RHOOXS	9.37	--	-0.064	-0.27	+0.18	Insign.	0.061	3.33	"
AAOXOS	38.8	--	-0.35	Insign.	0.77	Insign.	Insign.	22.2	"

Figure 20b

QHOOXS	198.0	--	-3.91	-6.11	8.43	Insign.	Insign.	173.0	All G levels NUCU, HTLT, HDWN
RHOOXS	7.77	--	-0.075	-0.19	+0.19	Insign.	0.06	3.96	"
AAOXOS	42.2	--	-0.300	Insign.	0.603	Insign.	Insign.	19.1	"

Figure 20c

Fig. 20A-C - Summary of coefficients from stepwise multiple regression profiles (Figures 12 through 15) and the peak value tables (Figures 17 through 19) indicated a much bigger effect on the dynamic response for the HTRT condition than for the HTLT condition. Comparison of the top, middle and bottom portions of Figure 20 support this asymmetry in response indicating much larger effects on peak values of interest when the head is rolled to the right than when it is rolled to the left.

In a previous paper presented at the Twenty-First Stapp Car Crash Conference, (3) it was indicated that the angle the angular velocity vector makes in the head anatomical coordinate system (RANGLE angle) is approximately constant during the time for which the magnitude of the angular velocity vector was significant. The head rotation for most runs appeared to be taking place around a fixed axis between the anatomical X and -Z axis. The apparent fixed axis made an angle of approximately 35 degrees with the anatomical X axis for most subjects. Because of the possible implications to modeling the response to +Y accelerations, this same angle was calculated in this study for each initial condition .

The RANGLE angle is presented in the next to last column of Figures 5 through 8 for the NUCU, HTLT, HTRT and HDWN initial conditions respectively. This angle is shown for each subject at each G level as well as the average angle across G levels for each subject. The last column of these same figures indicates the standard deviation in this angle calculated in a time window where the resultant angular velocity was significant as indicated in the methods sections of this paper. The smaller the deviations in RANGLE angle the more reasonable the assumptions of a fixed axis model.

Observation of Figure 5 for the NUCU condition shows that this angle is approximately -35 degrees for all subjects and in most runs the standard deviation in this angle is relatively small. The fixed axis assumption is approximately true for the HTLT and HTRT initial conditions where the average angle is once again about -35 degrees. In the HDWN initial conditions however, the RANGLE angle is less than for other initial conditions and the variability in this angle is greater indicating a motion with more degrees of freedom than implied by the fixed axis model for this initial condition. This more complicated motion in the HDWN condition is easily observed in Figure 4.

A possible explanation for the near constant RANGLE angle can be obtained by considering a hinge point located between the head and neck links of a model in which the torque developed is negligible. Under these conditions a simple relationship exists between the linear acceleration of the head center of gravity and the angular accelerations of the head. This should provide an excellent means of locating the head/neck hinge point for modeling purposes and will be explored in detail in a subsequent paper.

CONCLUSIONS

A study of 100 (+Y) impact acceleration experiments on six human subjects in four different initial head and neck configurations has indicated the following:

1. Lateral bending of the head and neck in the direction of the acceleration induced motion significantly reduces the resultant peak head angular acceleration and velocity. This result for +Y acceleration is similar to that found in the -X direction.
2. Lateral bending of the head and neck in the direction of the acceleration induced motion often produces an angular acceleration profile with a deceleration peak greater than the acceleration peak. This result was also reported in the -X impact experiments.
3. Lateral bending of the head and neck in direction of the acceleration induced motion increases the linear resultant acceleration at the head anatomical origin.
4. Regression analysis indicates that the roll of the head has a larger but opposite effect to the roll of the neck, so that bending of the head relative to the neck in the direction of the induced motion tends to make the reduction of head angular acceleration and velocity greater.
5. Bending of the head and neck forward (pitch) increases the angular acceleration and velocity.
6. The effects of bending of the head and neck in the direction of the acceleration induced motion (roll) are greater than for the bending in the opposite direction.
7. The direction of the head angular velocity vector in the head anatomy is in most cases near constant for head and neck roll conditions but departs from this model quite significantly for the initial condition where the head and neck are pitched forward.
8. With the possible exception of the initial condition where the head and neck are pitched forward significantly, one should be able to approximate all of the other initial conditions in this study with the same type of fixed axis model.

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REFERENCES

1. C. L. Ewing, D. J. Thomas, L. Lustick, E. Becker, G. Willems and W. H. Muzzy III, "The Effects of the Initial Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to -Gx Impact Acceleration", Proceedings, Nineteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA, 1975.

2. C. L. Ewing, D. J. Thomas, L. Lustick, W. H. Muzzy III, G. Willems and P. L. Majewski, "The Effect of Duration, Rate of Onset and Peak Sled Acceleration on the Dynamic Response of the Human Head and Neck", Proceedings, Twentieth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA, 1976.

3. C. L. Ewing, D. J. Thomas, L. Lustick, W. H. Muzzy III, G. Willems and P. L. Majewski, "Dynamic Response of Human Head and Neck to +Gy Impact Acceleration", Proceed-

ings, Twenty-First Stapp Car Crash Conference, Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA, 1975.

4. C. L. Ewing and D. J. Thomas, "Human Head and Neck Response to Impact Acceleration", NAMRL Monograph 21 (1972), p. 84.

5. C. L. Ewing, D. J. Thomas, L. M. Patrick, C. W. Beeler and M. J. Smith, "Living Human Dynamic Response to -Gx Impact Acceleration. II Accelerations Measured on the Head and Neck", Proceedings, Thirteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA, 1969.

6. C. L. Ewing and D. J. Thomas, "Torque versus Angular Displacement Response of Human Head to -Gx Impact Acceleration", Proceedings, Seventeenth Stapp Car Crash Conference, Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA, 1973.

7. E. Becker and G. Willems, "An Experimental Validated 3-D Inertial Tracking Package for Application in Biodynamic Research", Proceedings, Nineteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA, 1975.

8. E. Becker, "A Photographic Data System for Determination of 3-Dimensional Effects of Multiaxis Impact Acceleration on Living Humans", Proceedings, Society of Photo-Optical Instrumentation Engineers, V.57, Box 1146, Palos Verdes Estates, CA 90274, 1975.

9. D. J. Thomas, "Specialized Anthropometry Requirements for Protective Equipment Evaluation", AGARD Conference Proceeding No. 110, Current Status in Aerospace Medicine, Glasgow, Scotland, 1972.

10. E. Becker, "Stereoradiographic Measurements for Anatomically Mounted Instruments", Proceedings, Twenty-First Stapp Car Crash Conference, Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA, 1977.

11. C. Clauser and K. Kennedy, "An Inquiry into the Ranges of Values Existing in the U. S. Navy Acceleration Study", 6570th Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, April 1975, Unpublished.

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