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Preliminary Study of the Effects of Combat Helmet on Head/Neck Response Under Rear/Side Impacts

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Biokinetics Report No. R08-16
Project Leader: Benoît Anctil, 613-736-0384
Contract No.: W7701-061933/001/QCL
Scientific Authority: Josée Manseau, 418-844-4000 ext. 4470

Defence R&D Canada – Valcartier

Contract Report
DRDC Valcartier CR 2008-392
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Abstract

This project defined the basis for a laboratory test procedure to evaluate the effects of a combat helmet on head/neck injury to vehicle occupants caused by IED explosions beside military vehicles. Laboratory test equipment was adapted to replicate the loading observed during full-scale trials at DRDC Valcartier. Two levels of loadings were considered to simulate neck loadings during full-scale IED testing and two head/neck surrogates, Hybrid III and EuroSID-2, were evaluated. Combat helmets caused moderate effects on the loading severity based on head acceleration and neck load recorded responses. Larger differences between helmeted head vs. bare head were observed for higher loading regimes. Finally, significant differences were also noted between the responses of the Hybrid III head-neck assembly in comparison with EuroSID-2.

Résumé

Ce projet défini les bases d'une procédure d'essai pour évaluer les effets du casque de combat sur les blessures au cou et à la tête aux passagers de véhicules causées par l'explosion d'engins artisanaux près des véhicules militaires. Des équipements de laboratoires ont été adaptés pour reproduire les conditions observées sur le terrain lors d'essais effectués à RDDC Valcartier. Deux niveaux de chargements ont été considérés pour simuler les réponses au cou observées lors de ces tests et deux ensembles tête/cou de mannequins, Hybrid III et EuroSID-2, ont été évalué. Les casques de combat affectent modérément la sévérité de chargement selon les accélérations à la tête et les chargement au cou mesurés. Les plus grands écarts entre les conditions avec et sans casque ont été observé lors des tests plus sévères. Finalement, des différences significatives ont aussi été noté entre les ensembles tête-cou Hybrid III et EuroSID-2.

Executive Summary

This project aimed at defining a method to evaluate the effects of a combat helmet on head/neck response of occupants inside vehicles subjected to Improvised Explosive Devices (IEDs).

Biokinetics's air cannon apparatus was adapted to reproduce the loading recorded on Hybrid III mannequins during field trials conducted by DRDC Valcartier. Two scenarios, representing high and low severity loading conditions, were defined to simulate experimental testing conditions. A Hybrid III head-neck surrogate was used for rear impact conditions. For side loadings, a EuroSID-2 head-neck assembly was acquired for comparison with the Hybrid III surrogate. Tests were conducted with and without combat helmet for each configuration.

For rear loading conditions, tests conducted with helmet showed lower head linear acceleration, whereas neck loads were increased or decreased depending on the head movement direction. The differences are larger for higher loading regimes.

For side loading conditions, the Euro-SID II recorded lower head accelerations and significantly lower neck loads for lateral bending moment (-Mx) and tension force (+Fz), compared to the Hybrid III The differences between tests conducted with and without helmet were not as significant as the rear loading conditions.

In conclusion, this study clearly showed the difference between the Hybrid III and the EuroSID II head/neck surrogates, but the effect of the helmet in terms of increasing or decreasing the head/neck loads, needs to be further investigated.

Sommaire

Ce projet avait pour but de définir une méthode permettant d'évaluer les effets du casque de combat sur la réponse du cou et de la tête des occupants de véhicules soumis à des engins explosifs improvisés (EEI) .

Le canon pneumatique de Biokinetics a été adapté pour reproduire des chargements enregistrés sur des mannequins Hybrid III lors de tests effectués sur le terrain par RDDC Valcartier. Deux scénarios, représentants des sévérités faibles et élevées furent définis pour simuler les niveaux de chargements vus lors de tests expérimentaux. Un ensemble tête/cou Hyrid III a été utilisé pour les chargements arrière. Pour les chargements latéraux, un ensemble tête/cou EuroSID-2 a été acquis pour le comparer au mannequin Hybrid III. Les tests ont été effectués avec et sans casque de combat pour chacune des configurations.

Pour les tests à chargements arrières, la présence du casque a diminué les accélérations à la tête, mais a augmenté ou diminué les chargements au cou, dépendamment de l'orientation du mouvement de la tête. Les différences étaient plus élevées pour les chargements plus sévères.

Pour les tests a chargements latéraux, l'EuroSID II a démontré des accélérations à la tête plus faible que l'Hybrid III, ainsi qu'un moment latéral (-Mx) et une force de tension (+Fz) beaucoup plus faible. Les différences entre les tests effectués avec ou sans casques n'étaient pas aussi importantes que pour les conditions de chargements arrière.

En conclusion, cette étude a clairement démontré la différence entre les deux modèles tête/cou Hybrid III et EuroSID II, mais l'effet du casque en terme de réduction ou d'augmentation du chargement au cou et à la tête, doit être étudié un peu plus en profondeur.

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1. Introduction

The Weapons Effects and Protection Section of Defence R&D Canada – Valcartier is studying methods for evaluating injury risk to occupants in vehicles subjected to blast landmines and IEDs (Improvised Explosive Devices). The main objective of the current program is to evaluate the effects of a combat helmet on head/neck response measured with a surrogate head/neck assembly subjected to impact conditions simulating an IED explosion on the side of a military vehicle where occupants may be subjected to rear or side loading, depending on their position in the vehicle (e.g. passengers vs. driver). Both scenarios were reproduced in the current effort.

This preliminary study establishes a basis for future development of a laboratory test procedure to evaluate the performance of vehicle safety measures. Biokinetics' air cannon was used to simulate impact conditions experienced by vehicle occupants during an IED explosion. Two head/neck surrogates, Hybrid III and EuroSID-2, were used to quantify loading severity. The Hybrid III head/neck was used for rear and side impact scenarios while " the EuroSID-2 head/neck was only used for side impact testing.

This report presents an evaluation of the effect of a combat helmet on neck loads and head accelerations . In addition, the Hybrid III and EuroSID-2 responses are compared for the different loading conditions.

2. Selection of Head/Neck Surrogate

The first Side Impact Dummy (SID) was developed by the Highway Safety Research Institute (HSRI). It was introduced in 1979 by the National Highway Traffic Safety Administration (NHTSA) in the United States. SID was the first attempt to develop an instrumented dummy specifically designed for side impact scenario. In the 1980's, the European Commission developed EUROSID-1 to improve passive side impact safety with a more biofidelic crash test dummy. At approximately the same time, NHTSA developed BioSID in United States. Along with the two separate dummies were two unique standards. EUROSID-2 (ES-2) was later introduced to harmonize both European and North American standards. ES-2 was meant to address the shortcomings of the EUROSID-1 while maintaining it's superior biofidelity. This resulted in a superior side impact dummy to both EUROSID-1 and BioSID. More recently, a further improved mannequin, WorldSID, was introduced to replace all other side impact dummies. While it is available from dummy manufacturers, it is still in a development stage and has not been included in vehicle regulations yet.

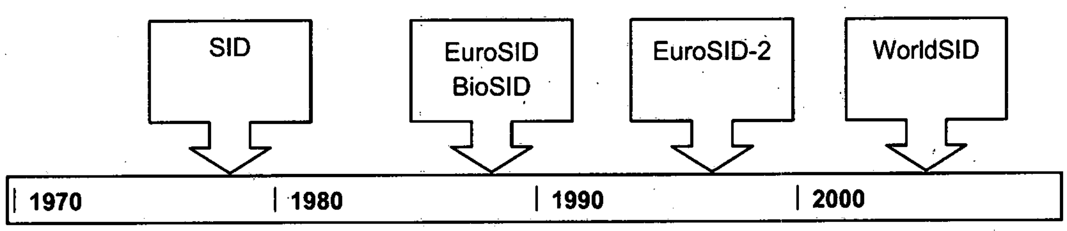

Figure 1: Side impact dummy development timeline.

ES-2 represents the most advanced side impact dummy approved by NHTSA for vehicle certification. It has the highest level of biofidelity for a regulated dummy used under vehicle crash conditions. It is therefore recommended to use this dummy for the present study even though ES-2 has not been validated for blast scenarios. It is expected that the blast effects on vehicle occupants can be compared to typical passenger vehicle crashes.

3. Materials and Methods

3.1. Test Setup

The initial task for this investigation was to determine a method by which the detonation of an IED beside a vehicle could be simulated in the laboratory environment. Biokinetics' air cannon facility, utilising the linear rail, was envisaged as the appropriate tool for the simulation. The initial approach was to mount the head-neck assembly (Hybrid III or EuroSID-II) onto the linear rail carriage (Figure 2). The carriage-head-neck assembly was accelerated along the rail and then decelerated. This deceleration pulse was intended to impart a motion to the head which would simulate the response observed in the blast tests. Blast trial response data for Mx and My were provided by DRDC-Valcartier (Figure 3 and Figure 4) to tune the response for the side and rear impact conditions, respectively.

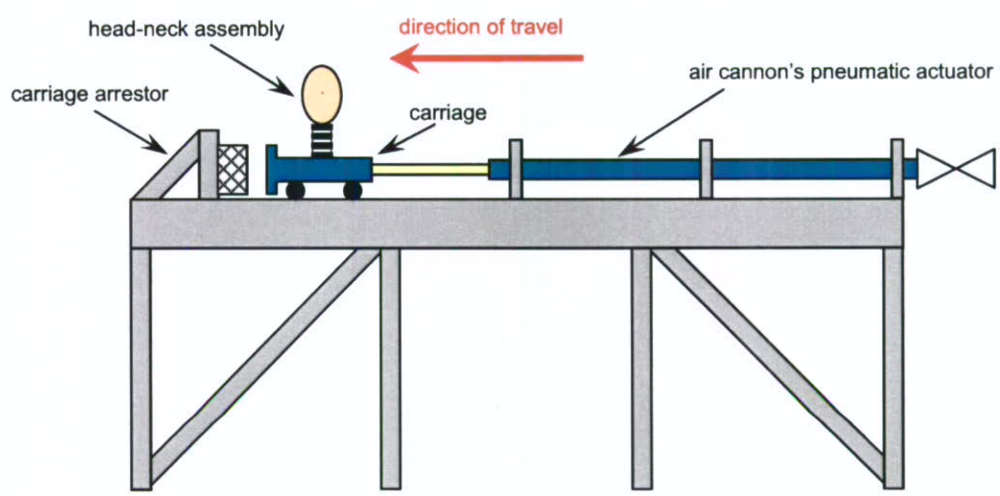

Figure 2: Schematic view of the original test setup.

To stop the carriage, a steel end plate was fabricated for the linear rail. The carriage would come to a stop against this plate, allowing the head to continue, generating the desired head movement, and thus neck response. Various impact attenuating materials were placed between the plate and the carriage. This provided a method to tune the impact pulse to obtain the desired neck response. Materials such as aluminum hexcell, expanded polypropylene, and expanded polystyrene, in varying thicknesses were attempted. This approach was not producing responses that were in the realm of the blast tests. The neck response was approaching the desired level as the deceleration pulse became more severe (increased carriage speed in conjunction with only 1" of EPS material). However, concern over equipment damage forced the re-evaluation of the simulation methodology.

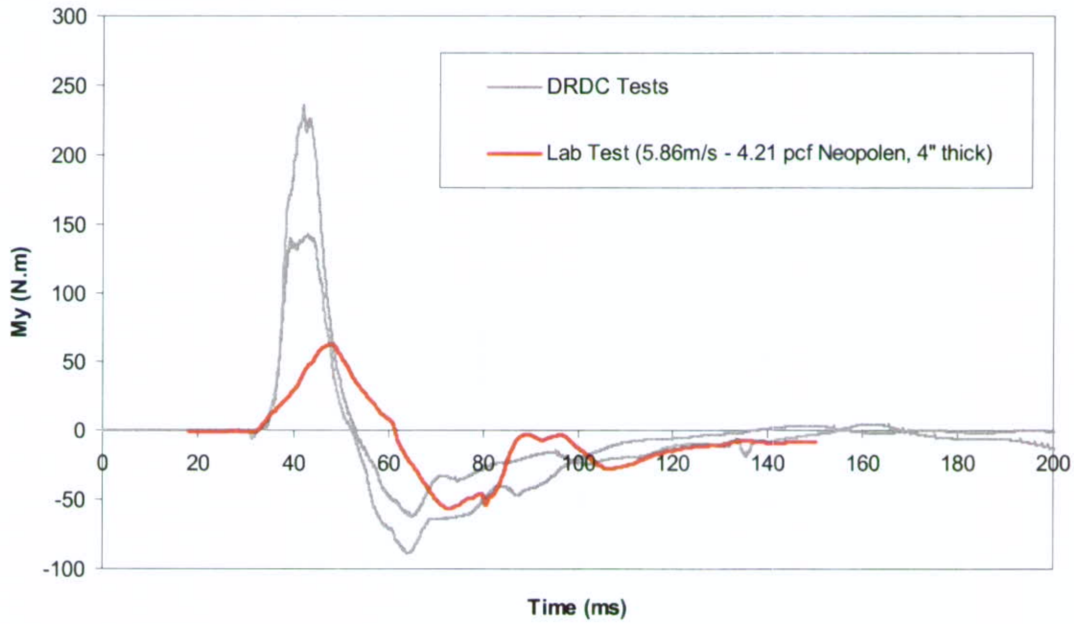

Figure 3: Field trials (DRDC) vs. laboratory test results for rear impacts (initial setup).

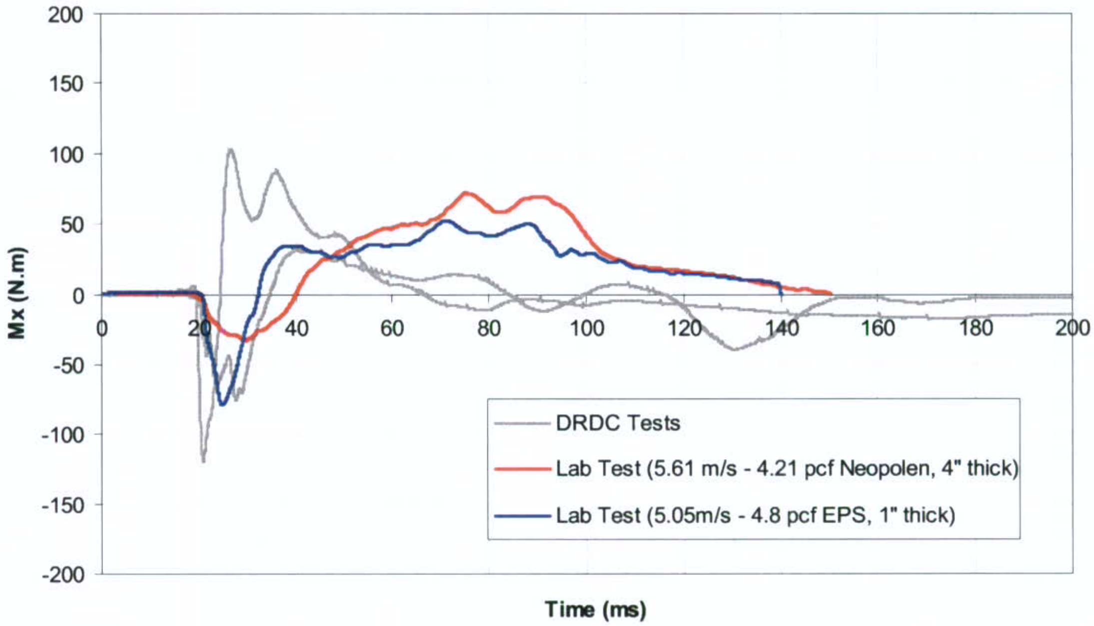

Figure 4: Field trials (DRDC) vs. laboratory test results for side impacts (initial setup).

In evaluating the high speed video, it was clear that a more severe acceleration pulse was required to obtain the desired neck response. It was proposed to mount the headform on a linear bearing system at the end of the linear rail. The base upon which the head-neck assembly was mounted would be impacted using the linear rail carriage, thus accelerating the base of the neck (Figure 5). This method was also viewed to be a closer simulation of the motion which was occurring in the blast environment.

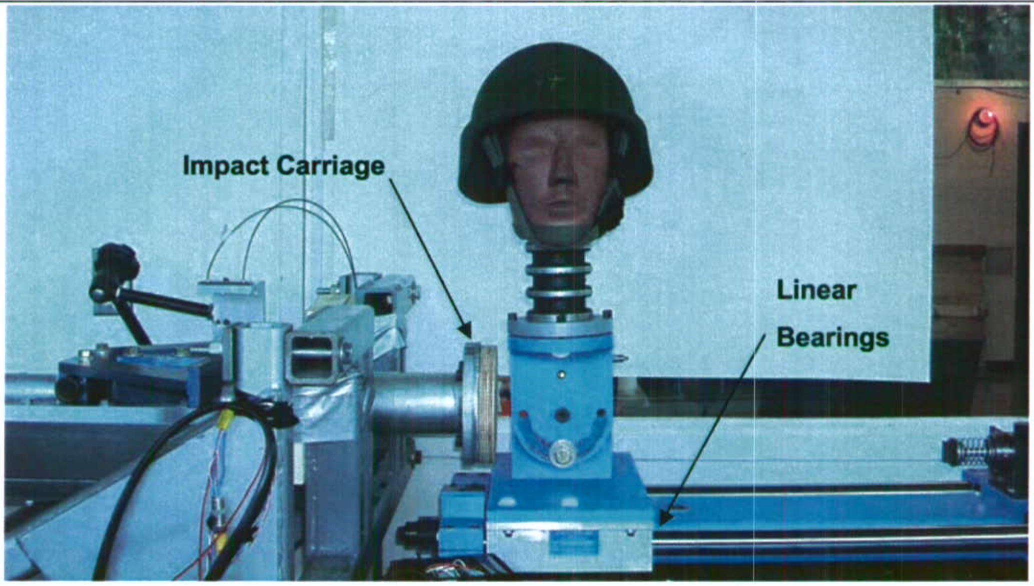

Figure 5: Final Test Set-up

*Note: For side impacts, the head was turned the opposite direction to what is shown

The impactor carriage is accelerated on parallel rails using a piston which is inserted into the barrel of the air cannon (Figure 6). The piston is stopped prior to the carriage reaching the end of the rails. This provides a short distance before impact during which the carriage is in a free glide phase, not being accelerated by the air piston. In order to prevent metal on metal contact between the impactor carriage and the neck base slider, a piece of ¾" plywood was added to the impactor strike face. This plywood was replaced when it was deemed that excessive damage had occurred. The mass of the impactor carriage is 31.67 kg, and the velocity was measured using a twin beam optical velocity gate positioned such that it was just prior to impact, during the carriages free glide phase. An accelerometer (PCB 350B03) was mounted to the neck base slider to provide characterization of the slider motion once it has been impacted.

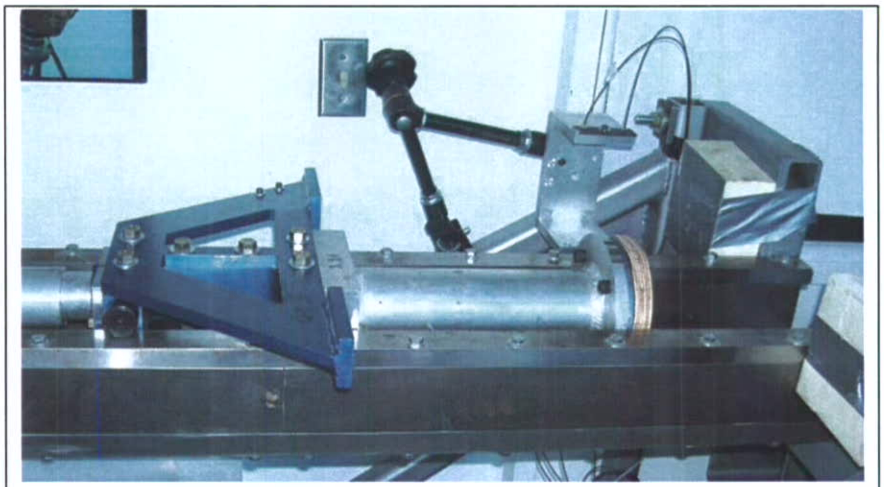

Figure 6: Impact Carriage

Data provided by DRDC Valcartier for neck bending moments Mx and My was utilised to determine the input conditions that best simulated the blast trials conditions. It was determined that a speed of 7.25 m/s was a speed which produced an adequate neck response, while not producing undue risk to the test equipment. A second speed was targeted which would produce a neck response of approximately 50% of the response from the 7.25 m/s trials. It was found that a speed of 3.7 m/s resulted in the desired neck response amplitude. The neck responses for the selected test conditions are presented in Figure 7 and Figure 8. The resulting test matrix is presented in Table 1.

For the helmeted trials, a sized medium CG634 was used. Consistent positioning was ensured by the use of a NOCSAE nose gauge prior to each test. After every trial, both helmeted and bare headed, the angle of the neck base was checked and adjusted as necessary to maintain the neck in a vertical position (±0.5°).

Table 1: Test Matrix.

Impact Speed	Test ID	Number of Repetitions	Impact Orientation	Dummy head/neck	Helmet
A 3.7 m/s	1	3	Side	H3	No
	2	3	Side	ES2	No
	3	3	Rear	H3	No
	4	3	Side	H3	Yes
	5	3	Side	ES2	Yes
	6	3	Rear	H3	Yes
B 7.25 m/s	7	3	Side	H3	No
	8	3	Side	ES2	No
	9	3	Rear	H3	No
	10	3	Side	H3	Yes
	11	3	Side	ES2	Yes
	12	3	Rear	H3	Yes

ES2: EuroSID-2 headform and neck
H3: Hybrid III headform and neck

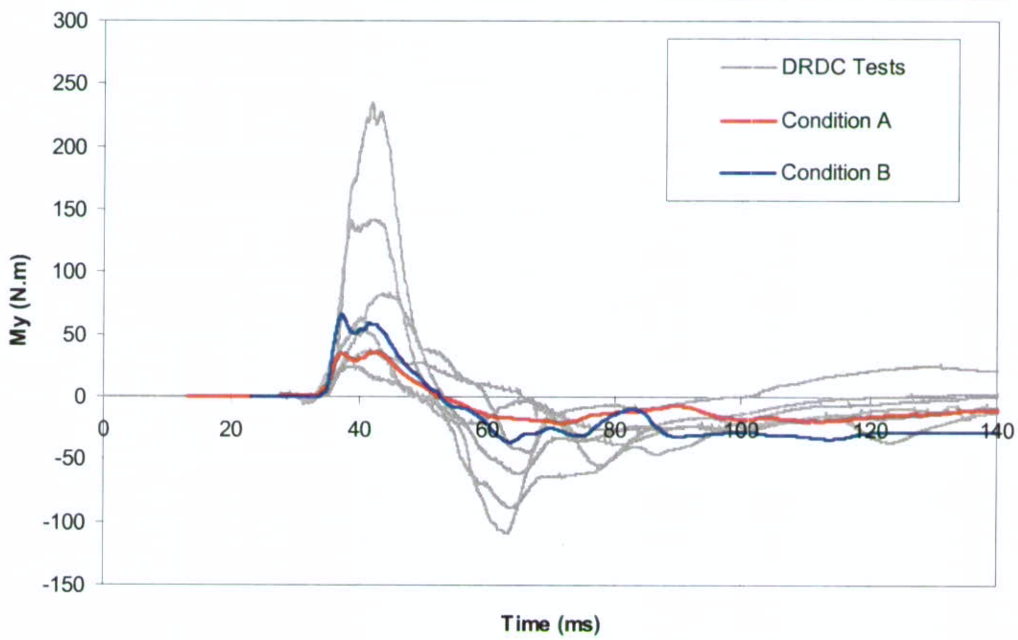

Figure 7: Field trials (DRDC) vs. laboratory test results for rear impacts (final setup).

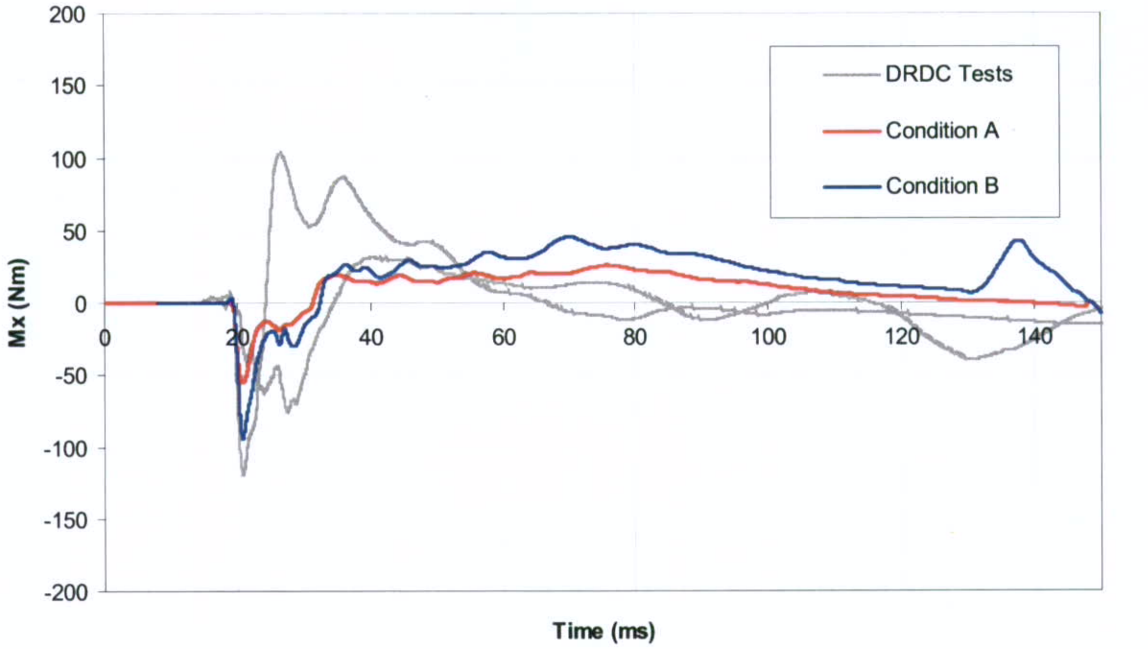

Figure 8: Field trials (DRDC) vs. laboratory test results for side impacts (final setup).

3.2. Instrumentation

Both headform-neck assemblies were instrumented with accelerometers to measure head response, and upper neck load cells to measure neck response. The loadcells for both the Hybrid III (Denton 1716AJ) and EuroSID II (Denton 4085J) were six axis units, measuring 3 orthogonal forces and three orthogonal moments. The six accelerometer package (SAP) (all PCB 350B03) was used to determine both rotational as well and linear accelerations for both headforms.

The sampling rate was set to 60 kHz. Head accelerations and neck forces were filtered using a phaseless Class 1000 lowpass filter (1650 Hz at -3dB) while neck moment signals were filtered with a phaseless Class 600 lowpass filter (1000 Hz at -3dB) as specified by SAE J211.

4. Results and Discussion

Peak values for the different parameters evaluated are listed in Appendix A and the filtered signals are shown in Appendix B. Note that only the first 100 ms of the neck responses were used in the analysis to avoid considering the response when the carriage is arrested. The following Sections summarize the main outcomes as follows:

- Section 4.1: rear impacts
- Section 4.2: side impacts
- Section 4.3: high-speed video still images
- Section 4.4: SAP measurements
- Section 4.5: discussion

In sections 4.1 and 4.2, the first figures compare the peak values to the injury tolerance levels identified in Table 2 to illustrate the severity of impact. Note that these criteria were established from direct impact to the head as opposed to inertial loading. The following bar graphs show normalized peak values and finally, selected signals are used to compare visually the effect of helmet under rear impact and the difference between the Hybrid III and ES-2 headorms for side impact. Angular velocity and accelerations are not presented due to SAP measurement problems, as discussed in Section 4.4.

Table 2: Injury Criteria

	Parameter	Threshold	Injury Outcome	Reference
Neck	Tension* (+Fz)	+3290 N (0 ms) +2815 N (35 ms) +1097 N (60 ms)	<5% AIS 3	(Mertz 2002)
	Compression (-Fz)	-4000 N (0 ms) -1100 N (30 ms)	<5% AIS 3	(Mertz 2002)
	Shear (±Fx or ±Fy)	±3100 N (0 ms) ±1500 N (25 ms) ±1500 N (35 ms) ±1100 N (45 ms)	<5% AIS 3	(Mertz 2002)
	Flexion (+Mocy)	+190 N.m	<5% AIS 3	(Mertz 2002)
	Extension* (-Mocy)	-77 N.m	<5% AIS 3	(Mertz 2002)
	Lateral Flexion (±Mx)	±60 N.m	≥ AIS 2	(Soltis 2001)
Head	Resultant Linear Acceleration	80 g	50% risk of concussion	(Pellman, Viano et al. 2003)
	Severity Index (SI)	300	50% risk of concussion	(Pellman, Viano et al. 2003)
	Head Injury Criterion (HIC)	250	10% risk of AIS 2+	(Prasad and Mertz 1985)

* Minimum Muscle Tone

4.1. Rear Impacts

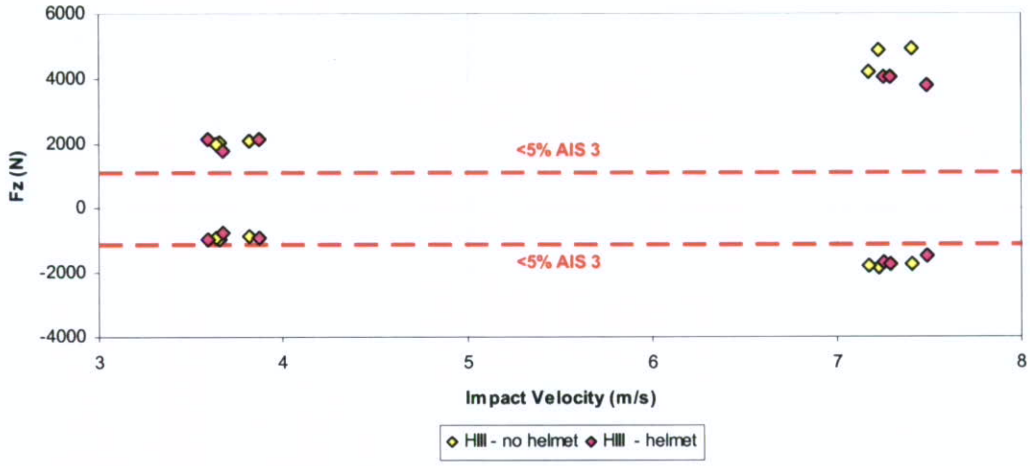

Figure 9: Neck peak force (Fz) vs. impact velocity – rear impacts.

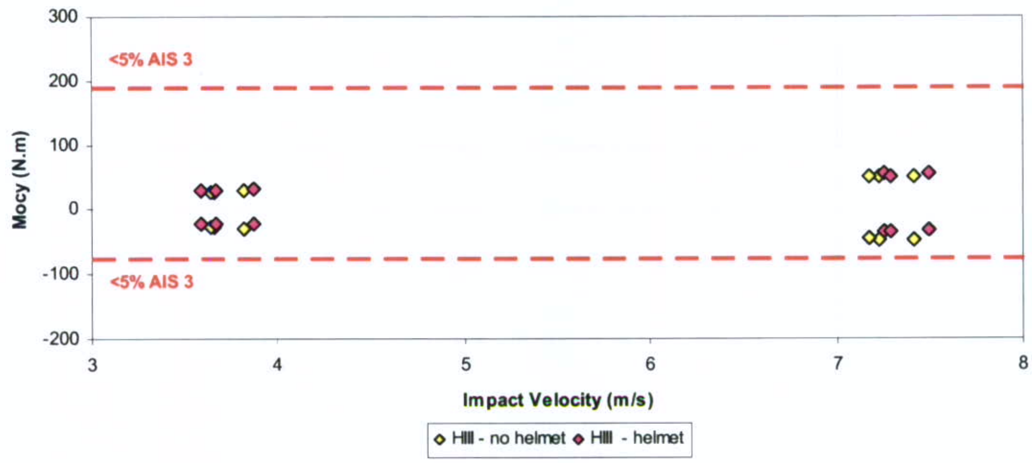

Figure 10: Neck peak moment (Mocy) vs. impact velocity – rear impacts.

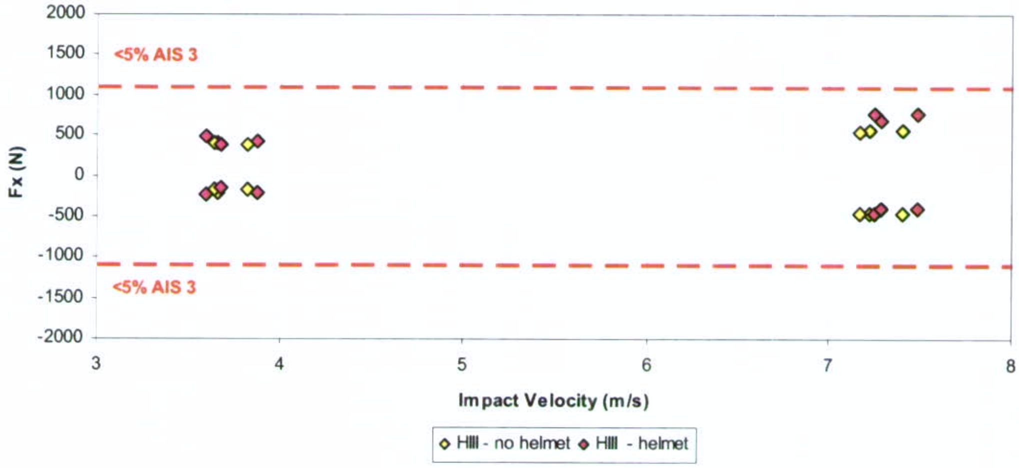

Figure 11: Neck peak force (Fx) vs. impact velocity – rear impacts.

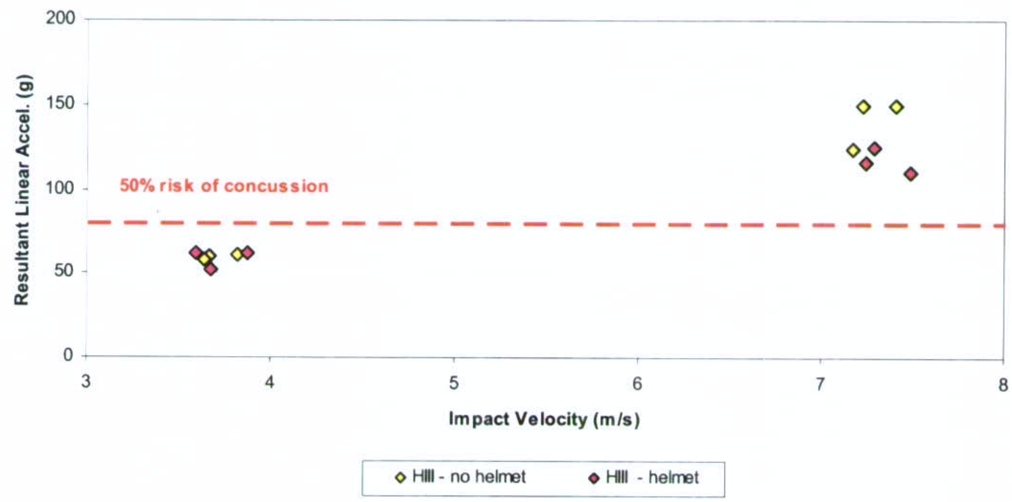

Figure 12: Head peak resultant linear acceleration vs. impact velocity – rear impacts.

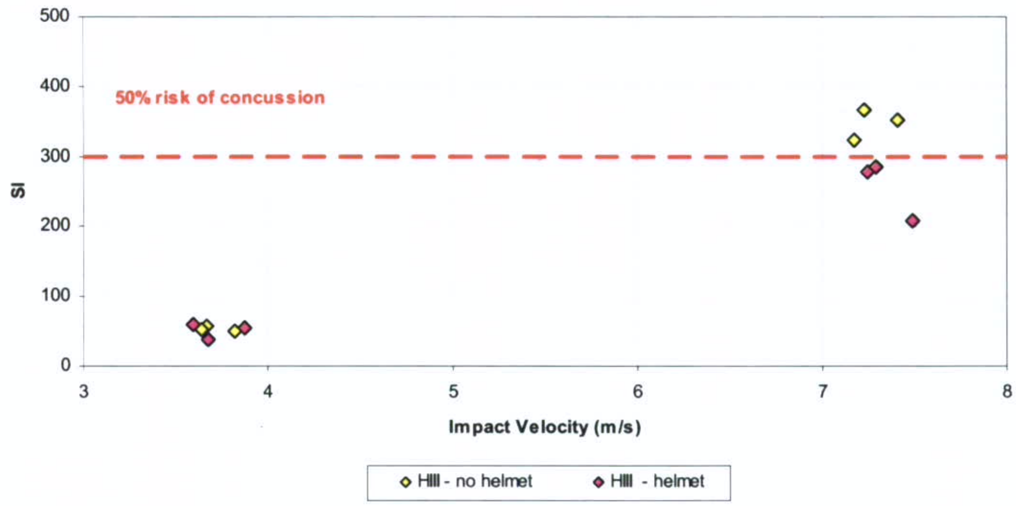

Figure 13: Severity Index vs. impact velocity – rear impacts.

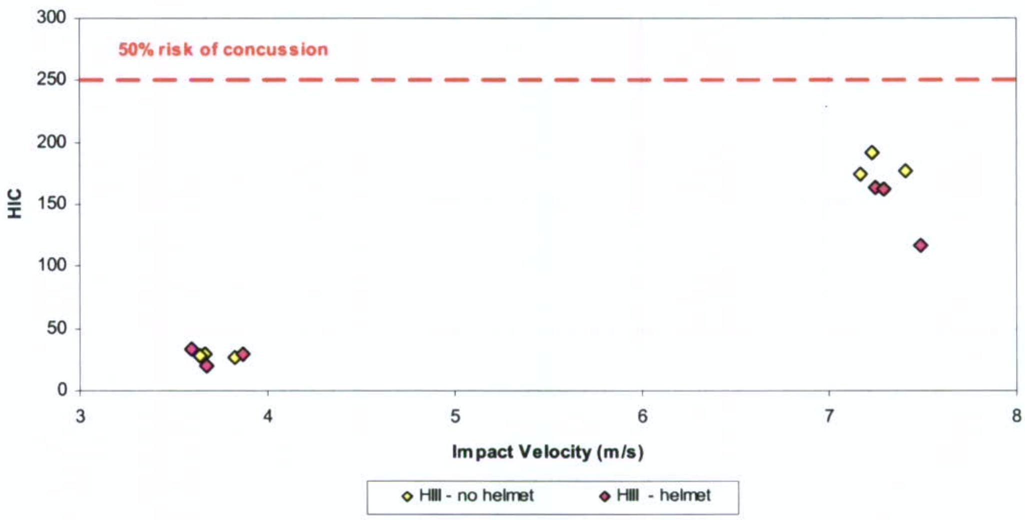

Figure 14: Head Injury Criterion vs. impact velocity – rear impacts.

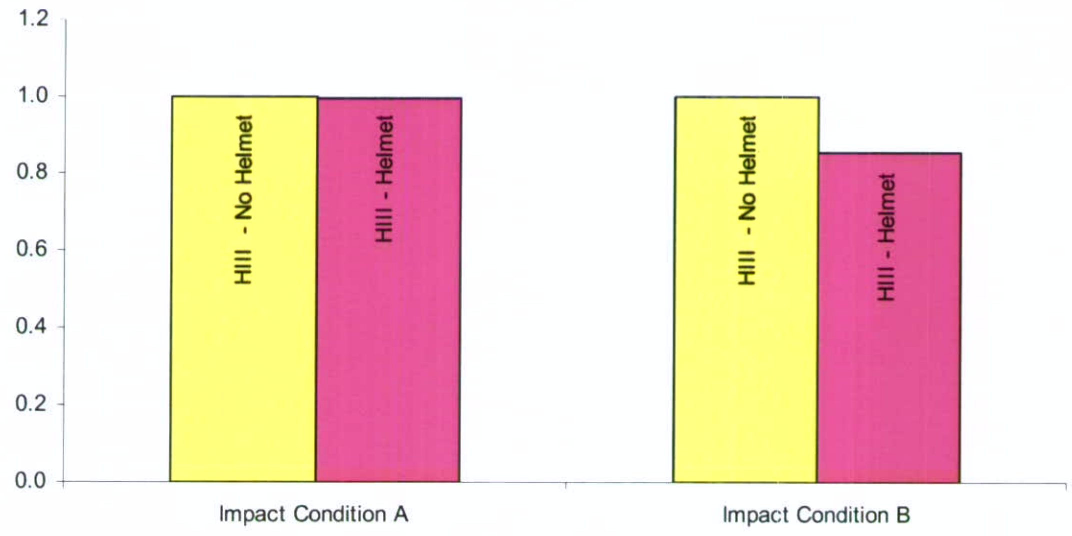

Figure 15: Average neck tension +Fz (normalized) – rear impacts.

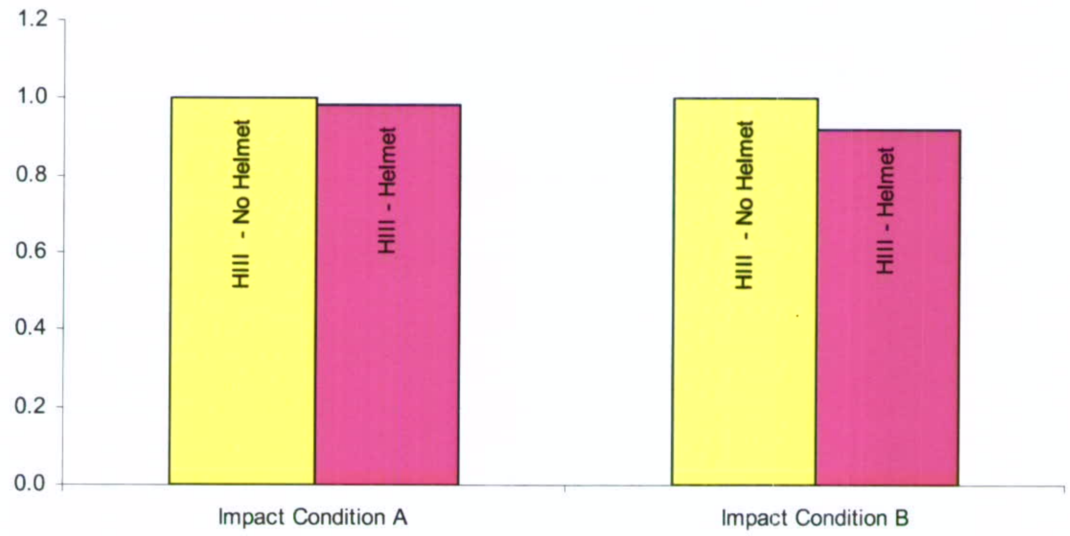

Figure 16: Average neck compression -Fz (normalized) – rear impacts.

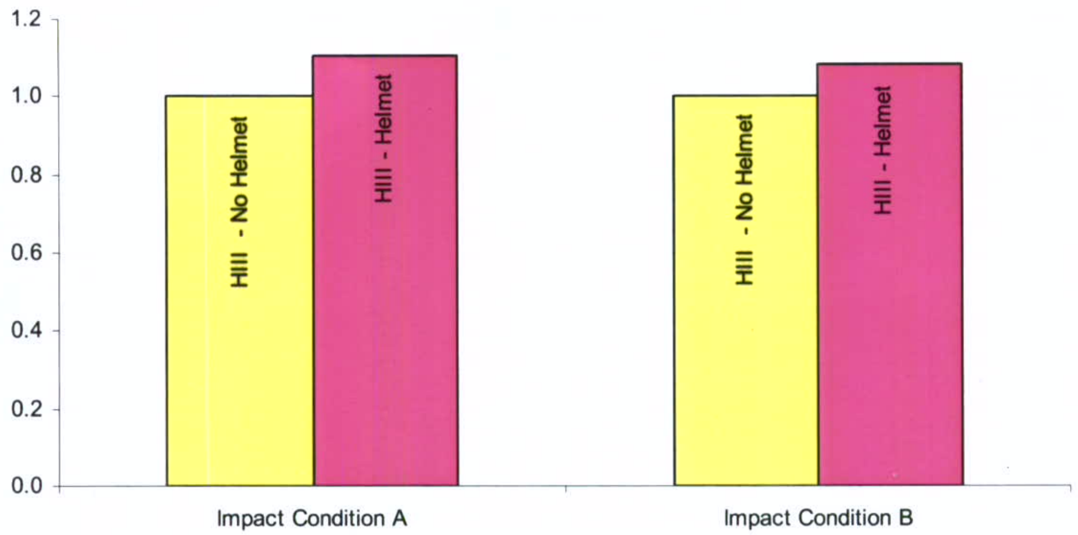

Figure 17: Average neck flexion +Mocy (normalized) – rear impacts.

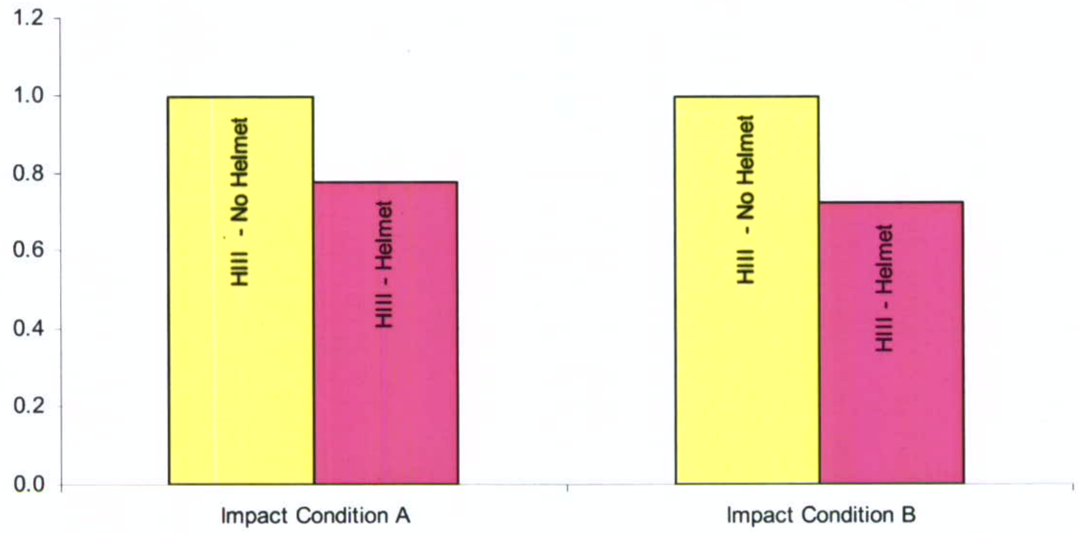

Figure 18: Average neck extension -Mocy (normalized) – rear impacts.

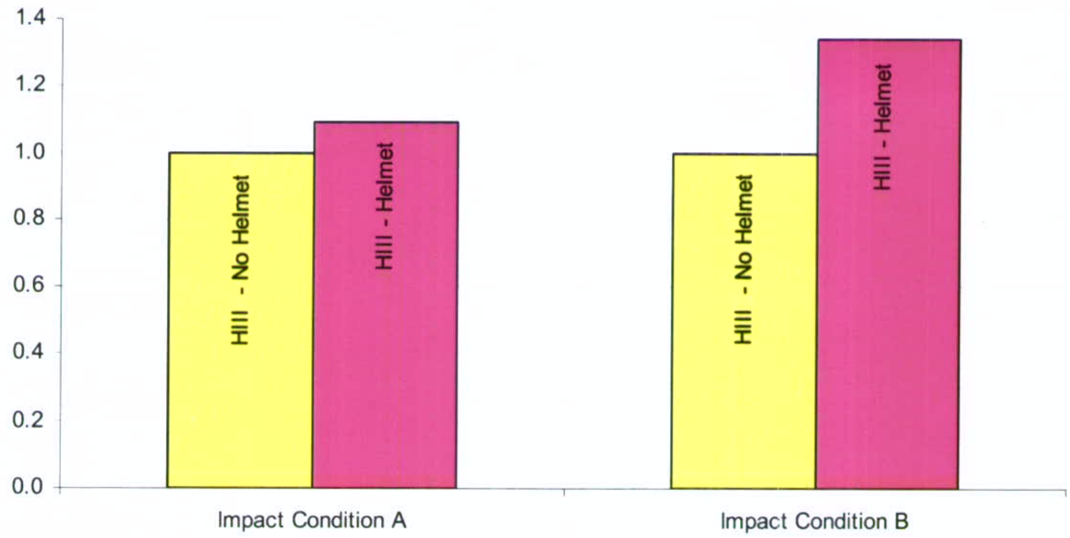

Figure 19: Average neck shear +Fx (normalized) – rear impacts.

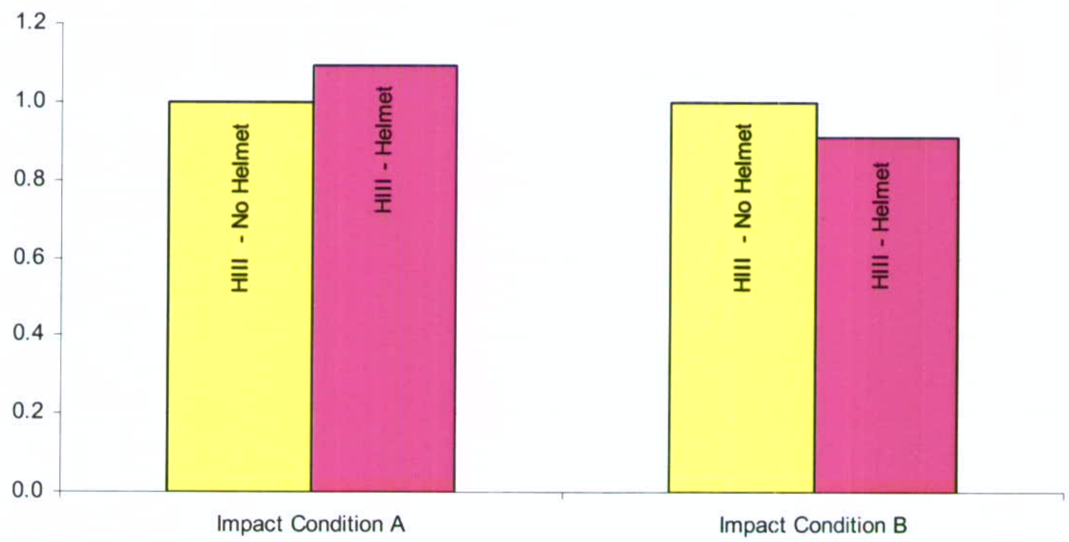

Figure 20: Average neck shear -Fx (normalized) – rear impacts.

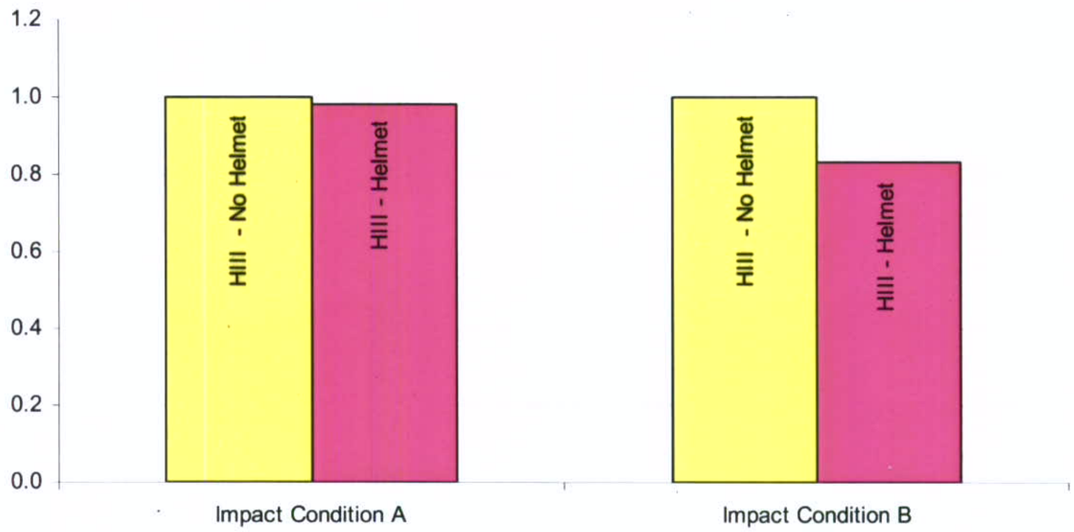

Figure 21: Average resultant linear acceleration (normalized) – rear impacts.

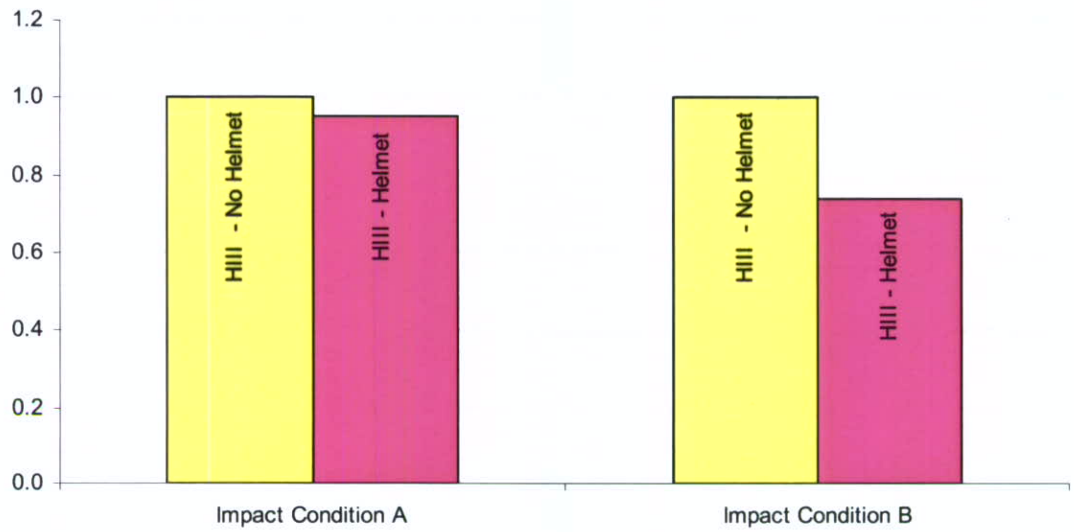

Figure 22: Average SI (normalized) – rear impacts.

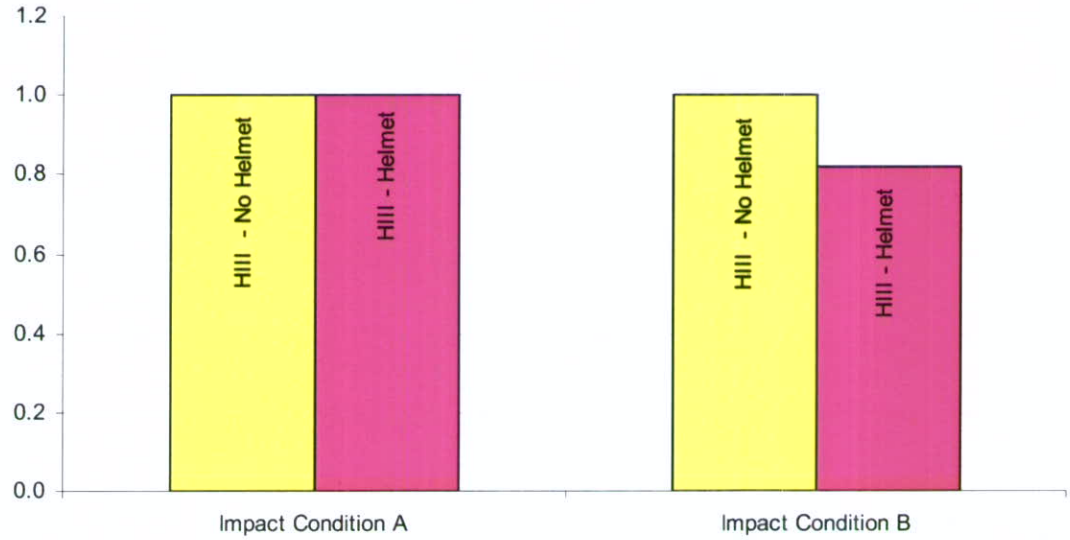

Figure 23: Average HIC (normalized) – rear impacts.

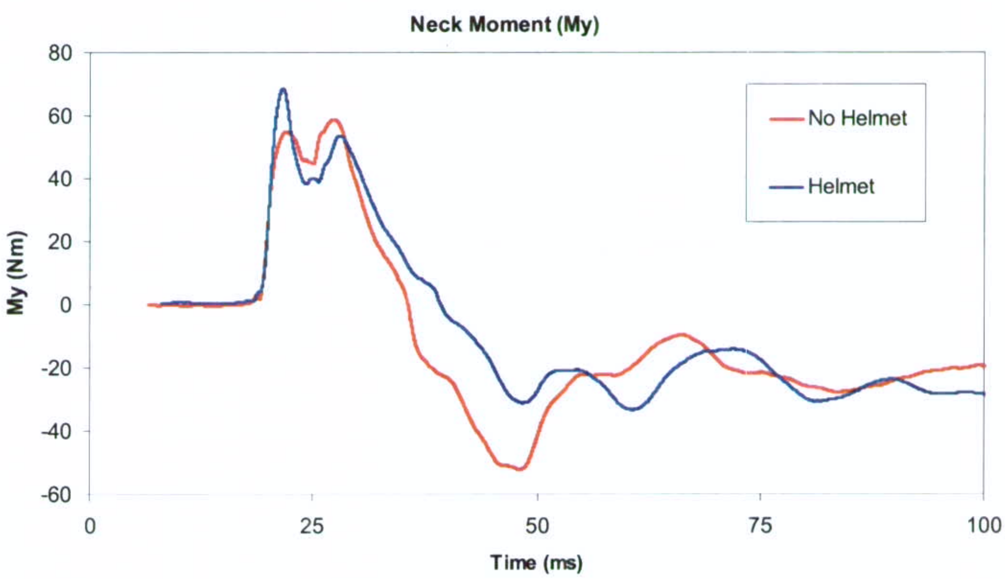

Figure 24: Rear impact, H3, cond B, helmet vs. no helmet – Neck moment (My)

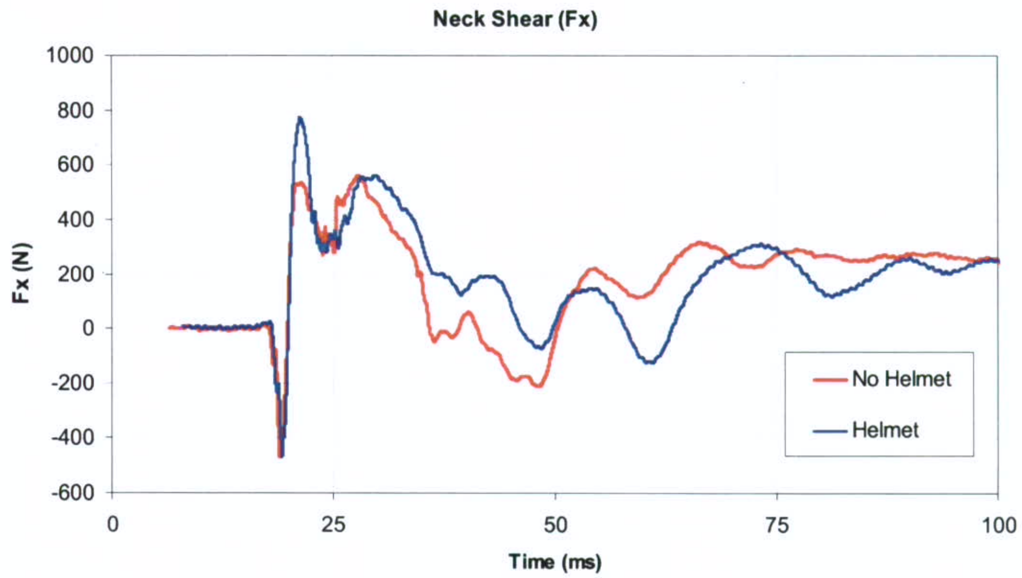

Figure 25: Rear impact, H3, cond B, helmet vs. no helmet – Neck shear force (Fx)

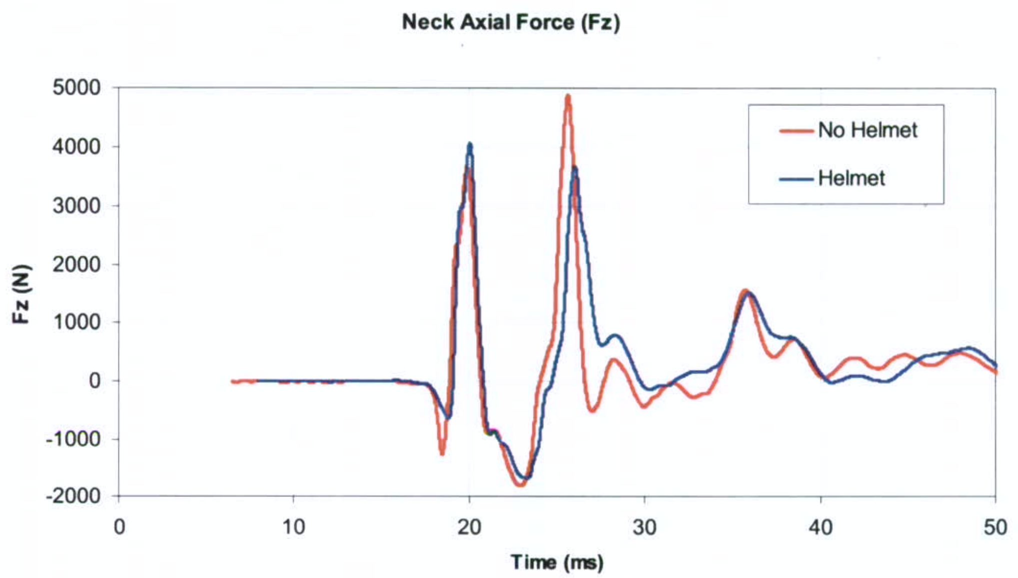

Figure 26: Rear impact, H3, cond B, helmet vs. no helmet – Neck axial force (Fz)

4.2. Side Impacts

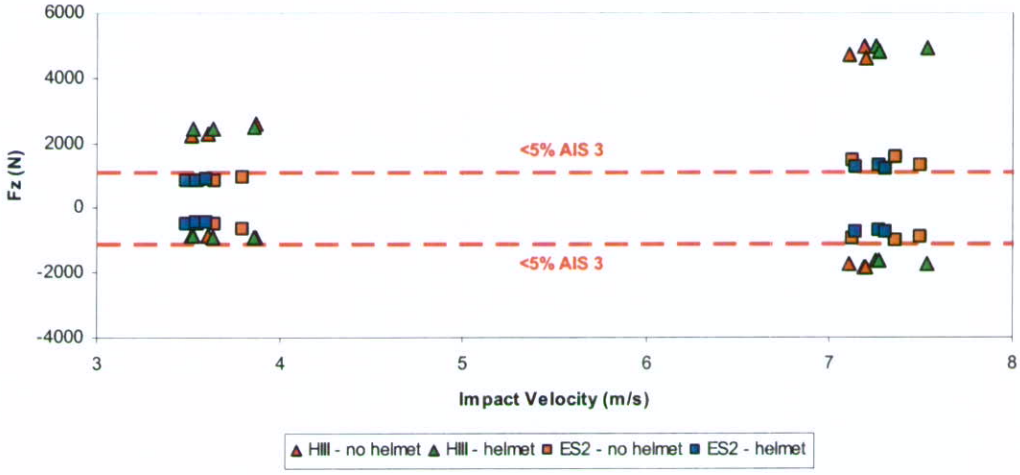

Figure 27: Neck peak force (Fz) vs. impact velocity – side impacts.

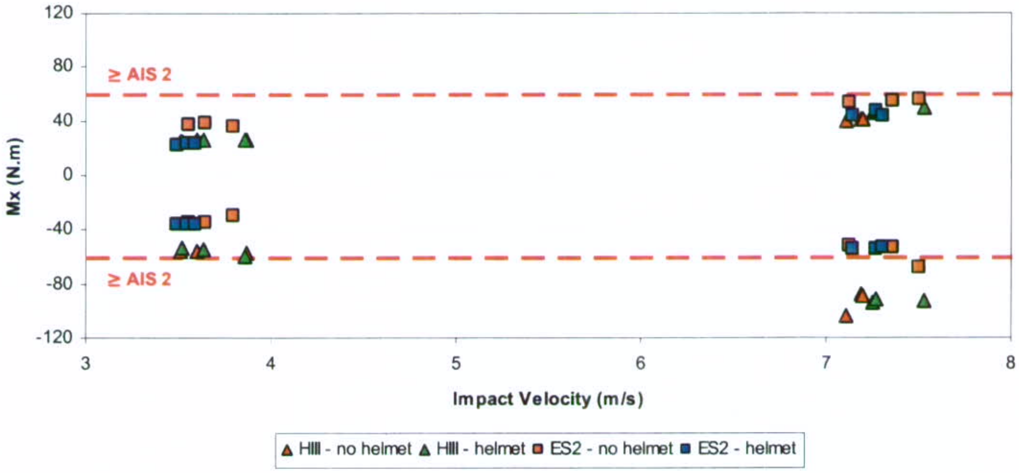

Figure 28: Neck peak moment (Mx) vs. impact velocity – side impacts.

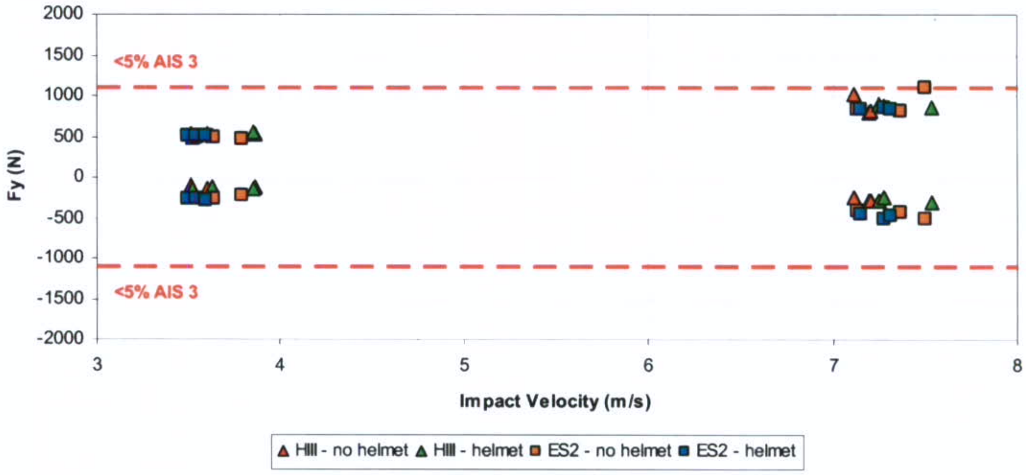

Figure 29: Neck peak force (Fy) vs. impact velocity – side impacts.

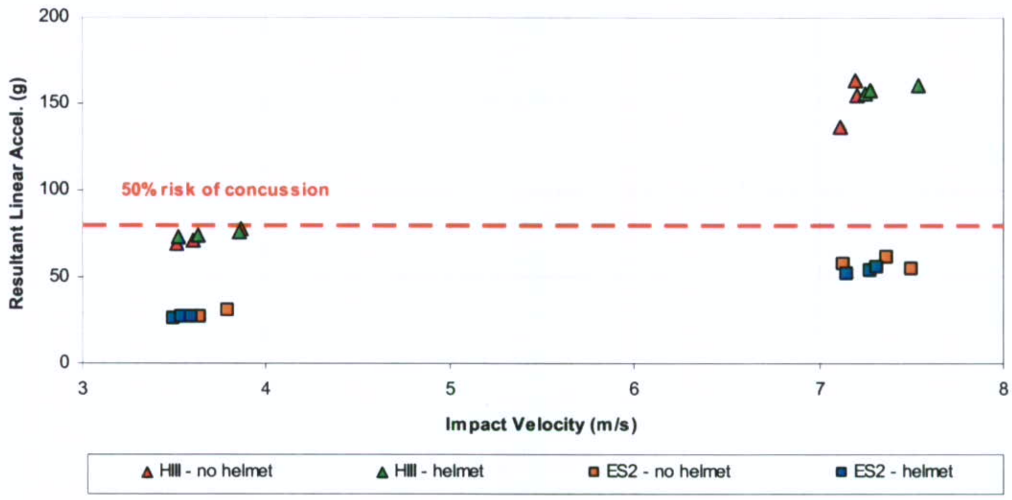

Figure 30: Head peak resultant linear acceleration vs. impact velocity – side impacts.

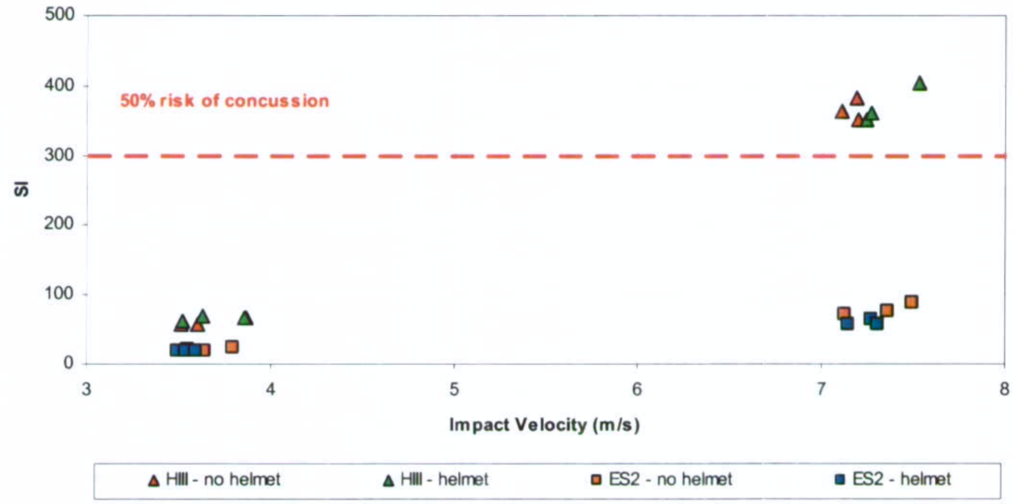

Figure 31: Severity Index vs. impact velocity – side impacts.

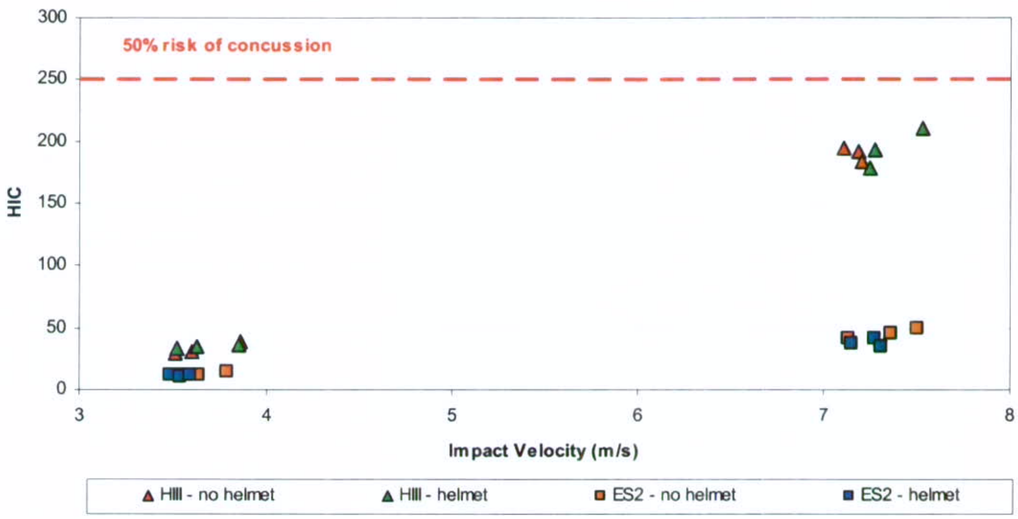

Figure 32: Head Injury Criterion vs. impact velocity – side impacts.

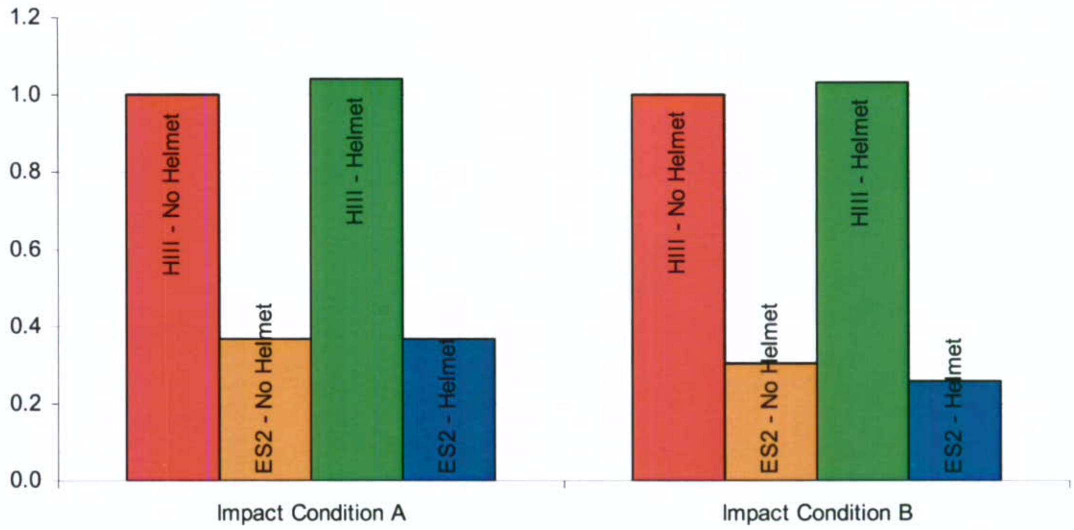

Figure 33: Average neck tension +Fz (normalized) – side impacts.

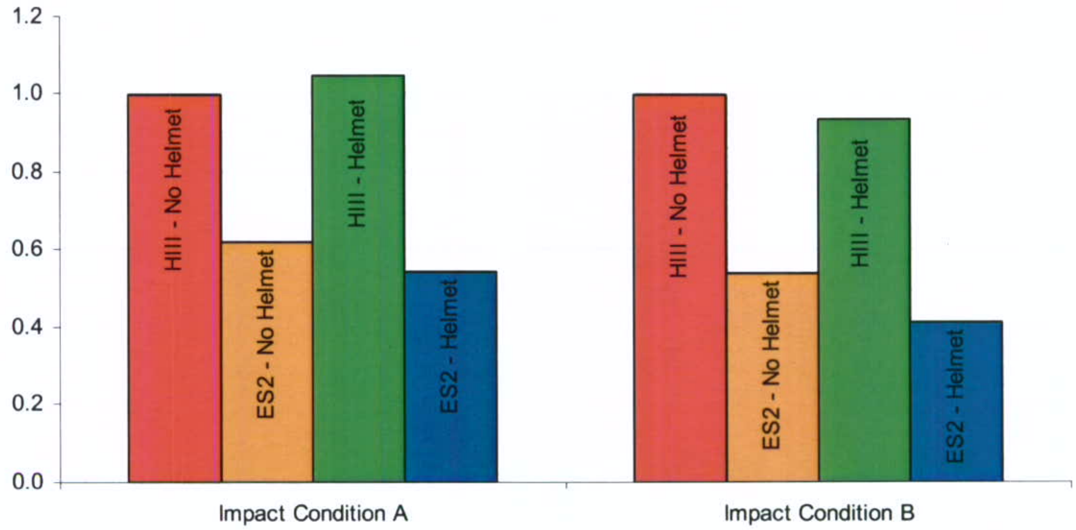

Figure 34: Average neck compression -Fz (normalized) – side impacts.

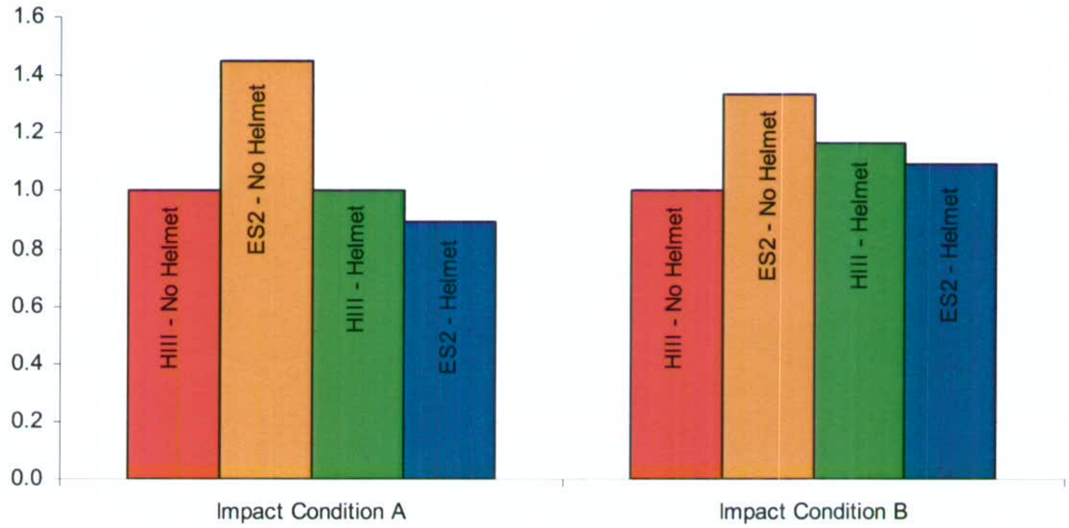

Figure 35: Average neck flexion +Mx (normalized) – side impacts.

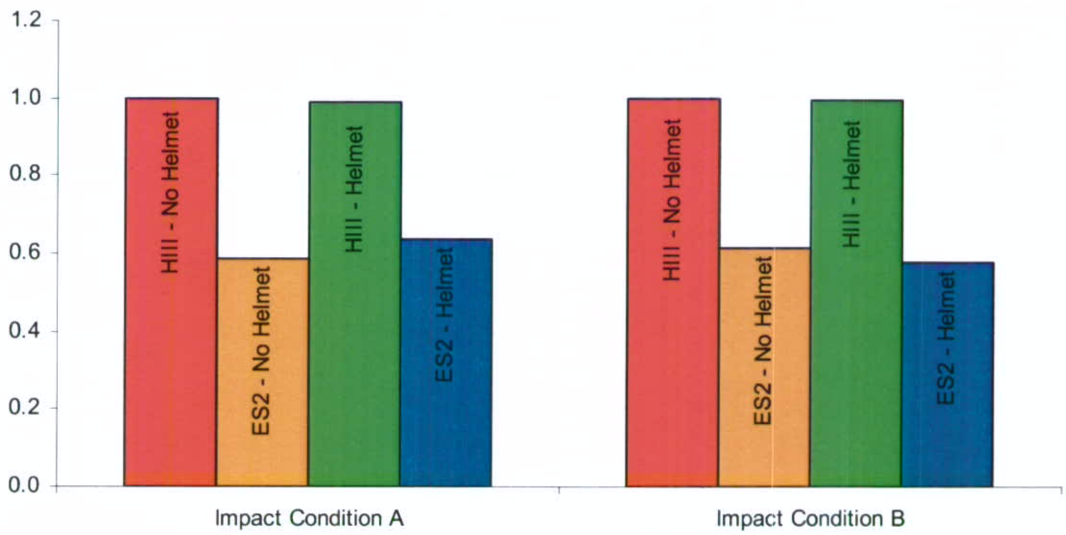

Figure 36: Average neck extension -Mx (normalized) – side impacts.

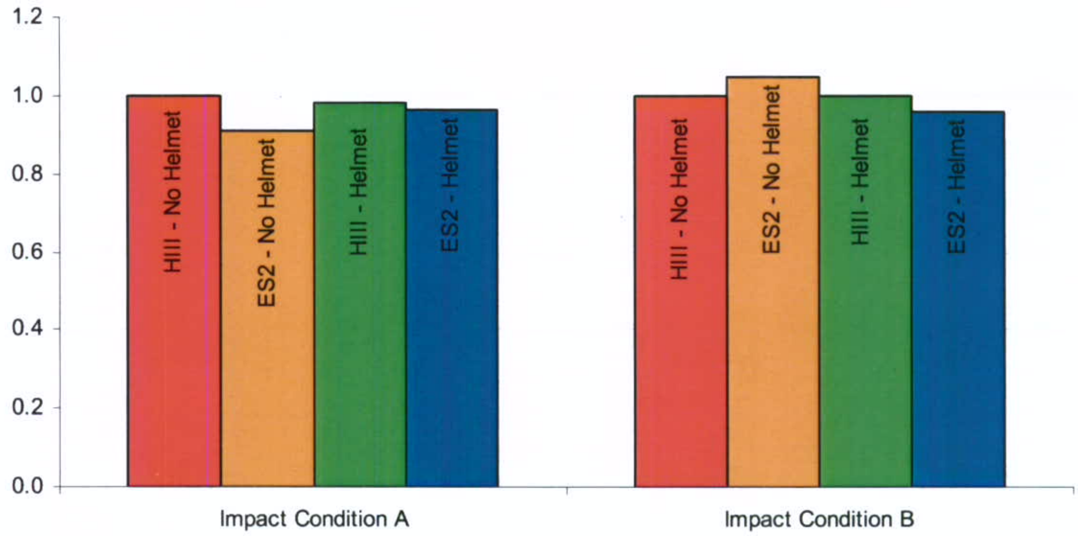

Figure 37: Average neck force +Fy (normalized) – side impacts.

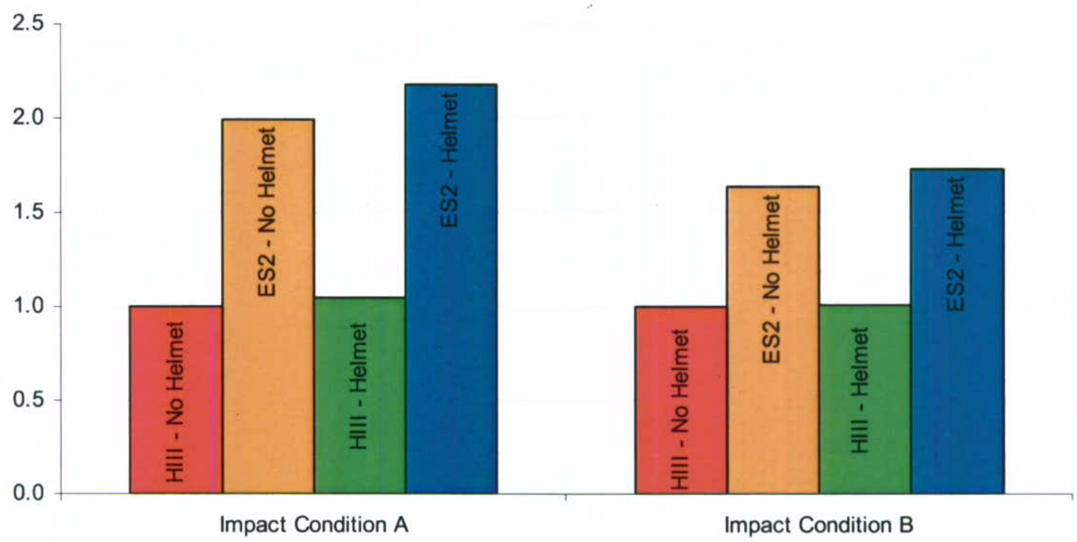

Figure 38: Average neck force -Fy (normalized) – side impacts.

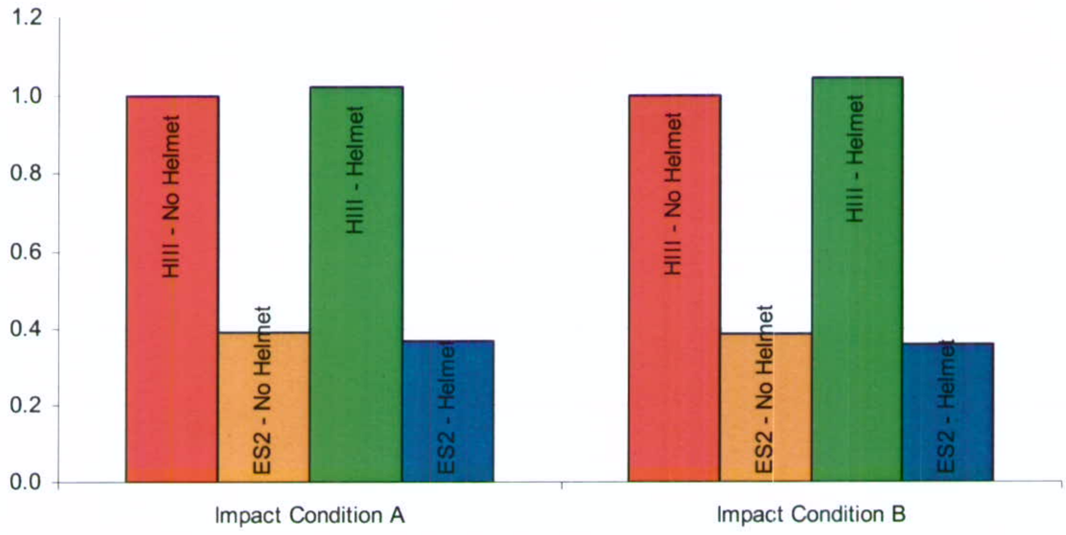

Figure 39: Average resultant linear acceleration (normalized) – side impacts.

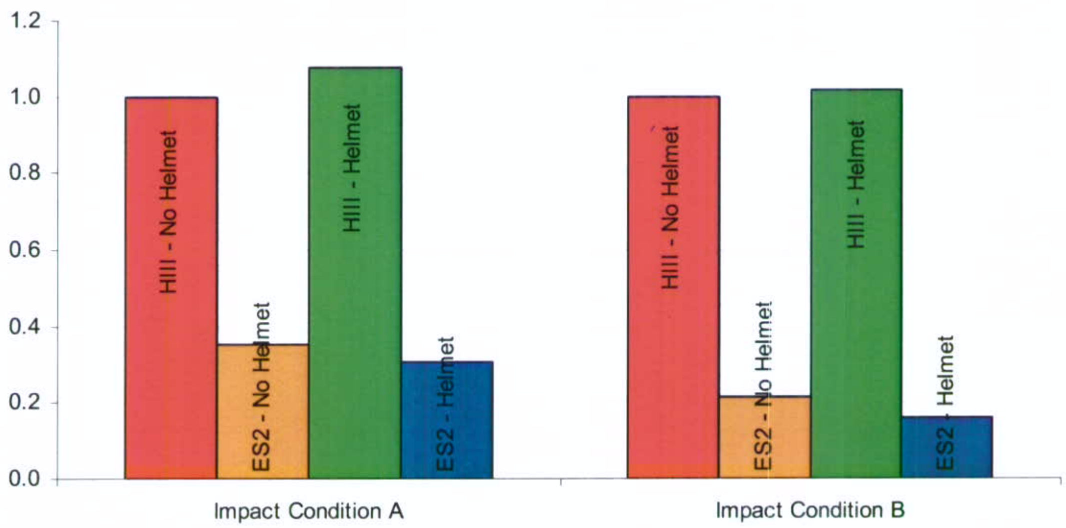

Figure 40: Average SI (normalized) – side impacts.

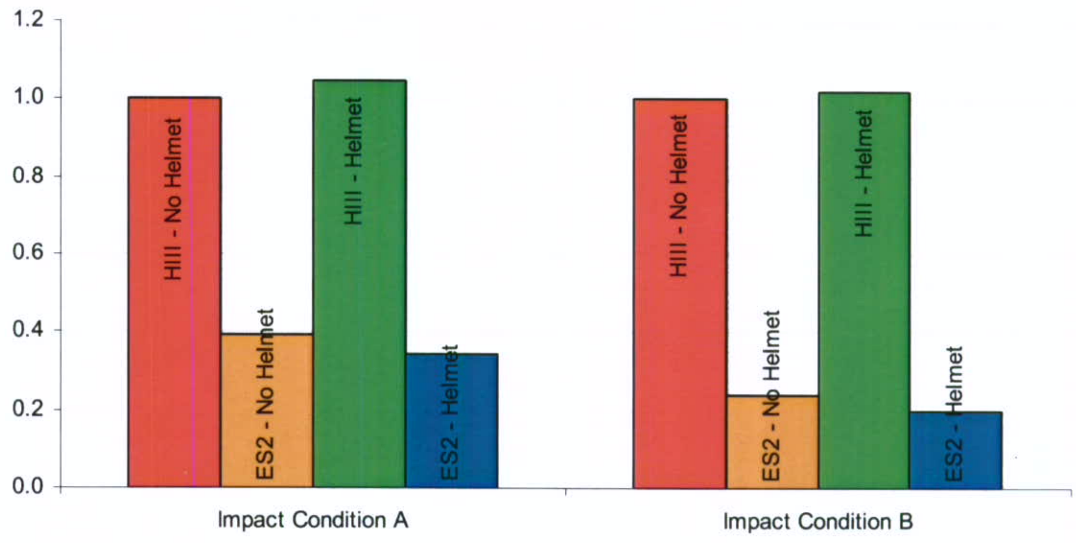

Figure 41: Average HIC (normalized) – side impacts.

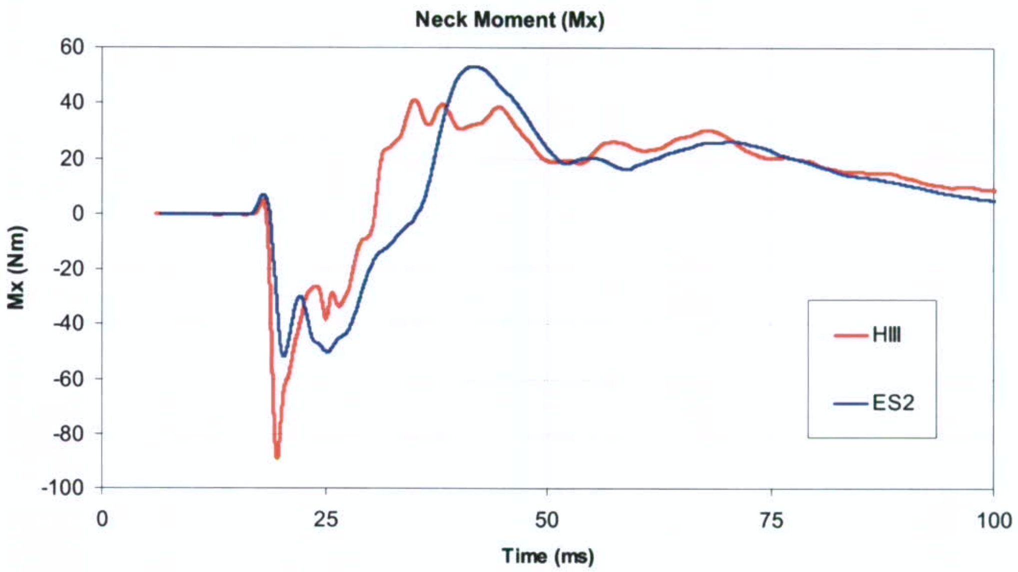

Figure 42: Side impact, cond B, no helmet, ES-2 vs. H3 – Neck moment (Mx)

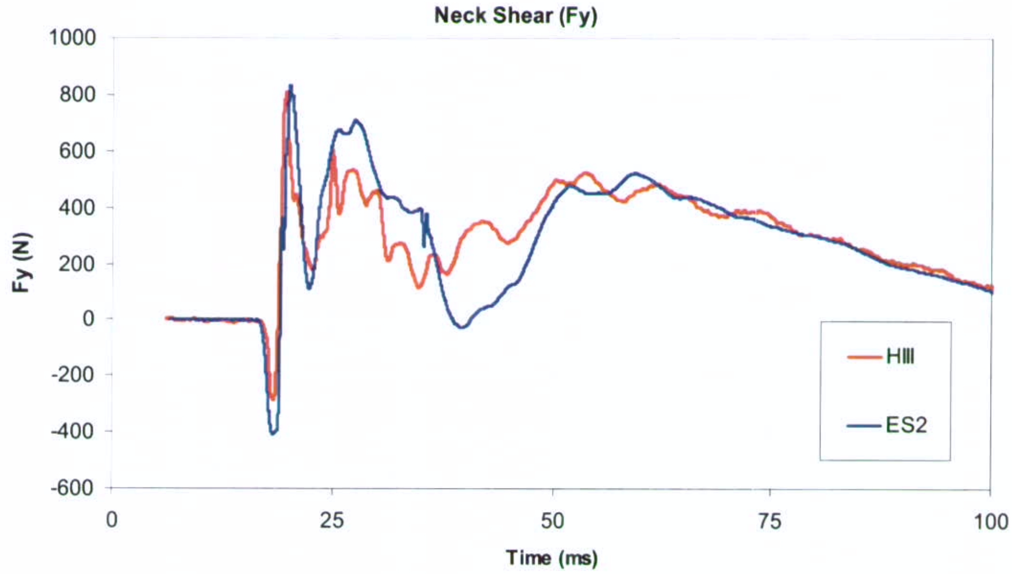

Figure 43: Side impact, cond B, no helmet, ES-2 vs. H3 – Neck shear force (Fy)

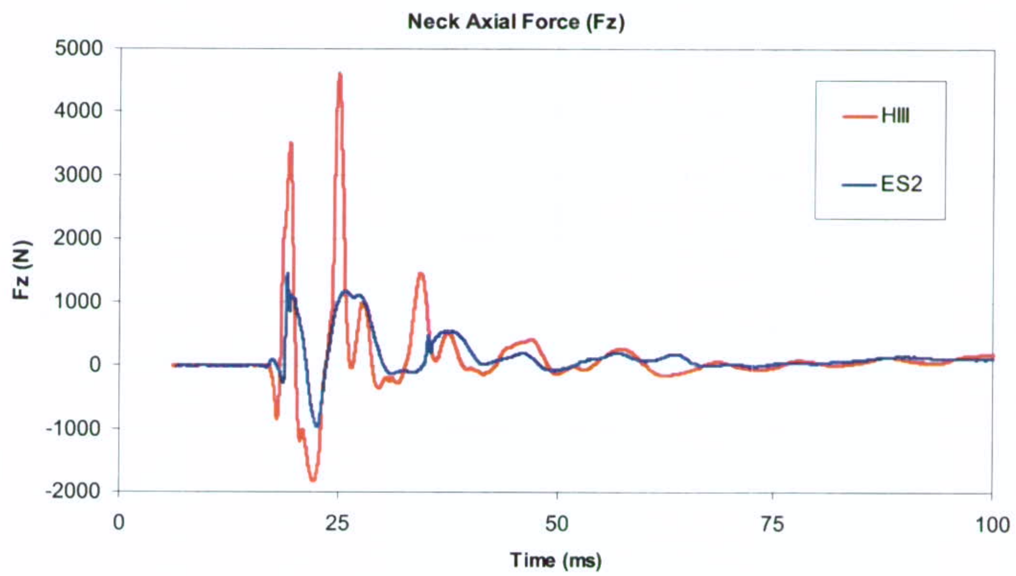

Figure 44: Side impact, cond B, no helmet, ES-2 vs. H3 – Neck axial force (Fz)

4.3. High-speed videos

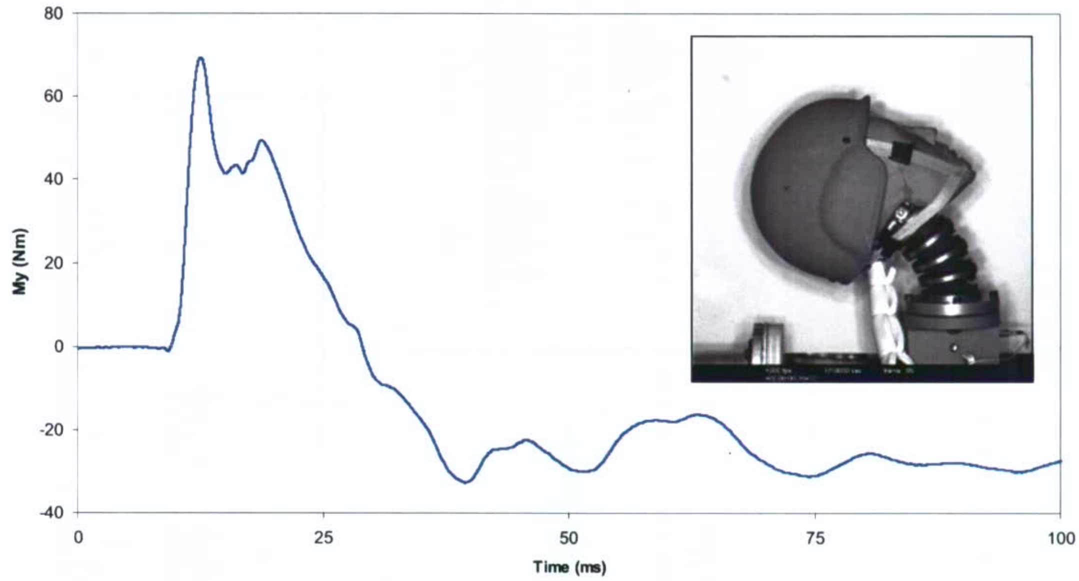

Figure 45: Rear impact, H3, cond B, – Neck moment (My)

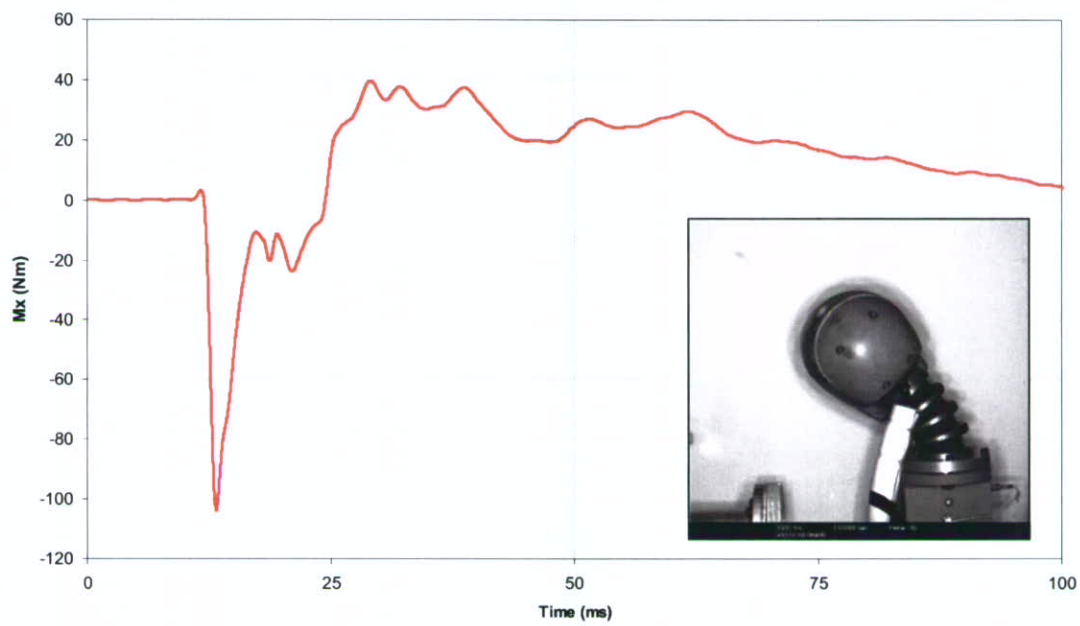

Figure 46: Side impact, cond B, no helmet, H3 – Neck moment (Mx)

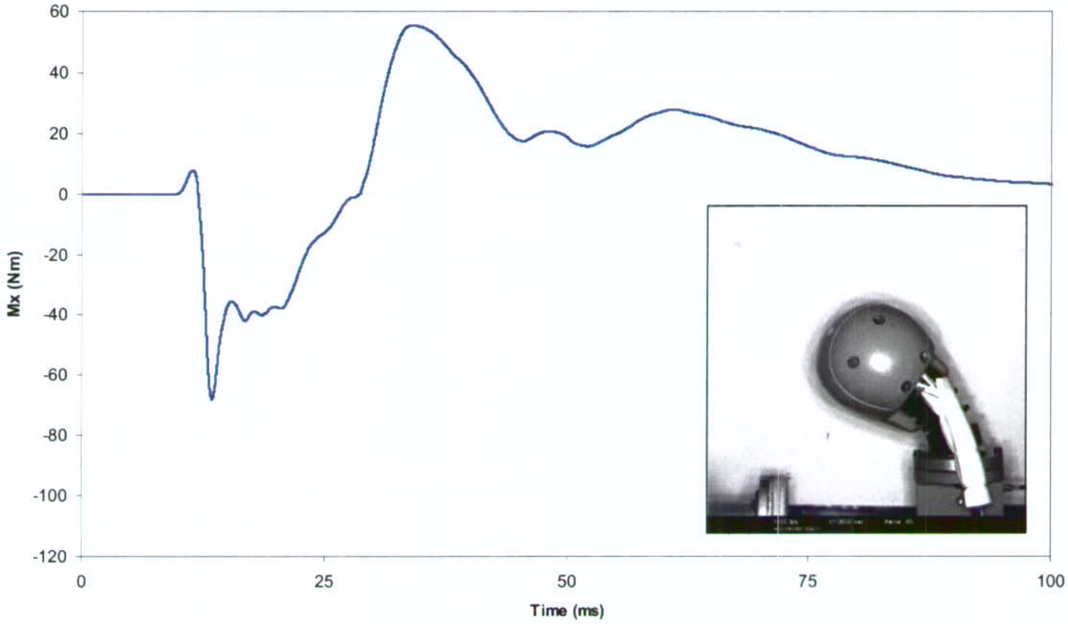

Figure 47: Side impact, cond B, no helmet, ES-2 – Neck moment (Mx)

4.4. SAP Measurements

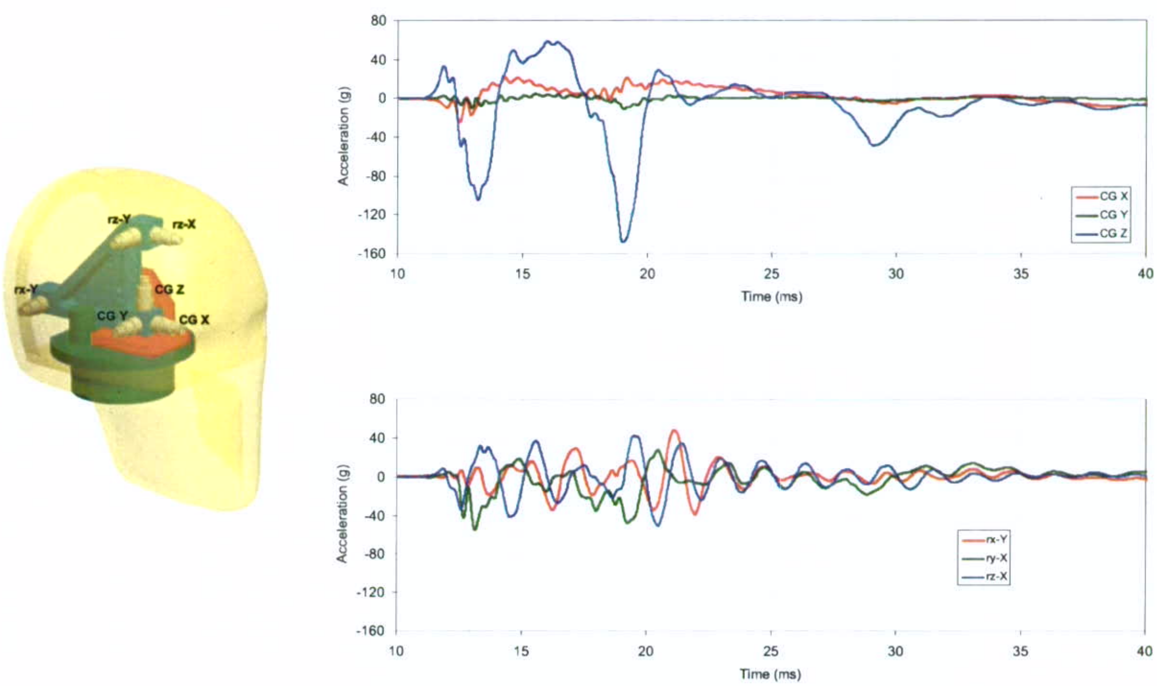

Figure 48 - Rear impact, H3 – no helmet, cond B

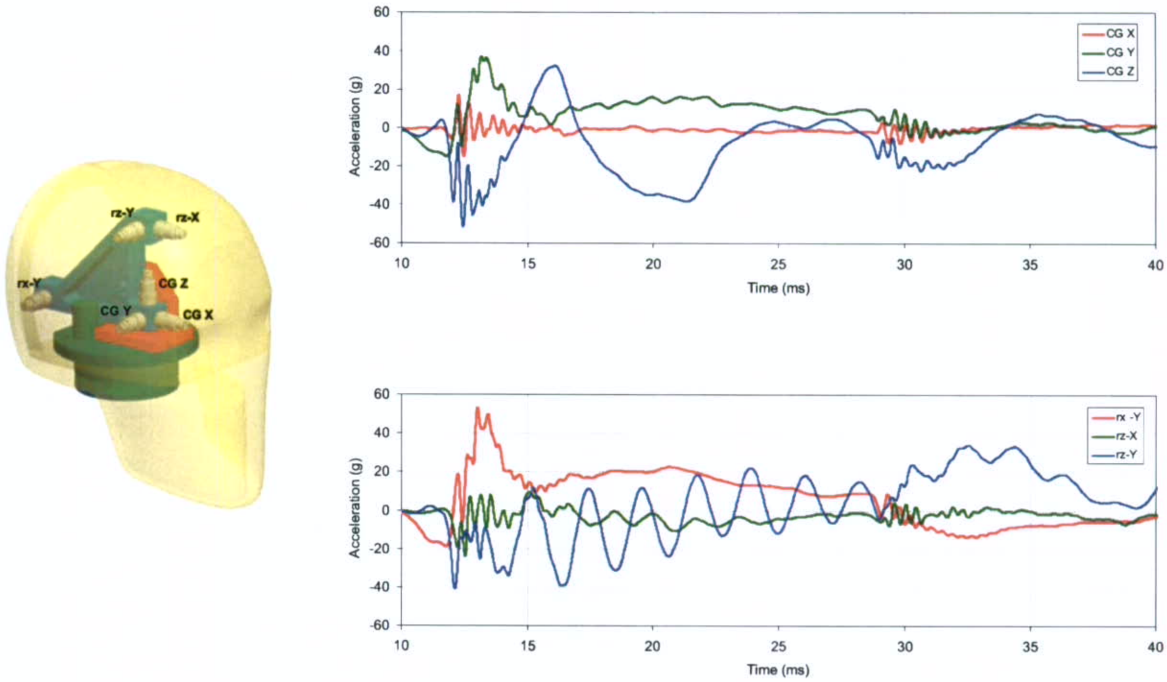

Figure 49 - Side impact, ES-2 – no helmet, cond B

5. Discussion & Conclusions

Rear and side impact tests were performed to evaluate the effect of combat helmet on head/neck response for two surrogates, the Hybrid III (H3) and the EuroSID II (ES-2). Rear impact tests were done with the H3 only and side impact tests were done with both surrogates. Impact tests were performed under two different loading conditions (A & B) to reproduce the neck response of crash test mannequins measured during full-scale vehicle tests at DRDC Valcartier.

Few trends were observed even though the number of test repetitions was limited. First, the helmet was found to have more effect for rear impacts, especially at higher loading conditions (B). However, the helmet had the effect of increasing or decreasing the amplitude of the neck loads, depending on the timing in the signal. Because of that, it is hard to conclude if the helmet increases or decreases the risk of neck injury at this point. In terms of head linear accelerations, the helmet clearly reduced the amplitude in case of rear impact.

Differences were observed between the Hybrid III and Euro-SID II recorded responses, particulary for the amplitude and shape of the axial force (Fz), but there is currently not enough information to identify the most suitable surrogate for side blast loading conditions. A suggested approach is to define appropriate injury prediction model and associated criterion to quantify impact severity. The surrogate predicting higher injury risk can be identified as the most conservative option. Further comparison between Hybrid III and Euro-SID II should also include experimental tests with complete mannequins impacted directly on the shoulder as experienced in vehicle blast scenarios.

Finally, the SAP was used in this study. Although the severity of the loadings was moderate (HIC < 250), resonance was observed for a number of of acceleration signals. This phenomenon was also experienced in full-scale vehicle tests at DRDC Valcartier. Further investigations are required to understand and correct this problem.

6. References

Mertz, H. J. (2002). Anthropomorphic Test Devices. Accidental Injury Biomechanics and Prevention. A. N. Nahum and J. W. Melvin. New York, Springer: 72-88.

Pellman, E. J., D. C. Viano, et al. (2003). "Concussion in Professional Football: Reconstruction of Game Impacts and Injuries." Neurosurgery **53**(4): 799-814.

Prasad, P. and H. J. Mertz (1985). "The position of the United States Delegates to the ISO Working Group on the Use of HIC in the Automotive Environment." SAE **85**(1246).

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7. List of Abbreviations

DRDC	Defence Research and Development Canada
IED	Improvised Explosive Device
Fx	Neck Force (x-direction)
Fy	Neck Force (y-direction)
Fz	Neck Force (z-direction)
Mx	Neck Moment (x-direction)
My	Neck Moment (y-direction)
Mocy	Neck Moment about Occipital Condyle (y-direction)
SAP	Six-Accelerometer Package
SI	Severity Index
HIC	Head Injury Criterion
HIII/H3	Hybrid III
ES-2/ES2	EuroSid 2
CG634	Combat Helmet model CG634
NOCSAE	National Operating Committee on Standards for Athletic Equipment
PCB	PCB Piezotronics Inc. (a manufacturer of piezoelectric quartz sensors, accelerometers, and associated electronics for the measurement of dynamic pressure, force, and vibration)
SAE	Society of Automotive Engineers

8. Distribution List

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Appendix A Test Results

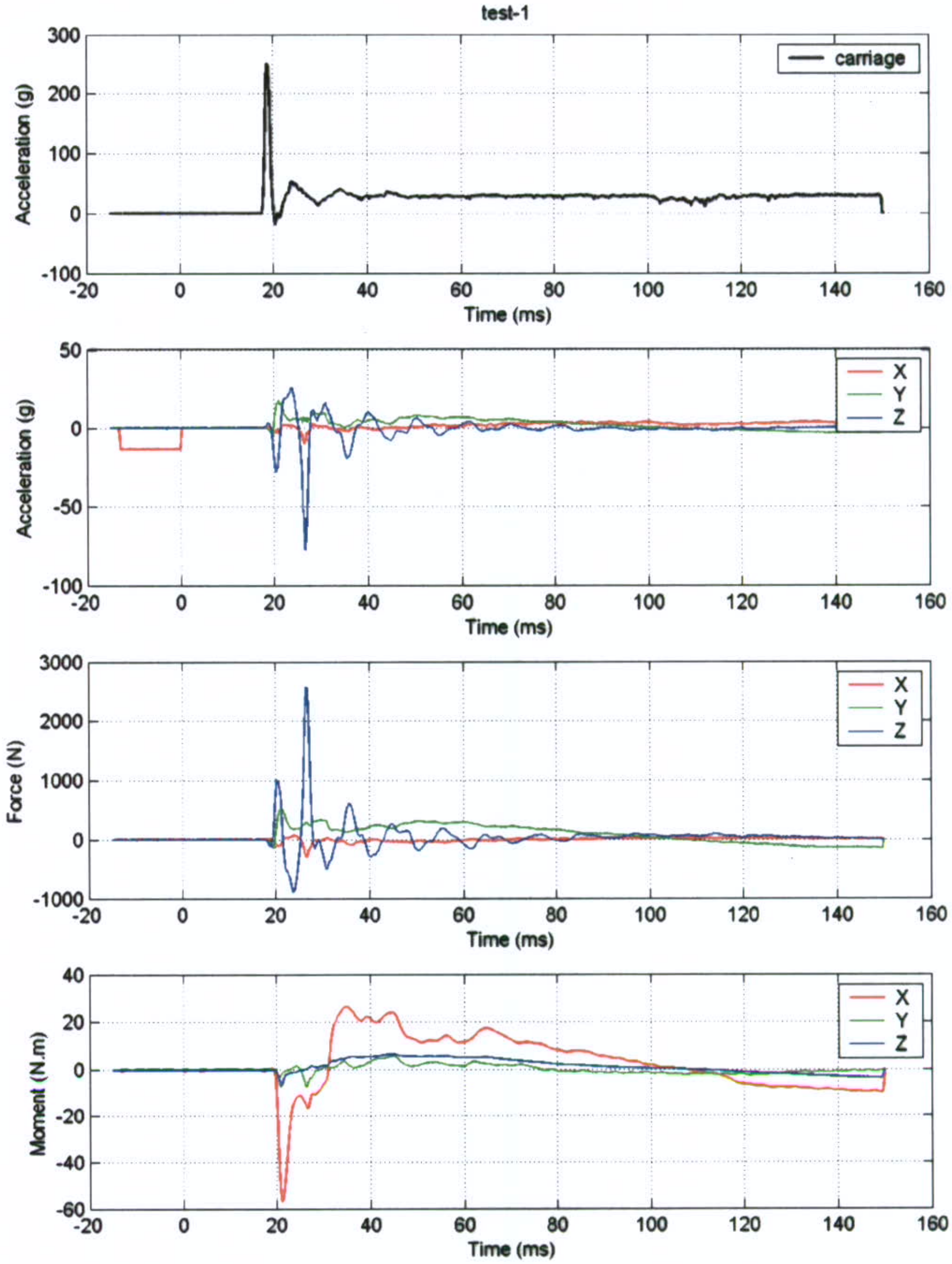
Test #	Impact Condition	Test ID	Repetition #	Impact Orientation	ATD	Helmet	Target Velocity	Impact Velocity	Video	Peak Carriage Accel. (g)
1			1	Side	Hybrid III	No	3.7	3.86	No	251
2		1	2	Side	Hybrid III	No	3.7	3.51	Yes	282
3			3	Side	Hybrid III	No	3.7	3.6	No	293
4			1	Side	ES-2	No	3.7	3.79	No	264
5		2	2	Side	ES-2	No	3.7	3.64	Yes	365
6			3	Side	ES-2	No	3.7	3.55	No	337
7			1	Rear	Hybrid III	No	3.7	3.66	No	334
8		3	2	Rear	Hybrid III	No	3.7	3.82	Yes	315
9			3	Rear	Hybrid III	No	3.7	3.64	No	297
10	A		1	Side	Hybrid III	Yes	3.7	3.85	No	321
11		4	2	Side	Hybrid III	Yes	3.7	3.63	No	307
12			3	Side	Hybrid III	Yes	3.7	3.52	Yes	305
13			1	Side	ES-2	Yes	3.7	3.49	No	341
14		5	2	Side	ES-2	Yes	3.7	3.54	Yes	354
15			3	Side	ES-2	Yes	3.7	3.59	No	371
16			1	Rear	Hybrid III	Yes	3.7	3.59	Yes	311
17		6	2	Rear	Hybrid III	Yes	3.7	3.67	No	309
18			3	Rear	Hybrid III	Yes	3.7	3.87	No	340
19			1	Side	Hybrid III	No	7.25	7.11	Yes	840
20		7	2	Side	Hybrid III	No	7.25	7.19	No	941
21			3	Side	Hybrid III	No	7.25	7.2	No	915
22			1	Side	ES-2	No	7.25	7.13	No	1043
23		8	2	Side	ES-2	No	7.25	7.5	Yes	994
24			3	Side	ES-2	No	7.25	7.36	No	1097
25			1	Rear	Hybrid III	No	7.25	7.23	Yes	930
26		9	2	Rear	Hybrid III	No	7.25	7.41	No	895
27			3	Rear	Hybrid III	No	7.25	7.17	No	1141
28	B		1	Side	Hybrid III	Yes	7.25	7.25	No	619
29		10	2	Side	Hybrid III	Yes	7.25	7.27	Yes	664
30			3	Side	Hybrid III	Yes	7.25	7.53	No	838
31			1	Side	ES-2	Yes	7.25	7.27	Yes	1045
32		11	2	Side	ES-2	Yes	7.25	7.15	No	1061
33			3	Side	ES-2	Yes	7.25	7.31	No	1060
34			1	Rear	Hybrid III	Yes	7.25	7.49	Yes	741
35		12	2	Rear	Hybrid III	Yes	7.25	7.25	No	833
36			3	Rear	Hybrid III	Yes	7.25	7.29	No	986

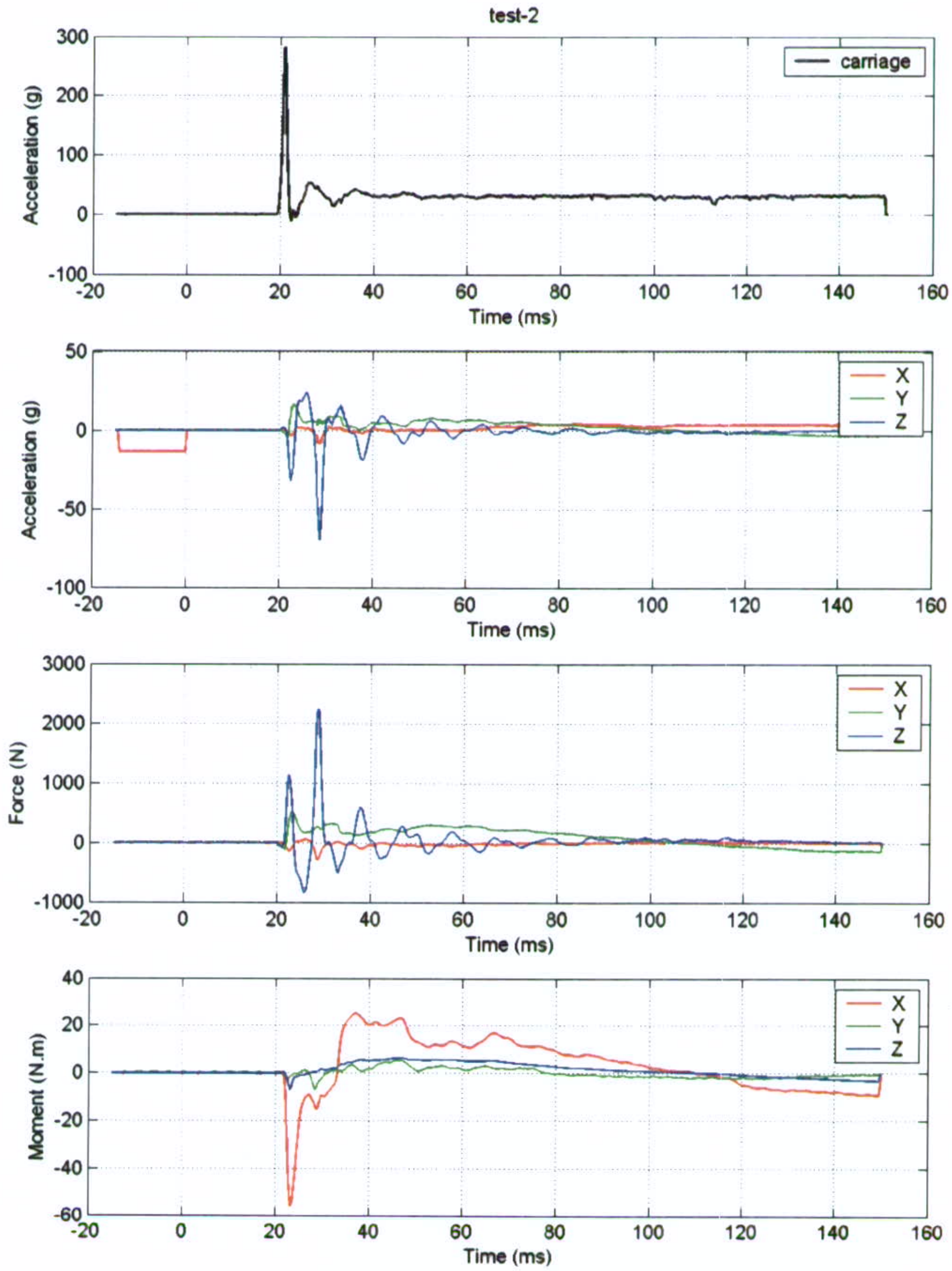
Test #	Nij	Nij quad	Nij moment (N.m)	Nij force (N)	Extension max (N)	Time at Emax (ms)	Flexion max (N)	Time at Fmax (ms)	Compression max (N)	Time at Cmax (ms)	Tension max (N)	Time at Tmax (ms)
1	0.38	2	-1.0	2573.7	-2.2	41.1	6.5	60.0	-888.5	38.8	2575.2	41.7
2	0.34	2	-1.3	2252.2	-2.2	43.1	6.3	61.5	-843.7	40.9	2254.1	43.7
3	0.34	2	-1.5	2289.3	-2.7	42.6	6.3	61.3	-856.6	40.4	2291.3	43.3
4	0.14	3	1.5	930.0	-2.6	56.7	2.2	75.4	-624.7	40.8	930.1	45.0
5	0.13	3	2.4	853.7	-2.4	57.9	3.0	43.6	-490.9	41.8	853.7	45.5
6	0.13	3	1.3	839.9	-1.9	56.3	2.5	63.4	-495.9	42.3	840.0	46.2
7	0.38	3	26.8	2022.3	-28.3	63.7	27.5	44.0	-939.3	40.6	2022.3	43.6
8	0.39	3	27.3	2061.7	-29.3	63.2	28.2	43.6	-838.8	40.1	2061.7	42.6
9	0.37	3	26.0	1961.8	-28.3	64.2	27.0	44.5	-888.8	40.8	1961.8	43.6
10	0.38	2	-1.3	2510.1	-3.3	41.3	6.5	70.2	-919.0	39.1	2514.6	42.0
11	0.36	2	-0.9	2456.7	-2.1	42.6	6.5	73.8	-912.0	40.3	2461.6	43.4
12	0.36	2	-1.1	2426.3	-2.2	43.2	6.3	72.2	-875.5	40.8	2430.0	43.8
13	0.13	3	2.3	856.5	-1.7	67.6	3.2	77.6	-490.3	42.6	856.6	46.4
14	0.13	3	2.3	857.4	-1.6	67.2	3.5	76.9	-462.3	42.1	857.4	45.9
15	0.13	3	1.8	882.7	-1.6	66.8	3.5	76.4	-459.7	41.8	882.7	45.7
16	0.40	3	27.1	2128.3	-22.4	74.2	30.0	39.3	-969.6	40.8	2128.4	43.9
17	0.35	3	29.5	1756.1	-21.4	114.6	29.8	43.7	-750.0	40.2	1756.1	43.2
18	0.41	3	31.1	2123.3	-22.8	112.8	31.7	42.6	-905.3	39.2	2123.3	42.2
19	0.69	3	0.6	4731.3	-7.3	35.0	10.9	53.9	-1727.6	30.9	4731.3	27.9
20	0.76	2	-4.3	4971.2	-8.5	35.2	11.0	54.0	-1810.6	31.1	4971.2	33.9
21	0.71	2	-4.7	4600.8	-8.6	35.3	10.4	54.2	-1836.3	31.2	4601.5	33.9
22	0.22	3	1.5	1461.3	-6.7	46.5	6.0	53.8	-966.9	31.1	1461.3	27.7
23	0.22	2	-4.2	1287.6	-7.5	46.2	7.8	54.1	-901.9	31.0	1288.4	36.0
24	0.24	3	1.5	1590.6	-8.1	46.8	5.9	54.6	-1022.0	31.5	1590.6	27.8
25	0.85	3	44.5	4874.6	-48.5	56.4	49.3	35.8	-1817.7	31.4	4874.6	34.1
26	0.87	3	46.6	4910.4	-47.6	56.2	49.8	35.5	-1736.9	31.4	4910.4	34.0
27	0.75	3	44.2	4185.2	-46.5	57.4	49.0	36.1	-1789.5	31.8	4185.2	34.7
28	0.75	2	-2.4	4987.8	-7.2	34.7	13.7	65.3	-1625.8	30.5	4989.1	33.4
29	0.73	2	-3.7	4823.7	-7.2	34.6	14.3	65.7	-1641.5	30.6	4823.7	33.4
30	0.74	2	-3.4	4926.7	-8.0	34.4	14.7	65.0	-1757.7	30.5	4926.7	33.2
31	0.22	2	-3.94	1285.09	-7.35	49.92	11.31	67.90	-688.08	31.10	1286.42	35.98
32	0.20	2	-2.76	1239.17	-8.18	50.25	11.23	68.22	-751.31	31.45	1241.49	36.00
33	0.19	2	-3.74	1134.59	-6.21	50.32	12.62	68.30	-776.28	31.37	1192.36	27.78
34	0.67	3	36.92	3786.37	-33.73	111.07	55.86	27.65	-1482.75	29.48	3786.37	32.48
35	0.68	3	29.09	4053.21	-34.27	112.02	55.33	28.65	-1694.24	30.33	4063.26	27.03
36	0.72	3	39.19	4065.15	-35.26	88.40	49.35	29.30	-1739.72	30.38	4066.09	33.28

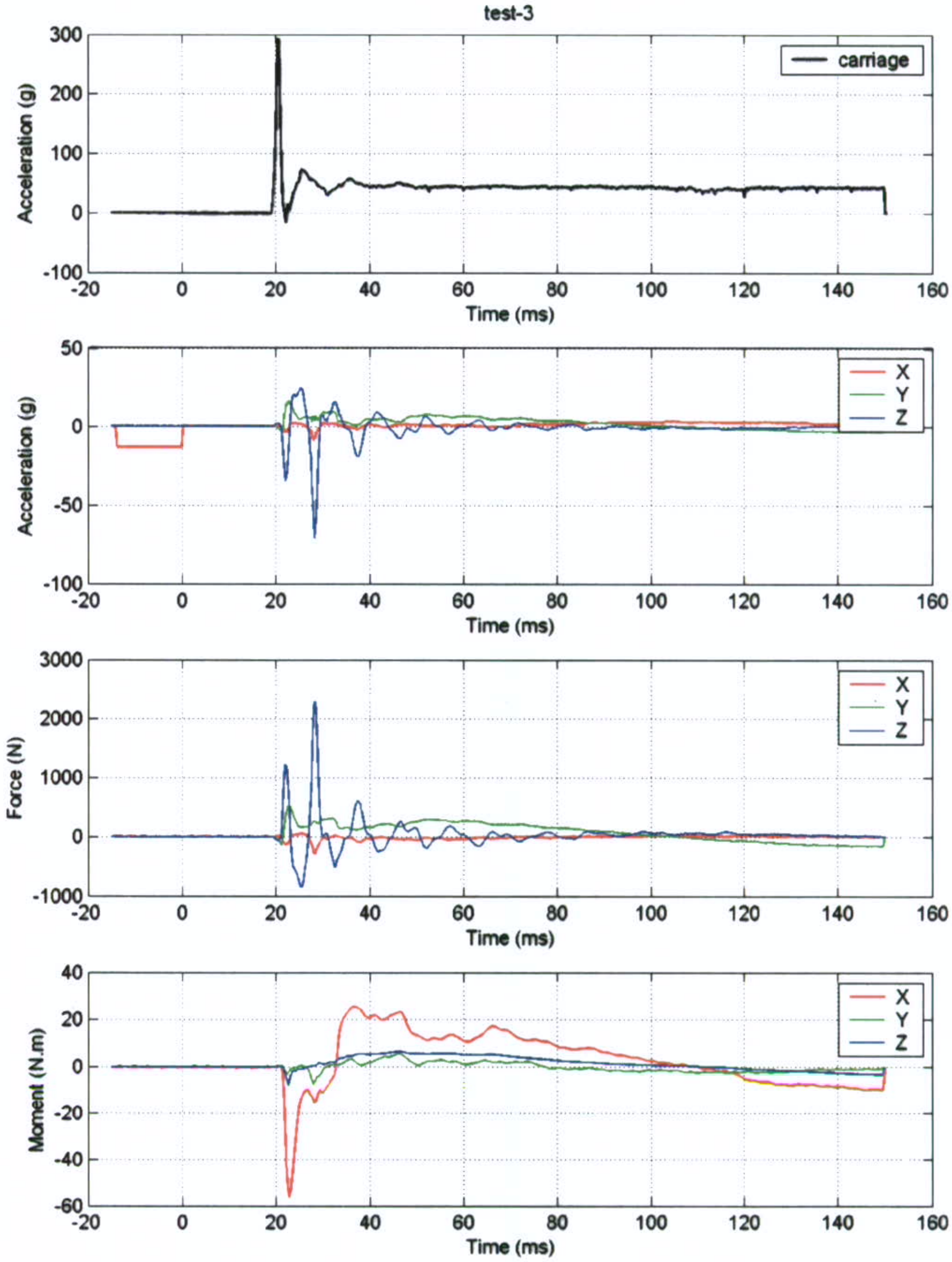
Test #	Fx max (N)	Fx min (N)	Fy max (N)	Fy min (N)	Fz max (N)	Fz min (N)	Mx max (N.m)	Mx min (N.m)	My max (N.m)	My min (N.m)	Mocy max (N.m)	Mocy min (N.m)	Mz max (N.m)	Mz min (N.m)
1	73.7	-300.7	533.9	-132.3	2575.2	-888.5	26.5	-57.3	5.8	-7.1	6.5	-2.2	6.6	-6.9
2	62.2	-275.4	531.9	-108.9	2254.1	-843.7	25.2	-55.5	5.4	-6.8	6.3	-2.2	6.4	-6.9
3	51.9	-289.7	523.8	-136.8	2291.3	-856.6	25.4	-56.0	5.5	-7.1	6.3	-2.7	6.6	-7.1
4	42.0	-42.8	467.2	-215.2	930.1	-624.7	36.3	-29.7	2.6	-3.2	2.2	-2.6	3.6	-0.1
5	36.7	-54.2	492.6	-268.4	853.7	-490.9	38.3	-34.7	3.5	-3.0	3.0	-2.4	3.7	0.0
6	30.9	-53.3	486.6	-267.9	840.0	-495.9	37.1	-34.5	3.1	-2.7	2.5	-1.9	3.5	-0.1
7	407.7	-222.6	25.3	-25.4	2022.3	-939.3	1.5	-2.9	34.5	-30.0	27.5	-28.3	1.1	-0.4
8	375.8	-166.7	27.7	-28.7	2061.7	-838.8	2.5	-2.0	34.3	-30.6	28.2	-29.3	1.2	-0.4
9	393.6	-169.6	33.0	-24.7	1961.8	-888.8	2.3	-2.6	33.1	-29.6	27.0	-28.3	1.1	-0.5
10	56.0	-307.8	561.1	-134.1	2514.6	-919.0	26.1	-59.1	5.8	-7.7	6.5	-3.3	5.2	-7.5
11	79.9	-282.9	505.6	-127.5	2461.6	-912.0	26.1	-54.9	6.2	-6.5	6.5	-2.1	5.3	-6.8
12	61.7	-305.3	494.1	-132.8	2430.0	-875.5	25.0	-52.8	5.6	-7.1	6.3	-2.2	5.2	-6.6
13	32.8	-38.2	507.9	-262.3	856.6	-490.3	22.2	-36.0	3.8	-2.0	3.2	-1.7	2.0	-0.3
14	27.2	-45.1	510.4	-272.0	857.4	-462.3	23.5	-35.5	3.9	-1.9	3.5	-1.6	2.5	-0.2
15	28.0	-44.4	514.0	-287.5	882.7	-459.7	23.3	-35.6	3.9	-2.1	3.5	-1.6	2.8	-0.5
16	475.7	-239.3	21.3	-30.6	2128.4	-969.6	3.1	-1.7	38.1	-22.6	30.0	-22.4	1.1	-0.2
17	387.4	-160.6	18.7	-27.7	1756.1	-750.0	2.0	-2.1	35.2	-21.3	29.8	-21.4	1.0	-0.2
18	419.2	-211.8	31.4	-26.8	2123.3	-905.3	2.2	-3.4	37.7	-21.3	31.7	-22.8	1.2	-0.5
19	161.6	-517.3	1029.7	-251.1	4731.3	-1727.6	39.6	-103.8	9.4	-13.7	10.9	-7.3	11.6	-11.3
20	167.5	-587.4	800.7	-283.6	4971.2	-1810.6	41.0	-87.5	9.6	-14.8	11.0	-8.5	11.3	-8.5
21	182.2	-543.8	809.5	-287.8	4601.5	-1836.3	41.2	-88.9	8.8	-14.5	10.4	-8.6	11.3	-8.9
22	69.2	-129.1	835.9	-410.8	1461.3	-966.9	53.2	-51.8	6.3	-8.9	6.0	-6.7	7.1	-0.2
23	48.5	-151.3	1104.8	-513.3	1288.4	-901.9	55.5	-68.1	8.3	-10.2	7.8	-7.5	8.0	0.0
24	85.5	-151.3	825.4	-424.2	1590.6	-1022.0	54.0	-52.6	6.3	-10.7	5.9	-8.1	7.2	0.0
25	562.7	-469.5	71.8	-41.6	4874.6	-1817.7	5.2	-6.2	58.8	-52.2	49.3	-48.5	3.2	-1.1
26	558.1	-458.7	54.5	-45.2	4910.4	-1736.9	4.1	-5.1	59.3	-51.6	49.8	-47.6	3.2	-1.2
27	550.1	-452.2	48.3	-33.4	4185.2	-1789.5	4.8	-4.1	58.4	-50.0	49.0	-46.5	2.7	-0.9
28	145.9	-606.8	891.8	-280.9	4989.1	-1625.8	45.6	-94.6	12.9	-13.3	13.7	-7.2	9.0	-10.3
29	143.3	-582.2	874.6	-250.1	4823.7	-1641.5	47.4	-91.9	13.3	-14.0	14.3	-7.2	9.3	-10.7
30	169.0	-583.7	867.0	-297.7	4926.7	-1757.7	49.0	-92.5	13.5	-14.1	14.7	-8.0	9.6	-10.7
31	98.6	-114.2	855.8	-508.0	1286.4	-688.1	46.5	-53.9	13.0	-9.3	11.3	-7.4	4.5	-0.3
32	100.8	-129.4	830.8	-440.5	1241.5	-751.3	42.8	-54.9	13.0	-10.4	11.2	-8.2	5.1	-0.2
33	96.0	-140.6	840.5	-477.1	1192.4	-776.3	43.5	-52.9	14.3	-8.7	12.6	-6.2	5.3	-0.1
34	777.9	-391.8	48.7	-59.3	3786.4	-1482.7	4.9	-5.3	69.3	-32.6	55.9	-33.7	2.4	-1.1
35	772.7	-466.4	62.5	-79.8	4063.3	-1694.2	6.3	-4.4	68.7	-33.3	55.3	-34.3	2.3	-1.0
36	688.9	-398.6	38.3	-68.8	4066.1	-1739.7	5.8	-4.1	61.3	-37.1	49.4	-35.3	2.0	-0.6

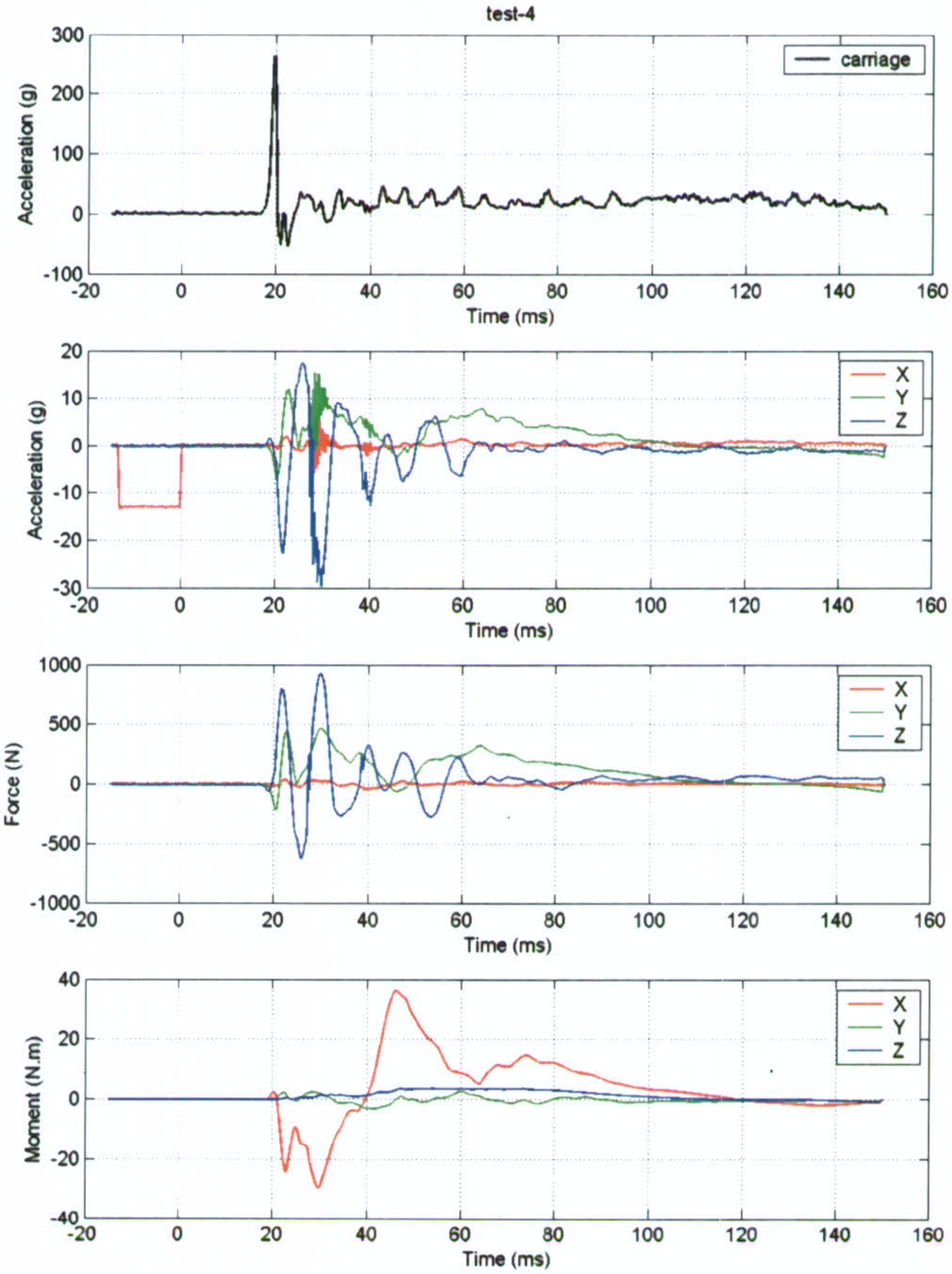
Test #	Ar (g)	α (rad/s²)	ω (rad/s)	SI	HIC	HIP (W)
1	77.6	8769	21	67.9	38.4	1485.1
2	69.6	8702	22	57.8	30.1	1541.9
3	70.7	8833	19.2	58.6	30.4	1278.4
4	31.1	5864	26.2	24.4	14.8	1770.6
5	26.6	4856	29.1	20	11.8	1811.2
6	27.1	4753	28.7	21	12.2	1866.1
7	60.3	6134	23.7	58.5	29.9	2595.3
8	60.8	5675	25.9	51	26.5	2257
9	58.3	5746	24.6	52.4	27.9	2455
10	76.4	8560	21.5	67.3	35.5	1343.1
11	74.0	9110	20	68.5	34.8	1294.7
12	72.6	8658	18.4	62.5	33.2	1102.6
13	26.1	4480	24.2	19	11.7	1696
14	26.6	4840	24.8	18.2	10.8	1853
15	27.3	4974	27	19.5	11.5	2039.6
16	62.1	5779	20.2	60.8	34.1	2532.9
17	52.0	5256	20.8	38.6	20.5	2101
18	62.0	6255	21.2	55	29.8	2498.9
19	136.3	21601	36	364.3	194.7	5872.6
20	163.4	16564	37.8	383.3	191.5	5182.4
21	154.4	16601	39.1	351.2	183.4	4748.2
22	57.9	12893	48.4	72.1	42	6363.8
23	54.5	10236	48.6	88.9	50.1	6467.6
24	61.9	13506	47.9	77.5	44.9	6675.6
25	149.5	13017	42.4	365.8	191.3	10768.1
26	149.9	13626	45.4	350.7	176.2	11463.5
27	124.4	12173	42.5	323.8	174.1	9009.8
28	156.2	18876	34.9	350.8	177.6	5282.7
29	158.1	17004	36.3	360.4	193	4540.5
30	160.4	17676	38	404.5	209.6	5034
31	53.6	8515	42.2	63.4	41.4	6084
32	52.1	10272	43.5	58.3	37.7	5972.7
33	56.2	9386.6	41.5	56.7	34.7	5355.5
34	110.7	8584	29	207	117.1	6913.3
35	116.3	12608	31.9	278.7	163.9	6840.7
36	124.7	11300	37	285	161.6	8104.1

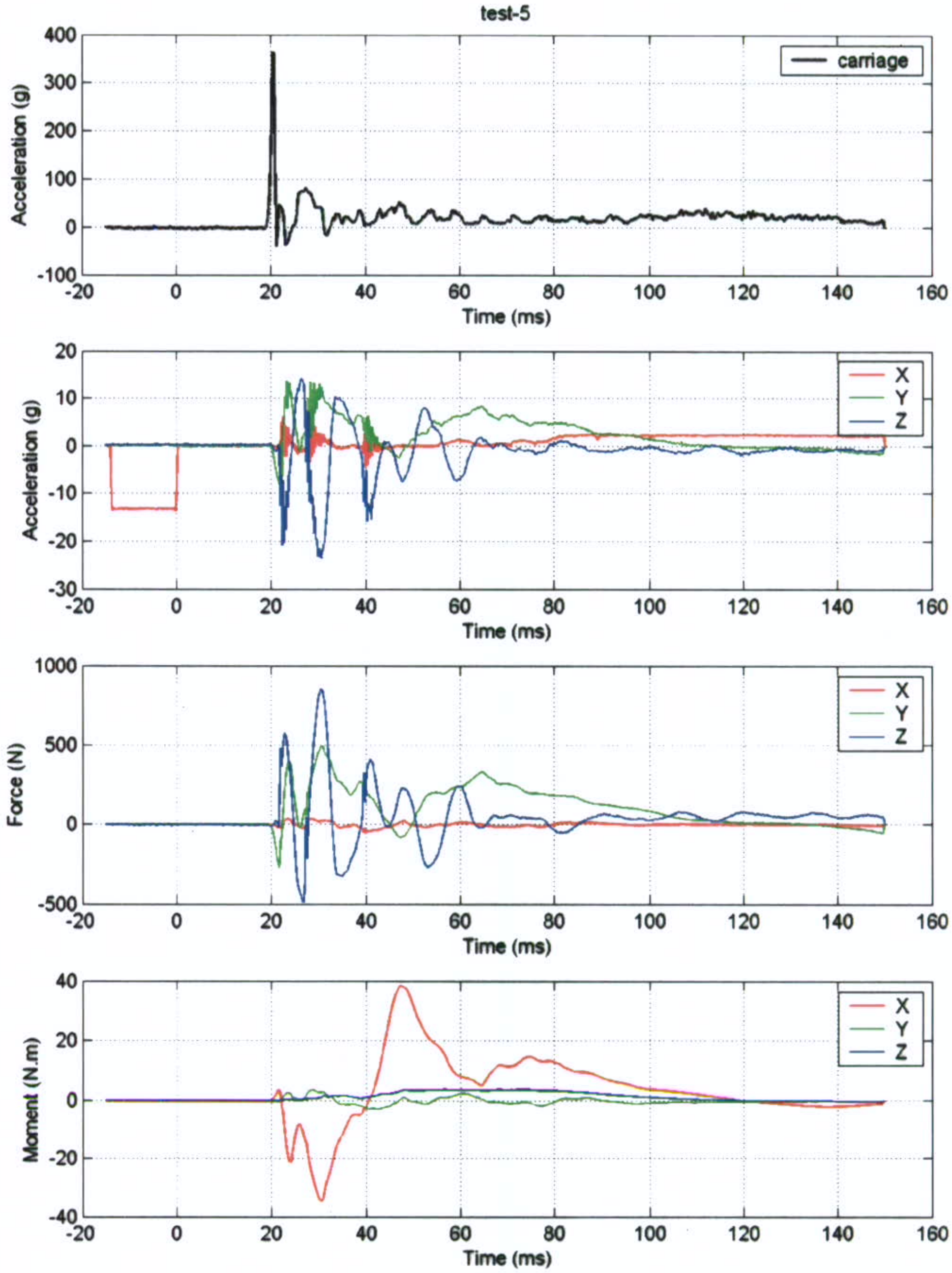
Appendix B Filtered Signals

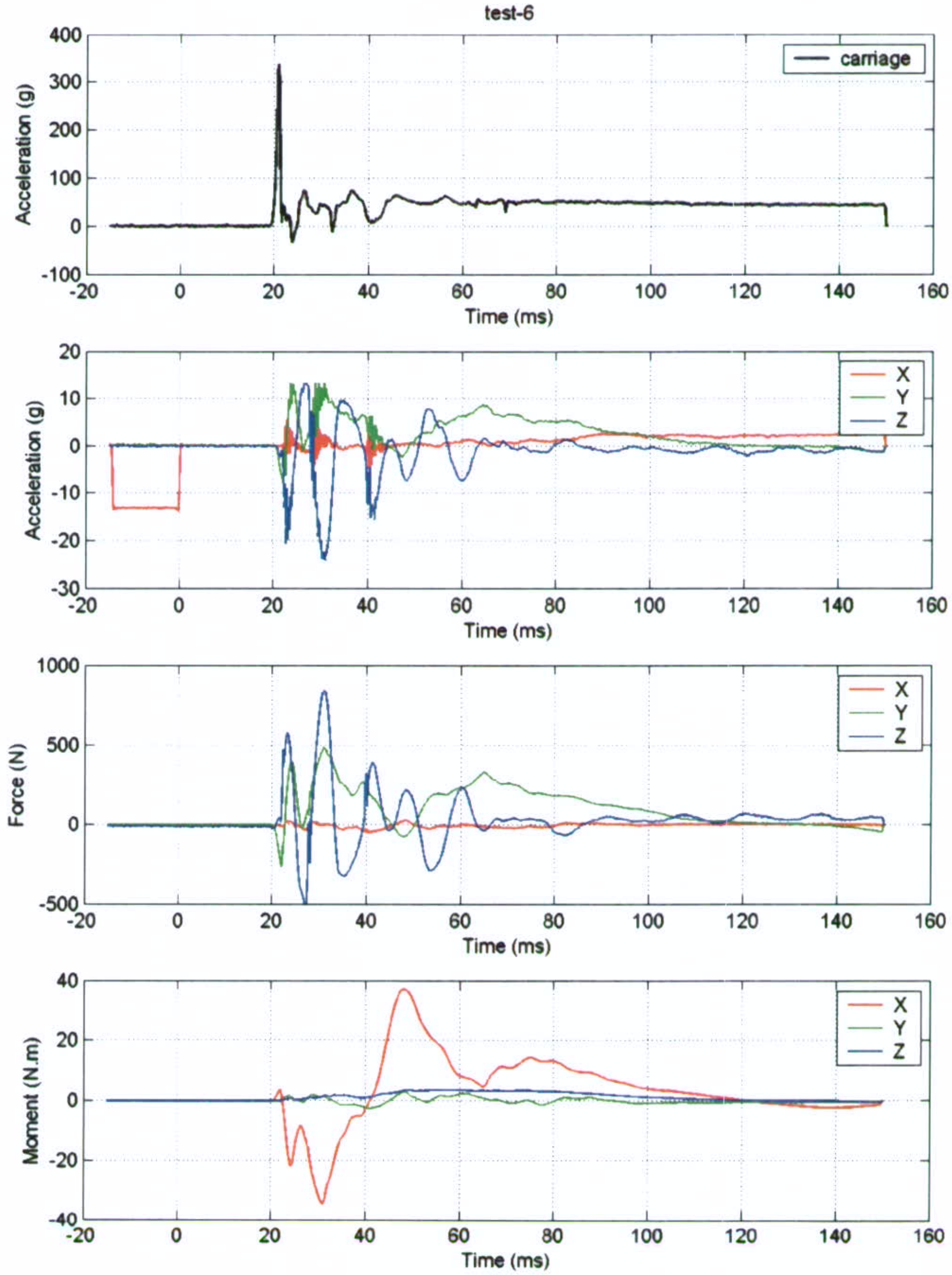

test-1
Acceleration (g)
carriage
Time (ms)
Acceleration (g)
X
Y
Z
Time (ms)
Force (N)
X
Y
Z
Time (ms)
Moment (N.m)
X
Y
Z
Time (ms)

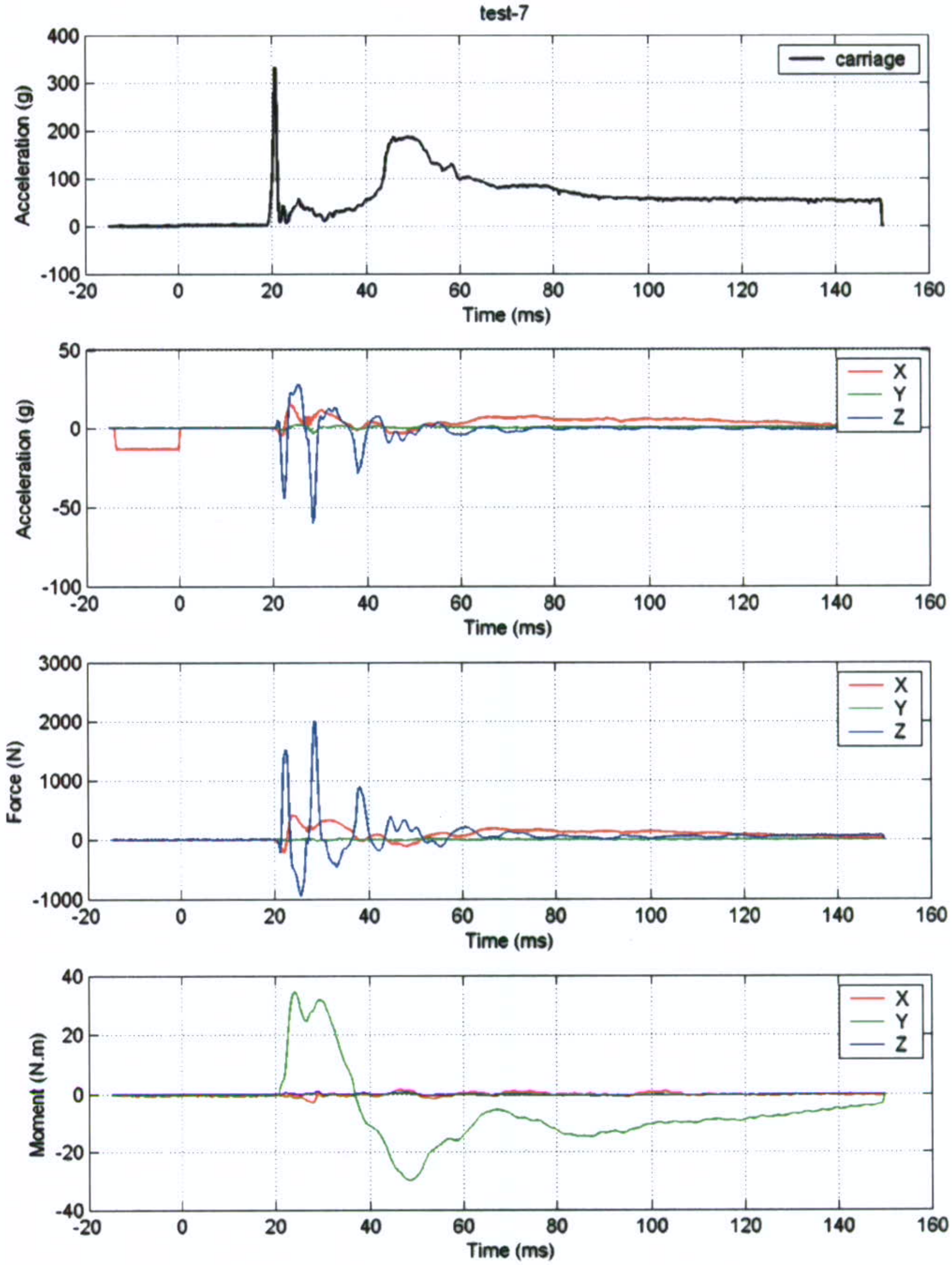

test-2
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

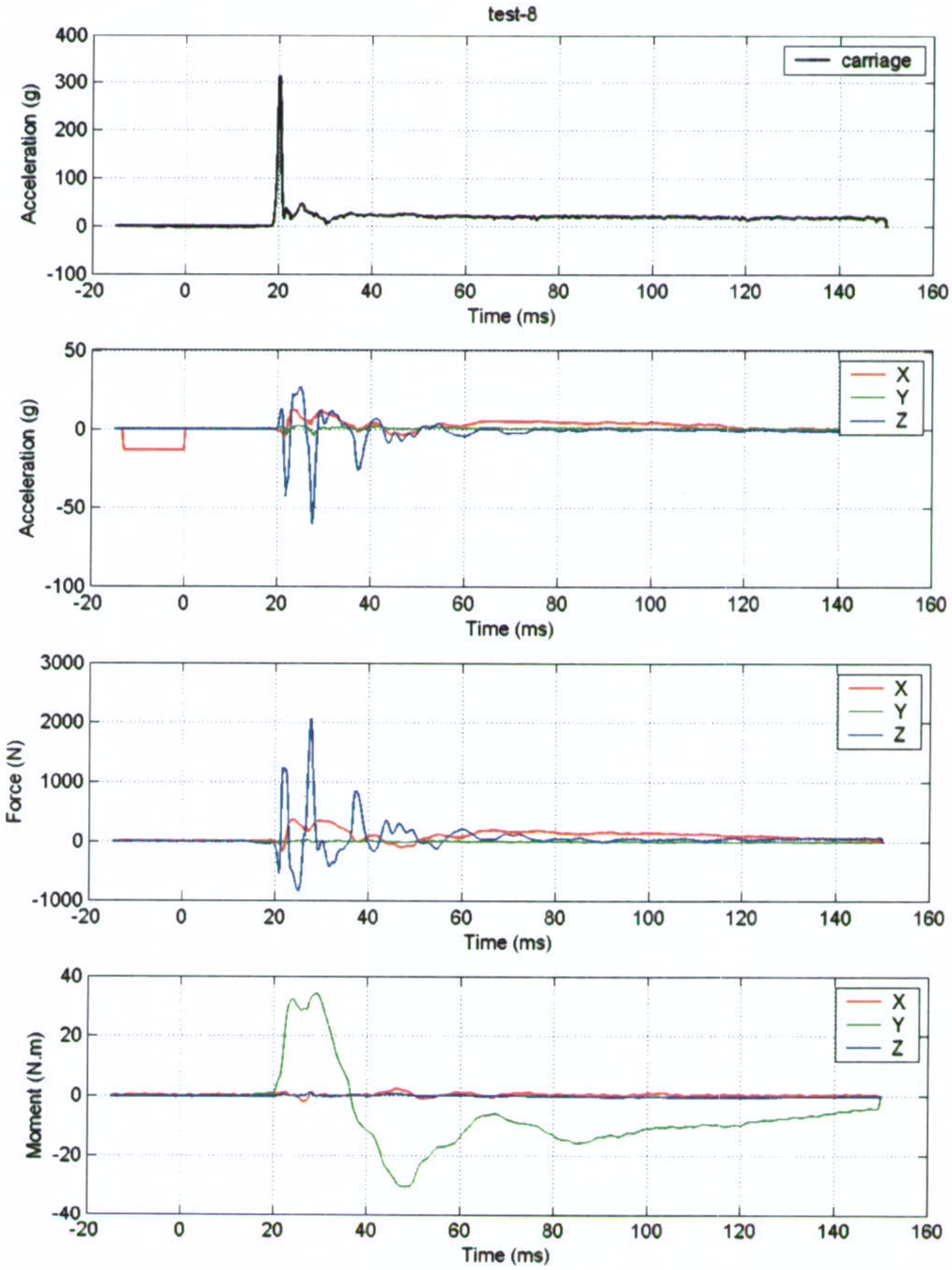

test-3
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

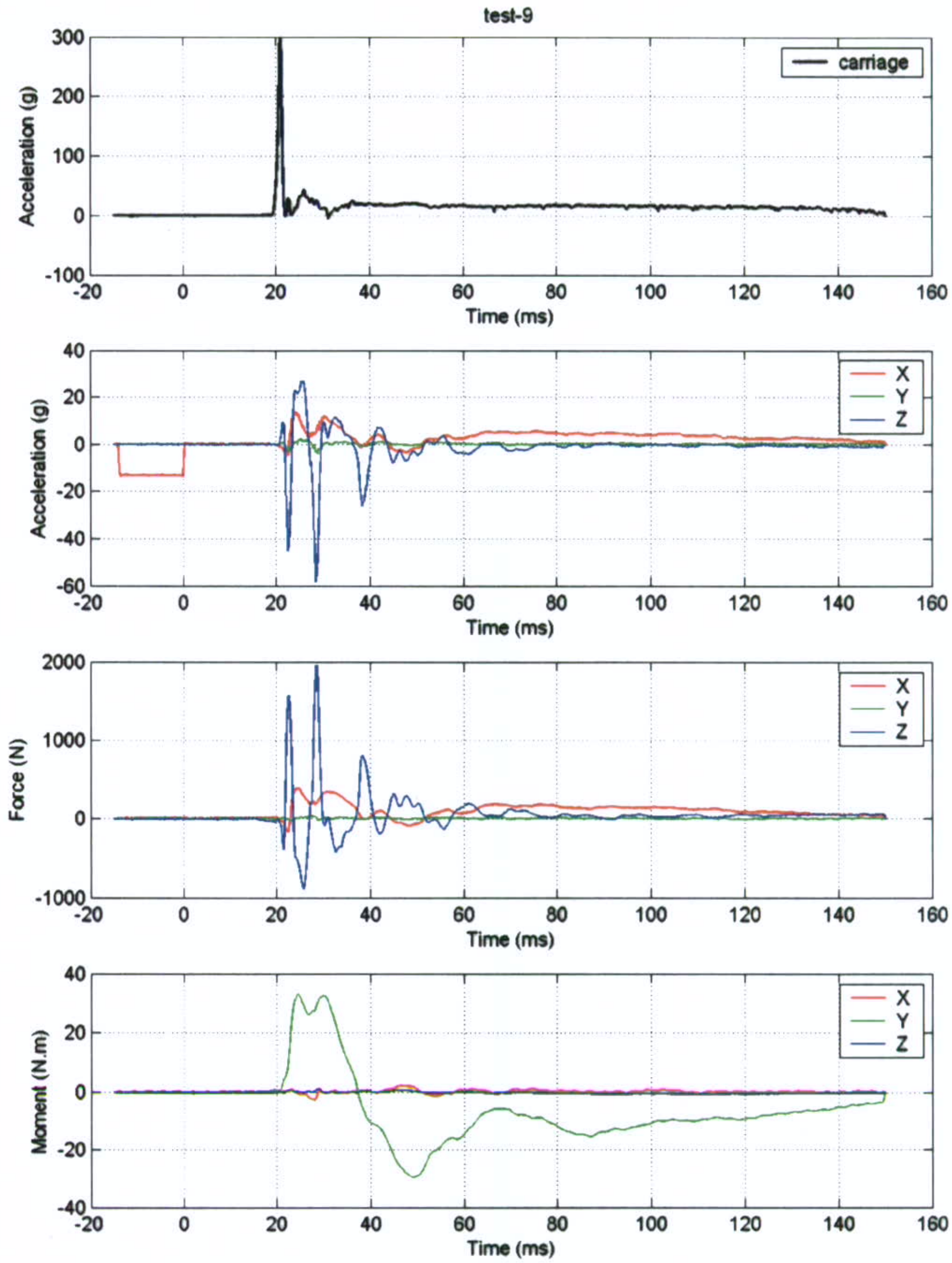

test-4
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

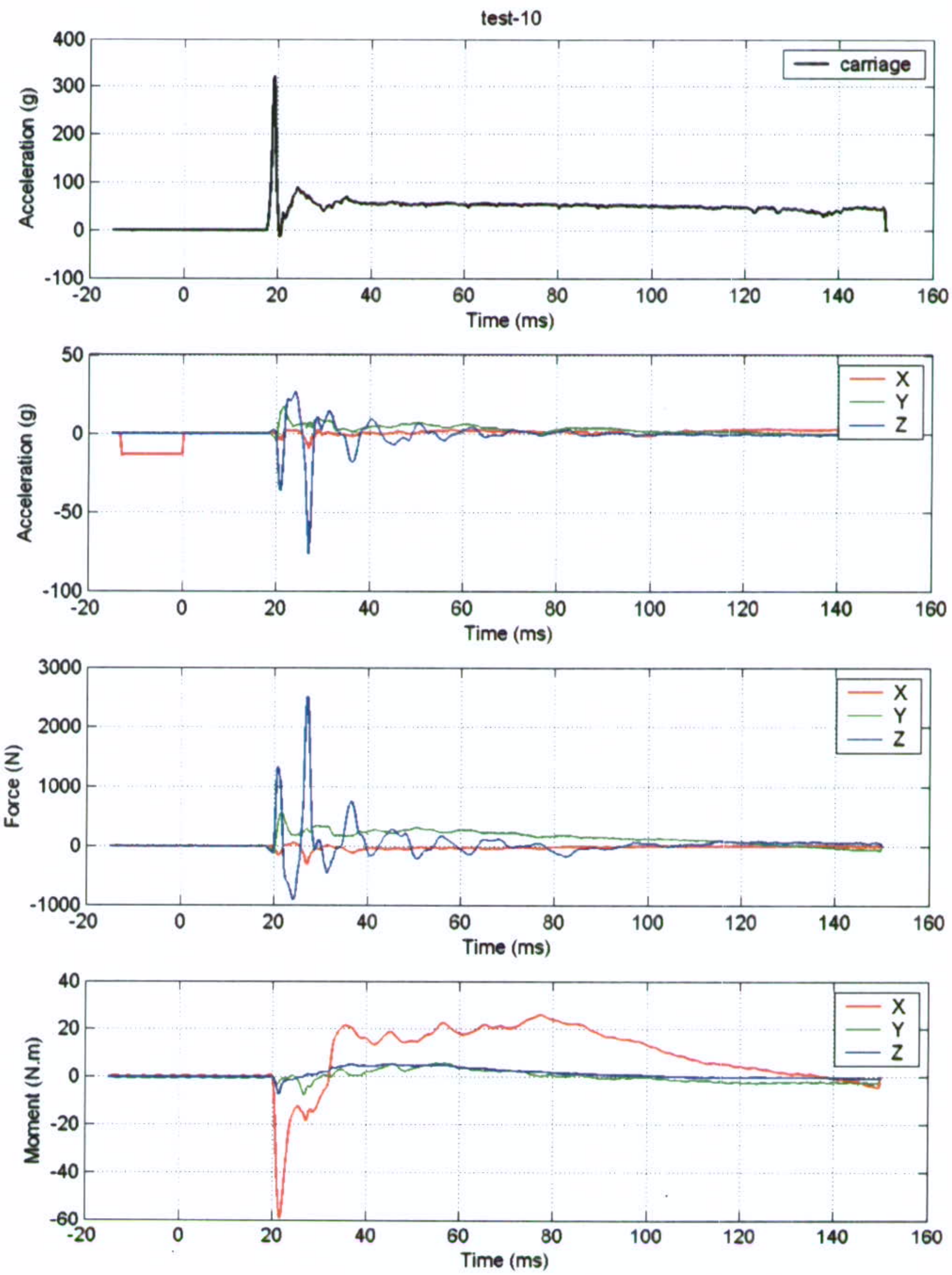

test-5
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

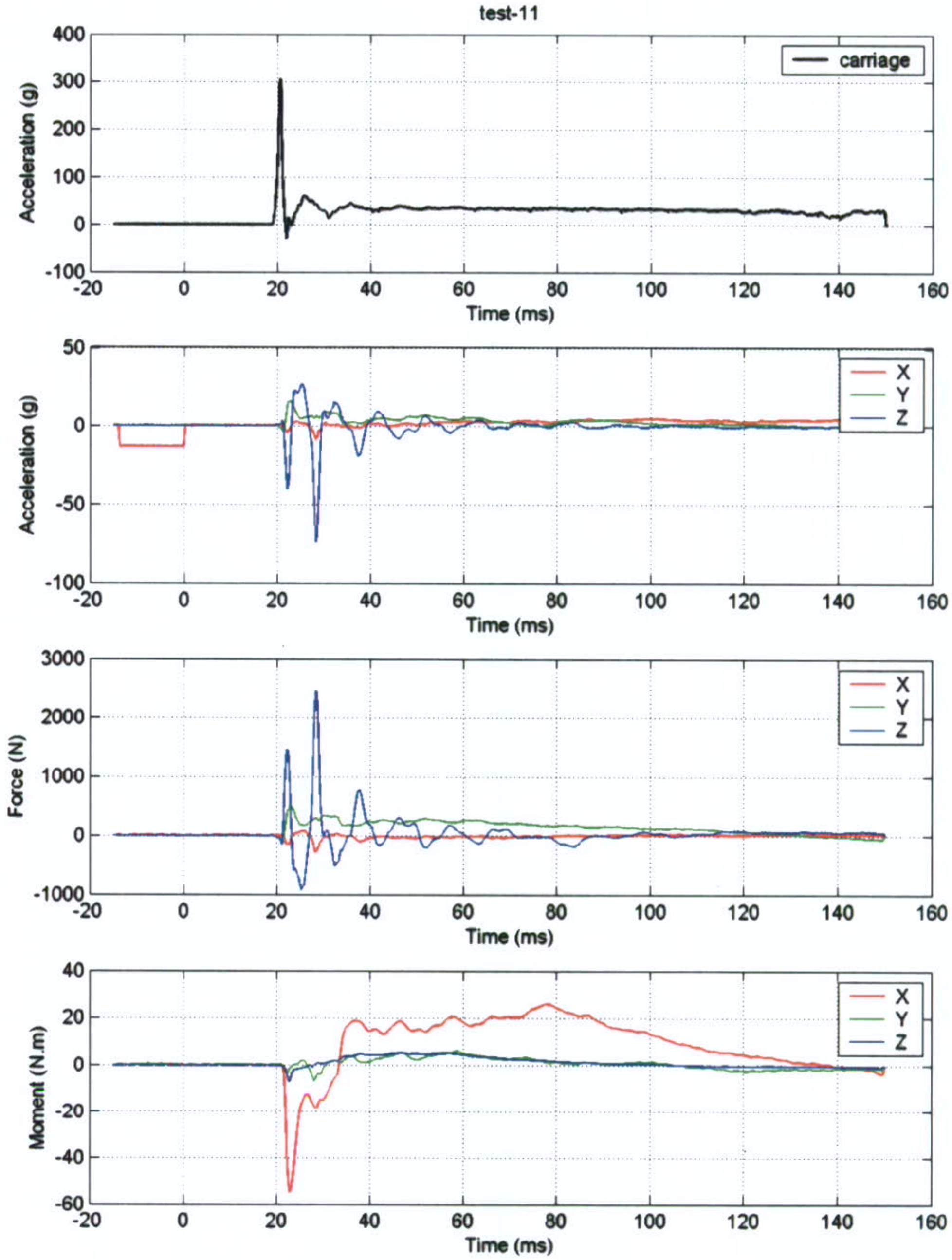

test-6
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

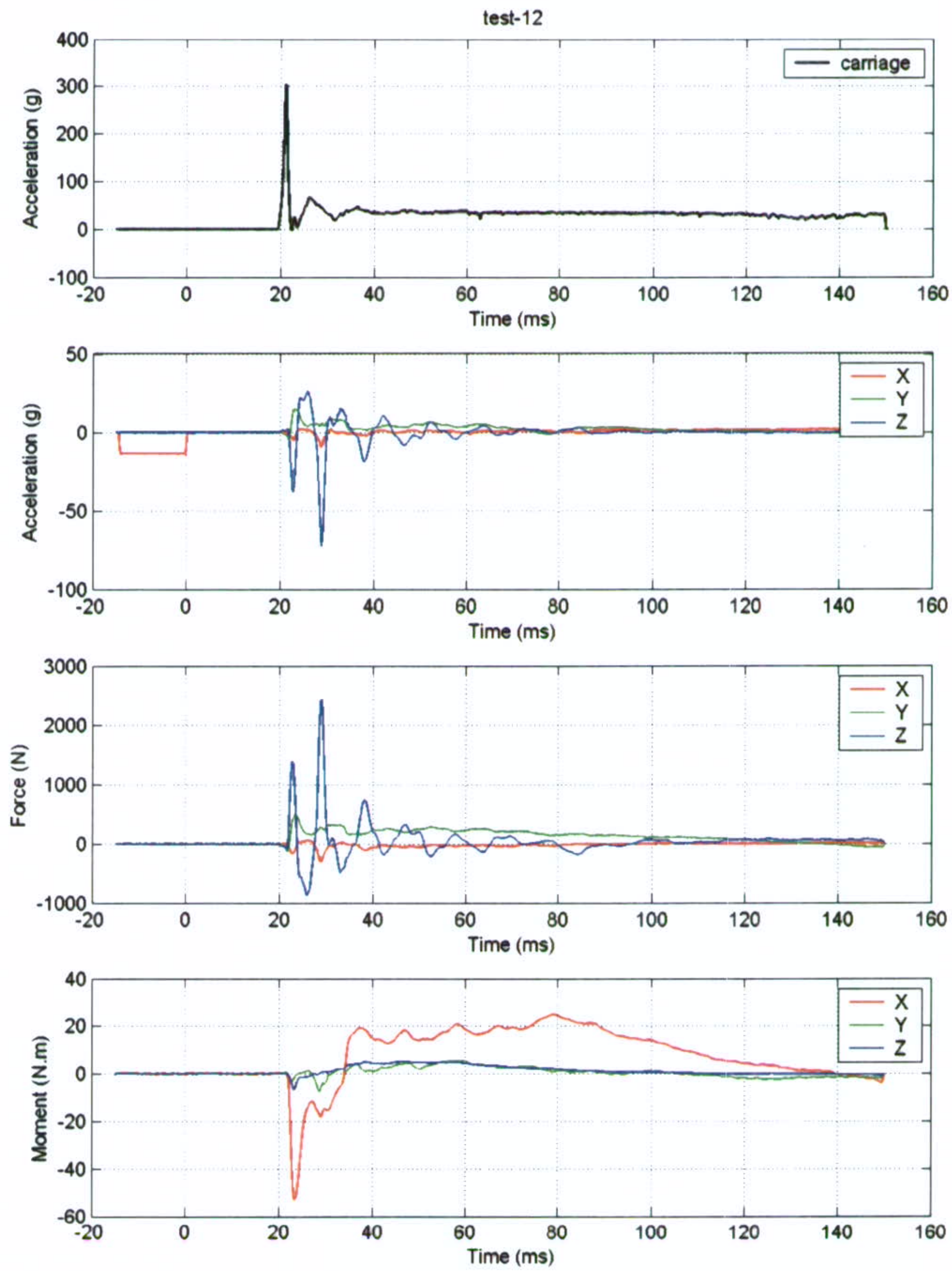

test-7
Acceleration (g)
Time (ms)
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)
X
Y
Z

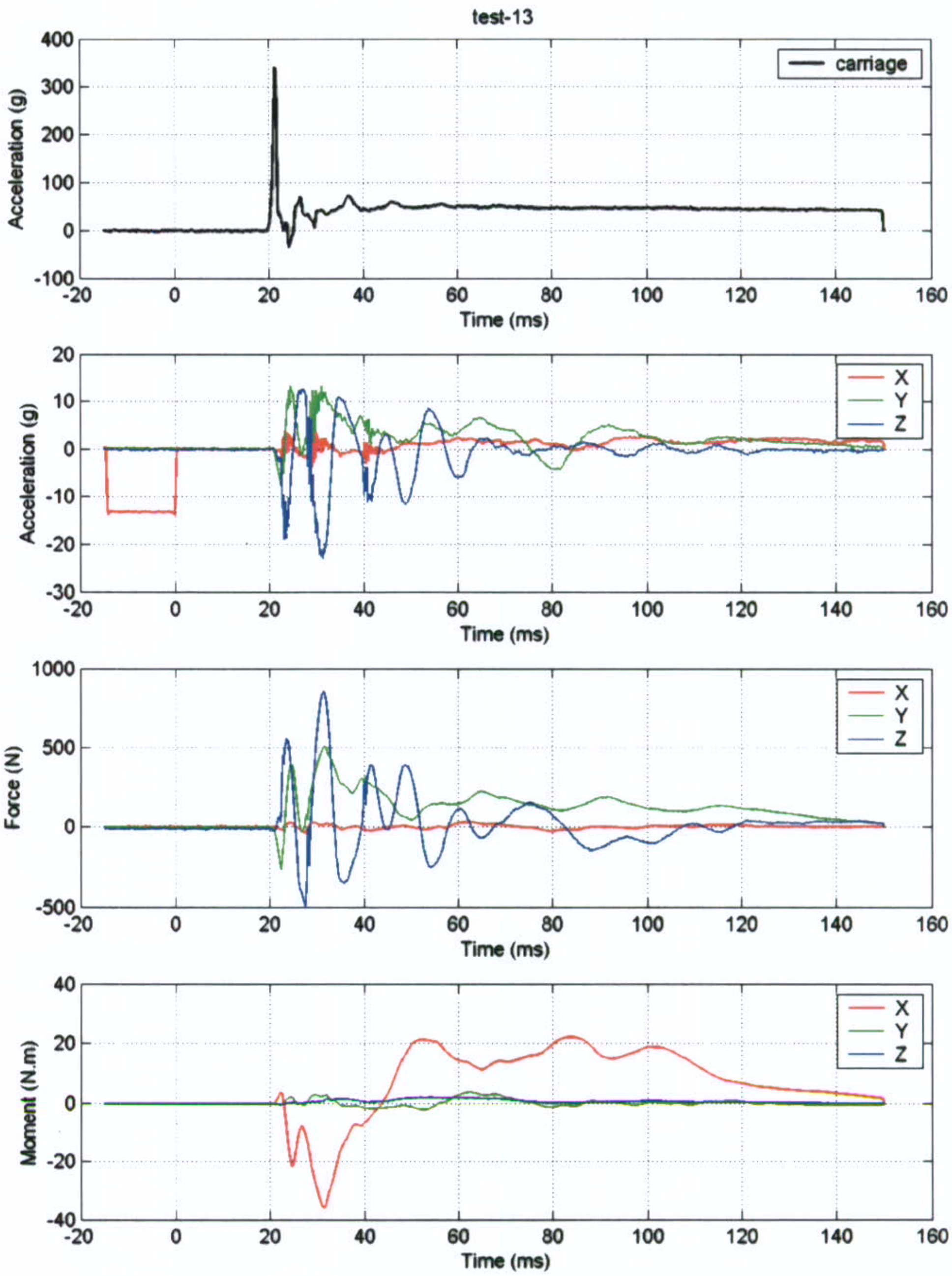

test-8
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

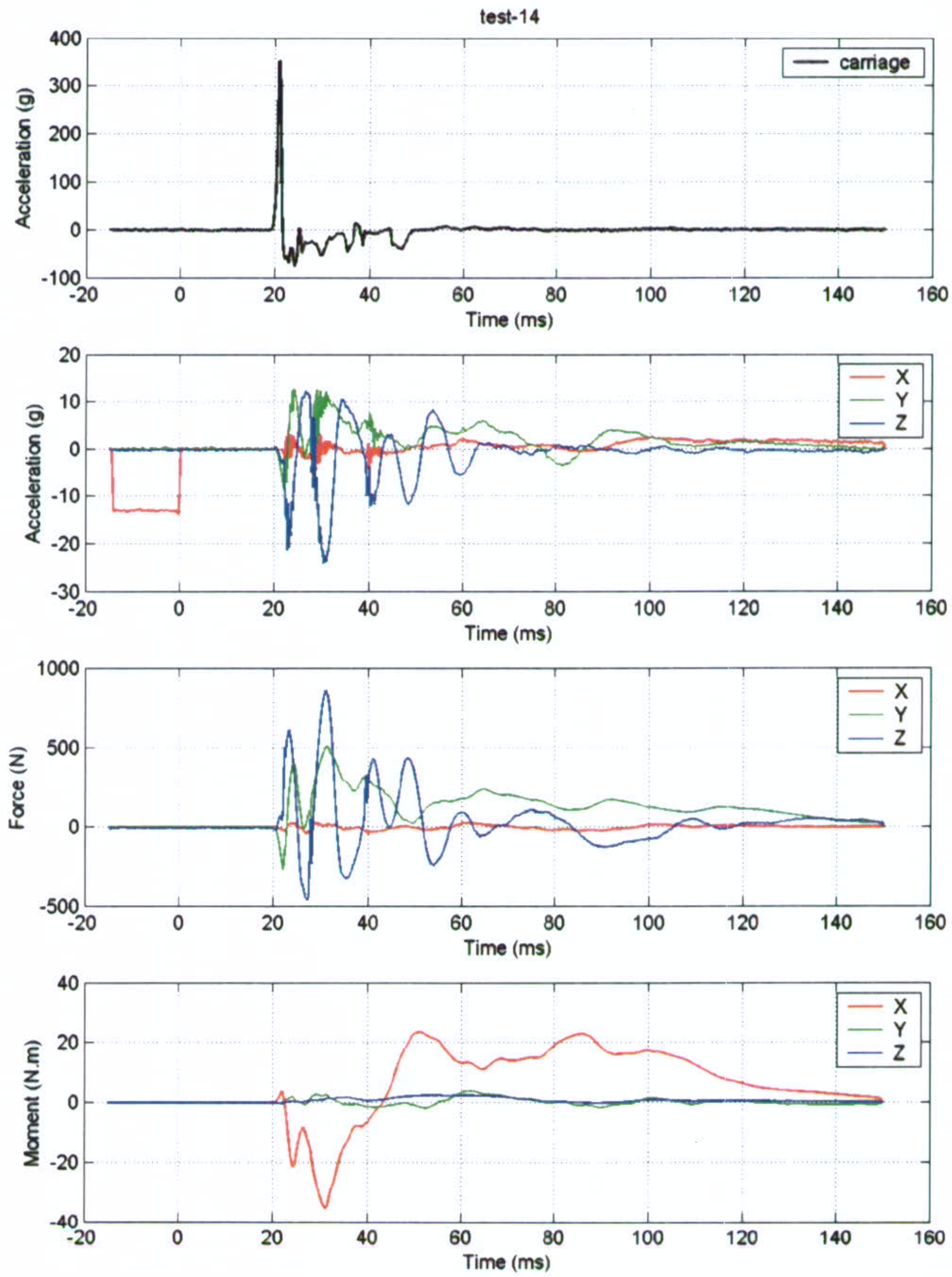

test-9
Acceleration (g)
carriage
Time (ms)
Acceleration (g)
X
Y
Z
Time (ms)
Force (N)
X
Y
Z
Time (ms)
Moment (N.m)
X
Y
Z
Time (ms)

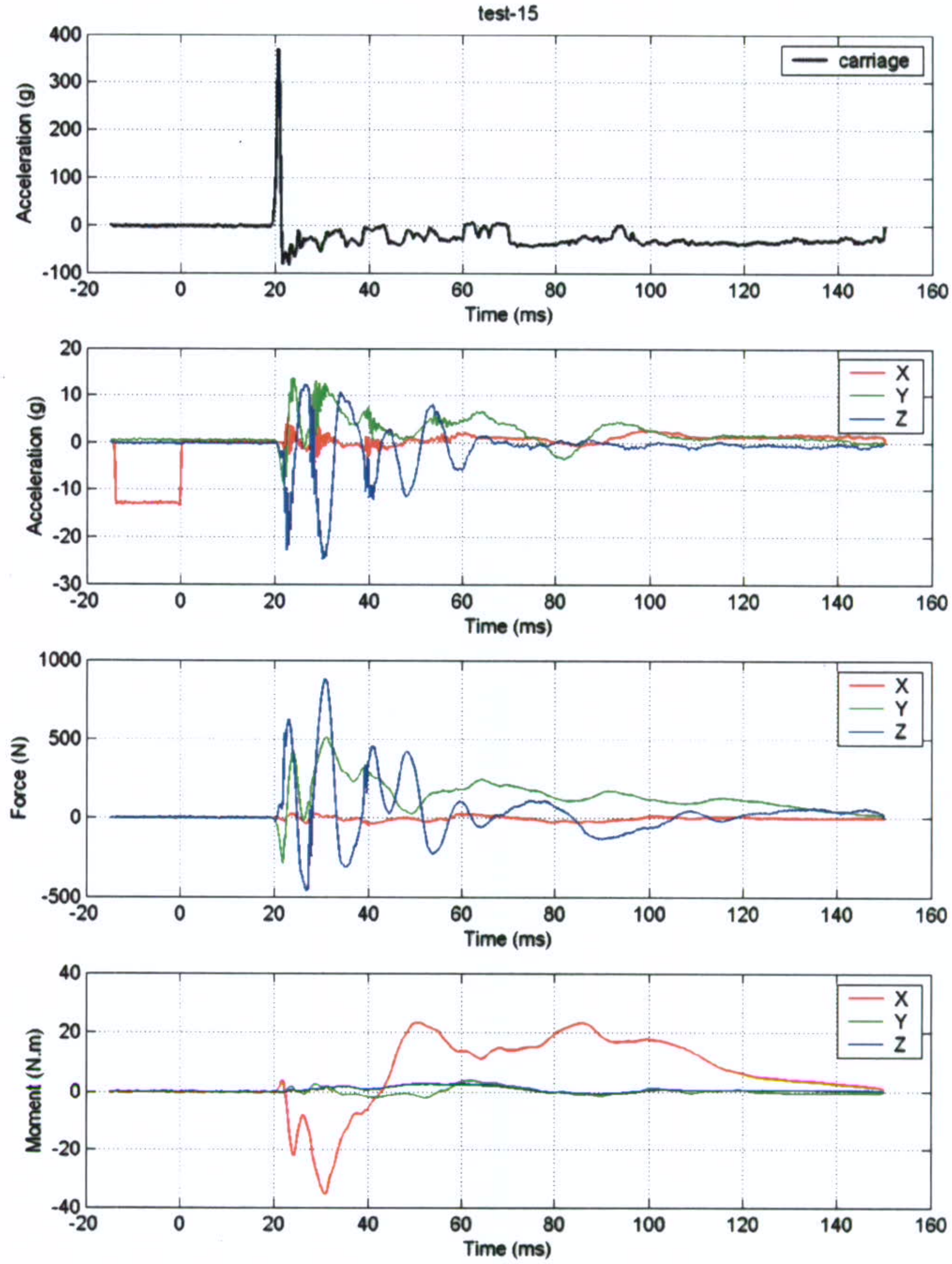

test-10
Acceleration (g)
carriage
Time (ms)
Acceleration (g)
X
Y
Z
Time (ms)
Force (N)
X
Y
Z
Time (ms)
Moment (N.m)
X
Y
Z
Time (ms)

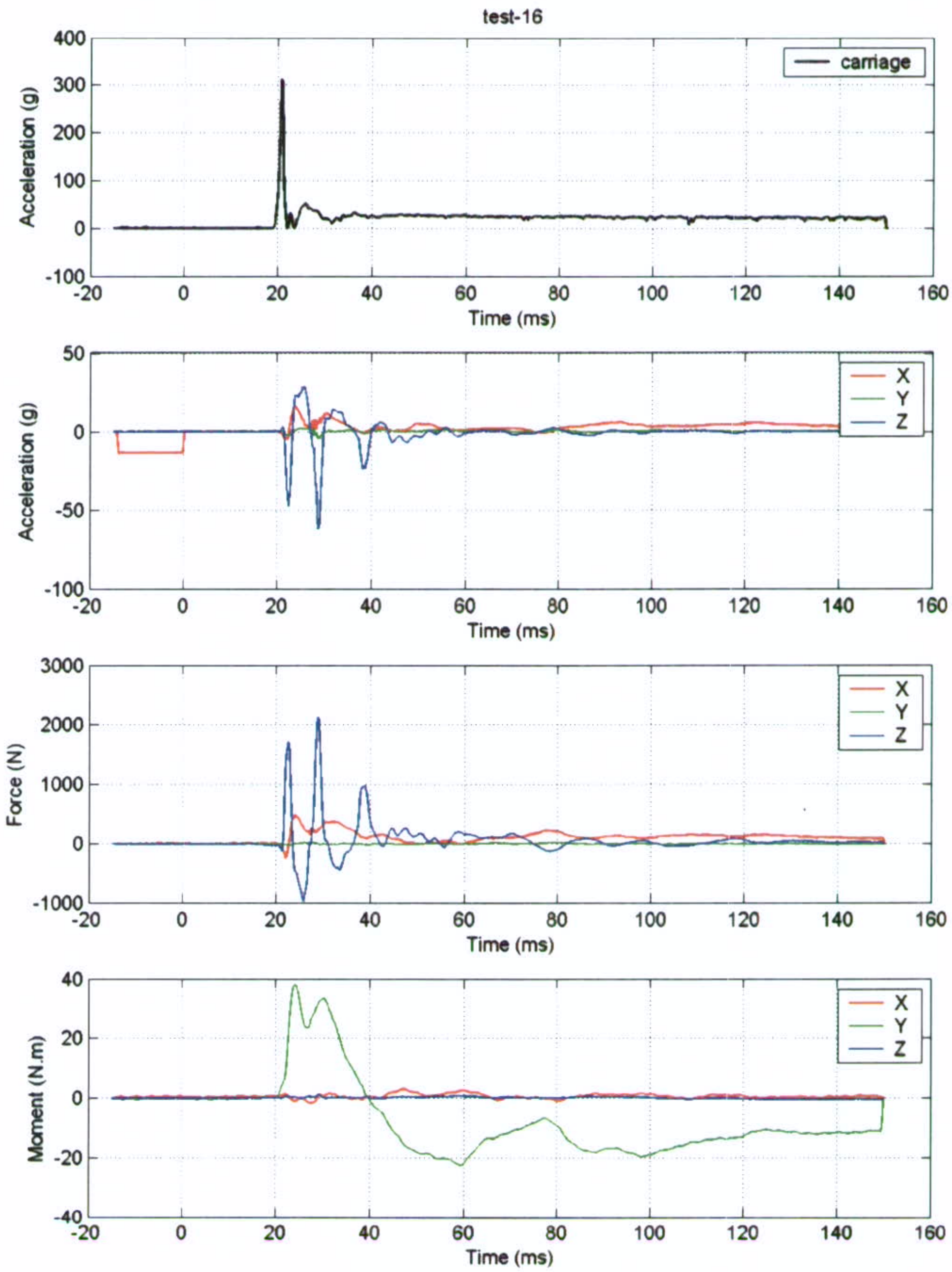

test-11
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

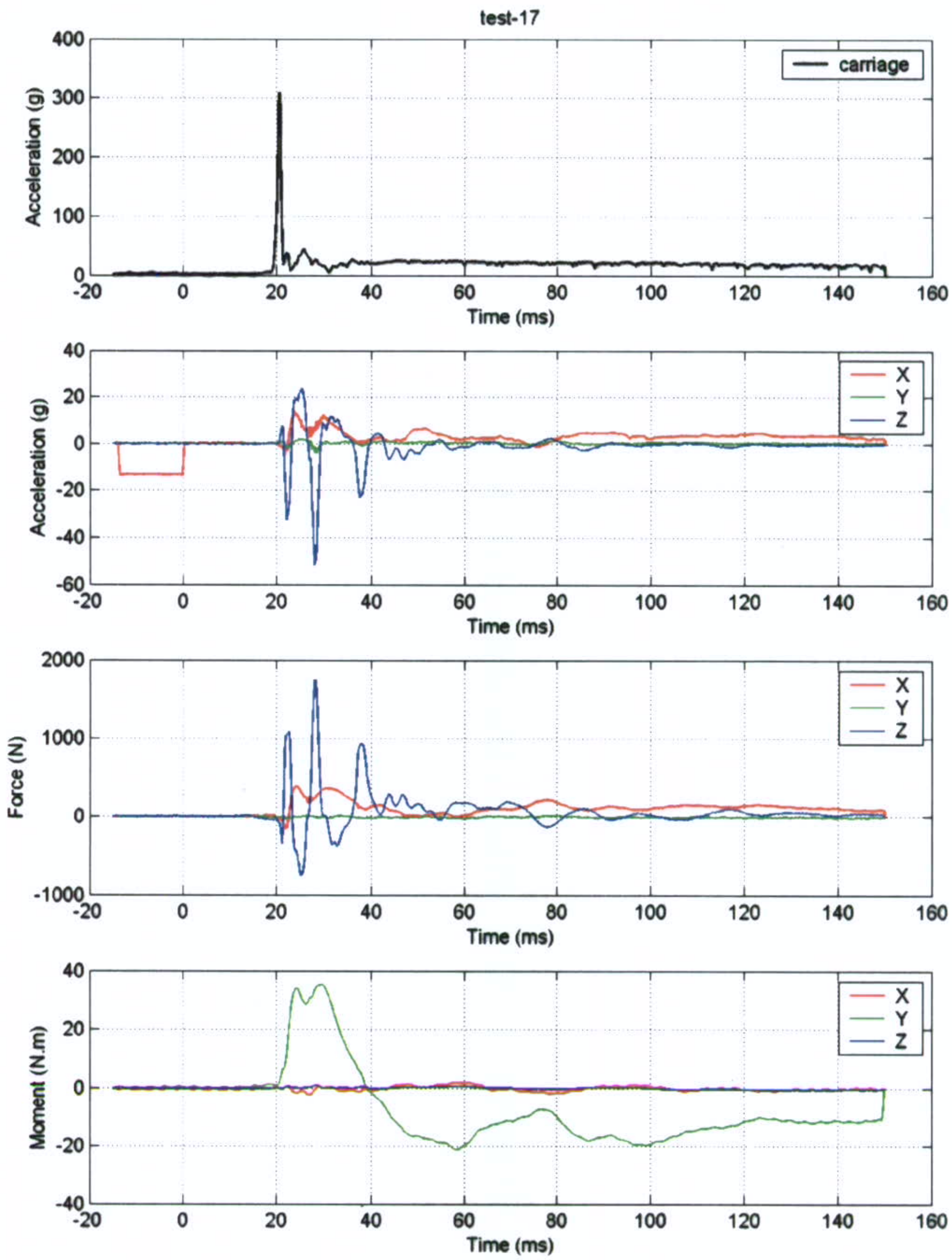

test-12
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

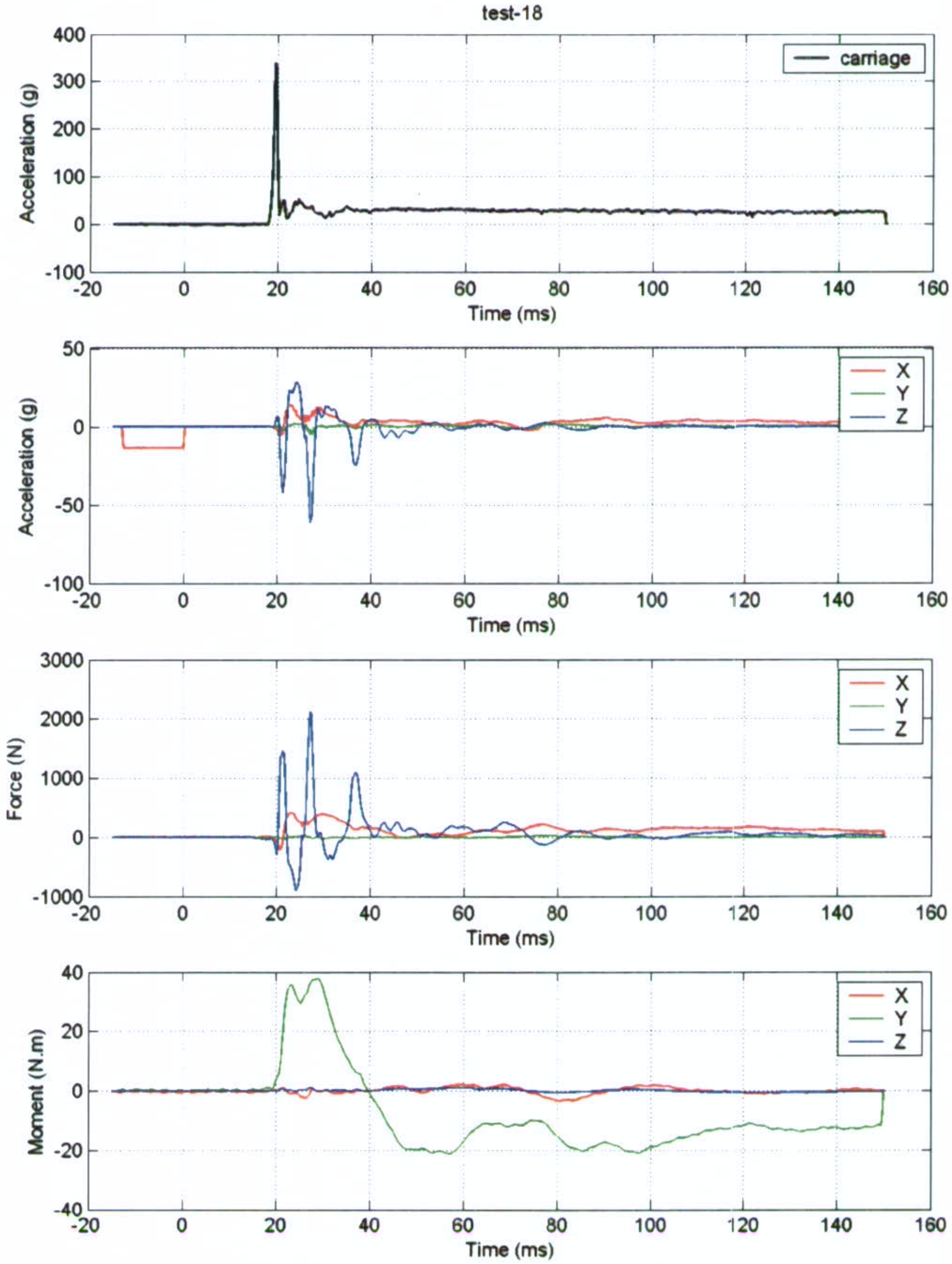

test-13
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

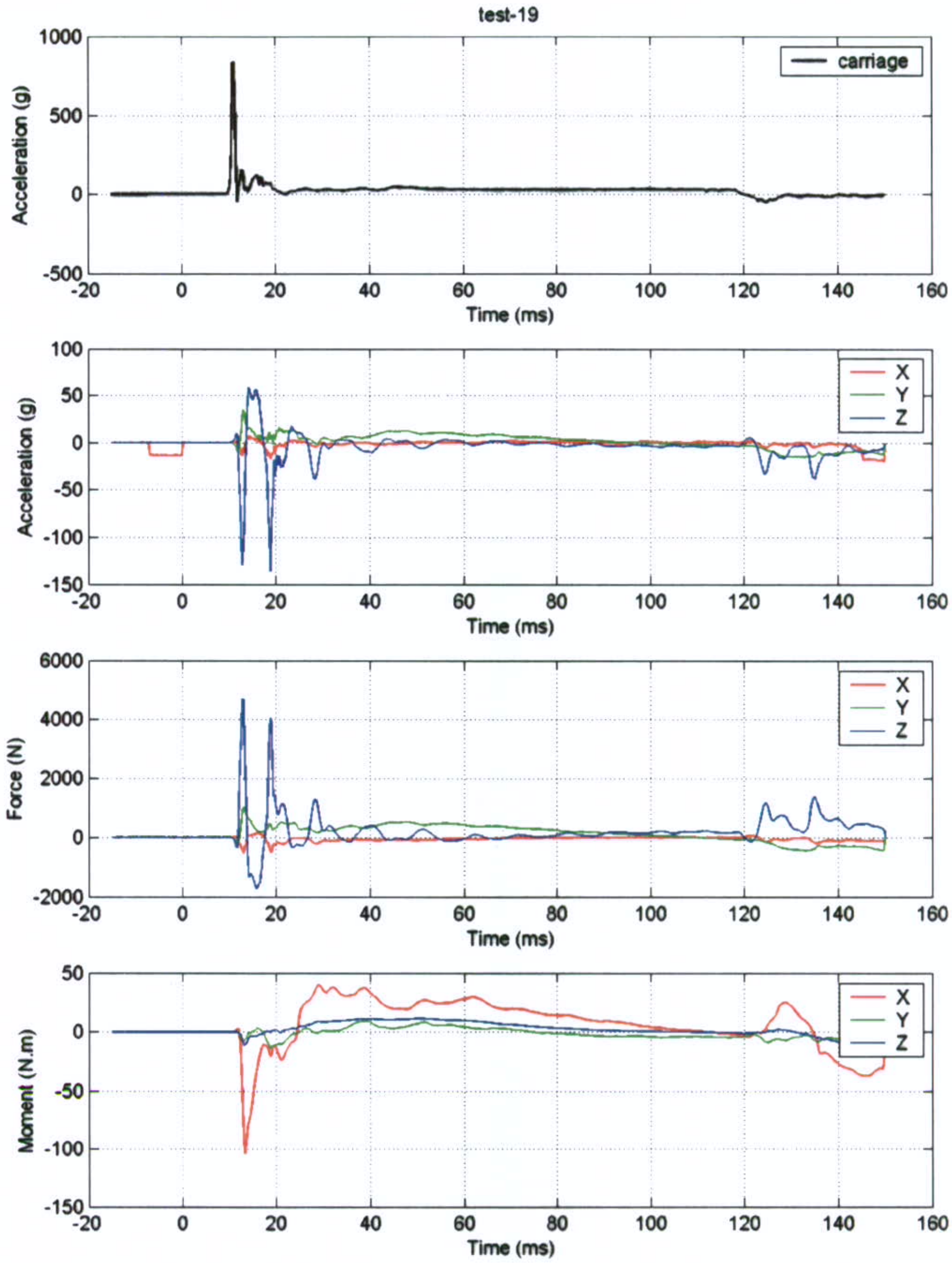

test-14
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

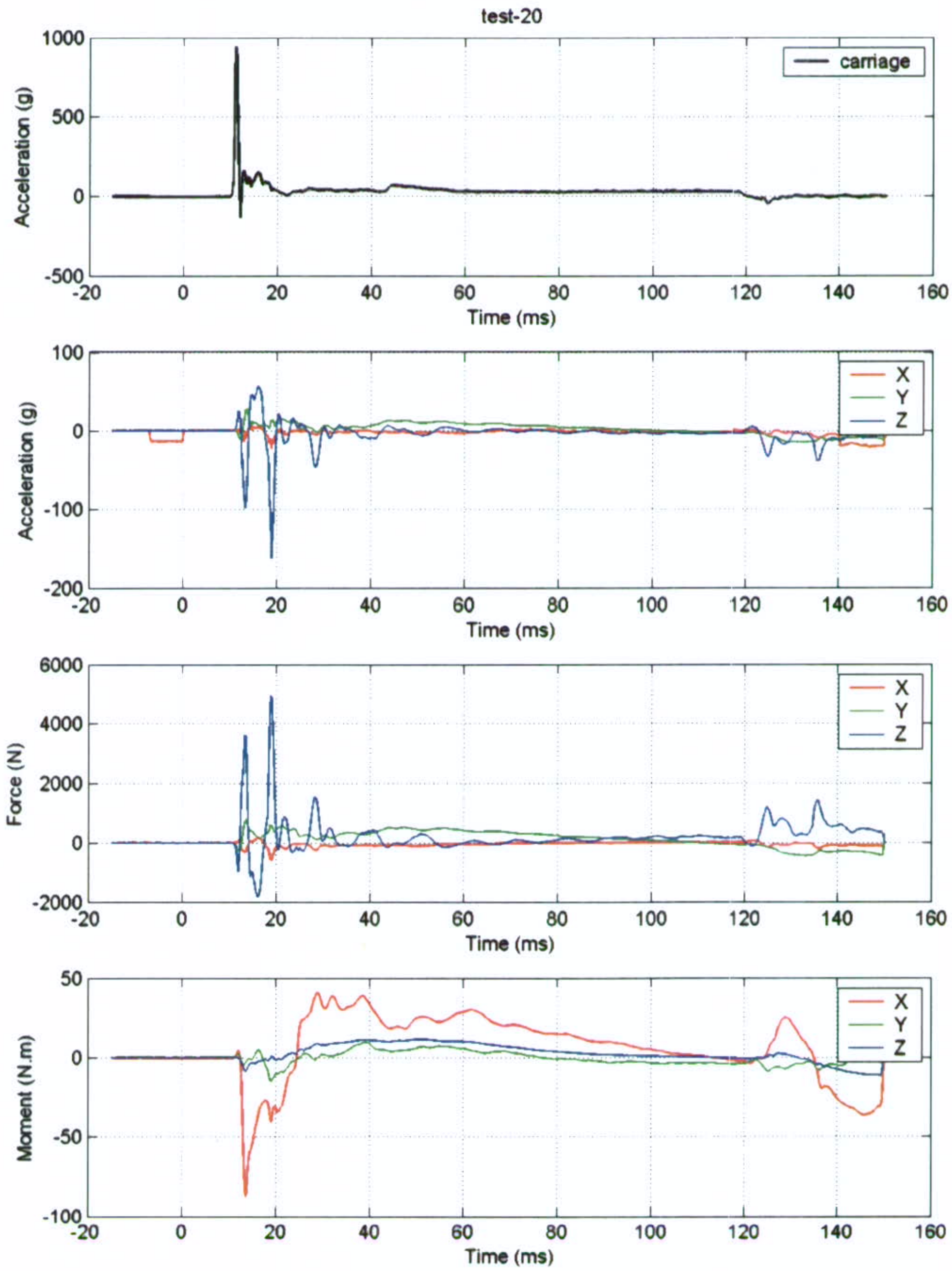

test-15
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

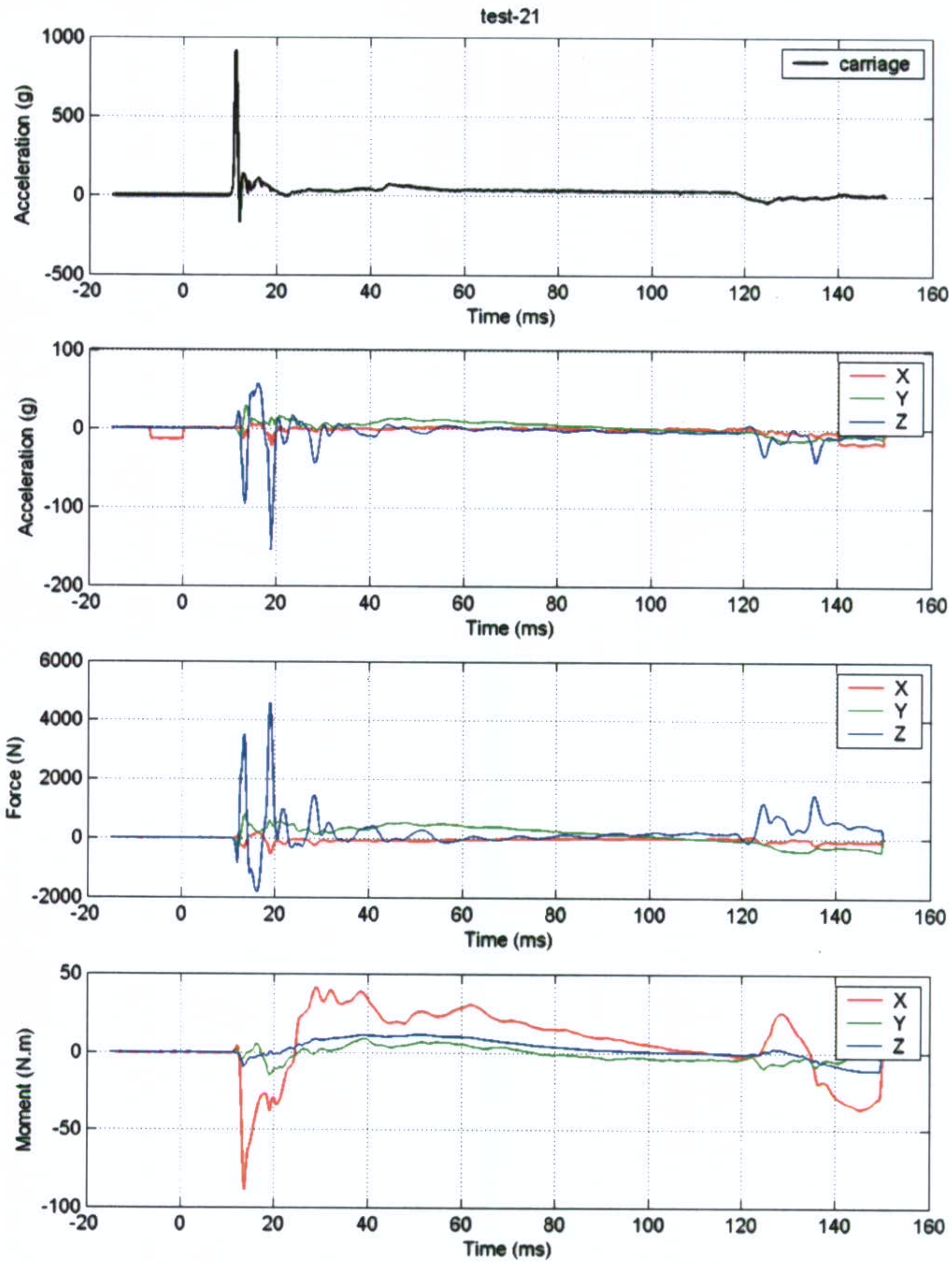

test-16
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

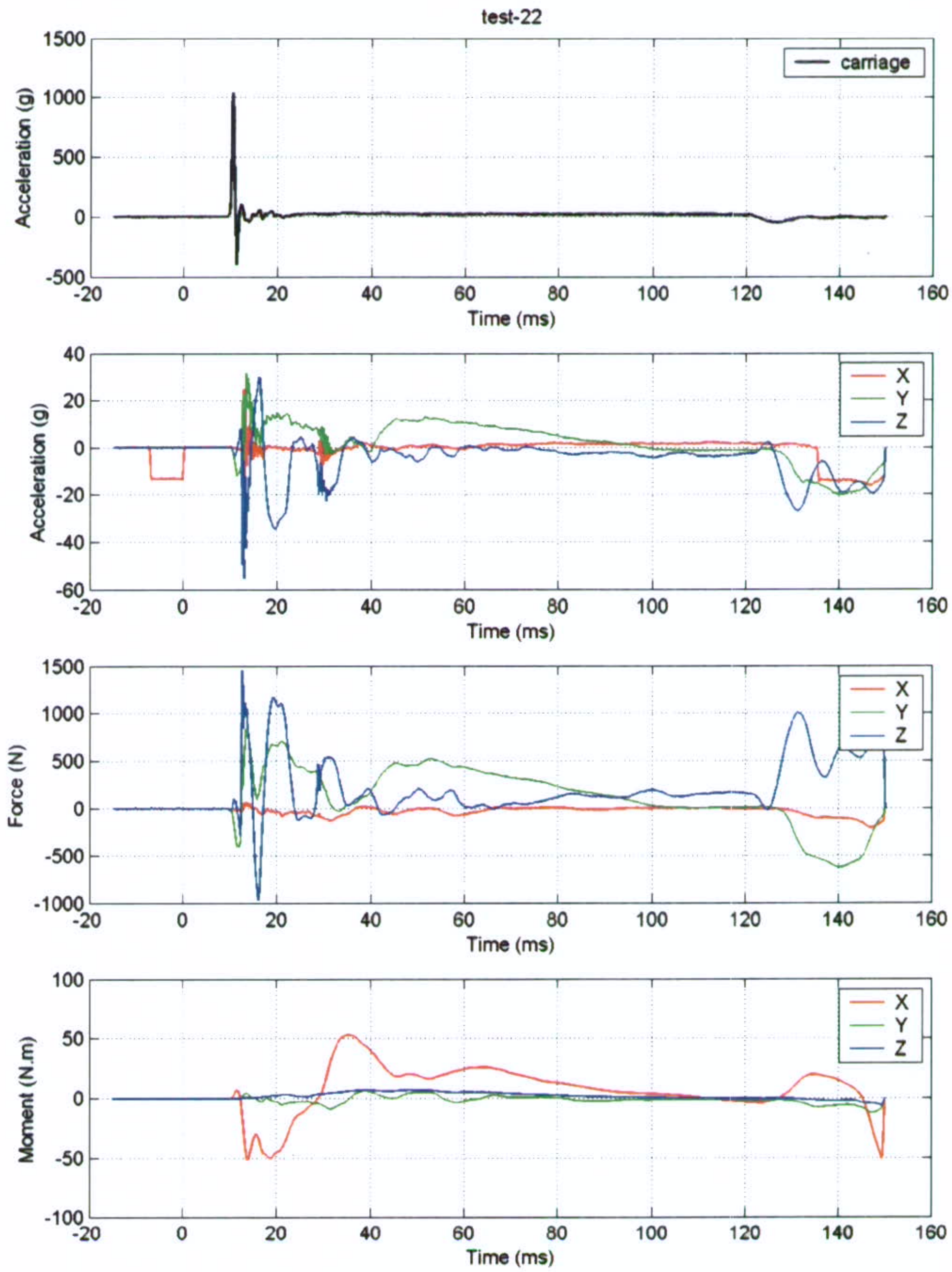

test-17
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

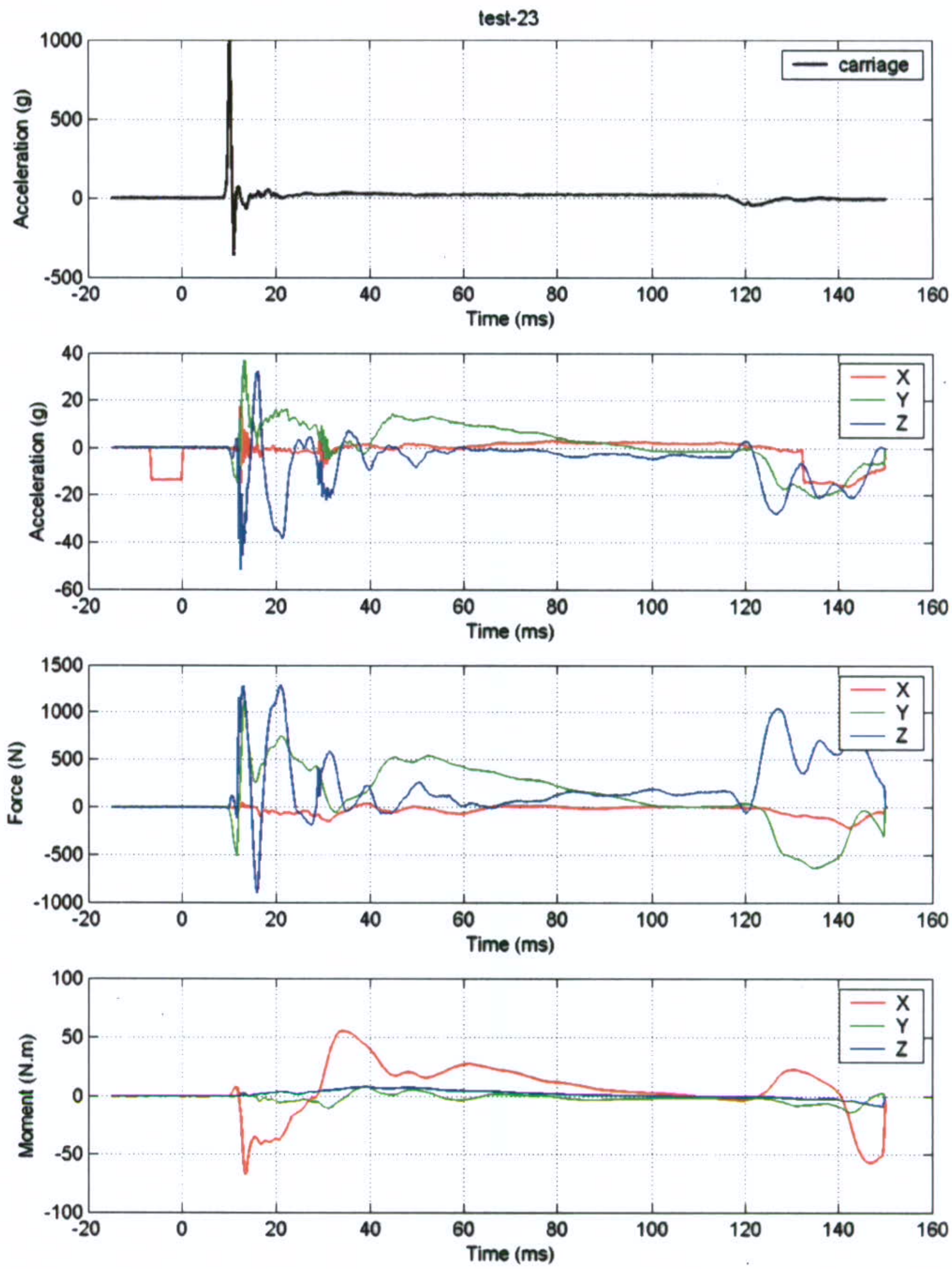

test-18
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

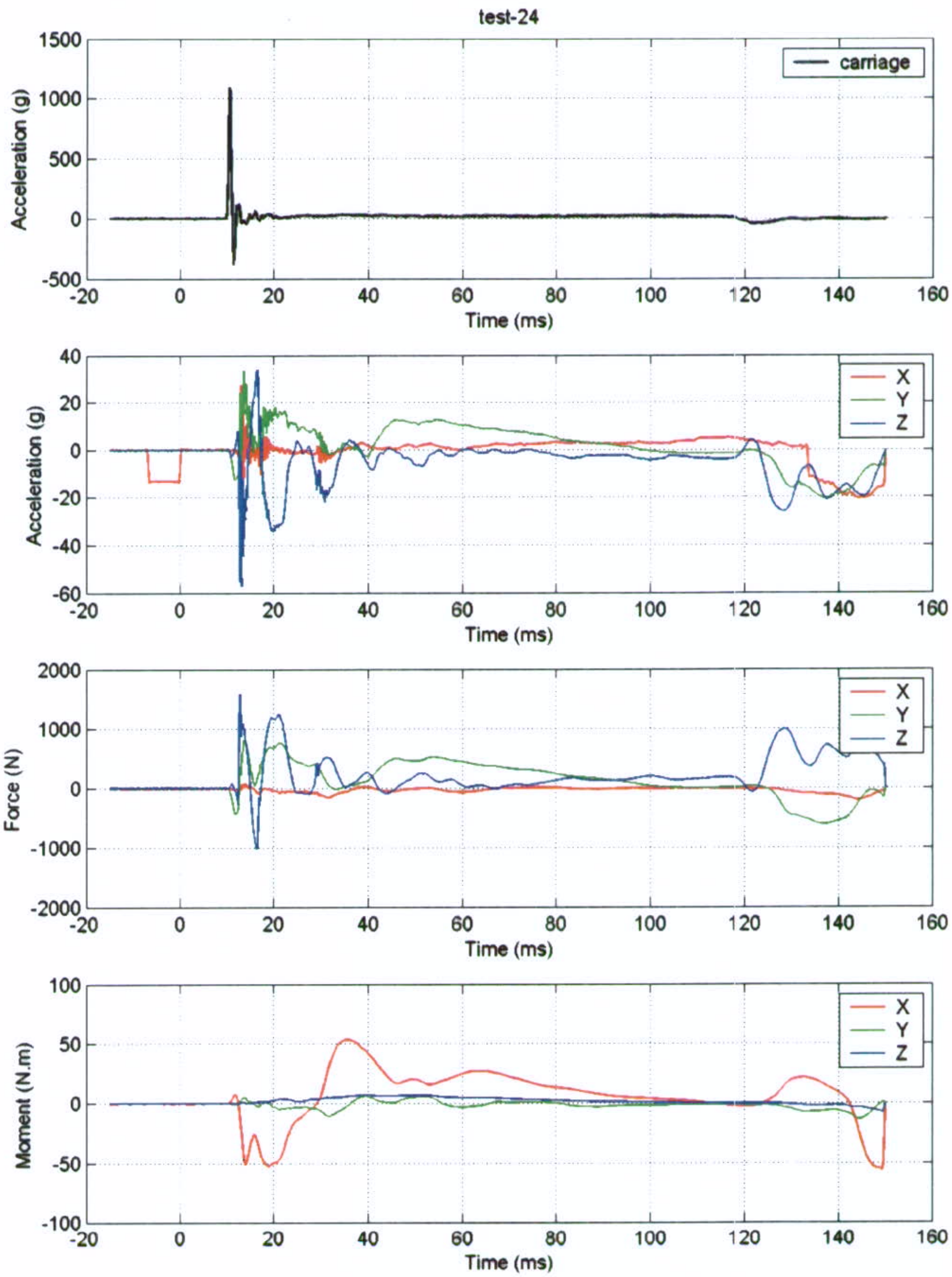

test-19
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

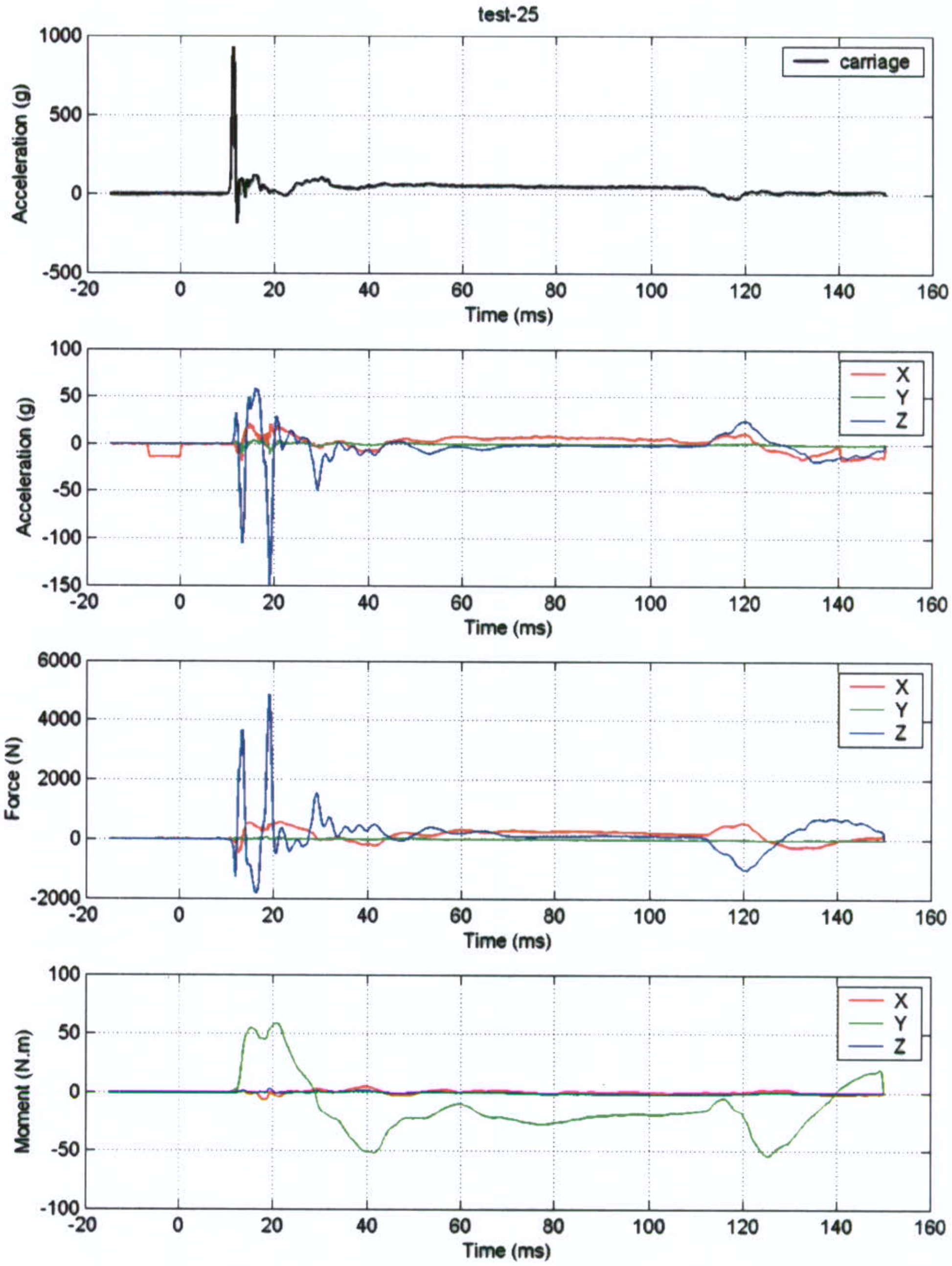

test-20
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

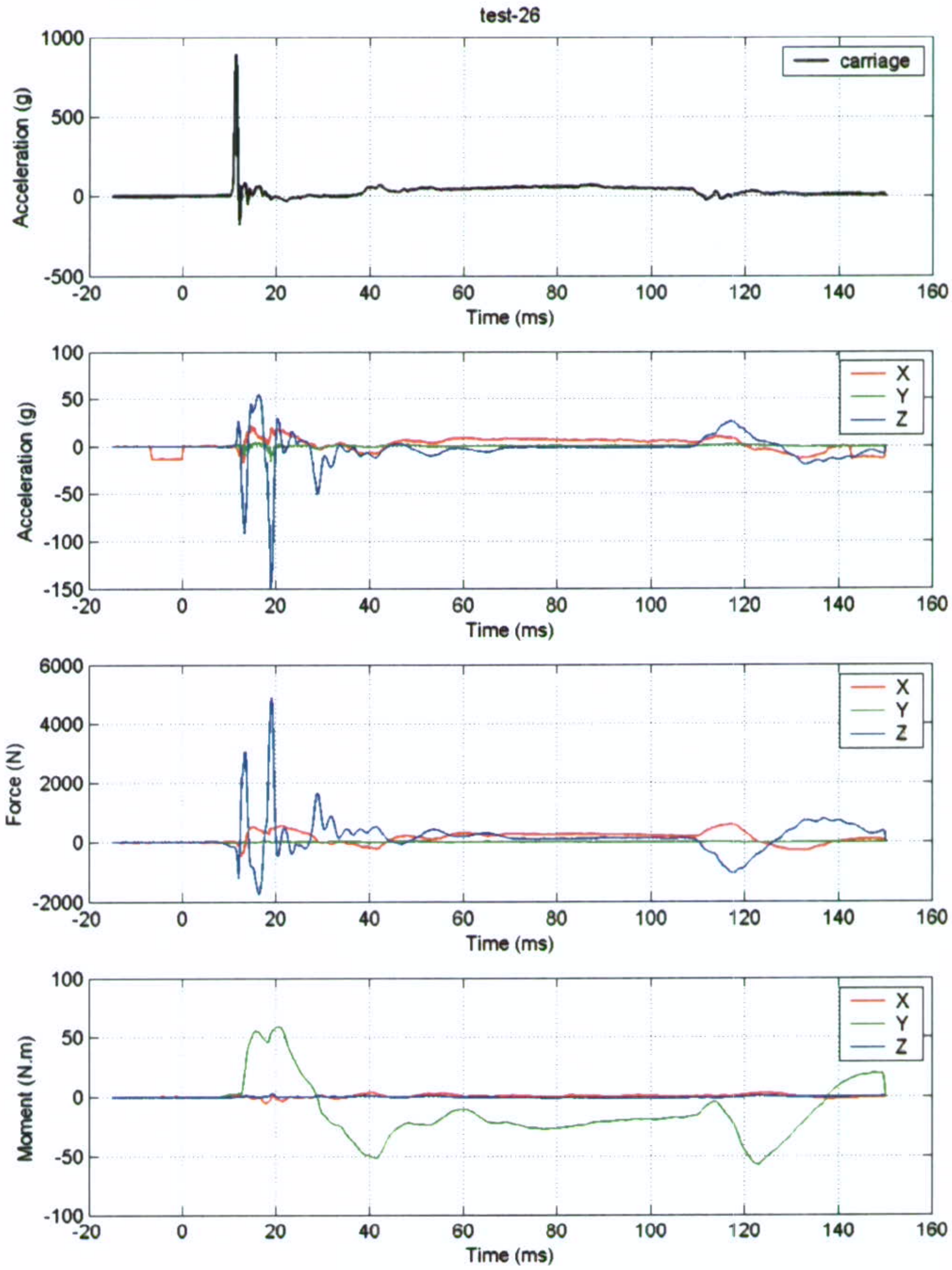

test-21
1000
500
0
-500
Acceleration (g)
carriage
-20
0
20
40
60
80
100
120
140
160
Time (ms)
100
0
-100
-200
Acceleration (g)
X
Y
Z
Time (ms)
6000
4000
2000
0
-2000
Force (N)
X
Y
Z
Time (ms)
50
0
-50
-100
Moment (N.m)
X
Y
Z
Time (ms)

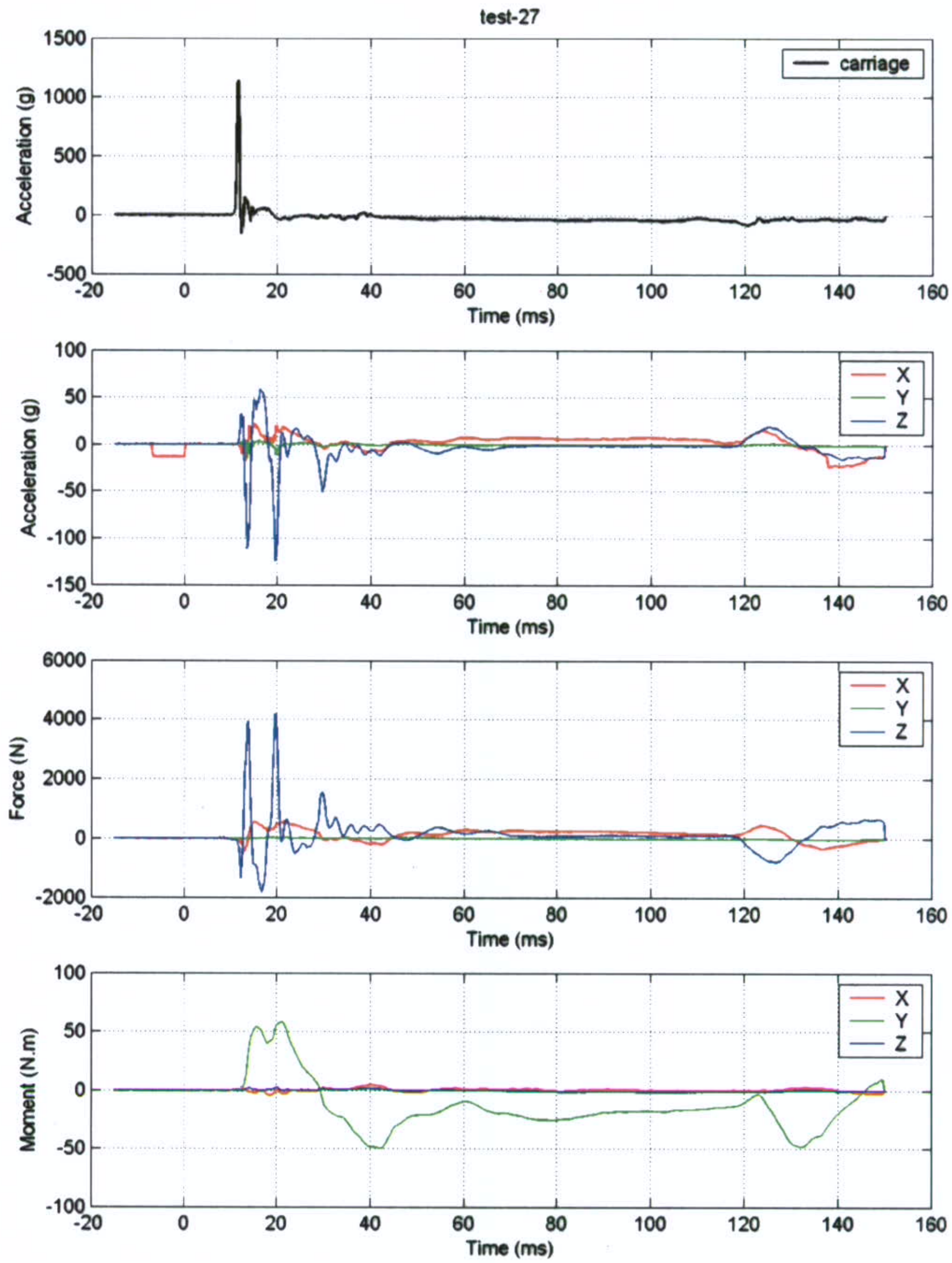

test-22
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

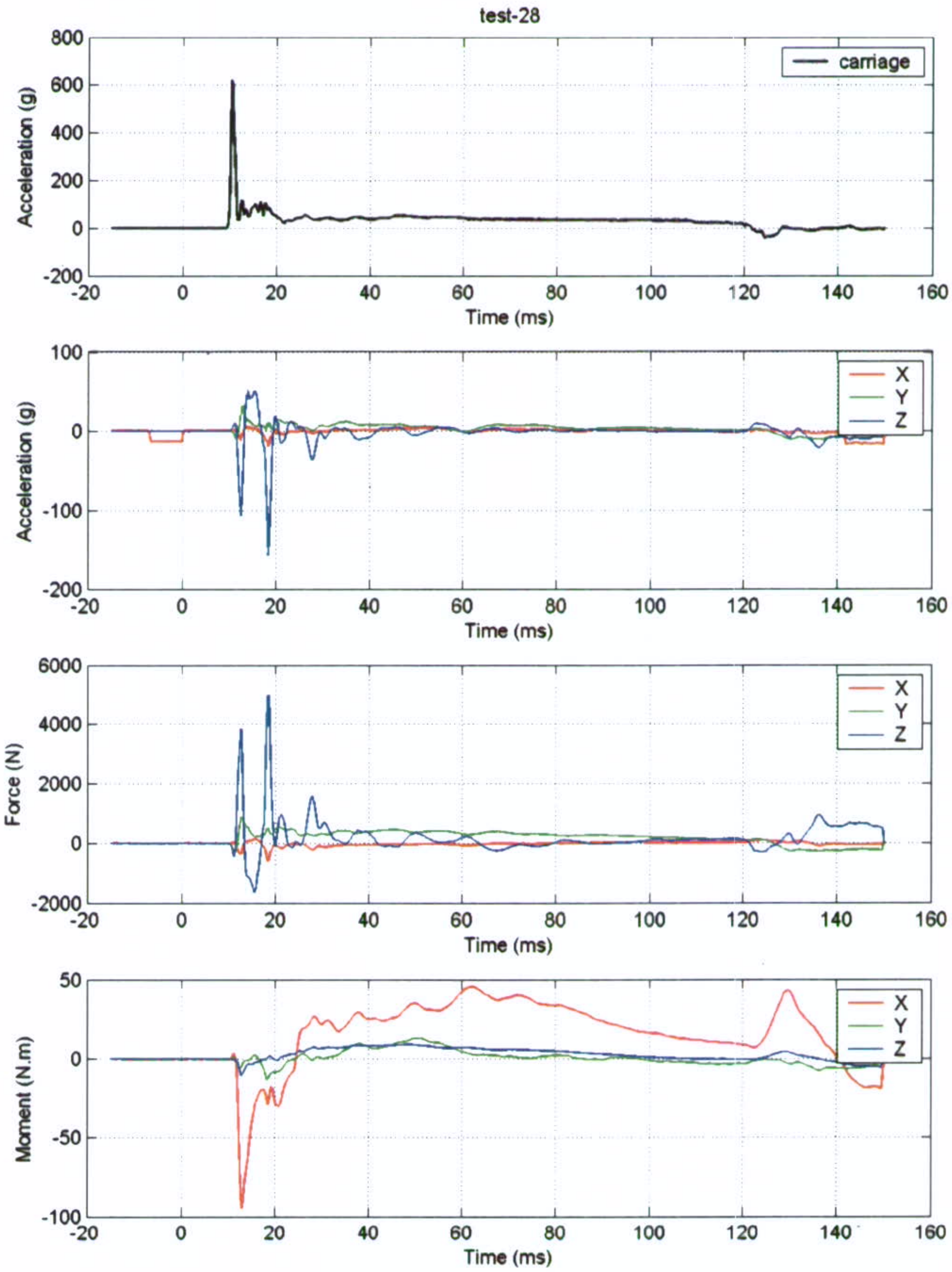

test-23
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

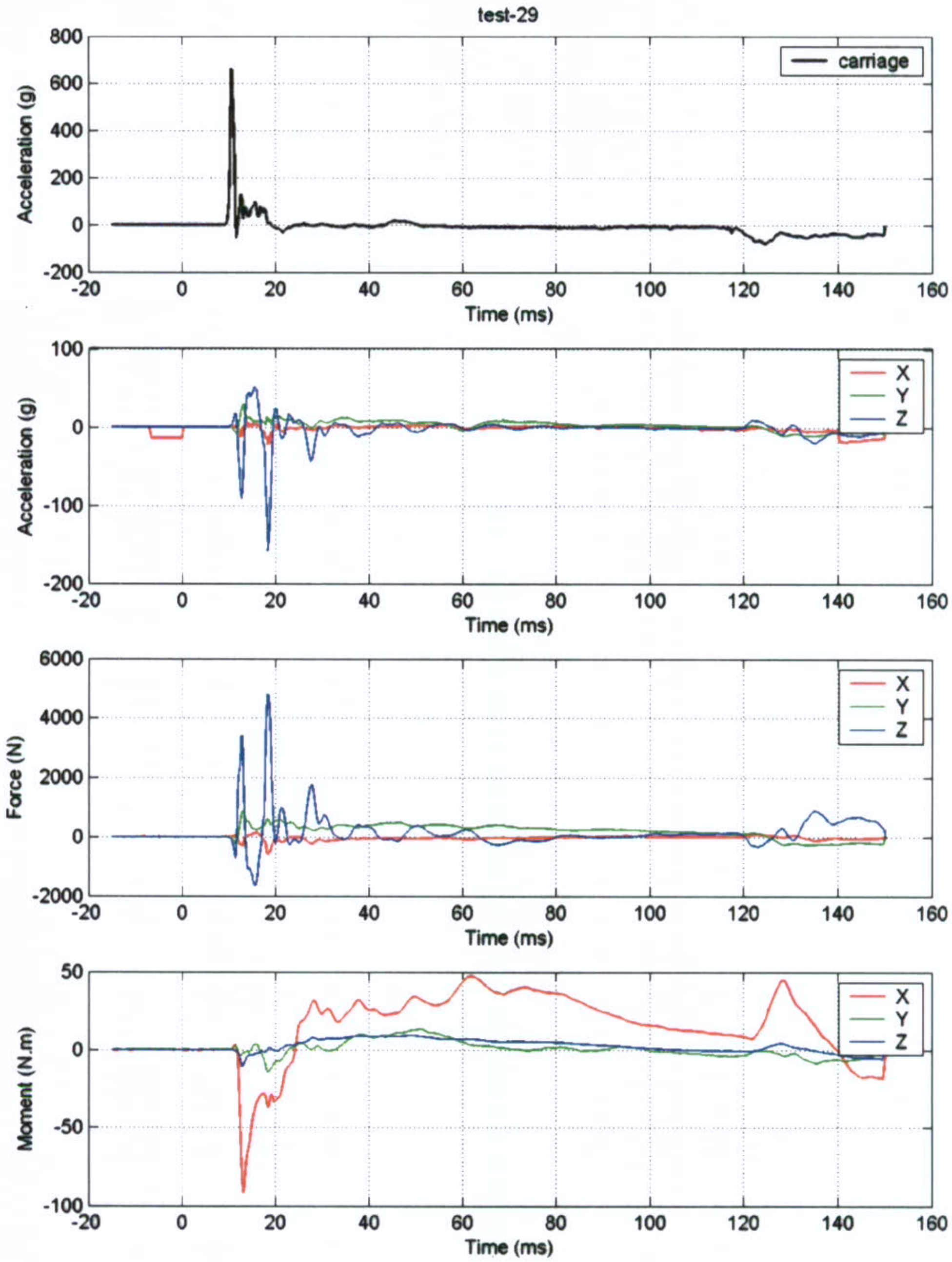

test-24
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

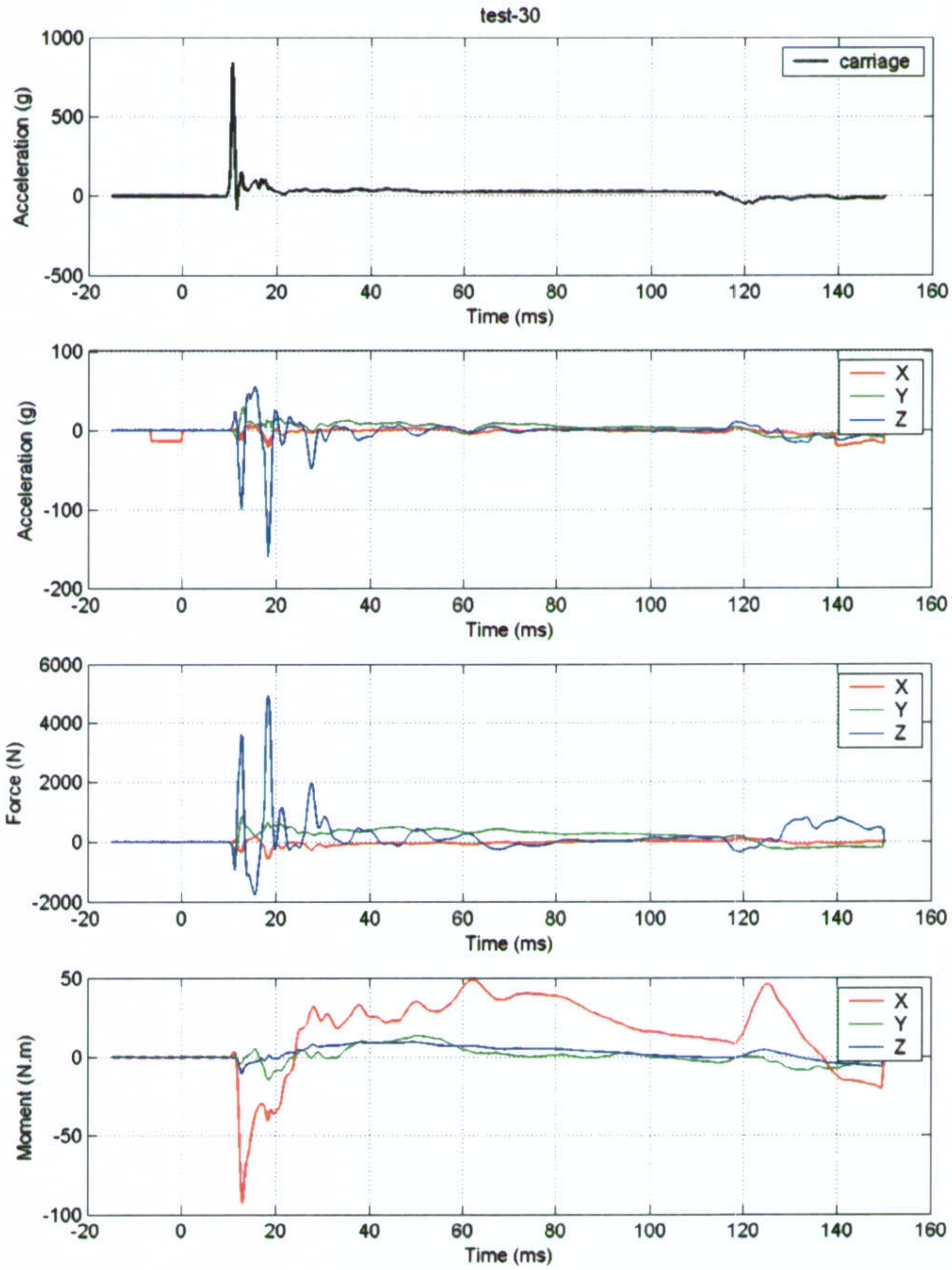

test-25
Acceleration (g)
carriage
Time (ms)
Acceleration (g)
X
Y
Z
Time (ms)
Force (N)
X
Y
Z
Time (ms)
Moment (N.m)
X
Y
Z
Time (ms)

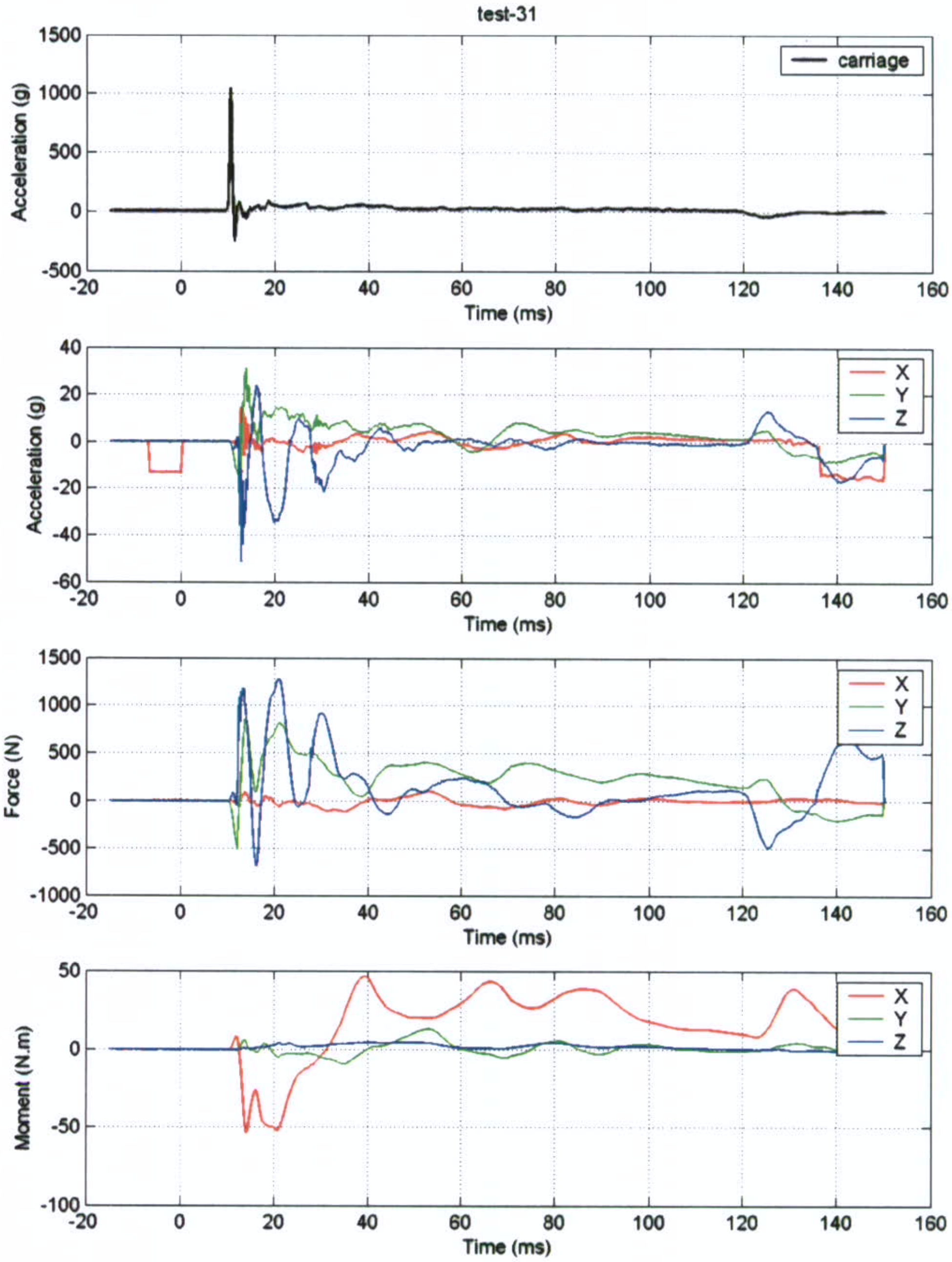

test-26
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

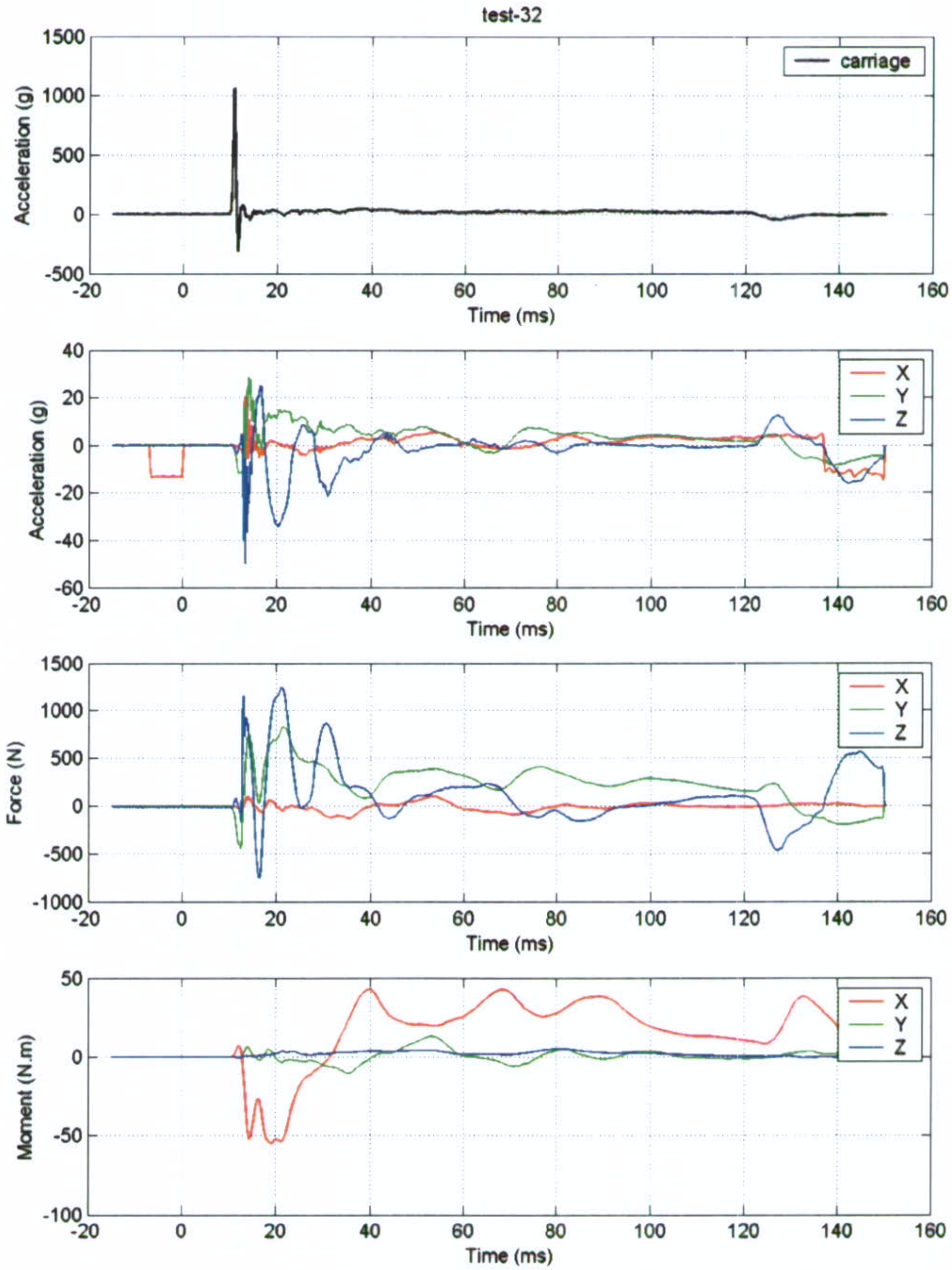

test-27
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

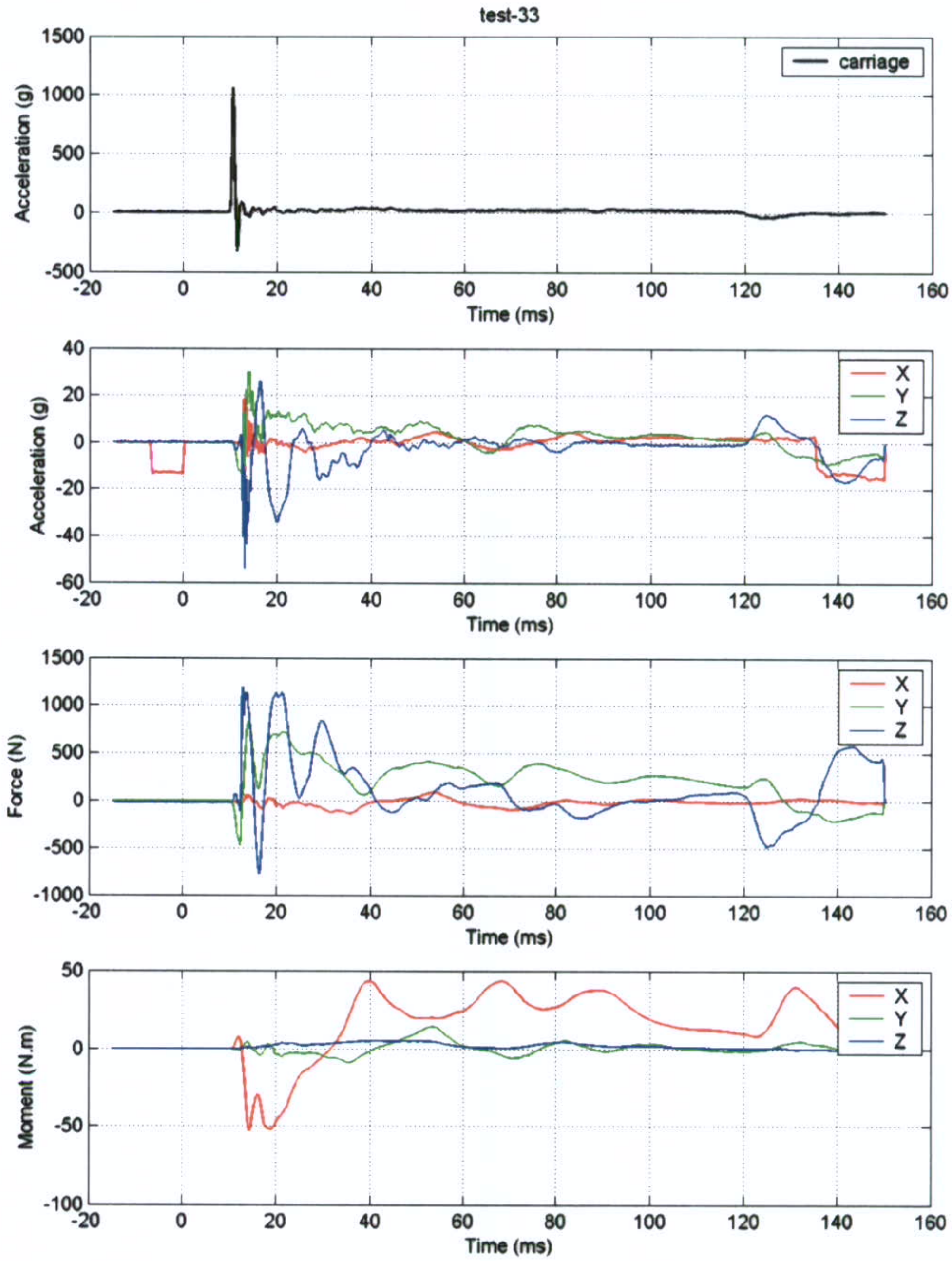

test-28
Acceleration (g)
carriage
Time (ms)
Acceleration (g)
X
Y
Z
Time (ms)
Force (N)
X
Y
Z
Time (ms)
Moment (N.m)
X
Y
Z
Time (ms)

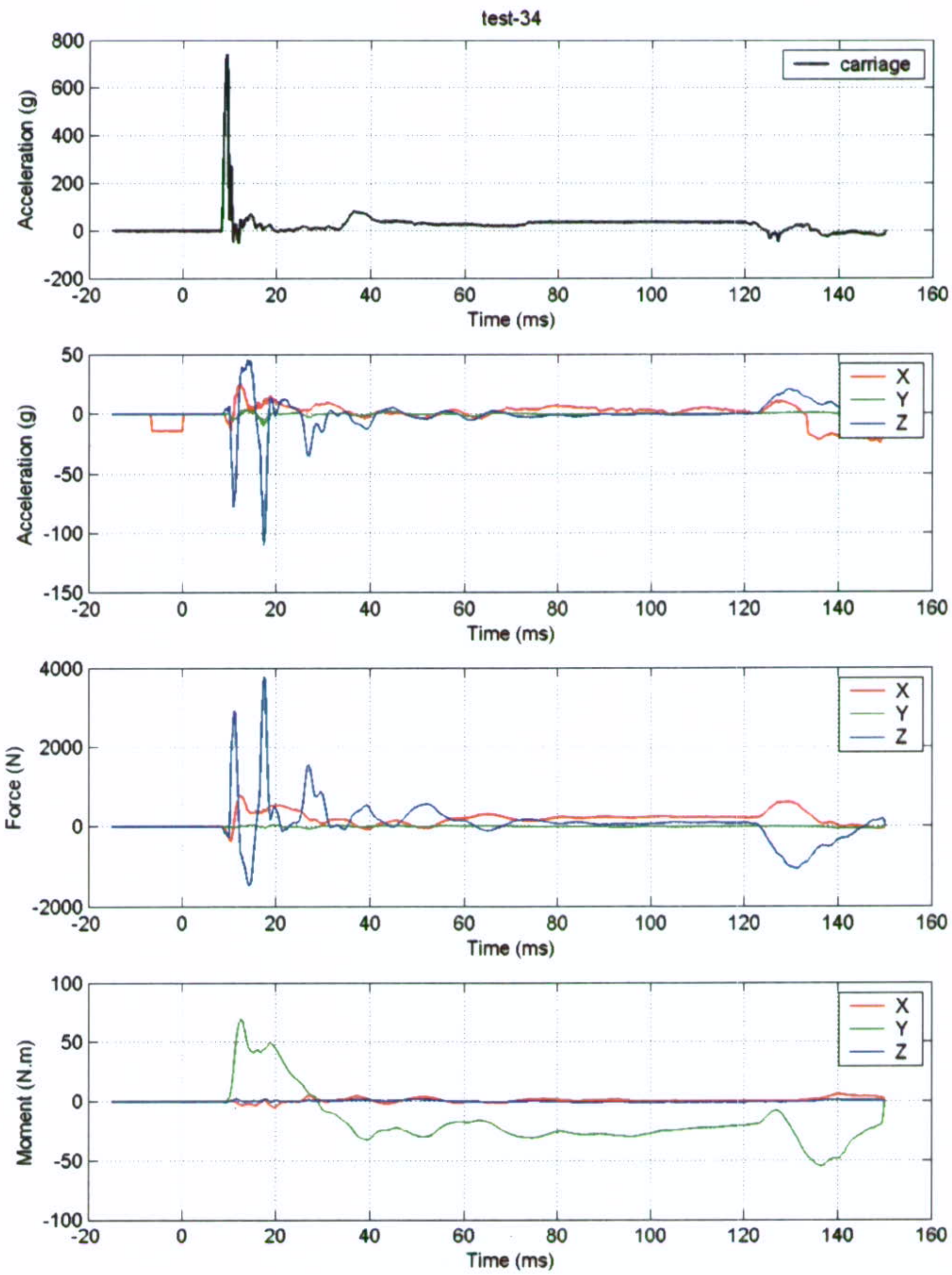

test-29
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

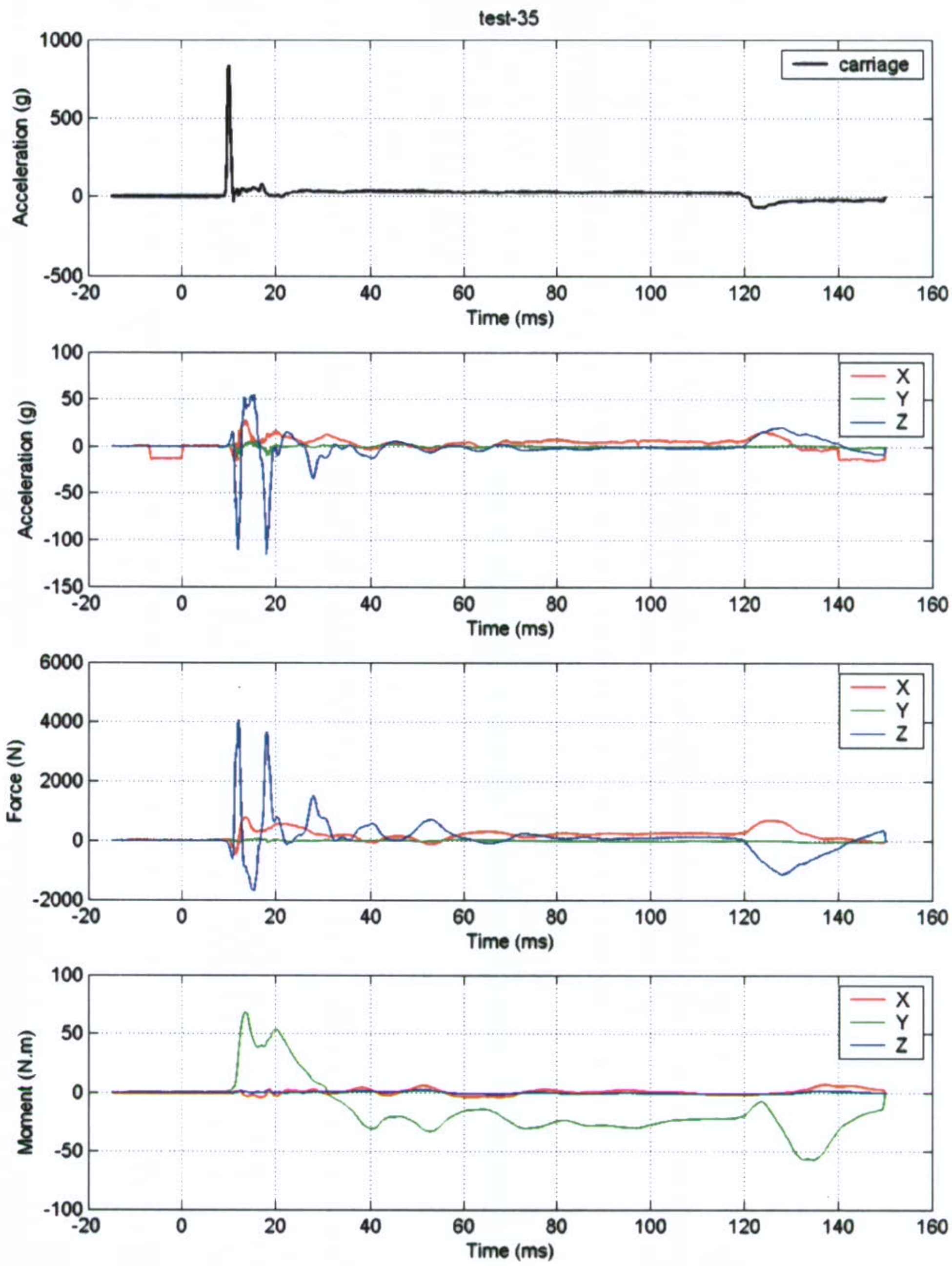

test-30
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)

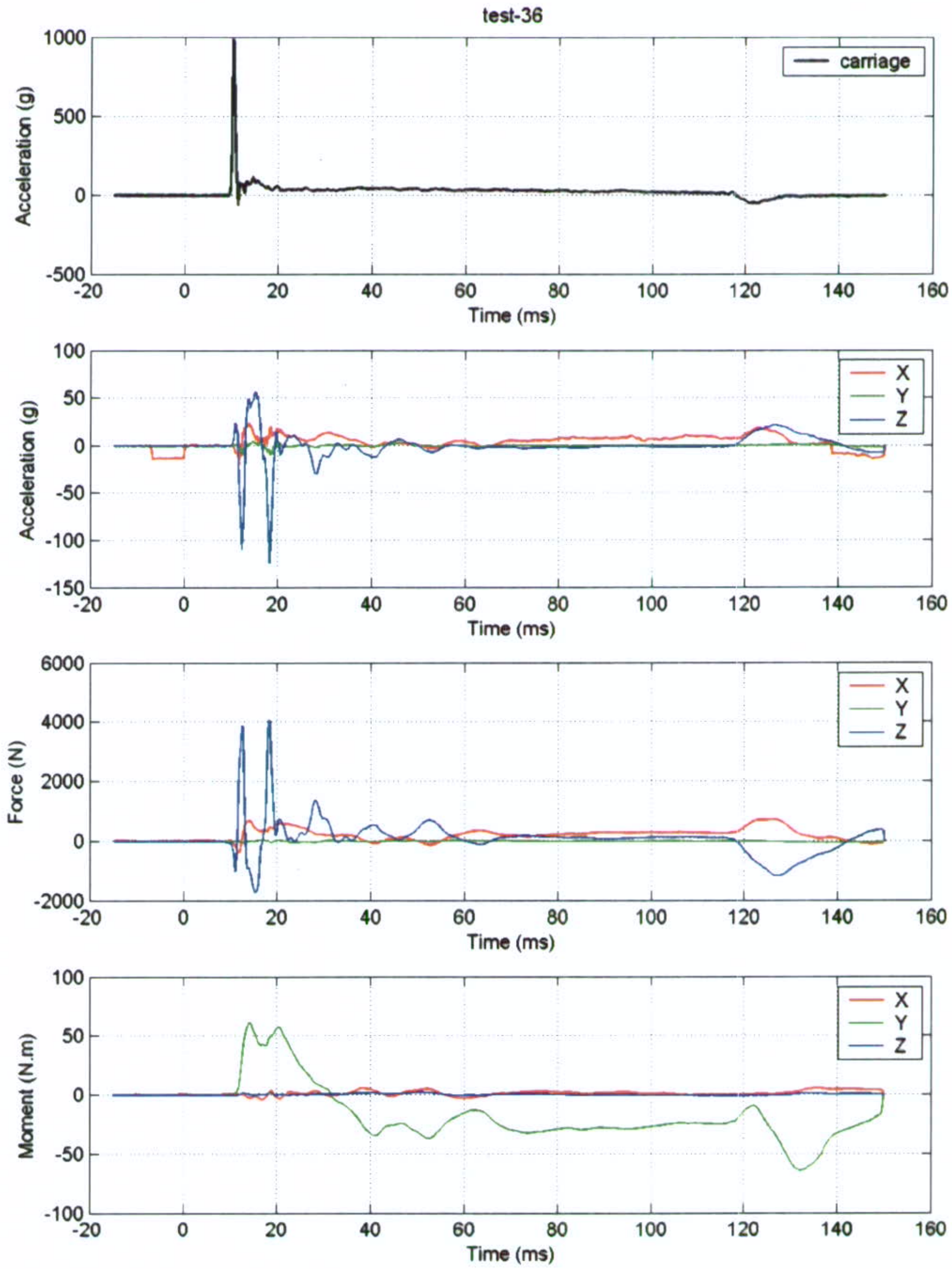

test-31
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)


test-32
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)


test-33
Acceleration (g)
carriage
Time (ms)
Acceleration (g)
X
Y
Z
Time (ms)
Force (N)
X
Y
Z
Time (ms)
Moment (N.m)
X
Y
Z
Time (ms)


test-34
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
Force (N)
Time (ms)
Moment (N.m)
Time (ms)


test-35
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)


test-36
carriage
Acceleration (g)
Time (ms)
X
Y
Z
Acceleration (g)
Time (ms)
X
Y
Z
Force (N)
Time (ms)
X
Y
Z
Moment (N.m)
Time (ms)

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Anctil, B., Wonnacott, M., Sullivan, S.

5. DATE OF PUBLICATION (month and year)	6a. NO. OF PAGES	6b .NO. OF REFERENCES
February 2009	78	4

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(U) This project defined the basis for a laboratory test procedure to evaluate the effects of a combat helmet on head/neck injury to vehicle occupants caused by IED explosions beside military vehicles. Laboratory test equipment was adapted to replicate the loading observed during full-scale trials at DRDC Valcartier. Two levels of loadings were considered to simulate neck loadings during full-scale IED testing and two head/neck surrogates, Hybrid III and EuroSID-2, were evaluated. Combat helmets caused moderate effects on the loading severity based on head acceleration and neck load recorded responses. Larger differences between helmeted head vs. bare head were observed for higher loading regimes. Finally, significant differences were also noted between the responses of the Hybrid III head-neck assembly in comparison with EuroSID 2.

(U) Ce projet défini les bases d'une procédure d'essai pour évaluer les effets du casque de combat sur les blessures au cou et à la tête aux passagers de véhicules causées par l'explosion d'engins artisanaux près des véhicules militaires. Des équipements de laboratoires ont été adaptés pour reproduire les conditions observées sur le terrain lors d'essais effectués à RDDC Valcartier. Deux niveaux de chargements ont été considérés pour simuler les réponses au cou observées lors de ces tests et deux ensembles tête/cou de mannequins, Hybrid III et EuroSID 2, ont été évalué. Les casques de combat affectent modérément la sévérité de chargement selon les accélérations à la tête et les chargement au cou mesurés. Les plus grands écarts entre les conditions avec et sans casque ont été observé lors des tests plus sévères. Finalement, des différences significatives ont aussi été noté entre les ensembles tête-cou Hybrid III et EuroSID-2.

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Head
Neck
Injury assessment
Rear impact
Lateral impact
Vehicle
Combat helmet
Hybrid III
EuroSID II
IEDs (Improvised Explosive Devices)