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Title of Study	FMVSS 213: Investigation of Booster Seat Performance Metrics
Test Performer	TRI-University of Michigan Transportation Research Institute
Test Reference Number	NT1811
Contract Number	DTNH22-15-D-00017
Test Date	5/31/2018

Test ID: NT1811
Date performed: 5-31-2018
Test Personnel: MM, KDK, NRO, KB, JB

Test Type: Tests used the 2018 version of the proposed FMVSS 213 upgraded test bench (version 2018) with associated belt anchorages and a three-point belt with the surrogate shoulder belt retractor (version 2, 2018).

Purpose of Tests: To explore candidate booster metrics that assess the potential for occupant submarining and the quality of seat belt routing.

ATD: Hybrid III 6YO (tests NT1801-39) & Hybrid III 10YO (tests NT1840-45)

Test Configuration:

All tests run with FMVSS 213 pulse.

All tests run with FMVSS 213 (2014) updated dummy seating procedure and dummy add-ons (lap shield and posterior-pelvic pad).

The surrogate retractor (version 2) was configured to allow for ~50 mm of webbing payout to be similar to OEM retractor payouts. Tests NT1801-04 were run with the surrogate retractor pins in setting 3 and all subsequent tests (NT1805-45) were run with setting 2.

In tests NT1828-45, several layers of gaffer's tape were used to cover the gap between the dummy's shoulder and neck under the chest jacket to protect the dummy's chest bib should the shoulder belt fall into the gap.

Test configurations involve varying booster model.

Table 1: Child restraint information and adjustments

Booster Type	Mass (kg)	Headrest Position From Full Down	Vertical height top edge of HR to back shell on C/L (in)	Other Adjustments
Aidia Pathfinder	5.1	2 up	8.5	
BabyTrend 3-in-1	6.1	2 up	10.25	
Britax Pioneer	9.6	4 up	6	
Combi Kobuk	4.1	4 up	14	
Cosco Easy Elite	5.2	Full up	4.5	
Evenflo BigKid Amp HB	2.9	3 up	10	
Graco 4Ever	10.0	8 up	8.5	
Graco TurboBooster BB	2.0	N/A	N/A	Armrests lowest
Graco TurboBooster HB	3.6	2 up	12	Armrests lowest
Incognito	0.2	N/A	N/A	
LilFan	1.0	N/A	N/A	Shoulder guide fit to dummy
Mifold	0.7	N/A	N/A	Belt guides 1 position out

Table 2: Test conditions

TestID	Retract Pin Set	ATD	Booster Type
NT1801	3	6YO	Graco TB
NT1802	3	6YO	Cosco EE
NT1803	3	6YO	Britax Pioneer
NT1804	3	6YO	Graco 4ever
NT1805	2	6YO	No booster
NT1806	2	6YO	Graco TB – HB
NT1807	2	6YO	Evenflo BK Amp
NT1808	2	6YO	Combi Kobuk
NT1809	2	6YO	Aidia
NT1810	2	6YO	BT Hybrid 3n1
NT1811	2	6YO	Graco TB HB
NT1812	2	6YO	Cosco EE
NT1813	2	6YO	Brtiax Pioneer
NT1814	2	6YO	Graco 4ever
NT1815	2	6YO	Aidia
NT1816	2	6YO	Evenflo BK Amp
NT1817	2	6YO	Combi Kobuk
NT1818	2	6YO	BT Hybrid 3n1
NT1819	2	6YO	Cosco EE
NT1820	2	6YO	Graco TB HB
NT1821	2	6YO	Brtiax Pioneer
NT1822	2	6YO	Graco 4ever
NT1823	2	6YO	Combi Kobuk
NT1824	2	6YO	Aidia
NT1825	2	6YO	Evenflo BK Amp
NT1826	2	6YO	BT Hybrid 3n1
NT1827	2	6YO	Graco TB HB
NT1828	2	6YO	LilFan
NT1829	2	6YO	LilFan
NT1830*	2	6YO	Incognito
NT1831	2	6YO	LilFan
NT1832*	2	6YO	Incognito
NT1833*	2	6YO	Mifold
NT1834*	2	6YO	Incognito
NT1835*	2	6YO	Mifold
NT1836*	2	6YO	Mifold
NT1837	2	6YO	No booster
NT1838	2	6YO	No booster
NT1839	2	6YO	No booster
NT1840	2	10YO	Cosco EE
NT1841	2	10YO	Graco TB BB
NT1842	2	10YO	Combi Kobuk
NT1843	2	10YO	BT Hybrid 3n1
NT1844*	2	10YO	Incognito
NT1845	2	10YO	No booster

* The booster fits through the gap at the bight of the seat fixture, so it was positioned with the rear edge in line with the seatback plane.

Table 3. Summary of results

TestID	HIC (36 ms)	Chest 3ms Clip (*g*)	Max Chest Angle (deg)	Result Lumb Force (N)	Result Lumb Moment (Nm)	Left Upper ASIS Force (N)	Left Lower ASIS Force (N)	Right Upper ASIS Force (N)	Right Lower ASIS Force (N)	Result Neck Force (N)	Result Neck Moment (Nm)	Head Excur (mm)	Knee Excur (mm)	Retract Payout (mm)
NT1801*	1415.0	58.2	37.7	1499.5	49.3	-435.0	-969.5	-374.0	-826.3	2920.0	60.0	646	656	88
NT1802**	2479.9	55.0	-12.4	2742.1	84.5	-1079.3	-527.4	-976.4	-546.5	8136.6	134.3	640	807	78
NT1803***	874.5	57.4	38.5	1896.1	43.3	-762.0	-906.8	-525.5	-781.8	2329.4	42.0	666	702	87
NT1804	1125.6	54.7	12.4	1599.4	35.7	-322.4	-747.5	-282.1	-689.3	na	52.9	588	719	82
NT1805	822.0	57.9	-1.9	1925.9	65.7	-967.8	-1020.3	-1067.6	-974.9	3348.3	41.8	474	582	55
NT1806	1163.5	55.4	23.6	1815.0	44.3	-380.6	-741.7	-291.0	-627.7	2794.1	48.3	592	648	53
NT1807	984.6	51.1	19.2	1764.6	50.3	-368.8	-681.5	-265.6	-537.5	2513.7	51.1	599	670	54
NT1808***	829.1	57.3	33.9	2350.7	62.2	-334.0	-932.7	-250.8	-587.9	2416.0	49.3	623	643	52
NT1809	891.6	55.1	22.3	1374.0	34.7	-428.9	-676.4	-328.1	-522.1	2522.2	47.7	595	646	57
NT1810	873.3	47.5	17.2	1764.8	43.7	-251.5	-852.9	-159.1	-742.0	2357.4	43.0	568	664	51
NT1811	968.9	55.2	29.7	1702.1	47.7	-404.6	-792.8	-311.0	-569.8	2542.6	48.0	603	644	51
NT1812	1717.4	49.0	-12.4	2333.4	46.2	-914.9	-562.6	-830.0	-550.4	5958.8	97.6	597	777	46
NT1813	701.0	50.1	27.2	1680.7	40.3	-417.8	-554.3	-290.6	-514.3	2206.5	45.7	609	684	45
NT1814	986	51.7	-1.3	1725.8	38.7	-237.6	-612.3	-330.7	-539.2	3009.2	60.69	568	712	49
NT1815	955	54.4	25.0	1537.9	37.4	-434.3	-583.1	-366.8	-509.1	2516.9	49.1	598	656	52
NT1816	844.5	52.8	15.8	1575.8	52.1	-387	-606.6	-289.4	-465.8	2409	42.5	585	670	48
NT1817***	745.4	58.5	39.1	2245.4	60.6	-383.7	-807.2	-315.6	-542.1	2212.9	46.8	621	640	51
NT1818	916.7	48.3	18.5	1817.4	46.2	-280.2	-856.7	-225.5	-716	2462.1	46.5	578	663	47
NT1819	1687.4	51.5	-13.5	1996	51.3	-982.6	-560.8	-830.9	-557	5540.2	87.5	594	779	48
NT1820	989.3	53.4	22.3	1488.1	40.8	-371.4	-776.1	-309.4	525	2531.1	47	588	646	51
NT1821	807.6	50.5	25.6	1687.6	37.2	-377.8	-623.3	-303.8	-506	2323	52.4	605	689	55
NT1822	877.3	49.5	4.6	1688	37.1	-202.8	-594.8	-271.6	-531.3	2425.6	49.5	571	707	54
NT1823***	744.9	57.2	37.7	2228.3	63	-396.8	-849.1	-353.1	-609.9	2248	46.5	626	634	51
NT1824	823.9	51.7	17.3	1521.5	40.4	-413.5	-677	-348.7	-547.7	2390.3	46.5	587	657	48
NT1825	909.5	51.7	20.4	1630.3	52	-420.3	-652.1	-329.9	-560.5	2523.3	51.1	596	669	54

* The lap belt and lap shield went into a gap between the dummy's pelvis and thigh.
** The lap belt up off of the pelvis and into the dummy's abdominal cavity.
*** The dummy rolled out of the shoulder belt.

TestID	HIC (36 ms)	Chest 3ms Clip (*g*)	Max Chest Angle (deg)	Result Lumb Force (N)	Result Lumb Moment (Nm)	Left Upper ASIS Force (N)	Left Lower ASIS Force (N)	Right Upper ASIS Force (N)	Right Lower ASIS Force (N)	Result Neck Force (N)	Result Neck Moment (Nm)	Head Excur (mm)	Knee Excur (mm)	Retract Payout (mm)
NT1826	946.4	45.7	18.2	1889.3	47.3	-250.3	-865	-176.1	-651.1	2509.2	47.7	575	662	54
NT1827	951.5	54.3	26.7	1683.3	46.9	-372	-698.1	-304.4	-515.8	2549.6	49.5	593	639	55
NT1828	974.54	56.4	6.9	1269.5	38.2	-342.5	-656.3	-263.2	-528	2507.9	48.8	505	609	48
NT1829	1028.9	54.6	8.3	1237.2	37.3	-328.6	-719.8	-277.4	-624.2	2483.8	52.7	503	607	47
NT1830	749.3	41.8	-6.6	1383.2	51.4	-619.9	-918.7	-641.1	-902.7	2692.5	32.5	456	590	47
NT1831	949.5	54.9	13.7	1131.7	39.5	-310	-674.9	-306.6	-565.5	2542.7	49.3	507	604	46
NT1832	720	54.1	-7.0	1470.6	54.1	-665.9	-992.2	-652.4	-973.2	2744	30.8	453	587	48
NT1833$^{\alpha}$	839	45.9	-0.3	1649.2	40	-214.9	-227	-225.6	-158.9	3421.5	43.3	457	665	45
NT1834	755.3	50.7	-4.9	1464.3	52.7	-673.1	-922.5	-645.3	-918.1	2707.9	33.3	459	586	47
NT1835$^{\alpha}$	857.3	46.3	-1.1	1570.2	35.3	-186.4	-211	-223.9	-180.5	3558	46.2	460	660	47
NT1836$^{\alpha}$	904	44.7	1.5	1465.6	30.5	-172.6	-205.1	-204.7	-206.9	3372.3	44	469	671	50
NT1837	574	54.1	-7.9	1759.6	60.3	-1021.8	-969.1	-905	-884.3	3058.2	38.5	451	587	43
NT1838	560.7	55.4	-5.0	1789	63.1	-1069.8	-947.4	-884.7	-845.8	3120.2	36	445	586	43
NT1839	572.7	55.4	-5.4	1734.7	62	-1083.5	-974.5	-926.3	-855.6	2979.1	36.4	452	594	49
NT1840**	2090.8	49.1	-11.9	5093.4	317.5	-1126.1	-879.4	-1040.9	-802.8	6263.1	64.3	630	889	49
NT1841	975.4	51.1	8.2	1992.4	108.8	-255.7	-647.6	-261.2	-399.4	3391.4	54.6	573	699	49
NT1842	911.6	55.8	17.5	1564.8	141	-324.7	-873.7	-299.4	-487.2	2618.8	53.4	631	712	56
NT1843	1145.9	49.9	3.8	2119.1	117.3	-346	-773.4	-502	-629.4	3571.6	50.9	613	772	51
NT1844 $^{\alpha\alpha}$	1120.6	48.2	-2.9	1856.8	86.7	-712.9	-1112.7	-726	-1002.6	3339.5	44.1	512	698	49
NT1845 $^{**\alpha\alpha}$	786.7	49.2	-7.3	2295.7	131.7	-1272.4	-1161.9	-1215.1	-1053.6	3754.6	47.6	501	705	44

* The lap belt and lap shield went into a gap between the dummy's pelvis and thigh.
** The lap belt up off of the pelvis and into the dummy's abdominal cavity.
*** The dummy rolled out of the shoulder belt.
$^{\alpha}$ The dummy's abdomen insert flew out.
$^{\alpha\alpha}$ The shoulder belt went into the gap between the dummy's chest bib and neck.

UMTRI	Results	NT1811

Nominal = 30 mph / 20 g — Pressures: 108.5/985
Actual[P] = 47.8 km/h (29.7 mph) (84.8%) — Plateau Avg.= -20.3 G; Peak = -22.2 G

Dummy: Hybrid III 6 Year Old (23.4 kg) — Buck Weight: 1970
Buck: Proposed FMVSS 213 Bench (per 2018 drawings), steel plate, extensions

Graco TB HB
3-point belt, surrogate retractor LS

Sled Summary

Sled Pulse Duration = 76.6 ms
Sled Plateau Average Level = -20.3 G
Sled Decel Peak = -22.2 G
Efficiency = Vout / Vin = 21.9 / 25.9 = 84.8%
Sled Delta V = 47.8 kph (29.7 mph)
Stopping Dist. (est) = .521 m

Head Acceleration

X	**-36.5 g @ 59 ms**	10.1 g @ 254 ms
Y	**-13.0 g @ 93 ms**	6.9 g @ 109 ms
Z	-.2 g @ 12 ms	**75.0 g @ 68 ms**
Resultant	**Peak: 80.4 g @ 65 ms**	
H.I.C. (UN) = 986.6		From 50.9 to 109.5 ms
H.I.C. (36) = 968.9		From 52.9 to 88.9 ms
H.I.C. (15) = 728.6		From 58.8 to 73.8 ms
3.0 ms Clipped Peak = 79.4G		From: 64.2 to 67.2 ms
Total time over 80 G was 1.0 ms		

Chest Acceleration

X	**-55.4 g @ 45 ms**	6.8 g @ 139 ms
Y	-3.6 g @ 168 ms	**15.6 g @ 70 ms**
Z	-12.9 g @ 46 ms	**13.9 g @ 69 ms**
Resultant	**Peak: 56.9 g @ 46 ms**	
3.0 ms Clipped Peak = 55.2G		From: 43.6 to 46.6 ms
Total time over 60 G was 0.0 ms		

Upper Neck Force

Upper Neck Fx	-47.7 N (-10.7 lb) @ 20 ms	**895.4 N (201.3 lb) @ 59 ms**
Upper Neck Fy	**-249.3 N (-56.0 lb) @ 80 ms**	223.8 N (50.3 lb) @ 99 ms
Upper Neck Fz	**-2465.4 N (-554.3 lb) @ 68 ms**	72.3 N (16.3 lb) @ 19 ms
Resultant	**Peak: 2542.6 N (571.6 lb) @ 68 ms**	

Continued on Page 2

Upper Neck Moment

Upper Neck Mx	-2.3 N-m (-20.4 in-lb) @ 49 ms	**23.1 N-m (204.6 in-lb) @ 96 ms**
Upper Neck My	**-47.5 N-m (-420.2 in-lb) @ 56 ms**	34.8 N-m (307.8 in-lb) @ 100 ms
Upper Neck Mz	-7.0 N-m (-61.9 in-lb) @ 95 ms	**9.7 N-m (86.0 in-lb) @ 63 ms**
Resultant	**Peak: 48.0 N-m (425.1 in-lb) @ 56 ms**	

Left ASIS

Left A.S.I.S. Upper Fx	-404.6 N (-91.0 lb) @ 42 ms	**449.2 N (101.0 lb) @ 81 ms**
Left A.S.I.S. Lower Fx	**-792.8 N (-178.2 lb) @ 67 ms**	32.8 N (7.4 lb) @ 165 ms

Right ASIS

Right A.S.I.S. Uppe...	**-311.0 N (-69.9 lb) @ 42 ms**	215.7 N (48.5 lb) @ 95 ms
Right A.S.I.S. Lowe...	**-569.8 N (-128.1 lb) @ 67 ms**	1.0 N (.2 lb) @ 5 ms

Lumbar Force

Lumbar Fx	**-819.5 N (-184.2 lb) @ 44 ms**	699.2 N (157.2 lb) @ 77 ms
Lumbar Fy	-31.2 N (-7.0 lb) @ 189 ms	**970.3 N (218.1 lb) @ 71 ms**
Lumbar Fz	-618.1 N (-139.0 lb) @ 49 ms	**1350.8 N (303.7 lb) @ 104 ms**
Resultant	**Peak: 1702.1 N (382.7 lb) @ 76 ms**	

Lumbar Moment

Lumbar Mx	-6.6 N-m (-58.0 in-lb) @ 167 ms	**45.4 N-m (401.7 in-lb) @ 71 ms**
Lumbar My	-16.9 N-m (-149.5 in-lb) @ 66 ms	**39.3 N-m (347.7 in-lb) @ 44 ms**
Lumbar Mz	**-8.6 N-m (-76.4 in-lb) @ 78 ms**	.1 N-m (.9 in-lb) @ 12 ms
Resultant	**Peak: 47.7 N-m (422.3 in-lb) @ 68 ms**	

Belt Loads

Left Lap Belt Load	-20.3 N (-4.6 lb) @ 149 ms	**2930.1 N (658.7 lb) @ 42 ms**
Right Lap Belt Load	-23.1 N (-5.2 lb) @ 93 ms	**3648.6 N (820.2 lb) @ 42 ms**

Pelvis Acceleration

X	**-51.0 g @ 39 ms**	16.9 g @ 140 ms
Y	**-10.3 g @ 71 ms**	10.3 g @ 141 ms
Z	-5.7 g @ 135 ms	**26.2 g @ 58 ms**
Resultant	**Peak: 52.7 g @ 40 ms**	

Pelvic Angle

Pelvis Anglular Rat...	**-1475.6 deg/s @ 140 ms**	590.5 deg/s @ 169 ms
Pelvic Angle	**-14.9 ° @ 141 ms**	.2 ° @ 226 ms

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UMTRI	Results	NT1811

Chest Angle

Chest Angular Rate ...	**-1134.2 deg/s @ 50 ms**	499.7 deg/s @ 167 ms
Chest Angle	**-46.1 ° @ 118 ms**	1.2 ° @ 291 ms

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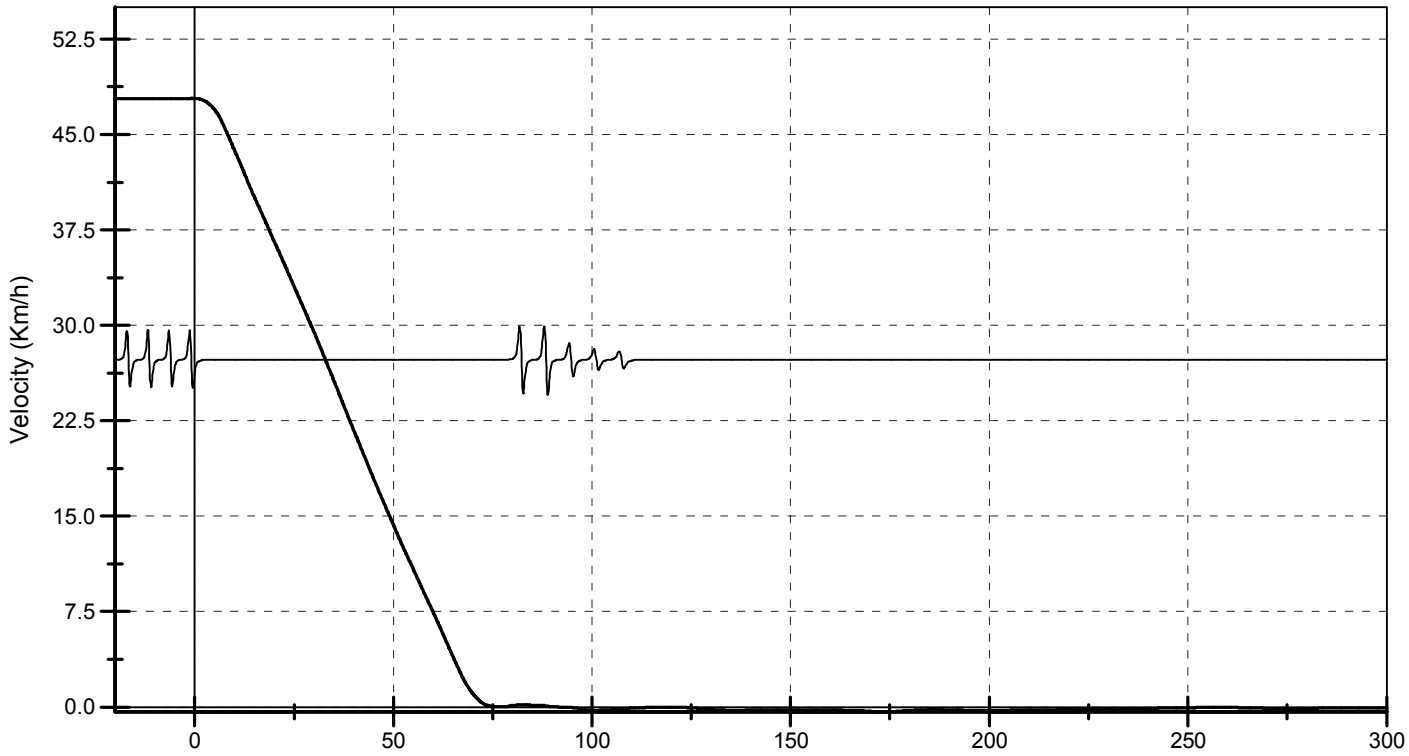
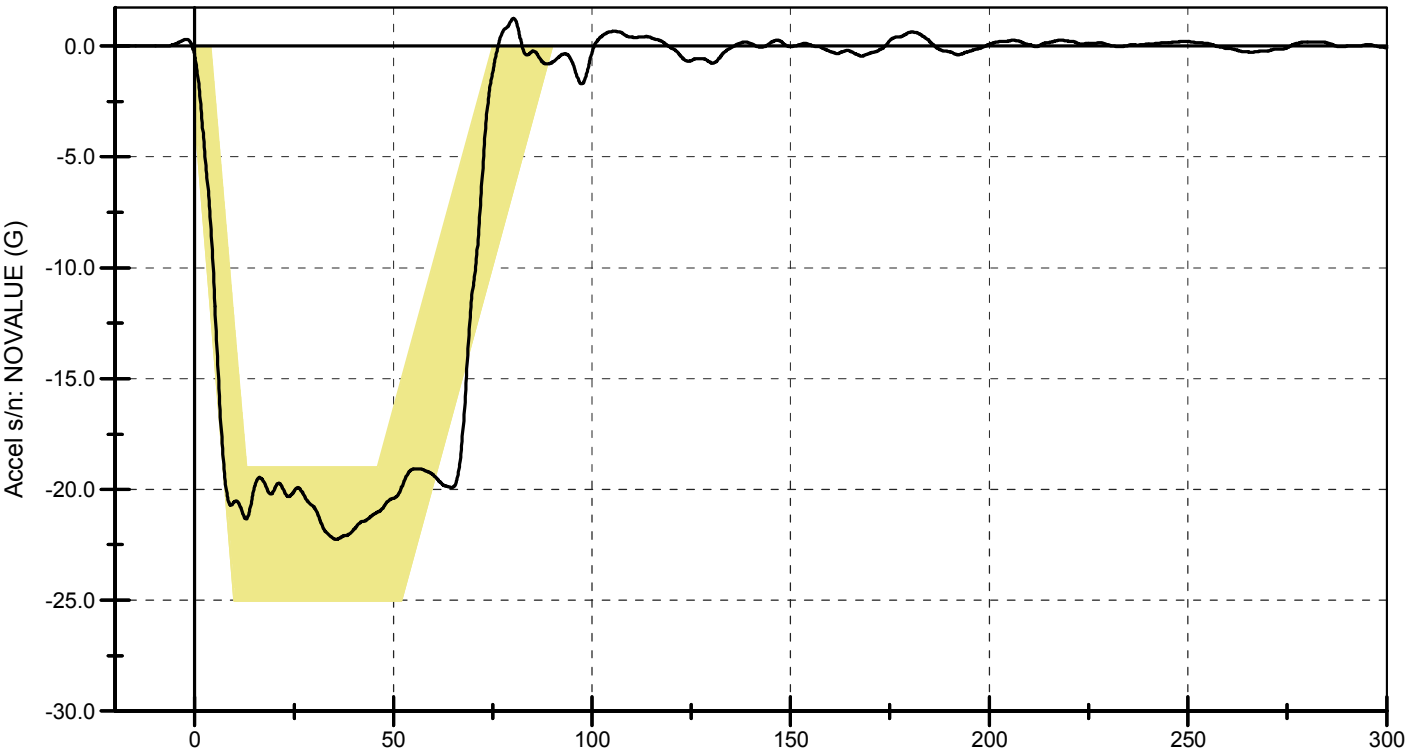
Sled Summary

NT1811





Sled Decel Peak = -22.2 G
Sled Plateau Average Level = -20.3 G
Sled Pulse Duration = 76.6 ms

Stopping Dist. (est) = .521 m
Sled Delta V = 47.8 kph (29.7 mph)
Efficiency = Vout / Vin = 21.9 / 25.9 = 84.8%

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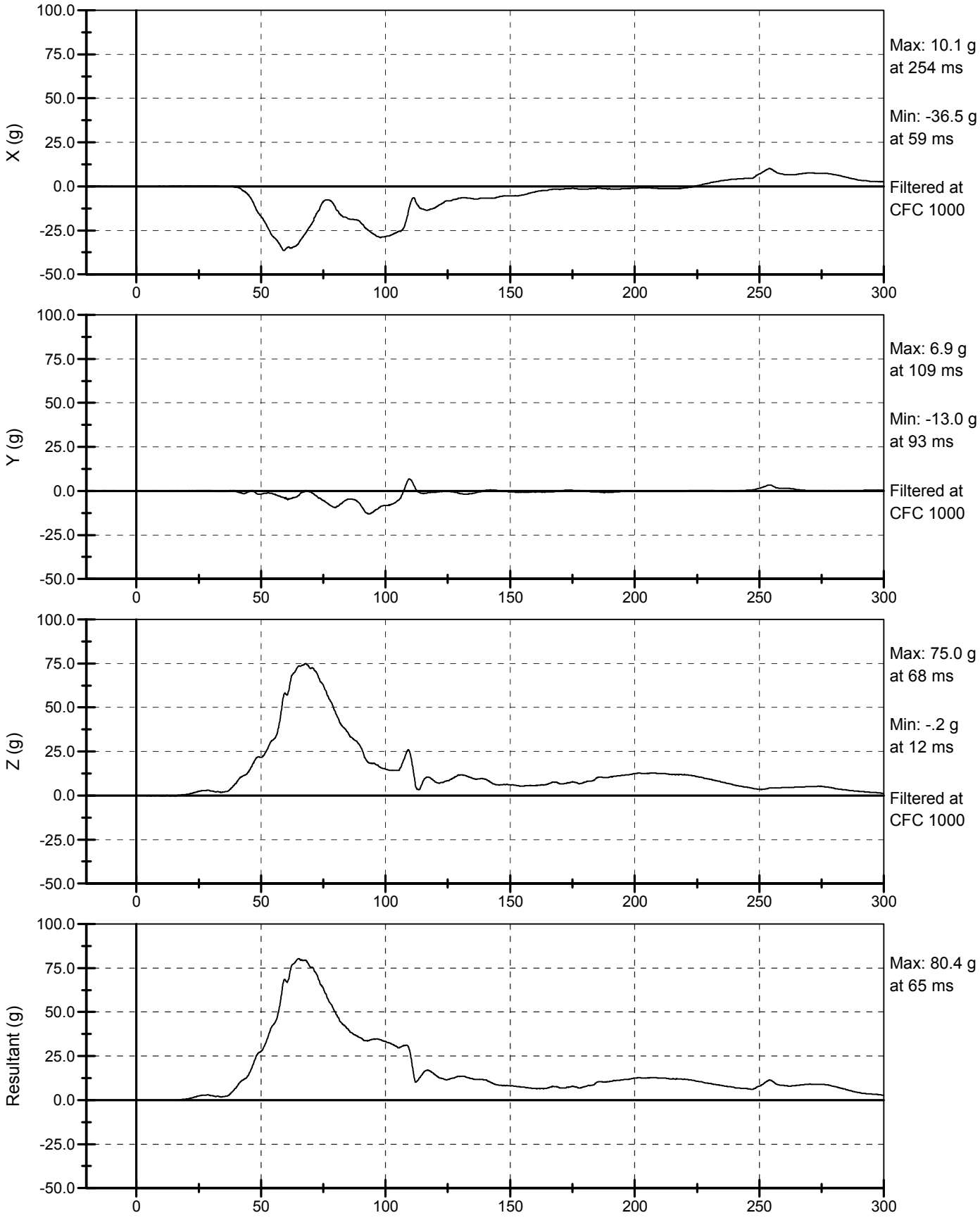
Head Acceleration

NT1811



H.I.C. (15) = 728.6 From: 58.8 to 73.8 ms

H.I.C. (36) = 968.9 From: 52.9 to 88.9 ms

H.I.C. (UN) = 986.6 From: 50.9 to 109.5 ms

Total time over 80 G was 1.0 ms

3.0 ms Clipped Peak = 79.4G From: 64.2 to 67.2 ms

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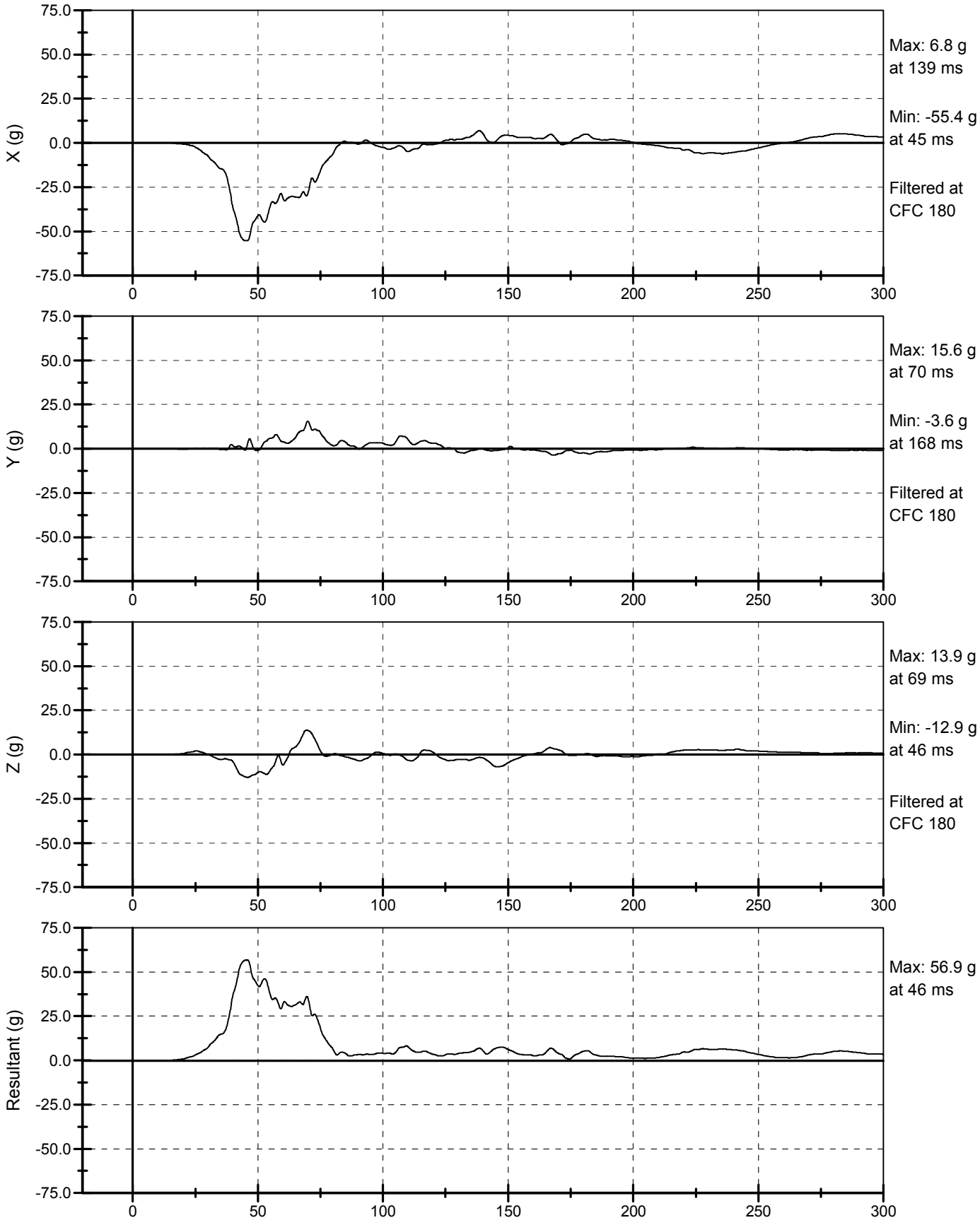
Chest Acceleration

NT1811



Total time over 60 G was 0.0 ms

3.0 ms Clipped Peak = 55.2G

From: 43.6 to 46.6 ms

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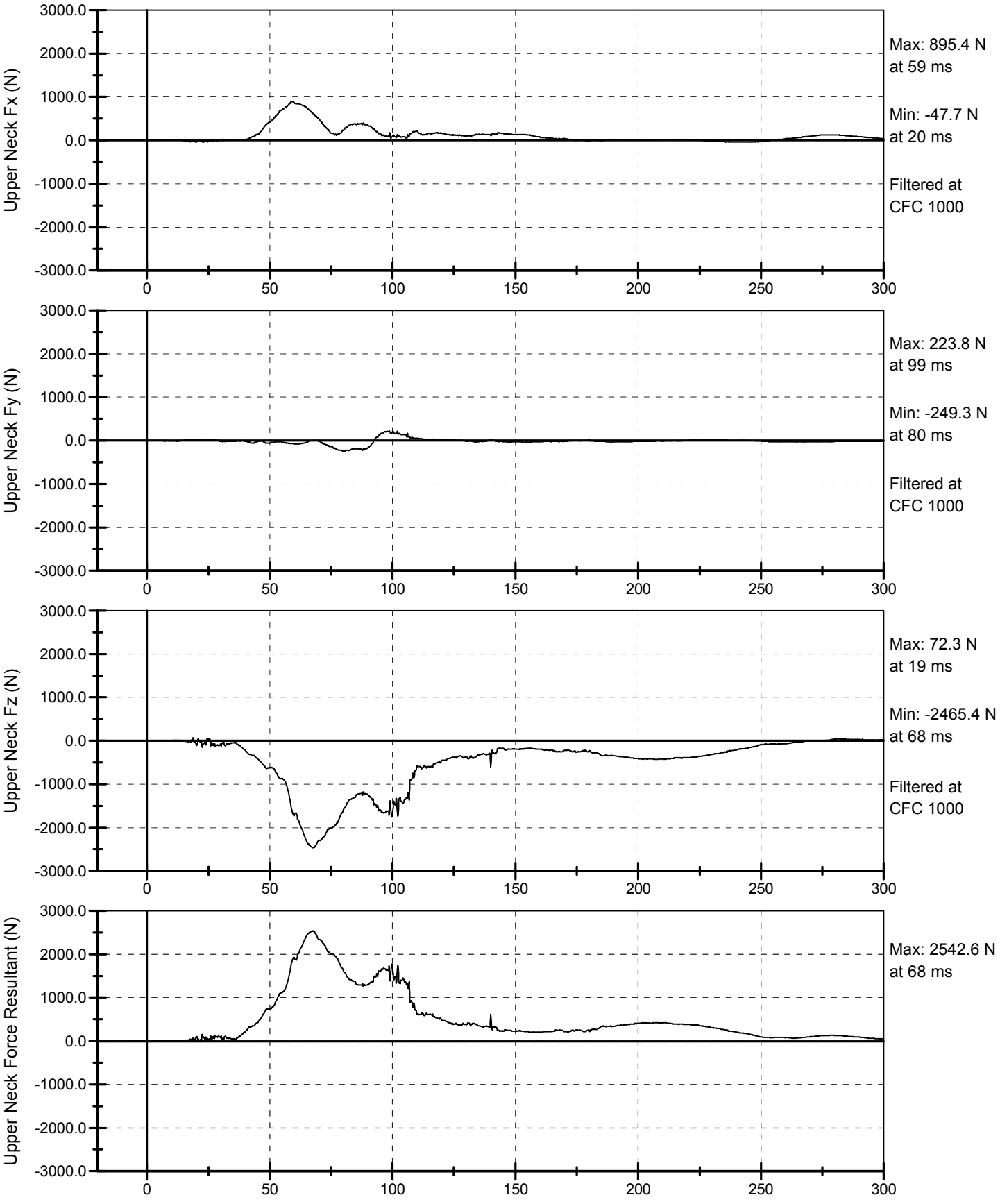
Upper Neck Force

NT1811



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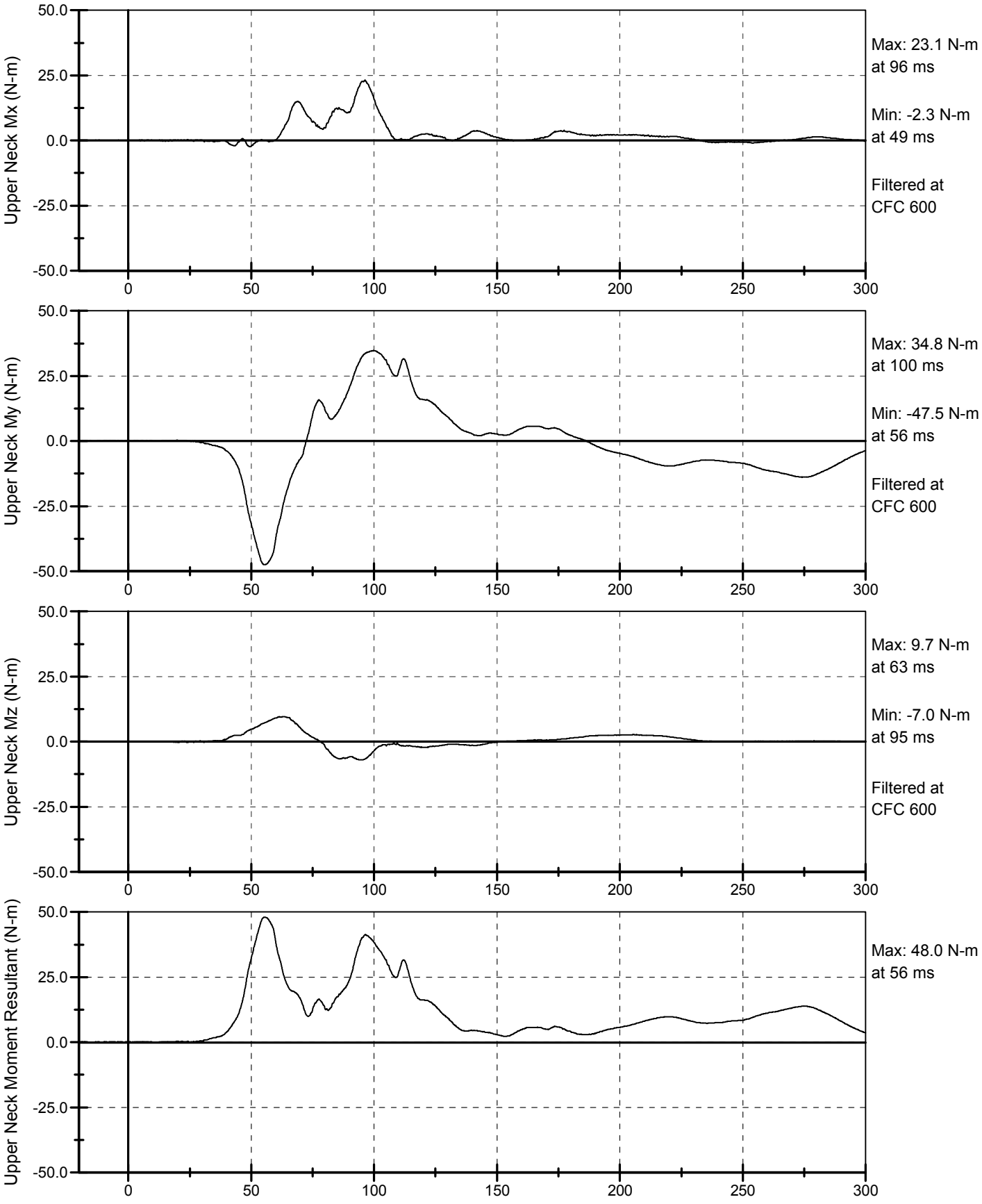
Upper Neck Moment

NT1811



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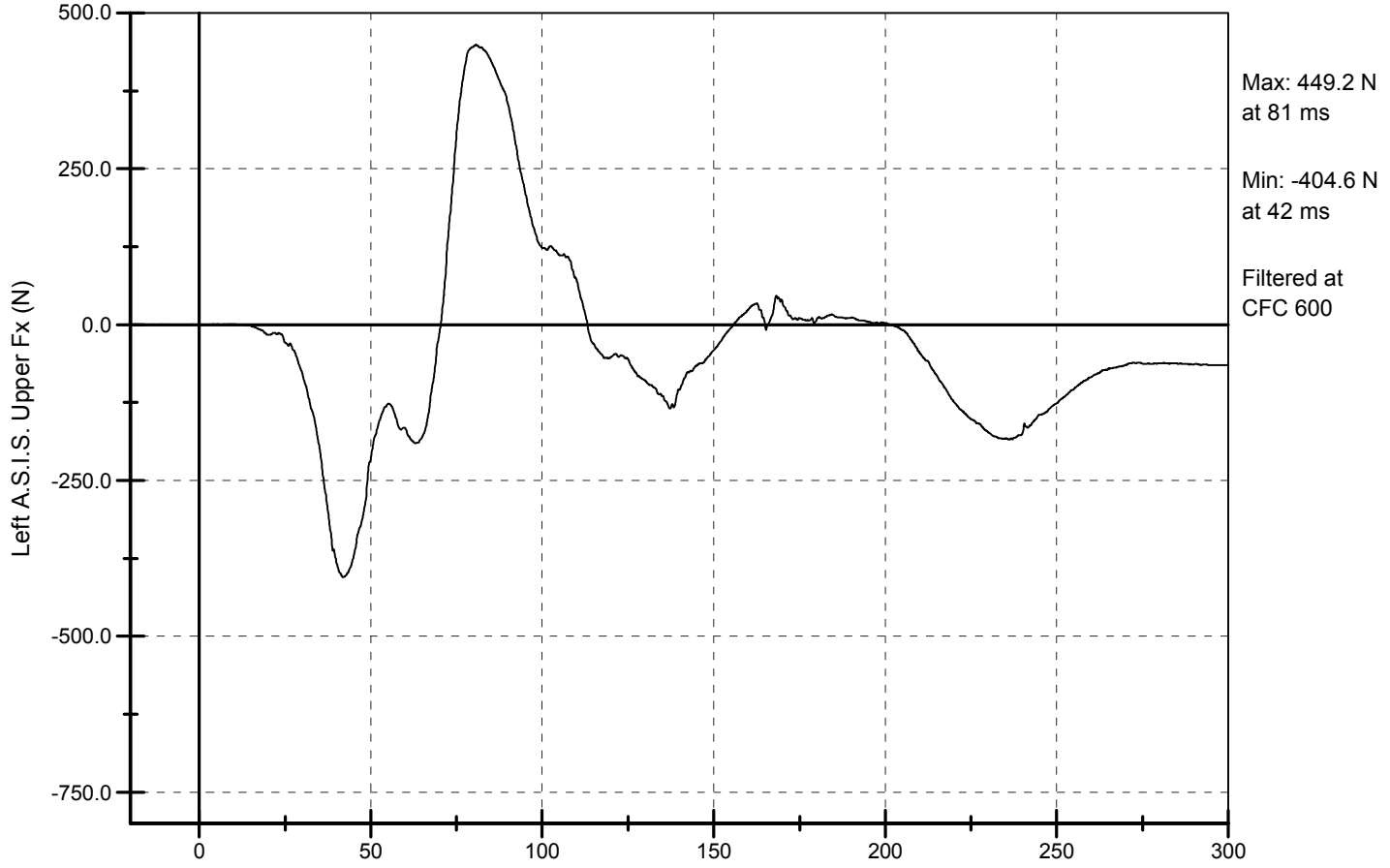
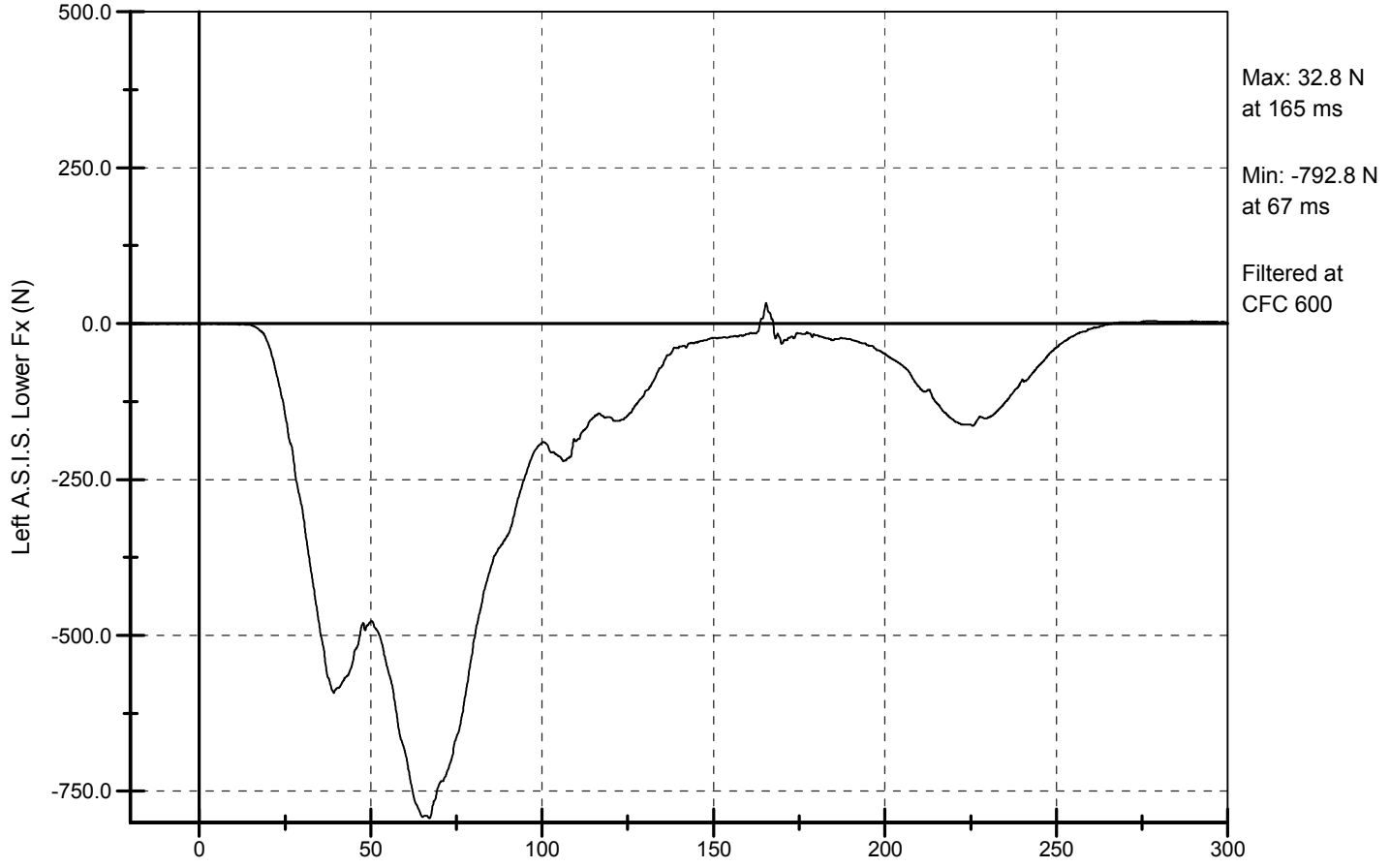
Left ASIS

NT1811





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Right ASIS

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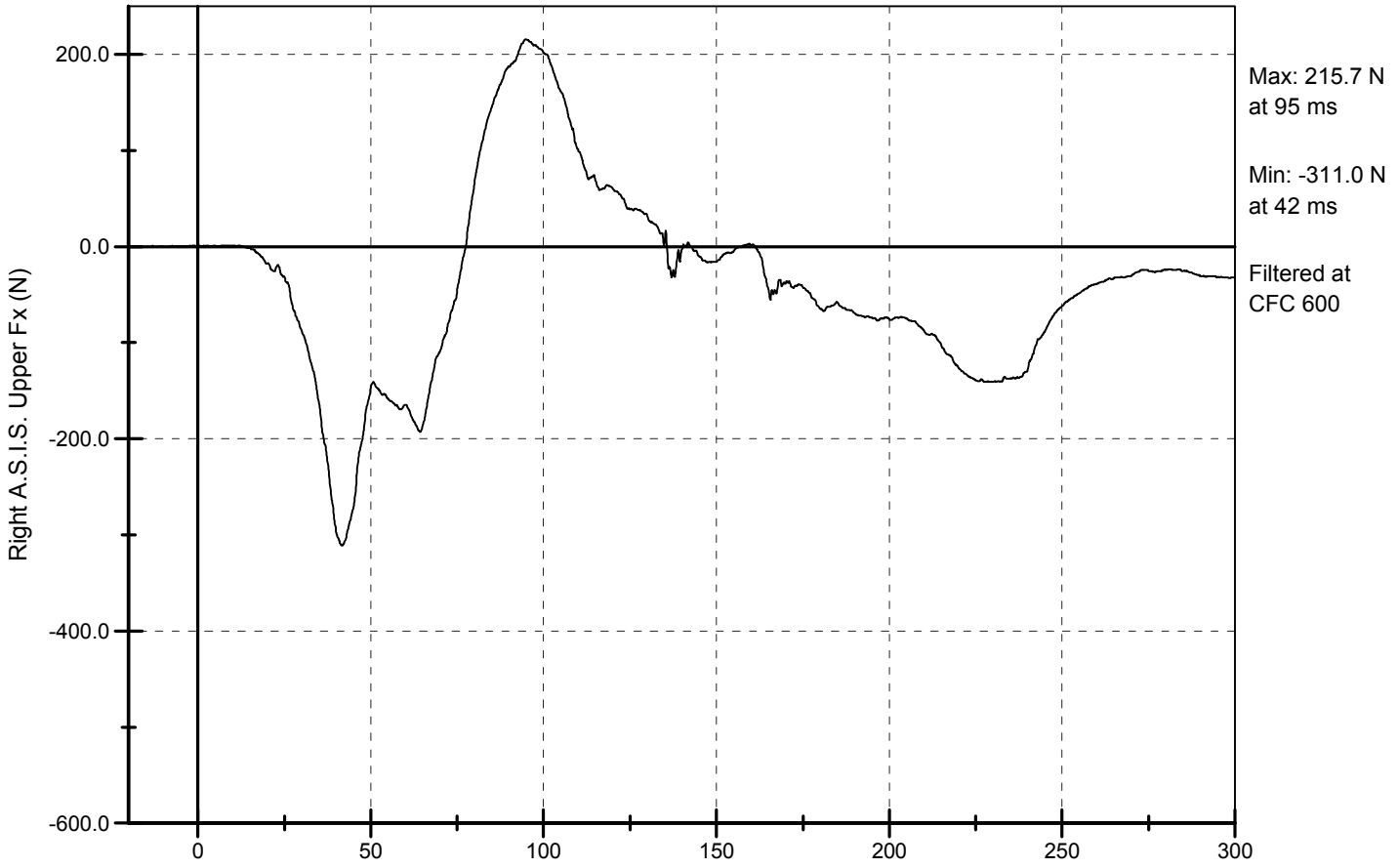

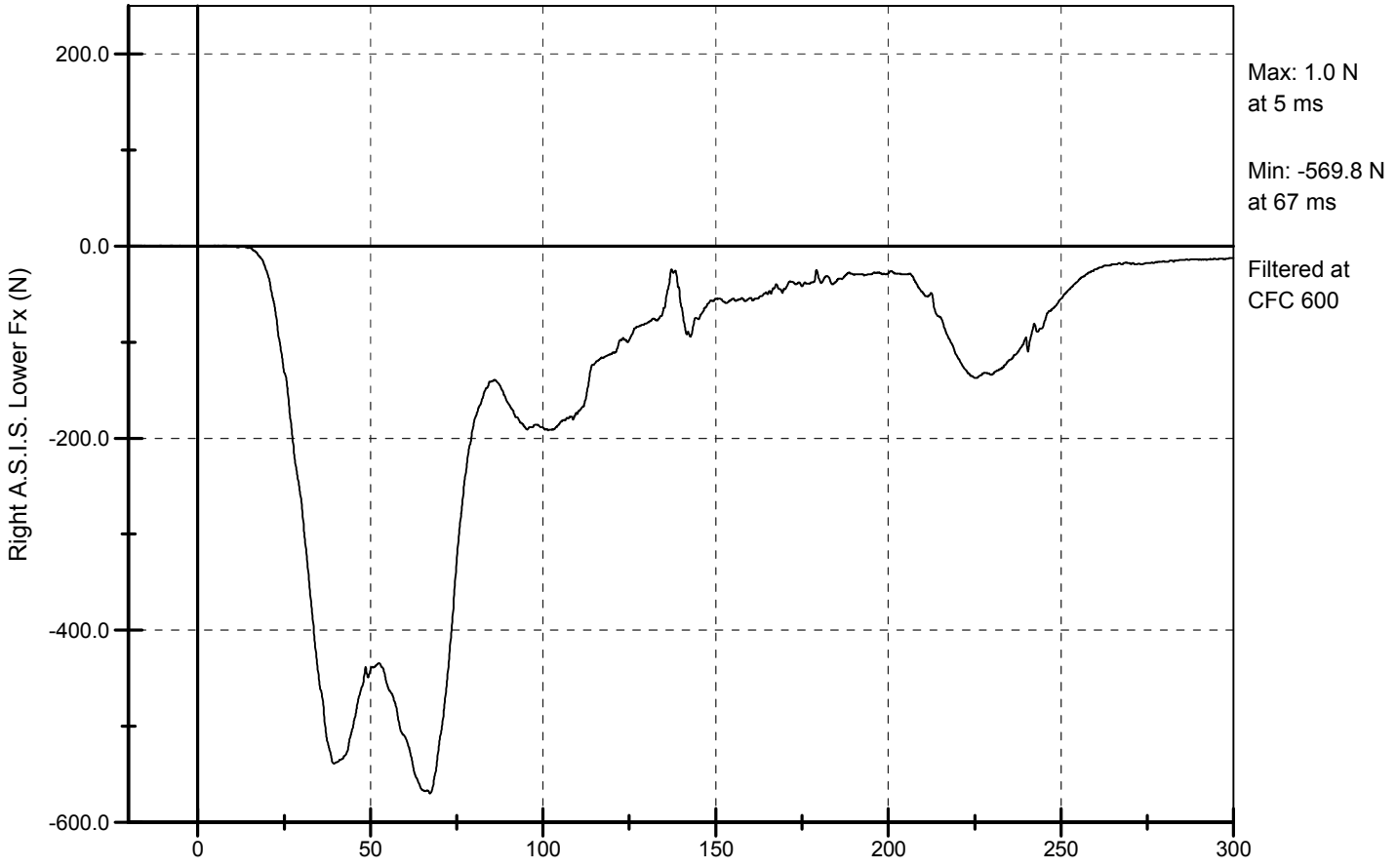

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Lumbar Force

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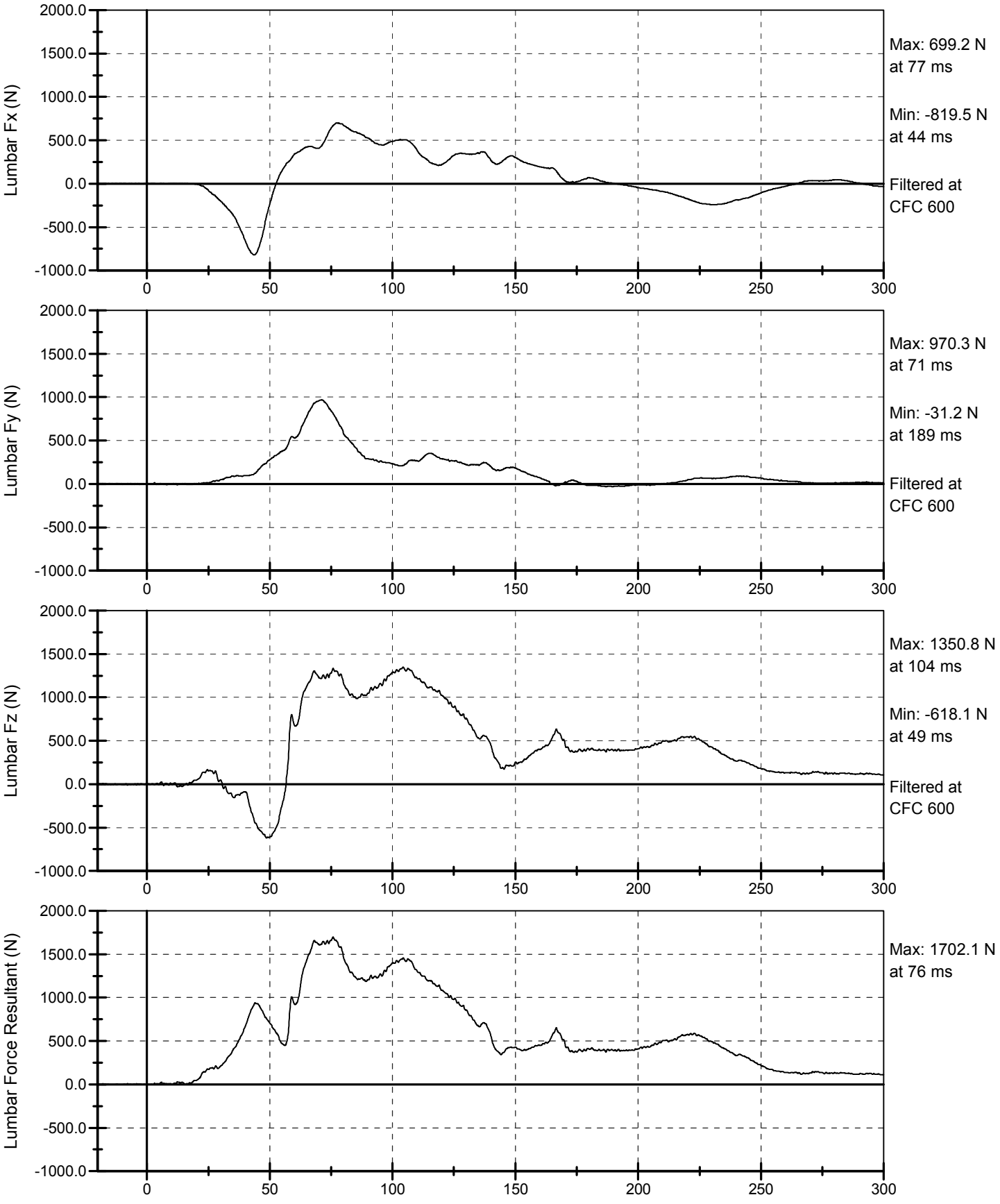

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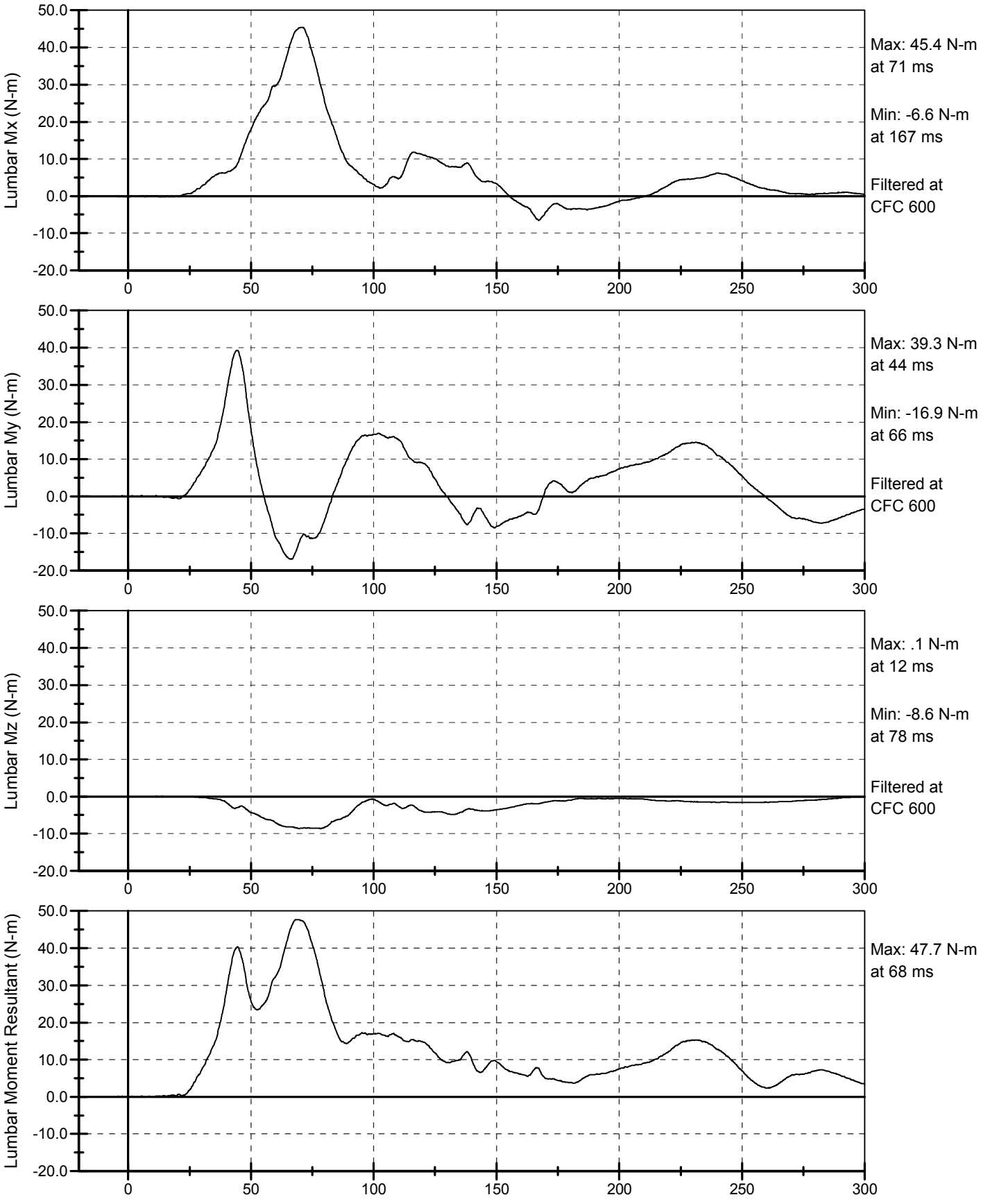
Lumbar Moment

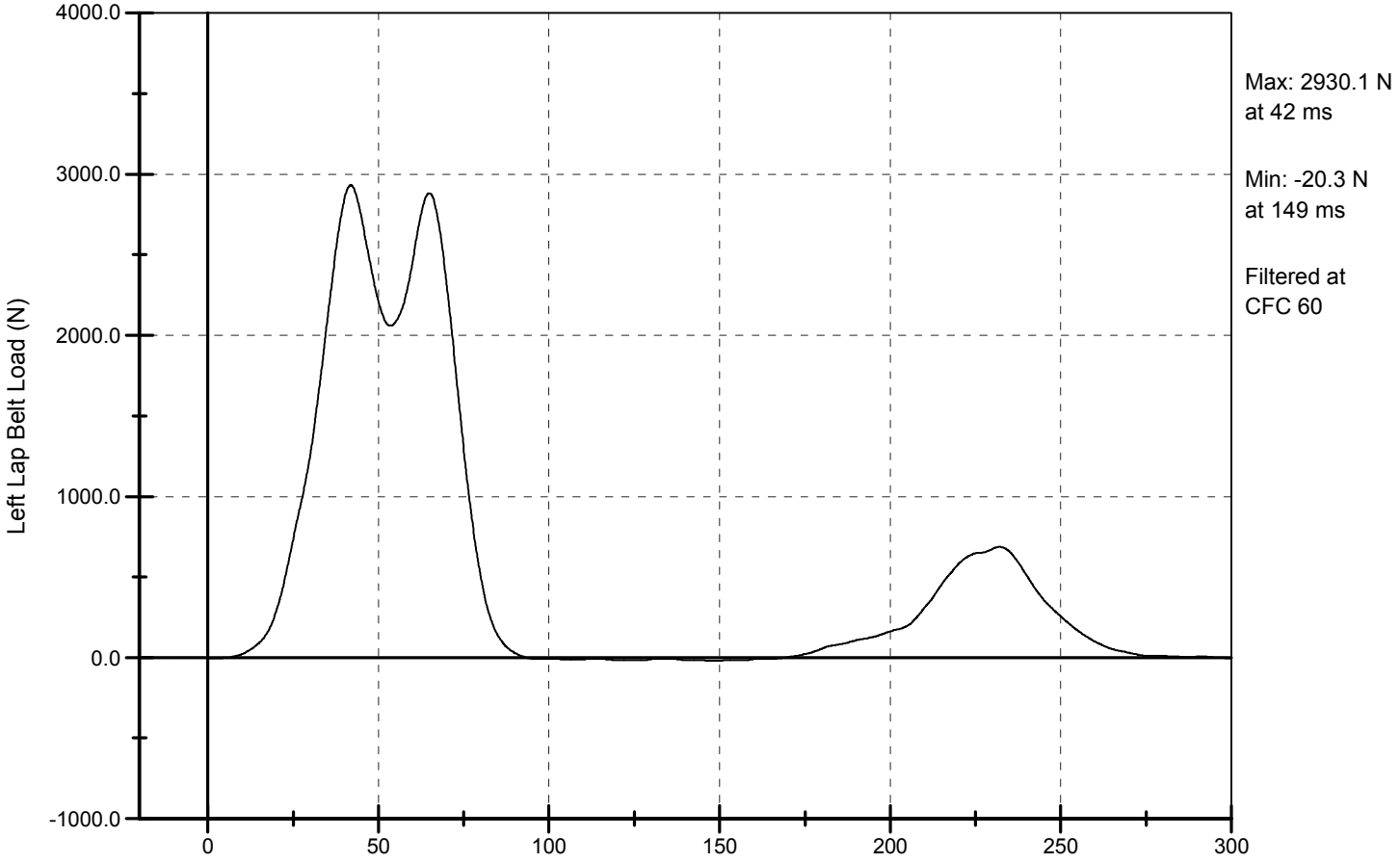
NT1811

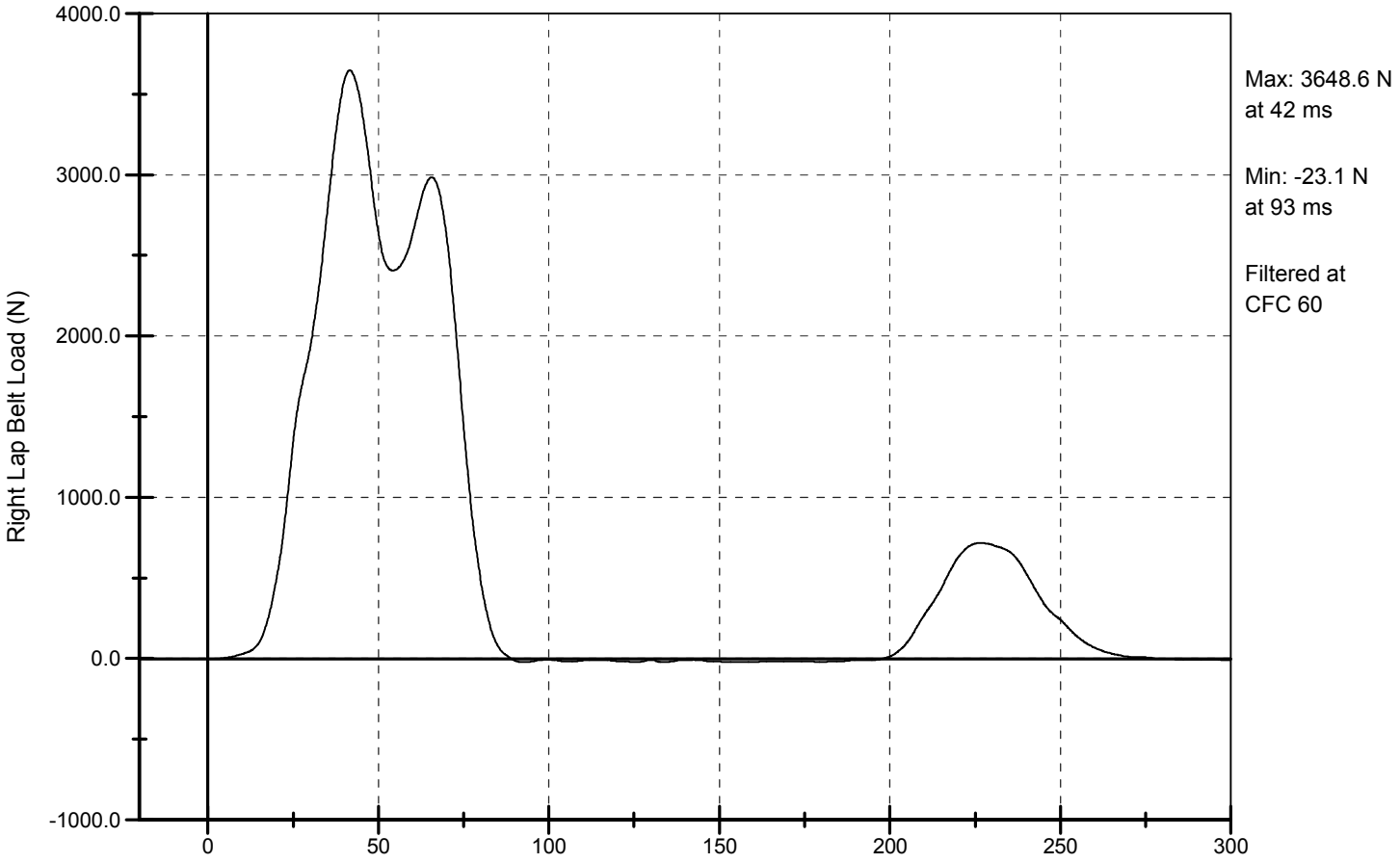


UMTRI

Belt Loads

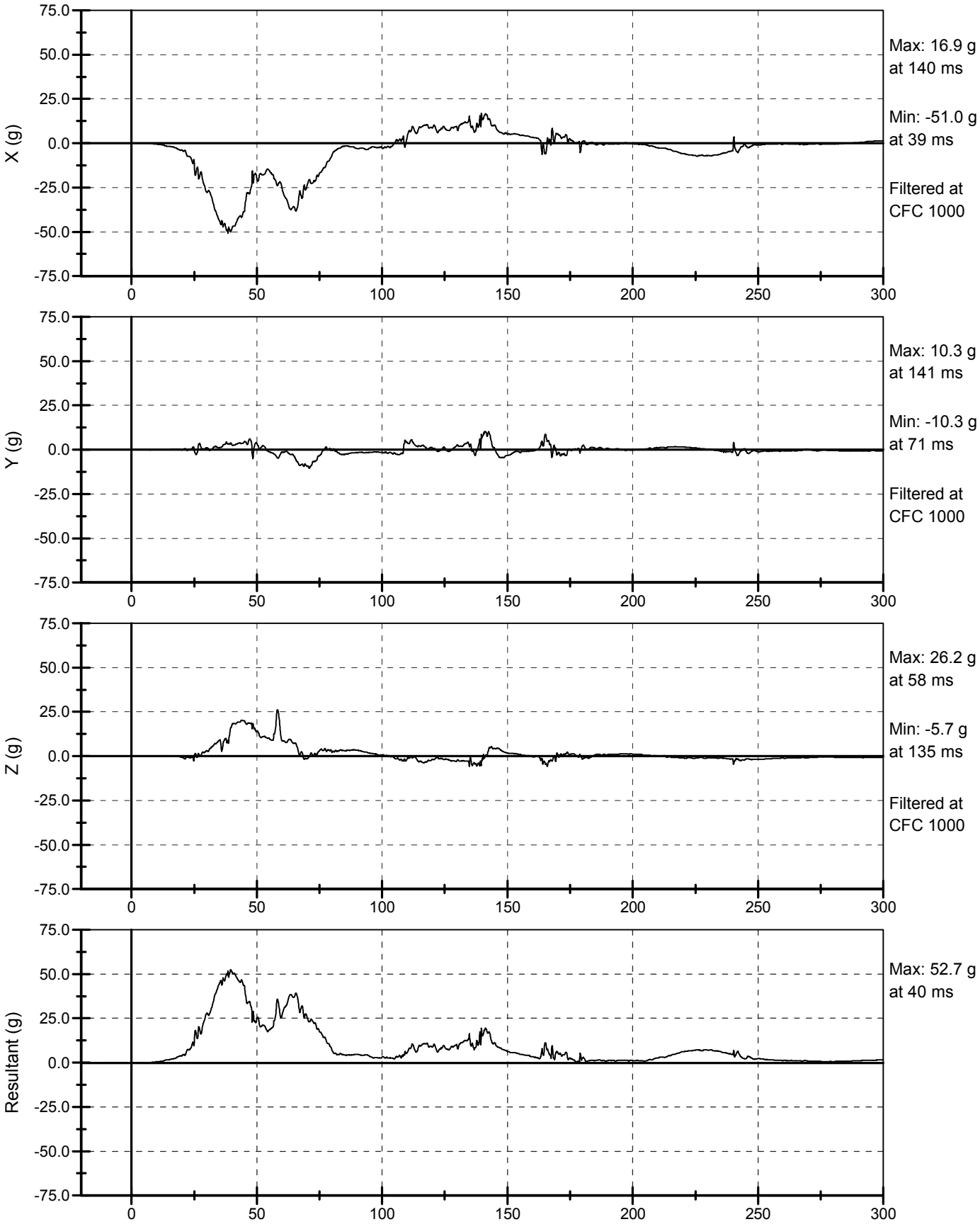
NT1811





UMTRI

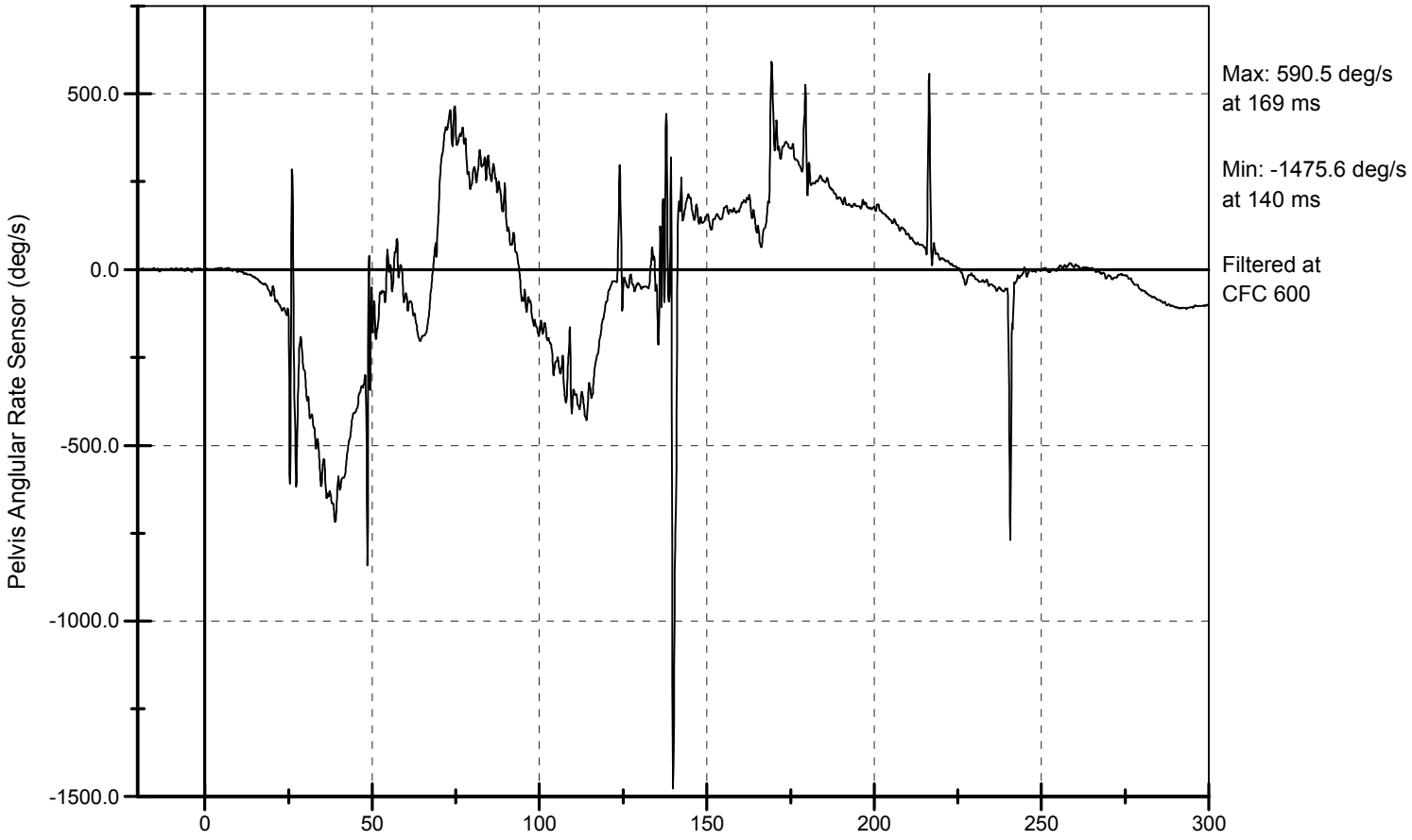
Pelvis Acceleration NT1811

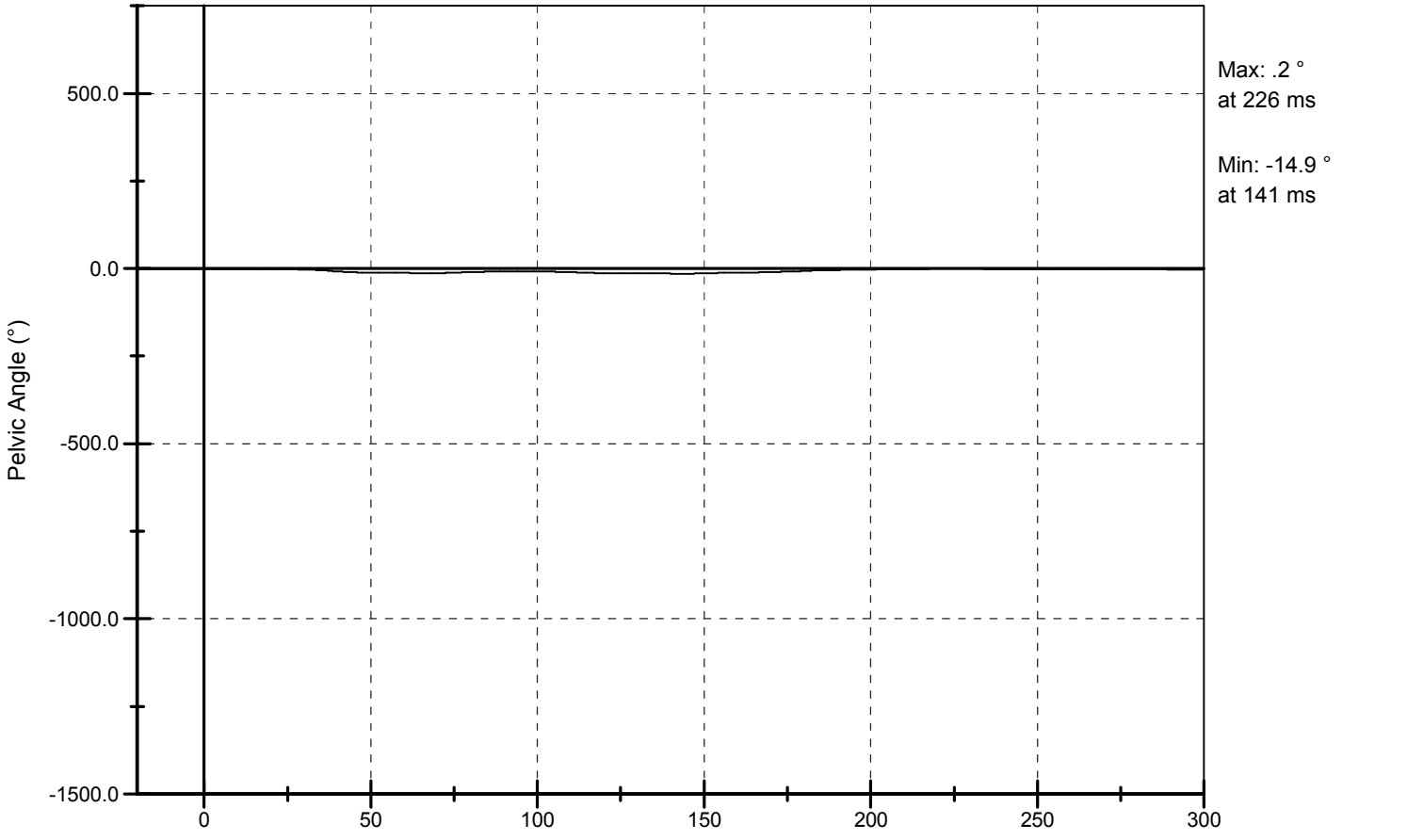


UMTRI

Pelvic Angle

NT1811

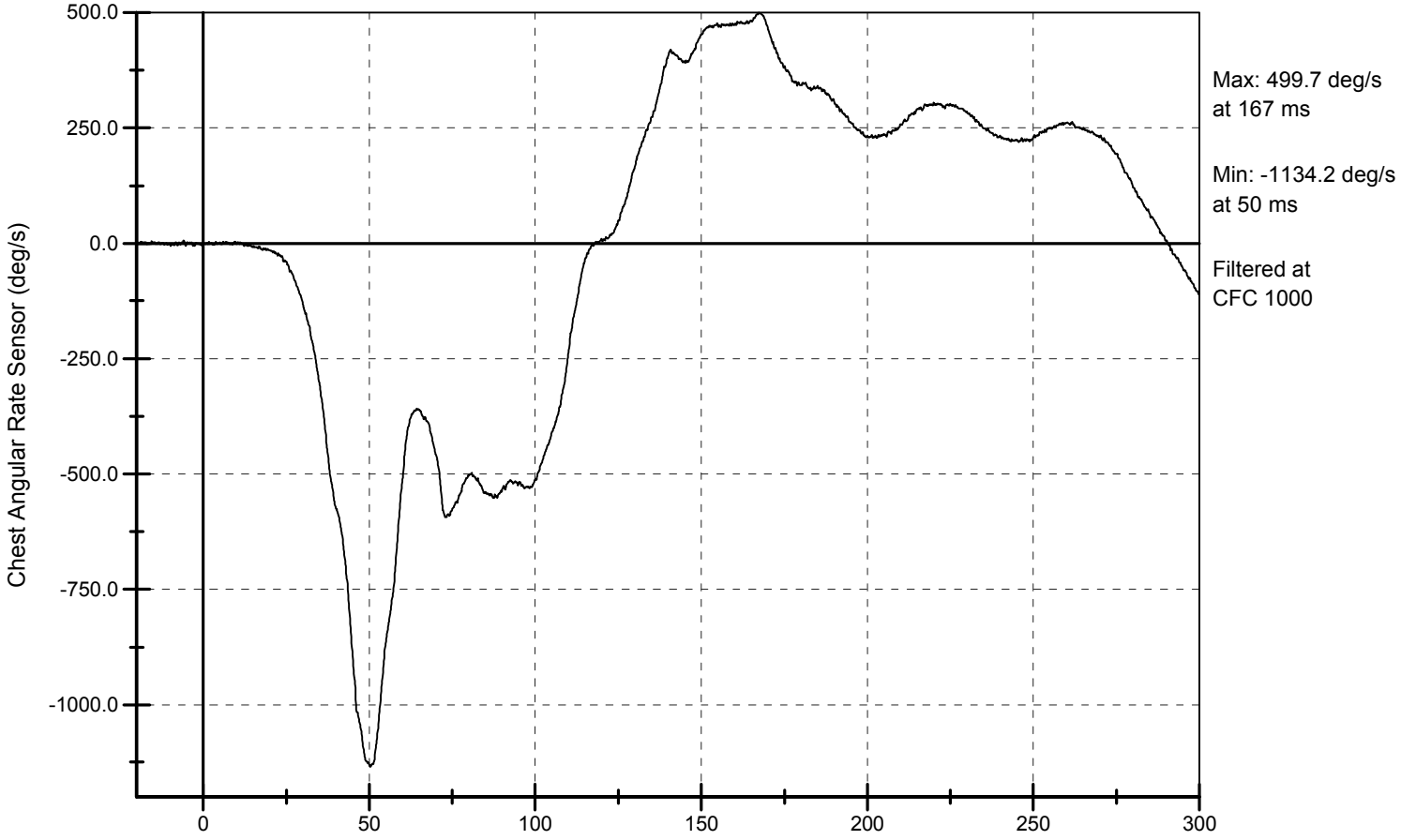


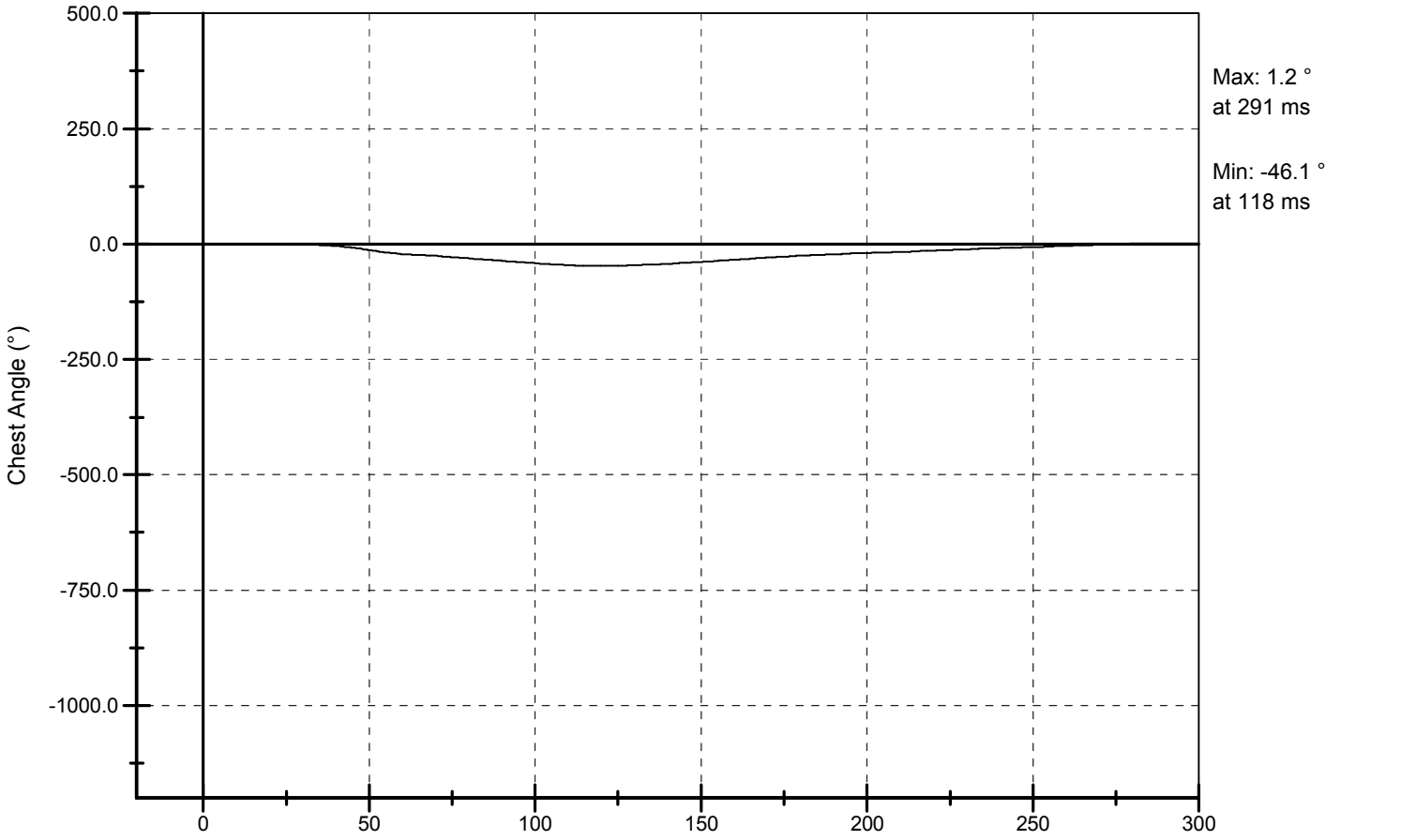


UMTRI

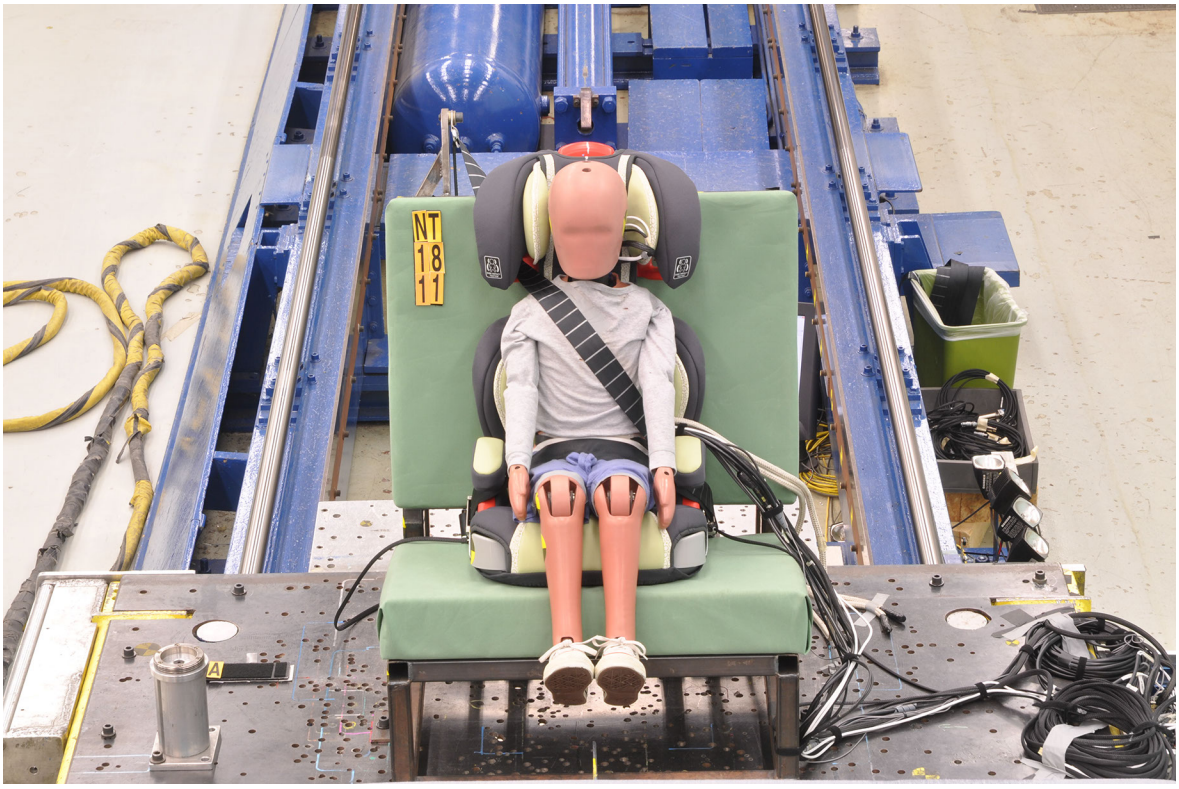
Chest Angle

NT1811





NT1811 PRETEST PHOTOS



nt1811PreFront.JPG

nt1811PreFrontRight.JPG

NT1811 PRETEST PHOTOS

nt1811PreRight.JPG

nt1811PreRightRetractor.JPG

NT1811 PRETEST PHOTOS

nt1811PreDRing.JPG

nt1811PreRearRetractor.JPG

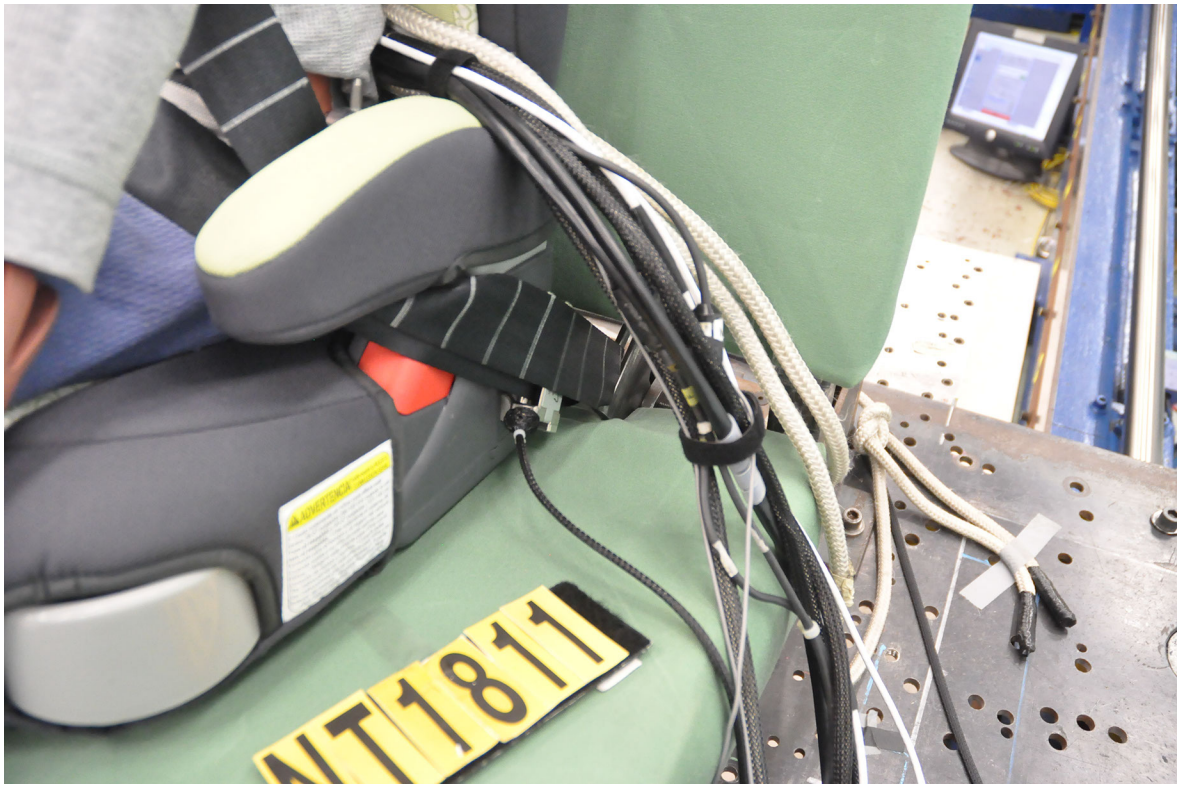
NT1811 PRETEST PHOTOS

nt1811PreBeltRight.JPG

nt1811PreRightAnchor.JPG

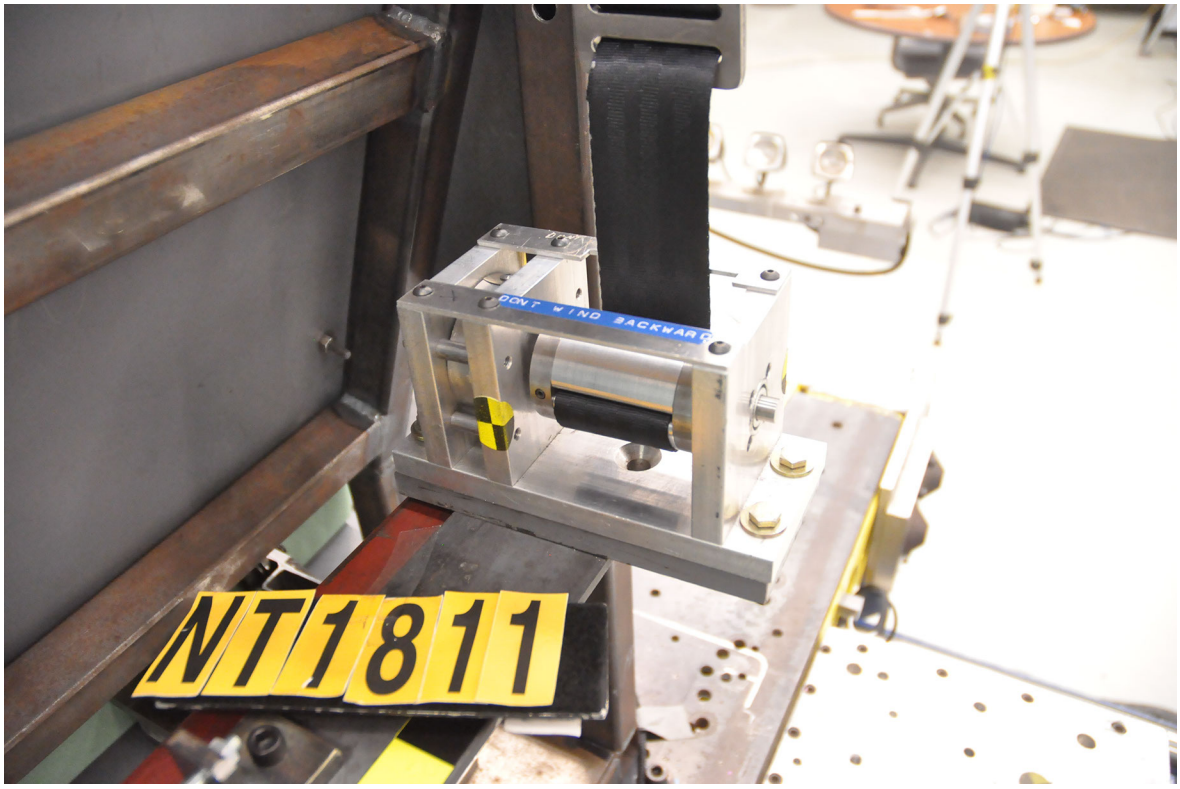
NT1811 PRETEST PHOTOS

nt1811PreBeltLeft.JPG



nt1811PreLeftAnchor.JPG

NT1811 PRETEST PHOTOS



nt1811PreRetractorSpool.JPG

nt1811PreBeltShoulder.JPG

NT1811 PRETEST PHOTOS

nt1811PreBeltLap.JPG

NT1811 POSTTEST PHOTOS

nt1811PostFront.JPG

nt1811PostFrontRight.JPG

NT1811 POSTTEST PHOTOS

nt1811PostRight.JPG

nt1811PostRightRetractor.JPG

NT1811 POSTTEST PHOTOS

nt1811PostBeltShoulder.JPG

nt1811PostRetractorSpool.JPG

NT1811 POSTTEST PHOTOS

nt1811PostBeltRight.JPG

nt1811PostRightAnchor.JPG

NT1811 POSTTEST PHOTOS

nt1811PostDRing.JPG

nt1811PostBeltLeft.JPG

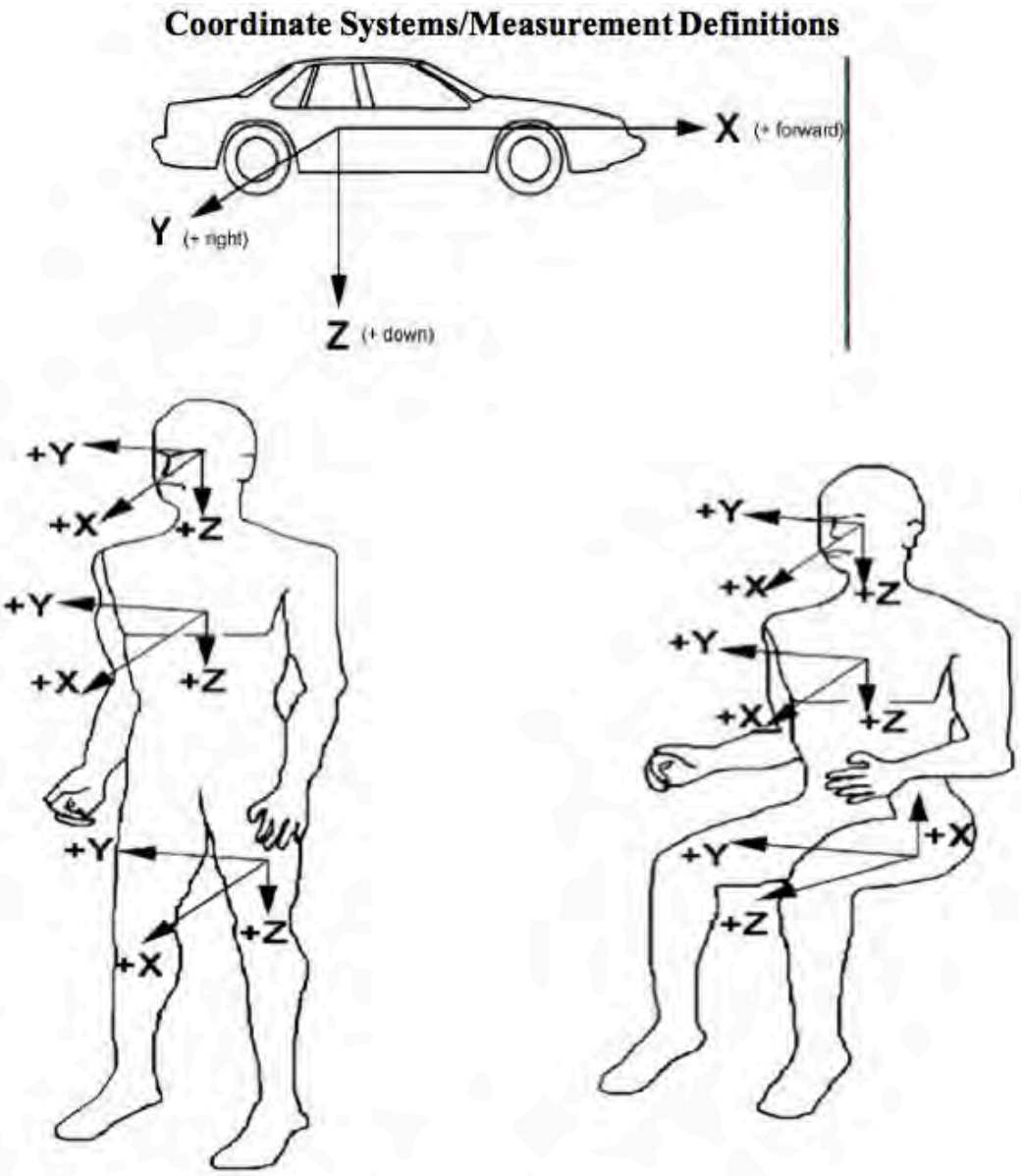
NT1811 POSTTEST PHOTOS

nt1811PostBeltLap.JPG

nt1811PostLeftAnchor.JPG

Appendix A

Coordinate System / Measurement Definitions



*Figures obtained from **NHTSA Test Reference Guide Version 5**
Volume II: Biomechanical Tests

Table A- 1 Dummy Manipulations for Checking Recorded Load Cell Polarity Relative to Sign Convention

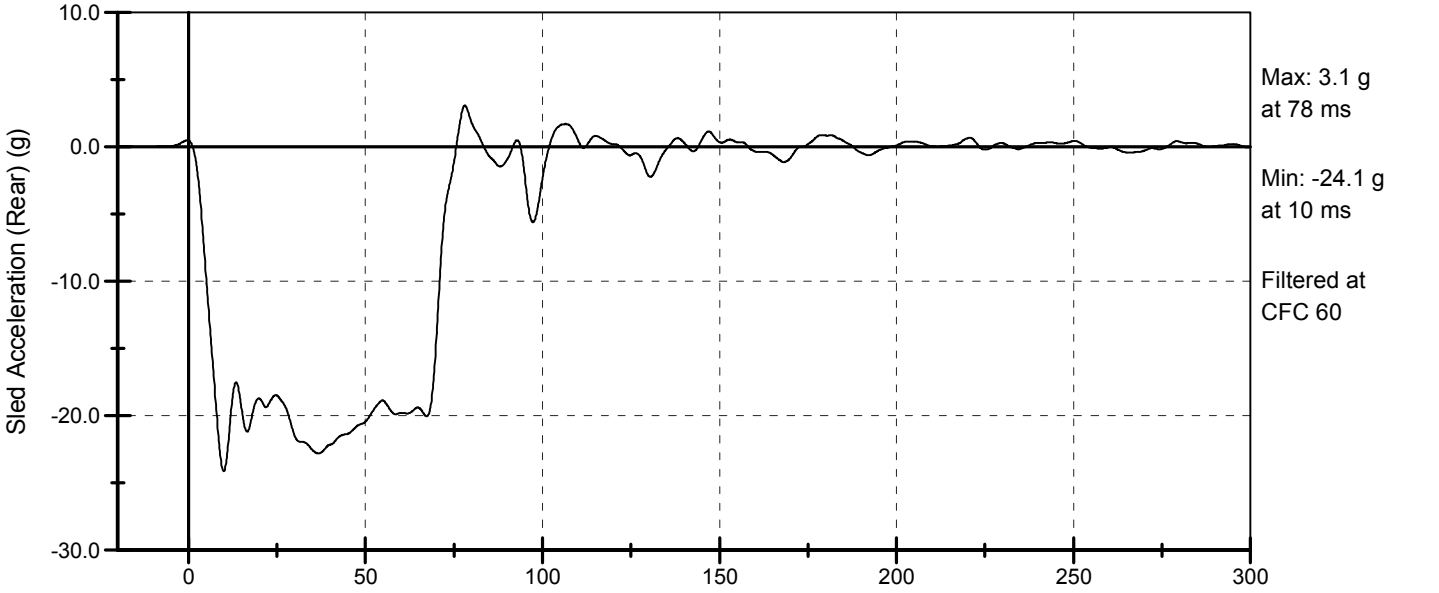
Load Cell	Measure	Dummy Manipulations	Polarity
Upper and lower neck loads	Fx	Head rearward, chest forward	+
	Fy	Head leftward, chest rightward	+
	Fz	Head upward, chest downward	+
	Mx	Left ear toward left shoulder	+
	My	Chin toward sternum	+
	Mz	Chin toward left shoulder	+
Left shoulder loads (BIOSID)	Fx	Left shoulder forward, chest rearward	+
	Fy	Left shoulder rightward, chest leftward	+
	Fz	Left shoulder downward, chest upward	+
Right shoulder loads (BIOSID)	Fx	Right shoulder forward, chest rearward	+
	Fy	Right shoulder rightward, chest leftward	+
	Fz	Right shoulder downward, chest upward	+
Clavicle loads	Fx	Shoulder forward, chest rearward	+
	Fz	Shoulder downward, chest rearward	+
Upper and lower lumbar spine	Fx	Chest rearward, Pelvis forward	+
	Fy	Chest leftward, pelvis rightward	+
	Fz	Chest upward, pelvis downward	+
	Mx	Left shoulder toward left hip	+
	My	Sternum toward front of legs	+
	Mz	Right shoulder forward, left shoulder rearward	+
Sacrum load (BIOSID)	Fy	Left H-point pad leftward, chest rightward	+
Left iliac load (BIOSID)	Fy	Left iliac rightward, chest leftward	+
Right iliac load (BIOSID)	Fy	Right iliac rightward, chest leftward	+
Pubic load (side impact)	Fy	Right H-point pad leftward, left pad rightward	(-)
Crotch belt loads	Fx	Pubic rearward, pelvis forward	(-)
	Fz	Pubic upward, chest downward	(-)
Iliac lap belt loads	Fx	Upper iliac spine rearward, chest forward	(-)
	My	Upper iliac spine rearward, chest forward	+
Left side abdominal load (Eurosid-1)	Fy	Left side of abdomen rightward, chest leftward	+
Right side abdominal load (Eurosid-1)	Fy	Right side of abdomen leftward, chest rightward	(-)
Femur loads	Fx	Knee upward, upper femur downward	+

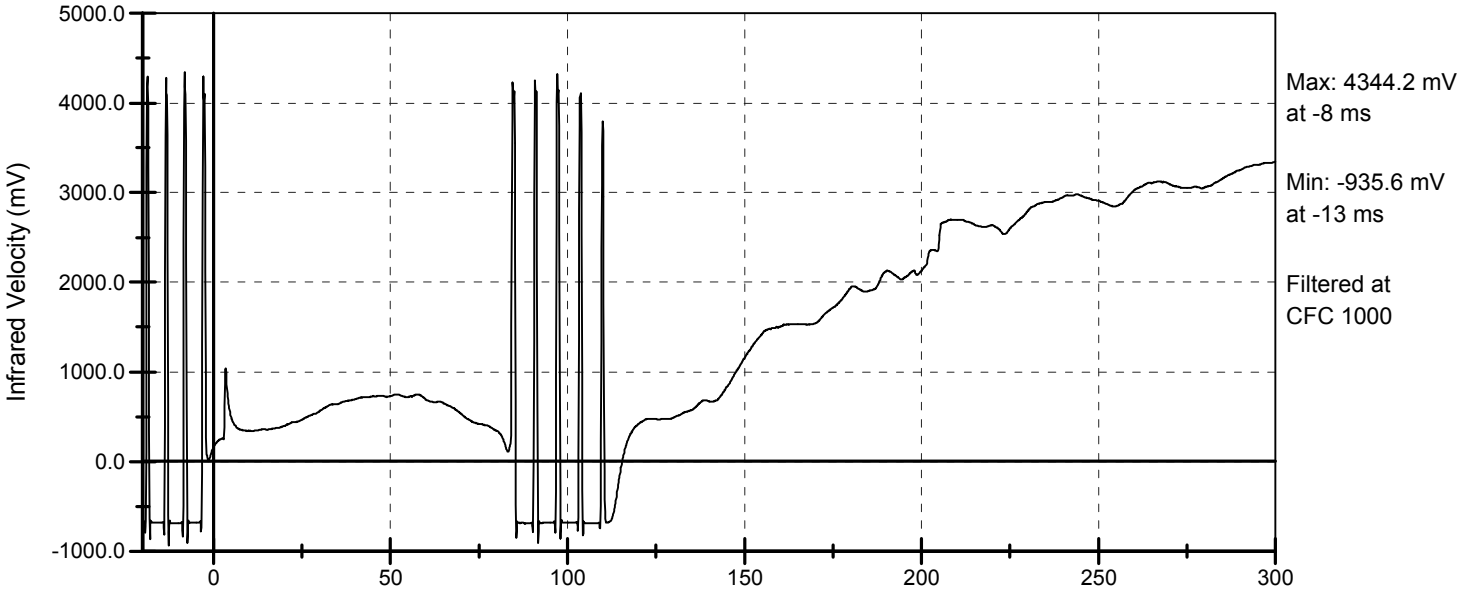
Load Cell	Measure	Dummy Manipulations	Polarity
(dummy in seated position, femurs horizontal)	Fy	Knee rightward, upper femur leftward	+
	Fz	Knee forward, pelvis rearward	+
	Mx	Knee leftward, hold upper femur in place	+
	My	Knee upward, hold upper femur in place	+
	Mz	Tibia leftward, hold pelvis in place	+
Knee clevis	Fz	Tibia downward, femur upward	+
Upper tibia loads	Fz	Tibia downward, femur upward	+
	Mx	Ankle leftward, hold knee in place	+
	My	Ankle forward, bottom of knee clevis rearward	+
Lower tibia loads	Fx	Ankle forward, knee rearward	+
	Fy	Ankle rightward, knee leftward	+
	Mx	Ankle leftward, hold knee in place	+
	My	Ankle forward, bottom of knee clevis rearward	+

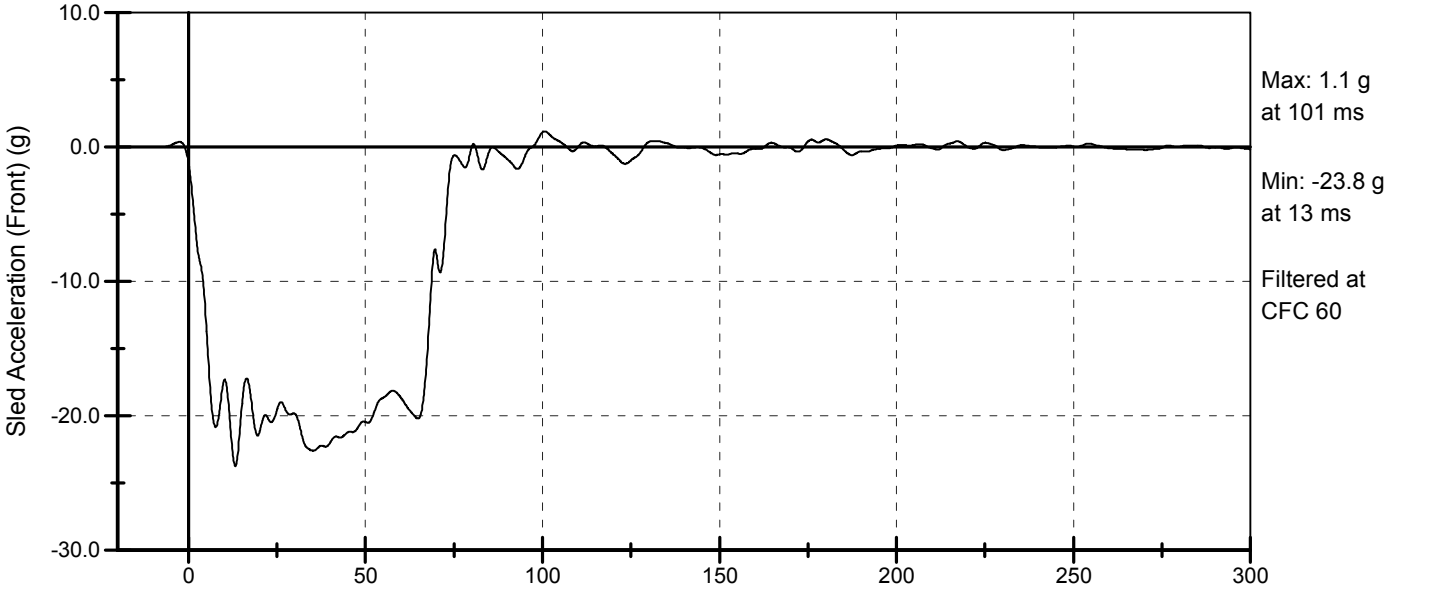
Appendix B

Test Signals

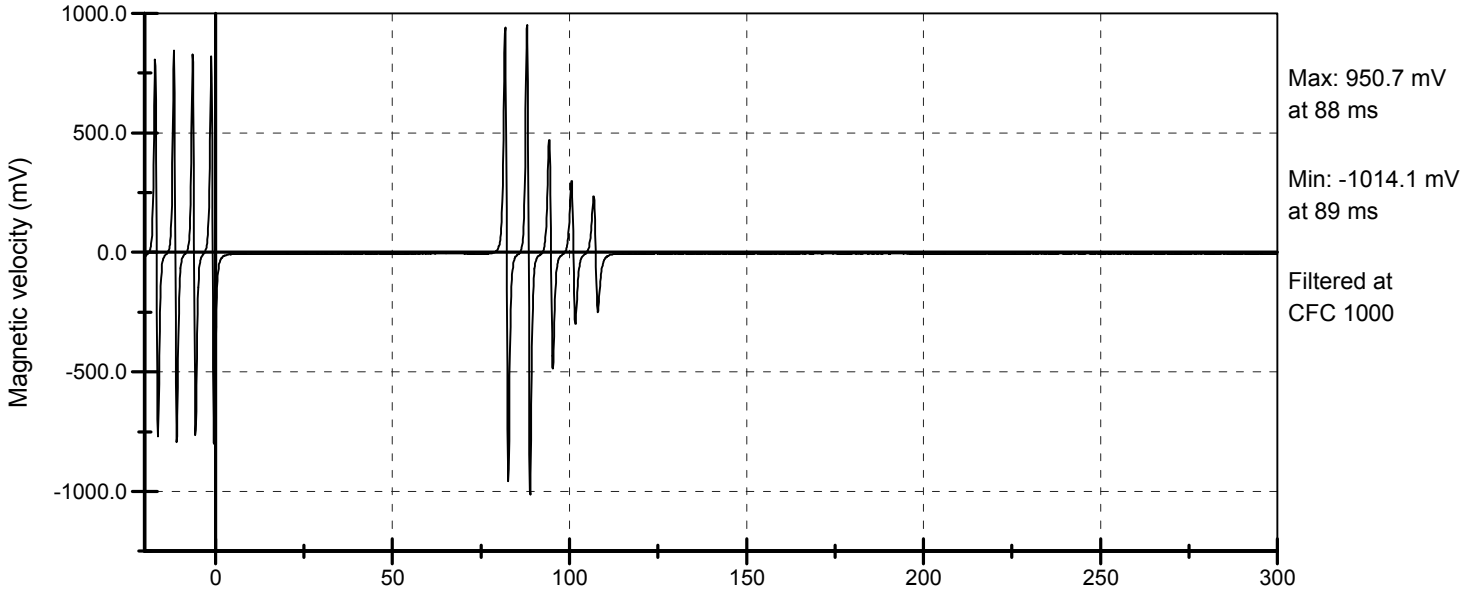
UMTRI Test Signals 1 NT1811

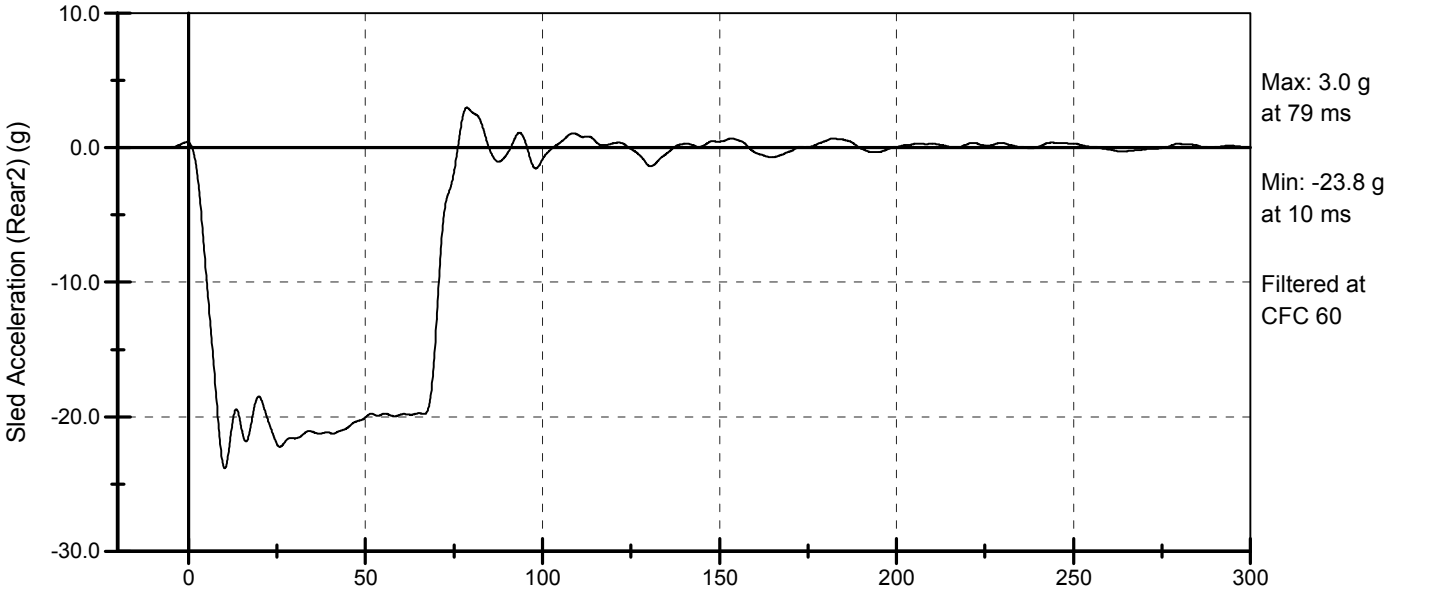


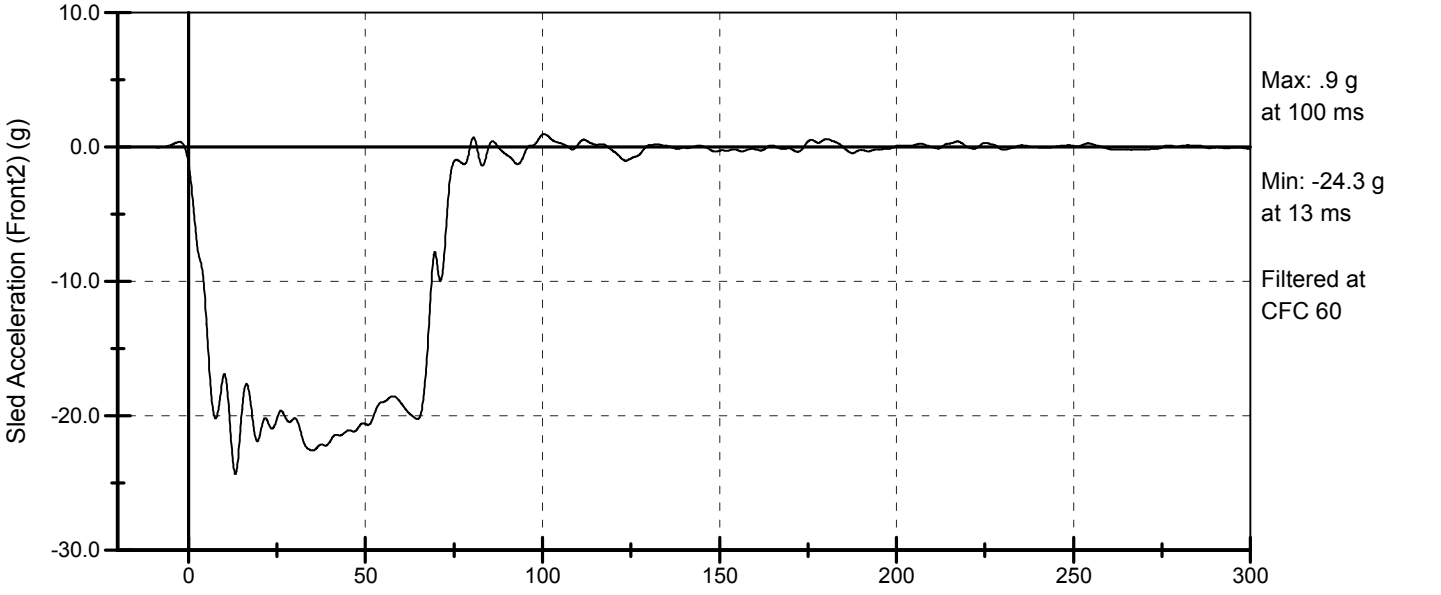




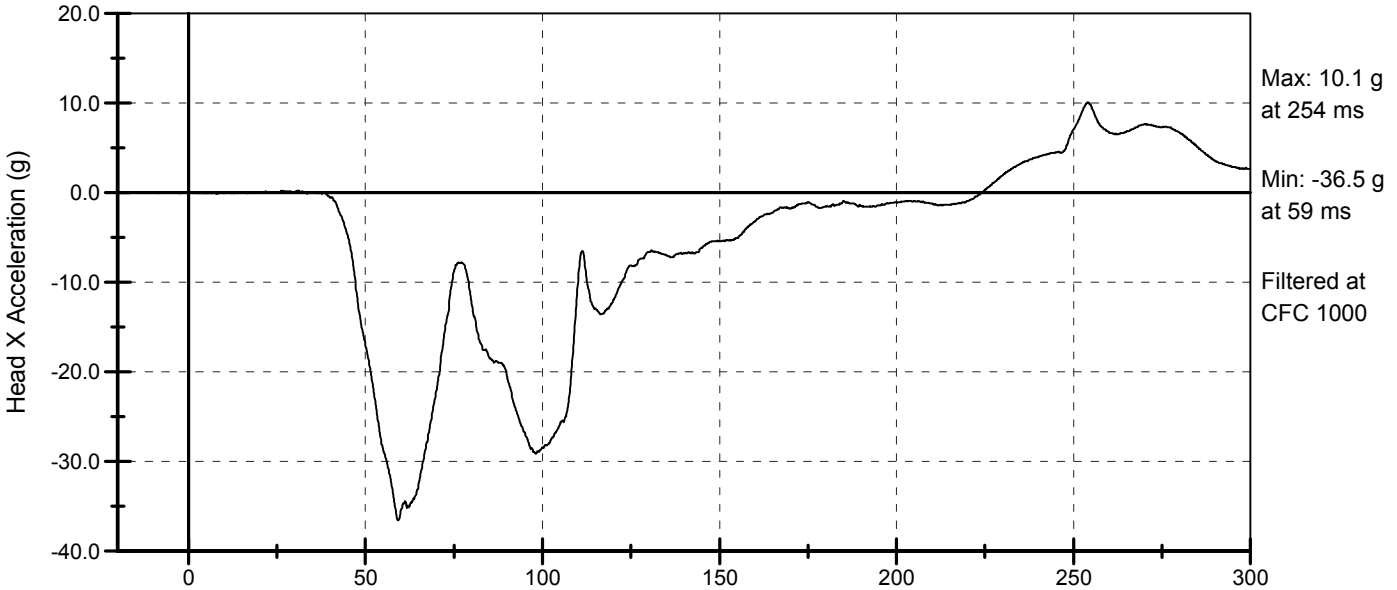
UMTRI Test Signals 2 NT1811

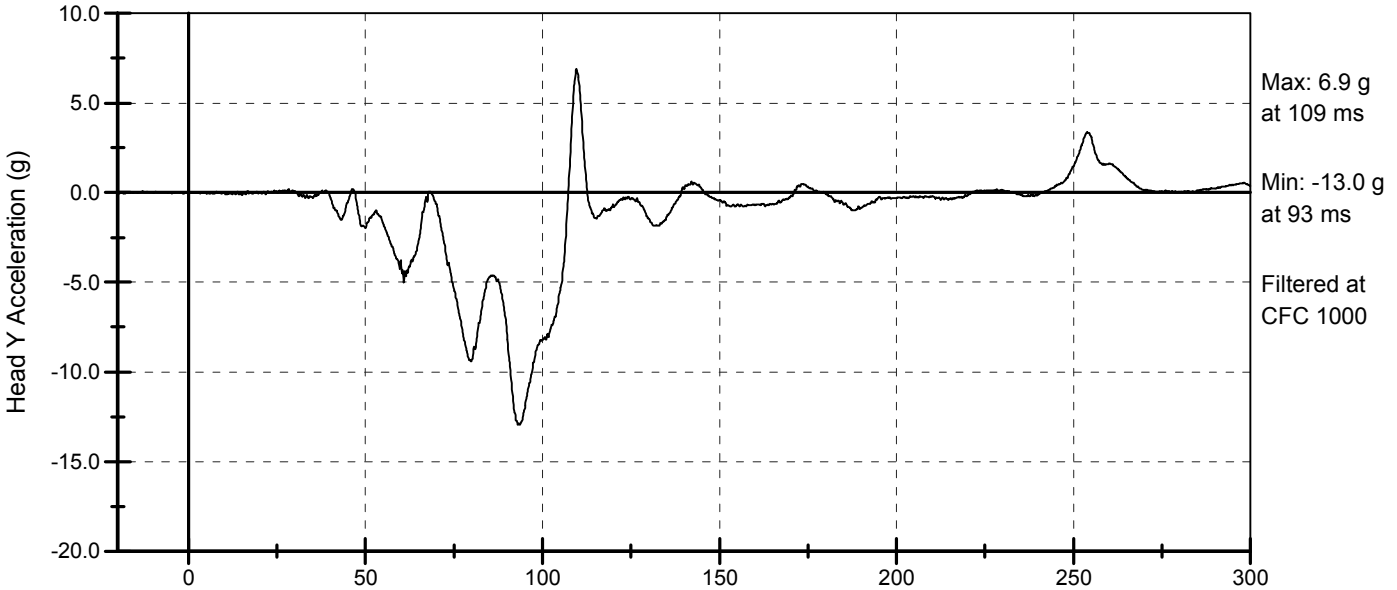


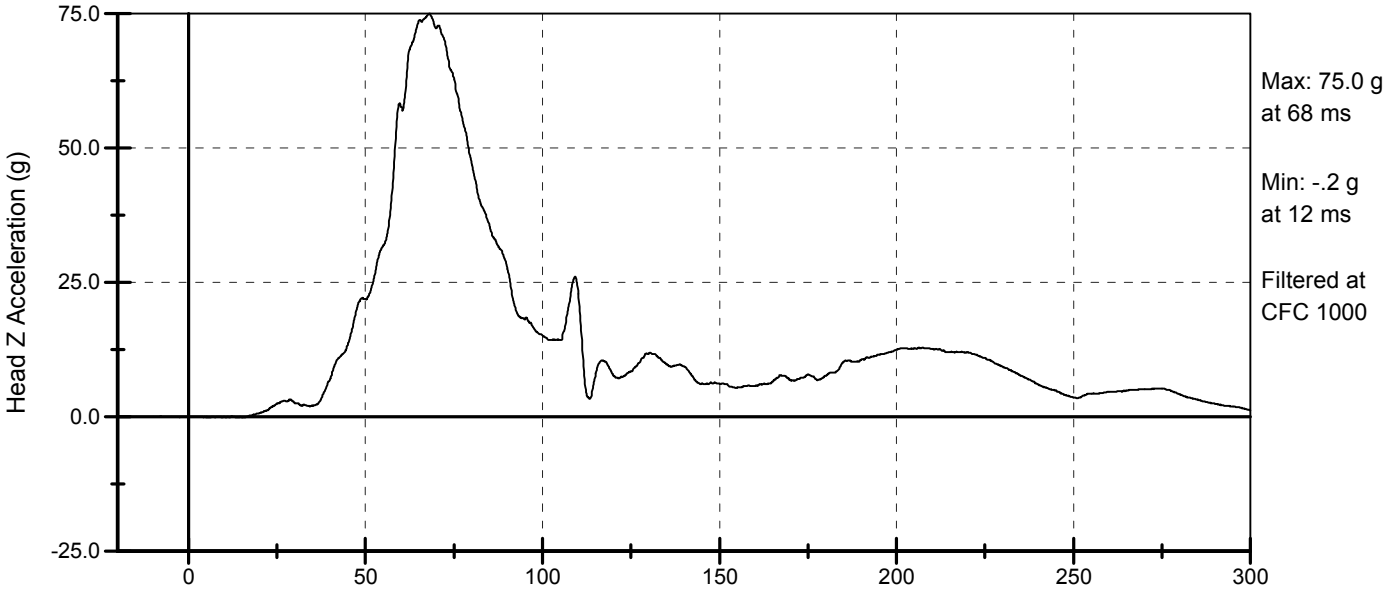




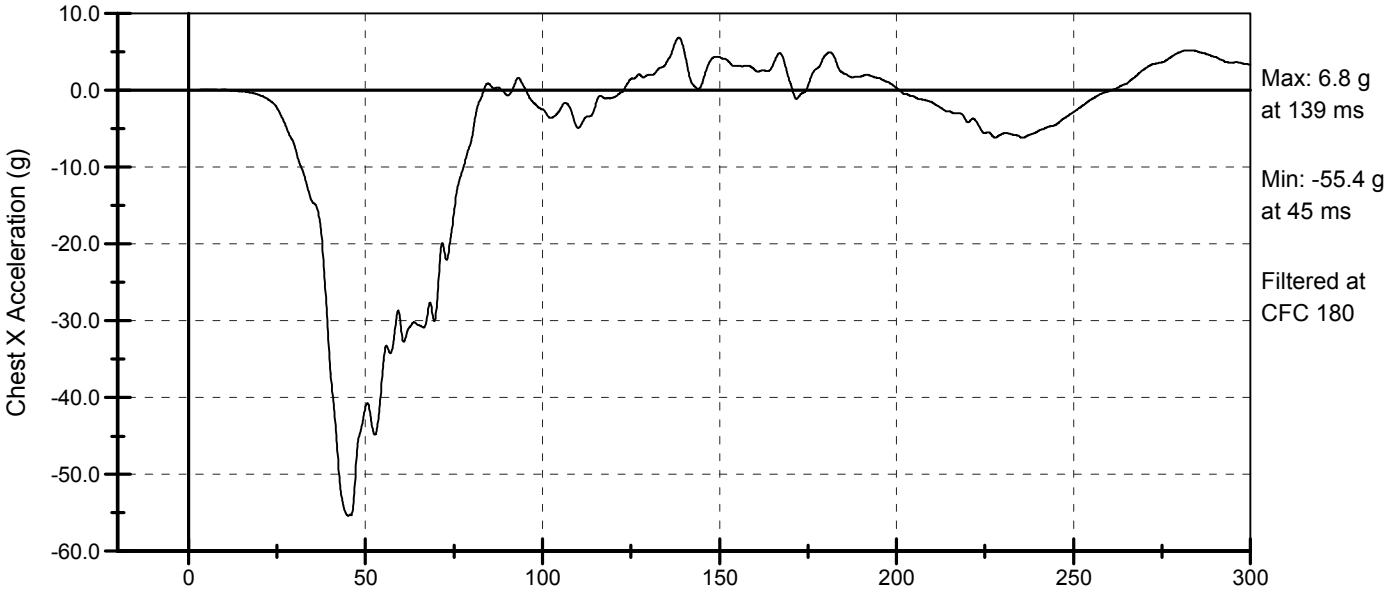
UMTRI Test Signals 3 NT1811

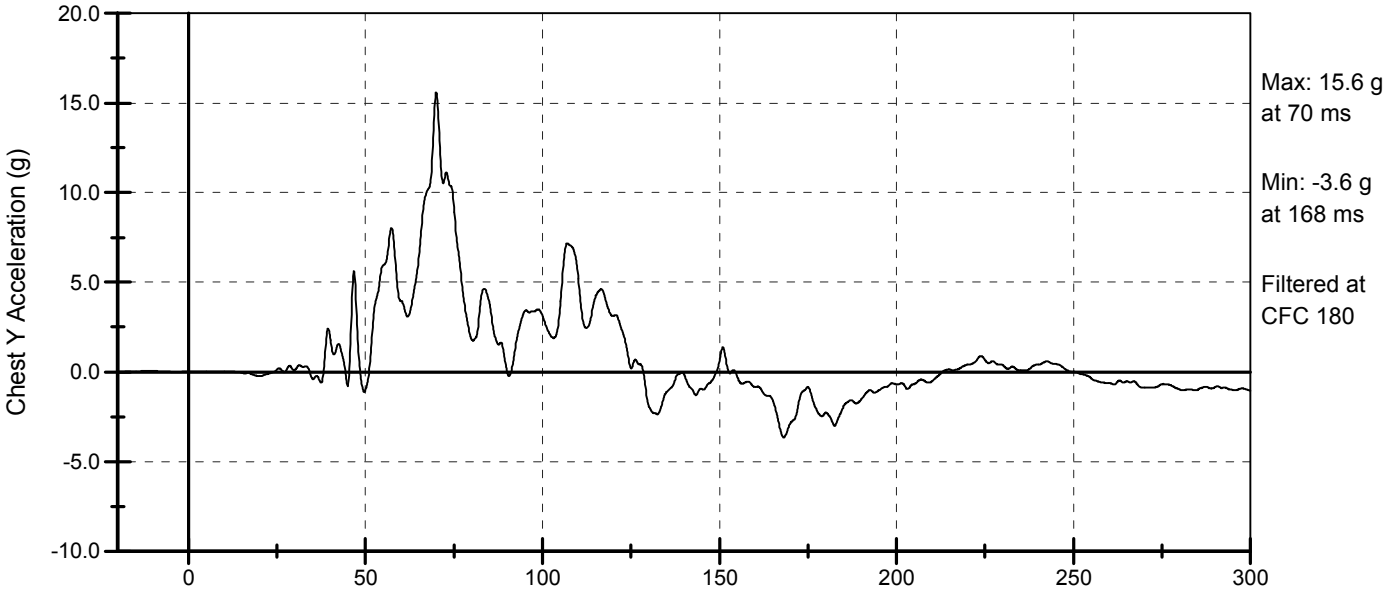


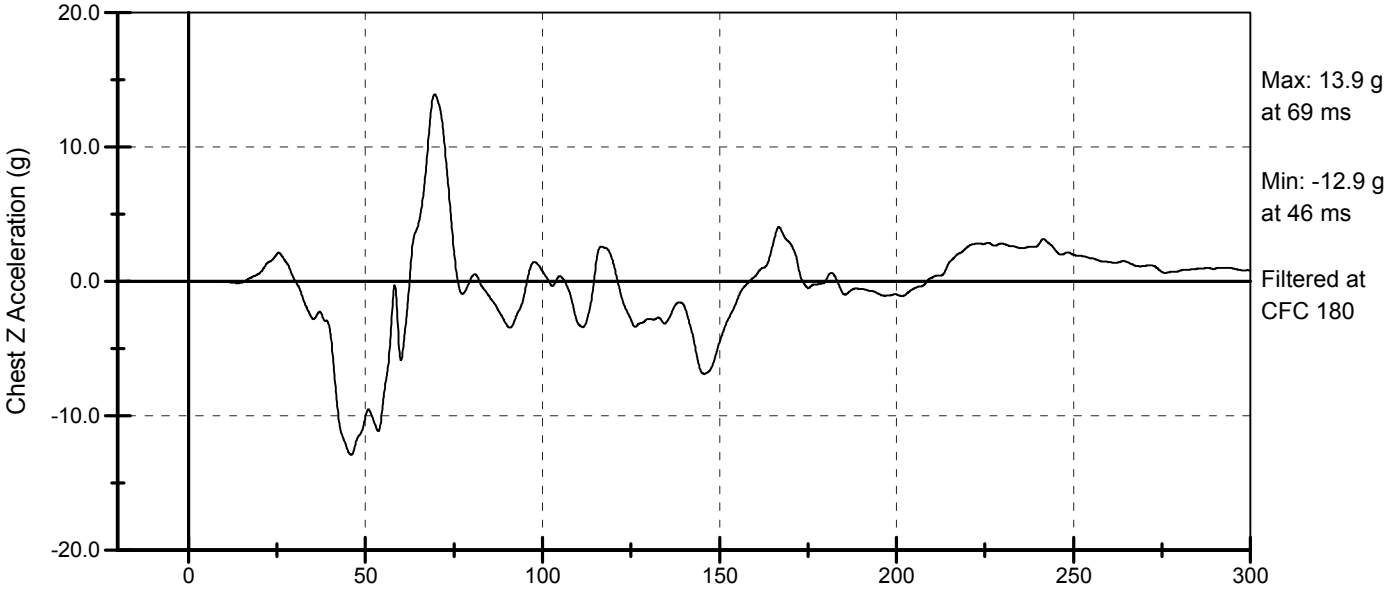


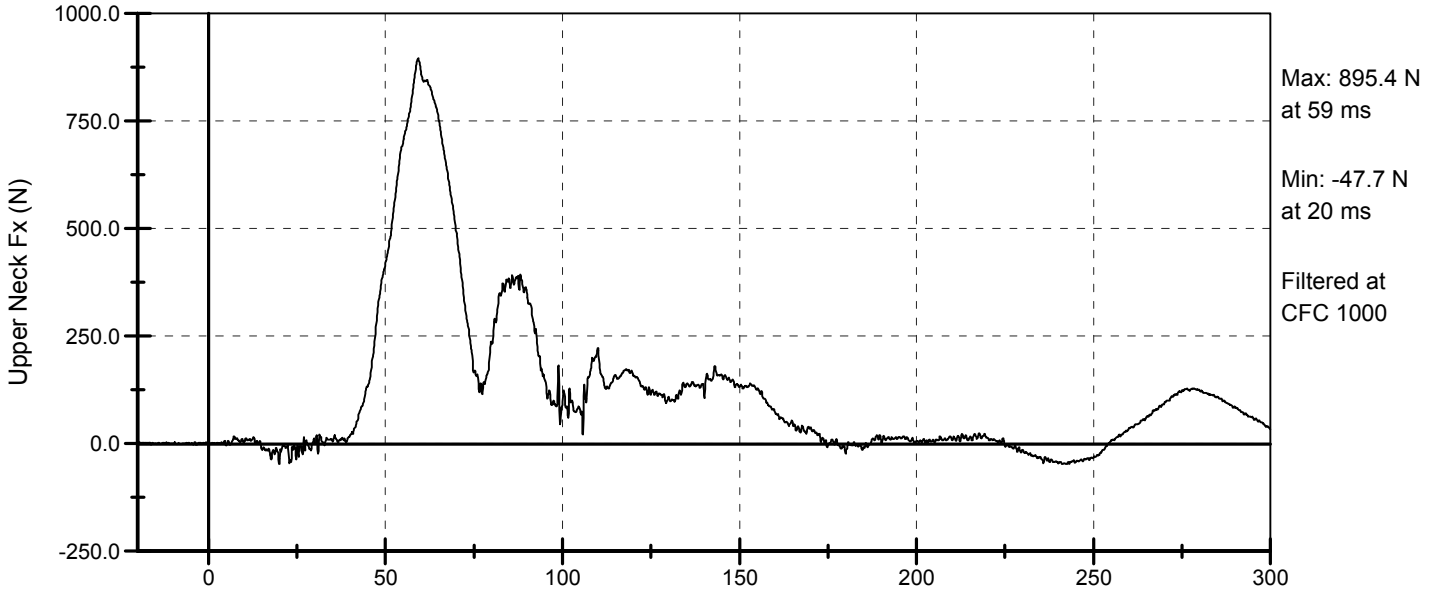


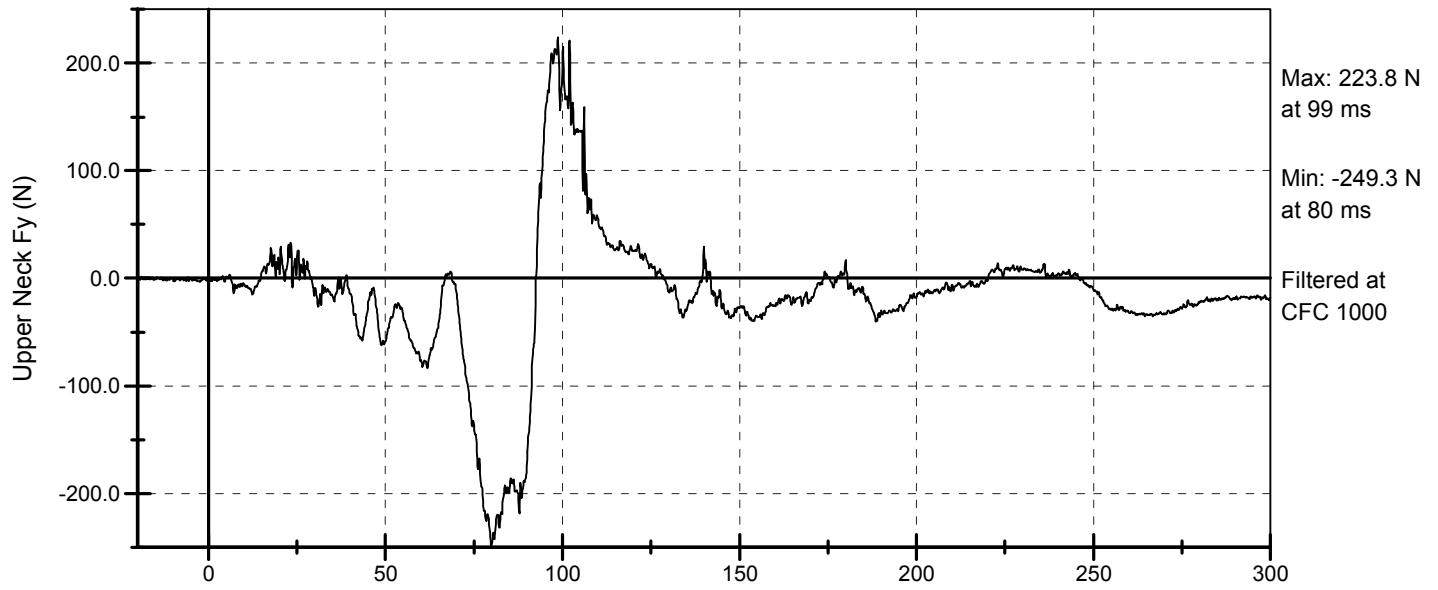
UMTRI Test Signals 4 NT1811

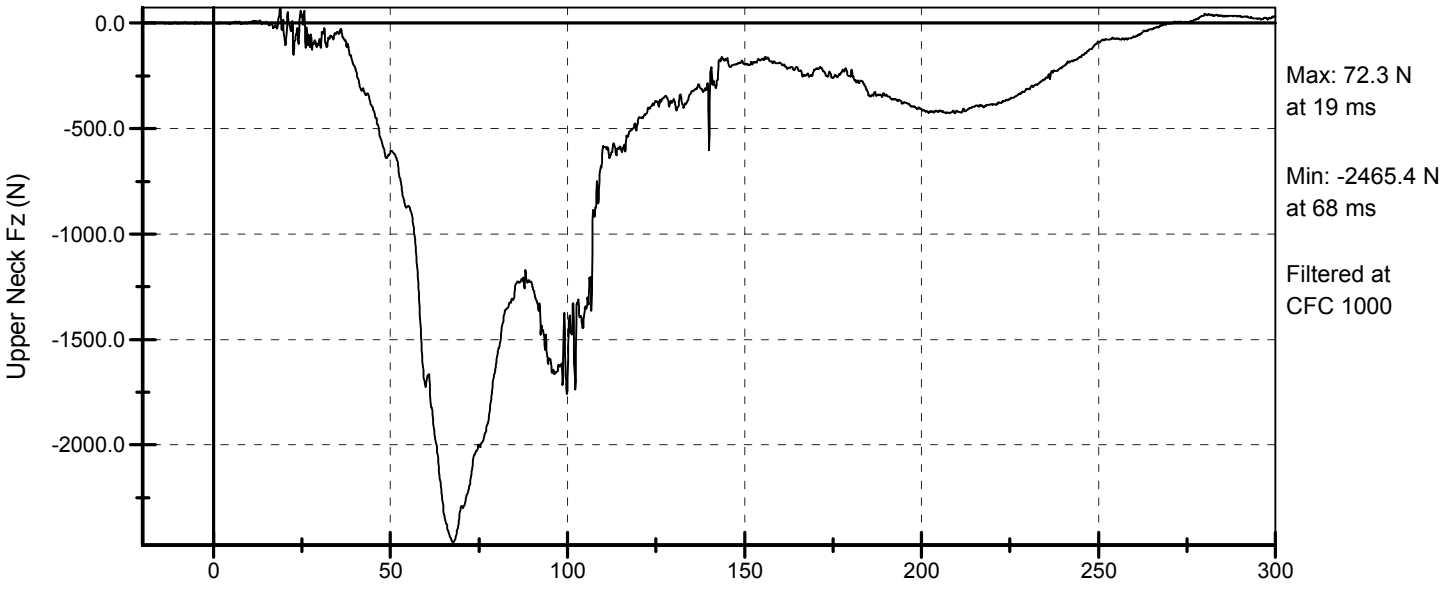


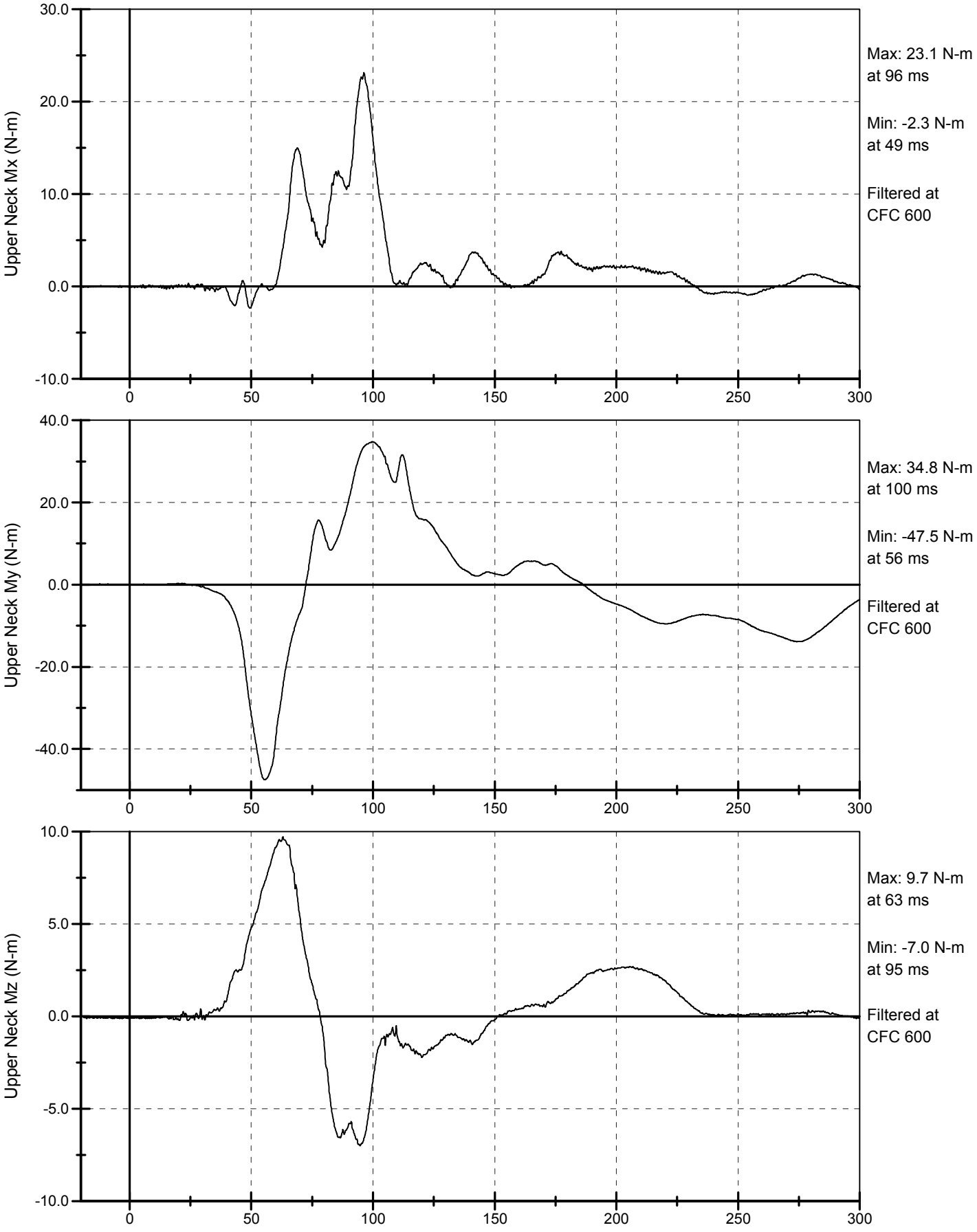


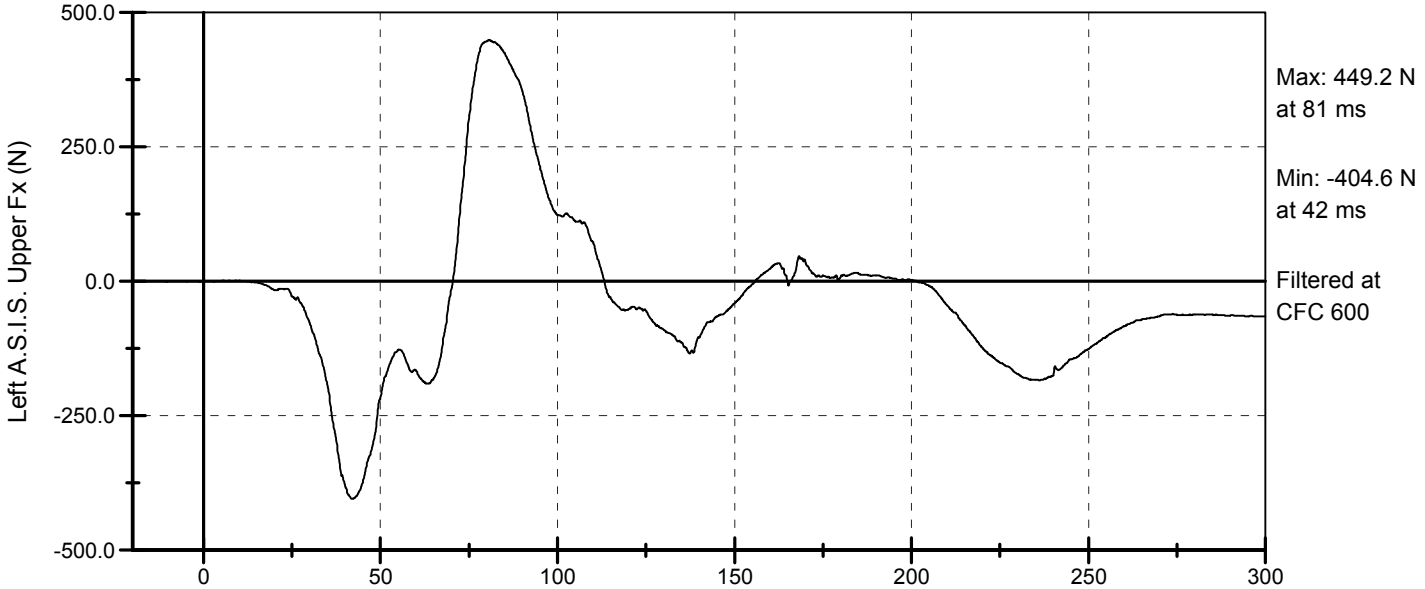


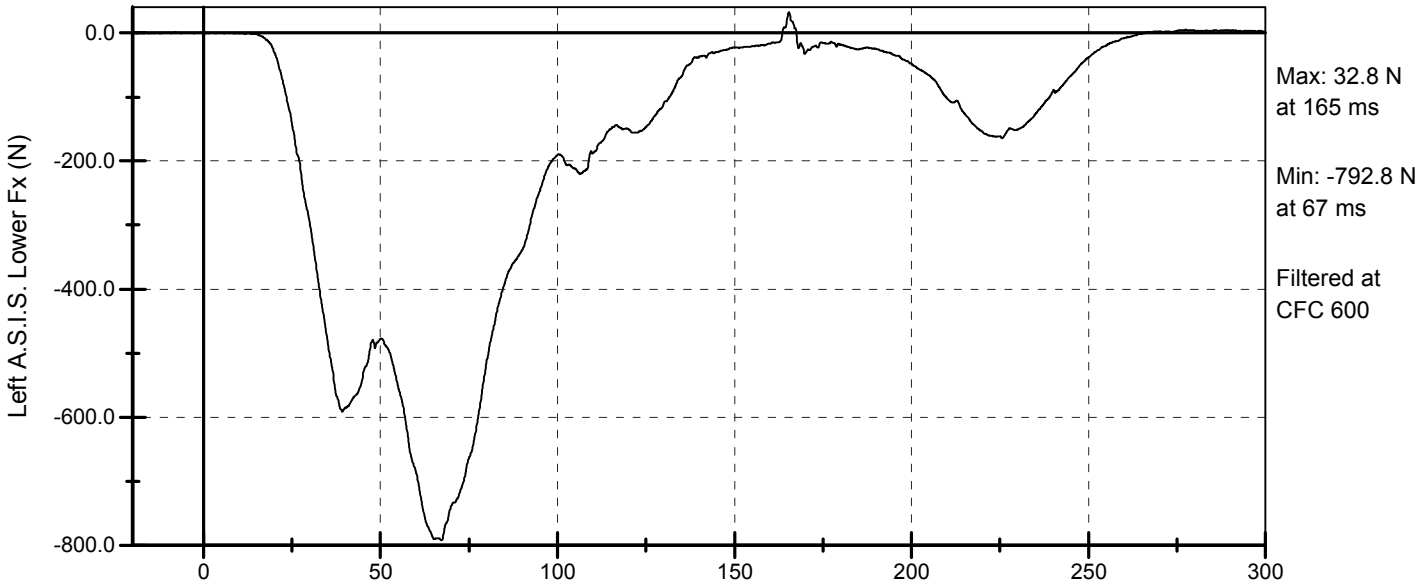

Upper Neck Fx (N)
1000.0
750.0
500.0
250.0
0.0
-250.0
0
50
100
150
200
250
300
Max: 895.4 N
at 59 ms
Min: -47.7 N
at 20 ms
Filtered at
CFC 1000

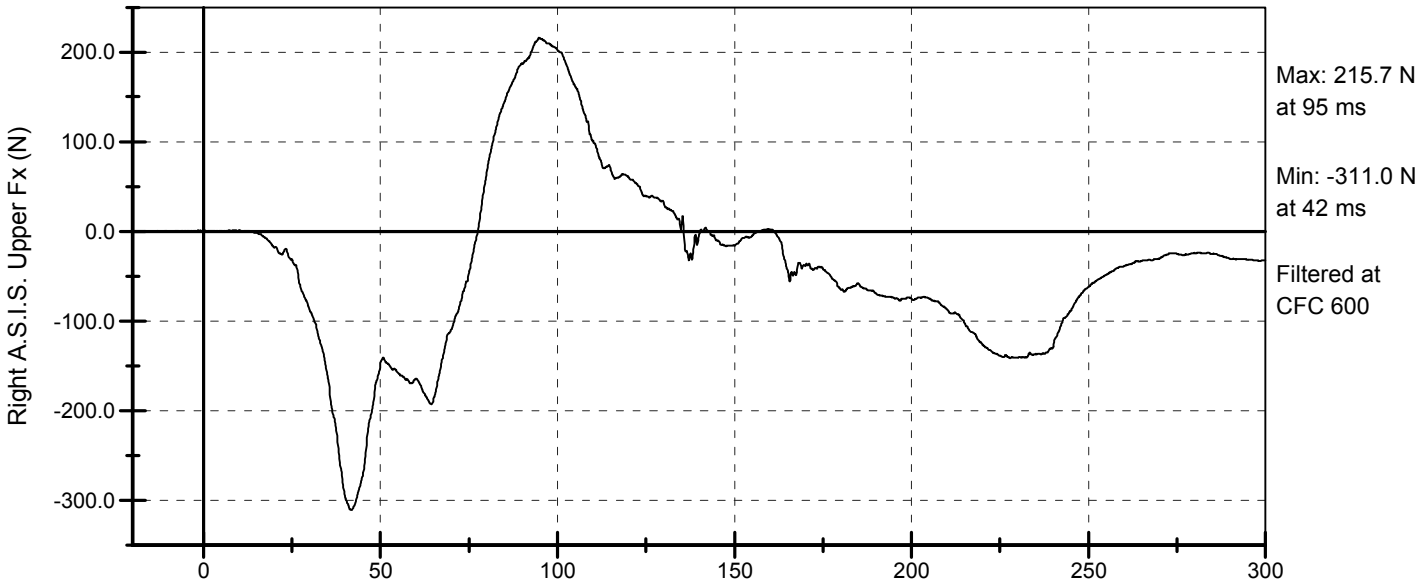

Upper Neck Fy (N)
200.0
100.0
0.0
-100.0
-200.0
0
50
100
150
200
250
300
Max: 223.8 N
at 99 ms
Min: -249.3 N
at 80 ms
Filtered at
CFC 1000

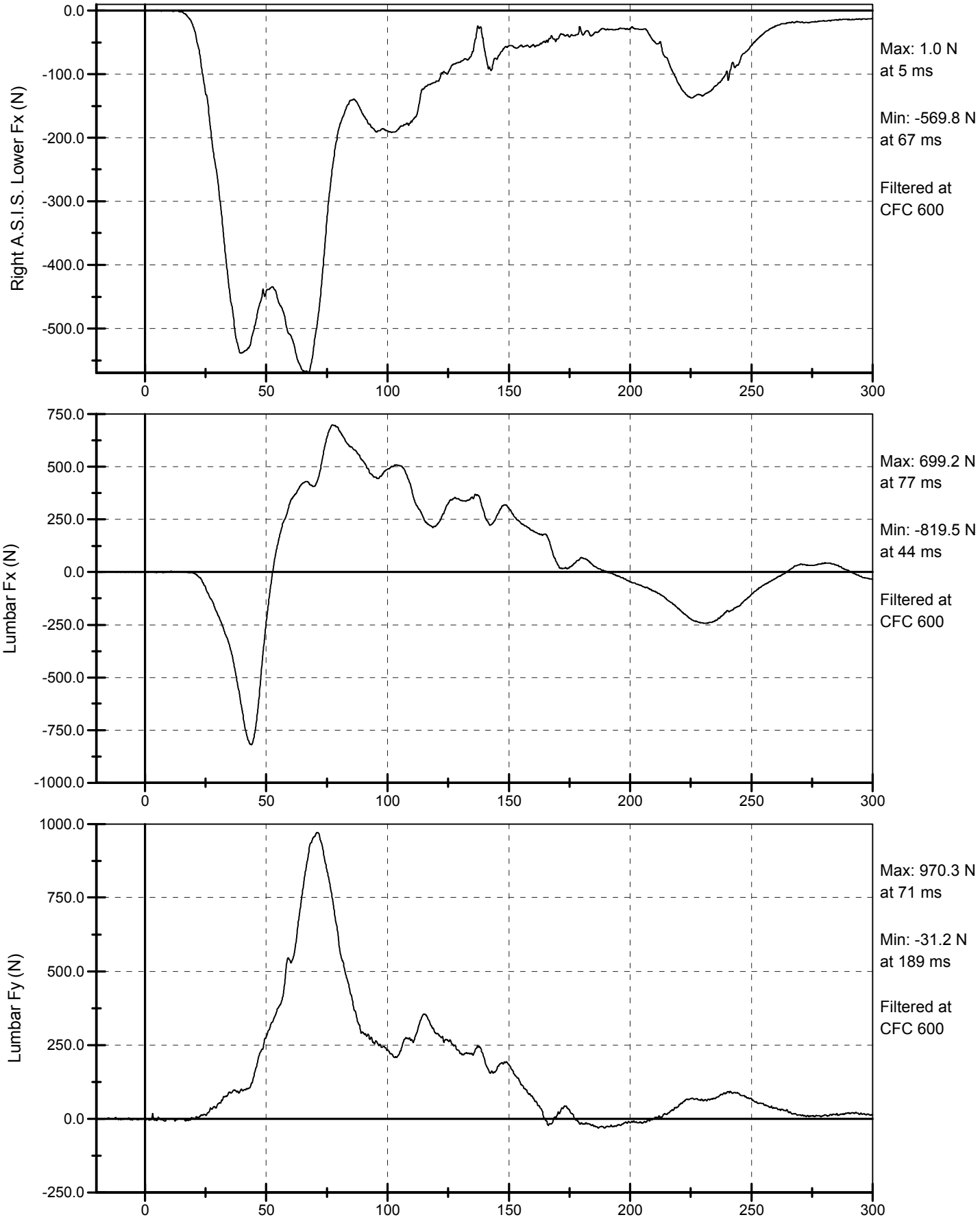

Upper Neck Fz (N)
0.0
-500.0
-1000.0
-1500.0
-2000.0
0
50
100
150
200
250
300
Max: 72.3 N
at 19 ms
Min: -2465.4 N
at 68 ms
Filtered at
CFC 1000

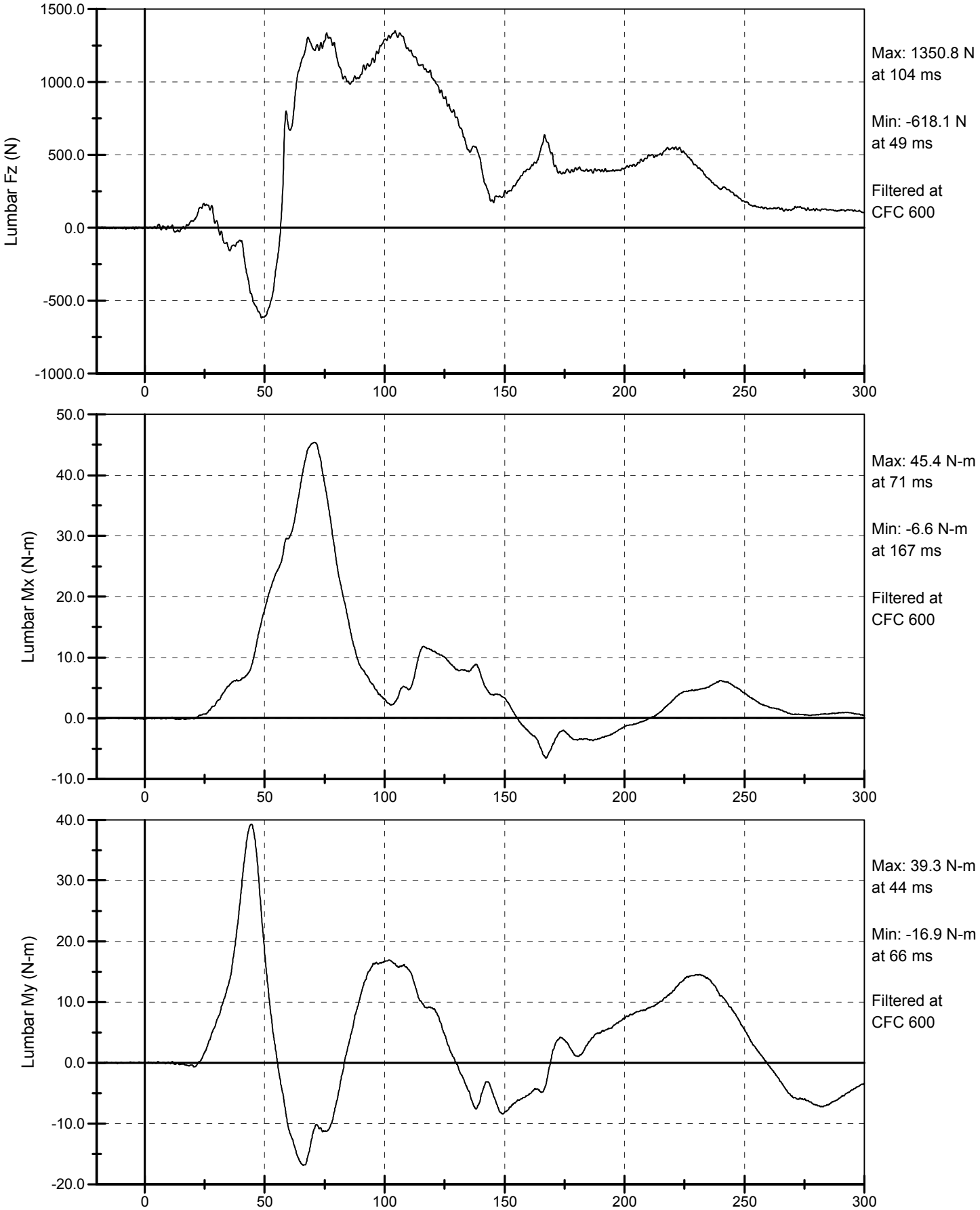

Upper Neck Mx (N-m)
30.0
20.0
10.0
0.0
-10.0
0
50
100
150
200
250
300
Max: 23.1 N-m
at 96 ms
Min: -2.3 N-m
at 49 ms
Filtered at
CFC 600
Upper Neck My (N-m)
40.0
20.0
0.0
-20.0
-40.0
0
50
100
150
200
250
300
Max: 34.8 N-m
at 100 ms
Min: -47.5 N-m
at 56 ms
Filtered at
CFC 600
Upper Neck Mz (N-m)
10.0
5.0
0.0
-5.0
-10.0
0
50
100
150
200
250
300
Max: 9.7 N-m
at 63 ms
Min: -7.0 N-m
at 95 ms
Filtered at
CFC 600


Left A.S.I.S. Upper Fx (N)
500.0
250.0
0.0
-250.0
-500.0
0
50
100
150
200
250
300
Max: 449.2 N
at 81 ms
Min: -404.6 N
at 42 ms
Filtered at
CFC 600

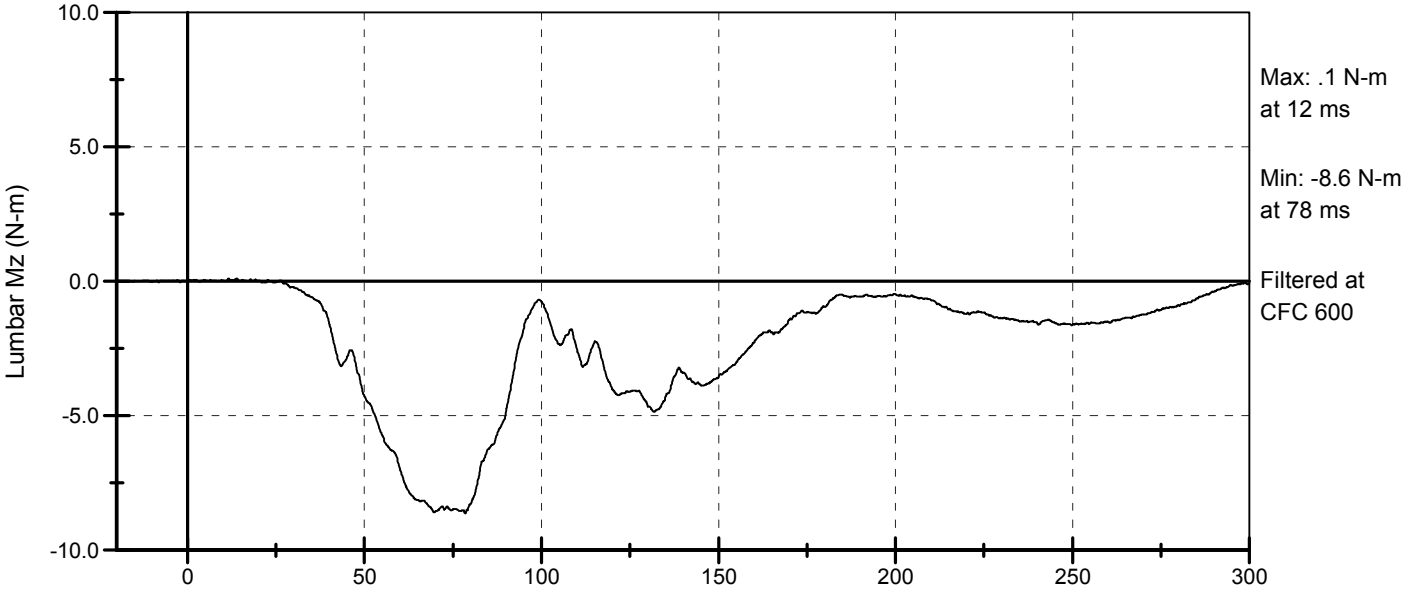

Left A.S.I.S. Lower Fx (N)
0.0
-200.0
-400.0
-600.0
-800.0
0
50
100
150
200
250
300
Max: 32.8 N
at 165 ms
Min: -792.8 N
at 67 ms
Filtered at
CFC 600

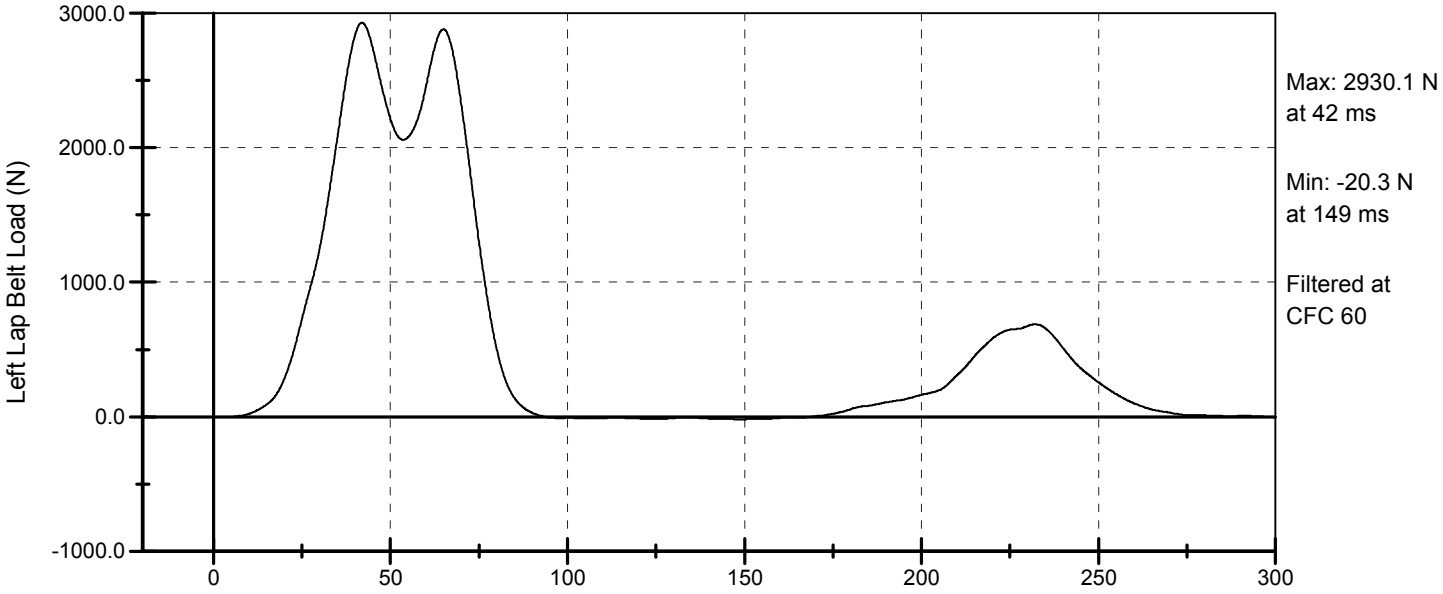

Right A.S.I.S. Upper Fx (N)
200.0
100.0
0.0
-100.0
-200.0
-300.0
0
50
100
150
200
250
300
Max: 215.7 N
at 95 ms
Min: -311.0 N
at 42 ms
Filtered at
CFC 600


Right A.S.I.S. Lower Fx (N)
0.0
-100.0
-200.0
-300.0
-400.0
-500.0
0
50
100
150
200
250
300
Max: 1.0 N
at 5 ms
Min: -569.8 N
at 67 ms
Filtered at
CFC 600
Lumbar Fx (N)
750.0
500.0
250.0
0.0
-250.0
-500.0
-750.0
-1000.0
Max: 699.2 N
at 77 ms
Min: -819.5 N
at 44 ms
Filtered at
CFC 600
Lumbar Fy (N)
1000.0
750.0
500.0
250.0
0.0
-250.0
Max: 970.3 N
at 71 ms
Min: -31.2 N
at 189 ms
Filtered at
CFC 600

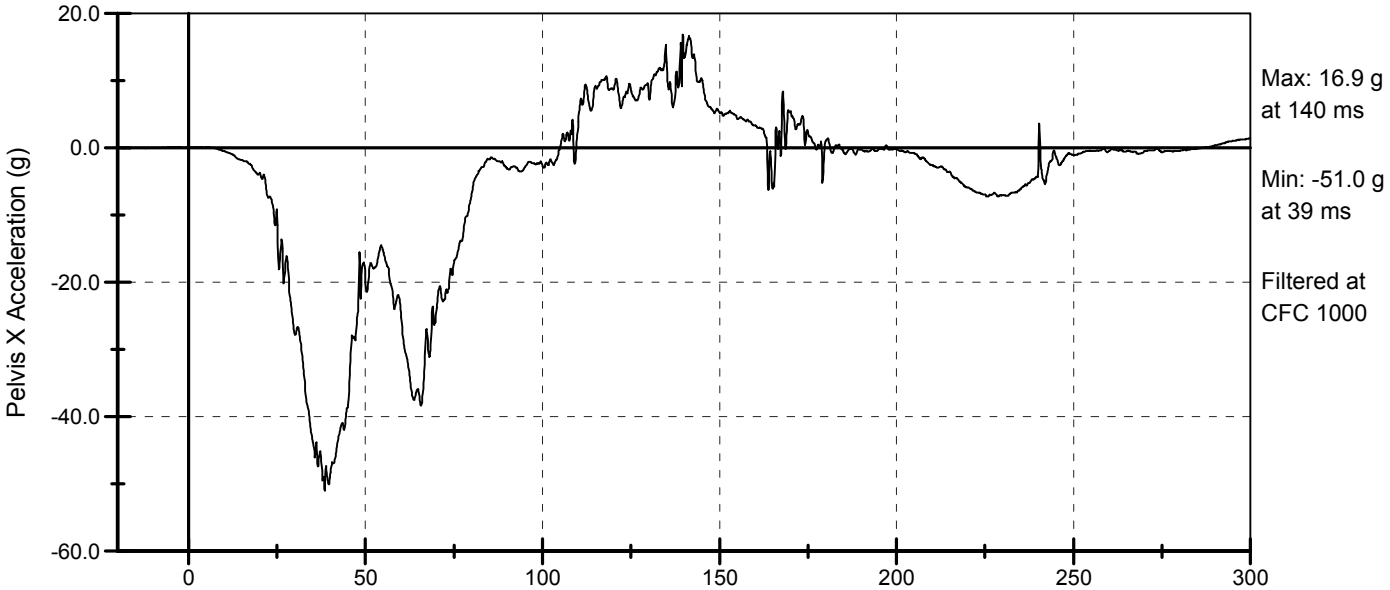

Lumbar Fz (N)
1500.0
1000.0
500.0
0.0
-500.0
-1000.0
0
50
100
150
200
250
300
Max: 1350.8 N
at 104 ms
Min: -618.1 N
at 49 ms
Filtered at
CFC 600
Lumbar Mx (N-m)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
Max: 45.4 N-m
at 71 ms
Min: -6.6 N-m
at 167 ms
Filtered at
CFC 600
Lumbar My (N-m)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
Max: 39.3 N-m
at 44 ms
Min: -16.9 N-m
at 66 ms
Filtered at
CFC 600

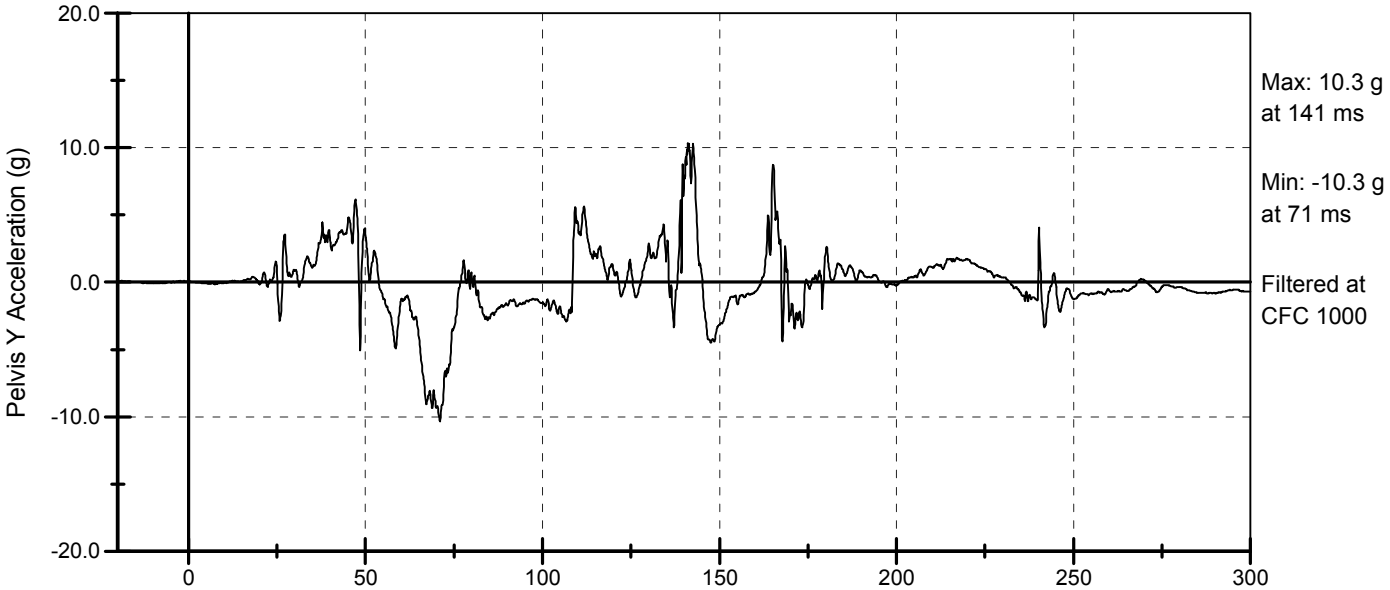
UMTRI Test Signals 10 NT1811

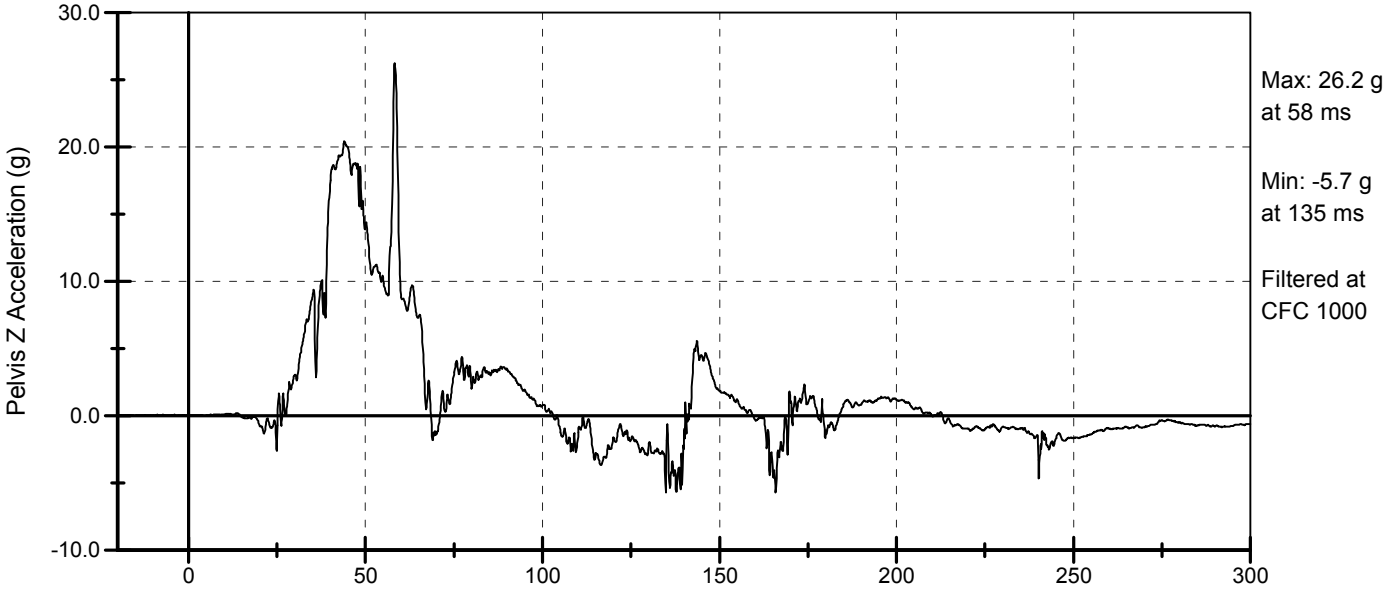




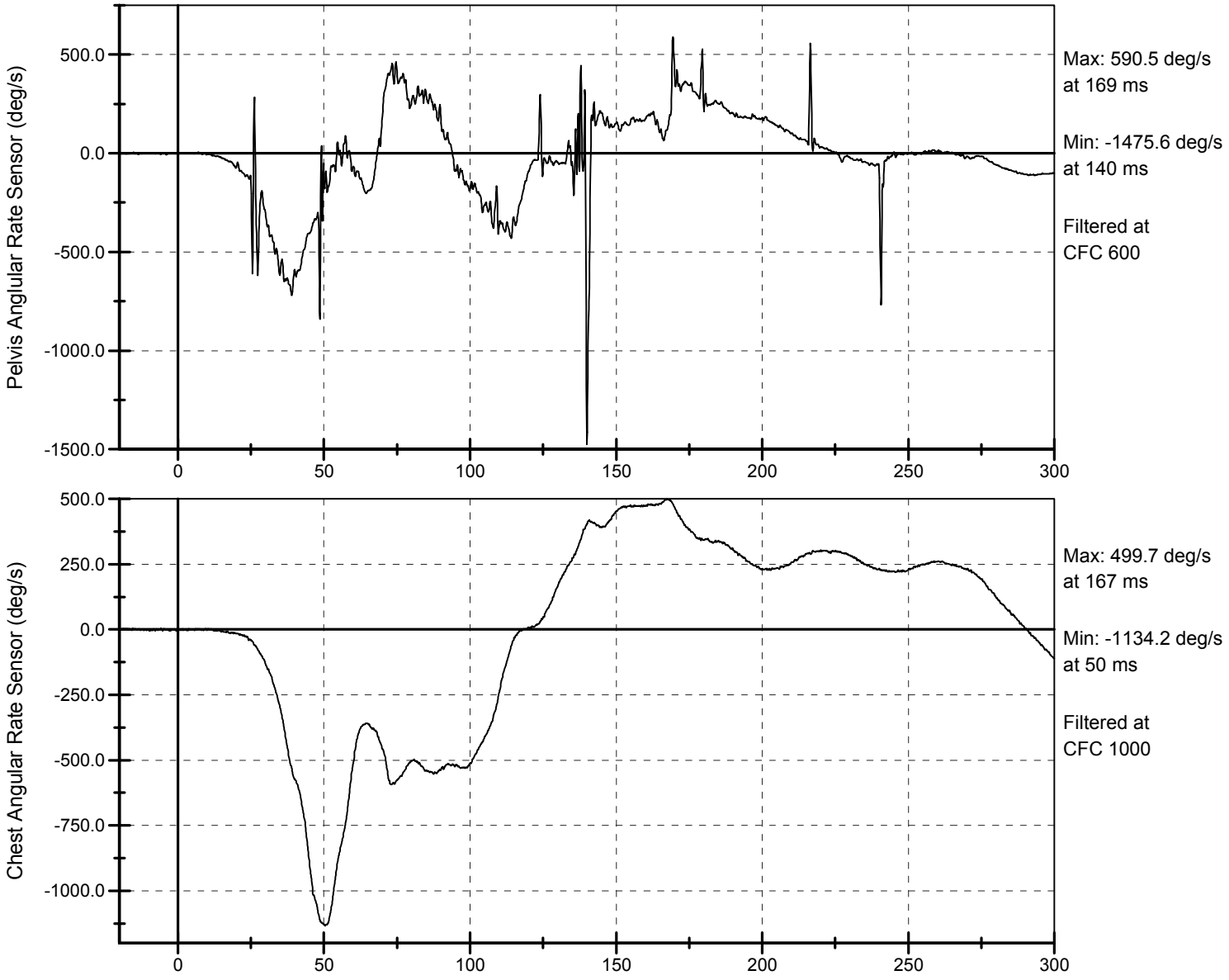
UMTRI Test Signals 11 NT1811







UMTRI Test Signals 12 NT1811



Appendix C

Channel Information

UMTRI	Instrumentation	NT1811

Nominal = 30 mph /20 g — Pressures: 108.5/985
Actual[P] = 47.8 km/h (29.7 mph) (84.8%) — Plateau Avg.= -20.3 G; Peak = -22.2 G

Dummy: Hybrid III 6 Year Old (23.4 kg) — Buck Weight: 1970
Buck: Proposed FMVSS 213 Bench (per 2018 drawings), steel plate, extensions

Graco TB HB
3-point belt, surrogate retractor

Data Collection Hardware:

Rack 3 S/N: DR0211
- Module 1 S/N: DM0033
- Module 2 S/N: DM0113
- Module 3 S/N: DM1568
- Module 4 S/N: DM0938
- Module 5 S/N: DM0937

Location	Channel Descripton	Transducer	Filter (CFC)	Sens. (mv/eu)	SN Ratio (dB)	Cal Date	EU
001. 3-1-1	Sled Accel (Rear)	A7232_EG50	60	-2.17E-02	74.70	1/20/17	g
002. 3-1-2	Infrared Velocity	Velocity_IR	1000	1.00E+00	59.74	1/29/16	mV
003. 3-1-3	Sled Accel (Front)	A7232_EJ18	60	-1.84E-02	74.63	6/25/15	g
004. 3-1-4	Magnetic velocity	SledLabBackup	1000	1.00E+00	78.57	1/29/16	mV
005. 3-1-5	Sled Accel (Rear2)	A7232_ABEF2	60	-2.00E-02	73.70	7/27/17	g
006. 3-1-6	Sled Accel (Front2)	A7232_EG60	60	-1.99E-02	74.04	4/18/18	g
007. 3-1-7	Head X Accel	98I98H14-K10	1000	2.22E-02	75.83	5/7/18	g
008. 3-1-8	Head Y Accel	98I98H31-Z09	1000	-2.24E-02	77.29	5/7/18	g
009. 3-2-1	Head Z Accel	98J98I21-F03	1000	-2.33E-02	73.76	5/7/18	g
010. 3-2-2	Chest X Accel	98A21-F11	180	2.12E-02	75.94	4/7/17	g
011. 3-2-3	Chest Y Accel	98A21-F05	180	-2.08E-02	75.55	5/7/18	g
012. 3-2-4	Chest Z Accel	98A21-F15	180	-2.28E-02	76.53	5/7/18	g
013. 3-2-5	Upper Neck Fx	IF205-1019 Upper Neck	1000	-1.94E-04	75.06	2/19/09	N
014. 3-2-6	Upper Neck Fy	IF205-1019 Upper Neck	1000	1.87E-04	74.15	2/19/09	N
015. 3-2-7	Upper Neck Fz	IF205-1019 Upper Neck	1000	9.80E-05	73.63	2/19/09	N
016. 3-2-8	Upper Neck Mx	IF205-1019 Upper Neck	600	-6.04E-03	75.47	2/19/09	N-m
017. 3-3-1	Upper Neck My	IF205-1019 Upper Neck	600	5.86E-03	76.81	2/19/09	N-m
018. 3-3-2	Upper Neck Mz	IF205-1019 Upper Neck	600	8.27E-03	78.41	2/19/09	N-m
019. 3-3-3	Left A.S.I.S. Upper F	3745_121_Upper_Fx	600	4.35E-04	70.87	4/26/05	N
020. 3-3-4	Left A.S.I.S. Lower F	3745_121_Lower_Fx	600	4.39E-04	71.78	4/26/05	N
021. 3-3-5	Right A.S.I.S. Upper	3746_112_Upper_Fx	600	4.52E-04	71.06	4/26/05	N
022. 3-3-6	Right A.S.I.S. Lower	3746_112_Lower_Fx	600	4.54E-04	72.25	4/26/05	N
023. 3-3-7	Lumbar Fx	IF-459_101_Fx	600	1.53E-04	74.88	8/14/06	N
024. 3-3-8	Lumbar Fy	IF-459_101_Fy	600	-1.53E-04	70.79	8/14/06	N
025. 3-4-1	Lumbar Fz	IF-459_101_Fz	600	6.00E-05	71.86	8/14/06	N
026. 3-4-2	Lumbar Mx	IF-459_101_Mx	600	4.64E-03	76.59	8/14/06	N-m
027. 3-4-3	Lumbar My	IF-459_101_My	600	4.62E-03	71.94	8/14/06	N-m
028. 3-4-4	Lumbar Mz	IF-459_101_Mz	600	8.58E-03	77.72	8/14/06	N-m

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Location	Channel Descripton	Transducer	Filter (CFC)	Sens. (mv/eu)	SN Ratio (dB)	Cal Date	EU
029. 3-4-5	Left Lap Belt Load	Q121FG_EL20-S458-16kN	60	1.37E-04	76.25	9/15/17	N
030. 3-4-6	Right Lap Belt Load	T130MZ_EL20-S458-16kN	60	1.62E-04	75.82	6/21/17	N
031. 3-4-8	Pelvis X Accel	03L03K20-F01	1000	2.03E-02	78.32	10/19/06	g
032. 3-5-1	Pelvis Y Accel	99L99L06-L20	1000	-2.54E-02	77.88	10/19/06	g
033. 3-5-2	Pelvis Z Accel	02E02E01-F02	1000	2.00E-02	78.14	10/19/06	g
034. 3-5-3	Pelvis Anglular Rate	ARS0044_deg	600	1.24E+00	53.21	11/29/06	deg/s
035. 3-5-4	Chest Angular Rate Se	ARS0045_deg	1000	1.27E+00	54.72	11/29/06	deg/s

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