Hand Control
Usage and Safety Assessment

Final Report
August 2001

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National Highway Transportation Safety Administration

Automobile Safety Laboratory
University of Virginia

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15. Abstract

Hand controls are devices used by people who are unable to operate the brake and accelerator pedals with their feet due to physical impairment. This report summarizes a series of studies designed to:
1] determine how many drivers are using hand controls and other adaptive devices.
2] evaluate hand control reliability.
3] evaluate the injury potential of hand controls in a frontal crash.

A gathering of state data on driver license restrictions related to adaptive driving aids failed to produce enough information to allow an estimation of national adaptive device usage.

Hand control reliability was assessed by testing five representative hand controls in accordance with the August 1990 revision of the SAE standard J1903 – *Recommended Practice Automotive Adaptive Driver Controls, Manual.* The five hand controls passed the vibration, cyclic load, and service overload tests. All of the hand controls failed the corrosion resistance test. Recommendations were made to improve the SAE standard. Three portable hand controls were tested also. All ultimately passed the vibration, cyclic load, and service overload tests.

The potential for hand controls to pose an injury threat in frontal crashes involved several investigations including six frontal sled tests. The findings include the following:
1] Hand controls do not present increased risk of head contact injury in a frontal collision.
2] The use of hand controls does not necessarily require a closer-to-the-wheel sitting position and associated elevated risk of injury from air bag deployment.
3] Hand controls, and the knee bolster modifications necessary for their installation, minimally affected crash safety. The most severe injury observed in the sled tests was a moderate knee laceration. Injury criteria values such as Head Injury Criteria (HIC), chest g's, femur load, and the tibia index, were unaffected by the presence of the hand control.

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METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32) (5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

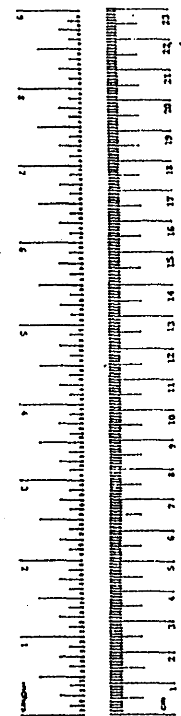
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

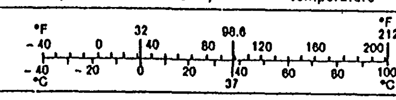
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

Table of Contents

Executive Summary

Hand controls are devices used by people who are unable to operate the brake and accelerator pedals with their feet due to physical impairment. Hand controls are (typically) rod linkages attached at the lower end to the brake and accelerator pedals. The rods are supported by a bracket mounted underneath the steering column and terminate in a single handle positioned near the perimeter of the steering wheel. Pushing this handle pushes the brake pedal. Moving this handle back or down, or twisting the handle pushes the accelerator pedal (Fig. 1). This report summarizes task work designed to:
1] determine how many drivers are using hand controls and other adaptive devices.
2] evaluate hand control function and reliability.
3] evaluate the injury potential of hand controls in a frontal crash.

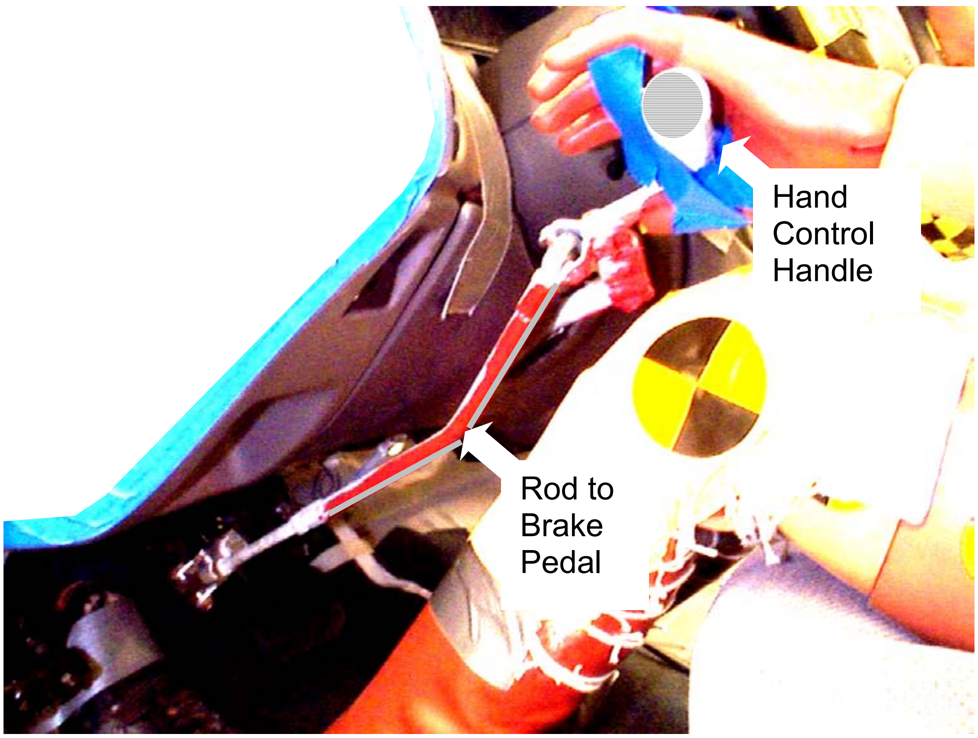


Figure 1. Typical hand control installation.

Task 1
Estimating the number of people in the United States using various types of adaptive driving equipment.

The first step in defining the needs of drivers who use adaptive equipment such as hand controls is to determine the number of people using these devices. Unfortunately, this information is very difficult to find. There is no national database that tracks adaptive control use. Therefore, we explored state sources for this information.

The Department of Motor Vehicles from most of the individual states were contacted to gather information on the number of drivers with license restrictions related to adaptive driving equipment. We requested the number of current restrictions for different categories of adaptive devices. We received responses from 13 states. Some states did not keep such records. Others were not able to provide them to us.

Some states, such as California, recorded only the number of restrictions issued annually rather than recording the running total of active restrictions that we requested. We found substantial differences in how states recorded license restrictions. Lack of consistent terminology and different ways of classifying and grouping adaptive devices greatly hindered our ability to interpret the data. Responses related to hand controls, prosthetic aids, automatic transmission, power steering, and steering control devices were the most commonly reported items.

Task 2
Crash Avoidance Evaluation of Manual Hand Controls

Task 2 evaluated hand control function and reliability. Five commonly-used hand controls (Table 1) were tested in accordance with the August 1990 revision of the SAE standard J1903 - *Recommended Practice Automotive Adaptive Driver Controls, Manual.* We inspected the hand control device documentation and construction and conducted vibration, environmental, cyclic load, and service overload testing.

Table 1. Evaluated Manual Hand Controls

Manufacturer	Model	Operation Method Brake / Gas
Wells-Engberg Co. Inc.	CT-100 Rotary	Push /Twist
Manufacturing and Production Services Corp. (MPS)	Monarch Mark 1-A	Push /Right Angle
Drive-master Co. Inc.	Ultra-lite XL	Push/Pull
Howell Ventures LTD	Sure Grip	Push/Pull
Mobility Products and Design (MPD)	3500	Push/Right Angle

Vibration Test
The hand controls were rigidly mounted in test rigs. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. All of the hand controls passed this test without sustaining damage or loosening of fasteners.

Electromechanical Environmental Test
The hand control was suspended in a corrosion chamber and subjected to two periods of salt fog exposure at an elevated temperature in accordance with ASTM B117-97. The environmental test was run a second time to confirm the test results. All of the controls failed both times because corrosion products were present on surfaces that could come in contact with the driver.

High-Cycle Test
The hand controls were subjected to 250,000 cycles of loading that simulated braking and accelerating. No failures occurred at any point in the testing of the five hand controls.

Service Overload Testing
All of the hand controls ultimately passed this test that involved applying 150 lbf to the handle in the brake mode and 30 lbf in the accelerator mode. Two failures occurred in the initial round of testing due, in part, to ambiguity in the SAE J1903 test procedures.

In the course of conducting the SAE J1903 tests, we evaluated the clarity and objectivity of the standard itself. In general, the SAE J1903 was complete and easy to follow. However, we found some sections that could be improved. Section 4 of SAE J1903 details the requirements that an acceptable hand control must meet. Section 4 attempts to encompass a wide range of performance and non-performance related items. Consequently, it is somewhat vague. Section 5 of SAE J1903 details the actual inspection and testing procedures that should be used to ascertain the compliance to the requirements in Section 4. Some of the testing procedures are difficult to apply to certain types of hand controls.

Overall, the standard's performance requirements were rigorous but reasonable. However, we recommend that the SAE Adaptive Devices Committee examine the Electromechanical Environmental Test and Section 4.2.1 that prohibits modifications to vehicle safety systems. None of the tested hand controls passed the Environmental test. Moreover, contrary to Section 4.2.1, we had to modify the knee bolster component of the occupant restraint system to accommodate the installation of the hand controls.

Task 2.1
Crash Avoidance Evaluation of Portable Hand Controls

Task 2.1 evaluated hand control reliability. Three portable hand controls (Table 2) were tested in accordance with the August 1990 revision of the SAE standard J1903 - *Recommended Practice Automotive Adaptive Driver Controls, Manual.* We conducted vibration, cyclic load, and service overload testing. The environmental test was not performed. Note that SAE J1903 was not intended for portable hand controls.

Table 2. Evaluated Portable Hand Controls

Manufacturer	Model	Operation Method Brake / Gas
McSquared Design	PHC III	Push / Pull
Handicaps, Inc.	Portable Control	Push / Push
Judson Enterprises, Inc.	Peddle Master	Push / Push

Vibration Test
The hand controls were rigidly mounted in test rigs. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. All of the hand controls passed this test without sustaining damage or loosening of fasteners.

Electromechanical Environmental Test
This test was not conducted with the portable hand controls.

High-Cycle Test
The hand controls were subjected to 250,000 cycles of loading that simulated braking and accelerating. The Peddle Master failed at its attachment to the brake pedal at approximately 230,000 cycles. We retested another Peddle Master unit that successfully completed the 250,000 cycles without failure. No failures occurred at any point in the testing of the other two controls.

Service Overload Testing
All of the hand controls ultimately passed this test that involved applying 150 lbf to the handle in the brake mode and 30 lbf in the accelerator mode.

Task 3
Crash Worthiness Assessment of Manual Hand Controls

Background
Hand controls were developed before the advent of widespread automotive safety awareness and active research. The following concerns have been raised regarding hand controls in the event of a frontal collision.

1. Head injury: The head may hit the hand control handle and/or mounting hardware.
2. Injury to drivers of short stature: If the driver must sit closer to the steering wheel to operate the hand control, there exists an increased risk of injury caused by air bag deployment.
3. Leg injury: Metal rods and linkages are mounted near knees and lower legs.
4. Compromised knee bolster: Device installation sometimes requires cutting the knee bolster, an integral part of the occupant restraint system. Weakening the knee bolster has the potential to allow greater forward movement of the knees during a crash. In addition to the possibility of lower extremity injury, the changed kinematics may affect upper body motion and degrade belt and air bag performance, which, in turn, may be reflected in higher loads and accelerations.

Head Injury
Consumers and rehabilitation professionals have asked about the potential for head injury from the hand control. This concern regarding head injury can be addressed using Federal Motor Vehicle Safety Standard 201 (FMVSS 201). This standard prescribes a method to predict driver's head contacts in a frontal collision. The 201 head impact area was mapped onto the instrument panel of a 1998 Ford Taurus equipped with a floor-mounted shifter. The handle of the hand controls extended from the steering column past the rim of the steering wheel in a manner similar to that of column-mounted shift levers and turn signal indicators. National Highway Safety Traffic Administration (NHTSA) staff pointed out that FMVSS 201 does not apply to these components. Except for the handle, the hand control components lie outside the mapped head impact zone. We concluded that hand controls do not present an increased risk of head contact injury in a frontal collision.

Injury to Drivers of Short Stature
NHTSA recommends that drivers sit with their chests at least 10" from the air bag module *(Air Bags and On-Off Switches NHTSA Publication DOT HS 808 629)*. This seating position limits the chance of injury due to air bag deployment. If drivers must sit closer than ten inches to the steering wheel/air bag in order to reach the controls, they may be vulnerable to injuries caused by a deploying air bag.

We investigated the possible effect on small female driver seating position due to the use of hand controls. In discussions with driver evaluators, we found no consensus regarding whether use of a hand control requires a closer-to-the-wheel sitting position.

We positioned a 5th percentile female crash dummy in our 1998 Ford Taurus test buck in accordance with specifications of the new FMVSS 208 frontal impact safety standard that indicates that the seat should be placed in its full forward position[1]. The chest-to-wheel center measurement for this configuration and dummy placement was 9.5", slightly closer to the air bag than NHTSA recommends.

1. Department of Transportation National Highway Traffic Safety Administration 49 CFR Parts 552, 571, 585, and 595 [Docket No. NHTSA 99-6407; Notice 1] RIN 2127-AG70 Federal Motor Vehicle Safety Standards; Occupant Crash Protection. Supplemental notice of proposed rulemaking (SNPRM). iii. Location and Seating Procedure for 5th Percentile Adult Female Dummy.

Leg Injury

Compromised Knee Bolster

Concerns three and four, related to leg injury and knee bolster modification, were investigated by conducting six 48 km/h frontal sled tests. The tests, conducted using a Hybrid III 50th percentile male dummy seated in the driver's position of our 1998 Ford Taurus test buck (Fig. 2), included a baseline test with no hand control and five tests each using one of the hand controls listed in Table 1. The tests used a 3-point occupant restraint belt and an air bag. Table 3 summarizes the test results.

We found that the hand controls and the knee bolster modifications necessary for their installation minimally affected crash safety. The most severe predicted injury was a moderate knee laceration. More generous radiuses on components mounted near the knees would reduce the risk and severity of lacerations. Injury criteria values such as HIC, chest g's, femur load, and the tibia index, were unaffected by the presence of the hand control (Fig 3). The results and conclusions of this study are based on a single crash condition. Hand controls and structurally compromised knee bolsters may perform differently in other crash environments. Modifications to the knee bolster structure should be avoided and, if possible, minimized in all cases.

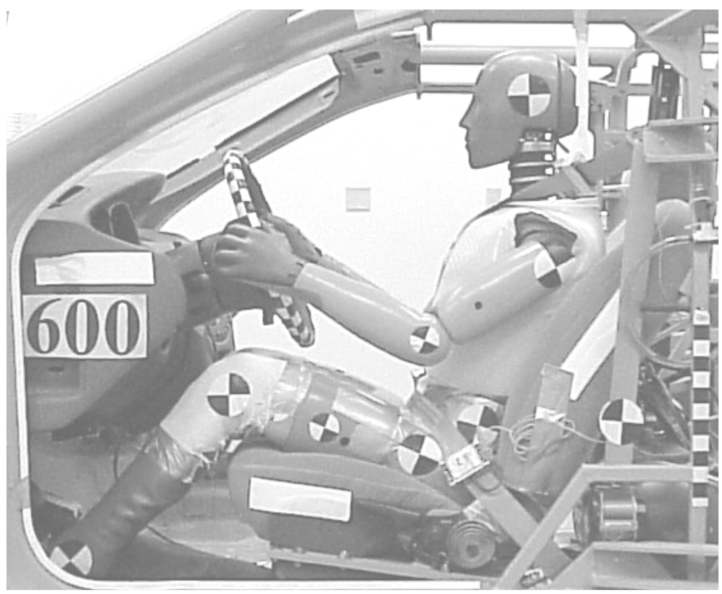


Figure 2. Pre-test dummy position for baseline test 600.

Table 3. Summary Sled Test Results

SUMMARY OF RESULTS						
Test ID	**600**	**601**	**602**	**603**	**604**	**605**
Hand Control	Baseline (no control)	Wells Engberg	MPS Monarch Mark 1-A	Drive-master Ultra-lite XL	Howell Ventures Sure Grip	MPD 3500
SLED PARAMETERS						
ΔV (km/h)	48.1	48.1	47.9	48.1	48.4	48.4
Max. Sled Deceleration (g's)	21	21	21	21	21	21
RESTRAINT DATA (MAXIMUMS)						
Outer Lap load (kN)	7.3	8.1	6.4	7.6	6.9	7.3
Upper Shoulder load (kN)	7.7	8.0	Sensor Failure	8.9	8.8	8.8
OCCUPANT PARAMETERS						
Head CG resultant acceleration (g's)	58	59	58	62	63	62
Chest CG resultant acceleration (g's)	46	48	49	51	49	52
Pelvis CG resultant acceleration (g's)	61	68	62	66	63	70
INJURY CRITERIA (MAXIMUMS)						
HIC Criteria < 1000	461	491	495	563	551	557
Femur (kN) Left / Right Criteria < 10 kN	0.2 / 0.5	0.2 / 1.0	1.2 / 0.1	0.2 / 0.1	1.1 / 0.7	0.4 / 0.1
Tibia Index Left / Right Criteria < 1.3	0.2 / 0.3	0.1 / 0.3	0.2 / 0.2	0.2 / 0.3	0.2 / 0.3	0.1 / 0.2
KNEE CONTACTS w/ HAND CONTROL						
Left Knee	-	Contact	Moderate Cut	Contact	Contact	Contact
Right Knee	-	None	None	Minor Abrasion + Cut	Minor Abrasion	None

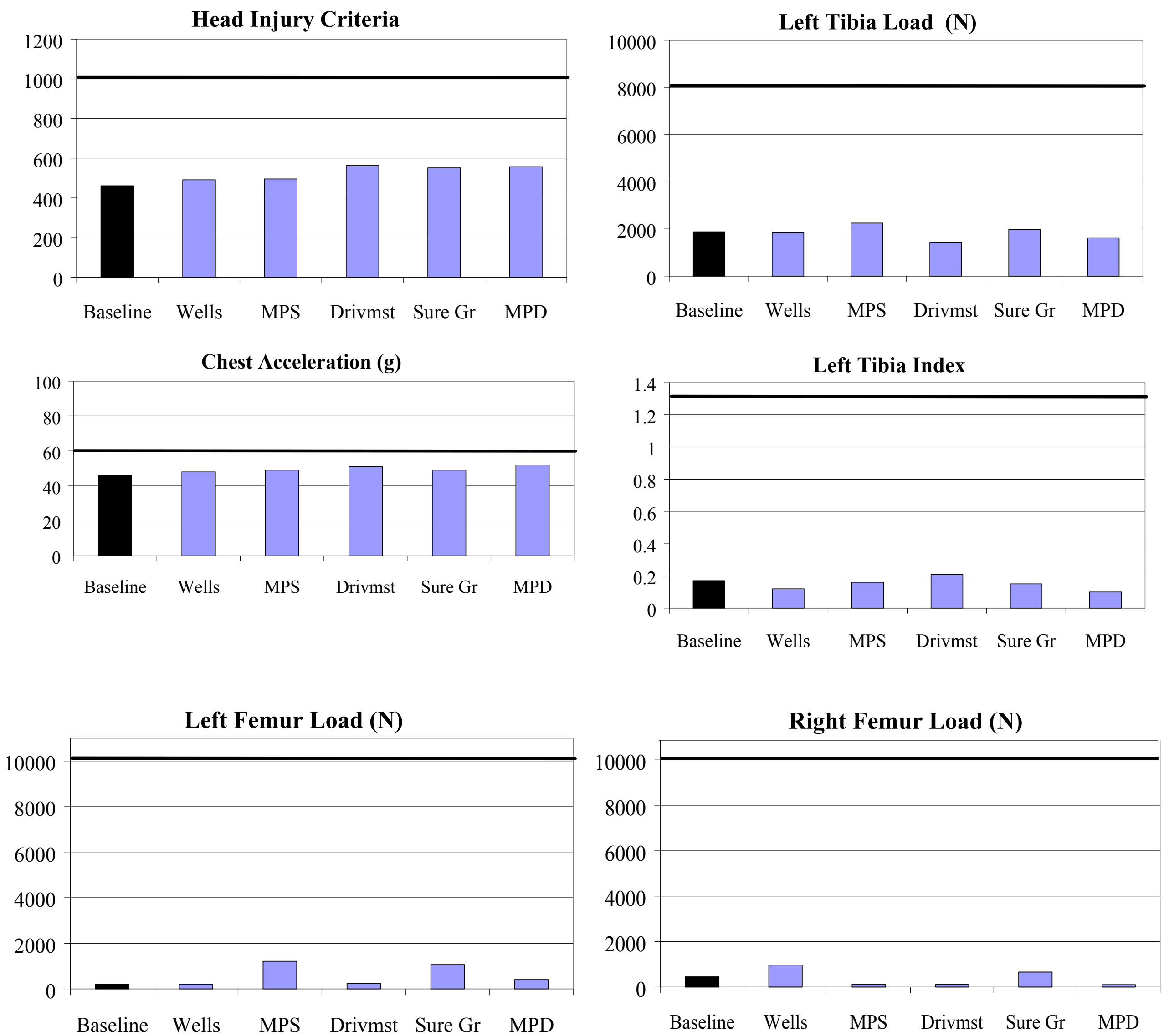


Figure 3. Injury criteria charts. The bold horizontal line indicates the injury threshold value.

Task Report

Task 1
Estimating the number of people in the United States using various types of adaptive driving equipment.

Background
The first step in defining the needs of drivers who use adaptive equipment is to determine the number of people using these devices. Unfortunately, this information is very difficult to find. There is no national database that tracks adaptive control use. Therefore, we explored state sources for this information.

Method
The Department of Motor Vehicles from most of the states were contacted to gather the number of drivers with license restrictions related to adaptive driving equipment. We requested the number of current restrictions for different categories of adaptive devices (Table 4). Contact people in the state motor vehicle departments were identified by driver evaluators and by consulting *The MVR Book, Motor Services Guide* (1999, Sankey M ed. BRB Publications Inc, Tempe, AZ).

Results and Discussion
Table 5 summarizes the results of the license restrictions by state. We received responses from 13 states. Some states did not keep such records. Others were not able to provide them. Some states, such as California, recorded only the number of restrictions issued annually rather than recording a running total of active restrictions that we requested.

We found substantial differences in how states recorded license restrictions. Ohio and New York provided the most detailed information. Oklahoma reported a prosthetic aid restriction and a general category restriction involving turn signal indicator/power steering/and/or steering control knob. Oklahoma officials suggested that hand controls and other devices may be grouped under a "detailed restriction" category.

Lack of consistent terminology and different ways of classifying and grouping adaptive devices greatly hindered our ability to interpret the data. The first column of Table 5 lists the terminology reported by the respondents. Although the table grouped like terms (in our estimation), we did not attempt to combine responses. We had difficulty determining if states reported a summary number of restrictions for a device and then reported a subset of the restrictions specific to a particular kind of device. For example, Illinois reported 2123 "Prosthetic aids" and 306 "Mechanical + prosthetic aids". In this case, we were unable to determine if the 2123 count included the 306 subset. In general, respondents were unable to clarify how the restrictions were categorized.

"All hand controls (no feet)", "hand controls", "prosthetic aid", "automatic transmission", "power steering", and "steering knob/v-grip spinner+wheel spinner+spinner knob" are the most commonly reported items.

After combining the "All hand controls (no feet)" and "hand controls" categories, we used this information to estimate the total number of drivers who use hand controls in the US. We also computed this estimate for the "prosthetic aid" category (Table 6). A total of eight states reported usable data in the combined hand controls category. California data was excluded for the reason cited above (see Table 5). Nine states reported in the "prosthetic aid" category. Analysis of the data, described in Table 6, suggests that there are approximately 90,000 licenses specifying the use hand controls and approximately 45,000 for the use of prosthetic aids.

Limitations in the collection of the data and subsequent estimate analysis should be noted. The states reported cumulative numbers of licenses for adaptive devices for count dates that ranged over a three-year period (Michigan 10/96 - Louisiana 5/99). Our analysis assumed that device use did not vary over this time period. The data was not randomly sampled (See the notes for Table 6 for further discussion.).

Table 4. Adaptive Devices for Drivers

1. Hand controls – allows braking and gas with a lever mounted near the steering wheel
2. Steering devices – makes it easier to turn the wheel i.e. "spinner knob"
3. Prosthetic aids such as artificial arms, hands, or legs.
4. Parking brake modifications
5. Pedal extensions
6. Crossover gear or turn signal levers
7. Left foot accelerators
8. Reduced/low/zero effort steering
9. Reduced effort braking
10. Joystick control
11. Remote switches for lights, wipers etc.
12. Wheelchair lift
13. Wheelchair ramp
14. Wheelchair tiedown
15. Automatic door openers
16. Lowered (van) floors
17. Raised (van) roofs and doors
18. 6-way powered driver seat
19. Wheelchair and scooter lifts and carriers

Table 5. Adaptive Device Survey Results

	Kansas	Oklahoma	Illinois	Michigan	W. Virginia	Virginia	Minnesota	N. Dakota	New York	Nevada	Ohio	California	Louisiana
Number of licensed drivers in 1998 [A] (Millions)	1.85	2.31	7.70	6.80	1.28	4.79	2.87	0.46	10.55	1.25	7.94	20.50	2.74
Date count was received. Unless otherwise specified, most counts were taken 2-3 months prior to this date.	1/12/99	1/21/99	1/19/99	Count as of 10/21/1996	6/30/97	1/7/97	6/19/98	1/15/99	3/15/99	Count for 1996	3/22/99	1998/9 Not cumulative. Only for 12 mo. period.	5/25/99
All hand controls (no feet)				**2702**		**1958**	**1449**		**4852**		**5100**		**1128**
Hand controls					**347**			**285**				**720**	
Hand control, clutch				64		12					278		
Hand control, brake				371		92			485			159	
Hand control light beam							4624						
Brake and accelerometer controls													144
Mechanical aid	1424		13645										
Prosthetic aid	**48**	**541**	**2123**		**188**	**370**	**711**	**126**	**1749**		**3511**	**46**	
Automatic drive or artificial limb required											1616		
Mechanical+ prosthetic aid	11		306								5127		
All foot controls						6							
Modified brake											2033		
Modified emergency brake											1281		
Foot-operated parking brake									102				
Power brakes								5	912				
Extended foot pedals								2					

Note A – Source: Traffic Safety Facts 1998, State Traffic Data, National Center for Statistics and Analysis, Research and Development, 400 Seventh St. SW Washington, DC 20590.

Table 5. Adaptive Device Survey Results (cont.)

	Kansas	Oklahoma	Illinois	Michigan	W. Virginia	Virginia	Minnesota	N. Dakota	New York	Nevada	Ohio	California	Louisiana
Adjustable seat												93	
Automatic seat										372			
Adequate under cushion (to raise driver)												140	
Elevated driver seat							1296	8					
Turn indicator / power steering or steering knob		2165											
Modified turn signal											2687	147	
Mechanical turn signals					69	499				980			160
Turn lever extension						102							
Gear shift extension						12							
Modified accelerator											3317		
Left foot accelerator						292		34	2374	184			79
Gas pedal extension						74				491			44
Built- up seat/pedals/shoes									1204				
Built-up clutch pedal						11							
Built-up brake pedal						51							
Built- up dimmer						14					5031		
Steering knob/V-grip/ spinner								**75**				**516**	
Wheel spinner									**4462**				
Spinner knob				**1506**		**459**					**11818**		
Quad grip w/pin						31							
Automatic steering and power steering glove						9							
Yolk spinner						15							
Tri-pin						57							
Amputee ring						5							
Power steering								**64**	**2664**	**1279**	**698**		**1310**
Automatic transmission							**4621**		**12882**	**2657**	**21631**		**3606**

Table 6. Estimates for the total number (τ) of hand control devices and prosthetic aids utilized by license drivers in the United States.

Adaptive Device	Estimated Total $\hat{\tau}_r$	SE $\hat{\tau}_r$	95% Lower CL τ	95% Upper CL τ
Hand Controls +	88082	7652.20	73083	103080
Prosthetic Aid*	43623	9639.09	24730	62516

+ states contributing information: Michigan, W. Virginia, Virginia, Minnesota, N. Dakota, New York, Ohio, and Louisiana.
* states contributing information: Kansas, Oklahoma, Illinois, W. Virginia, Virginia, Minnesota, N. Dakota, New York, and Ohio.

Estimation Procedure

The parameter estimates in Table 1 for estimating the total number of licensed drives in the United States who utilize hand controls, and for estimating the total number of licensed drivers who utilize prosthetic aids, were computed under the assumption that the data were collected by a simple random cluster sampling design1,2. In the estimation of the population parameters, we assumed that each of the 50 states within the United States represent a cluster; the primary sample unit. We also assumed that the secondary units within each cluster consisted of all licensed driver within the cluster. The estimators that were utilized in the estimation of population totals and associated standard errors and confidence limits (CL) are presented below.

Estimates

The total number of licensed drives within the United States who utilize a hand control device is estimated to be 88082 [95% CL (77083, 103080)], while the total number of licensed drivers in the United States who utilize a prosthetic aid is estimated to be 43623 [95% CL (24730, 62516)].

Potential Selection Bias

Only a small subset of the 50 states within the United States responded to what was originally intended to be a complete census of licensed drivers within the United States. The resulting data collection process most closely resembles a simple random cluster sampling design, in which only a subset of the primary units sampled is randomly selected, while within the selected primary units all secondary units are sampled. The primary sampling units in this survey (states) were not selected by chance, so there is the potential for selection bias to be introduced into the estimation process. The magnitude of the bias induced by non-probability sampling may be negligible if the sample of licensed drivers from the states that responded to the survey is representative of the licensed drivers in the United States.

Definitions (Taken from Thompson's "Sampling", page 116)	**Estimators**
Let N = the number of primary units in the population. n = the number primary units in the sample. M_i = the number of secondary units in the ith primary unit. $M = \sum_{i=1}^{N} M_i$, the number of secondary units in the population. y_{ij} = the value of the variable of interest of the jth secondary unit in the ith primary unit. $y_i = \sum_{j=1}^{M_i} y_{ij}$, the total of the y values in the ith primary unit. $r = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} M_i}$, the sample ratio.	$\hat{\tau}_r = rM$, the ratio estimator of the population total. $\hat{var}(\hat{\tau}_r) = \frac{N(N-n)}{n(n-1)} \sum_{i=1}^{n} (y_i - rM_i)^2$, the unadjusted variance estimator. $\tilde{var}(\hat{\tau}_r) = \left(\frac{nM}{N\sum_{i=1}^{n} M_i}\right)^2 \hat{var}(\hat{\tau}_r)$, the adjusted variance estimator.

Literature Cited

1) Levy, P.S., Lemeshow S. *Sampling of Populations: Methods and Applications*. 1991. John Wiley & Sons. NY.
2) Thompson, S.K. *Sampling*. 1992. John Wiley & Sons. NY.

Task 2
Crash Avoidance Evaluation of Manual Hand Controls

Background
Hand controls can affect the ability of a driver to avoid a crash because they change the way the driver brakes and accelerates. Task 2 evaluated hand control reliability using the Society of Automotive Engineers (SAE) J1903 - Recommended Practice Automotive Adaptive Driver Controls. This document establishes a uniform procedure for evaluating the quality and service performance of hand controls, aftermarket devices for which there is no federal safety standard. Recommendations are made concerning product documentation, installation, and design. Inspection and testing procedures are specified.

Method
The performance of five hand controls, selected to be representative of the most popular models and methods of operation (Table 1), was assessed using methods described in the August 1990 revision of the SAE J1903. We inspected the hand control device documentation and construction and conducted vibration, environmental, cyclic load, and service overload testing.

Hand Control Loading Procedures and Apparatus
In accordance with section 5.4.3 of SAE J1903, each of the five hand controls was subjected to high-cycle testing. In this test, each hand control was rigidly mounted in a testing frame (Fig. 4). Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 50 lb weight was connected to a cable providing brake loading. A 10 lb weight was connected to a cable providing accelerator loading. A motor rotated an eccentric wheel that alternately lifted each weight off the ground. The loading was applied alternately between the braking direction and the accelerator direction. At multiples of 50,000 cycles, we inspected the unit for damage and loose fasteners. The total number of cycles performed was 250,000.

Service overload testing was performed in accordance with section 5.4.4 of SAE J1903. This test simulated a 150 lbf load to the brake and a 30 lbf load to the accelerator. Loading was accomplished through cables and with the hand control mounted in the High-Cycle test apparatus. We carefully loaded the brake and accelerator with weights and maintained the load for 30 seconds.

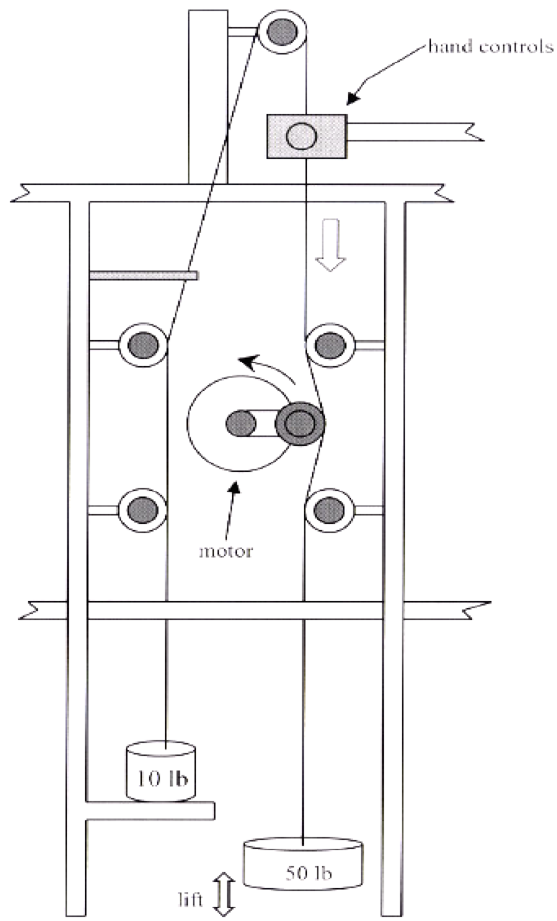


Figure 4. High-cycle testing apparatus. The same configuration was used for the service overload testing.

Laboratory Tests Reports

Individual test reports were prepared for each of the hand controls. The reports follow the Task 2 General Comments and Recommendations. Results of testing in compliance with SAE J1903 Sections 4 and 5 are presented along with photographic documentation of the performance tests.

Discussion

Vibration Test

The hand controls were rigidly mounted in test rigs. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. All of the hand controls passed this test without sustaining damage or loosening of fasteners.

Electromechanical Environmental Test

The hand control was suspended in a corrosion chamber and subjected to two period of salt fog exposure at an elevated temperature in accordance with ASTM B117-97. The electromechanical environmental test was run a second time to confirm test results. All of the controls failed both times because corrosion products were present on surfaces that could come in contact with the driver.

High-Cycle Test

No failures occurred at any point in the testing of the five hand controls.

We identified two points of ambiguity in section 5.4.3 that require interpretation. With four fundamentally different methods of operating the hand controls represented, application of the specified loads are subject to individual interpretation as we found with respect to the Wells-Engberg CT-100 and the Howell Sure Grip. The Wells-Engberg CT-100 brake actuation is straightforward and uncomplicated. The accelerator actuation is via a twisting action on the handle. The standard does not describe how the test load is to be applied to controls that require a rotary input. The Howell Sure Grip functions of braking and applying the accelerator were difficult to separate. Pushing the control handle forward activates the brake. While pushing the handle forward to apply the brake, the operator must also apply a reverse moment to avoid application of the accelerator. In applying the accelerator, the operator applies a moment to the handle. If a simultaneous application of the brake is to be avoided, the operator must also apply a rearward-directed force to the handle. The standard does not specify how to apply test loads to hand controls that function similar to the Howell Sure-Grip.

The specified maximum cyclic period of 1 second is not explicitly defined. If alternating loads (brake / accelerator) are applied in succession, the 1-second rule could be applied in two different ways. One interpretation is that the 1-second maximum is from one brake to the next brake actuation. In another interpretation, the 1-second maximum is from brake actuation to the subsequent accelerator actuation. We are concerned that dynamic effects may appear if the period between actuations is too short. In this testing series, the 1-second maximum was taken to mean that the period between brake actuation and accelerator actuation. Two test cells were used in the high-cycle test series, one with a period of 1 second and the other with a period of 0.67 second. A period of less than 0.67 second would probably have resulted in dynamic effects such as bouncing of the hand control and the applied weight.

Service Overload Testing

When first tested, two of the hand controls exhibited failure, as defined in Section 4.6.5, during the application of the 150 lbf brake load. The Wells Engberg CT-100 threaded brake rod bent with the application of 150 lbf. The Monarch Mark 1A threaded brake rod bent upon application of 100 lbf. Both of the hand controls were tested with a significant portion of the threaded brake rod extended from the guide tube in compliance with Section 5.4.4 of J1903 that states "….adjustments shall be made to so that maximum forces are transmitted by the control assembly for the applied forces specified." We interpreted this statement to mean that the hand control should be adjusted to represent a worse-case loading condition. In the case of the brake rod assembly, this meant extending the threaded rod to its longest setting.

A review of the tests revealed that the amount of brake rod extension was unreasonable relative to the range of adjustment required in actual vehicles. In SAE J1903, Section 4.6 Performance Requirements and Section 5.4 Performance Tests, there are statements that suggest that manufacturer adjustment specifications should be observed when preparing the hand controls for testing. In the case of the Wells-Engberg CT-100, we failed to follow the manufacturer's warnings relative to the limit of brake rod extension. In the case of the Monarch Mark 1A, there was no designation of maximum brake rod extension. We straightened the threaded rods, reduced the amount of extension to the maximum specified by Wells-Engberg and retested both of the hand controls. Both controls passed the test with no sign of permanent deformation. In the Monarch Mark 1A case of an unspecified threaded rod extension length, the standard is unclear as to what length the hand control linkage should be tested.

General Comments and Recommendations

In the course of conducting the SAE J1903 tests, we evaluated the clarity and objectivity of the standard itself. Table 7 summarizes our observations in addition to those made relative to the performance tests above. As indicated above, clarification is needed with respect to how the controls are to be adjusted for mechanical testing. Section 4 of SAE J1903 details the requirements that an acceptable hand control must meet. Because Section 4 attempts to encompass a wide range of performance and non-performance related items, it is somewhat vague. Section 5 of SAE J1903 details the actual inspection and testing procedures that should be used to ascertain the compliance to the requirements in section 4. Some of the testing procedures are difficult to apply to certain types of hand controls.

Overall, the SAE J1903 performance requirements were rigorous but reasonable. However, the Electromechanical Environmental Test may be too stringent. Section 4.2.1, that prohibits modifications to vehicle safety systems, prohibits knee bolster modifications required to install all of the tested controls. We recommend that the SAE Adaptive Devices Committee consider these observations when it considers revising the standard.

Table 7. Evaluation of SAE J1903 Sections 4 and 5

Section 4. Requirements

4.1 Documentation

4.1.1 Straightforward, understandable, and applicable to almost all possible designs.
4.1.2 Straightforward and understandable, but difficult to quantify. Quality control could range from ISO 9001 to simple visual inspection by an assembly person.
4.1.3 Straightforward and understandable.
4.1.4 Straightforward and understandable.
4.1.5 Straightforward and understandable. Many of the manufacturers recommend installation by a trained professional. The instructions for all of the tested products were sufficiently clear for a moderately skilled person to install the hand control.
4.1.6 Straightforward and understandable. The manufacturers provided a wide range of styles of manuals with each hand control.
4.1.7 Straightforward and understandable. There was a wide range of maintenance procedures provided by the manufacturers. While the requirements are very detailed, few of the manufacturers included similar detail in their maintenance procedures in this much detail.
4.1.8 All of the hand controls were somewhat universal in their intended installation, so this heading is marginally applicable in most situations.

4.2 Installation

4.2.1 This heading is fairly clear and understandable, but none of the manufacturers met the requirements. Alteration to the knee bolster was required by all of the tested hand controls. For an individual that is somewhat unfamiliar with FMVSS procedures and the effects of certain interior components (knee bolster), this requirement could be interpreted in many different ways.
4.2.2 This heading is vague and difficult for a manufacturer to comply with. The manufacturer would be required to determine the SAE specifications for many parts on a myriad of intended vehicles in order to comply with this requirement.
4.2.3 See above (4.2.2).
4.2.4 This heading is straightforward and understandable. With the exception of tools needed to modify the knee bolsters, all of the tested manufacturers supplied the needed hardware and some form of a parts list.
4.2.5 Straightforward and understandable.
4.2.6 Vague and subject to individual interpretation. While all of the manufacturers made some attempt to retain the functionality of the conventional vehicle controls, the requirement of “unimpeded use” is vague and subject to individual interpretation.
4.2.7 Vague and subject to interpretation. Without specific knowledge of FMVSS procedures and individual vehicle safety items, it is difficult for a manufacturer to interpret and comply with this requirement.

4.3 Design

4.3.1 The requirement that the product be “manufactured according to standard engineering practices” is vague and subject to individual interpretation.
4.3.2 Vague, but understandable.
4.3.3 This heading is clear, but dependent upon factors such as occupant size.
4.3.4 See 4.2.6.
4.3.5 Straightforward and understandable.
4.3.6 This section is clear and understandable, but still open to some degree of individual interpretation. The definition of a sharp edge is an example.
4.3.7 Straightforward, but somewhat open to individual interpretation.
4.3.8 Straightforward and understandable.
4.3.9 This section is vague and very open to individual interpretation.

4.4 Selection of Components

4.4.1 See 4.2.2.
4.4.2 See 4.2.2.

Table 7. Evaluation of SAE J1903 Sections 4 and 5 (cont.)

4.5 Manufacturing Quality

4.5.1 Vague and subject to individual interpretation.
4.5.2 This section is somewhat vague in the requirement to "resist corrosion". This subject is covered in the environmental test of section 4.6.3.
4.5.3 Straightforward and understandable.
4.5.4 Straightforward and understandable.

4.6 Performance Requirements

4.6.1 This section is somewhat vague. The requirement that the hand control must last as long as the vehicle may be difficult for the manufacturer to interpret.
4.6.2 Straightforward and understandable.
4.6.3 Straightforward, but very open to individual interpretation. The requirement of no "degradation or loss of surface" is vague.
4.6.4 Straightforward and understandable.
4.6.5 Straightforward and understandable.

Section 5 Inspection and Testing Procedures

5.1 Receiving Inspection

5.1.1 Straightforward.
5.1.2 Straightforward and understandable.
5.1.3 Straightforward and understandable with the exceptions of items h and i. These requirements aren't strongly defined in the SAE J1903 documentation.
5.1.4 Vague and subject to individual interpretation. As workmanship is an entirely subjective quantity, it would be difficult for a manufacturer to quantify this.

5.2 Mounting

5.2.1 Straightforward.
5.2.2 Straightforward and understandable.
5.2.3 See 4.2.2.
5.2.4 See 4.3.3.
5.2.5 Vague and subjective.
5.2.6 Straightforward and understandable.

5.3 Installation

5.3.1 See 4.2.1.
5.3.2 Straightforward, but subjective.
5.3.3 See 4.2.6.
5.3.4 Vague, but understandable.
5.3.5 Straightforward, but subjective in interpretation. As vehicles can undergo a wide range of accelerations during normal operation, this requirement is difficult to quantify.

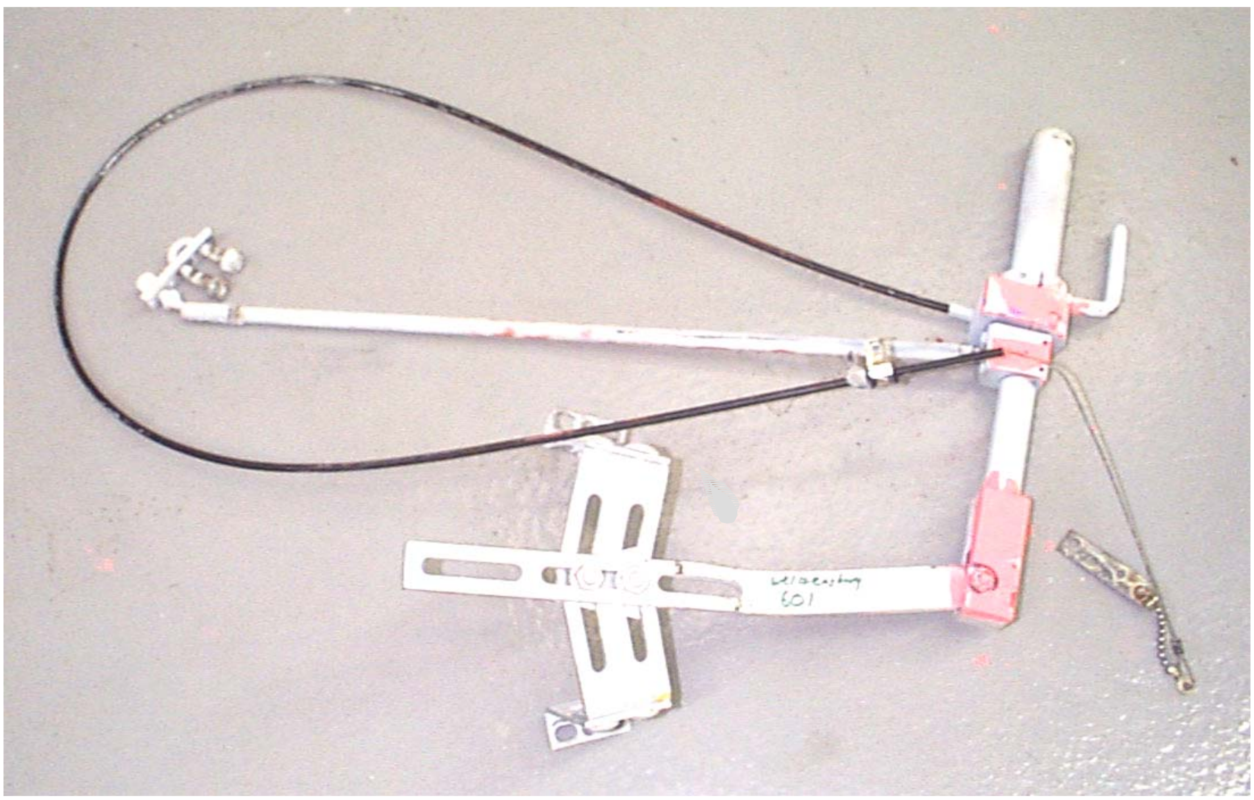
5.4 Performance Tests

5.4.1 Straightforward, but subject to individual interpretation.
5.4.2 Straightforward and understandable.
5.4.3 Straightforward, but subject to individual interpretation of test setup.
5.4.4 Straightforward and understandable.

SAE J1903
Recommended Practice Automotive Adaptive Driver Controls, Manual
1990 Revision

Test Results

Model:	**CT-100 Rotary**
Manufacturer:	**Wells-Engberg Co., Inc.** **P.O. Box 6388** **Rockford, IL 61125** **(800)-642-3628**



Summary of Test Results in Accordance with SAE J1903 Section 4 and Section 5

• Introduction

Several hand control devices for automobiles were submitted for evaluation in accordance with SAE J1903. Section 1 through Section 3 can be categorized as design and definition, and thus will not be addressed in this report. The compliance of this product to Section 4 and Section 5 of SAE J1903 is summarized in this report.

Section 4: Requirements

• Procedure

Using the documentation provided by the manufacturer and the test results from Section 5, each item in Section 4 was addressed. Any and all points of failure of this hand control were noted.

• Points of Failure

In the interest of brevity, only deficient items related to Section 4 will be addressed here.

4.1.1 Model number was not identified on the product.
4.1.6 d No signs of possible malfunction were noted in the documents.
4.1.6 e No actions to be taken in the event of product failure were noted in the documents.
4.2.1 As described in the installation manual, some component mounting may require alteration to the knee bolster. Because it is an integral part of the general crashworthiness of a vehicle, alteration of the knee bolster has the potential to impact FMVSS.
4.2.7 See above.
4.6.3 Some degradation or loss of surface finish was noted after the electromechanical environmental test.

Section 5: Inspection and Testing Procedures

• Procedure

Using the documentation provided by the manufacturer and the test results from Section 5, each item in this section was addressed. Any and all points of failure of this hand control were noted.

• Points of Failure

In the interest of brevity, only deficient items related to Section 5 will be addressed here.

5.1.3a Model number not identified on product
5.4.2 The product presented several surfaces of corrosion that could be contacted by the operator.

• Test Procedure and Test Setup General Descriptions

Vibration Test:

The hand control product was rigidly mounted in a test rig. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. At the end of each session, the product was inspected for damage and any loosening of fasteners.

Electromechanical Environmental Test:

The hand control product was suspended in a corrosion chamber by small ropes and subjected to corrosion testing in accordance with ASTM B117-97.

The electromechanical environmental test was run a second time to confirm test results. No significant changes in results were noted in the second test.

High-Cycle Test:

For the high-cycle test, each hand control product was rigidly mounted in a testing frame. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 50lb weight was connected to the cable attached to the brake. A 10lb weight was connected to the cable attached to the accelerator. A motor, with an eccentric, then rotated, alternately lifting each weight off of the ground. The loading was applied alternately between the braking direction and the accelerator direction. At multiples of 50,00 cycles, the unit was inspected for damage and loose fasteners. The total number of cycles performed was 250,000.

Service Overload:

The hand control was mounted in the testing frame in the same manner as in the high-cycle test. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 10lb weight was applied to the accelerator cable for a minimum period of 30 seconds. After the removal of the accelerator load, the brake load was applied. Three 50lb weights were used to apply the total load of 150lb. The weights were applied as carefully as possible to minimize any dynamic effects.

- ## Mechanical Testing Results Summary

Two areas of failure for this hand control were observed under section 5.4.2 and section 4.6.3. Section 5.4.2 and section 4.6.3 are related, so this really constitutes one failure that is addressed under two different sections..

Section 5.4.2 states "…and shall not present any corrosion products to surfaces that can be contacted by the driver (see 4.6.3)." As can be seen in the photographs in Appendix B, there were several areas of failure.

Section 4.6.3 states "…the product shall continue to function without exhibiting degradation or loss of surface finish…". Several areas of the hand control, documented in Appendix B, exhibited loss of surface finish.

- ## Mechanical Testing Detailed Results

Vibration Test:

The vibration tests were carried out on January 19, 1999. Photographic documentation of the vibration tests can be found in Appendix A. No failures or loosening of fasteners was noted.

Electromechanical Environmental Test:

The electromechanical environmental test was carried out in accordance with ASTM B 117-97. Photographs of the 1st test setup and of the post test product can be seen in Appendix B. Corrosion was evident in several areas which are detailed in Appendix B. The electromechanical environmental test was carried out a 2nd time with similar results. The photographic documentation of the 2nd test is contained in Appendix C.

High-Cycle Test:

The high-cycle test was carried out from June 11, 1999 to June 30, 1999. Inspections were made at 50,000 cycle intervals until the test unit reached the prescribed 250,000 cycles. No damage to the hand control device or loosening of of fasteners was noted during any of the cycles. The overall function and rigidity of the hand control device was good throughout the *high-cycle testing phase. A test log is contained in Appendix E. Photographic documentation of the Hand control in the testing apparatus is provided in Appendix D.*

<u>Service Overload</u>*:*

The accelerator load of 10lb and the braking load of 150lb were held by the hand control with no apparent deformation or problems.

Wells-Engberg CT-100

Appendix A

Photographic Coverage of Vibration Test

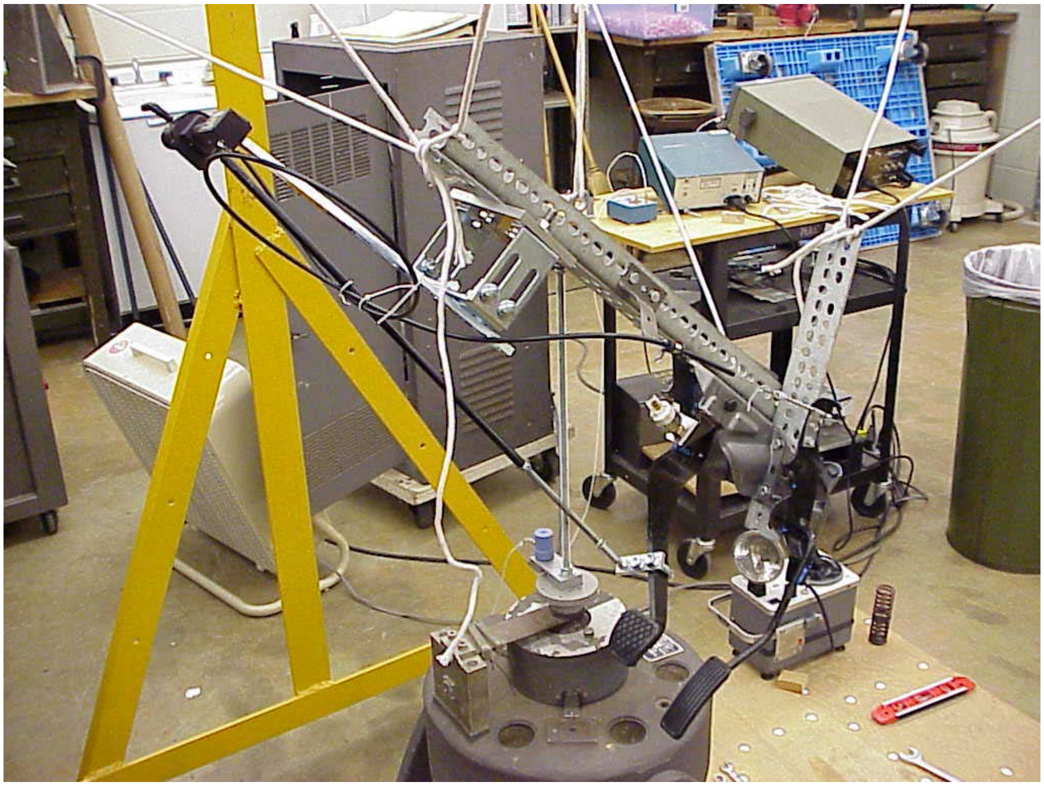


Photo #1 **(Wells-Engberg CT-100: Vibration Test)**

Photo #2 **(Wells-Engberg CT-100: Vibration Test)**

Photo #3 **(Wells-Engberg CT-100: Vibration Test)**

Photo #4 **(Wells-Engberg CT-100: Vibration Test)**

Photo #5 **(Wells-Engberg CT-100: Vibration Test)**

Photo #6 **(Wells-Engberg CT-100: Vibration Test)**

Photo #7 **(Wells-Engberg CT-100: Vibration Test)**

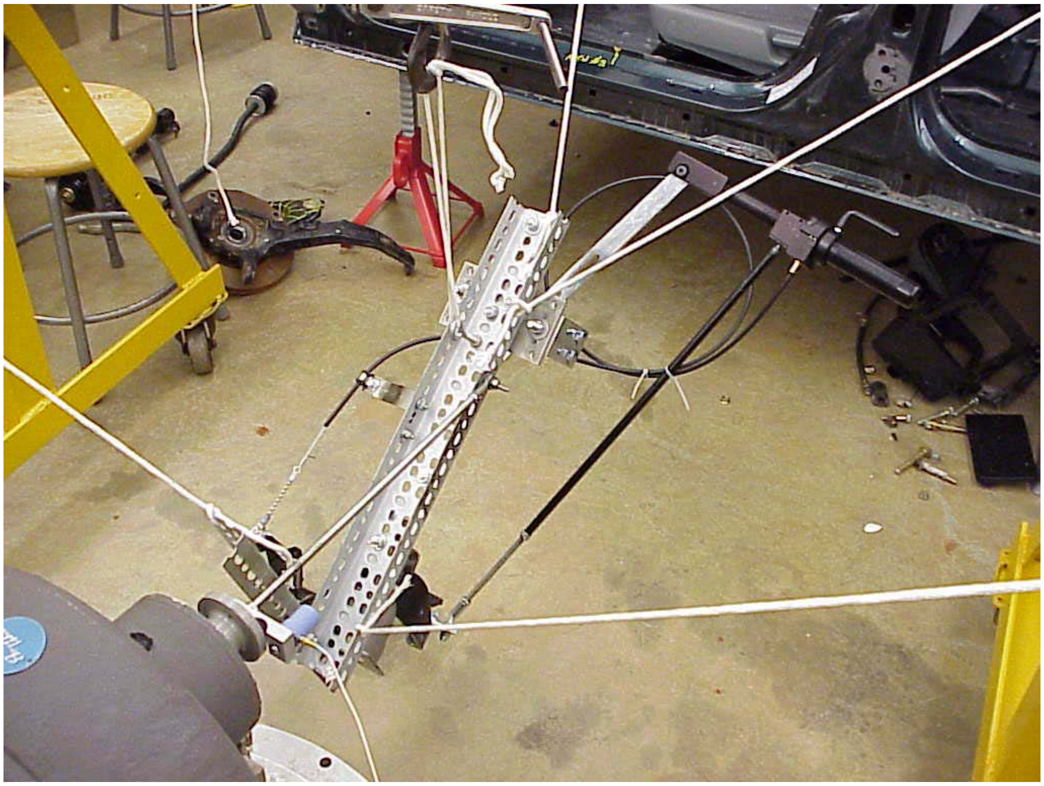


Photo #8 **(Wells-Engberg CT-100: Vibration Test)**

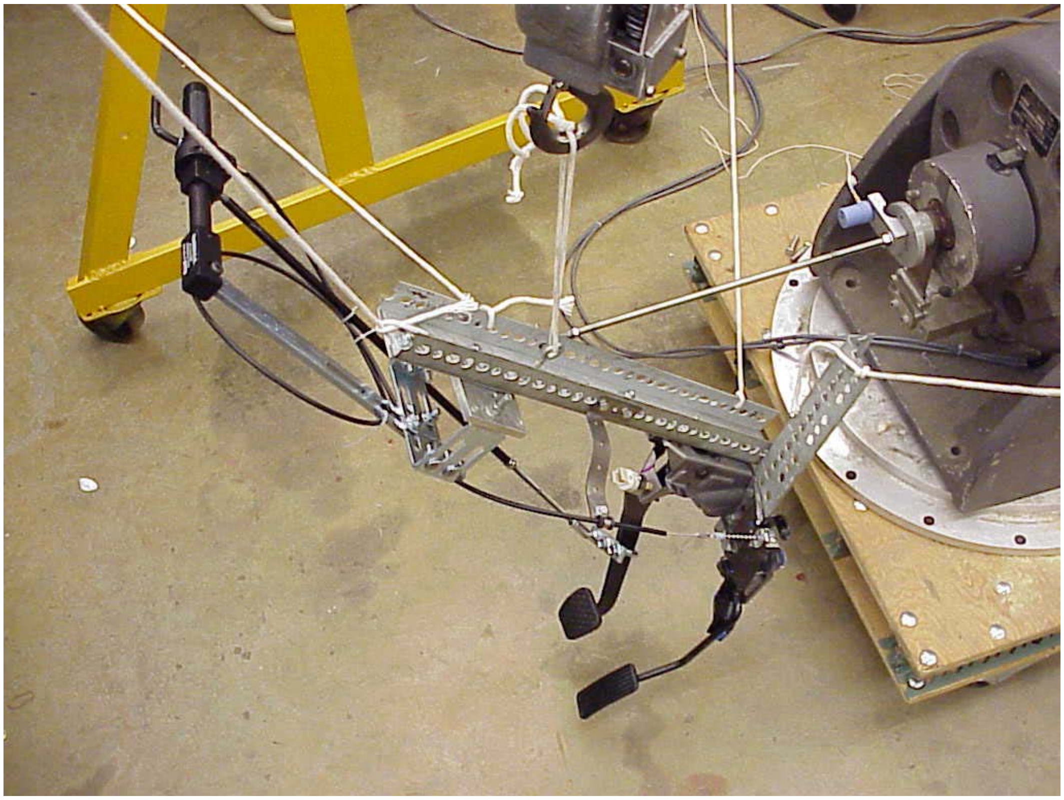


Photo #9 **(Wells-Engberg CT-100: Vibration Test)**

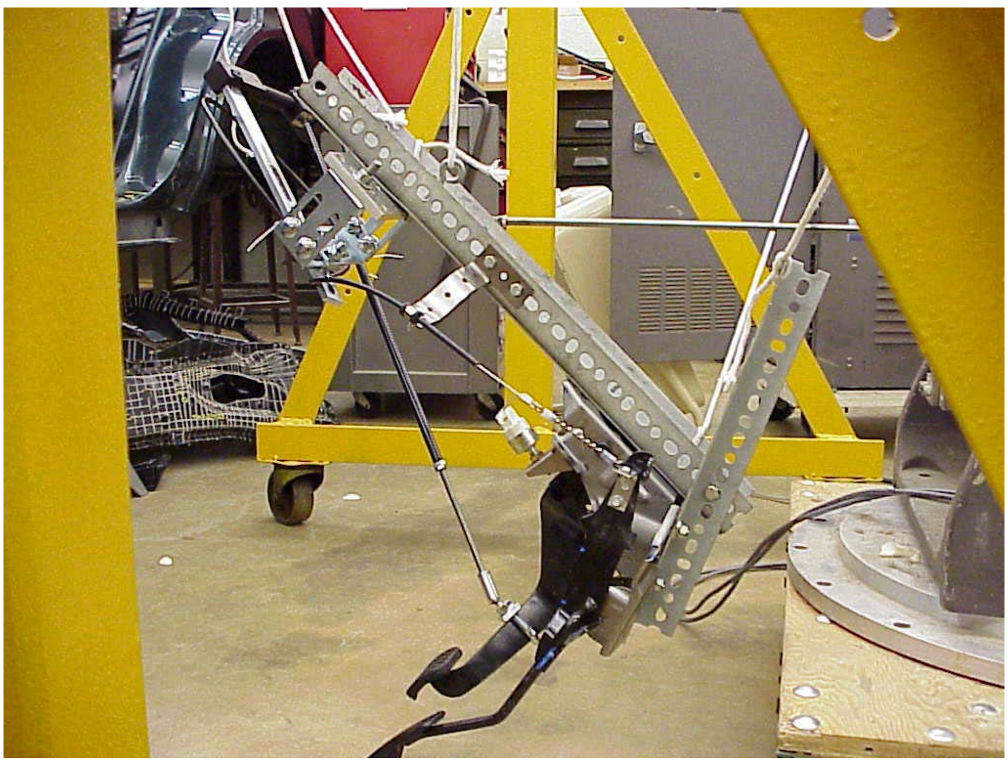


Photo #10 **(Wells-Engberg CT-100: Vibration Test)**

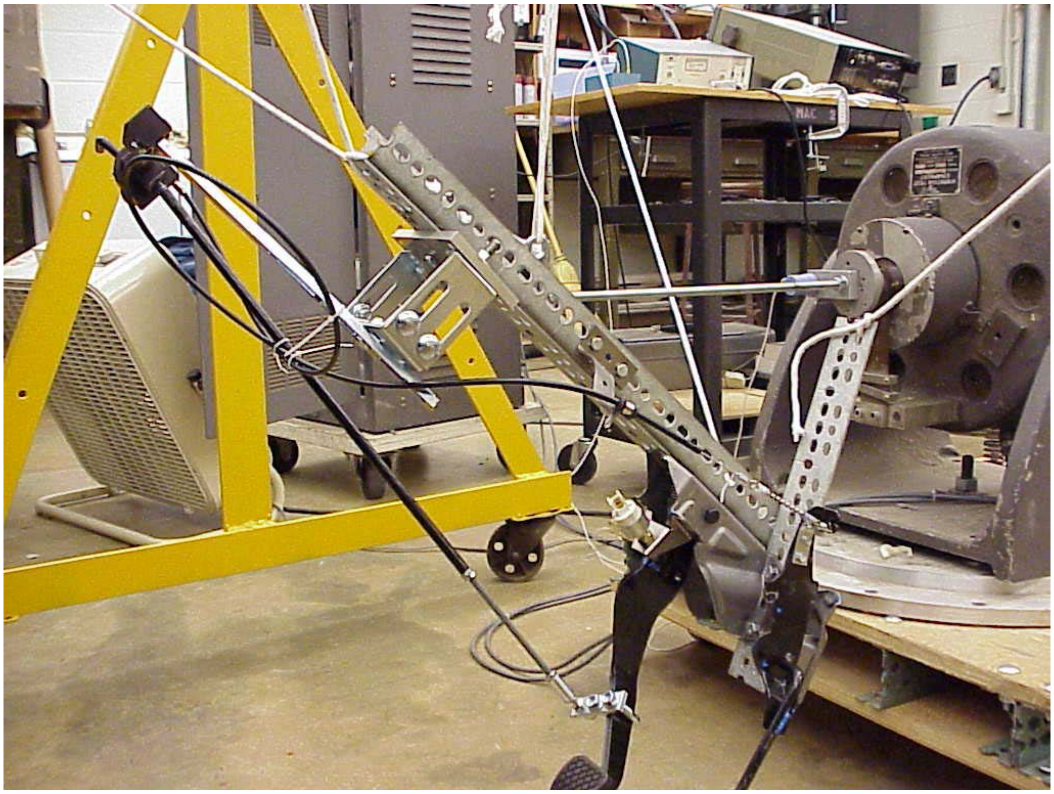


Photo #11 (Wells-Engberg CT-100: Vibration Test)

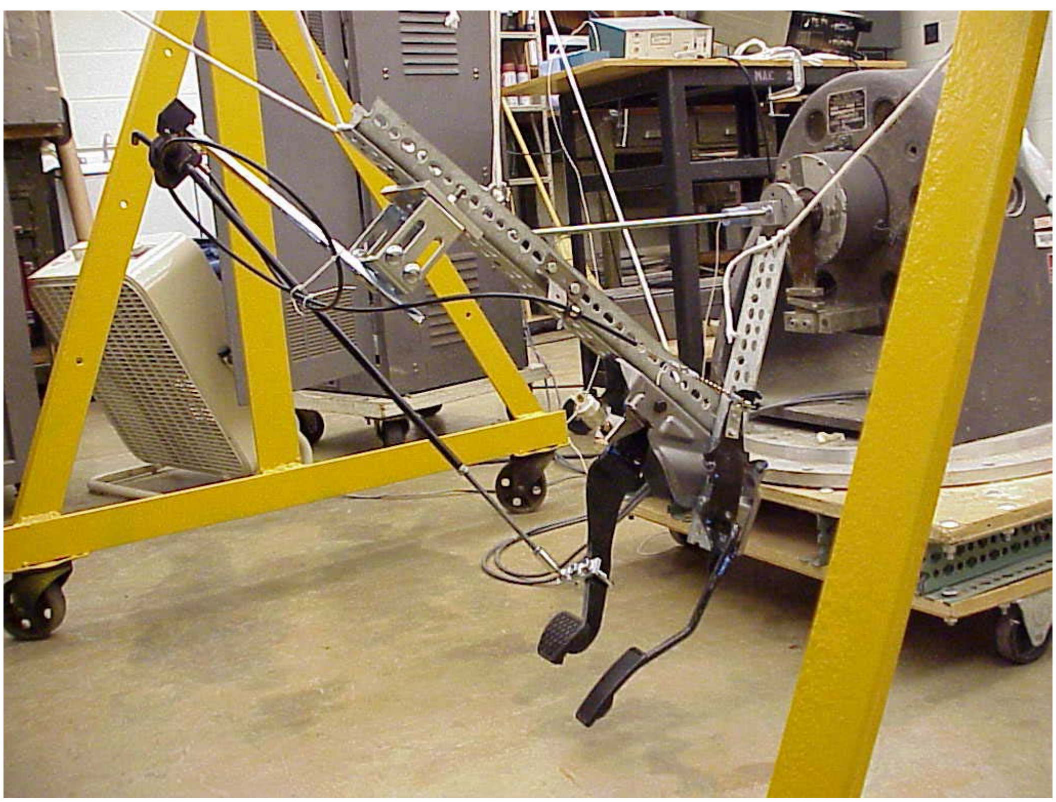


Photo #12 (Wells-Engberg CT-100: Vibration Test)

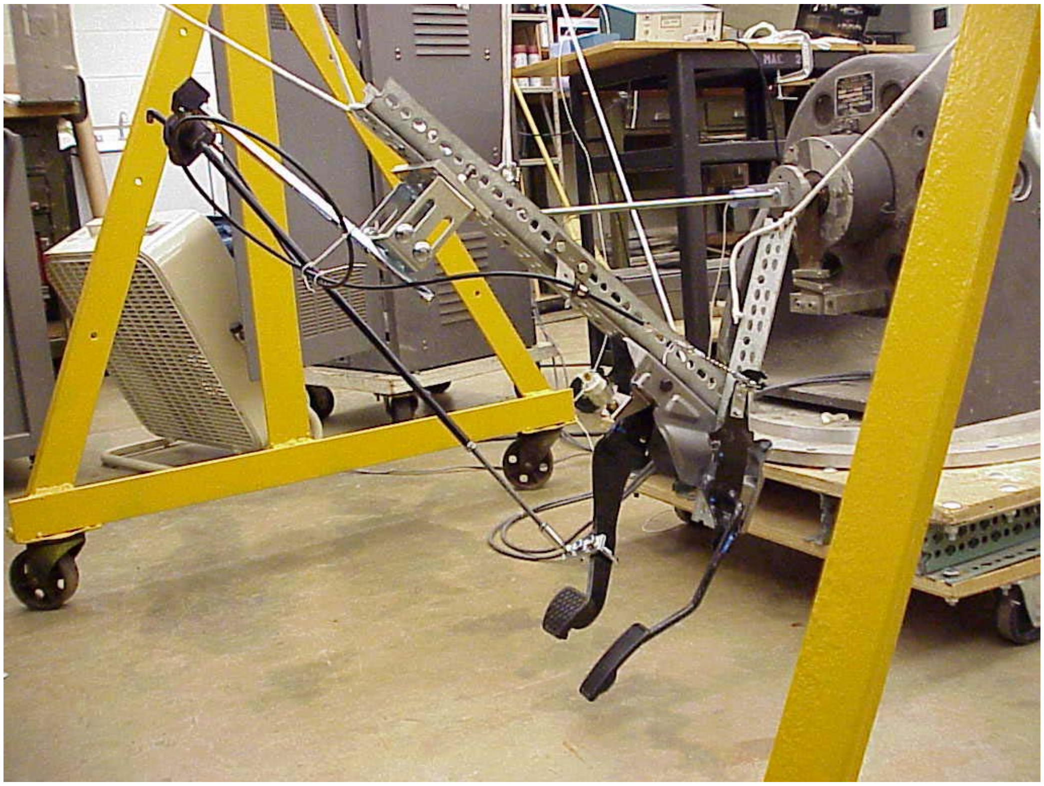


Photo #13 **(Wells-Engberg CT-100: Vibration Test)**

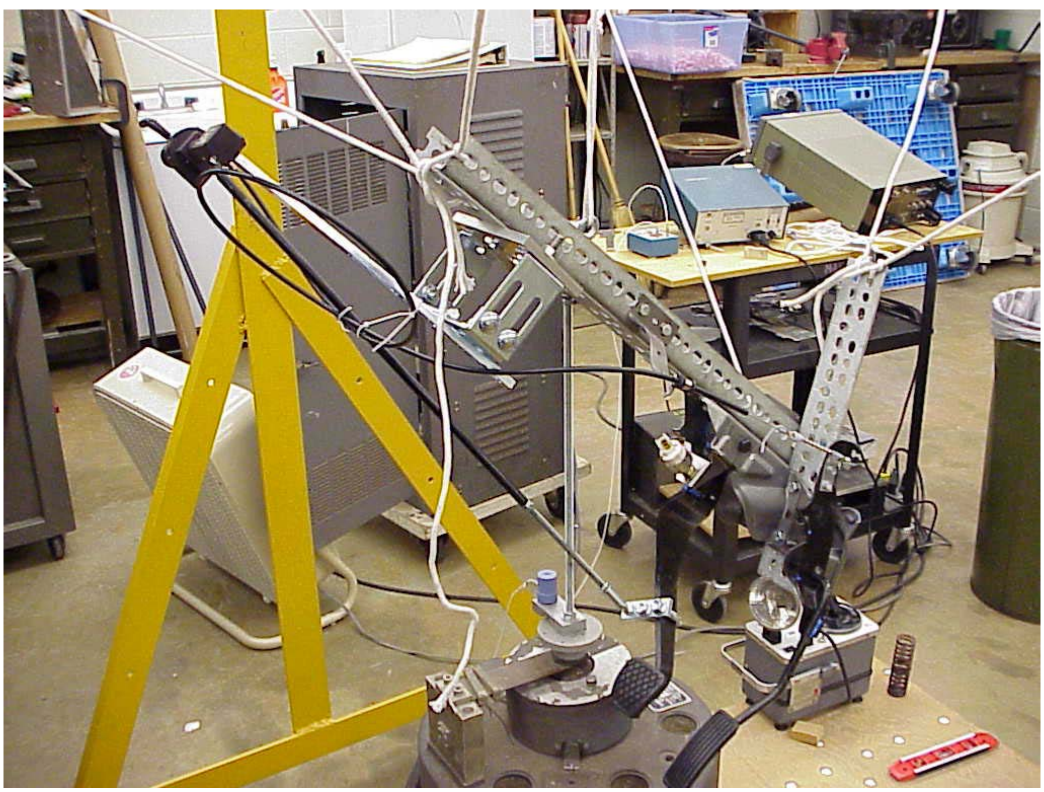


Photo #14 (Wells-Engberg CT-100: Vibration Test)

Wells-Engberg CT-100

Appendix B

Photographic Coverage of 1st Electromechanical Environmental Test

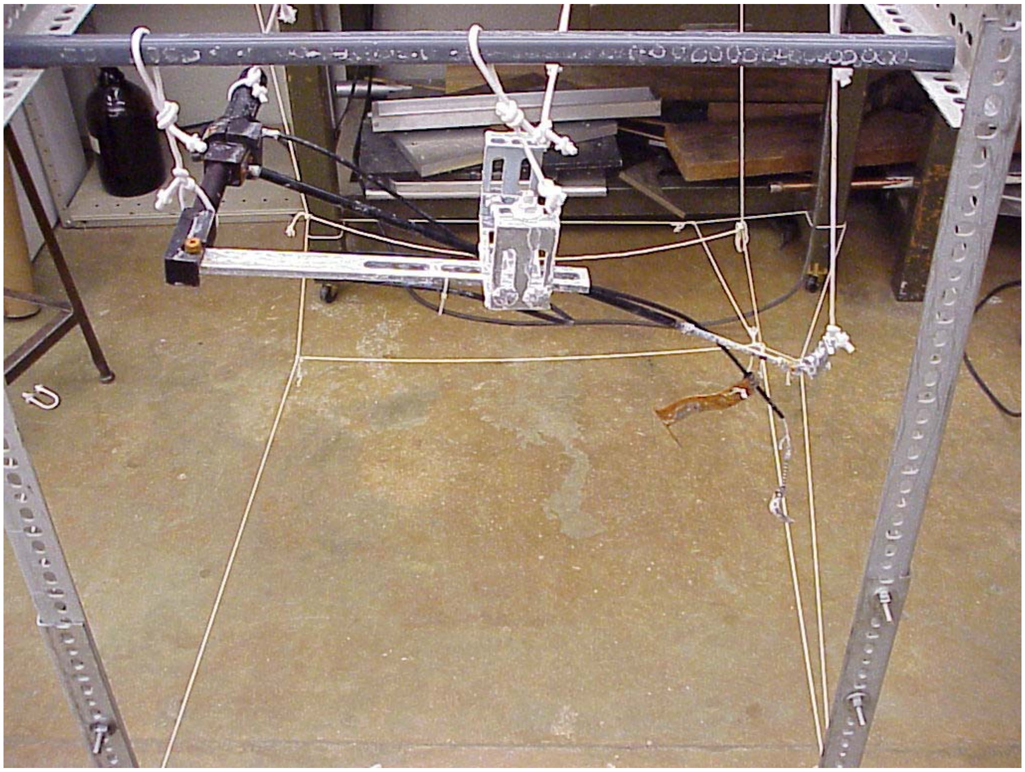


Photo #1 **(Wells-Engberg CT-100: 1st Environmental Test)**

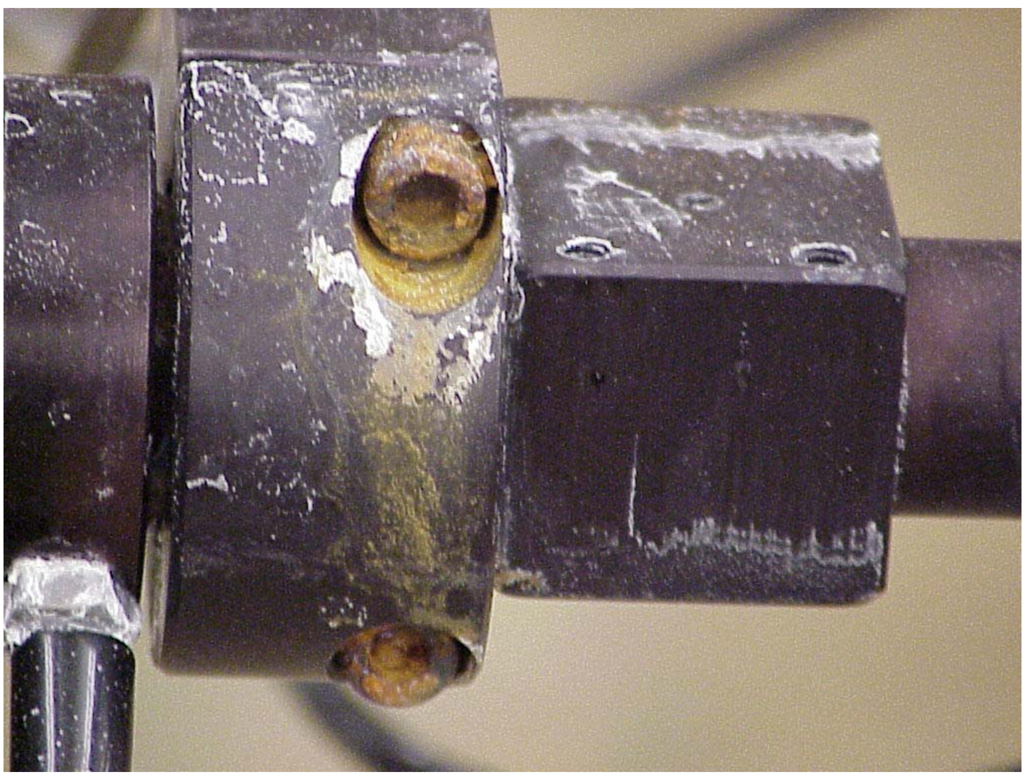


Photo #2 **(Wells-Engberg CT-100: 1st Environmental Test)**

Photo #3 **(Wells-Engberg CT-100: 1st Environmental Test)**

Photo #4 **(Wells-Engberg CT-100: 1st Environmental Test)**

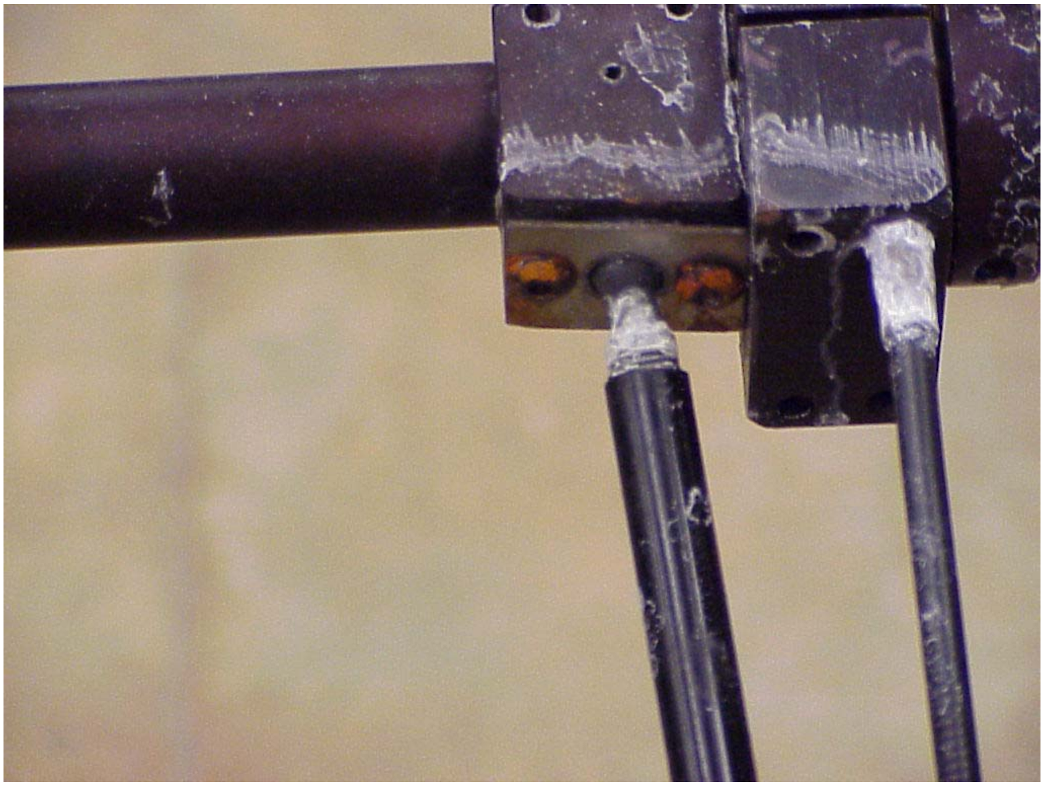


Photo #5 **(Wells-Engberg CT-100: 1st Environmental Test)**

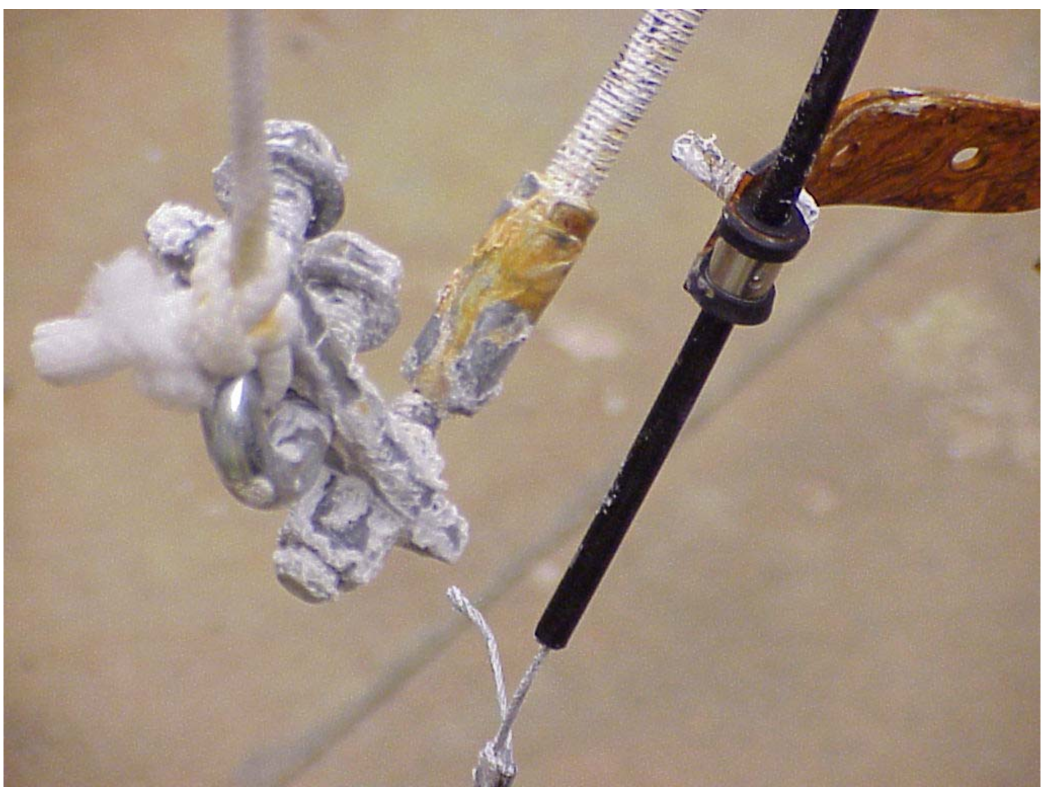


Photo #6 **(Wells-Engberg CT-100: 1st Environmental Test)**

Wells-Engberg CT-100

Appendix C

Photographic Coverage of 2nd Electromechanical Environmental Test

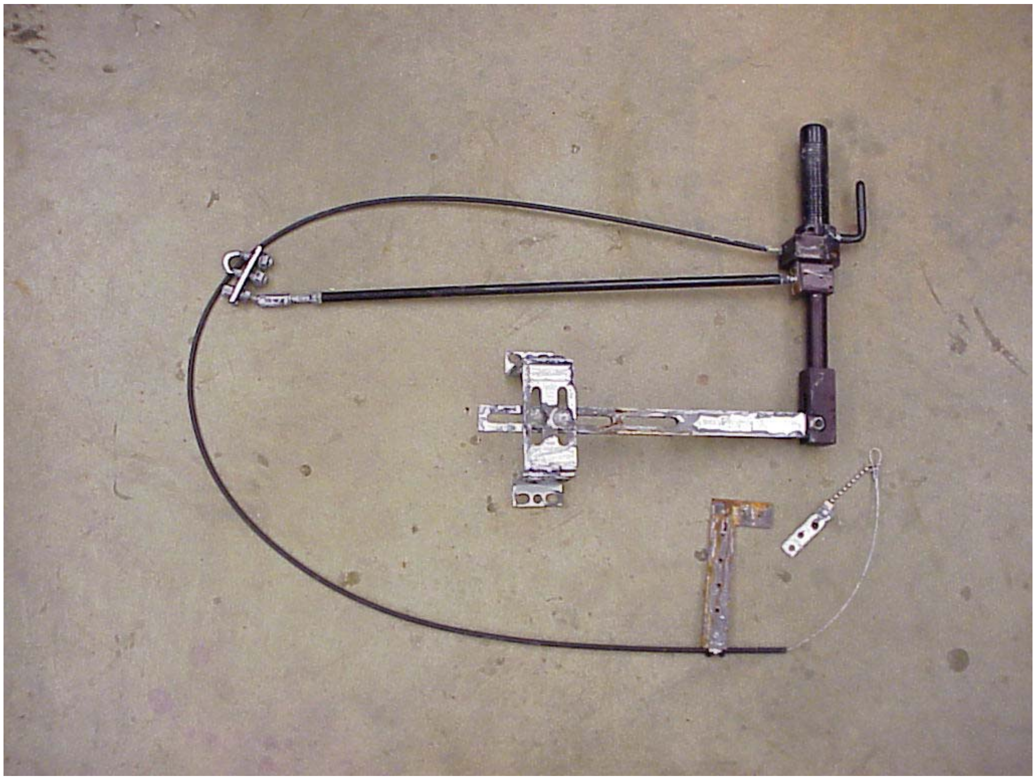


Photo #1 **(Wells-Engberg CT-100: 2nd Environmental Test)**

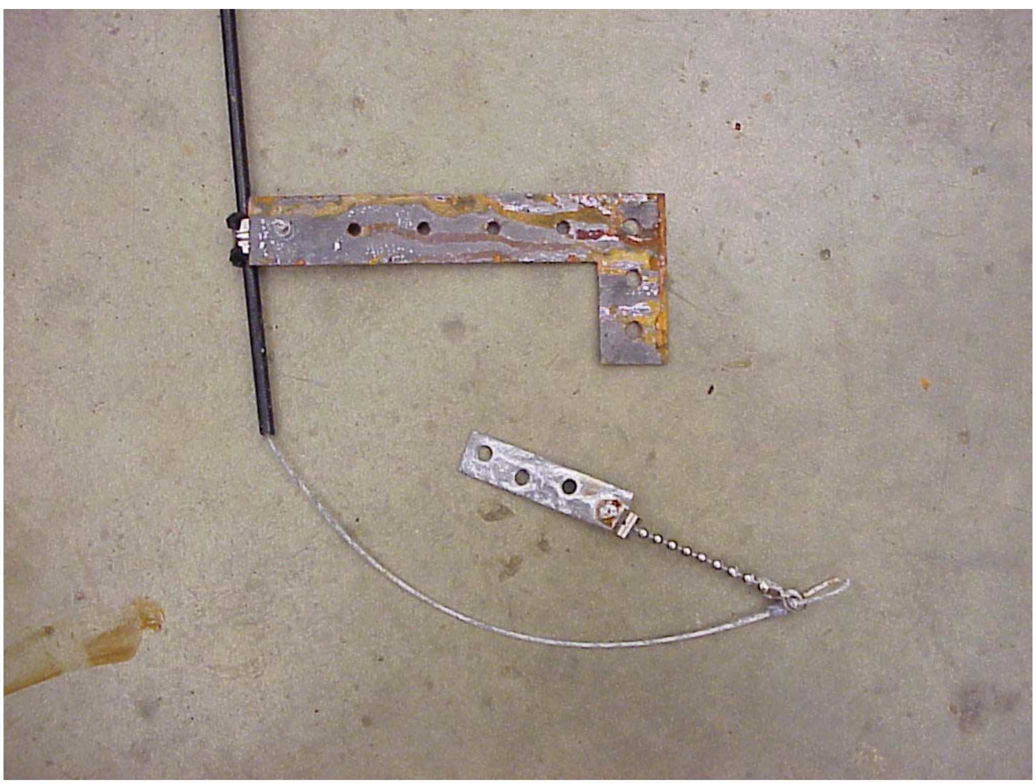


Photo #2 **(Wells-Engberg CT-100: 2nd Environmental Test)**

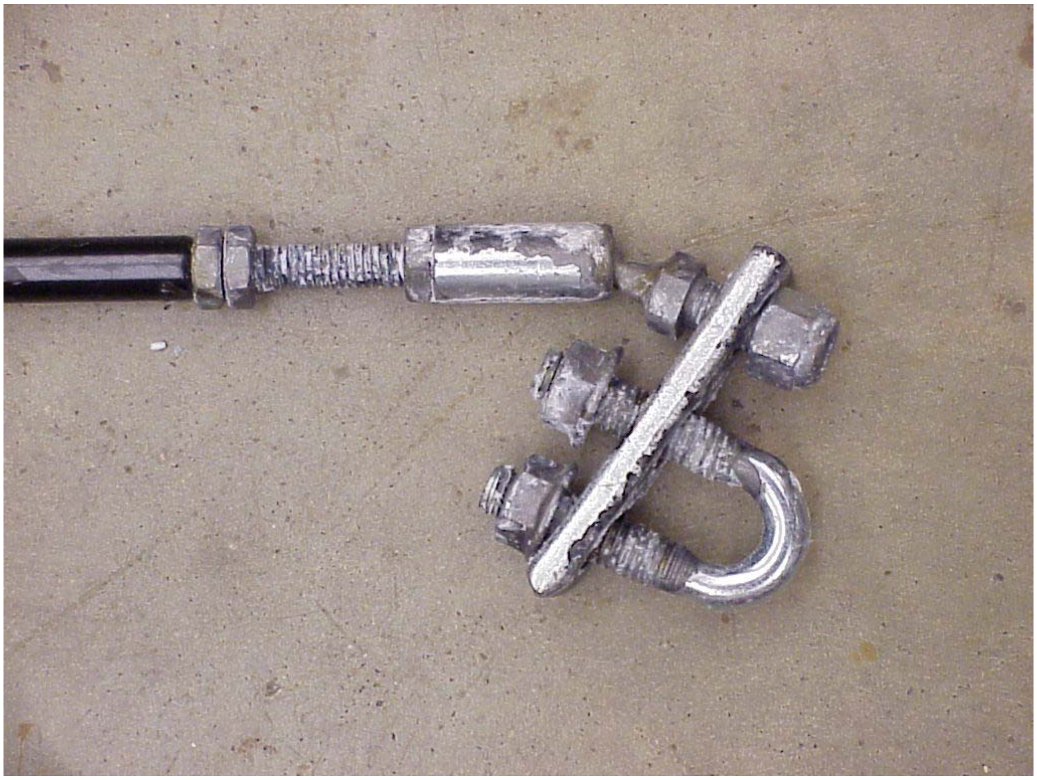


Photo #3 **(Wells-Engberg CT-100: 2nd Environmental Test)**

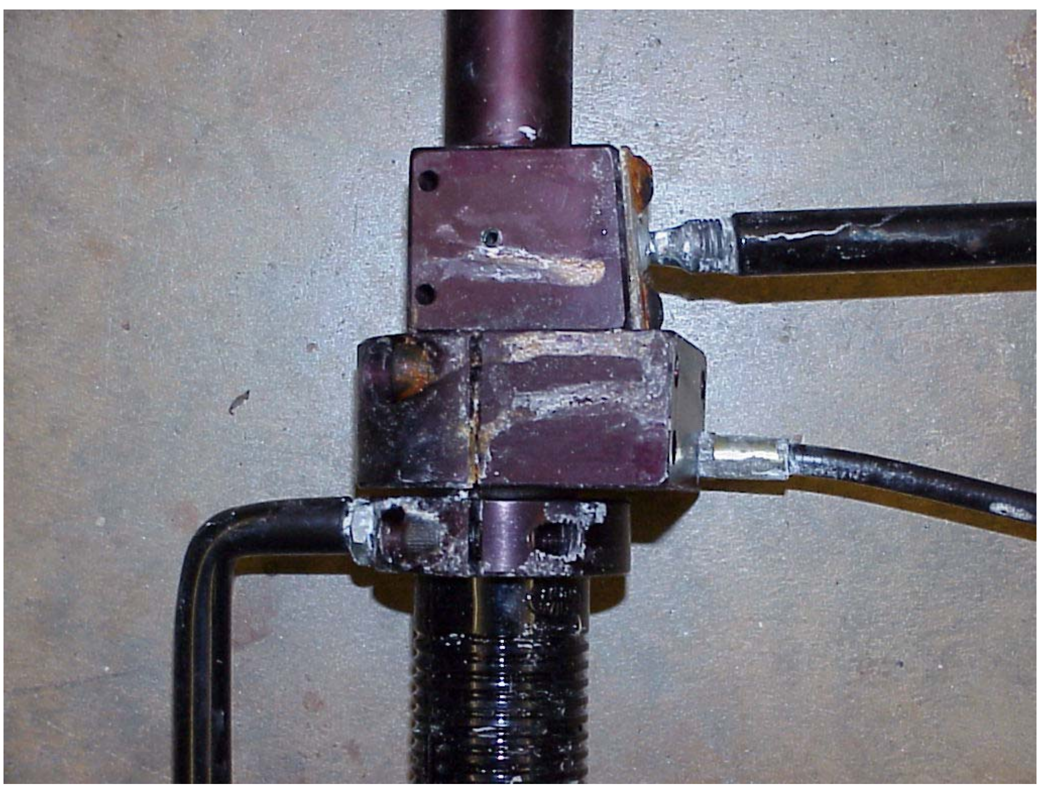


Photo #4 **(Wells-Engberg CT-100: 2nd Environmental Test)**

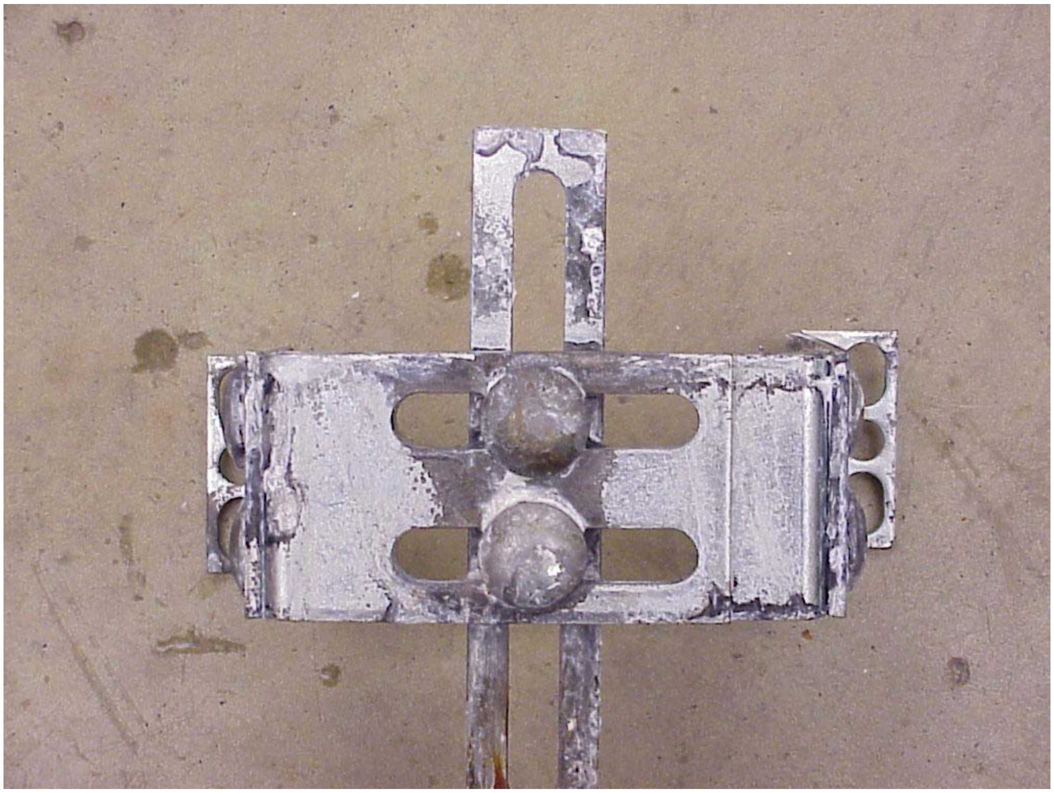


Photo #5 **(Wells-Engberg CT-100: 2nd Environmental Test)**

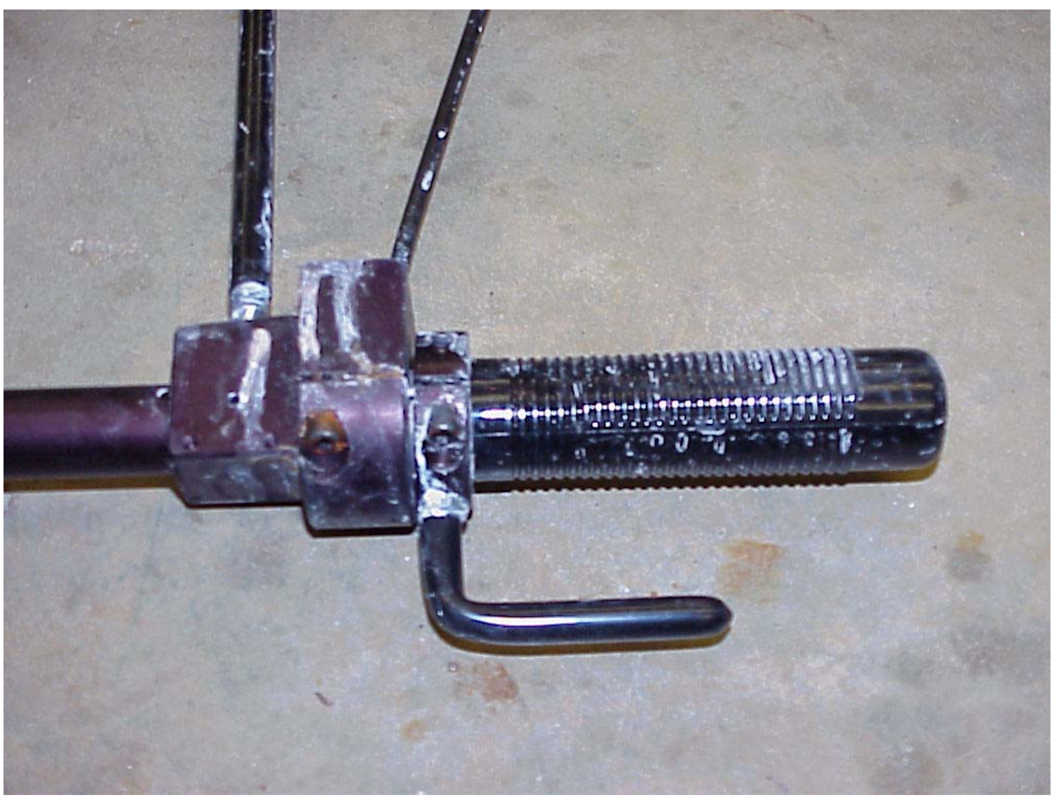


Photo #6 **(Wells-Engberg CT-00: 2nd Environmental Test)**

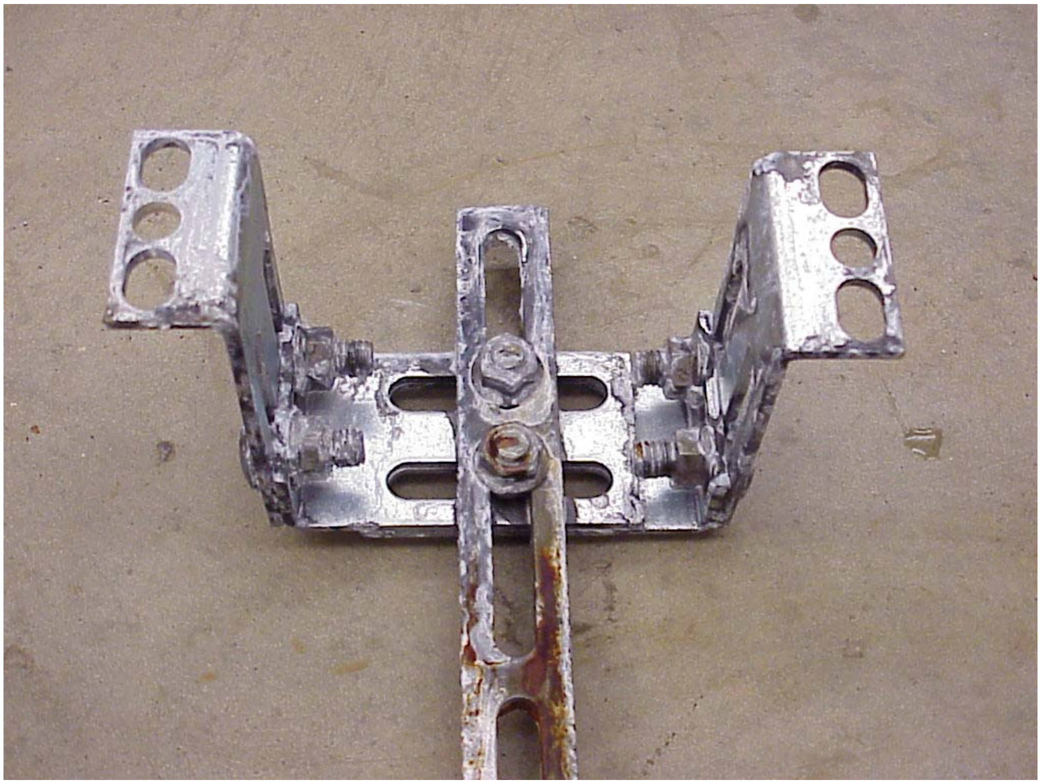


Photo #7 (Wells-Engberg CT-100: 2nd Environmental Test)

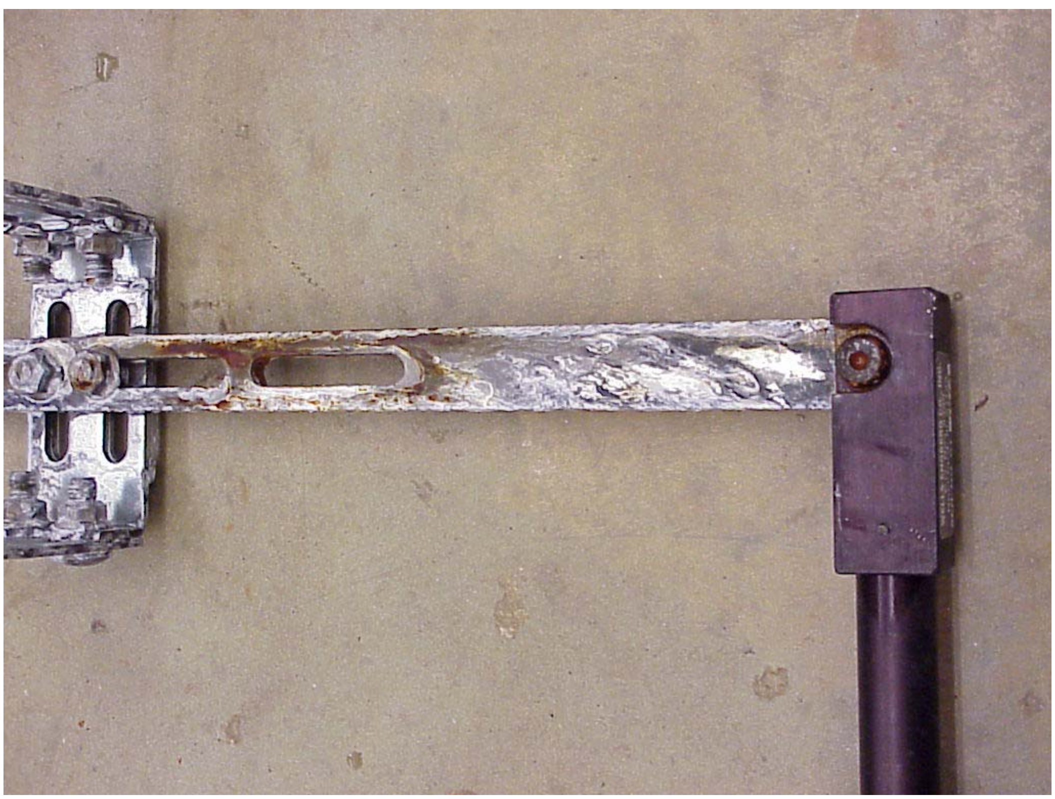


Photo #8 (Wells-Engberg CT-100: 2nd Environmental Test)

Wells-Engberg CT-100

Appendix D

Photographic Coverage of High-Cycle Test

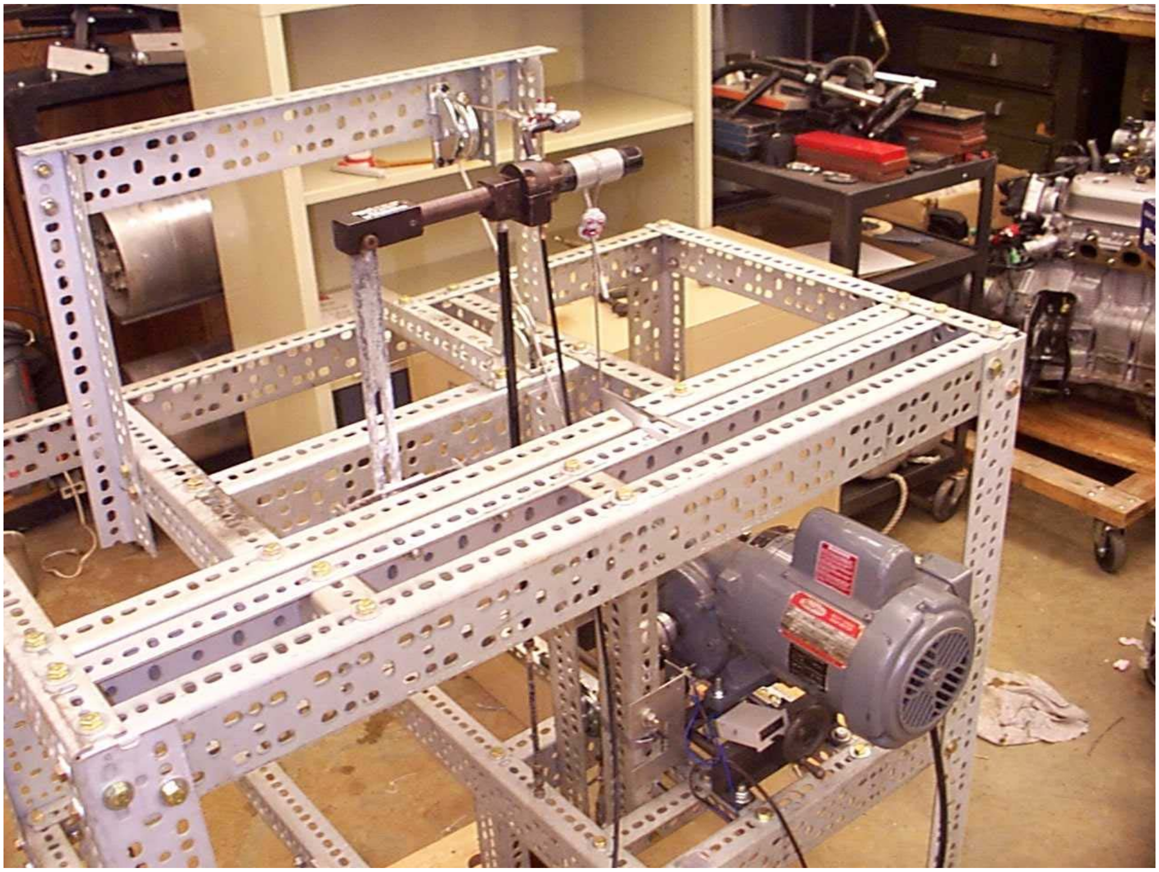


Photo #1 **(Wells-Engberg CT-100: High-Cycle Test)**

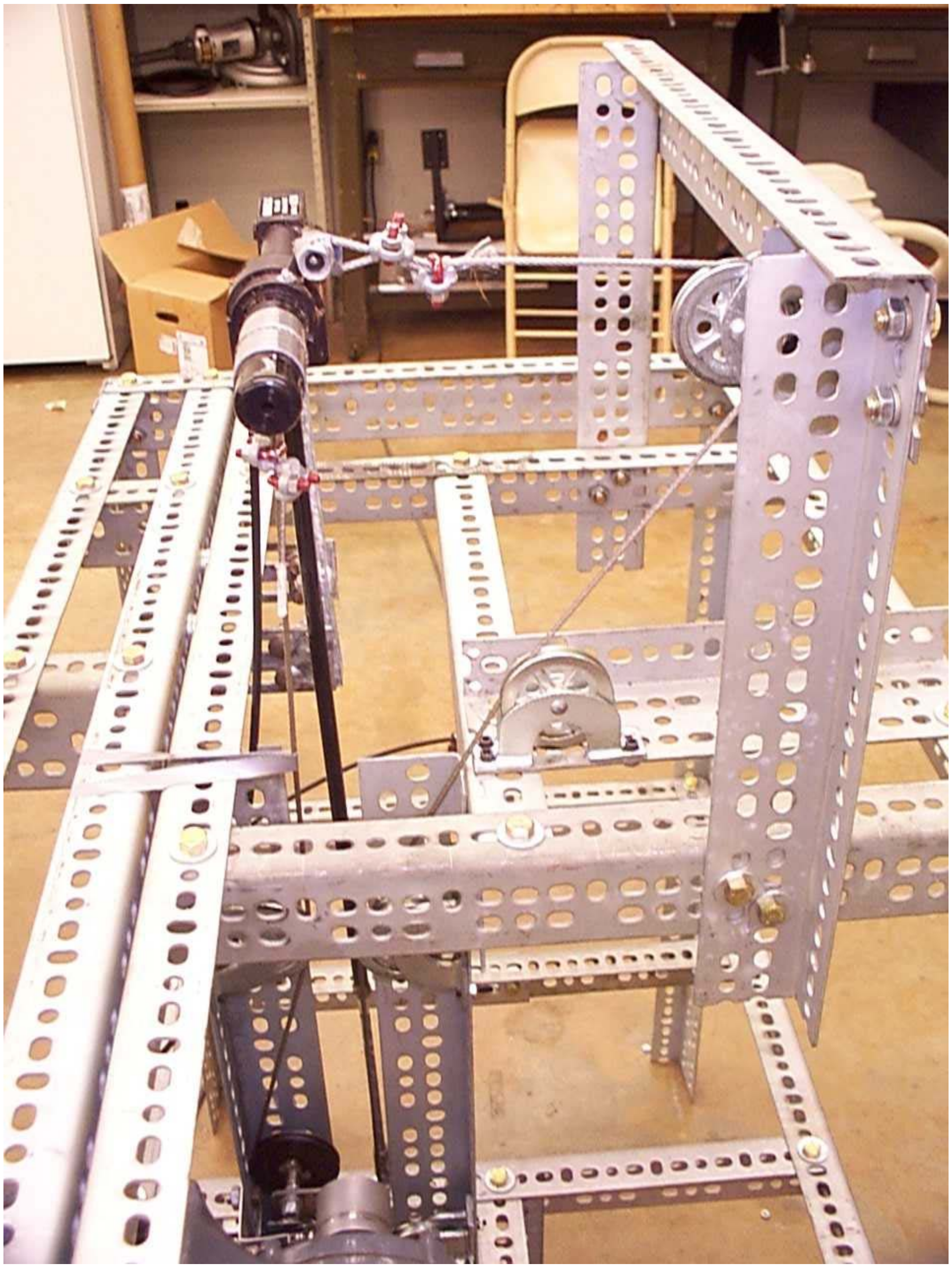


Photo #2 (Wells-Engberg CT-100: High-Cycle Test)

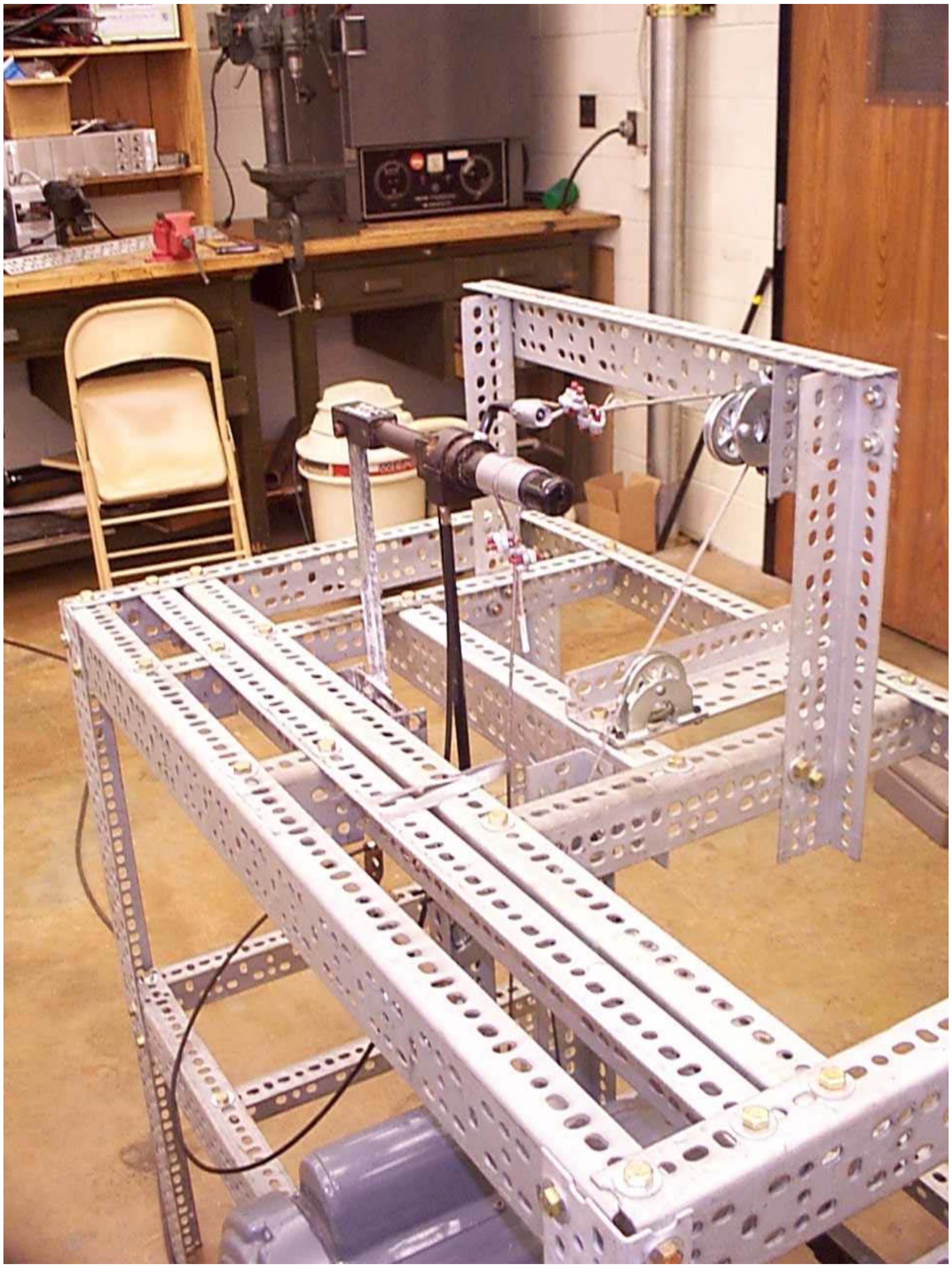


Photo #3 (Wells-Engberg CT-100: High-Cycle Test)

Wells-Engberg CT-100

Appendix E

Detailed Test Data Sheets for High-Cycle Test

Cycle Testing

Wells-Engberg

Date	Time	Event	Count	
07/13/99	4:05P	Start	0	
	10:27P	Stop	11760	
07/14/99	8:57A	Start	11760	
	11:59P	Stop	38775	
07/15/99	8:20a	Start	38775	**Note:** Hand control checked at 50,000
	6:20P	Stop	58570	cycles with no damage or loosening of fasteners
07/16/99	8:55A	Start	58570	
	2:20P	Stop	68320	
07/19/99	8:35A	Start	68320	
	11:59P	Stop	96040	
07/20/99	12:01A	Start	96040	**Note:** Hand control checked at 100,000
	11:59P	Stop	139180	cycles with no damage or loosening of fasteners
07/21/99	12:01A	Start	139180	**Note:** Hand control checked at 150,000
	10:35P	Stop	181762	cycles with no damage or loosening of fasteners
07/22/99	9:02A	Start	181762	**Note:** Hand control checked at 200,000
	9:41P	Stop	215956	cycles with no damage or loosening of fasteners
07/23/99	8:35A	Start	215956	
	5:18P	Stop	231620	
07/25/99	11:38A	Start	231620	
	6:54P	Stop	244759	
07/26/99	8:30A	Start	244759	**Note:** Hand control checked at 250000
	11:28A	Stop	250000	cycles with no damage or loosening of fasteners

Wells-Engberg CT-100

Appendix F

SAE J1903 Section 5 Summary

Model: CT-100 Rotary Hand Operated Driving Command
Manufacturer: Wells-Engberg Co., Inc.
P.O. Box 6388
Rockford, IL 61125
(800)-642-3628

Section 5: Inspection and Testing Procedures

5.1 Receiving Inspection

5.1.1 Packaging Integrity

Package was received with no damage.

5.1.2 Packing Documentation

Product was identified adequately

Model	*CT-100*
Serial No.	*6959*
Manufacturer	*Wells-Engberg Co., Inc.*

5.1.3 Verification of Contents

a. Product Identification
Model identification not found on the product

b. Quality Control Verification
Quality control verification was found

c. Warranty Information
Warranty information provided

d. Compliance Documentation as Required
No compliance information provided

e. Installation Instructions
Installation instructions provided in manual

f. Operating Instructions
Operating instructions provided in manual

g. Maintenance Instructions
Maintenance instructions provided in manual

h. Limitations
Limitation not defined in SAE J1903

i. Notifications
Notification was provided but not detailed

5.1.4 Workmanship

Workmanship of product was adequate

5.2 Mounting

5.2.1 Verification of Installation Procedures

Mounting adequately described in manual. Product was installed in a '98 Ford Taurus sled buck with minimal effort.

5.2.2 Adjustments

Adjustments to the product are adequate and can be locked in position.

5.2.3 Compatibility

All fasteners present were compatible

5.2.4 Human Factors

Human factors are adequate (push for brake / rotate down for throttle)

5.2.5 Contact Hazards

No contact hazards were apparent

5.2.6 Maintainability

Service maintenance is described in manual with lubrication and adjustment points easily accessible.

5.3 Installation

5.3.1 Vehicle Alterations

When installed in the '98 Ford Taurus sled buck, the hand control requires alterations to the knee bolster which, according to 4.2.1 of SAE J1903, possibly interferes with the function of the occupant protection features provided by the motor vehicle manufacturer under FMVSS.

5.3.2 Operation

Operating instructions are provided in the manual.

5.3.3 Conventional Use

No obvious obstructions noted.

5.3.4 Mounting

Mounting location is strong and secure.

5.3.5 Neutral Balance

The product will not activate the vehicle due to force by its own mass . This was not verified in an actual vehicle as specified by SAE J1903.

5.4 Performance Tests

As prescribed in SAE J1903, the vibration, environmental, high-cycle, and service overload tests were conducted on a single unit in the prescribed order.

5.4.1 Vibration Test

Vertical direction

Start:	*!2:05PM*	*1/19/99*
Stop:	*2:05PM*	*1/19/99*
Outcome:	*No loose connections found*	

Horizontal direction

Start:	*2:20PM*	*1/19/99*
Stop:	*4:25PM*	*1/19/99*
Outcome:	*No loose connections found*	

5.4.2 Electromechanical Environmental Test

Product was tested in accordance with ASTM B 117.

Post-test observations:

Corrosion of fastener connecting the brake tube to the control tube.

Corrosion on the main support bracket.

5.4.3 High-Cycle Test

No degradation of the product was noted throughout the high-cycle test.

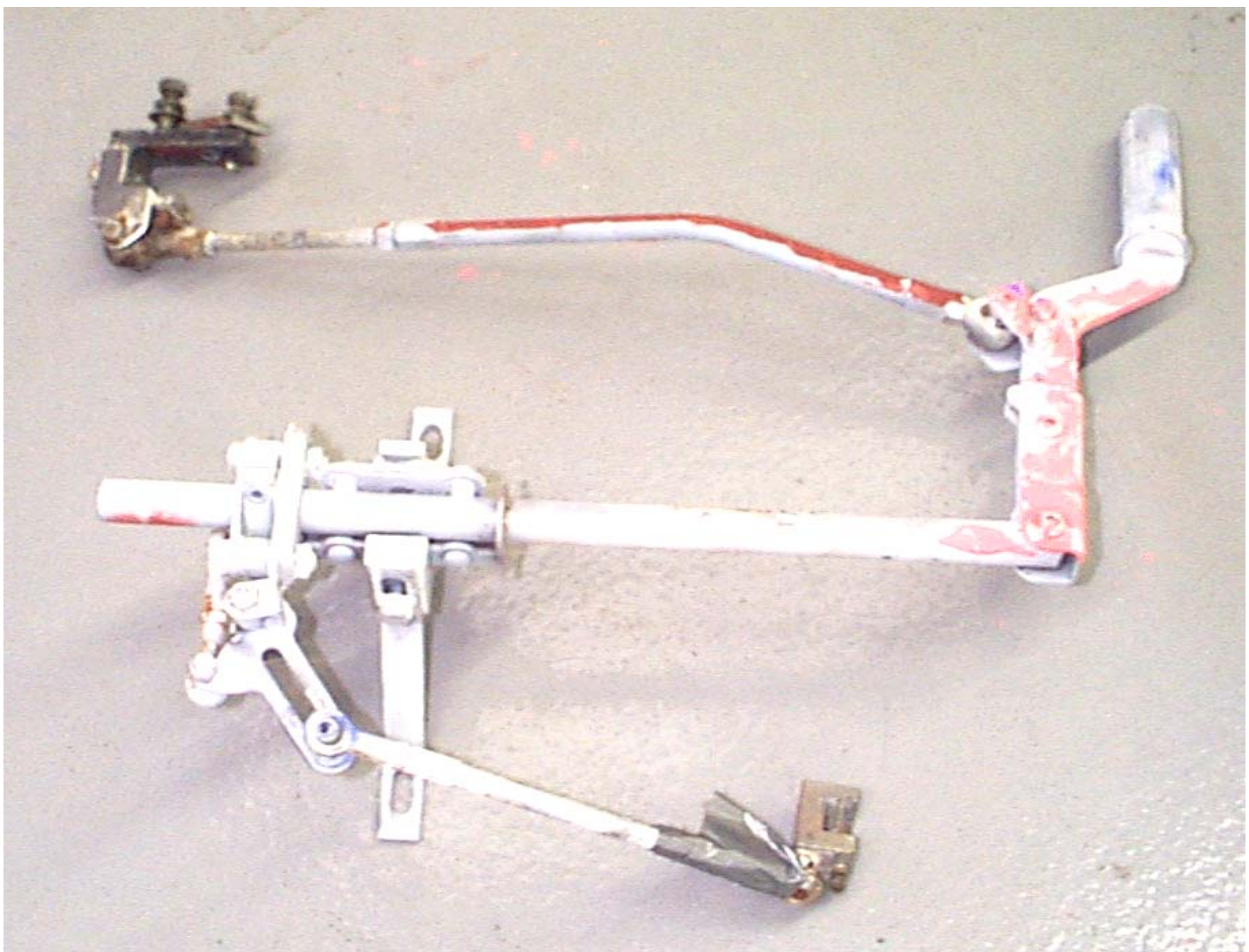
5.4.4 Service Overload

The hand control held the required braking and acceleration loads.

SAE J1903
Recommended Practice Automotive Adaptive Driver Controls, Manual
1990 Revision

Test Results

Model:	**Monarch Mark 1A**
Manufacturer:	**Manufacturing and Production Services Corp.** **7948 Ronson Road** **San Diego, CA 92111** **(800)-243-4051**



Summary of Test Results in Accordance with SAE J1903 Section 4 and Section 5

- **Introduction**

Several hand control devices for automobiles were submitted for evaluation in accordance with SAE J1903. Section 1 through Section 3 can be categorized as design and definition, and thus will not be addressed in this report. The compliance of this product to Section 4 and Section 5 of SAE J1903 is summarized in this report.

Section 4: Requirements

- **Procedure**

Using the documentation provided by the manufacturer and the test results from Section 5, each item in Section 4 was addressed. Any and all points of failure of this hand control were noted.

- **Points of Failure**

In the interest of brevity, only deficient items related to Section 4 will be addressed here.

4.1.1 Model number was not identified on the product.
4.1.6 d No signs of possible malfunction were noted in the documents.
4.1.6 e No actions to be taken in the event of product failure were noted in the documents.
4.2.1 As described in the installation manual, some component mounting may require alteration to the knee bolster. Because it is an integral part of the general crashworthiness of a vehicle, alteration of the knee bolster has the potential to impact FMVSS.
4.2.7 See above.
4.6.3 Some degradation or loss of surface finish was noted after the electromechanical environmental test.

Section 5: Inspection and Testing Procedures

• Procedure

Using the documentation provided by the manufacturer and the test results from Section 5, each item in this section was addressed. Any and all points of failure of this hand control were noted.

• Points of Failure

In the interest of brevity, only deficient items related to Section 5 will be addressed here.

5.1.3a Model number not identified on product
5.4.2 The product presented several surfaces of corrosion that could be contacted by the operator.

• Test Procedure and Test Setup General Descriptions

Vibration Test:

The hand control product was rigidly mounted in a test rig. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. At the end of each session, the product was inspected for damage and any loosening of fasteners.

Electromechanical Environmental Test:

The hand control product was suspended in a corrosion chamber by small ropes and subjected to corrosion testing in accordance with ASTM B117-97.
The electromechanical environmental test was run a second time to confirm test results. No significant changes in results were noted in the second test.

High-Cycle Test:

For the high-cycle test, each hand control product was rigidly mounted in a testing frame. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 50lb weight was connected to the cable attached to the brake. A 10lb weight was connected to the cable attached to the accelerator. A motor, with an eccentric, then rotated, alternately lifting each weight off of the ground. The loading was applied alternately between the braking direction and the accelerator direction. At multiples of 50,00 cycles, the unit was inspected for damage and loose fasteners. The total number of cycles performed was 250,000.

Service Overload:

The hand control was mounted in the testing frame in the same manner as in the high-cycle test. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 10lb weight was applied to the accelerator cable for a minimum period of 30 seconds. After the removal of the accelerator load, the brake load was applied. Three 50lb weights were used to apply the total load of 150lb. The weights were applied as carefully as possible to minimize any dynamic effects.

- <u>**Mechanical Testing Results Summary**</u>

Two areas of failure for this hand control were observed under section 5.4.2 and section 4.6.3. Section 5.4.2 and section 4.6.3 are related, so this really constitutes one failure that is addressed under two different sections..

Section 5.4.2 states "…and shall not present any corrosion products to surfaces that can be contacted by the driver (see 4.6.3)." As can be seen in the photographs in Appendix B, there were several areas of failure.

Section 4.6.3 states "…the product shall continue to function without exhibiting degradation or loss of surface finish…". Several areas of the hand control, documented in Appendix B, exhibited loss of surface finish.

- <u>**Mechanical Testing Detailed Results**</u>

<u>**Vibration Test:**</u>

The vibration tests were carried out on January 19, 1999. No failures or loosening of fasteners was noted.

<u>**Electromechanical Environmental Test:**</u>

The electromechanical environmental test was carried out in accordance with ASTM B 117-97. Photographs of the 1st test setup and of the post test product can be seen in Appendix A. Corrosion was evident in several areas which are detailed in Appendix A. The electromechanical environmental test was carried out a 2nd time with similar results. The photographic documentation of the 2nd test is contained in Appendix B.

<u>**High-Cycle Test:**</u>

The high-cycle test was carried out from June 11, 1999 to June 30, 1999. Inspections were made at 50,000 cycle intervals until the test unit reached the prescribed 250,000 cycles. No damage to the hand control device or loosening of fasteners was noted during any of the cycles. The overall function and rigidity of the hand control device was good throughout the high-cycle testing phase. A test log is contained in Appendix D. Photographic documentation of the Hand control in the testing apparatus is provided in Appendix C.

<u>**Service Overload**</u>*:*

The accelerator load of 10lb and the braking load of 150lb were held by the hand control with no apparent deformation or problems.

Monarch Mark 1A

Appendix A

Photographic Coverage of 1st Electromechanical Environmental Test

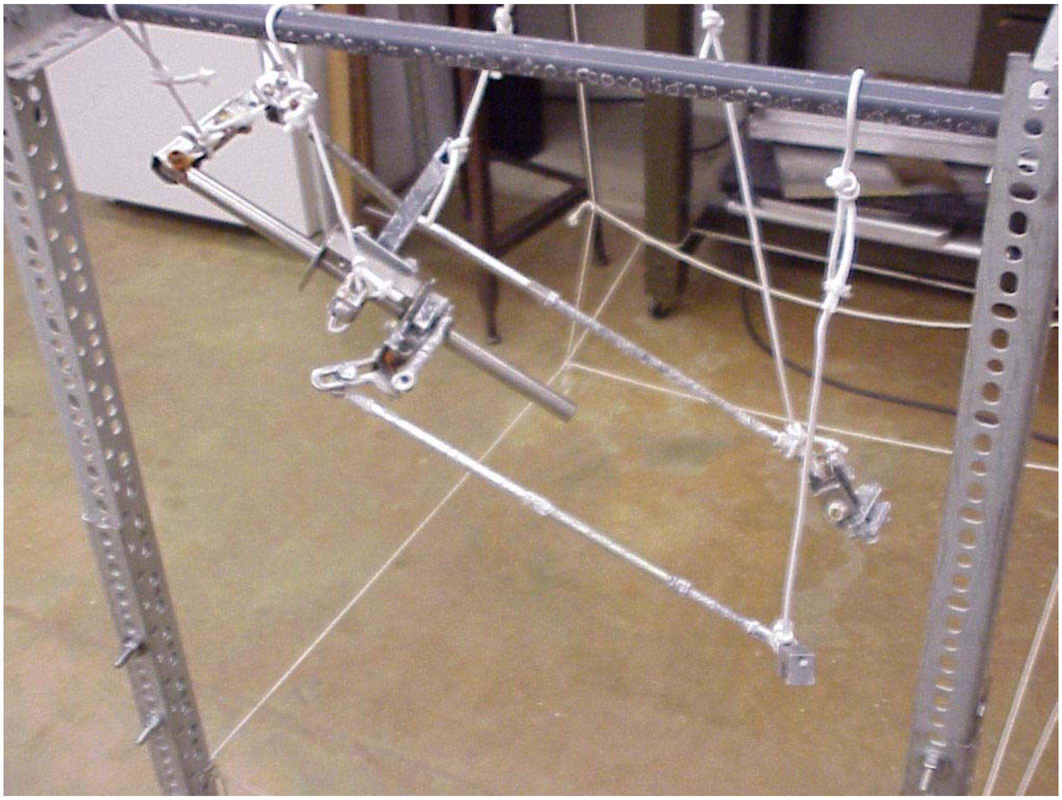


Photo #1 (Monarch Mark: 1st Environmental Test)

Photo #2 (Monarch Mark: 1st Environmental Test)

Photo #3 **(Monarch Mark: 1st Environmental Test)**

Photo #4 **(Monarch Mark: 1st Environmental Test)**

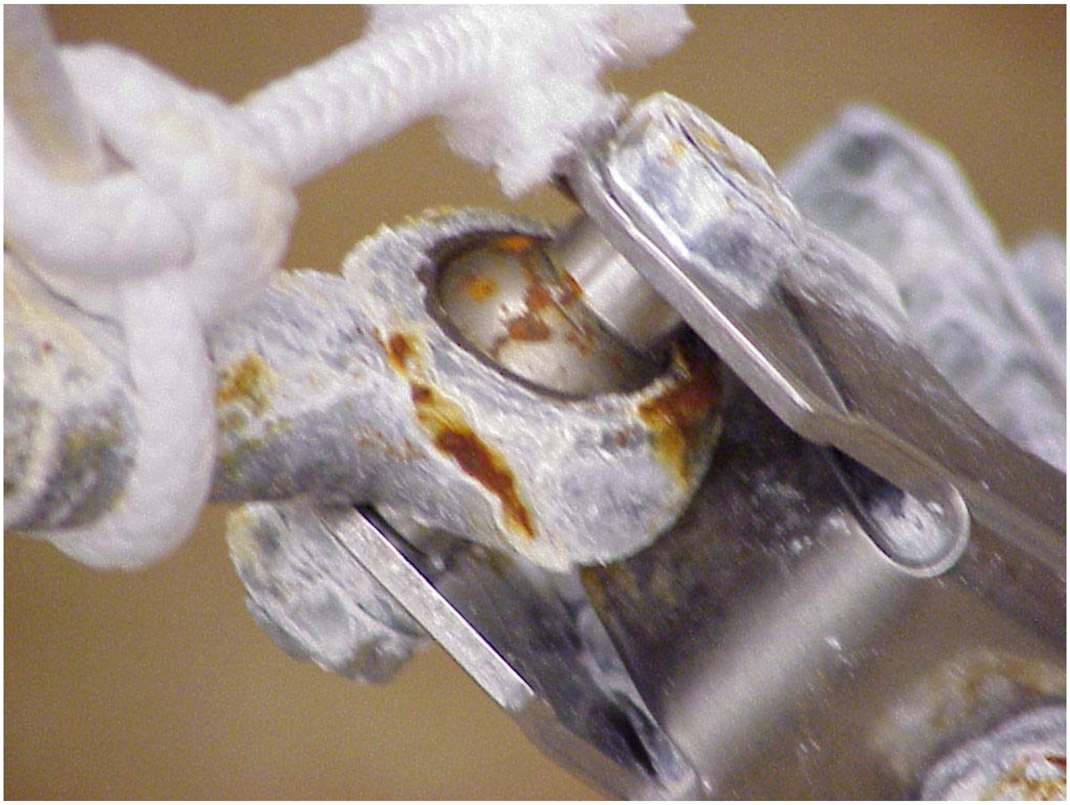


Photo #5 **(Monarch Mark: 1st Environmental Test)**

Monarch Mark 1A

Appendix B

Photographic Coverage of 2nd Electromechanical Environmental Test

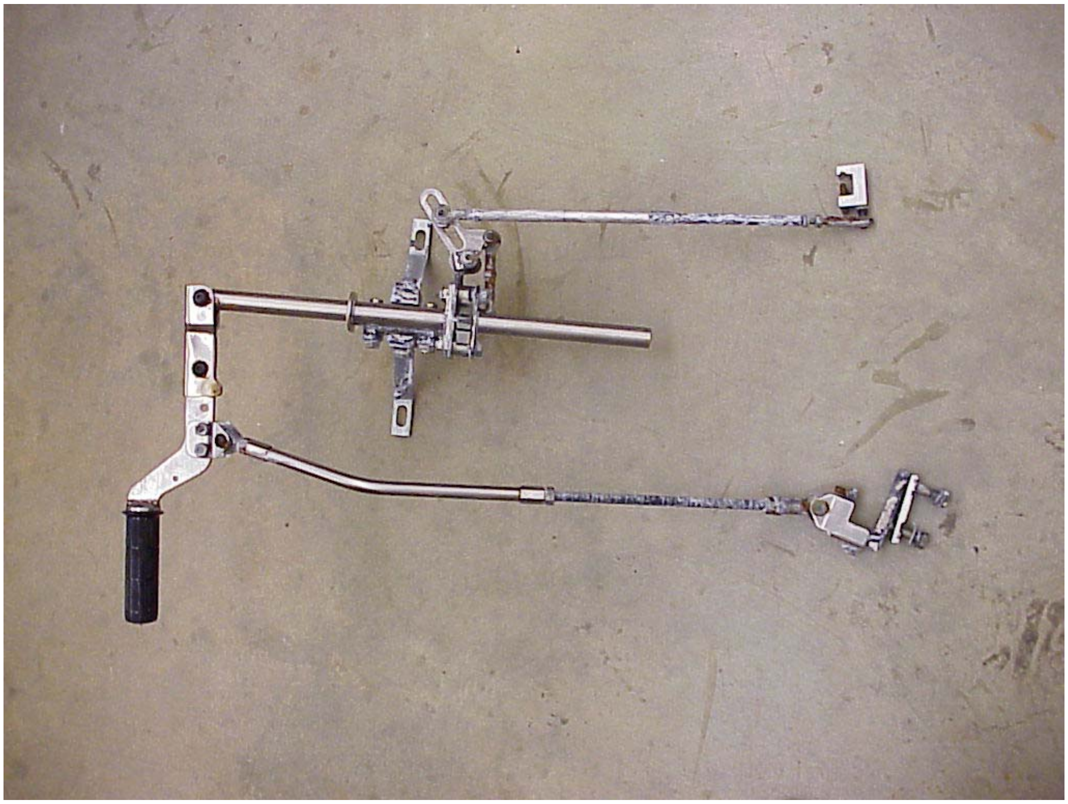


Photo #1 **(Monarch Mark: 2nd Environmental Test)**

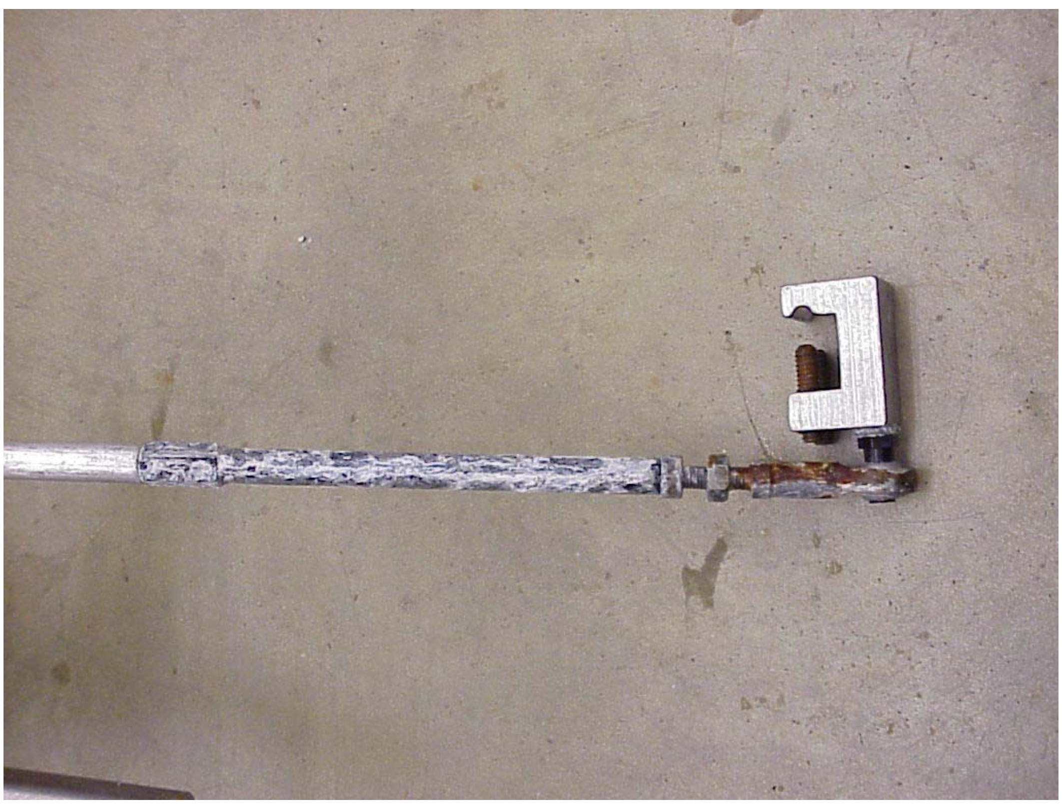


Photo #2 **(Monarch Mark: 2nd Environmental Test)**

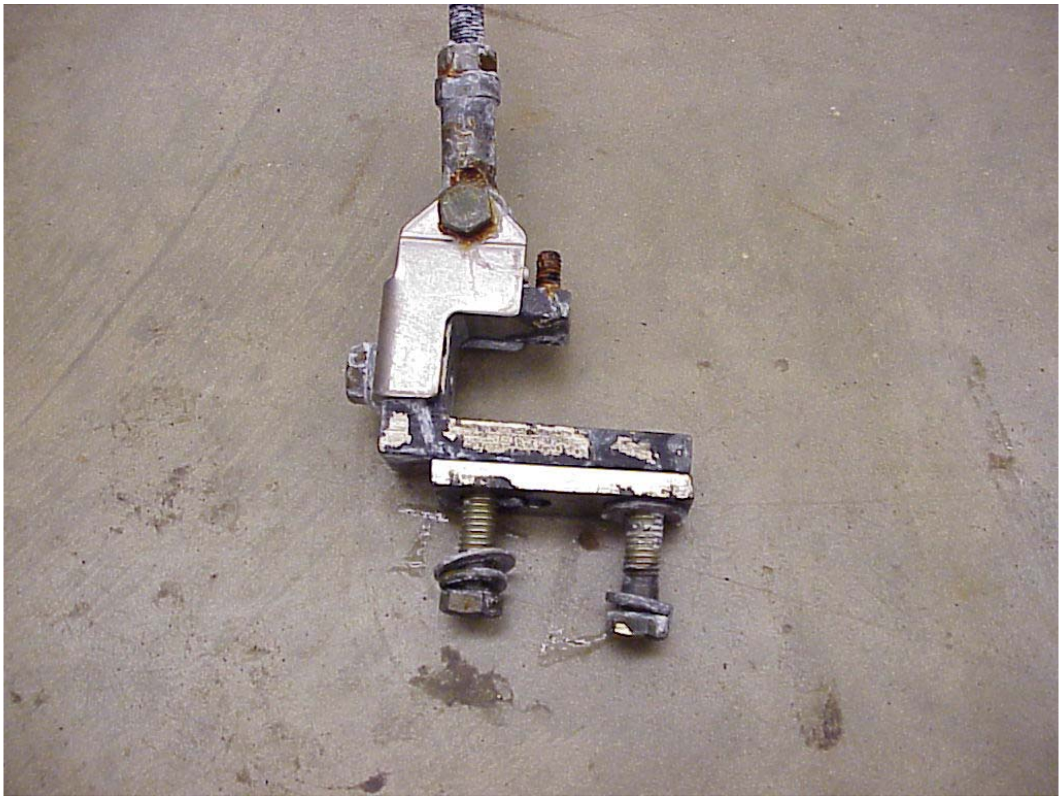


Photo #3 **(Monarch Mark: 2nd Environmental Test)**

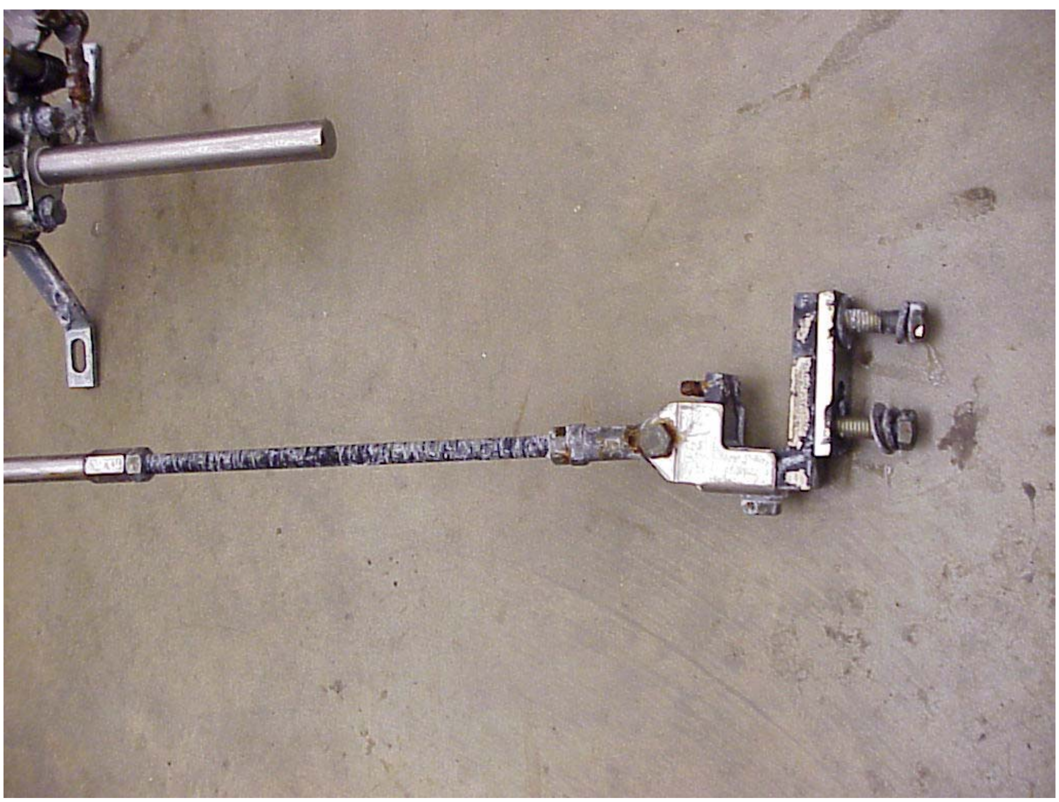


Photo #4 **(Monarch Mark: 2nd Environmental Test)**

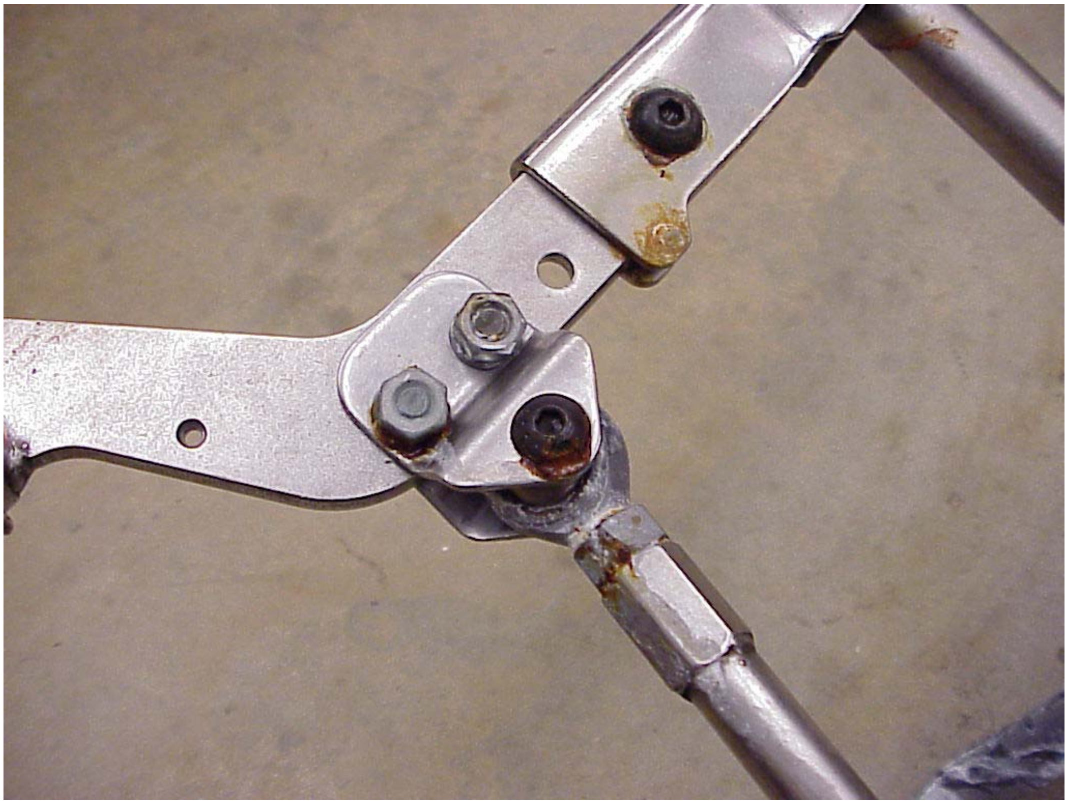


Photo #5 (Monarch Mark: 2nd Environmental Test)

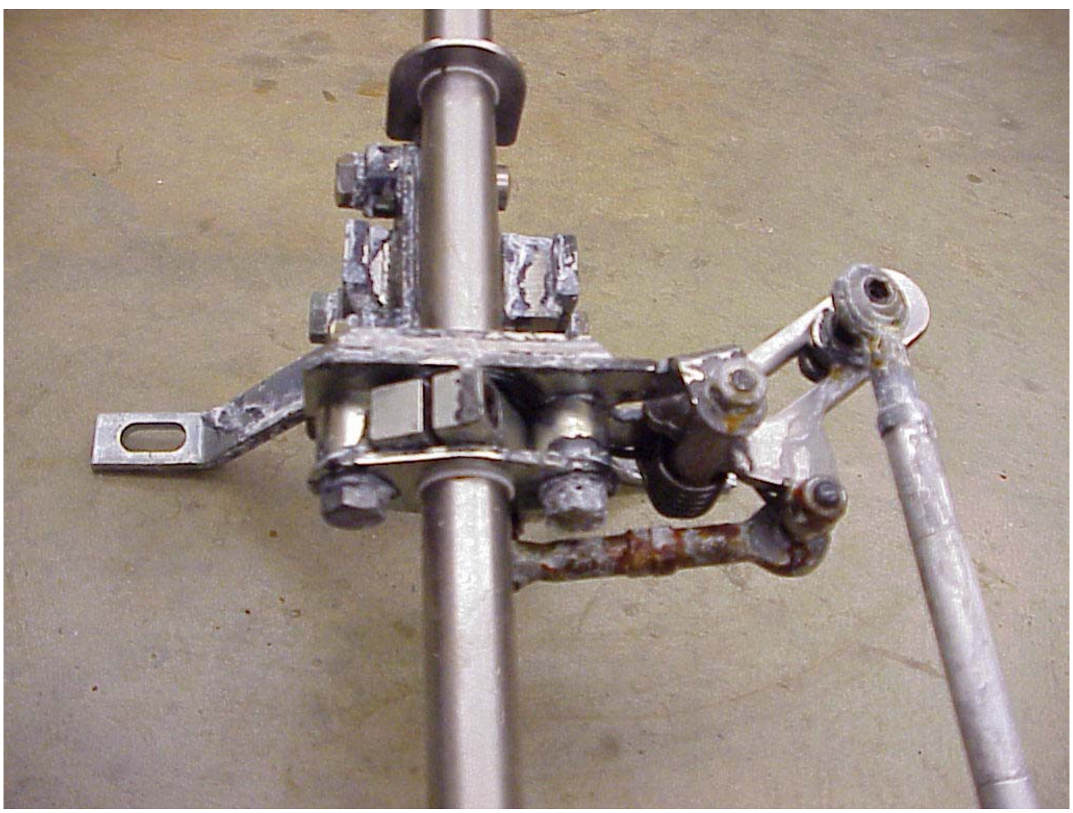


Photo #6 (Monarch Mark: 2nd Environmental Test)

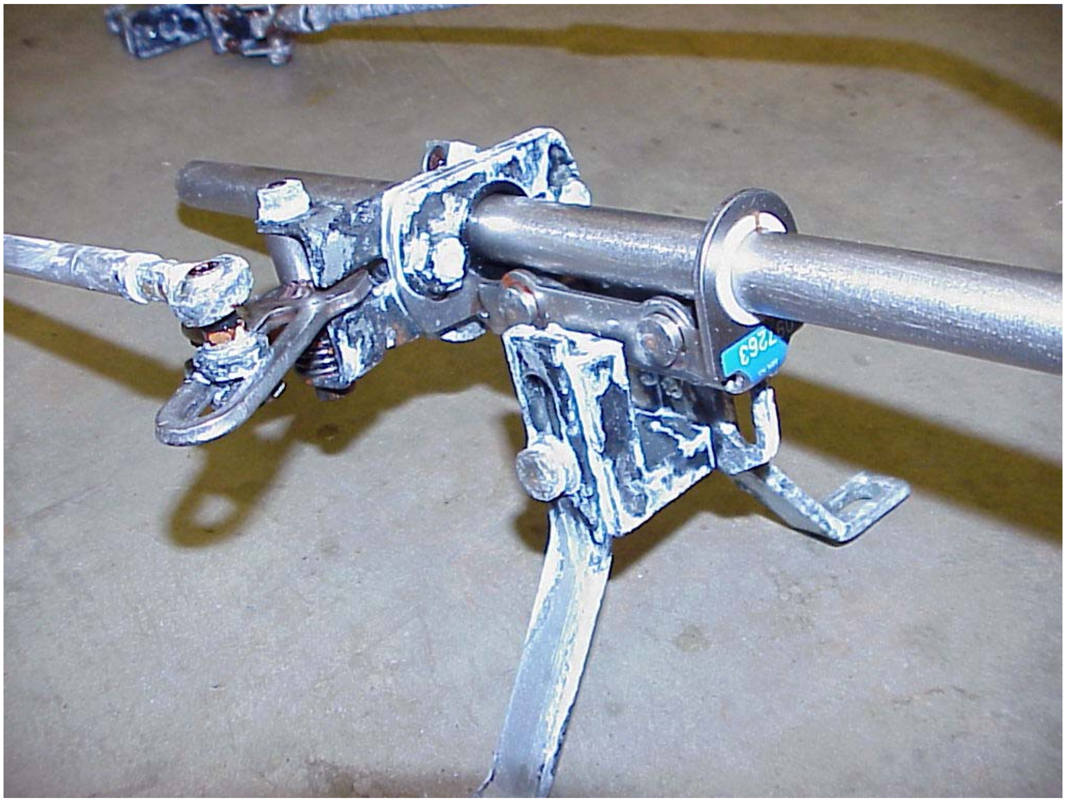


Photo #7 (Monarch Mark: 2nd Environmental Test)

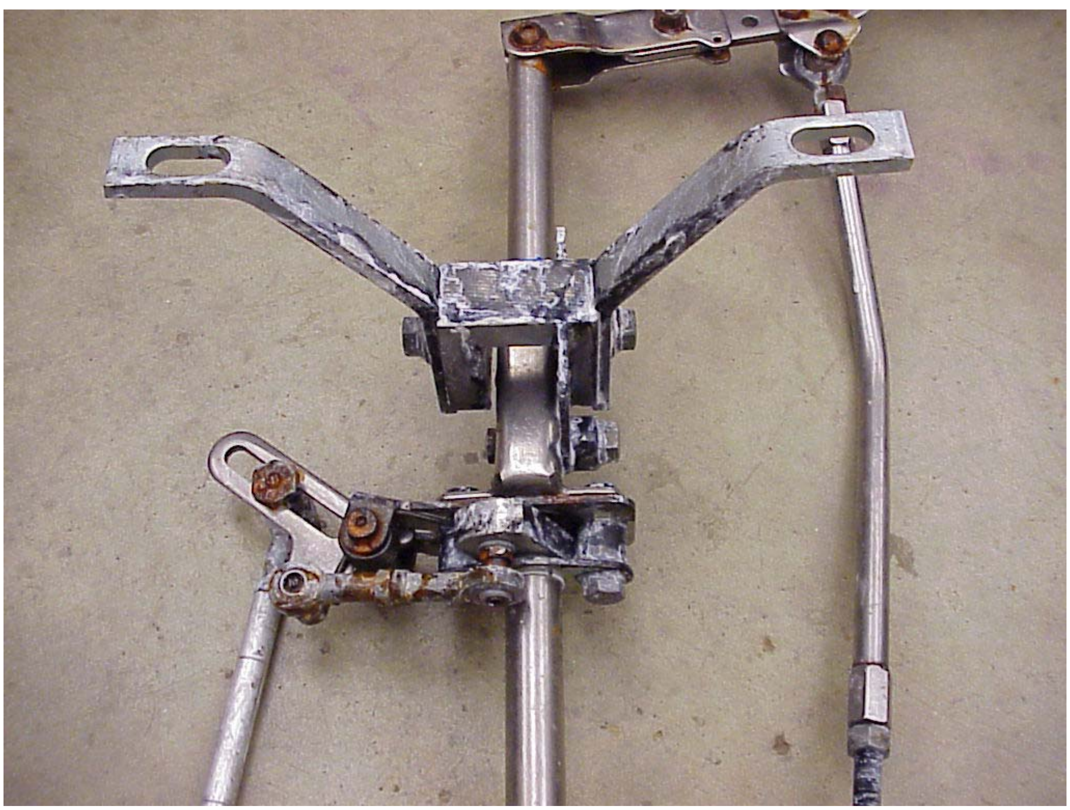


Photo #8 (Monarch Mark: 2nd Environmental Test)

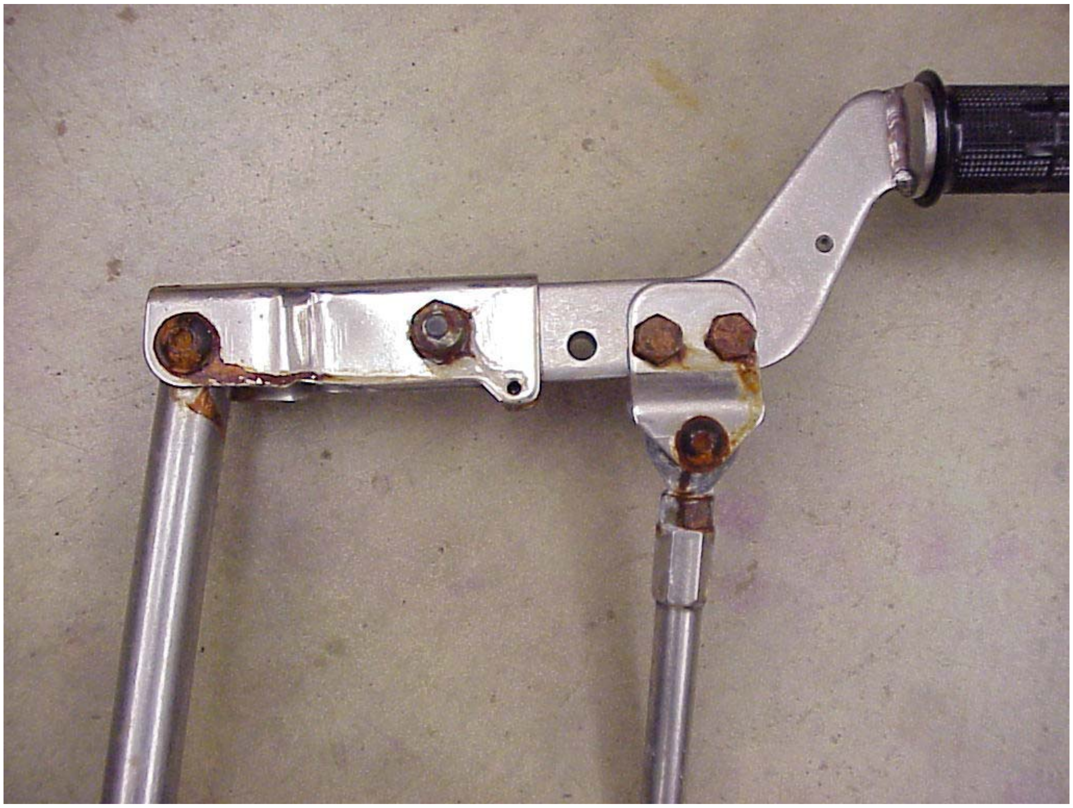


Photo #9 (Monarch Mark: 2nd Environmental Test)

Monarch Mark 1A

<u>Appendix C</u>

Photographic Coverage of High-Cycle Test

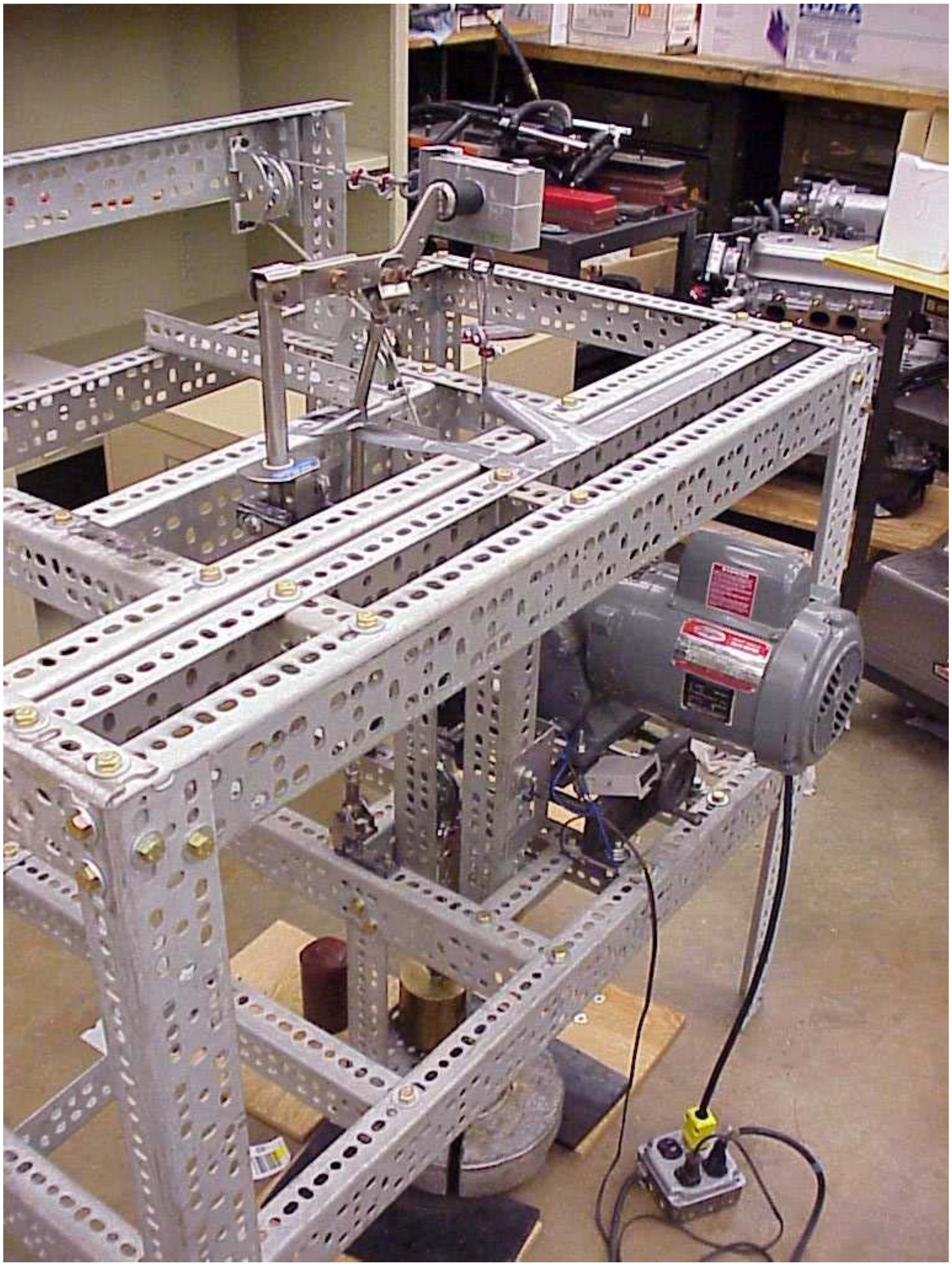


Photo #1 (Monarch Mark: High-Cycle Test)

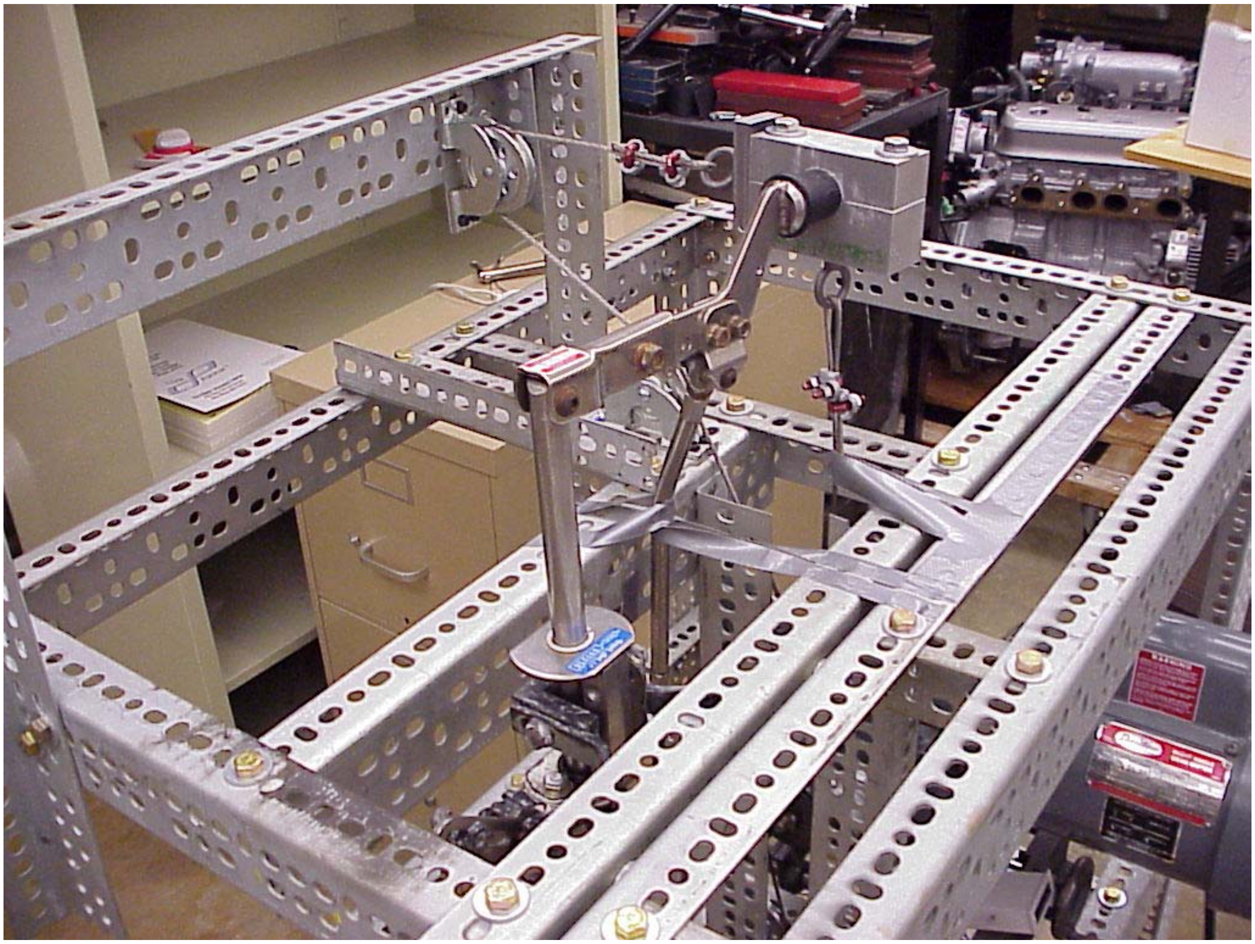


Photo #2 **(Monarch Mark: High-Cycle Test)**

Monarch Mark 1A

<u>Appendix D</u>

Detailed Test Data Sheets for High-Cycle Test

Cycle Testing
Monarch Mark 1A

Date	Time	Event	Count	
06/11/99	10:30A	Start	0	
	11:58A	Stop	2500	
	1:00P	Start	2500	
	2:11P	Stop	4350	
06/14/99	10:42A	Start	4350	
	11:52A	Stop	6502	
	1:50P	Start	6502	
	4:40P	Stop	11688	
06/15/99	8:38A	Start	11688	
	4:48P	Stop	26712	
06/16/99	8:45A	Start	26712	
	2:19P	Stop	36960	
06/17/99	8:40A	Start	36960	**Note:** Hand control checked at 50,000
	4:15P	Stop	50881	cycles with no damage or loosening of fasteners
06/18/99	8:52A	Start	50881	
	11:30A	Stop	55659	
	2:00P	Start	55659	
	3:00P	Stop	57513	
06/21/99	9:50A	Start	57513	
	4:10P	Stop	69194	
06/22/99	8:27A	Start	69194	
	11:30P	Stop	96884	
06/23/99	8:47A	Start	96884	**Note:** Hand control checked at 100,000
	10:45P	Stop	122669	cycles with no damage or loosening of fasteners
06/24/99	9:05A	Start	122669	
	9:10A	Stop	122836	**Note:** 50lb weight cable broke
	2:00P	Start	122836	
	10:45P	Stop	135914	
06/25/99	8:45A	Start	135914	
	2:47P	Stop	146765	
06/28/99	8:50A	Start	146765	**Note:** Hand control checked at 150,000
	11:59P	Stop	174035	cycles with no damage or loosening of fasteners
06/29/99	12:01A	Start	174035	**Note:** Hand control checked at 200,000
	11:59P	Stop	217175	cycles with no damage or loosening of fasteners
06/30/99	12:01A	Start	217175	**Note:** Hand control checked at 250000
	6:17P	Stop	250000	cycles with no damage or loosening of fasteners

Monarch Mark 1A

<u>Appendix E</u>

SAE J1903 Section 5 Summary

Model: Monarch Mark 1A
Manufacturer: Manufacturing and Production Services Corp.
7948 Ronson Road
San Diego, CA 92111
(800)-243-4051

Section 5: Inspection and Testing Procedures

5.1 Receiving Inspection
5.1.1 Packaging Integrity
Package was received with no damage.
5.1.2 Packing Documentation
Product was identified adequately.
Model: Monarch Mark 1a
Serial No. 090236
Manufacturer: Manufacturing and Production Services Corp.
5.1.3 Verification of Contents
a. Product Identification
Product was identified properly
b. Quality Control Verification
Quality control verification was not found
c. Warranty Information
Warranty information provided
d. Compliance Documentation as Required
No compliance information provided
e. Installation Instructions
Installation instructions provided in manual
f. Operating Instructions
Operating instructions provided in manual
g. Maintenance Instructions
Maintenance instructions provided in manual
h. Limitations
Limitations not defined in SAE J1903
i. Notifications
Notification was provided, but not detailed
5.1.4 Workmanship
Workmanship of product was adequate

5.2 Mounting

5.2.1 Verification of Installation Procedures

Mounting adequately described in manual. Product was installed in a '98 Ford Taurus sled buck with minimal effort.

5.2.2 Adjustments

Adjustments to the product are adequate and can be locked in position.

5.2.3 Compatibility

All fasteners present were compatible

5.2.4 Human Factors

Human factors are adequate (push for brake / rotate down for throttle)

5.2.5 Contact Hazards

No Contact hazards were apparent

5.2.6 Maintainability

Service maintenance is described in manual with lubrication and adjustment points easily accessible.

5.3 Installation

5.3.1 Vehicle Alterations

When installed in the '98 Ford Taurus sled buck, the hand control requires alterations to the knee bolster which, according to 4.2.1 of SAE J1903, possibly interferes with the function of the occupant protection features provided by the motor vehicle manufacturer under FMVSS.

5.3.2 Operation

Operating instructions are provided in the manual.

5.3.3 Conventional Use

No obvious obstructions noted.

5.3.4 Mounting

Mounting location is strong and secure.

5.3.5 Neutral Balance

The product will not activate the vehicle due to force by its own mass . This was not verified in an actual vehicle as specified by SAE J1903.

5.4 Performance Tests

As prescribed in SAE J1903, the vibration, environmental, high-cycle, and service overload tests were conducted on a single unit in the prescribed order.

5.4.1 Vibration Test

Vertical direction

Start:	*!2:05PM*	*1/19/99*
Stop:	*2:05PM*	*1/19/99*
Outcome:	*No loose connections found*	

Horizontal direction

Start:	*2:20PM*	*1/19/99*
Stop:	*4:25PM*	*1/19/99*
Outcome:	*No loose connections found*	

5.4.2 Electromechanical Environmental Test

Product was tested in accordance with ASTM B 117.

Post-test observations:

Corrosion of fastener connecting the brake tube to the control tube.

Corrosion on the main support bracket.

5.4.3 High-Cycle Test

No degradation of the product was noted throughout the high-cycle test.

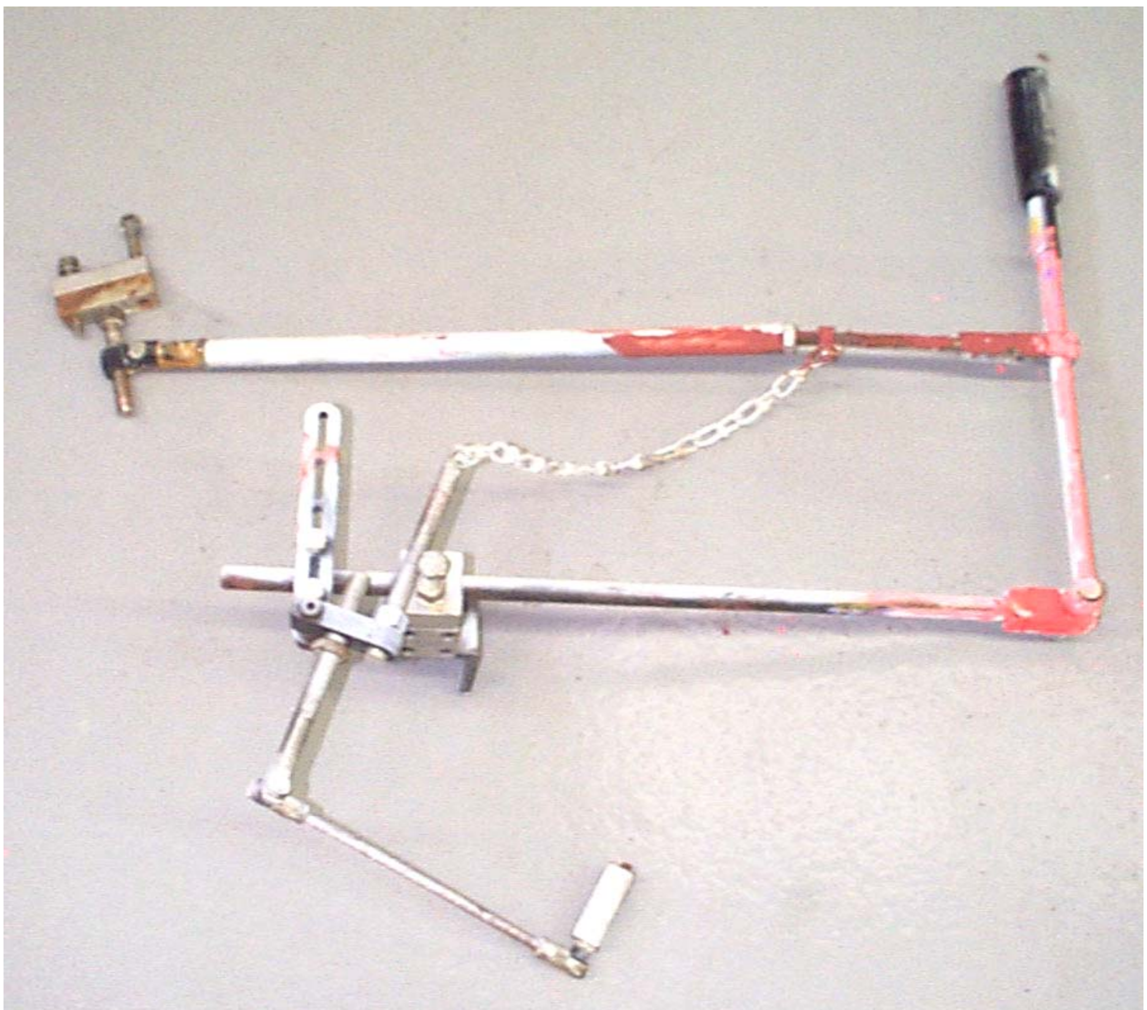
5.4.4 Service Overload

*The hand control held the required braking and acceleration loads***.**

SAE J1903
Recommended Practice Automotive Adaptive Driver Controls, Manual
1990 Revision

Test Results

Model:	**Ultra-Lite XL**
Manufacturer:	**Drive-Master Co., Inc.** **9 Spielman Road** **Fairfield, NJ 07004-3403** **(973)-808-9709**



Summary of Test Results in Accordance with SAE J1903 Section 4 and Section 5

- **Introduction**

Several hand control devices for automobiles were submitted for evaluation in accordance with SAE J1903. Section 1 through Section 3 can be categorized as design and definition, and thus will not be addressed in this report. The compliance of this product to Section 4 and Section 5 of SAE J1903 is summarized in this report.

Section 4: Requirements

- **Procedure**

Using the documentation provided by the manufacturer and the test results from Section 5, each item in Section 4 was addressed. Any and all points of failure of this hand control were noted.

- **Points of Failure**

In the interest of brevity, only deficient items related to Section 4 will be addressed here.

4.1.6 d No signs of possible malfunction were noted in the documents.
4.1.6 e No actions to be taken in the event of product failure were noted in the documents.
4.1.7 No maintenance procedures were provided.
4.2.1 As described in the installation manual, some component mounting may require alteration to the knee bolster. Because it is an integral part of the general crashworthiness of a vehicle, alteration of the knee bolster has the potential to impact FMVSS.
4.2.7 See above.
4.6.3 Some degradation or loss of surface finish was noted after the electromechanical environmental test.

Section 5: Inspection and Testing Procedures

• Procedure

Using the documentation provided by the manufacturer and the test results from Section 5, each item in this section was addressed. Any and all points of failure of this hand control were noted.

• Points of Failure

In the interest of brevity, only deficient items related to Section 5 will be addressed here.

5.1.3 b No quality control information was found.
5.4.3 The product presented several surfaces of corrosion that could be contacted by the operator.

• Test Procedure and Test Setup General Descriptions

Vibration Test:

The hand control product was rigidly mounted in a test rig. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. At the end of each session, the product was inspected for damage and any loosening of fasteners.

Electromechanical Environmental Test:

The hand control product was suspended in a corrosion chamber by small ropes and subjected to corrosion testing in accordance with ASTM B117-97.
The electromechanical environmental test was run a second time to confirm test results. No significant changes in results were noted in the second test.

High-Cycle Test:

For the high-cycle test, each hand control product was rigidly mounted in a testing frame. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 50lb weight was connected to the cable attached to the brake. A 10lb weight was connected to the cable attached to the accelerator. A motor, with an eccentric, then rotated, alternately lifting each weight off of the ground. The loading was applied alternately between the braking direction and the accelerator direction. At multiples of 50,00 cycles, the unit was inspected for damage and loose fasteners. The total number of cycles performed was 250,000.

Service Overload:

The hand control was mounted in the testing frame in the same manner as in the high-cycle test. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 10lb weight was applied to the accelerator cable for a minimum period of 30 seconds. After the removal of the accelerator load, the brake load was applied. Three 50lb weights were used to apply the total load of 150lb. The weights were applied as carefully as possible to minimize any dynamic effects.

- ## Mechanical Testing Results Summary

Two areas of failure for this hand control were observed under section 5.4.2 and section 4.6.3. Section 5.4.2 and section 4.6.3 are related, so this really constitutes one failure that is addressed under two different sections..

Section 5.4.2 states "…and shall not present any corrosion products to surfaces that can be contacted by the driver (see 4.6.3)." As can be seen in the photographs in Appendix B, there were several areas of failure.

Section 4.6.3 states "…the product shall continue to function without exhibiting degradation or loss of surface finish…". Several areas of the hand control, documented in Appendix B, exhibited loss of surface finish.

- ## Mechanical Testing Detailed Results

Vibration Test:

The vibration tests were carried out on January 19, 1999. No failures or loosening of fasteners were noted.

Electromechanical Environmental Test:

The electromechanical environmental test was carried out in accordance with ASTM B 117-97. Photographs of the 1st test setup and of the post test product can be seen in Appendix A. Corrosion was evident in several areas which are detailed in Appendix A. The electromechanical environmental test was carried out a 2nd time with similar results. The photographic documentation of the 2nd test is contained in Appendix B.

High-Cycle Test:

The high-cycle test was carried out from June 11, 1999 to June 29, 1999. Inspections were made at 50,000 cycle intervals until the test unit reached the prescribed 250,000 cycles. No damage to the hand control device or loosening of fasteners was noted during any of the cycles. The overall function and rigidity of the hand control device was good throughout the *high-cycle testing phase. A test log is contained in Appendix D. Photographic documentation of the Hand control in the testing apparatus is provided in Appendix C.*

Service Overload:

The accelerator load of 10lb and the braking load of 150lb were held by the hand control with no apparent deformation or problems.

Ultra-Lite XL

<u>Appendix A</u>

Photographic Coverage of 1st Electromechanical Environmental Test

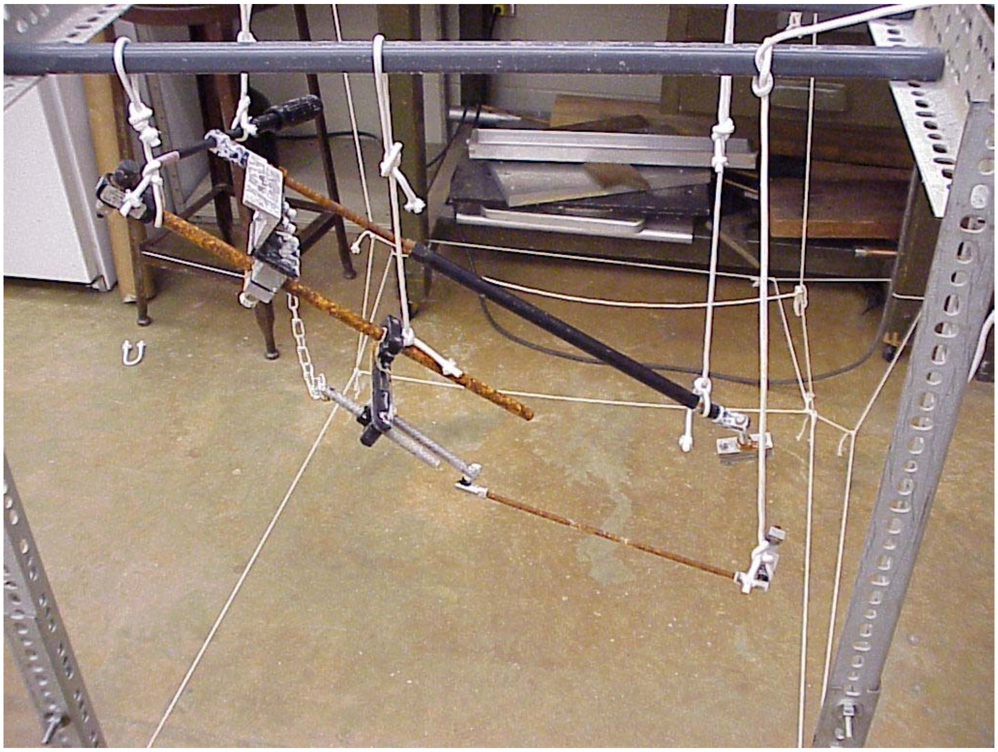


Photo #1 **(Ultra-Lite XL: 1st Environmental Test)**

Photo #2 **(Ultra-Lite XL: 1st Environmental Test)**

Photo #3 **(Ultra-Lite XL: 1st Environmental Test)**

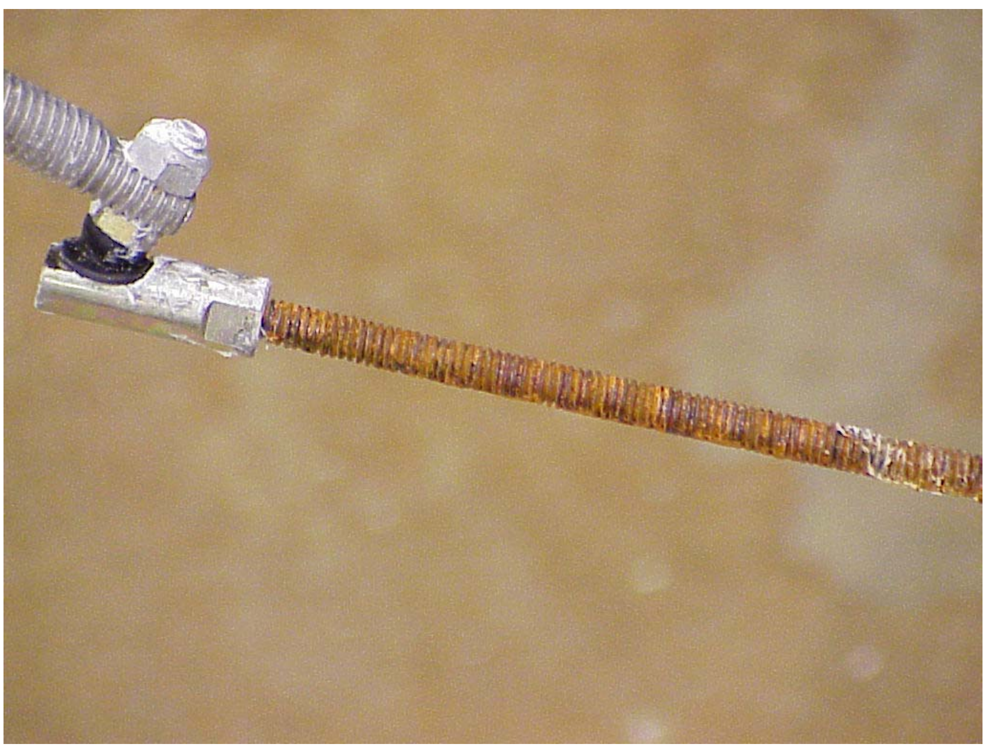


Photo #4 **(Ultra-Lite XL: 1st Environmental Test)**

Photo #5 **(Ultra-Lite XL: 1st Environmental Test)**

Photo #6 **(Ultra-Lite XL: 1st Environmental Test)**

Photo #7 (Ultra-Lite XL: 1st Environmental Test)

Ultra-Lite XL

Appendix B

Photographic Coverage of 2nd Electromechanical Environmental Test

Photo #1 **(Ultra-Lite XL: 2nd Environmental Test)**

Photo #2 **(Ultra-Lite XL: 2nd Environmental Test)**

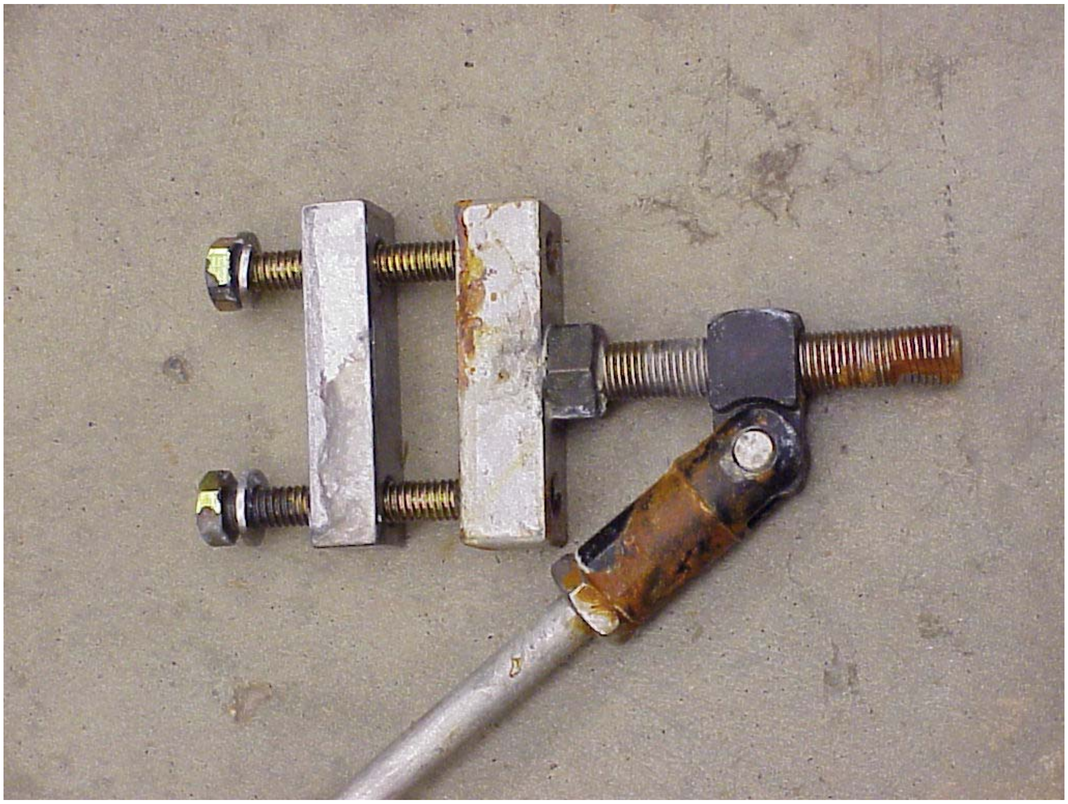


Photo #3 **(Ultra-Lite XL: 2nd Environmental Test)**

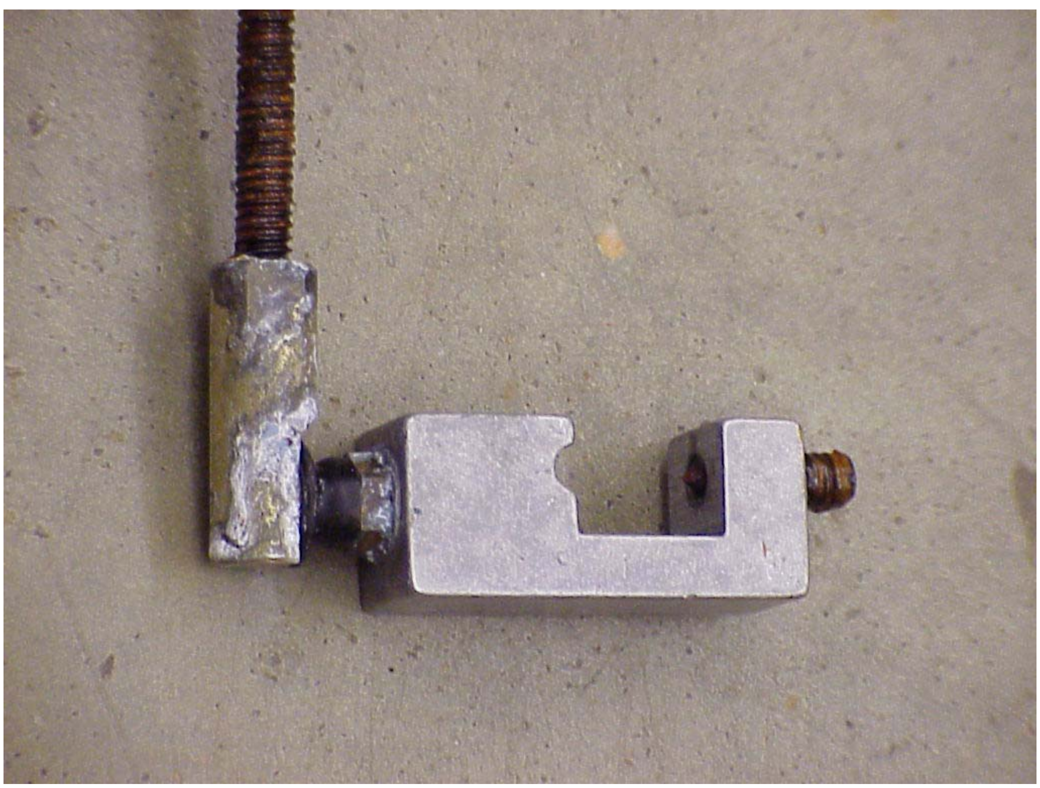


Photo #4 **(Ultra-Lite XL: 2nd Environmental Test)**

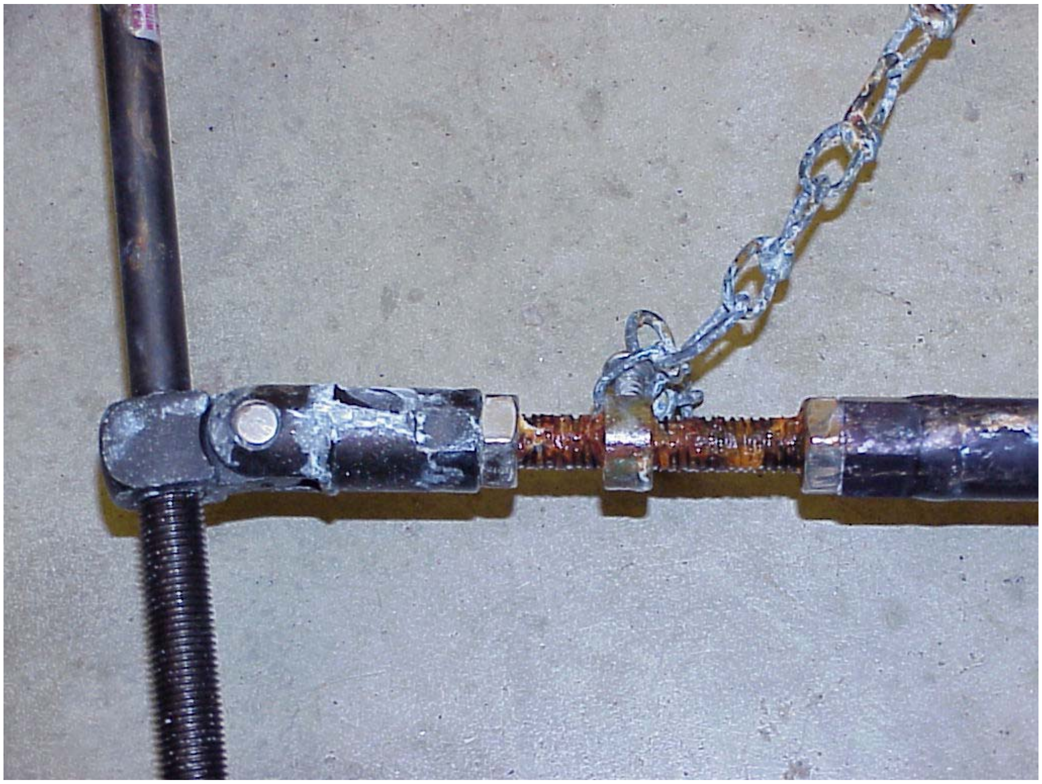


Photo #5 **(Ultra-Lite XL: 2nd Environmental Test)**

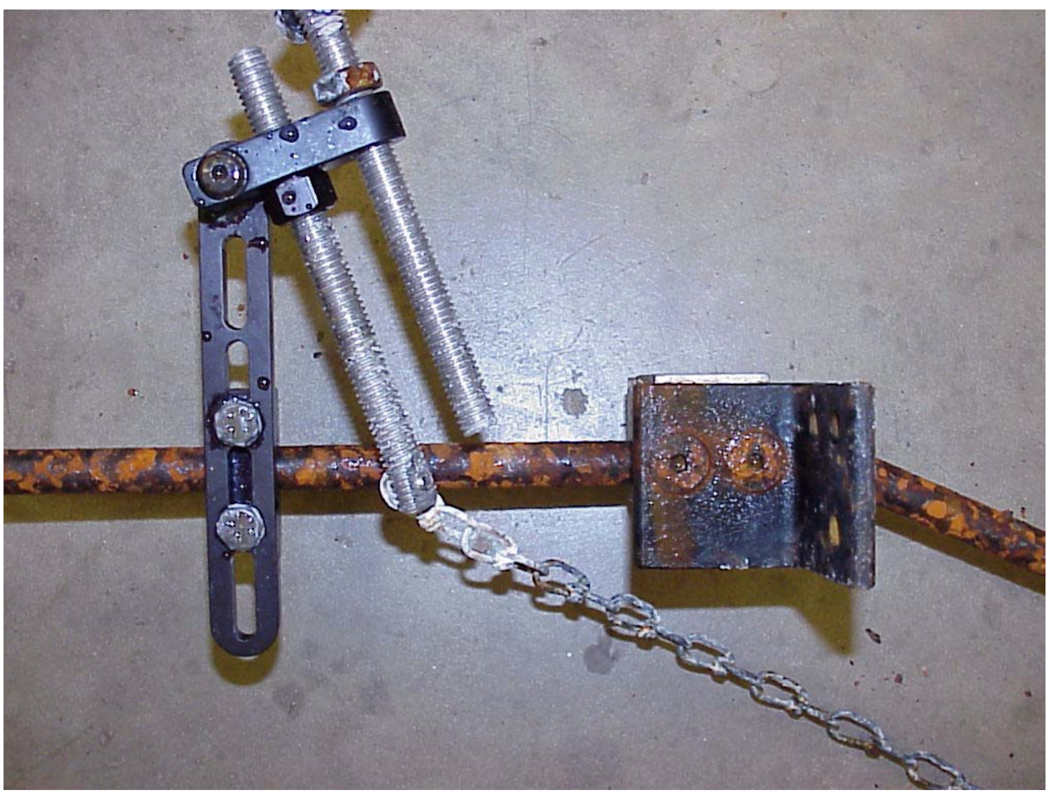


Photo #6 **(Ultra-Lite XL: 2nd Environmental Test)**

Ultra-Lite XL

Appendix C

Photographic Coverage of High-Cycle Test

Photo # 1 (Ultra-Lite XL: High-Cycle Test)

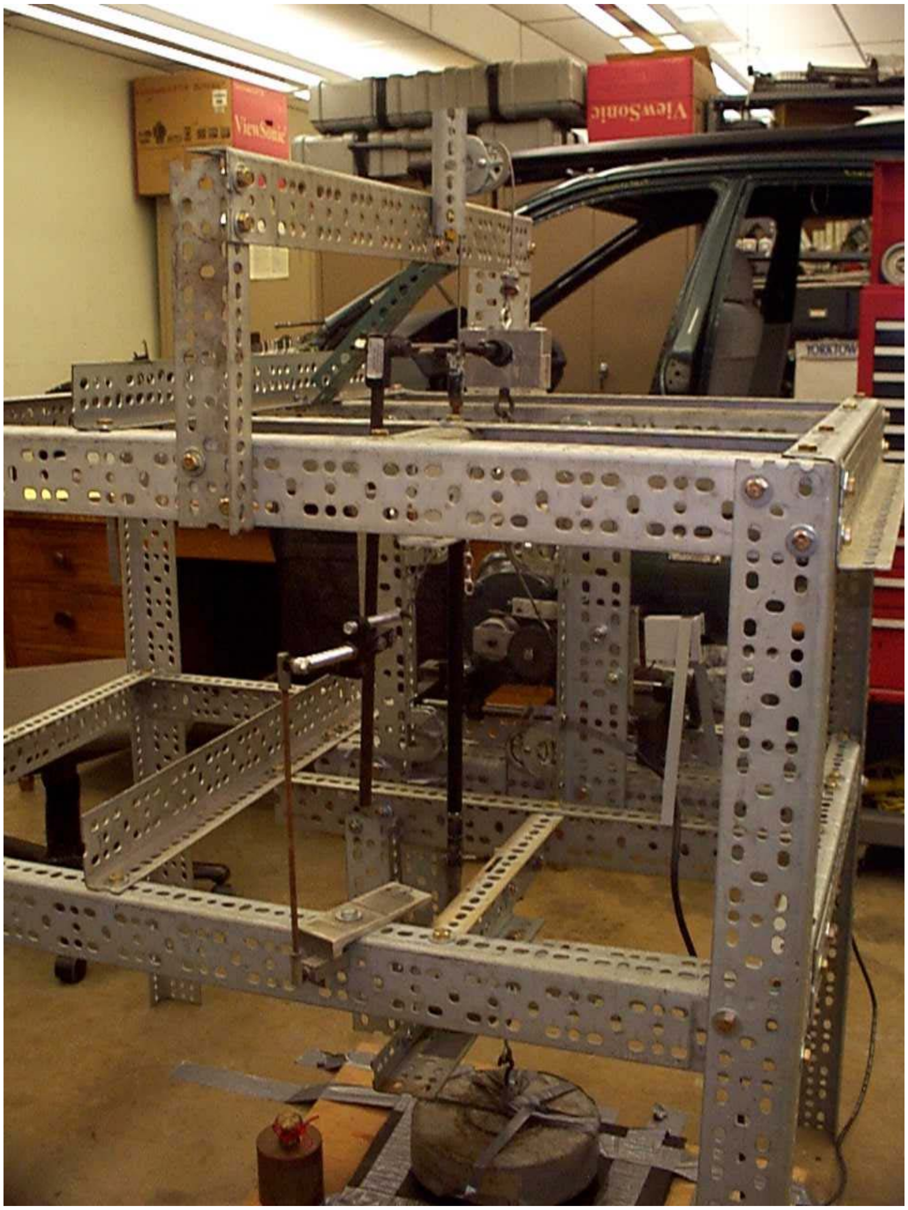


Photo #2 **(Ultra-Lite XL: High-Cycle Test)**

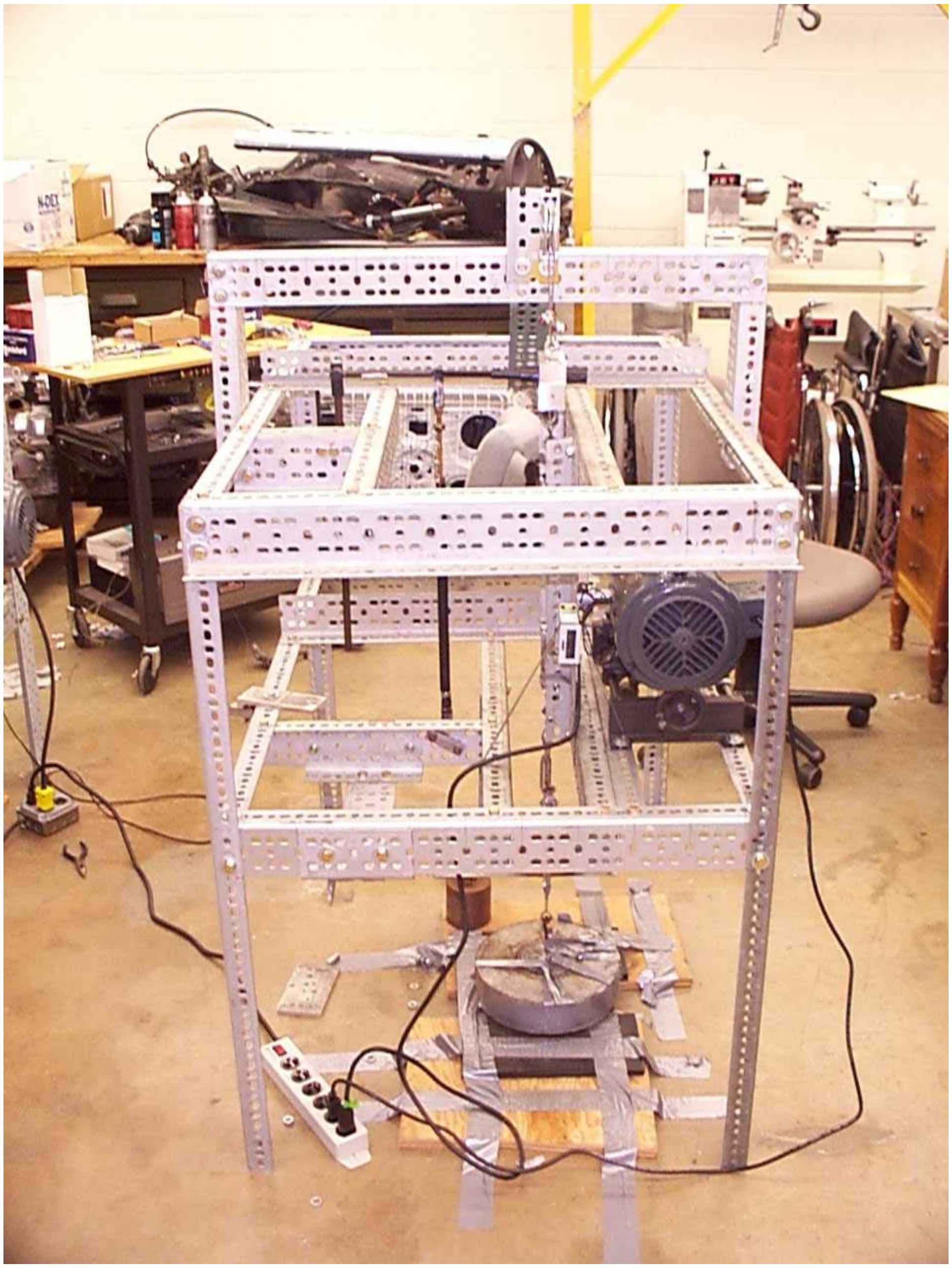


Photo #3 (Ultra-Lite XL: High-Cycle Test)

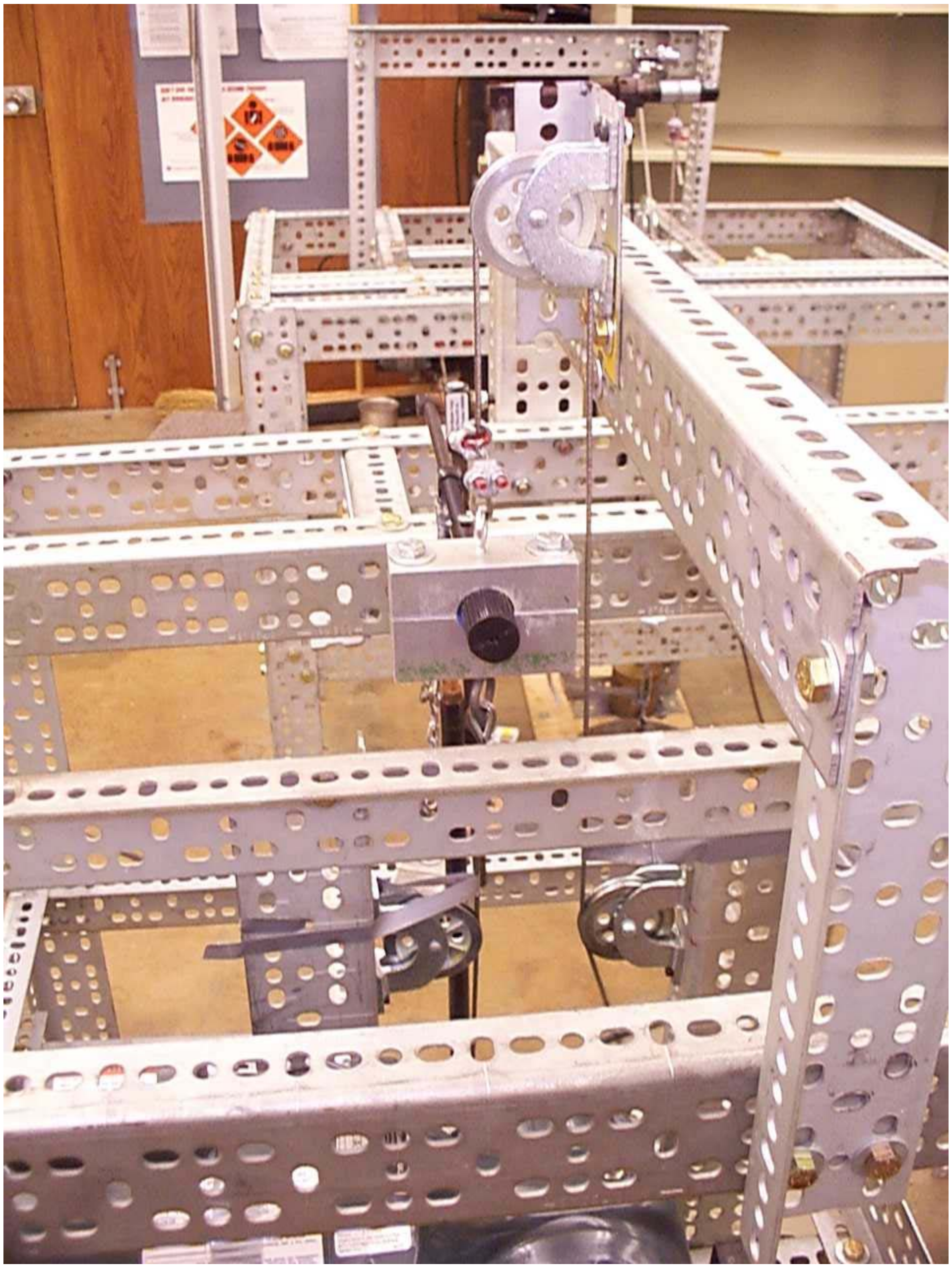


Photo #4 (Ultra-Lite XL: High-Cycle Test)

Ultra-Lite XL

Appendix D

Detailed Test Data Sheets for High Cycle Test

Cycle Testing
Ultra-Lite XL

Date	Time	Event	Count	
07/12/99	3:35P	Start	0	
	9:26P	Stop	15777	
07/13/99	8:45A	Start	15777	**Note:** Hand control checked at 50,000
	10:27P	Stop	52715	cycles with no damage or loosening of fasteners
07/14/99	8:57A	Start	52715	
	9:25P	Stop	86306	
07/15/99	8:20A	Start	86306	**Note:** Hand control checked at 100,000
	1:55P	Stop	101386	cycles with no damage or loosening of fasteners
07/16/99	8:55A	Start	101386	
	11:25A	Stop	108128	
07/19/99	8:35A	Start	108128	
	11:59P	Stop	149708	
07/20/99	12:00A	Start	149708	**Note:** Hand control checked at 150,000 and 200,000
	10:28P	Stop	210363	cycles with no damage or loosening of fasteners
07/21/99	9:03A	Start	210363	
	10:35P	Stop	244710	
07/22/99	9:02A	Start	244710	**Note:** Hand control checked at 250,000
	11:19P	Stop	250000	cycles with no damage or loosening of fasteners

Ultra-Lite XL

Appendix E

SAE J1903 Section 5 Summary

Model: Ultra-Lite XL
Manufacturer: Drive-Master Co., Inc.
9 Spielman Road
Fairfield, NJ 07004-3403
(973)-808-9709

Section 5: Inspection and Testing Procedures

5.1 Receiving Inspection
5.1.1 Packaging Integrity
Package was received with no damage.
5.1.2 Packing Documentation
Product was identified adequately.
Model: *Ultra-Lite XL*
Serial No. *8157*
Manufacturer: *Drive-Master Corporation*
5.1.3 Verification of Contents
a. Product Identification
Product was identified properly
b. Quality Control Verification
Quality control verification was found
c. Warranty Information
Warranty information provided
d. Compliance Documentation as Required
No compliance information provided
e. Installation Instructions
Installation instructions provided in manual
f. Operating Instructions
Operating instructions provided in manual
g. Maintenance Instructions
Maintenance instructions were not provided in manual
h. Limitations
Limitations not defined in SAE J1903
i. Notifications
Notification was provided, but not detailed
5.1.4 Workmanship
Workmanship of product was adequate

5.2 Mounting

5.2.1. Verification of Installation Procedures

Mounting adequately described in manual. Product was installed in a '98 Ford Taurus sled buck with minimal effort.

5.2.2 Adjustments

Adjustments to the product are adequate and can be locked in position.

5.2.3 Compatibility

All Fasteners present were compatible

5.2.4 Human Factors

Human factors are adequate (push for brake / rotate down for throttle)

5.2.5 Contact Hazards

No contact hazards were apparent

5.2.6 Maintainability

Maintenance procedures were not provided in the manual.

5.3 Installation

5.3.2 Vehicle Alterations

When installed in the '98 Ford Taurus sled buck, the hand control requires alterations to the knee bolster which, according to 4.2.1 of SAE J1903, possibly interferes with the function of the occupant protection features provided by the motor vehicle manufacturer under FMVSS.

5.3.3 Operation

Operating instructions are provided in the manual.

5.3.4 Conventional Use

No obvious obstructions noted.

5.3.5 Mounting

Mounting location is strong and secure.

5.3.6 Neutral Balance

The product will not activate the vehicle due to force by its own mass . This was not verified in an actual vehicle as specified by SAE J1903.

5.4 Performance Tests

As prescribed in SAE J1903, the vibration, environmental, high-cycle, and service overload tests were conducted on a single unit in the prescribed order.

5.4.1 Vibration Test

Vertical direction

Start:	*3:45PM*	*1/24/99*
Stop:	*5:45PM*	*1/24/99*
Outcome:	*No loose connections found*	

Horizontal direction

Start:	*5:55PM*	*1/24/99*
Stop:	*7:55PM*	*1/24/99*
Outcome:	*No loose connections found*	

5.4.2 Electromechanical Environmental Test

Product was tested in accordance with ASTM B 117.

Post-test observations:

Corrosion in several areas was noted.

5.4.3 High-Cycle Test

No degradation of the product was noted throughout the high-cycle test.

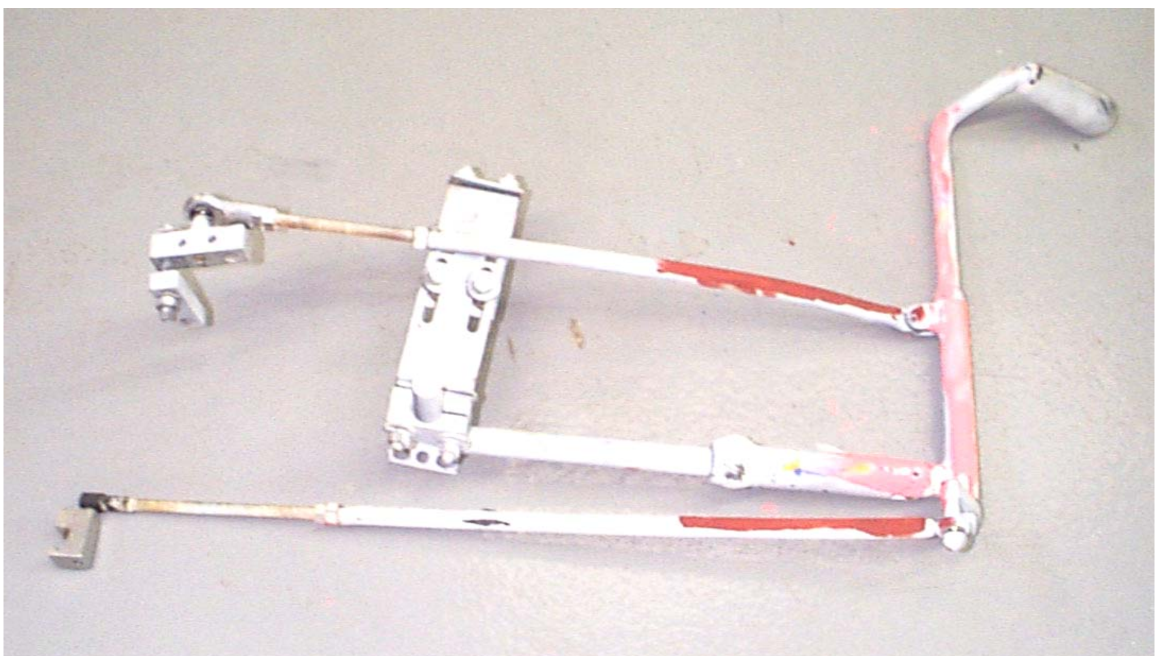
5.4.4 Service Overload

The hand control held the required braking and acceleration loads

SAE J1903
Recommended Practice Automotive Adaptive Driver Controls, Manual
1990 Revision

Test Results

Model: Sure Grip
Manufacturer: Howell Ventures LTD
850 Route 2 Hwy
Upper Kingsclear
New Brunswick, Canada
(506)-363-5289



Summary of Test Results in Accordance with SAE J1903 Section 4 and Section 5

- **Introduction**

Several hand control devices for automobiles were submitted for evaluation in accordance with SAE J1903. Section 1 through Section 3 can be categorized as design and definition, and thus will not be addressed in this report. The compliance of this product to Section 4 and Section 5 of SAE J1903 is summarized in this report.

Section 4: Requirements

- **Procedure**

Using the documentation provided by the manufacturer and the test results from Section 5, each item in Section 4 was addressed. Any and all points of failure of this hand control were noted.

- **Points of Failure**

In the interest of brevity, only deficient items related to Section 4 will be addressed here.

.

4.1.6 d No signs of possible malfunction were noted in the documents.

4.1.6 e No actions to be taken in the event of product failure were noted in the documents.

4.2.1 As described in the installation manual, some component mounting may require alteration to the knee bolster. Because it is an integral part of the general crashworthiness of a vehicle, alteration of the knee bolster has the potential to impact FMVSS.

4.2.7 See above.

4.6.3 Some degradation or loss of surface finish was noted after the electromechanical environmental test.

Section 5: Inspection and Testing Procedures

• Procedure

Using the documentation provided by the manufacturer and the test results from Section 5, each item in this section was addressed. Any and all points of failure of this hand control were noted.

• Points of Failure

In the interest of brevity, only deficient items related to Section 5 will be addressed here.

5.4.4 The product presented several surfaces of corrosion that could be contacted by the operator.

• Test Procedure and Test Setup General Descriptions

Vibration Test:

The hand control product was rigidly mounted in a test rig. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. At the end of each session, the product was inspected for damage and any loosening of fasteners.

Electromechanical Environmental Test:

The hand control product was suspended in a corrosion chamber by small ropes and subjected to corrosion testing in accordance with ASTM B117-97.

The electromechanical environmental test was run a second time to confirm test results. No significant changes in results were noted in the second test.

High-Cycle Test:

For the high-cycle test, each hand control product was rigidly mounted in a testing frame. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 50lb weight was connected to the cable attached to the brake. A 10lb weight was connected to the cable attached to the accelerator. A motor, with an eccentric, then rotated, alternately lifting each weight off of the ground. The loading was applied alternately between the braking direction and the accelerator direction. At multiples of 50,00 cycles, the unit was inspected for damage and loose fasteners. The total number of cycles performed was 250,000.

Service Overload:

The hand control was mounted in the testing frame in the same manner as in the high-cycle test. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 10lb weight was applied to the accelerator cable for a minimum period of 30 seconds. After the removal of the accelerator load, the brake load was applied. Three 50lb weights were used to apply the total load of 150lb. The weights were applied as carefully as possible to minimize any dynamic effects.

• Mechanical Testing Results Summary

Two areas of failure for this hand control were observed under section 5.4.2 and section 4.6.3. Section 5.4.2 and section 4.6.3 are related, so this really constitutes one failure that is addressed under two different sections.

Section 5.4.2 states "…and shall not present any corrosion products to surfaces that can be contacted by the driver (see 4.6.3)." As can be seen in the photographs in Appendix A and Appendix B, there were several areas of failure.

Section 4.6.3 states "…the product shall continue to function without exhibiting degradation or loss of surface finish…". Several areas of the hand control, documented in Appendix A and Appendix B, exhibited loss of surface finish.

• Mechanical Testing Detailed Results

Vibration Test:

The vibration tests were carried out on January 7, 1999. No failures or loosening of fasteners was noted.

Electromechanical Environmental Test:

The electromechanical environmental test was carried out in accordance with ASTM B 117-97. Photographs of the 1st test setup and of the post test product can be seen in Appendix A. Corrosion was evident in several areas which are detailed in Appendix A. The electromechanical environmental test was carried out a 2nd time with similar results. The photographic documentation of the 2nd test is contained in Appendix B.

High-Cycle Test:

The high-cycle test was carried out from July 22, 1999 to July 29, 1999. Inspections were made at 50,000 cycle intervals until the test unit reached the prescribed 250,000 cycles. No damage to the hand control device or loosening of fasteners was noted during any of the cycles. The overall function and rigidity of the hand control device was good throughout the *high-cycle testing phase. A test log is contained in Appendix D. Photographic documentation of the Hand control in the testing apparatus is provided in Appendix C.*

<u>Service Overload</u>:

The accelerator load of 10lb and the braking load of 150lb were held by the hand control with no apparent deformation or problems

Sure Grip

Appendix A

Photographic Coverage of 1st Electromechanical Environmental Test

Photo #1 **(Sure-Grip: 1st Environmental Test)**

Photo #2 **(Sure-Grip: 1st Environmental Test)**

Photo #3 **(Sure-Grip: 1st Environmental Test)**

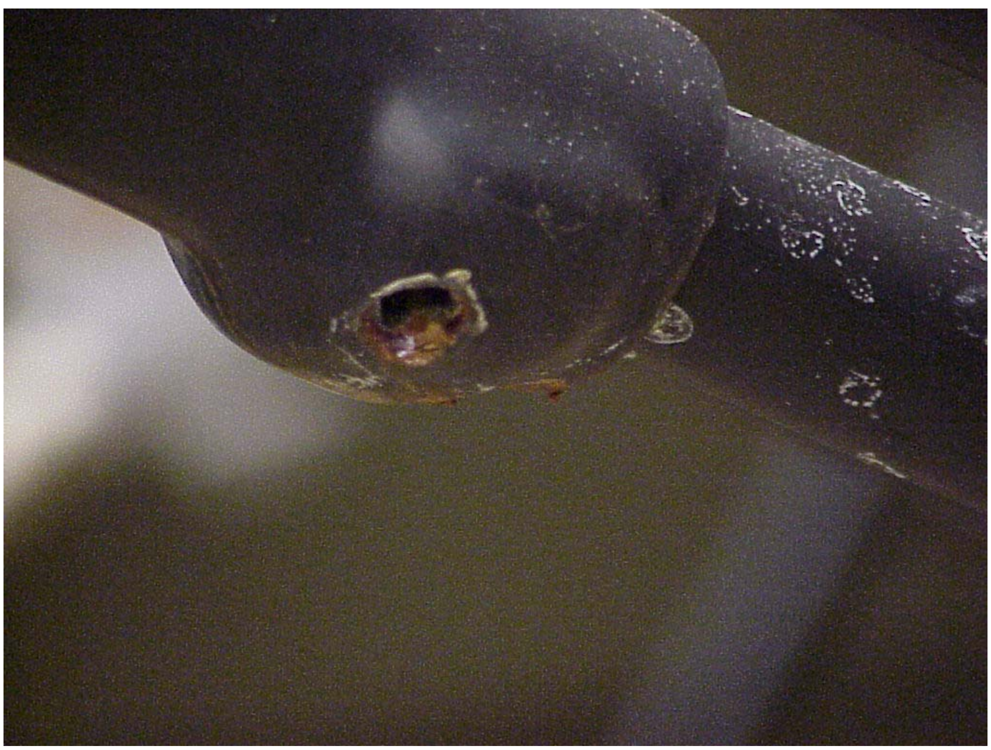


Photo #4 **(Sure-Grip: 1st Environmental Test)**

Photo #5 **(Sure-Grip: 1st Environmental Test)**

Photo #6 **(Sure-Grip: 1st Environmental Test)**

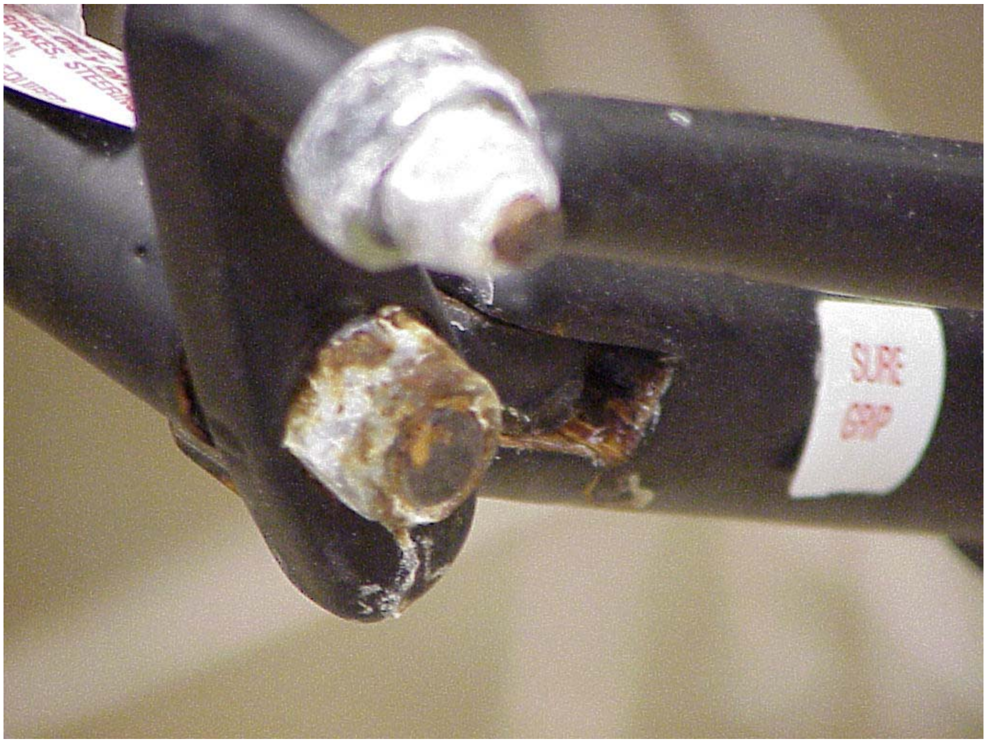


Photo #7 **(Sure-Grip: 1st Environmental Test)**

Photo #8 **(Sure-Grip: 1st Environmental Test)**

Sure Grip

Appendix B

Photographic Coverage of 2nd Electromechanical Environmental Test

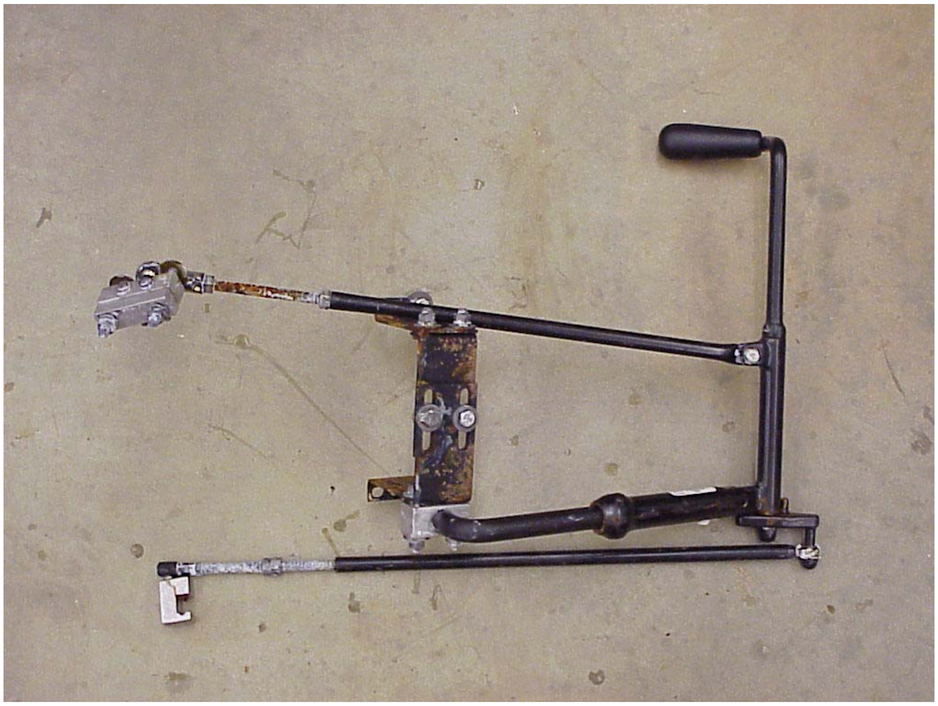


Photo #1 **(Sure-Grip: 2nd Environmental Test)**

Photo #2 **(Sure-Grip: 2nd Environmental Test)**

Photo #3 (Sure-Grip: 2nd Environmental Test)

Photo #4 (Sure-Grip: 2nd Environmental Test)

Photo #5 **(Sure-Grip: 2nd Environmental Test)**

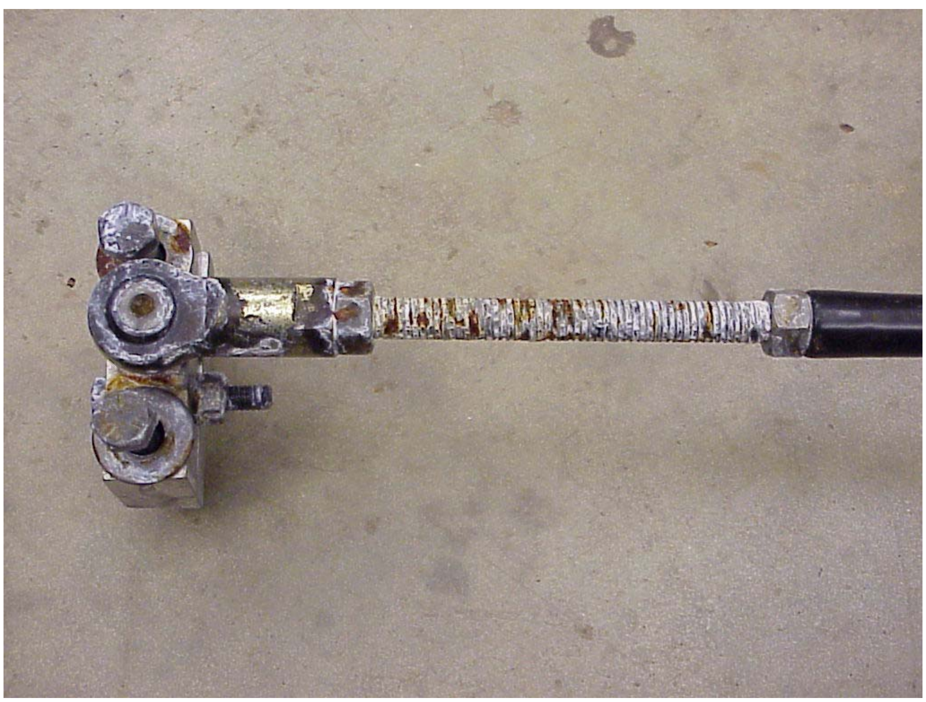


Photo #6 **(Sure-Grip: 2nd Environmental Test)**

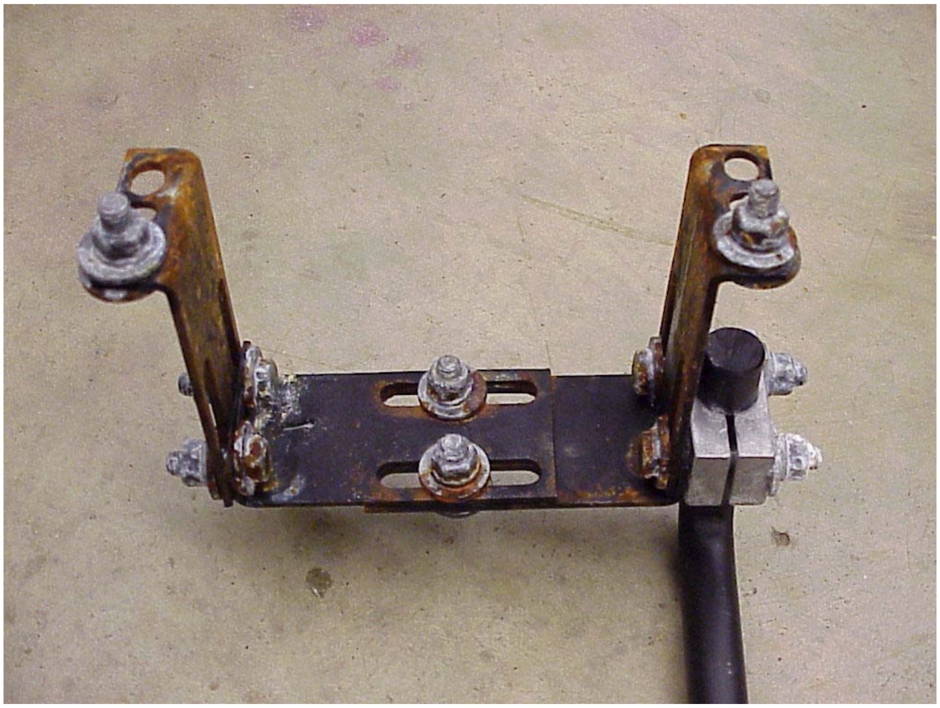


Photo #7 **(Sure-Grip: 2nd Environmental Test)**

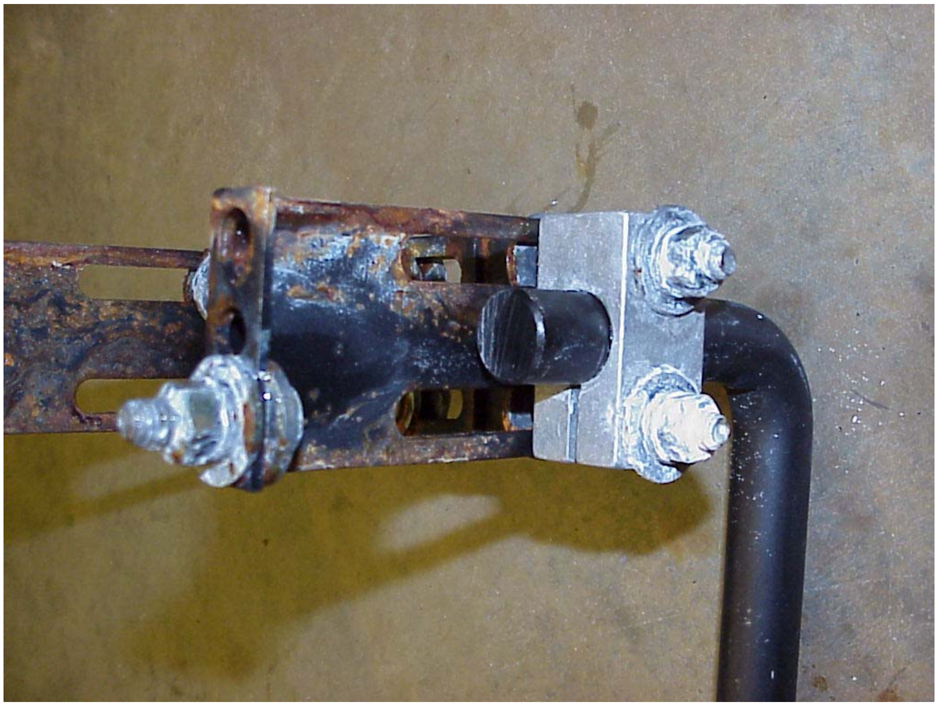


Photo #8 **(Sure-Grip: 2nd Environmental Test)**

Sure Grip

Appendix C

Photographic Coverage of High-Cycle Test

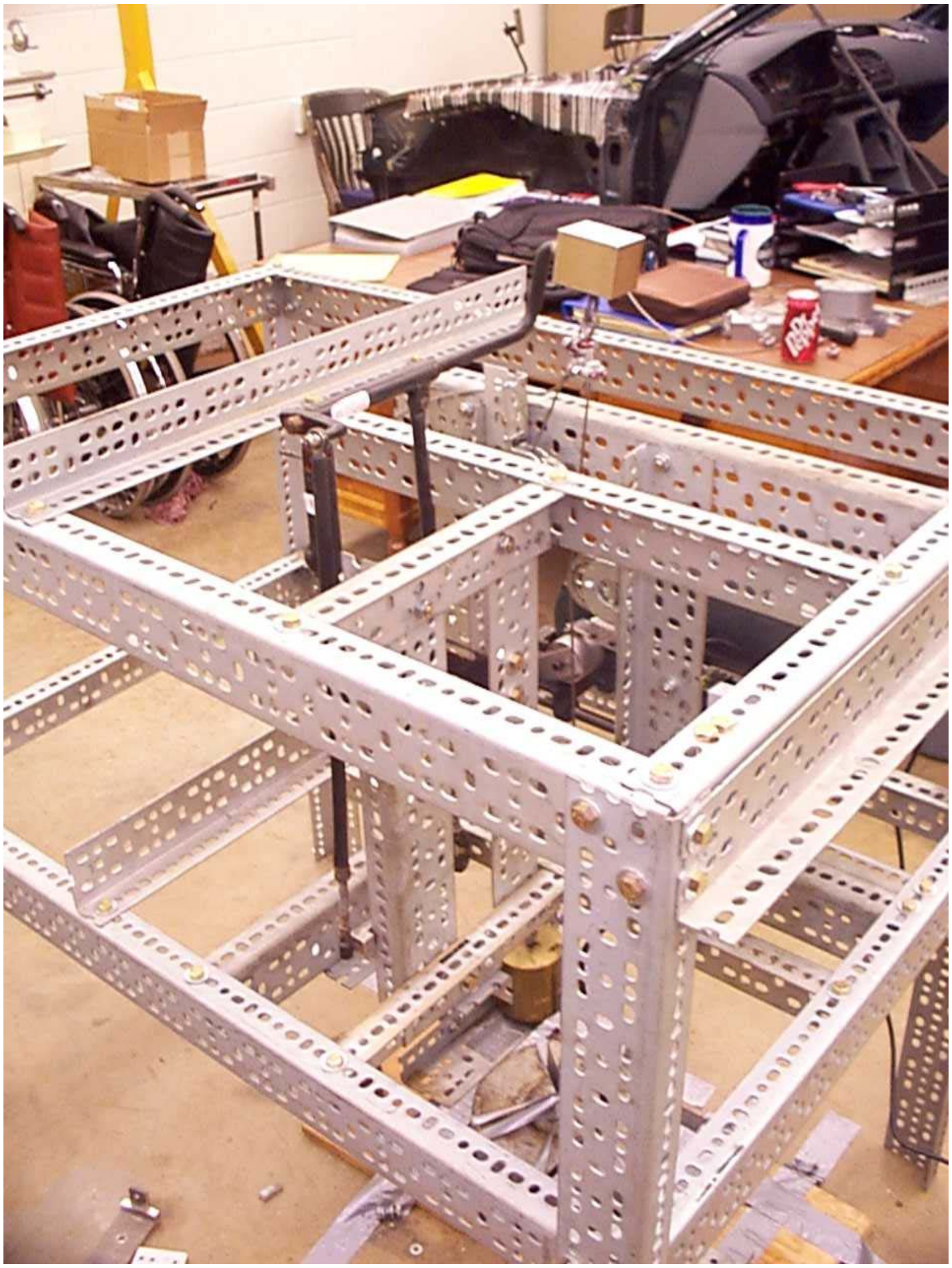


Photo #1 (Sure-Grip: High-Cycle Test)

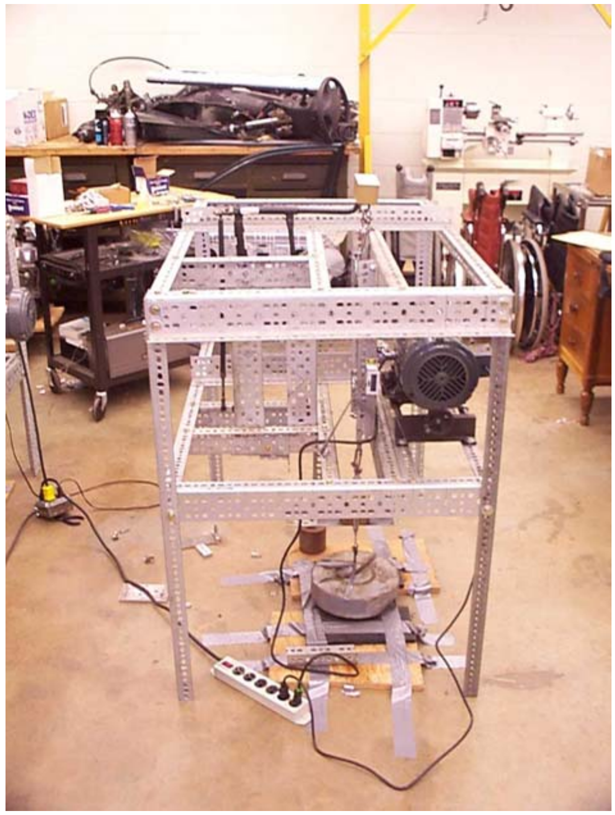


Photo #2 (Sure-Grip: High-Cycle Test)

Sure Grip

<u>Appendix D</u>

Detailed Test Data Sheets for High Cycle Test

Cycle Testing
Sure-Grip

Date	Time	Event	Count	
07/22/99	5:18P	Start	0	
	9:40P	Stop	11745	
07/23/99	8:35A	Start	11745	
	5:17P	Stop	35232	
07/25/99	11:38A	Start	35232	**Note:** Hand control checked at 50,000
	6:54P	Stop	54886	cycles with no damage or loosening of fasteners
07/26/99	8:30A	Start	54886	
	11:59P	Stop	96720	
07/27/99	12:01A	Start	96720	**Note:** Hand control checked at 100,000 and 150,000
	11:59P	Stop	161452	cycles with no damage or loosening of fasteners
07/28/99	12:01A	Start	161452	**Note:** Hand control checked at 200,000
	10:27P	Stop	221924	cycles with no damage or loosening of fasteners
07/29/99	8:31A	Start	221924	**Note:** Hand control checked at 250,000
	(Stop Time Not Recorded)			cycles with no damage or loosening of fasteners

Sure Grip

<u>Appendix E</u>

SAE J1903 Section 5 Summary

Model: Sure Grip
Manufacturer: Howell Ventures LTD
4850 Route 2 Hwy
Upper Kingsclear
New Brunswick, Canada
(506)-363-5289

Section 5: Inspection and Testing Procedures

5.1 Receiving Inspection
5,1,1 Packaging Integrity
Package was received with no damage.
5.1.2 Packing Documentation
Product was identified adequately.
Model: *Sure Grip (4993509)*
Serial No. 4518
Manufacturer: Howell Ventures LTD
5,1.3 Verification of Contents
j. Product Identification
Product was identified properly
k. Quality Control Verification
Quality control verification was not found
l. Warranty Information
Warranty information provided
m. Compliance Documentation as Required
No compliance information provided
n. Installation Instructions
Installation instructions provided in manual
o. Operating Instructions
Operating instructions not provided in manual
p. Maintenance Instructions
Maintenance instructions provided in manual
q. Limitations
Limitations not defined in SAE J1903
r. Notifications
Notification was provided, but not detailed
5.1.4 Workmanship
Workmanship of product was adequate
5.2 Mounting
5.2.1 Verification of Installation Procedures

Mounting adequately described in manual. Product was installed in a '98 Ford Taurus sled buck with minimal effort.

5.2.2 Adjustments

Adjustments to the product are adequate and can be locked in position.

5.2.3 Compatibility

All fasteners present were compatible

5.2.4 Human Factors

Human factors are adequate (push for brake / rotate down for throttle)

5.2.5 Contact Hazards

No contact hazards were apparent

5.2.6 Maintainability

Service maintenance is described in manual with lubrication and adjustment points easily accessible.

5.3 Installation

5.3.1 Vehicle Alterations

When installed in the '98 Ford Taurus sled buck, the hand control requires alterations to the knee bolster which, according to 4.2.1 of SAE J1903, possibly interferes with the function of the occupant protection features provided by the motor vehicle manufacturer under FMVSS.

5.3.2 Operation

Operating instructions are provided in the manual.

5.3.3 Conventional Use

No obvious obstructions noted.

5.3.4 Mounting

Mounting location is strong and secure.

5.3.5 Neutral Balance

The product will not activate the vehicle due to force by its own mass . This was not verified in an actual vehicle as specified by SAE J1903.

5.4 Performance Tests

As prescribed in SAE J1903, the vibration, environmental, high-cycle, and service overload tests were conducted on a single unit in the prescribed order.

5.4.1 Vibration Test

Vertical direction

Start:	*9:30AM*	*1/7/99*
Stop:	*11:30AM*	*1/7/99*
Outcome:	*No loose connections found*	

Horizontal direction

Start:	*1:30PM*	*1/7/99*
Stop:	*3:30PM*	*1/7/99*
Outcome:	*No loose connections found*	

5.4.2 Electromechanical Environmental Test

Product was tested in accordance with ASTM B 117-97.

Post-test observations:

Corrosion on several areas of the hand control was noted.

5.4.3 High-Cycle Test

No degradation of the product was noted throughout the high-cycle test.

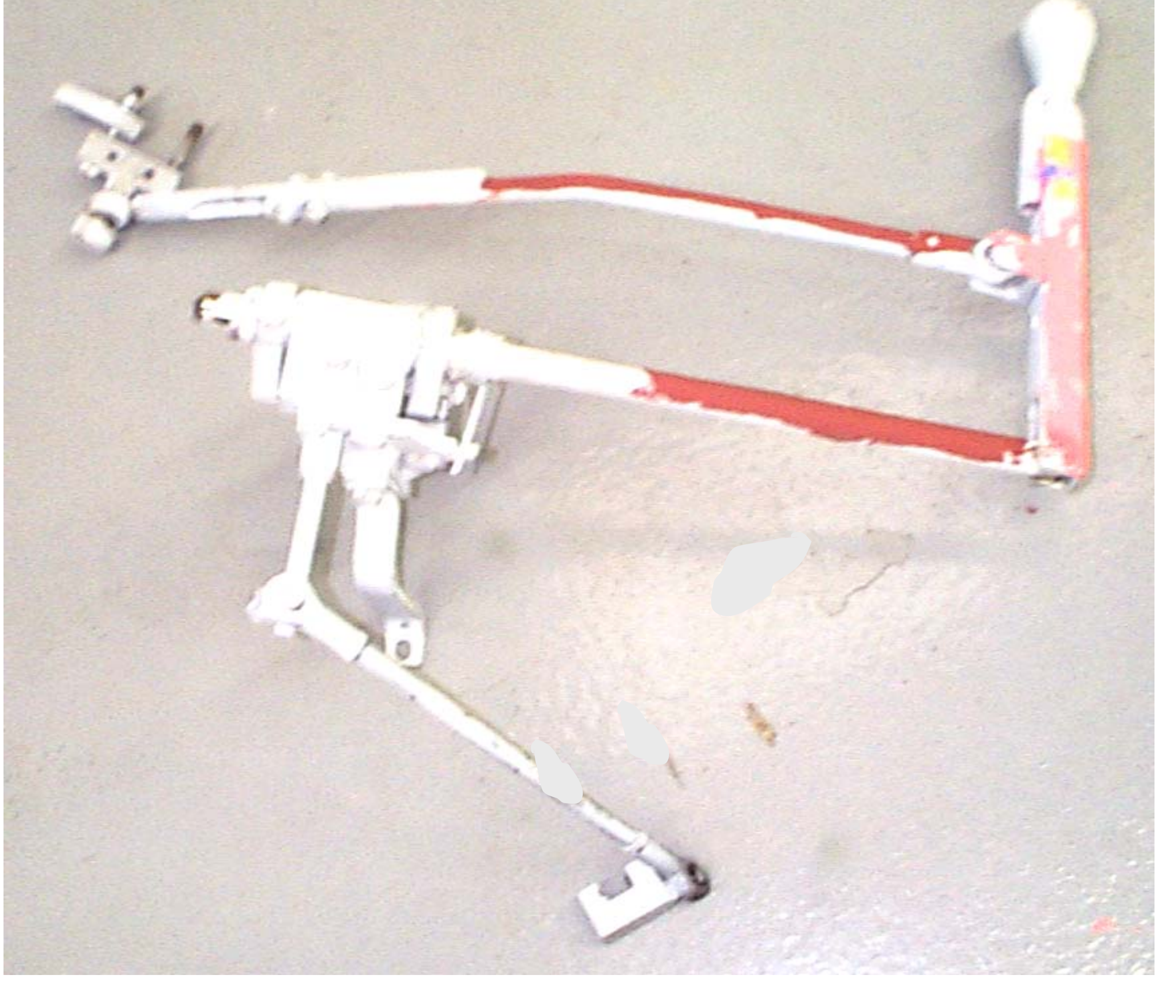
5.4.4 Service Overload

The hand control held the required braking and acceleration loads.

SAE J1903
Recommended Practice Automotive Adaptive Driver Controls, Manual
1990 Revision

Test Results

Model:	**MPD 3500**
Manufacturer:	**Mobility Products & Design**
	2800 Northwest Boulevard
	Minneapolis, MN 55441-2625
	(800)-488-7688



Summary of Test Results in Accordance with SAE J1903 Section 4 and Section 5

- **Introduction**

Several hand control devices for automobiles were submitted for evaluation in accordance with SAE J1903. Section 1 through Section 3 can be categorized as design and definition, and thus will not be addressed in this report. The compliance of this product to Section 4 and Section 5 of SAE J1903 is summarized in this report.

Section 4: Requirements

- **Procedure**

Using the documentation provided by the manufacturer and the test results from Section 5, each item in Section 4 was addressed. Any and all points of failure of this hand control were noted.

- **Points of Failure**

In the interest of brevity, only deficient items related to Section 4 will be addressed here.

4.1.1 Model number was not identified on the product.
4.1.2 No quality control information was found
4.1.6 d No signs of possible malfunction were noted in the documents.
4.1.6 e No actions to be taken in the event of product failure were noted in the documents.
4.2.1 As described in the installation manual, some component mounting may require alteration to the knee bolster. Because it is an integral part of the general crashworthiness of a vehicle, alteration of the knee bolster has the potential to impact FMVSS.
4.2.7 See above.
4.6.3 Some degradation or loss of surface finish was noted after the electromechanical environmental test.

Section 5: Inspection and Testing Procedures

• Procedure

Using the documentation provided by the manufacturer and the test results from Section 5, each item in this section was addressed. Any and all points of failure of this hand control were noted.

• Points of Failure

In the interest of brevity, only deficient items related to Section 5 will be addressed here.

5.1.3 a Model number was not identified on the product.
5.1.3 b No quality control information was found.
5.4.2 The product presented several surfaces of corrosion that could be contacted by the operator.

• Test Procedure and Test Setup General Descriptions

Vibration Test:

The hand control product was rigidly mounted in a test rig. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. At the end of each session, the product was inspected for damage and any loosening of fasteners.

Electromechanical Environmental Test:

The hand control product was suspended in a corrosion chamber by small ropes and subjected to corrosion testing in accordance with ASTM B117-97.

The electromechanical environmental test was run a second time to confirm test results. No significant changes in results were noted in the second test.

High-Cycle Test:

For the high-cycle test, each hand control product was rigidly mounted in a testing frame. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 50lb weight was connected to the cable attached to the brake. A 10lb weight was connected to the cable attached to the accelerator. A motor, with an eccentric, then rotated, alternately lifting each weight off of the ground. The loading was applied alternately between the braking direction and the accelerator direction. At multiples of 50,00 cycles, the unit was inspected for damage and loose fasteners. The total number of cycles performed was 250,000.

Service Overload:

The hand control was mounted in the testing frame in the same manner as in the high-cycle test. Through cables, loading was applied in a brake actuating direction and an accelerator actuating direction. A 10lb weight was applied to the accelerator cable for a minimum period of 30 seconds. After the removal of the accelerator load, the brake load was applied. Three 50lb weights were used to apply the total load of 150lb. The weights were applied as carefully as possible to minimize any dynamic effects.

• Mechanical Testing Results Summary

Two areas of failure for this hand control were observed under section 5.4.2 and section 4.6.3. Section 5.4.2 and section 4.6.3 are related, so this really constitutes one failure that is addressed under two different sections..

Section 5.4.2 states "…and shall not present any corrosion products to surfaces that can be contacted by the driver (see 4.6.3)." As can be seen in the photographs in Appendix B, there were several areas of failure.

Section 4.6.3 states "…the product shall continue to function without exhibiting degradation or loss of surface finish…". Several areas of the hand control, documented in Appendix B, exhibited loss of surface finish.

• Mechanical Testing Detailed Results

Vibration Test:

The vibration tests were carried out on January 14, 1999 and January 18, 1999. No failures or loosening of fasteners was noted.

Electromechanical Environmental Test:

The electromechanical environmental test was carried out in accordance with ASTM B 117-97. Photographs of the 1st test setup and of the post test product can be seen in Appendix A. Corrosion was evident in several areas which are detailed in Appendix A. The electromechanical environmental test was carried out a 2nd time with similar results. The photographic documentation of the 2nd test is contained in Appendix B.

High-Cycle Test:

The high-cycle test was carried out from June 17, 1999 to June 30, 1999. Inspections were made at 50,000 cycle intervals until the test unit reached the prescribed 250,000 cycles. No damage to the hand control device or loosening of fasteners was noted during any of the cycles. The overall function and rigidity of the hand control device was good throughout the high-cycle testing phase. A test log is contained in Appendix D. Photographic documentation of the Hand control in the testing apparatus is provided in Appendix C.

Service Overload:

The accelerator load of 10lb and the braking load of 150lb were held by the hand control with no apparent deformation or problems.

Mobility Products

Appendix A

Photographic Coverage of 1st Electromechanical Environmental Test

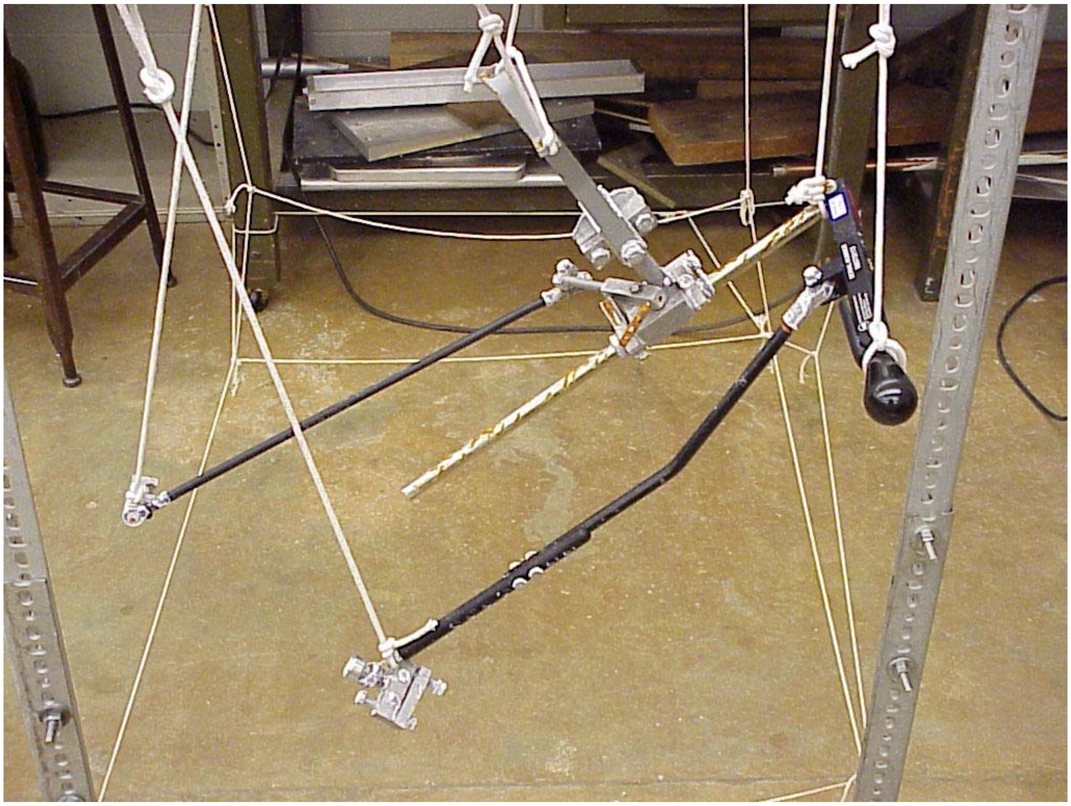


Photo #1 **(Mobility Products: 1st Environmental Test)**

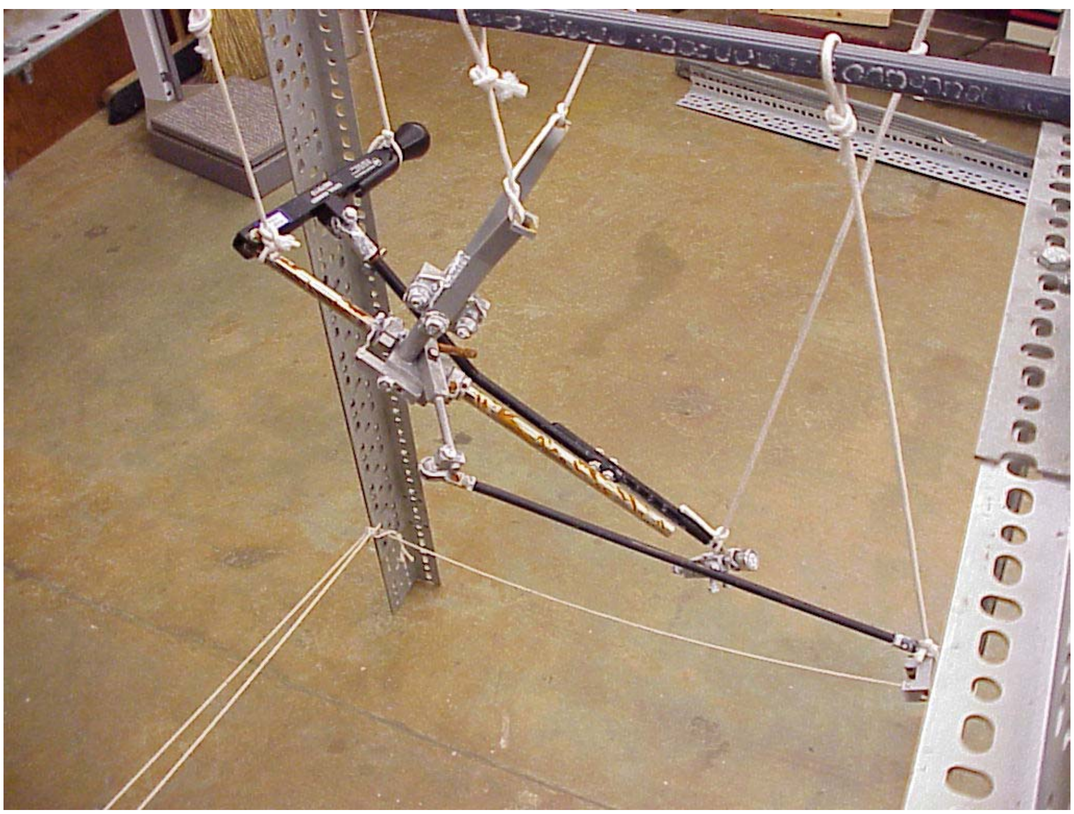


Photo #2 **(Mobility Products: 1st Environmental Test)**

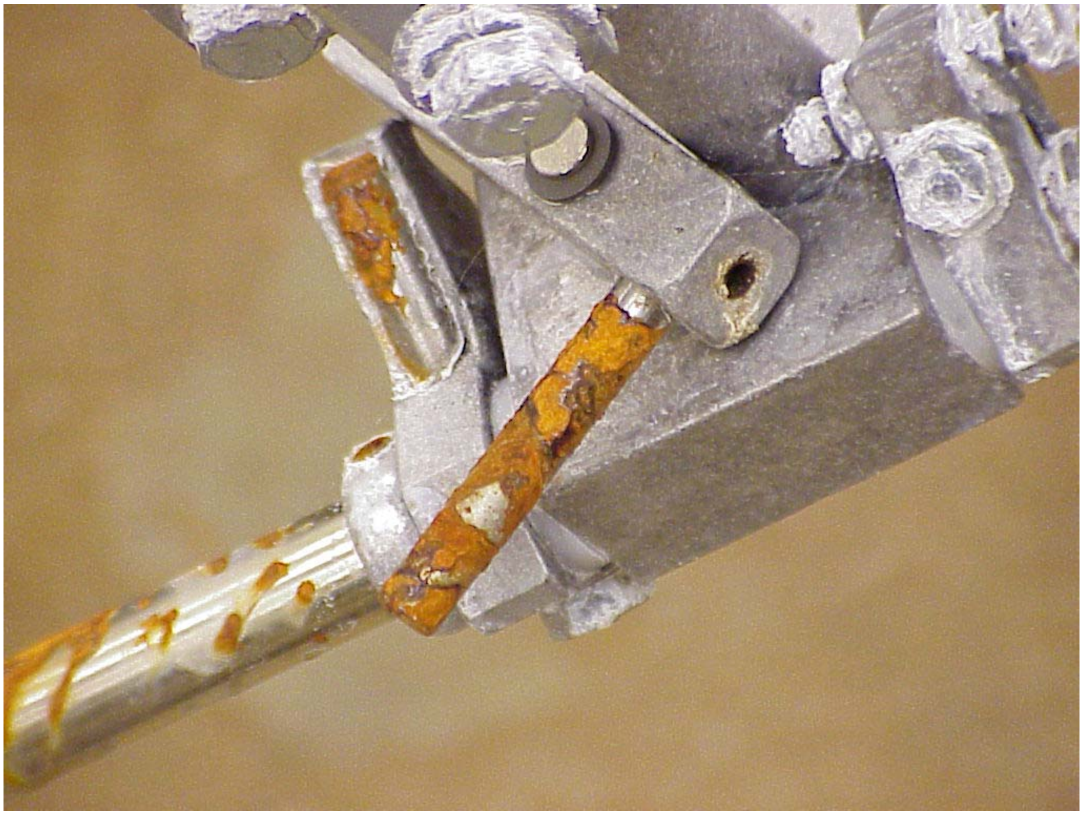


Photo #3 **(Mobility Products: 1st Environmental Test)**

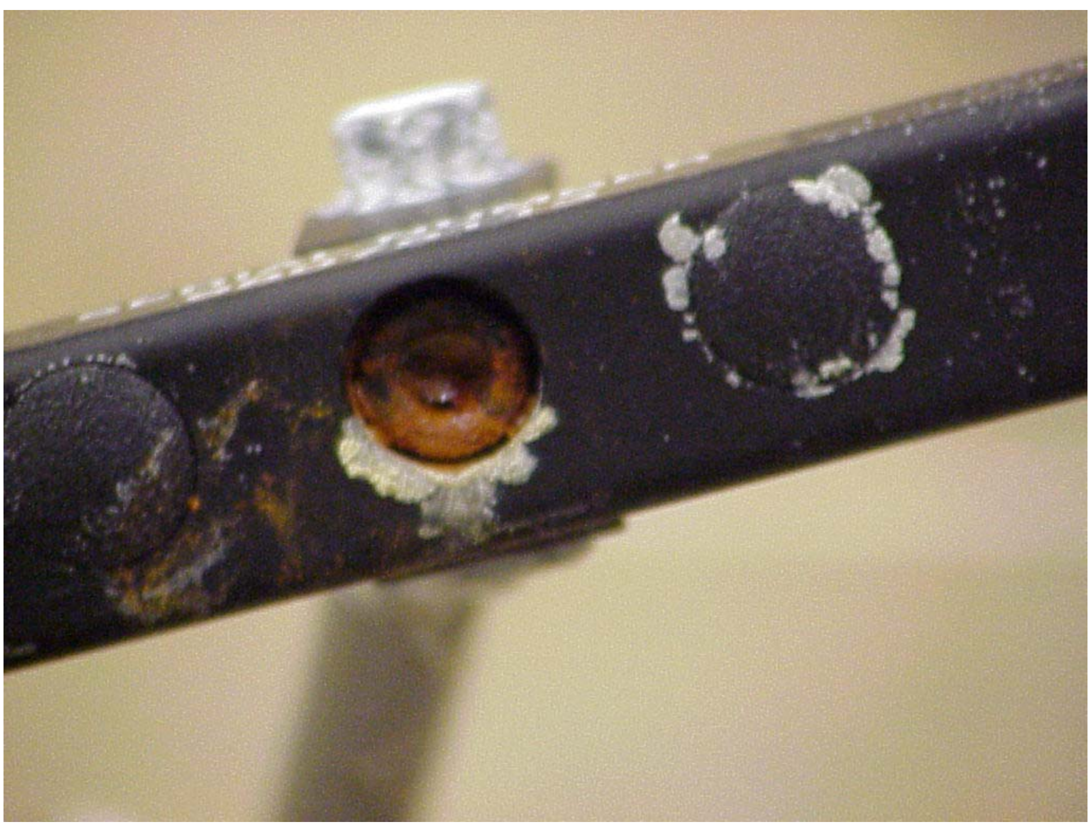


Photo #4 **(Mobility Products: 1st Environmental Test)**


Photo #5 **(Mobility Products: 1st Environmental Test)**

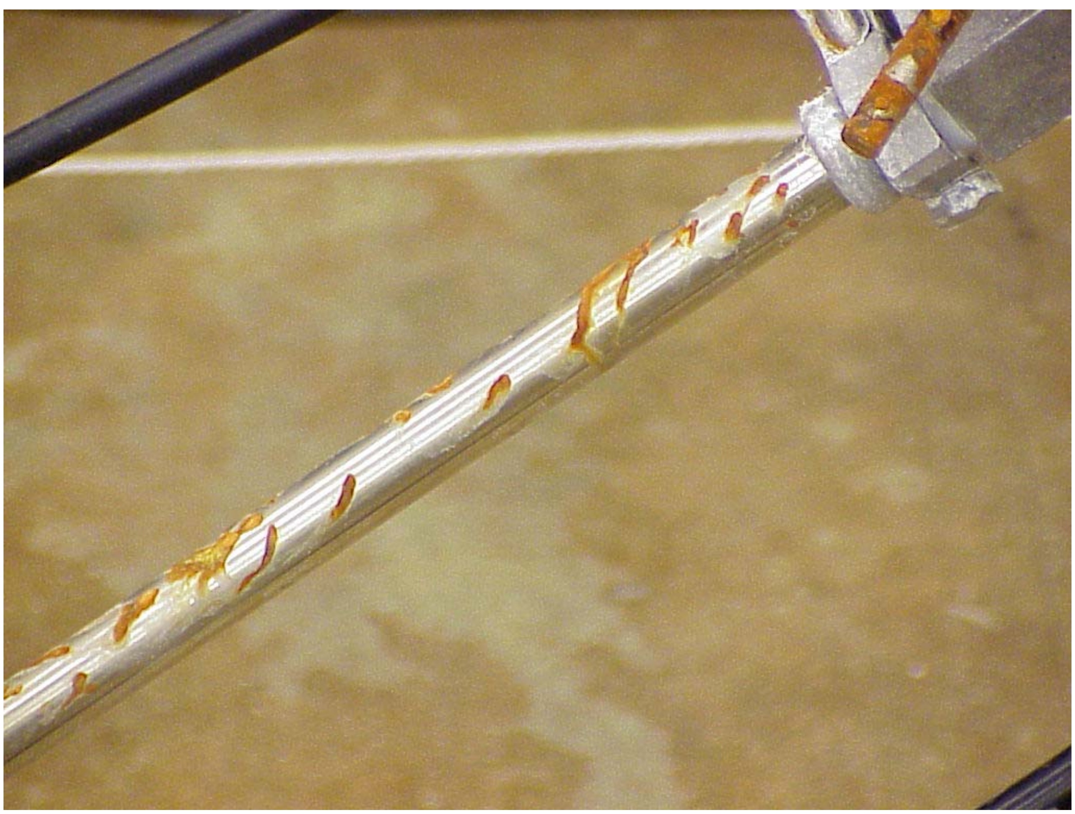


Photo #6 **(Mobility Products: 1st Environmental Test)**

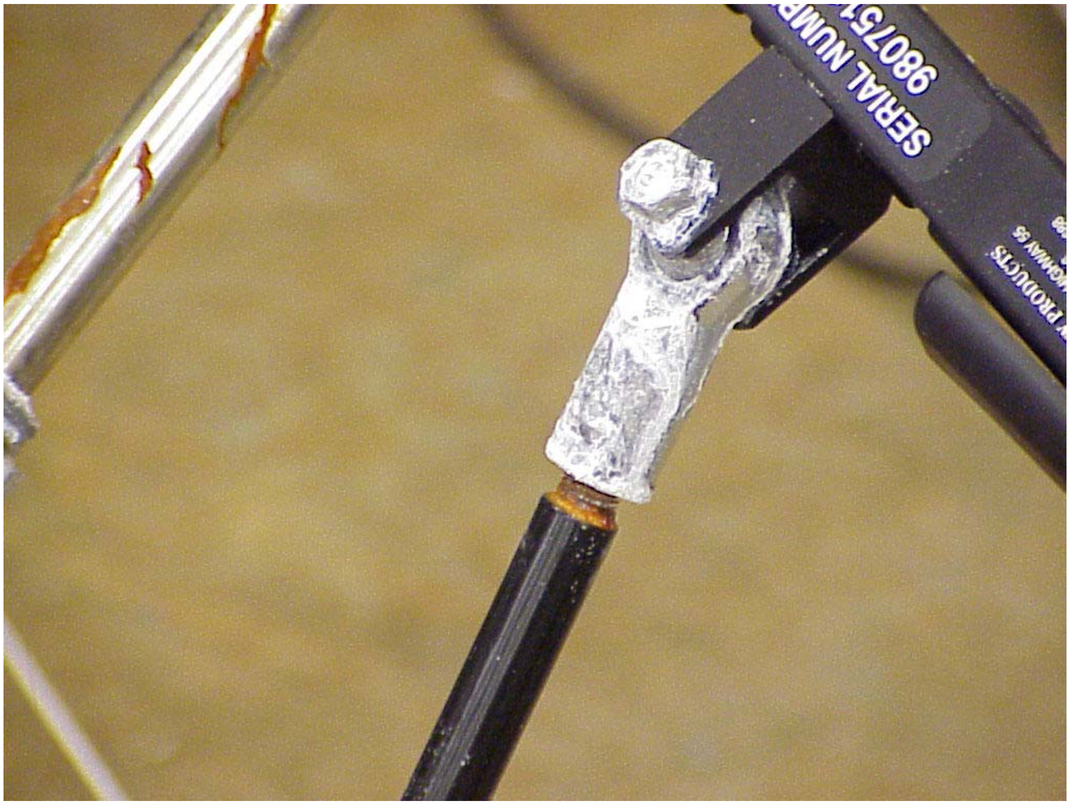


Photo #7 (Mobility Products: 1st Environmental Test)

Photo #8 (Mobility Products: 1st Environmental Test)

Photo #9 (Mobility Products: 1st Environmental Test)

Mobility Products

Appendix B

Photographic Coverage of 2nd Electromechanical Environmental Test

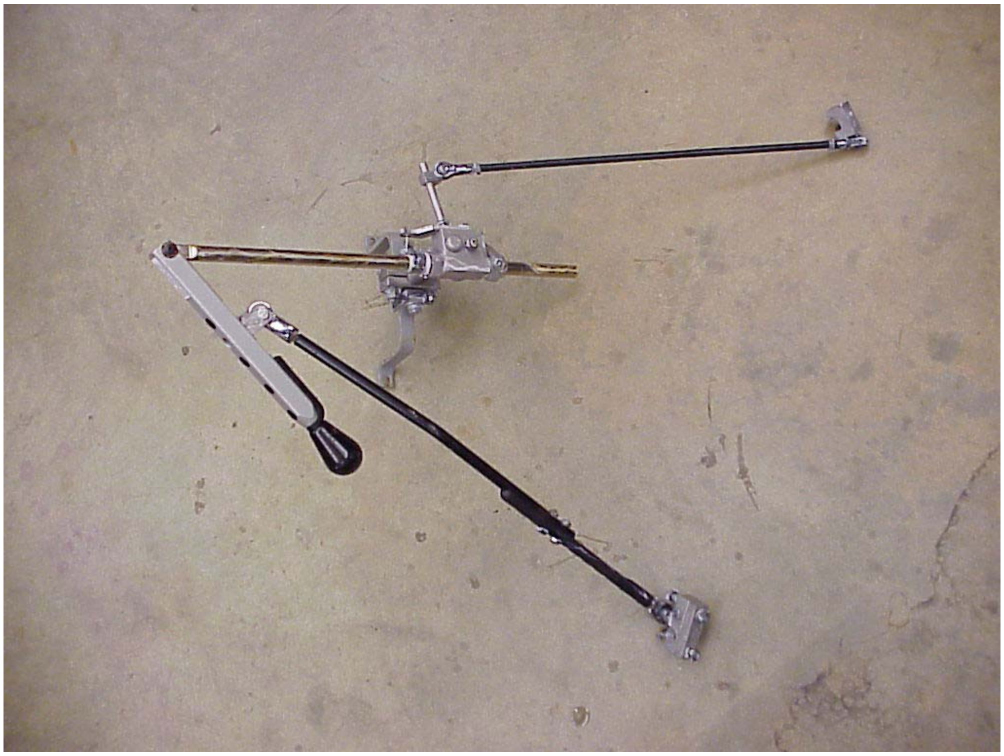


Photo #1 **(Mobility Products: 2nd Environmental Test)**

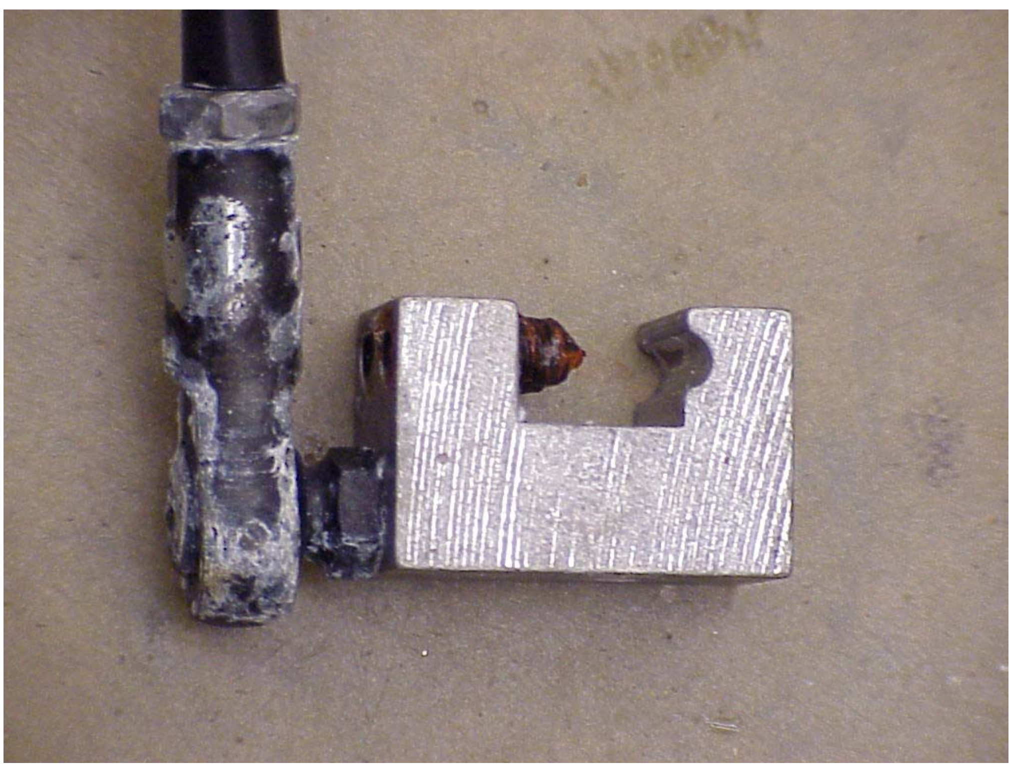


Photo #2 **(Mobility Products: 2nd Environmental Test)**

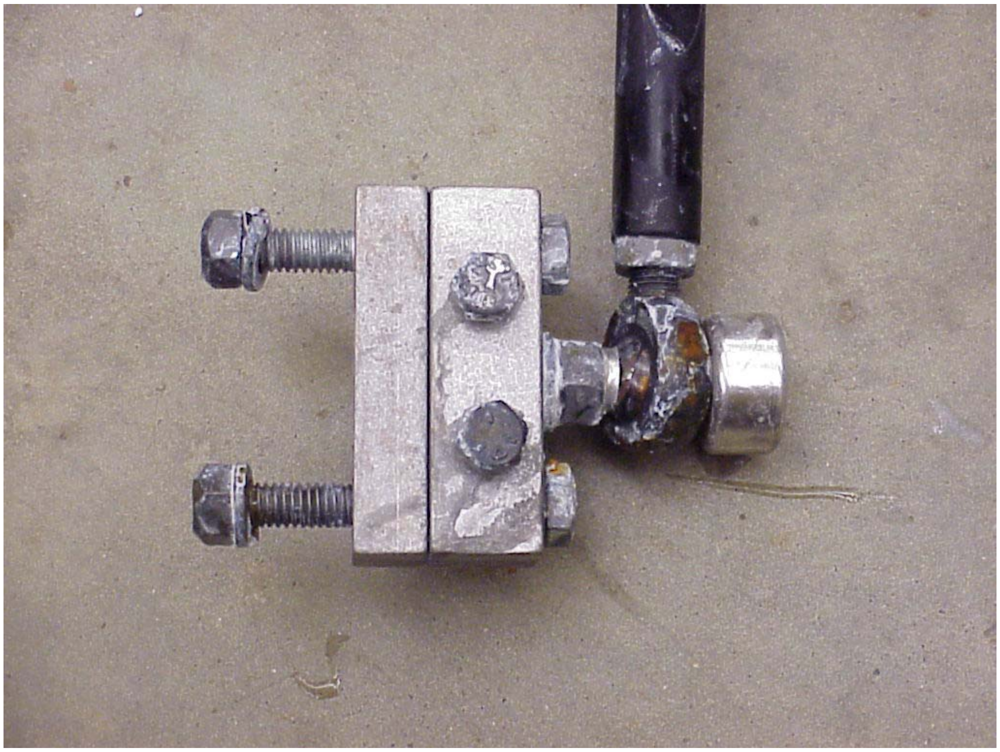


Photo #3 **(Mobility Products: 2nd Environmental Test)**

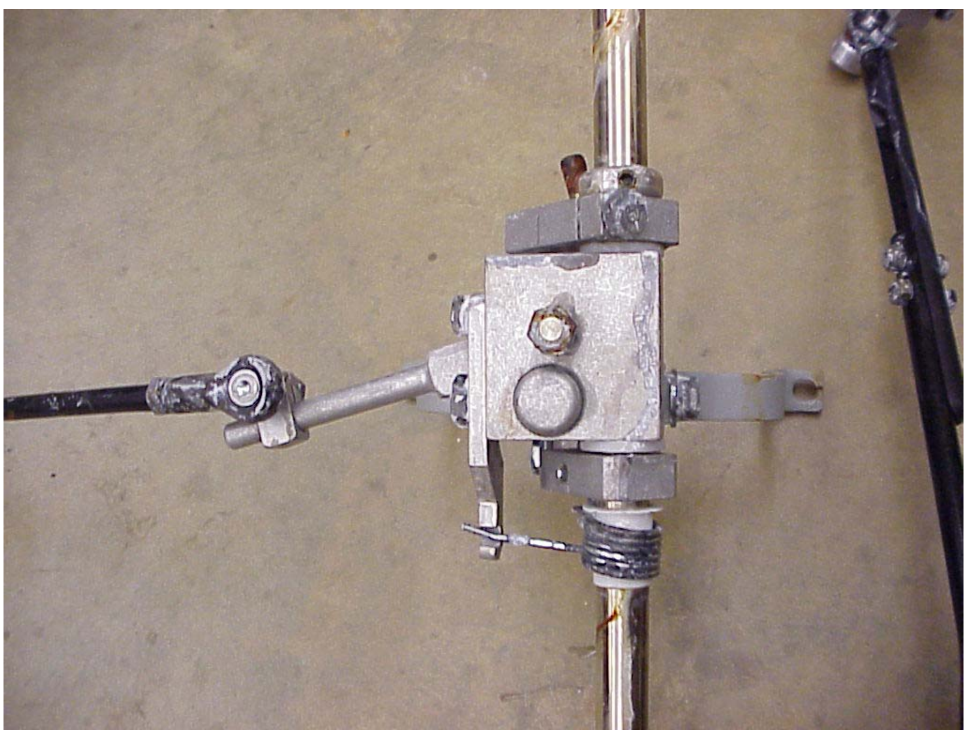


Photo #4 **(Mobility Products: 2nd Environmental Test)**

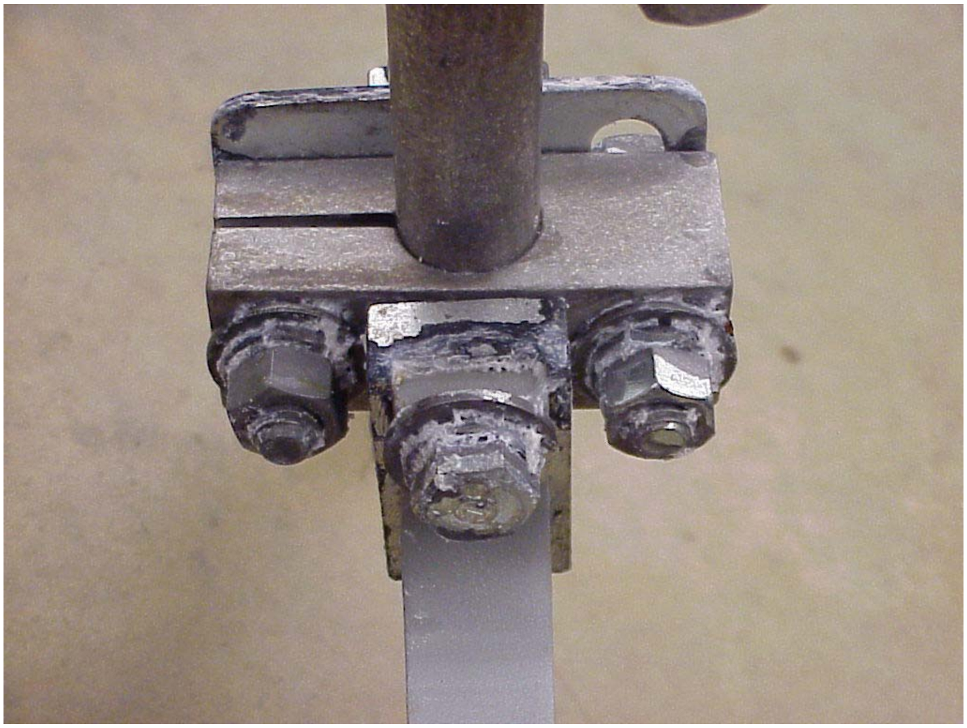


Photo #5 (Mobility Products: 2nd Environmental Test)

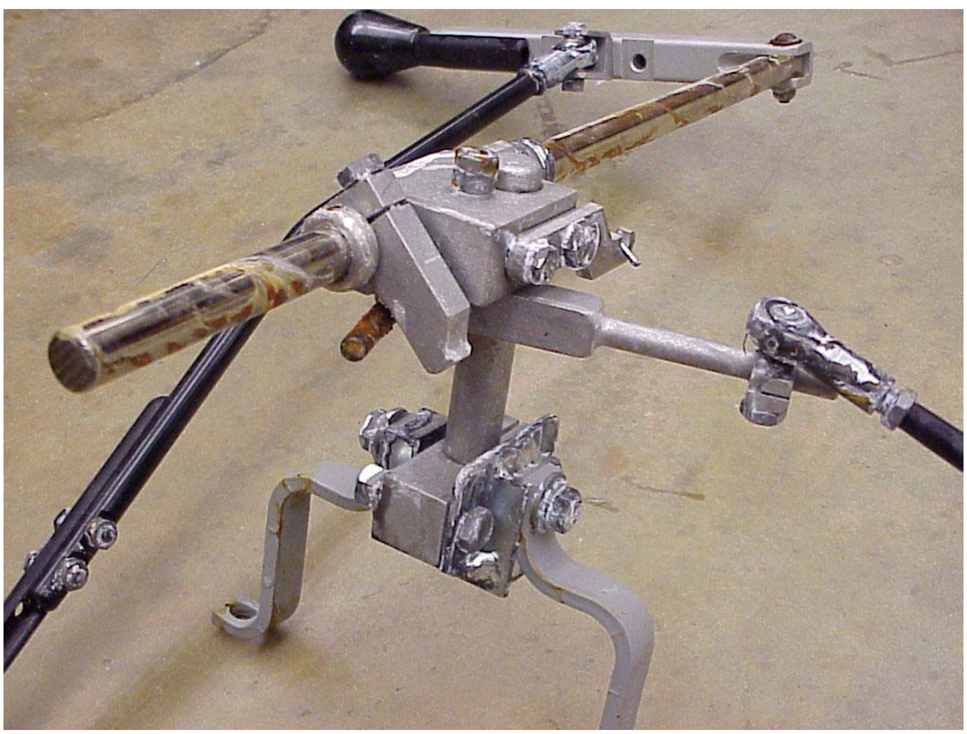


Photo #6 (Mobility Products: 2nd Environmental Test)

Photo #7 (Mobility Products: 2nd Environmental Test)

Mobility Products

<u>Appendix C</u>

Photographic Coverage of High-Cycle Test

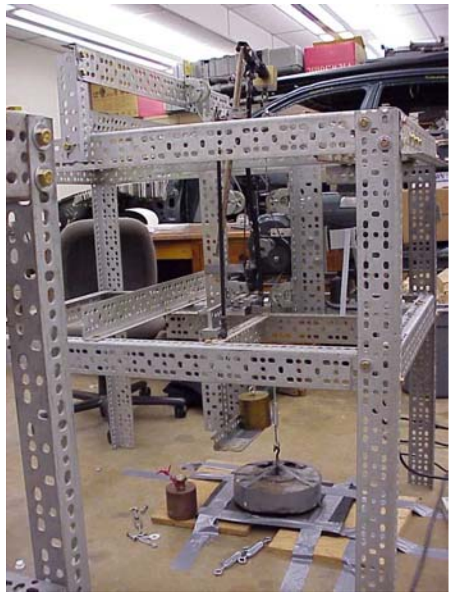


Photo #1 (Mobility Products: High-Cycle Test)

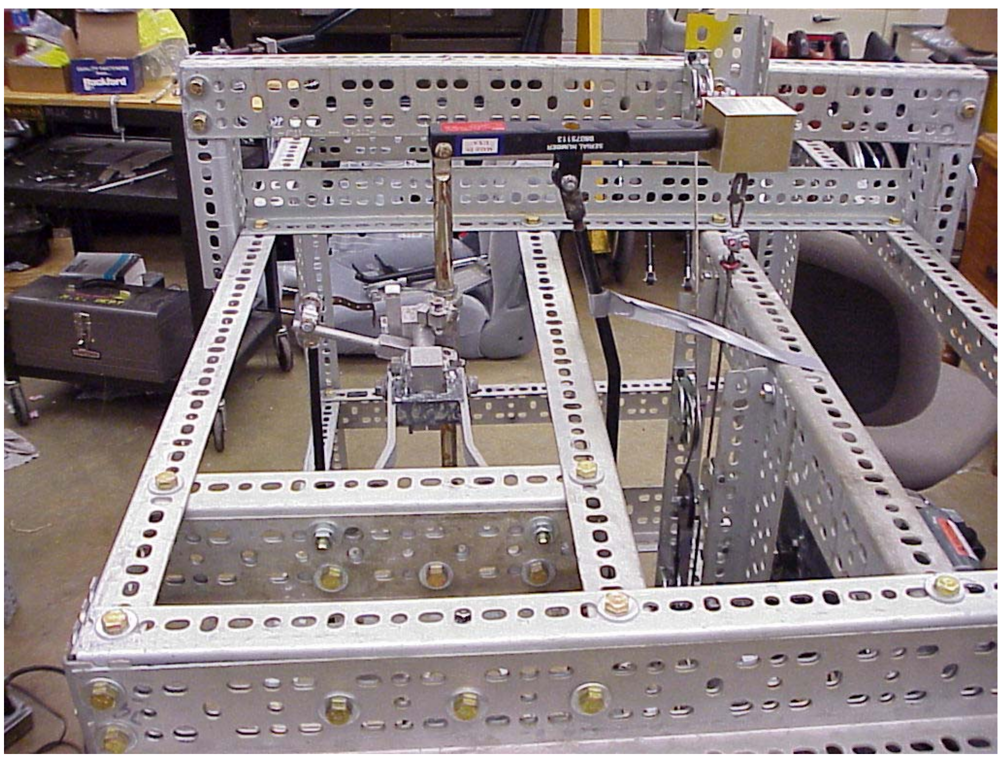


Photo #2 (Mobility Products: High-Cycle Test)

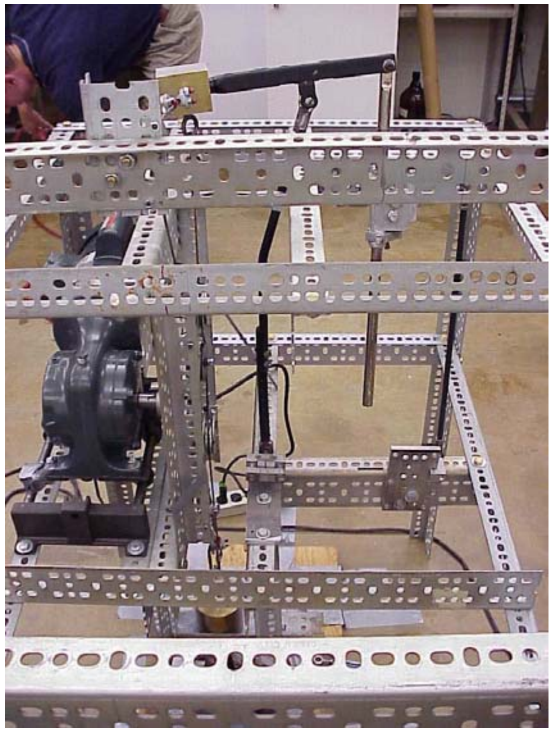


Photo #3 **(Mobility Products: High-Cycle Test)**

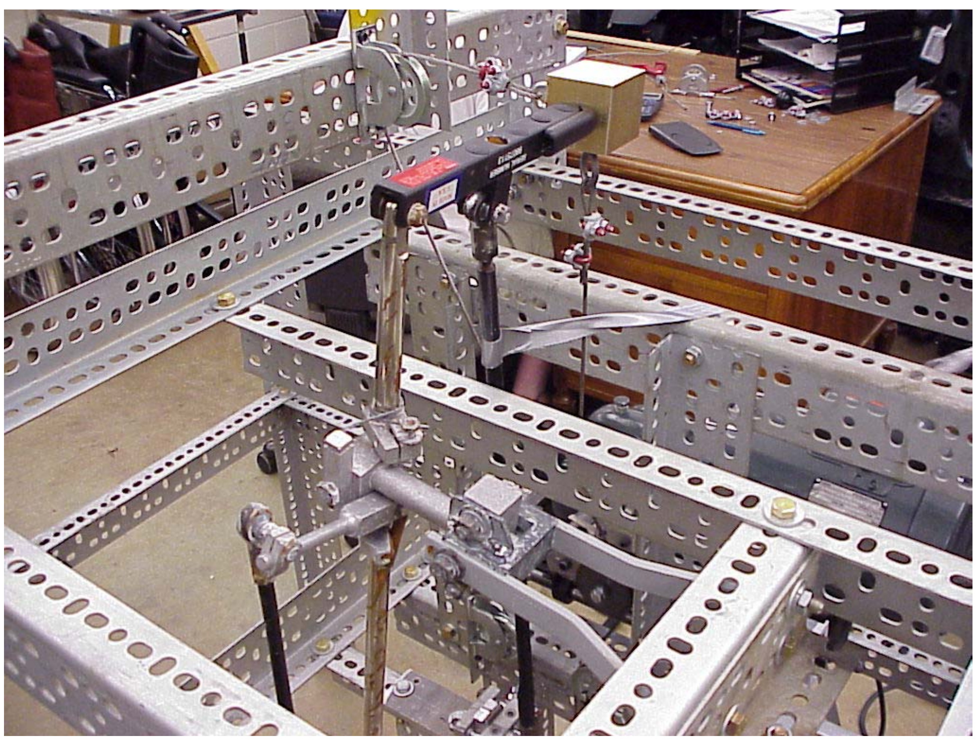


Photo #4 **(Mobility Products: High-Cycle Test)**

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Appendix D

Detailed Test Data Sheets for High Cycle Test

Cycle Testing
Mobility Products

Date	Time	Event	Count	
06/17/99	1:21P	Start	0	
	4:21P	Stop	8100	
06/18/99	8:52A	Start	8100	
	11:30A	Stop	15210	
	2:00P	Start	15210	
	3:00P	Stop	17910	
06/21/99	9:49A	Start	17910	
	4:11P	Stop	35100	
06/22/99	8:27A	Start	35100	**Note:** Hand control checked at 50,000
	11:30P	Stop	75735	cycles with no damage or loosening of fasteners
06/23/99	8:45A	Start	75735	**Note:** Hand control checked at 100,000
	10:45P	Stop	113535	cycles with no damage or loosening of fasteners
06/24/99	9:05A	Start	113535	
	1:00P	Stop	124110	
	2:00P	Start	124110	
	10:45P	Stop	147735	
06/25/99	8:45A	Start	147735	**Note:** Hand control checked at 150,000
	2:47P	Stop	164025	cycles with no damage or loosening of fasteners
06/28/99	8:50A	Start	164025	**Note:** Hand control checked at 200,000
	11:37P	Stop	204591	cycles with no damage or loosening of fasteners
06/29/99	8:20A	Start	204591	
	11:53P	Stop	247463	
06/25/99	8:10A	Start	247463	**Note:** Hand control checked at 250,000
	9:07A	Stop	250000	cycles with no damage or loosening of fasteners

Mobility Products

Appendix E

SAE J1903 Section 5 Summary

Model: MPD 3500
Manufacturer: Mobility Products & Design
2800 Northwest Boulevard
Minneapolis, MN 55441-2625
(800)-488-7688

Section 5: Inspection and Testing Procedures

5.1 Receiving Inspection

5.1.1 Packaging Integrity

Package was received with no damage.

5.1.2 Packing Documentation

Product was identified adequately.

Model: *3507*
Serial No. *98075113*
Manufacturer: *Mobility Products & Design*

5.1.3 Verification of Contents

a. Product Identification
Model identification not found on the product

b. Quality Control Verification
Quality control verification was not found

c. Warranty Information
Warranty information provided

d. Compliance Documentation as Required
No compliance information provided

e. Installation Instructions
Installation instructions provided in manual

f. Operating Instructions
Operating instructions provided in manual

g. Maintenance Instructions
Maintenance instructions provided in manual

h. Limitations
Limitations not defined in SAE J1903

i. Notifications
Notification was provided, but not detailed

5.1.4 Workmanship

Workmanship of product was adequate

5.2 Mounting

5.2.1 Verification of Installation Procedures

Mounting adequately described in manual. Product was installed in a '98 Ford Taurus sled buck with minimal effort.

5.2.2 Adjustments

Adjustments to the product are adequate and can be locked in position.

5.2.3 Compatibility

All fasteners present were compatible

5.2.4 Human Factors

Human factors are adequate (push for brake / twist for throttle)

5.2.5 Contact Hazards

No contact hazards were apparent

5.2.6 Maintainability

Service maintenance is described in manual with lubrication and adjustment points easily accessible.

5.3 Installation

5.3.1 Vehicle Alterations

When installed in the '98 Ford Taurus sled buck, the hand control requires alterations to the knee bolster which, according to 4.2.1 of SAE J1903, possibly interferes with the function of the occupant protection features provided by the motor vehicle manufacturer under FMVSS.

5.3.2 Operation

Operating instructions are provided in the manual.

5.3.3 Conventional Use

No obvious obstructions noted.

5.3.4 Mounting

Mounting location is strong and secure.

5.3.5 Neutral Balance

The product will not activate the vehicle due to force by its own mass . This was not verified in an actual vehicle as specified by SAE J1903.

5.4 Performance Tests

As prescribed in SAE J1903, the vibration, environmental, high-cycle, and service overload tests were conducted on a single unit in the prescribed order.

5.4.1 Vibration Test

Vertical direction

Start:	*9:30AM*	*1/7/99*
Stop:	*11:30AM*	*1/7/99*
Outcome:	*No loose connections found*	

Horizontal direction

Start:	*1:30PM*	*1/7/99*
Stop:	*3:30PM*	*1/7/99*
Outcome:	*No loose connections found*	

5.4.2 Electromechanical Environmental Test

Product was tested in accordance with ASTM B 117-97.

Post-test observations:

Corrosion of fasteners connecting the brake tube to the control tube.
Corrosion of the nut connecting the accelerator crank to the control tube.
Corrosion on the main support bracket.

5.4.3 High-Cycle Test

No degradation of the product was noted throughout the high-cycle test.

5.4.4 Service Overload

The hand control held the required braking and acceleration loads.

Task 2.1
Crash Avoidance Evaluation of Portable Hand Controls

Background
Task 2.0 evaluated the performance of hand controls that were designed for permanent installation. Task 2.1 evaluated three hand controls that were designed to allow rapid attachment and removal from a wide variety of vehicles. The promotional literature for these products targets drivers who need a temporary hand control for a borrowed or rented car. A limited phone review identified three products that met the commonly accepted characteristics of portable hand controls (Table 8).

Method
The reliability and durability of the portable hand controls were assessed using methods described in Task 2 above. We conducted vibration, cyclic load, and service overload testing. The environmental test was not conducted for the portable hand controls.

Vibration Test
The hand controls were rigidly mounted in test rigs. Cyclic loads were applied separately in the horizontal and the vertical directions for two hours each. All of the hand controls passed this test without sustaining damage or loosening of fasteners.

Electromechanical Environmental Test
This test was not conducted with the portable hand controls.

High-Cycle Test
The hand controls were subjected to 250,000 cycles of loading that simulated braking and accelerating. The Peddle Master failed at its attachment to the brake pedal at approximately 230,000 cycles (Fig. 9).We retested another Peddle Master unit that successfully completed the 250,000 cycles without failure. No failures occurred at any point in the testing of the other two controls.

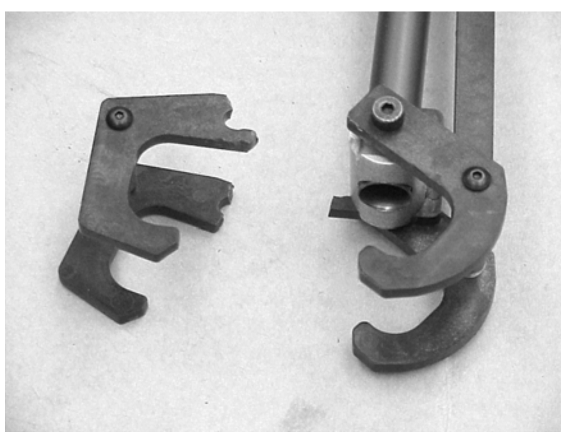
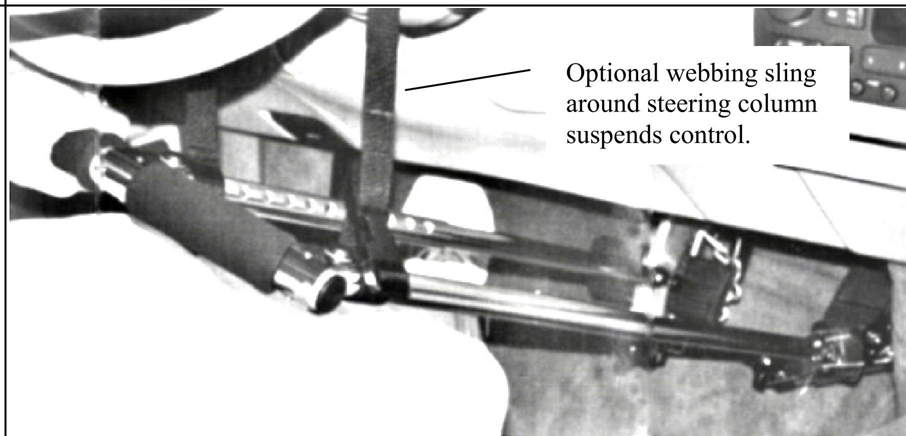
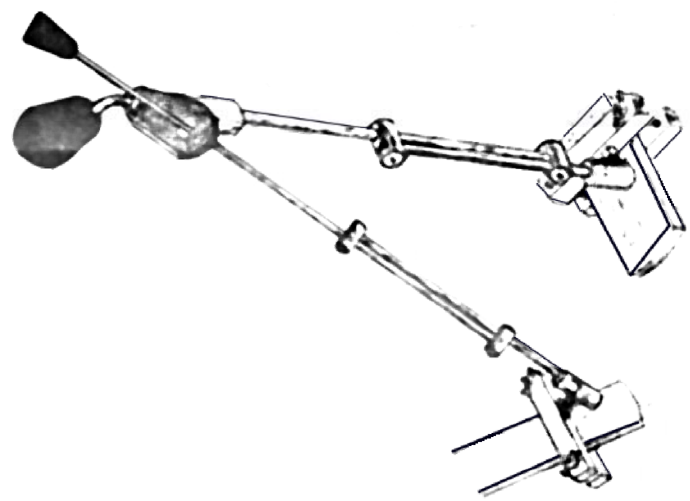
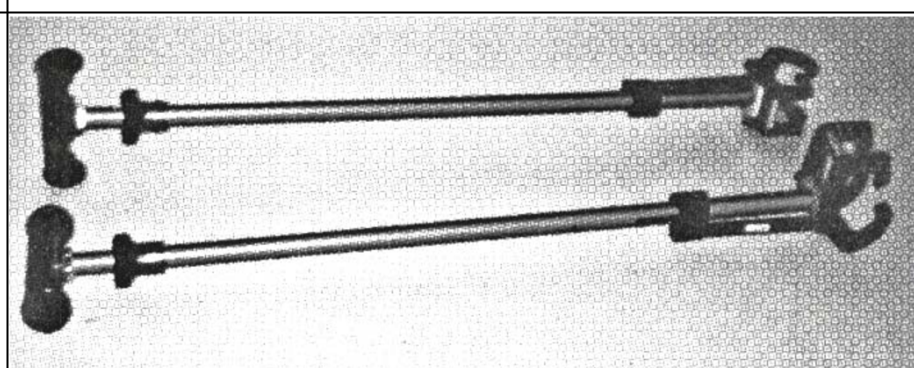


Figure 9. Peddle Master failure

Service Overload Testing
All of the hand controls ultimately passed this test that involved applying 150 lbf to the handle in the brake mode and 30 lbf in the accelerator mode.

Table 1. Evaluated Portable Hand Controls

Manufacturer	Model	Operation Method Brake / Gas	
McSquared Design	PHC III	Push / Pull	
Handicaps, Inc.	Portable Control	Push / Push	
Judson Enterprises, Inc.	Peddle Master	Push / Push	

Discussion

In contrast to the permanently installed controls evaluated in Task 2.0, the controls tested in Task 2.1 did not include a rigid mount to the steering column. Only one product, the PHC III, offered an optional webbing sling that looped around the steering column. The other products were designed to lay in the driver's lap or on the seat when not in use. The lack of a rigid mounting system may disqualify them from meeting some of the requirements of the SAE J1903 hand control standard:

> *1.3.2 Mounting: The product shall be designed to mount to the vehicle at a location that will reliably bear the service load and employ a means of attachment that will remain stable during the expected service life of the product.*

An additional provision of SAE J1903 disqualifies both the Handicaps Portable Control and the Judson Peddle Master:

> *1.3.3 Human Factors:….*
>
> *a. Throttle and brake activations require distinctly different directions of operator movement.*
>
> *b. Forward inertial movement of the operator cannot activate the throttle.*

The Handicaps control and the Peddle Master brake and throttle activations required a push. In both cases, inertial movement of the driver could activate throttle.

Although portable hand controls do not meet all of the SAE J1903 design specifications, they were successful in passing the mechanical performance specifications (with the exception of the first Peddle Master unit). While it is unlikely that users would approach the 250,000 operation cycles of the High Cycle Test (an approximation of ten years of continual use), some users may apply 150 lbf to the brake in a panic stop as is simulated in the Service Overload Test. Despite their lightweight construction, all of the controls passed the Service Overload Test.

Note that the lack of rigid steering column mounts required modifications to the loading fixtures that were designed and used for the permanently installed controls in Task 2. The fixture modifications included the addition of a support surface (Fig 10) and application of the load slightly off-axis. This arrangement resulted in a bending moment in the control shaft that may have resulted in a Service Overload Test that was more severe than that used for the permanently installed controls. The SAE J1903 test specifications, written for permanently installed controls, provide inadequate guidance for the testing of portable controls. Due to lack of a defined test procedure, it is possible that test results from another lab may be quite different than those reported by UVA.

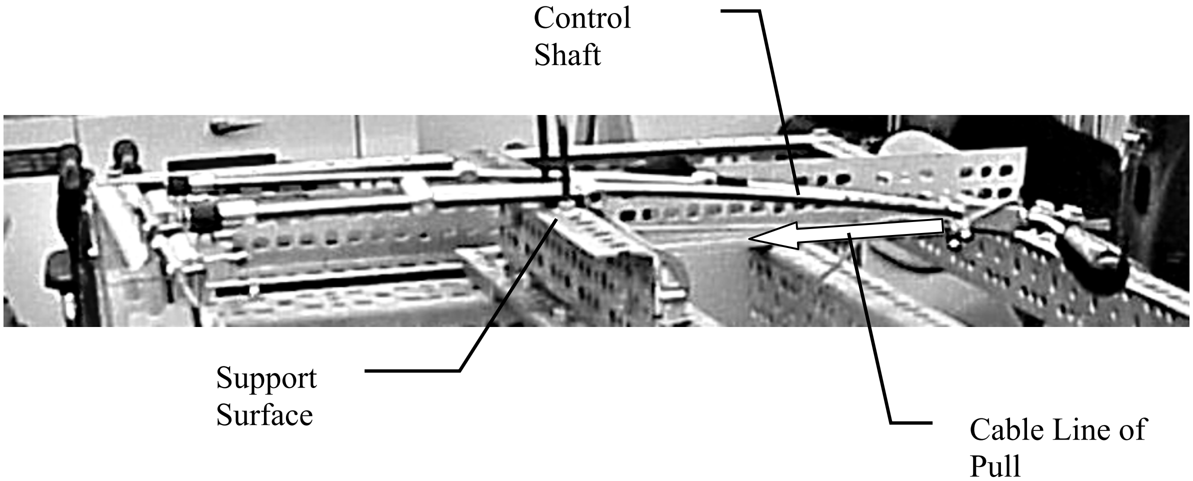


Figure 10. Hand control in test fixture. Support surface and application of the load slightly off-axis due to the line of pull of the loading cable resulted in a bending moment in the control shaft.

Conclusions
The results of Task 2.1 suggested that the three portable hand controls, when tested at UVA, met the strength and durability requirement of SAE J1903. Caution should be observed when interpreting these results because the SAE J1903 test procedure was not developed to ensure consistent lab-to-lab results with portable hand controls.

Task 3
Crash Worthiness Assessment of Manual Hand Controls

Background

Hand controls were developed before the advent of widespread automotive safety awareness and active research. It is unlikely that the designs were conceived with crash safety in mind. A review of hand control designs raised the following concerns in the event of a frontal collision.

1. Head injury: Will the head may hit the hand control handle and/or mounting hardware?
2. Injury to drivers of short stature: If the driver must sit closer to the steering wheel to operate the hand control, there exists an increased risk of injury caused by air bag deployment.
3. Leg injury: Metal rods and linkages are mounted near knees and lower legs.
4. Compromised knee bolster: Device installation usually requires cutting the knee bolster, an integral part of the occupant restraint system. Weakening the knee bolster has the potential to allow greater forward movement of the knees during a crash. In addition to the possibility of lower extremity injury, the changed kinematics may affect upper body motion and degrade belt and air bag performance, which, in turn, may be reflected in higher loads and accelerations.

The following include the methods used, the results, and discussion regarding our investigations of these concerns.

Head Injury

Consumers and rehabilitation professionals have asked about the potential for head injury from the hand control. This concern regarding head injury can be addressed using Federal Motor Vehicle Safety Standard 201 (FMVSS 201). This standard prescribes a method to predict driver's head contacts in a frontal collision. The FMVSS 201 head impact area was mapped onto the instrument panel of a 1998 Ford Taurus. The handle of the hand controls extended from the steering column past the rim of the steering wheel in a manner similar to that of column-mounted shift levers and turn signal indicators. NHTSA staff pointed out that FMVSS 201 did not apply to these components. Except for the handle, the hand control components lie outside the mapped head impact area. We concluded that hand controls do not present increased risk of head contact injury in a frontal collision.

Injury to Drivers of Short Stature

The National Highway Safety Traffic Administration (NHTSA) recommends that drivers sit with their chests at least 10" from the air bag module *(Air Bags and On-Off Switches NHTSA Publication DOT HS 808 629)*. This seating position limits the chance of injury due to air bag deployment. If drivers must sit closer than ten inches to the steering wheel/air bag in order to reach the controls, they may be vulnerable to injuries caused by a deploying air bag.

We investigated the possible effect on the small female driver seating position due to the use of hand controls. In discussions with driver evaluators, we found no consensus regarding whether use of a hand control usually requires a closer-to-the-wheel sitting position. The evaluators suggested that some drivers must sit closer to the wheel because of short arms, reduced range of motion, or reduced upper extremity strength. Other drivers, possessing average body proportions and upper extremity function, sit as would a driver who does not use a hand control.

We positioned a 5th percentile female crash dummy in our 1998 Ford Taurus test buck in accordance with specifications of the new FMVSS 208 frontal impact safety standard that indicates that the seat should be placed in its full forward position[1]. The chest-to-wheel center measurement for this configuration and dummy placement was 9.5", slightly closer to the air bag than NHTSA recommends. Note that NHTSA intends that the 10" recommended distance be interpreted as an approximate value. The NHTSA publication referenced above states "If you can get back *almost* 10 inches, the air bag will still help you in a crash." It is likely that many small females sit closer than 10" whether they are or are not hand control users. We measured 7.5" chest-to-wheel for an able-bodied 5th percentile female staff member who was asked to assume her normal driving position.

Without leaning forward or moving the shoulder forward, the dummy's range of elbow extension was such that she could push the handle of a hand control into the dash. This indicated greater than sufficient range to fully apply the brake.

1. Department of Transportation National Highway Traffic Safety Administration 49 CFR Parts 552, 571, 585, and 595 [Docket No. NHTSA 99-6407; Notice 1] RIN 2127-AG70 Federal Motor Vehicle Safety Standards; Occupant Crash Protection. Supplemental notice of proposed rulemaking (SNPRM). iii. Location and Seating Procedure for 5th Percentile Adult Female Dummy.

Leg Injury

Compromised Knee Bolster

Concerns three and four, related to leg injury and knee bolster modification, were investigated by conducting six frontal sled tests. The tests included a baseline test with no hand control and five tests each using one of the hand controls listed in Table 1. The complete description and results of these tests are contained in the following report, *Hand Control Sled Tests 600-605*.

We found that the hand controls and the knee bolster modifications necessary for their installation minimally affected crash safety. The most severe injury, predicted by a cut in the chamois overlaying the dummy knee, was a moderate knee laceration. More generous radiuses on components mounted near the knees would reduce the risk and severity of lacerations. Injury criteria values such as HIC, chest g's, femur load, and the tibia index, were unaffected by the presence of the hand control. The results and conclusions of this study are based on a single crash condition. Hand controls and structurally compromised knee bolsters may perform differently in other crash environments. Modifications to the knee bolster structure should be avoided or minimized.

48 km/h Frontal Sled Tests

Hand Control Sled Tests 600 - 605

Three-Point Belt and Air Bag

Hybrid III 50th Percentile Male ATD

A Report of Task 4 Activities
for
Hand Controls Usage and Safety Assessment
DTRS-57-97-C-00050, TTD#3

Prepared for
Transportation Systems Center
In consultation with
National Highway Transportation Safety Administration

by the

Automobile Safety Laboratory
of the
University of Virginia

Principal Investigator
Walter D. Pilkey
Morse Professor of Engineering

August 2001

ABSTRACT

This report describes University of Virginia Auto Safety Lab test numbers 600 - 605, frontal sled tests conducted using the Hybrid III 50th percentile male dummy seated in the driver's position. Tests 601-605 included one of five commonly used hand controls. Test 600, conducted without a hand control, served as a baseline. The 48 km/h tests used a 3-point belt and an air bag. These tests provided information regarding the crash safety of manual hand controls. The test results indicate that hand controls and the knee bolster modifications necessary for their installation minimally affected crash safety. The most severe predicted injury was a moderate knee laceration. Injury criteria values such as HIC, chest g's, femur load, and the tibia index were unaffected by the presence of the hand control.

Note that these tests represent a moderately high severity crash, but did not simulate conditions such as intrusion, a common condition in frontal crashes in which components such as the brake and accelerator pedals are pushed into the occupant compartment. Movement of these components may affect the potential for the attached hand control to cause injury to the driver. In addition, these tests did not simulate drivers that were restrained only by the air bag, a condition that results in increased forward driver movement and increased likelihood of contact with the dashboard, steering column, and hand controls. Therefore, although the simulated full frontal crash results reported here suggested minimal chance for injury from hand controls, other crash conditions may prove to be more injurious. To reduce the possibility for injury, manufacturers are encouraged to design hand controls to minimize the effects of possible contact with the driver and to avoid or minimize modifications to the knee bolster.

SUMMARY OF RESULTS						
Test ID	**600**	**601**	**602**	**603**	**604**	**605**
Hand Control	Baseline (no control)	Wells Engberg	MPS Monarch Mark 1-A	Drive-master Ultralite XL	Howell Ventures Sure Grip	MPD 3500
SLED PARAMETERS						
∆V (km/h)	48.1	48.1	47.9	48.1	48.4	48.4
Max. Sled Deceleration (g's)	21	21	21	21	21	21
RESTRAINT DATA (MAXIMUMS)						
Outer Lap load (kN)	7.3	8.1	6.4	7.6	6.9	7.3
Upper Shoulder load (kN)	7.7	8.0	Sensor Failure	8.9	8.8	8.8
OCCUPANT PARAMETERS						
Head CG resultant acceleration (g's)	58	59	58	62	63	62
Chest CG resultant acceleration (g's)	46	48	49	51	49	52
Pelvis CG resultant acceleration (g's)	61	68	62	66	63	70
INJURY CRITERIA (MAXIMUMS)						
HIC Criteria < 1000	461	491	495	563	551	557
Femur (kN) Left / Right Criteria < 10 kN	0.2 / 0.5	0.2 / 1.0	1.2 / 0.1	0.2 / 0.1	1.1 / 0.7	0.4 / 0.1
Tibia Index Left / Right Criteria < 1.3	0.2 / 0.3	0.1 / 0.3	0.2 / 0.2	0.2 / 0.3	0.2 / 0.3	0.1 / 0.2

1: INTRODUCTION

This report presents the results and analysis of crash simulation tests conducted at the Automobile Safety Laboratory (ASL). The tests were conducted from 12/13/99 to 12/16/99. This research was conducted as part of *Hand Controls Usage and Safety Assessment DTRS-57-97-C-00050, TTD#3.* The testing facility is operated by the Department of Mechanical, and Aerospace, Engineering at the University of Virginia, Charlottesville, Virginia.

1.1: RESEARCH OVERVIEW

At the ASL, anthropometric test dummies are used in a simulated automobile to evaluate current occupant interiors, restraint systems, dummy designs, instrumentation, federal safety standards, and injury criteria. Vehicle and occupant conditions have been duplicated in the laboratory sled test environment to reproduce events in actual crashes.

Tests 600-605 were conducted to investigate the crash safety of commonly used hand controls. The tests included an initial baseline test conducted without a hand control (Table 1). Hand controls are devices used by people who are unable to operate the brake and accelerator pedals due to physical impairment. Hand controls typically are rod linkages attached at the lower end to the brake and accelerator pedals. The rods are supported by a bracket mounted underneath the steering column and terminate in a single handle positioned near the perimeter of the steering wheel. Pushing this handle pushes the brake pedal. Moving this handle back or down, or twisting the handle pushes the accelerator pedal (Fig. 1).

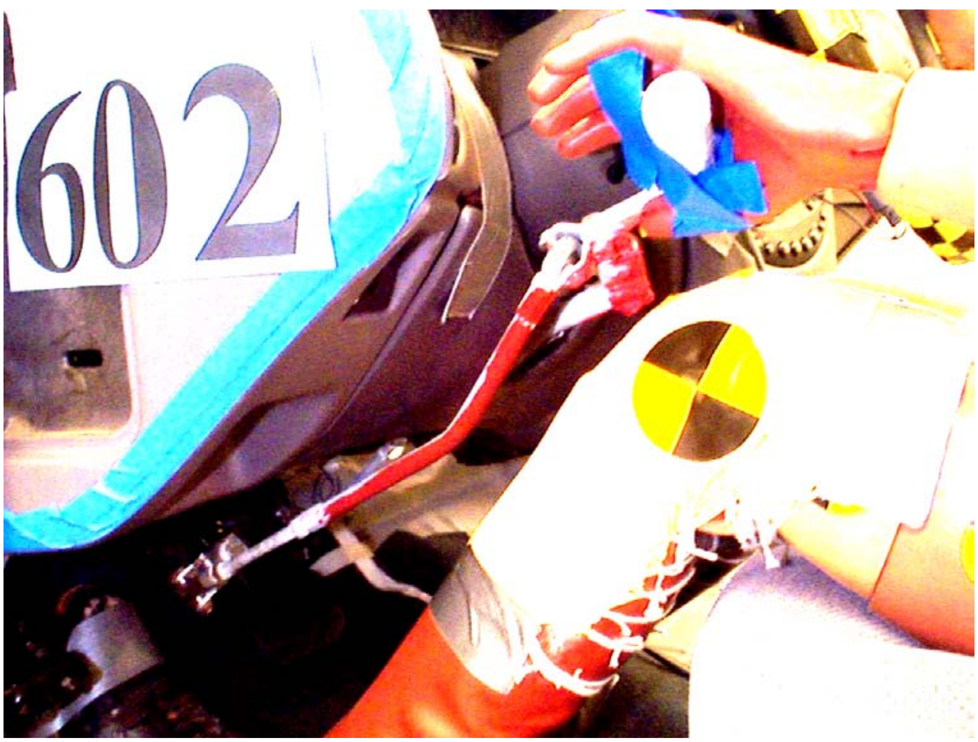


Figure 1. Typical hand control installation. MPS Monarch hand control pre-test 602.

Because hand controls were developed before the advent of widespread automotive safety awareness and active research, it is unlikely that the designs were conceived with crash safety in mind. The following concerns have been expressed:

1. Leg injury: Metal rods and linkages are mounted near knees and lower legs.
2. Compromised knee bolster: Device installation often requires cutting the knee bolster, an integral part of the occupant restraint system.

Weakening the knee bolster has the potential to allow greater forward movement of the knees during a crash. In addition to the possibility of lower extremity injury, the changed kinematics may affect upper body motion and degrade belt and air bag performance, which, in turn, may be reflected in higher loads and accelerations.

Table 1. Sled test matrix.

Test #	600	601	602	603	604	605
Manufacturer and Model	Baseline (no control)	Wells Engberg	MPS Monarch Mark 1-A	Drive-master Ultralite XL	Howell Ventures Sure Grip	MPD 3500
Operation: Brake/Gas	-	Push / Twist	Push / Right Angle	Push / Pull	Push / Pull	Push / Right Angle

1.2: TEST SUMMARY

The 48 km/h tests used a 3-point belt and air bag. The dummy was instrumented to record head acceleration, thoracic acceleration and deflection, pelvic acceleration, and femur loads. Left and right tibia loads and moments, restraint belt loads, and sled acceleration were also recorded. High-speed cameras produced images of the impact event.

2: TEST DESCRIPTION

The tests were conducted utilizing a 1998 Ford Taurus test fixture mounted on the carriage of the Automobile Safety Laboratory's Via Systems test sled (Table 2). The equipment involved is summarized in Tables 2 and 3, below. The test parameters including steering column and seat adjustments and dummy position were similar to those specified FMVSS 208.

Table 2. Mechanical Equipment

CRASH SIMULATOR:	
Type	VIA Systems deceleration test sled, model 713, with hydraulic decelerator, model 931-4000.
Decelerator orifice array	See UVA test # 570.
Instrumentation	1: Front center X-axis accelerometers (2) 2: Decelerator cylinder hydraulic pressure transducer (not used) 3: Stationary proximity-sensor & steel blade on sled to measure velocity
TEST FIXTURE (BUCK):	
Type	1998 Ford Taurus
Instrumentation	None
SEAT:	
Type	Reinforced OEM bucket seat with anti-submarining pan
Model	1998 Ford Taurus
Upholstery	Cloth
Condition	New
Instrumentation	None
Headrest	1998 Ford Taurus
STEERING COLUMN and WHEEL:	
Type	1998 Ford Taurus Tilt
Instrumentation	None
Angle	Mid tilt detent
Air bag Status	Active
RESTRAINTS	
SEAT BELT	
Type	1998 Ford Taurus 3-point unibelt
Condition	New
Instrumentation	1: Belt-tension load cells (3) near shoulder and lap section anchor points (outboard) and shoulder section near buckle (inboard) 2: Marked string pulled through foam block to measure belt spool-out
AIR BAG	
Type	1998 Ford Taurus
Part number	F8 DB 540 43
Condition	New
Deployment delay (after T_0)	13 ms
Instrumentation	None
KNEE BOLSTER :	
Type	1998 Ford Taurus

Table 3. High-Speed Motion Picture Cameras

Camera	Position, View	Make	Lens		Height (cm)	Speed (F/sec)
			Focal Length (mm)	Aperture (f:)		
1	Offboard driver's side, analysis view	CHSV	20.0	2.0	100	1000
2	Offboard passenger's side, overall	CHSV	35.0	2.0	100	1000
3	Offboard driver's side, backup	HSV	Zoom	8.0	98	1000

Notes:
CHSV = Kodak RO High Speed Video Color Camera
HSV = Kodak High Speed Black and White Video Camera

2.1: DATA ACQUISITION SYSTEM

Electronic signals from the sensors described in Section 2.2 were recorded and converted to digital data by the Laboratory's 128-channel DSP Technology, model TRAQ P data acquisition system. The data-collection process was controlled by DSP technology IMPAX 3.0 software. The post-test processing was done on IBM-compatible personal computers using ASL software.

2.2: INSTRUMENTATION

Accelerometers were mounted at the dummy's head center of gravity (CG), the chest CG, and the pelvis to assess the thoracic and head response (Table 4). A centrally mounted sternal slider was used to measure chest deformation. The dummy was also instrumented with a six-axis upper neck load cell, uniaxial load cells in the femurs, and multi-axial load cells in the proximal and distal tibias. Tension gauges recorded restraint belt loads. The sled deceleration time-history was recorded by redundant accelerometers located on the sled carriage.

Table 4. Sensor List

Measurement		Location		Axis[A]	Type	Manufacturer	Model
Crash Simulator	Sled Deceleration	Sled, Front, Center	1	XG	Accelerometer	Entran	EGC-500DS
			2	XG	Accelerometer	Entran	EGC-500DS
	Impact Velocity	Sled Track		XG	Blade and Pickup		
Restraints	Belt Load	Shoulder Belt	Upper	NA	Load Cell	Eaton Lebow	3419-3.5k
			Lower	NA	Load Cell	Eaton Lebow	3419-3.5k
		Lap Belt, Outer		NA	Load Cell	Eaton Lebow	3419-3.5k
50^{th} % Male Hybrid III	Head Acceleration	Head, Center of Gravity		X	Accelerometer	Endevco	7264A
				Y	Accelerometer	Endevco	7264A
				Z	Accelerometer	Endevco	7264A
	Chest Acceleration	Chest, Center of Gravity		X	Accelerometer	Endevco	7264A
				Y	Accelerometer	Endevco	7264A
				Z	Accelerometer	Endevco	7264A
	Pelvic Acceleration	Pelvis, Center of Gravity		X	Accelerometer	Endevco	7264A
				Y	Accelerometer	Endevco	7264A
				Z	Accelerometer	Endevco	7264A
	Chest Deflection	Sternum		X	Standard Hybrid III Sternum Slider Potentiometer		
	Femur Load	Femur, Left		Z	Load Cell	GSE	112435
		Femur, Right		Z	Load Cell	GSE	112435
	Tibia Moment	Tibia, Left Proximal		X	Load Cell	Denton	1583
		Tibia, Left Proximal		Y	Load Cell	Denton	1583
		Tibia, Left Distal		Y	Load Cell	Denton	1584
		Tibia, Right Proximal		X	Load Cell	Denton	1583
		Tibia, Right Proximal		Y	Load Cell	Denton	1583
		Tibia, Right Distal		Y	Load Cell	Denton	1584
	Tibia Load	Tibia, Left Distal		X	Load Cell	Denton	1584
		Tibia, Left Distal		Z	Load Cell	Denton	1584
		Tibia, Right Distal		X	Load Cell	Denton	1584
		Tibia, Right Distal		Z	Load Cell	Denton	1584

NOTES:

A – Frame of reference is local to the part or body segment on which the sensor is mounted..

G = Global frame of reference

NA = Not Applicable: Frame of reference is undefined or unrelated to defined frames of reference.

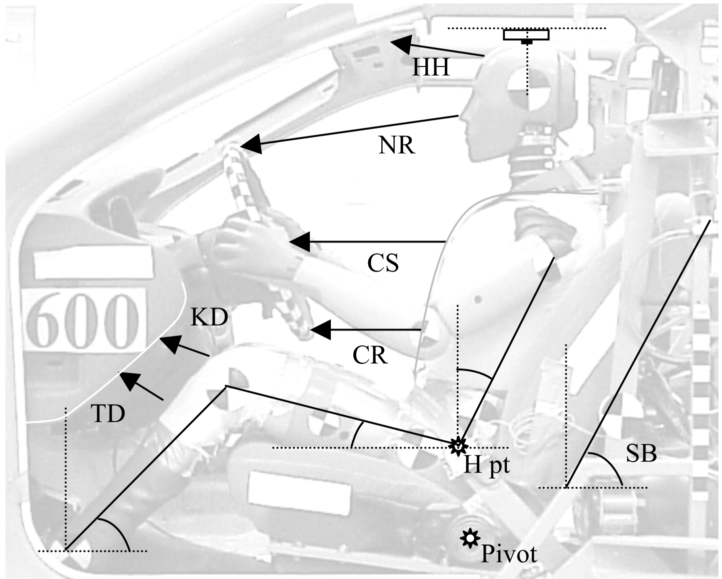
2.3: DUMMY PREPARATION

Preparation of the Hybrid III dummy included tightening of the neck and lumbar spine cables to the specified torque values and adjusting the joints to the standard “1-g” setting. Two layers of leather chamois were stretched over each knee to record cuts and abrasions.

2.4: TEST SET-UP AND DUMMY POSITIONING

The positioning of the seat, steering wheel, and dummy was done in accordance with FMVSS 208 testing guidelines. The position of the dummy was verified with information provided by the Ford. The left foot rested on the footrest; the right foot on the accelerator pedal. We recognize that hand control users may sit differently from drivers who use pedals but there is no one typical lower extremity position for this population. Therefore, we elected to use the FMVSS 208 position as it was designed to minimize test result variability. The only deviation to the FMVSS 208 positioning guidelines was the placement of the left hand on the control handle rather than on the steering wheel.

Final positioning of the occupant was performed with special emphasis on replicating the FMVSS 208 position used in baseline test. Chest-to-wheel center and knee-to-knee bolster were the primary measurements that were used to approximate the desired position. After positioning, measurements of anatomical landmarks and body segments were completed prior to launch (Fig. 2).



CS	Horizontal distance from chest to steering wheel hub.	**KD**	Closest distance from knee to bolster.
CR	Horizontal distance from chest to steering wheel lower rim.	**TD**	Closest distance from tibia to bolster.
NR	Distance of nose to upper rim.	**SB**	Angle from vertical of seat back taken 33 cm above back pivot.
HW	Horizontal distance from head to windshield.	**H**	Dummy H point. Reference for torso and femur angles.
HH	Distance from head to windshield header.	**Pivot**	Seat to back joint.
		NM	Not measured.

Test #	600	601	602	603	604	605
DIMENSIONS (cm)						
KD(L)	10.5	10.8	10.5	11.0	10.9	11.3
KD(R)	10.2	10.5	10.3	11.8	10.4	10.1
CS	32.6	31.4	32.8	32.4	32.6	33.2
TD(L)	12.6	12.9	13.3	12.8	13.3	13.2
TD(R)	11.0	11.8	11.7	10.8	12.3	10.4
ANGLES (degrees)						
HEAD	0	0	0	0	0	0
TORSO	24	24	24	23	24	26
PELVIC	24	22	23	24	25	25
FEMUR(L)	21	19	24	19	24	22
TIBIA(L)	47	44	47	45	47	44

Figure 2. Pre-test positioning for 600 (Baseline – no hand control). Dummy position for the other tests were similar with the exception that the left hand was placed on the hand control handle. The seat back angle (SB) was 29 degrees for all tests. The dummy's H point was 0.3-0.9 cm forward of the target location provided by Ford.

2.5: Device Installation

We asked the manufacturers to configure the hand controls for installation in a 1998 Ford Taurus. We followed the installation instructions that accompanied the controls. In addition, we consulted with a local experienced installer and contacted the manufacturers when questions arose. In general, we installed the controls in order to:

1. Place the handle within reach of the driver.
2. Provide full braking and gas range of motion.
3. Minimize hardware interference with the knees.

For most of the controls, this involved adjusting the mounting hardware so that the assembly was as close as possible to the lower surface of the steering column (allowing for full wheel tilt range). We sent photographs of the installations to the manufacturers for review. In all cases, the resulting control position required at least minor modification of the knee bolster. Slots and holes were necessary to allow pass-through of rods and linkages. In most cases, the bracket supporting the lower border of the bolster had to be removed. We tried to minimize the effect of the modifications on the structural integrity of the knee bolsters.

2.6: DATA ACQUISITION

The various system settings used for the impact data collection are summarized in Table 6. The arrival of the test sled at the impact end of the track activated the trigger circuitry, which simultaneously triggered the data acquisition system and the high-speed video system.

Table 5. Data Acquisition Parameters

Number of Data Channels Used	34
Sampling Rate	10,000 samples / second
Pre-Trigger Samples	1,280 / channel
Post-Trigger Samples	8,960 / channel
Total Samples	10,240 / channel
Pre-Trigger Duration	0.128 s.
Post-Trigger Duration	0.896 s.
Total Duration	1.024 s.
Anti-Aliasing Filter Cutoff Frequency	3300 Hz.

3: TEST RESULTS

3.1: DESCRIPTION OF RESULTS

Sensor and equipment failures are summarized in Table 6. In addition to the motion pictures, the results are presented in several different forms in this section. Table 7 contains the maximum and minimum values of the sensor data and the corresponding times at which they occurred. Data plots appear in Section 3.2. Photographic results, located in Section 3.3, include a summary of the minimum and maximum values of occupant displacements that were calculated from the analysis of high-speed video (Tables 8 - 13; Fig. 3).

Table 6. Sensor and Equipment Failures

Test	Item	Comment
600	Upper shoulder belt load cell	Failed during test.
602	Upper shoulder belt load cell	Failed during test.

Table 7. Sensor Data

Sensor Data Summary

Force-Limited Belt and Air Bag
Sled Tests 600-605

Measurement	Sensor Location	Unit	Filter Class	Axis[1]	Test Number	Minimum[2] Value	Minimum[2] Time	Maximum[2] Value	Maximum[2] Time
CRASH SIMULATOR									
Sled Deceleration	Sled, Front, Center, Sensor 1	g's	60	XG	600	-1	149	21	33
					601	-1	121	21	32
					602	-1	148	21	33
					603	-1	130	21	33
					604	-1	122	21	33
					605	-1	122	21	42
RESTRAINTS									
Belt Load	Shoulder Belt, Upper	N	180	NA	600	-6	144	7674	73
					601	-10	147	7959	71
					602	Sensor Failure			
					603	-17	166	8883	71
					604	-6	147	8841	71
					605	-10	152	8832	70
	Shoulder Belt, Lower	N	180	NA	600	Sensor Failure			
					601	-14	176	4992	73
					602	-16	160	4660	73
					603	-8	146	5291	69
					604	-6	194	5042	74
					605	-26	166	4264	73
	Lap Belt, Outer	N	180	NA	600	-14	155	7287	61
					601	-25	159	8100	63
					602	-17	154	6448	63
					603	-5	-6	7561	61
					604	-7	-9	6916	62
					605	-16	152	7277	63

Sensor Data Summary (cont.)

Measurement	Sensor Location	Unit	Filter Class	Axis[1]	Test Number	Minimum[2] Value	Minimum[2] Time	Maximum[2] Value	Maximum[2] Time
OCCUPANT									
Head Acceleration[6]	Head, Center of Gravity	g's	1000	X	600	-54	89	3	200
					601	-47	87	3	200
					602	-44	88	2	200
					603	-50	87	3	200
					604	-50	86	3	200
					605	-49	89	3	200
		g's	1000	Y	600	-7	95	1	143
					601	-19	94	2	143
					602	-20	97	2	151
					603	-14	97	2	141
					604	-20	99	3	148
					605	-18	97	3	148
		g's	1000	Z	600	-1	26	23	92
					601	-1	23	33	86
					602	-2	35	34	88
					603	-1	25	36	90
					604	-2	36	35	87
					605	-2	38	35	89
		g's	NA	RES	600	0	-3	58	89
					601	0	-1	59	86
					602	0	-4	58	89
					603	0	-3	62	90
					604	0	-7	63	88
					605	0	-4	62	89
Neck Load[3]	Neck Upper	N	180	X	600	-459	114	81	199
					601	-667	114	90	59
					602	-553	113	58	199
					603	-618	113	70	199
					604	-581	112	72	199
					605	-538	112	97	63

Sensor Data Summary (cont.)

Measurement	Sensor Location	Unit	Filter Class	Axis[1]	Test Number	Minimum[2] Value	Minimum[2] Time	Maximum[2] Value	Maximum[2] Time
Neck Load[3]	Neck Upper	N	180	Y	600	-88	83	65	129
					601	-189	102	50	62
					602	-211	107	81	62
					603	-106	100	78	135
					604	-198	103	56	60
					605	-160	102	82	137
		N	180	Z	600	-51	122	1182	80
					601	-62	121	1262	83
					602	-89	124	1274	84
					603	-72	121	1333	83
					604	-97	122	1301	83
					605	-50	38	1399	83
Neck Moment[3]	Neck Upper	N-m	180	X	600	-7	92	3	136
					601	-16	103	6	152
					602	-19	104	8	155
					603	-14	91	6	147
					604	-16	83	8	146
					605	-14	98	9	146
		N-m	180	Y	600	-17	79	28	105
					601	-16	74	33	102
					602	-28	74	33	102
					603	-21	76	45	101
					604	-27	72	37	99
					605	-26	77	40	100
		N-m	180	Z	600	-4	184	8	123
					601	-7	186	18	112
					602	-7	189	19	113
					603	-5	185	12	116
					604	-7	185	19	111
					605	-8	190	16	115

Sensor Data Summary (cont.)

Measurement	Sensor Location	Unit	Filter Class	Axis[1]	Test Number	Minimum[2] Value	Minimum[2] Time	Maximum[2] Value	Maximum[2] Time
Chest Acceleration	Chest Center of Gravity	G's	180	X	600	-1	194	46	69
					601	-1	146	48	67
					602	-1	124	48	66
					603	-2	126	51	68
					604	-1	122	48	65
					605	-1	199	51	65
		G's	180	Y	600	-5	60	1	42
					601	-4	69	1	182
					602	-3	70	1	126
					603	-2	52	2	74
					604	-4	70	1	121
					605	-4	59	1	121
		G's	180	Z	600	-5	66	5	95
					601	-6	66	5	97
					602	-7	65	8	77
					603	-7	68	6	58
					604	-7	65	7	75
					605	-10	65	6	92
		G's	NA	RES	600	0	-8	46	69
					601	0	-3	48	67
					602	0	-4	49	66
					603	0	3	51	68
					604	0	-8	49	65
					605	0	-7	52	65
Chest Deflection	Stermun (Chest slider)	mm	180	X	600	-38	80	0	27
					601	-38	81	0	27
					602	-35	91	0	26
					603	-38	90	0	28
					604	-39	91	0	25
					605	-38	79	0	29
Pelvic Acceleration	Pelvic Center of Gravity	G's	1000	X	600	-52	63	1	186
					601	-58	65	2	135
					602	-52	64	2	135
					603	-55	65	2	135
					604	-53	62	2	134
					605	-57	62	2	134

Sensor Data Summary (cont.)

Measurement	Sensor Location	Unit	Filter Class	Axis(1)	Test Number	Minimum(2)		Maximum(2)	
						Value	Time	Value	Time
Pelvic Acceleration	Pelvic Center of Gravity	G's	1000	Y	600	-10	57	4	68
					601	-7	59	5	69
					602	-7	60	4	88
					603	-5	56	6	87
					604	-7	58	5	70
					605	-8	56	5	86
		G's	1000	Z	600	-33	65	1	200
					601	-35	64	1	110
					602	-35	64	1	198
					603	-37	66	1	198
					604	-34	64	1	199
					605	-40	62	1	104
		G's	NA	RES	600	0	-4	61	63
					601	0	-4	68	65
					602	0	-4	62	64
					603	0	-6	66	65
					604	0	-5	63	62
					605	0	-5	70	62
Femur Load	Femur, Left	N	600	Z	600	-198	36	1015	58
					601	-212	38	1207	67
					602	-1223	50	411	69
					603	-231	33	1036	69
					604	-1066	45	869	68
					605	-407	48	1157	67
	Femur, Right	N	600	Z	600	-450	60	943	53
					601	-968	64	813	54
					602	-107	146	905	53
					603	-113	65	980	71
					604	-660	61	924	69
					605	-102	140	730	54
Tibia Moment	Proximal Tibia Left	N-m	600	X	600	-24	75	14	123
					601	-46	83	18	133
					602	-34	87	11	188
					603	-40	38	5	200
					604	-51	46	9	181
					605	-35	83	15	48

Sensor Data Summary (cont.)

Measurement	Sensor Location	Unit	Filter Class	Axis[1]	Test Number	Minimum[2] Value	Minimum[2] Time	Maximum[2] Value	Maximum[2] Time
Tibia Moment	Proximal Tibia Left	N-m	600	Y	600	-100	64	8	121
					601	-76	39	16	90
					602	-97	63	8	119
					603	-75	61	10	90
					604	-105	45	14	101
					605	-108	61	6	102
	Distal Tibia Left	N-m	600	Y	600	-34	62	4	200
					601	-27	64	13	48
					602	-34	63	3	96
					603	-47	80	13	44
					604	-34	88	11	50
					605	-19	65	14	48
	Proximal Tibia Right	N-m	600	X	600	-10	123	40	71
					601	-7	105	55	67
					602	-15	125	55	66
					603	-30	60	11	73
					604	-19	62	15	52
					605	-10	114	36	65
		N-m	600	Y	600	-94	58	12	94
					601	-120	58	17	92
					602	-100	58	18	94
					603	-116	56	17	93
					604	-112	56	15	96
					605	-110	57	12	91
	Distal Tibia Right	N-m	600	Y	600	-45	56	2	95
					601	-50	57	2	73
					602	-37	56	2	194
					603	-41	54	3	94
					604	-46	55	3	97
					605	-28	56	1	93
Tibia Load	Distal Tibia Left	N	600	X	600	-586	66	43	122
					601	-567	39	65	90
					602	-644	42	42	117
					603	-449	33	15	95
					604	-606	40	39	103
					605	-664	62	9	107

Sensor Data Summary (cont.)

Measurement	Sensor Location	Unit	Filter Class	Axis[1]	Test Number	Minimum[2] Value	Minimum[2] Time	Maximum[2] Value	Maximum[2] Time
Tibia Load	Distal Tibia Left	N	600	Z	600	-1881	38	118	113
					601	-1836	39	213	118
					602	-2250	41	135	115
					603	-1436	35	144	103
					604	-1976	40	161	104
					605	-1627	35	108	125
	Distal Tibia Right	N	600	X	600	-757	56	22	185
					601	-944	58	21	93
					602	-752	58	48	196
					603	-877	56	37	93
					604	-856	55	27	97
					605	-808	56	12	92
	Distal Tibia Right	N	600	Z	600	-1975	59	46	116
					601	-2422	58	76	102
					602	-2379	58	74	108
					603	-2846	56	39	113
					604	-2286	55	79	120
					605	-2815	55	40	106
INJURY CRITERIA									
HIC		NA	NA	NA	600	NA	NA	461	NA
(< 1000)		NA	NA	NA	601	NA	NA	491	NA
		NA	NA	NA	602	NA	NA	495	NA
		NA	NA	NA	603	NA	NA	563	NA
		NA	NA	NA	604	NA	NA	551	NA
		NA	NA	NA	605	NA	NA	557	NA
Tibia Index Left[4]		NA	NA	NA	600	NA	NA	0.17	63
(<1.3)		NA	NA	NA	601	NA	NA	0.12	64
		NA	NA	NA	602	NA	NA	0.16	63
		NA	NA	NA	603	NA	NA	0.21	80
		NA	NA	NA	604	NA	NA	0.15	88
		NA	NA	NA	605	NA	NA	0.10	34

Sensor Data Summary (cont.)

Measurement	Sensor Location	Unit	Filter Class	Axis[(1)]	Test Number	Minimum[(2)] Value	Minimum[(2)] Time	Maximum[(2)] Value	Maximum[(2)] Time
Tibia Index Right[(4)]		NA	NA	NA	600	NA	NA	0.25	56
(<1.3)		NA	NA	NA	601	NA	NA	0.29	57
		NA	NA	NA	602	NA	NA	0.22	56
		NA	NA	NA	603	NA	NA	0.26	55
		NA	NA	NA	604	NA	NA	0.27	55
		NA	NA	NA	605	NA	NA	0.2	56

NOTES:

(1) Frame of reference is local to the sensor unless otherwise specified.

G = Global frame of reference

NA = Not Applicable: Frame of reference is undefined or unrelated to defined frames of reference.

RES = Resultant

(2) The minimum and maximum values of the data, filtered to the SAE J-211 Channel Frequency Class listed in the Filter Class column, occurred at the times shown, in milliseconds after T_0.

(3) Neck load and moment data direct from load cell.

(4) Tibia index:

$$\frac{F}{Fcr} + \frac{M}{Mcr} \leq 1.3$$

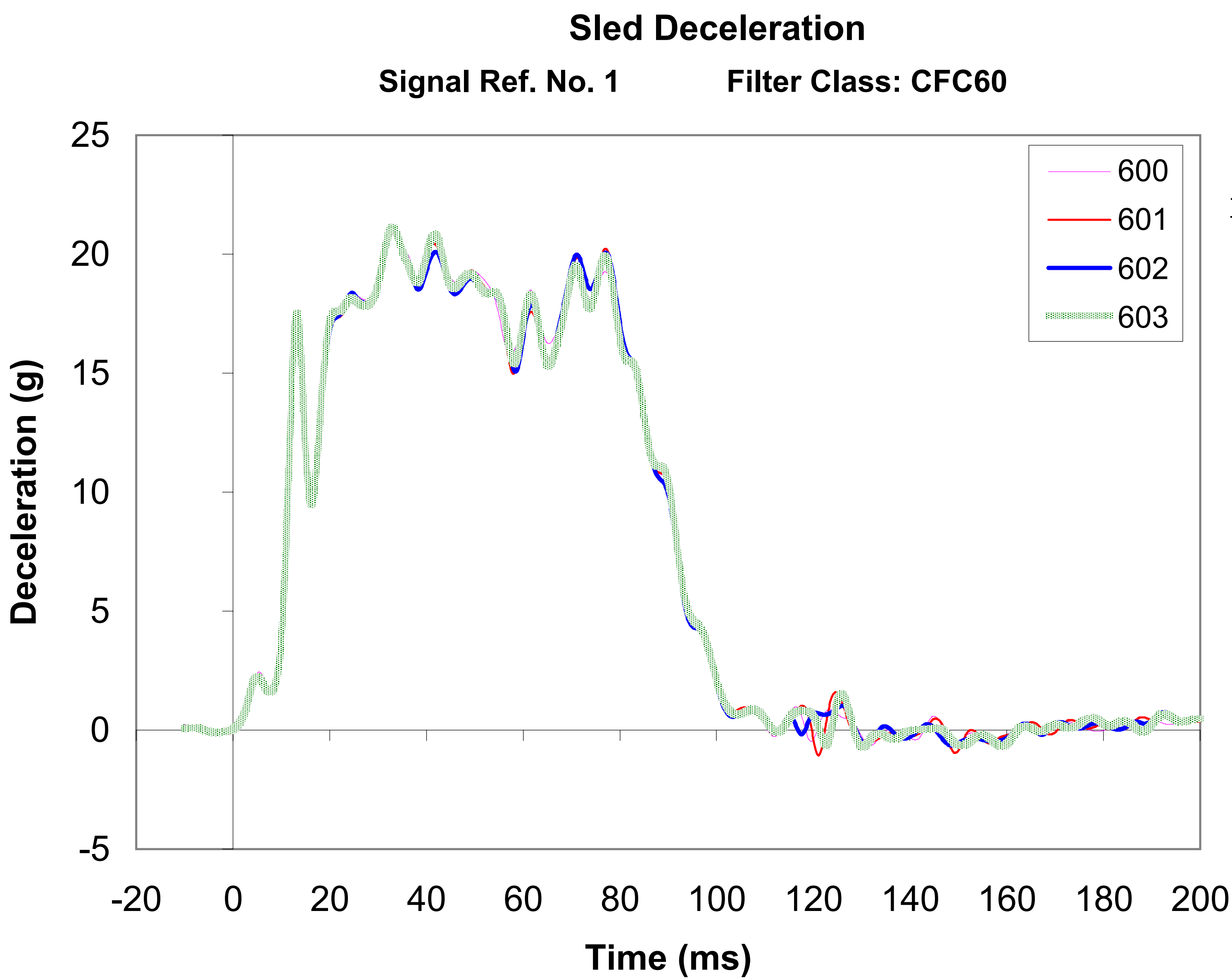
Where F = Distal tibia axial (z) force.

F_{cr} = 35.9 kN for a midsize male.

M = Distal tibia bending moment (y-Axis).

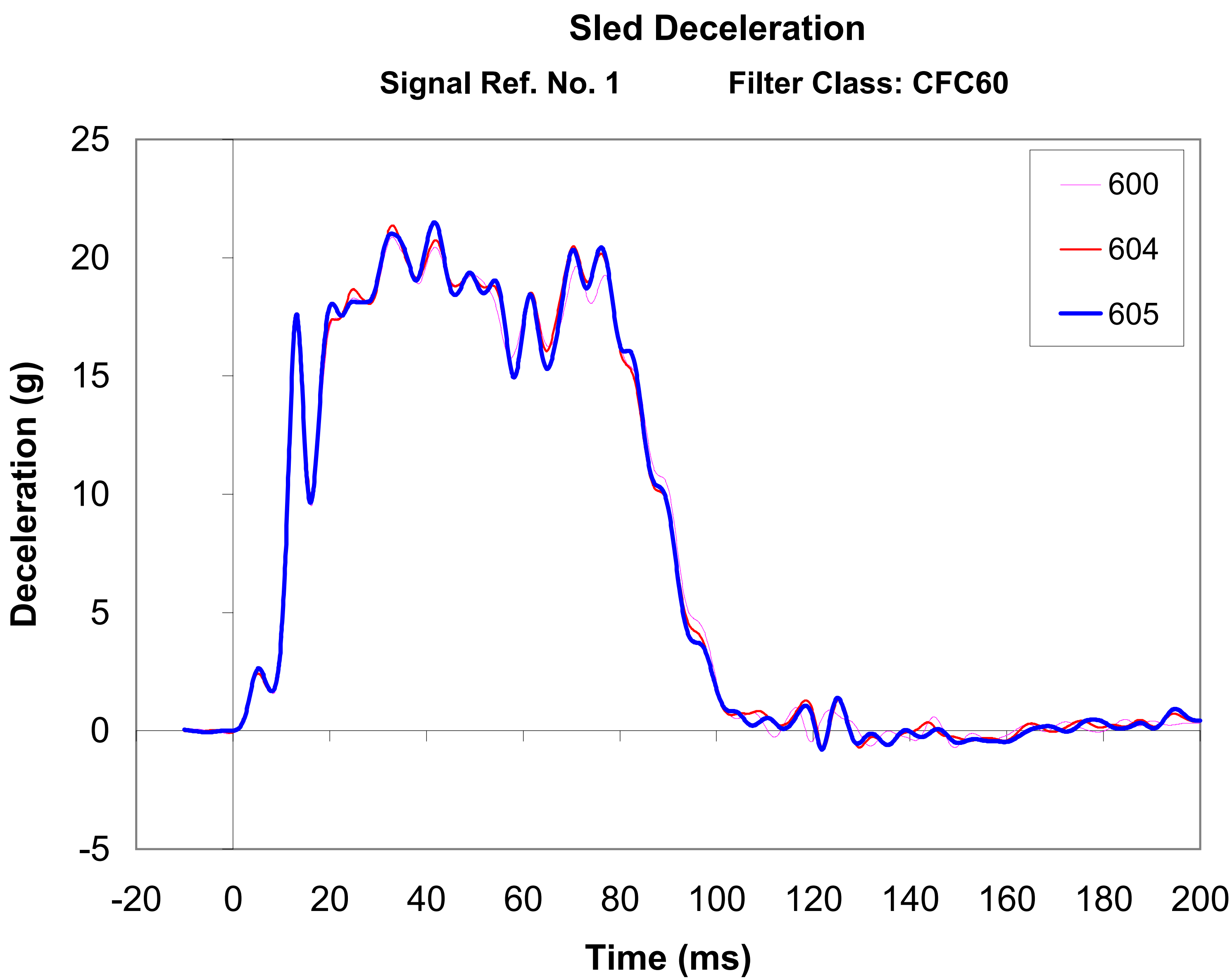
M_{cr} = 225 Nm for a midsize male.

3.2: SENSOR DATA PLOTS



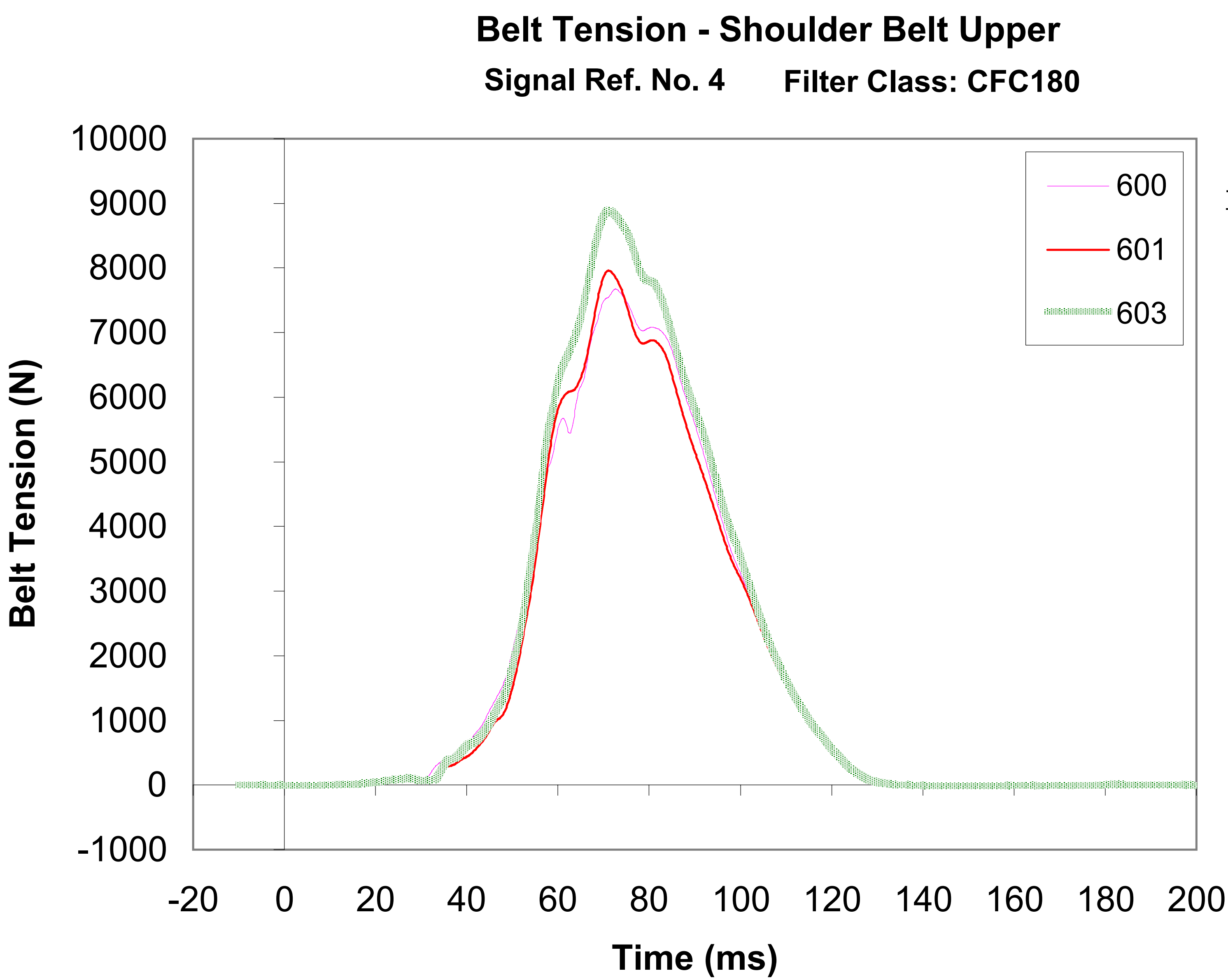
Maximum

Test #	Value	Time
600	21	33
601	21	33
602	21	33
603	21	33



Maximum

Test #	Value	Time
600	21	33
604	21	33
605	21	42

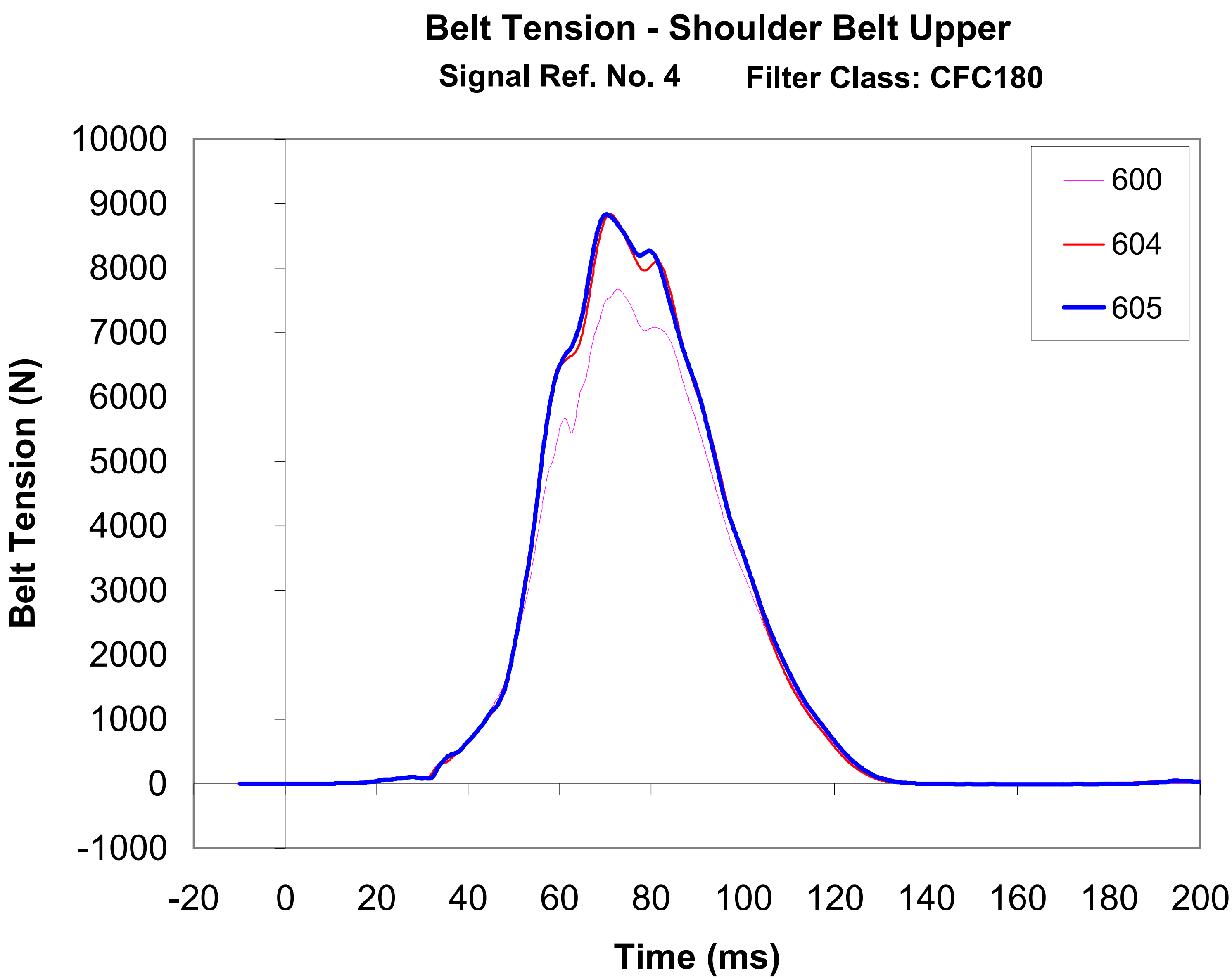


Maximum

Test #	Value	Time
600	7674	73
601	7959	71
602	Sensor Failure	
603	8883	71

Minimum

Test #	Value	Time
600	-6	144
601	-10	147
602	Sensor Failure	
603	-17	166

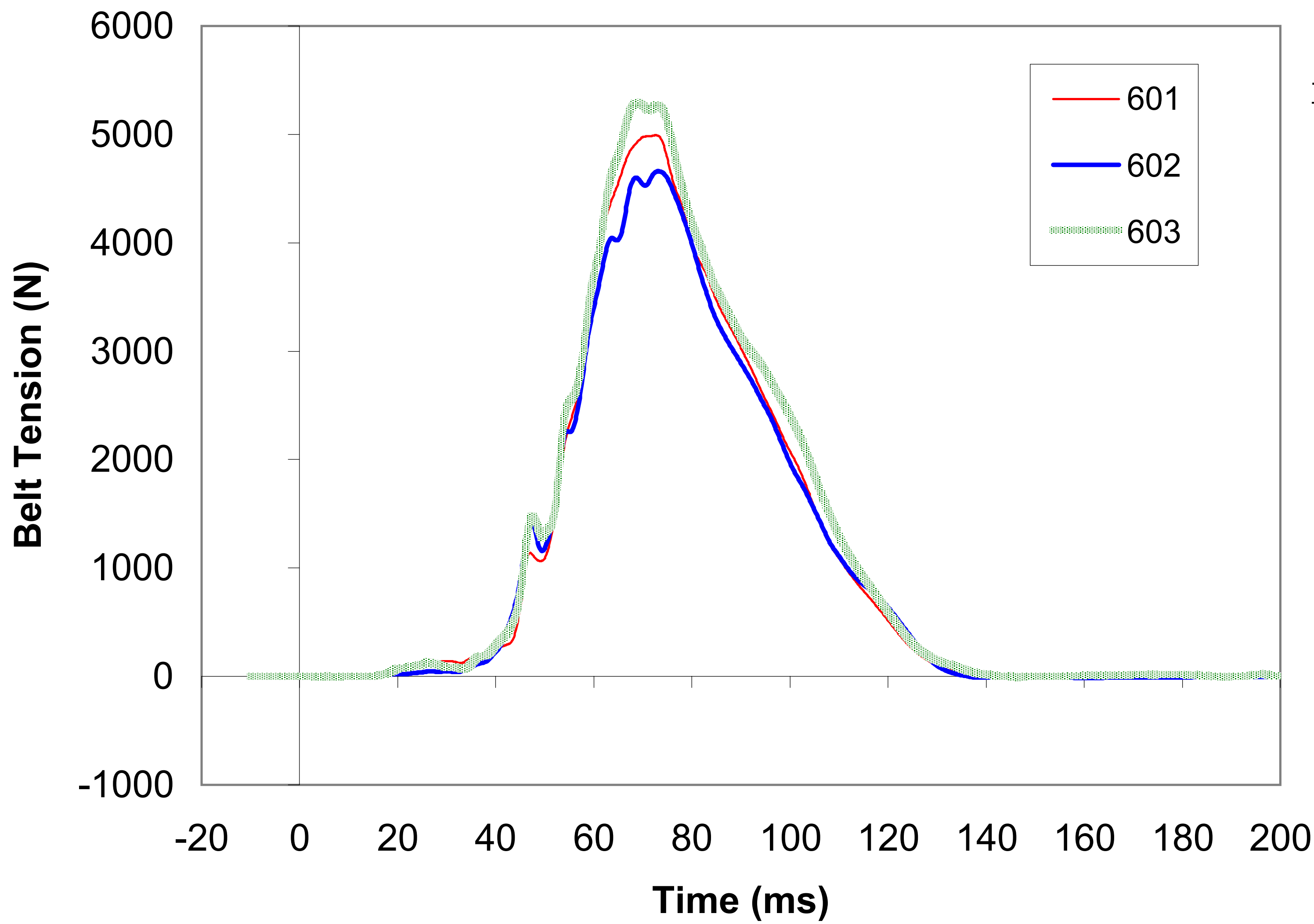


Maximum		
Test #	Value	Time
600	7674	73
604	8841	71
605	8832	70

Minimum		
Test #	Value	Time
600	-6	144
604	-6	147
605	-10	152

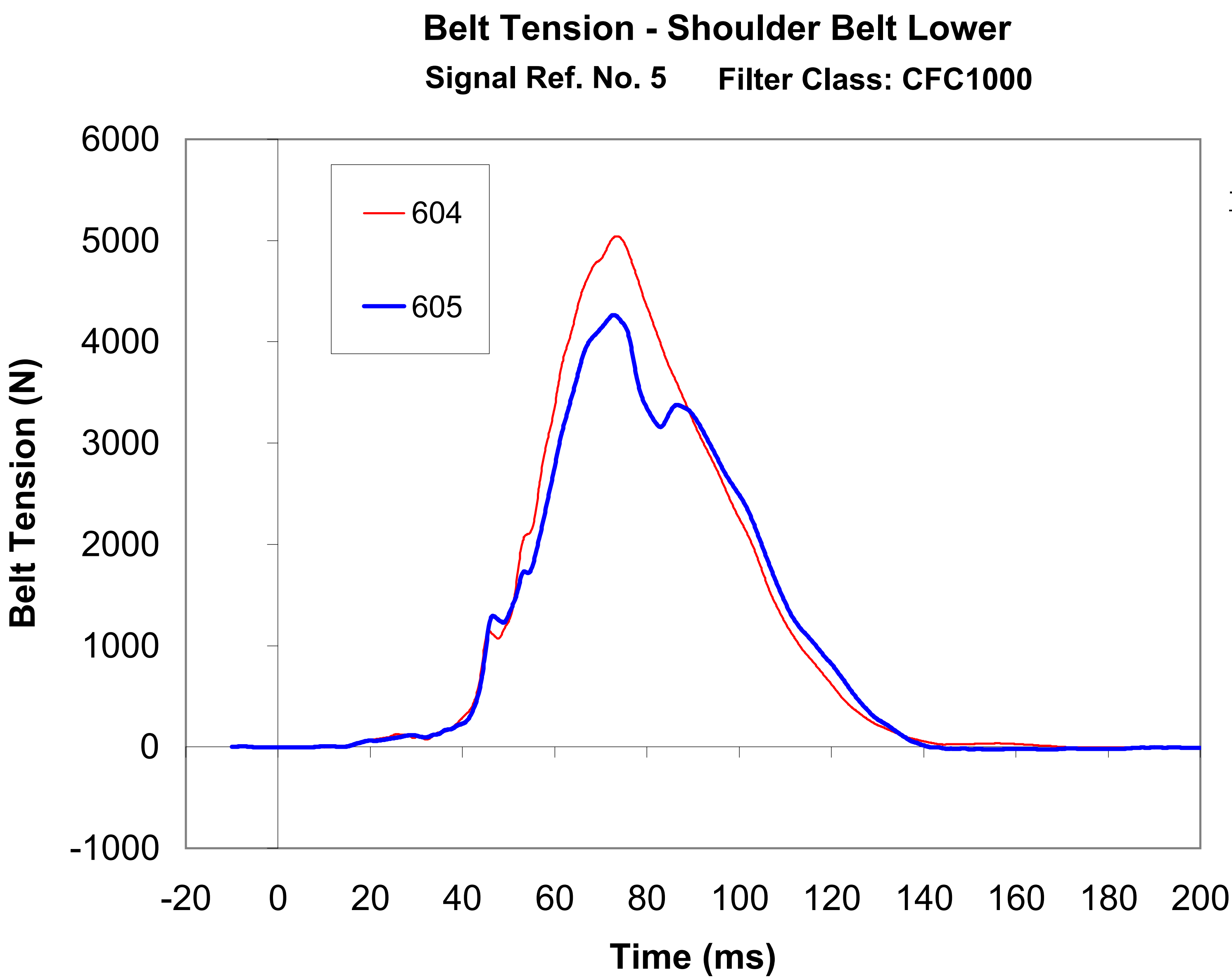
Belt Tension - Shoulder Belt Lower

Signal Ref. No. 5 Filter Class: CFC1000



Maximum

Test #	Value	Time
600	Sensor Failure	
601	4992	73
602	4660	73
603	5291	69

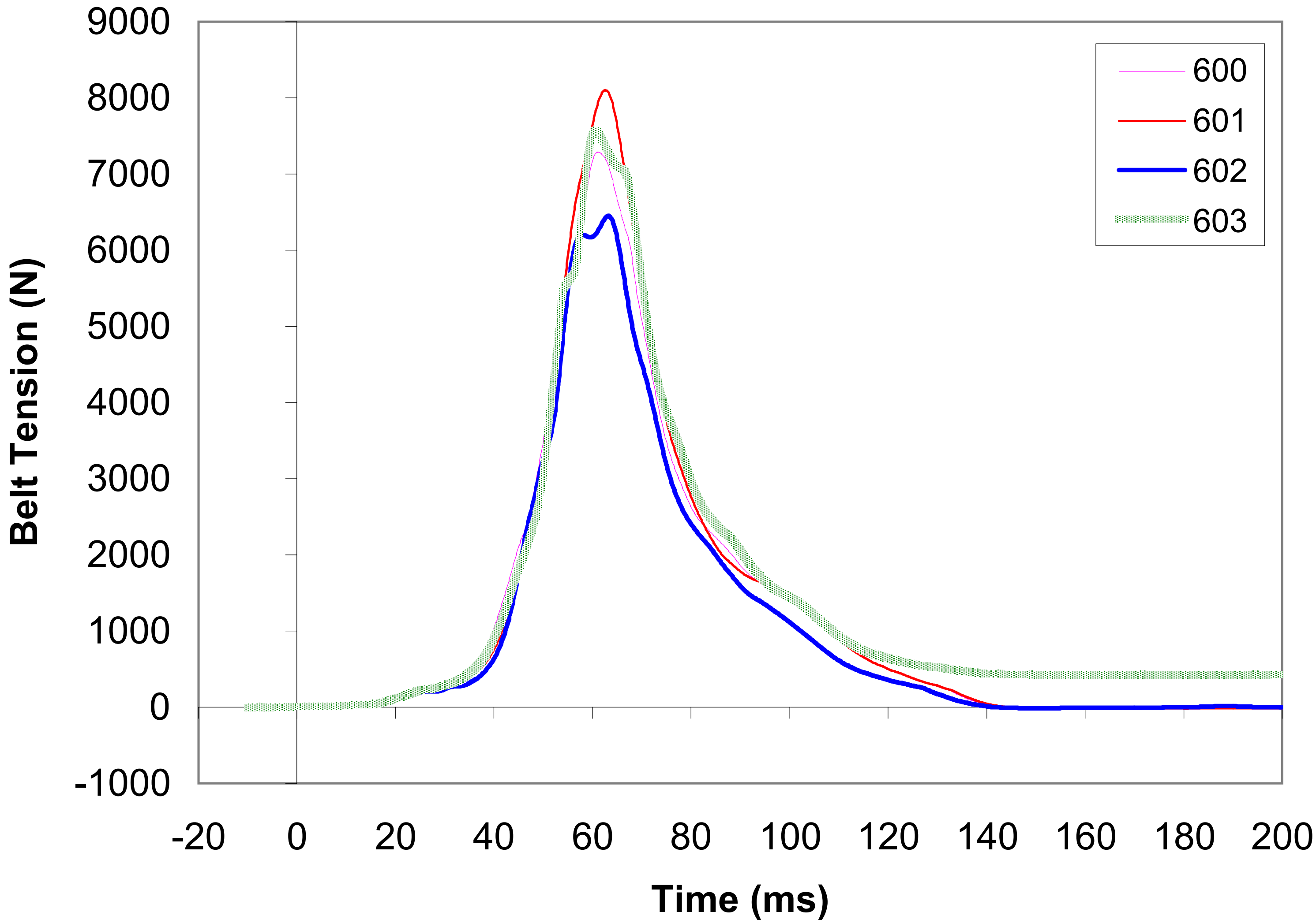


Maximum

Test #	Value	Time
600	Sensor Failure	
604	5042	74
605	4264	73

Belt Tension - Lap Belt Outer

Signal Ref. No. 6 Filter Class: CFC180

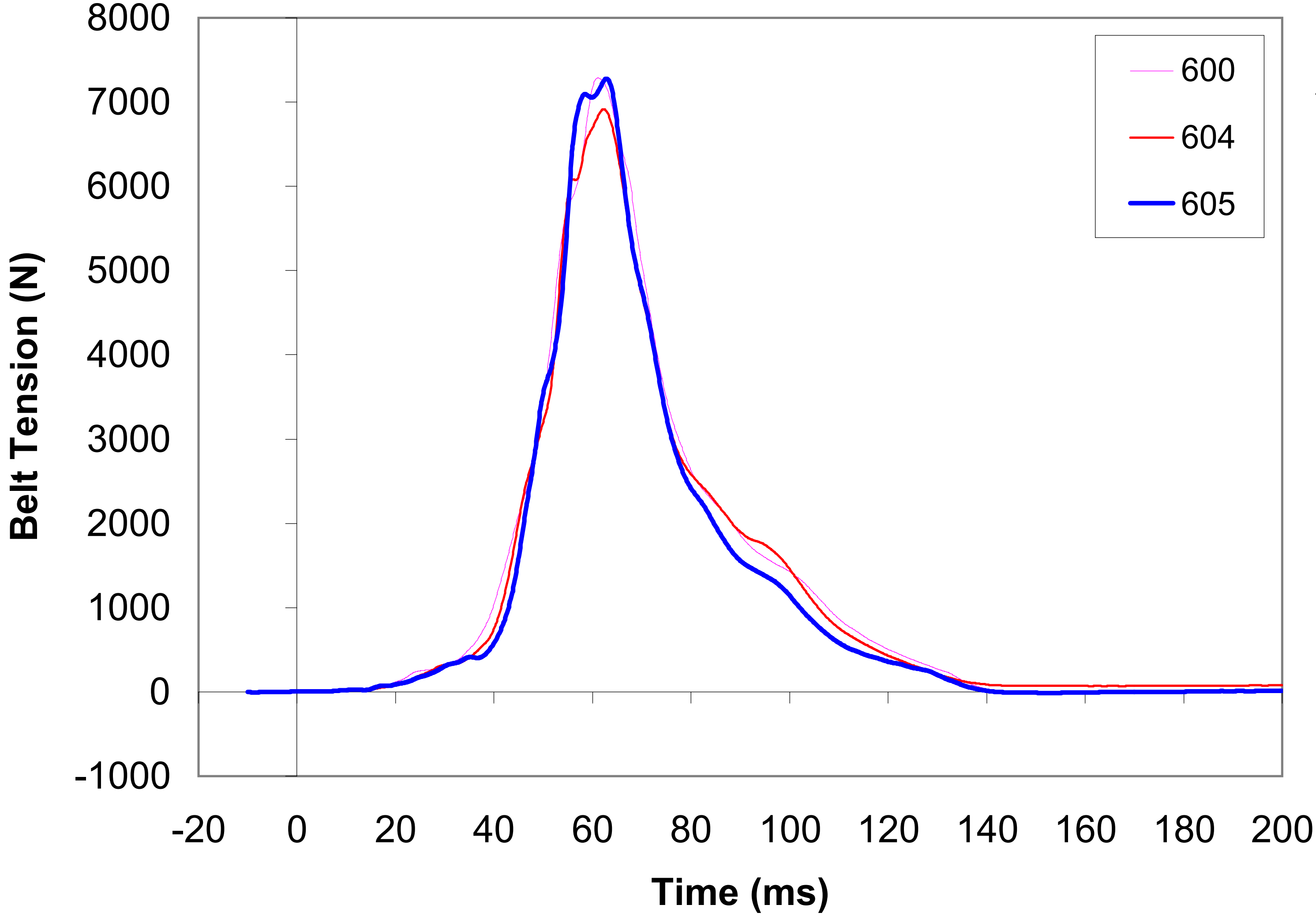


Maximum

Test #	Value	Time
600	7287	61
601	8100	63
602	6448	63
603	7561	61

Belt Tension - Lap Belt Outer

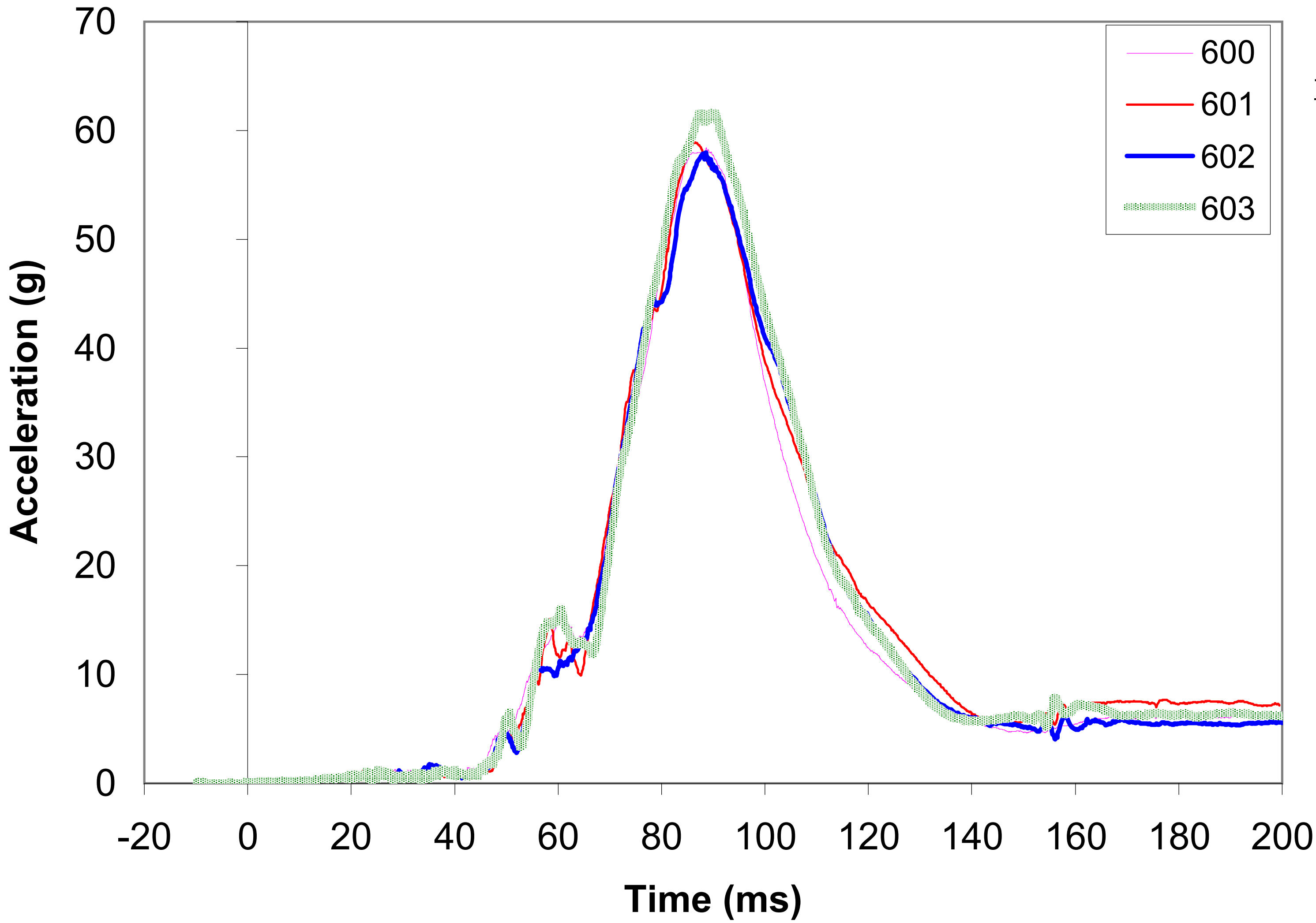
Signal Ref. No. 6 Filter Class: CFC180



Maximum

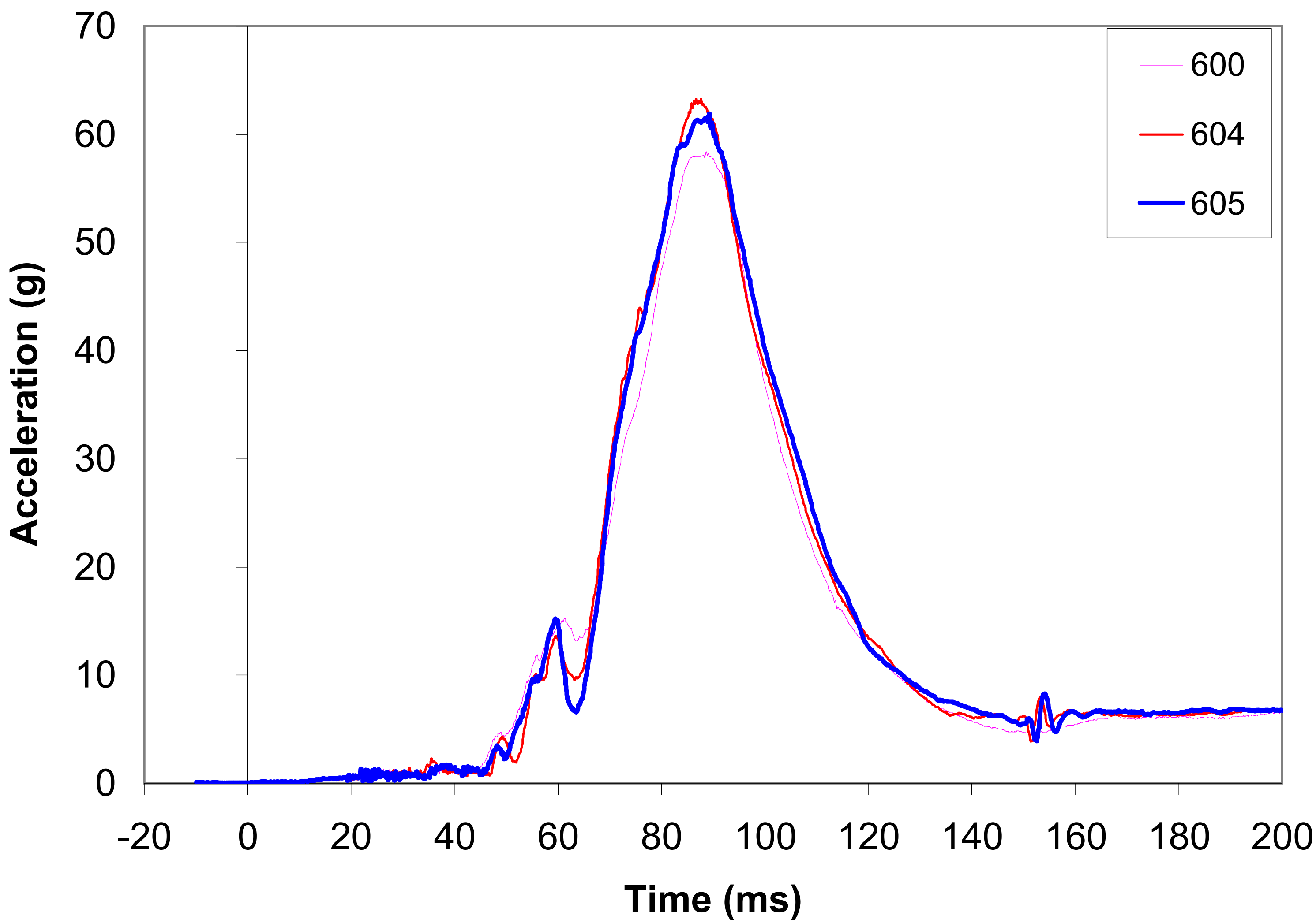
Test #	Value	Time
600	7287	61
604	6916	62
605	7277	63

Head CG Acceleration Resultant



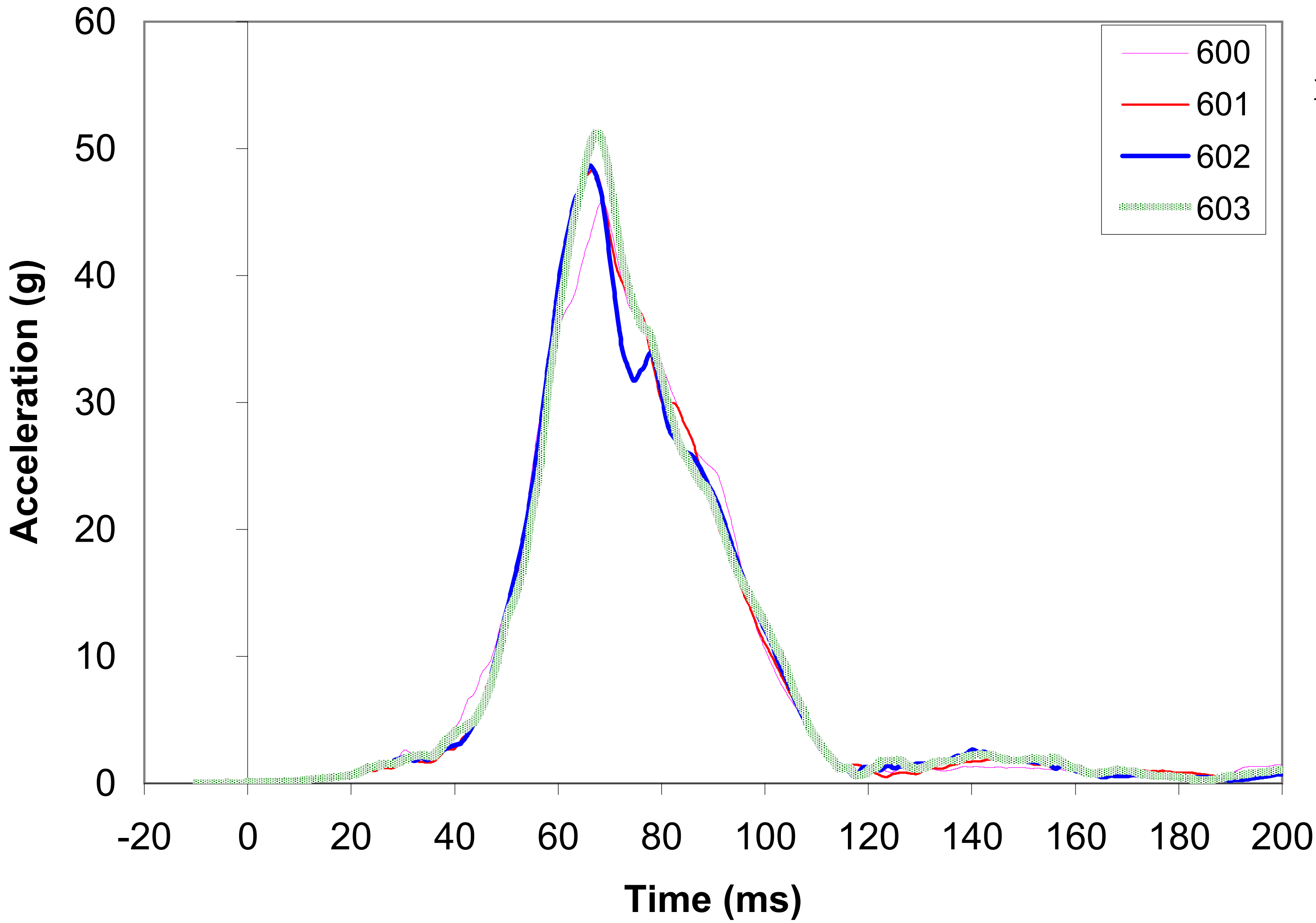
Maximum		
Test #	Value	Time
600	58	89
601	59	86
602	58	89
603	62	90

Head CG Acceleration Resultant



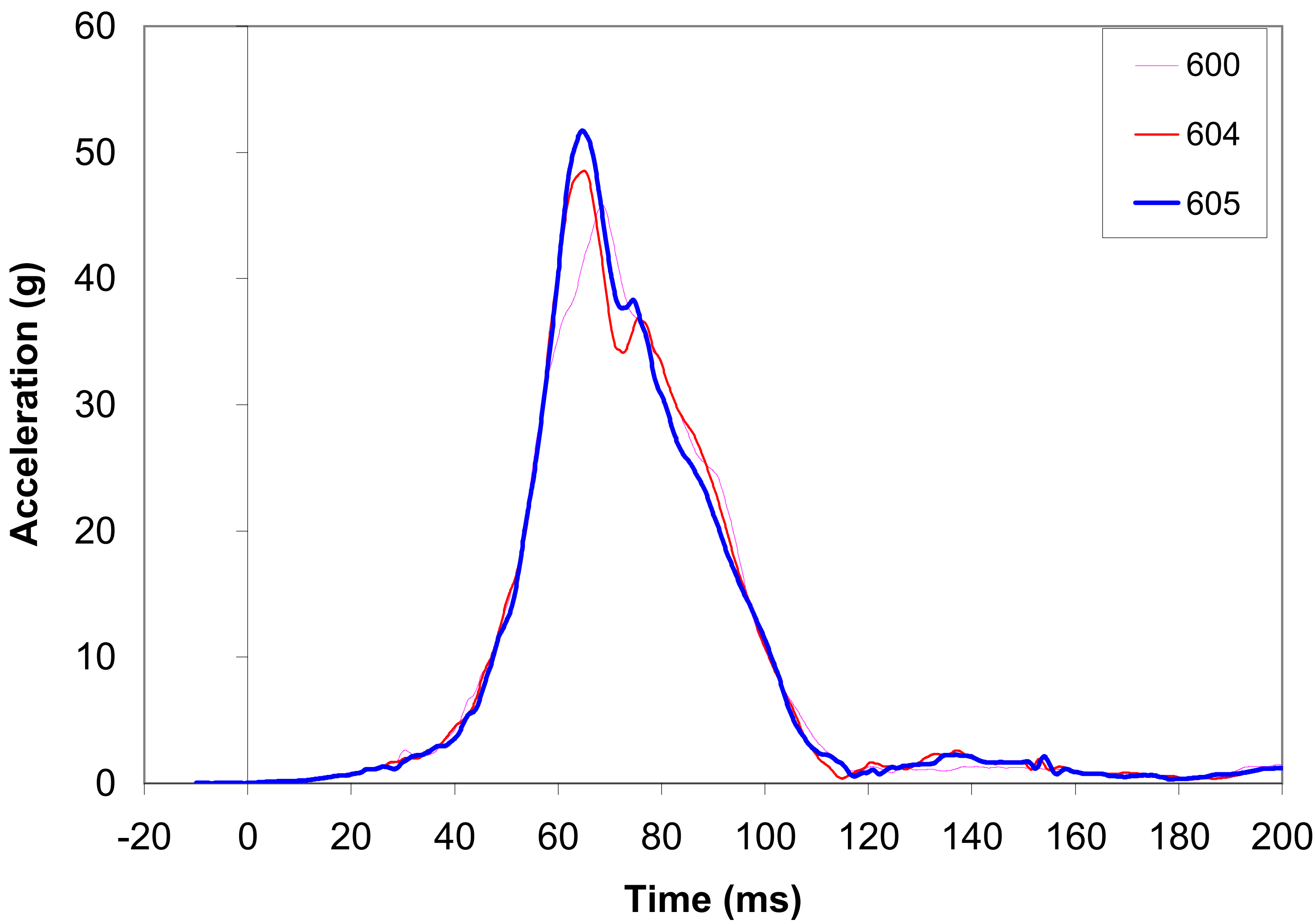
Test #	Maximum Value	Maximum Time
600	58	89
604	63	88
605	62	89

Chest CG Acceleration Resultant

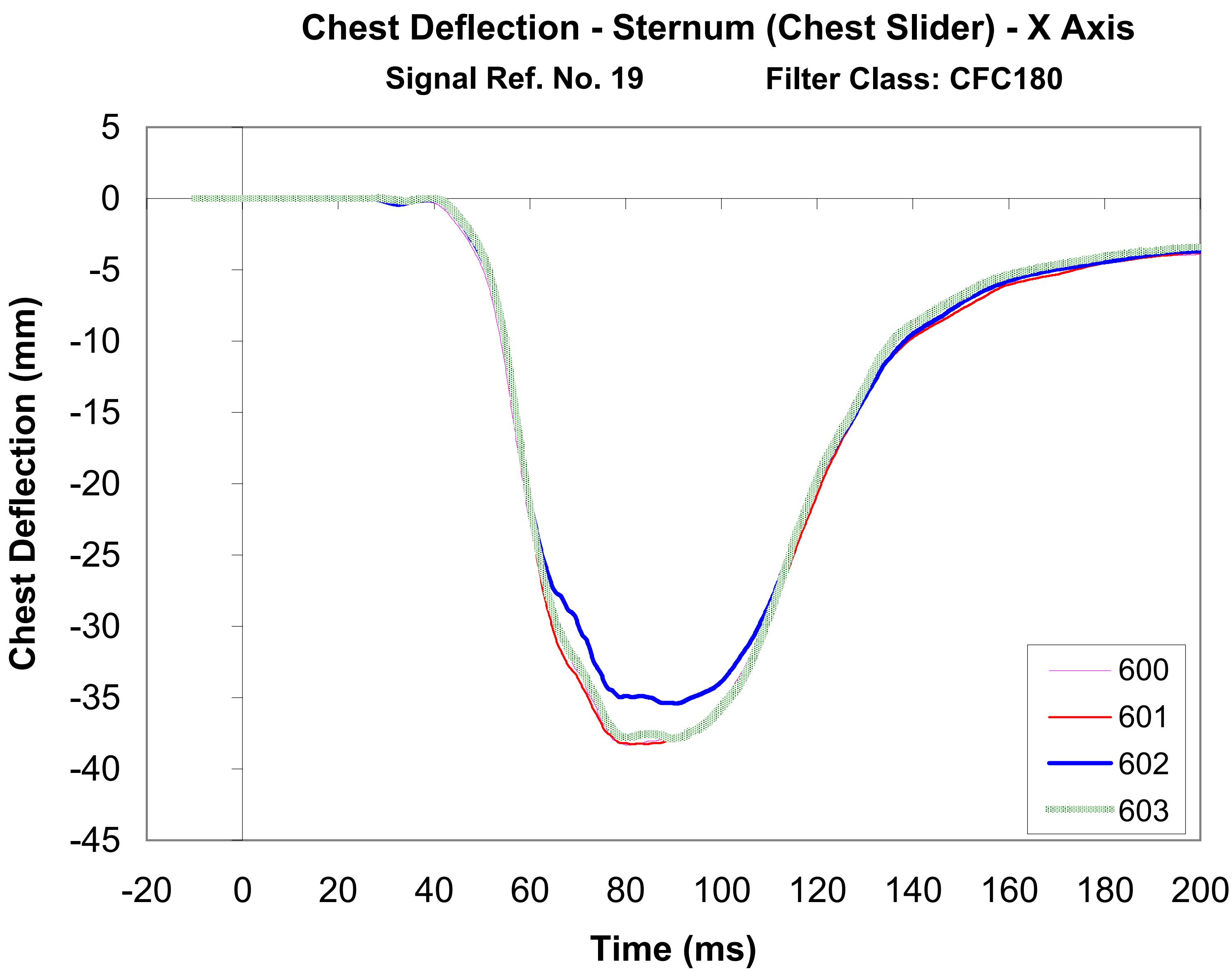


	Maximum	
Test #	Value	Time
600	46	69
601	48	67
602	49	66
603	51	68

Chest CG Acceleration Resultant

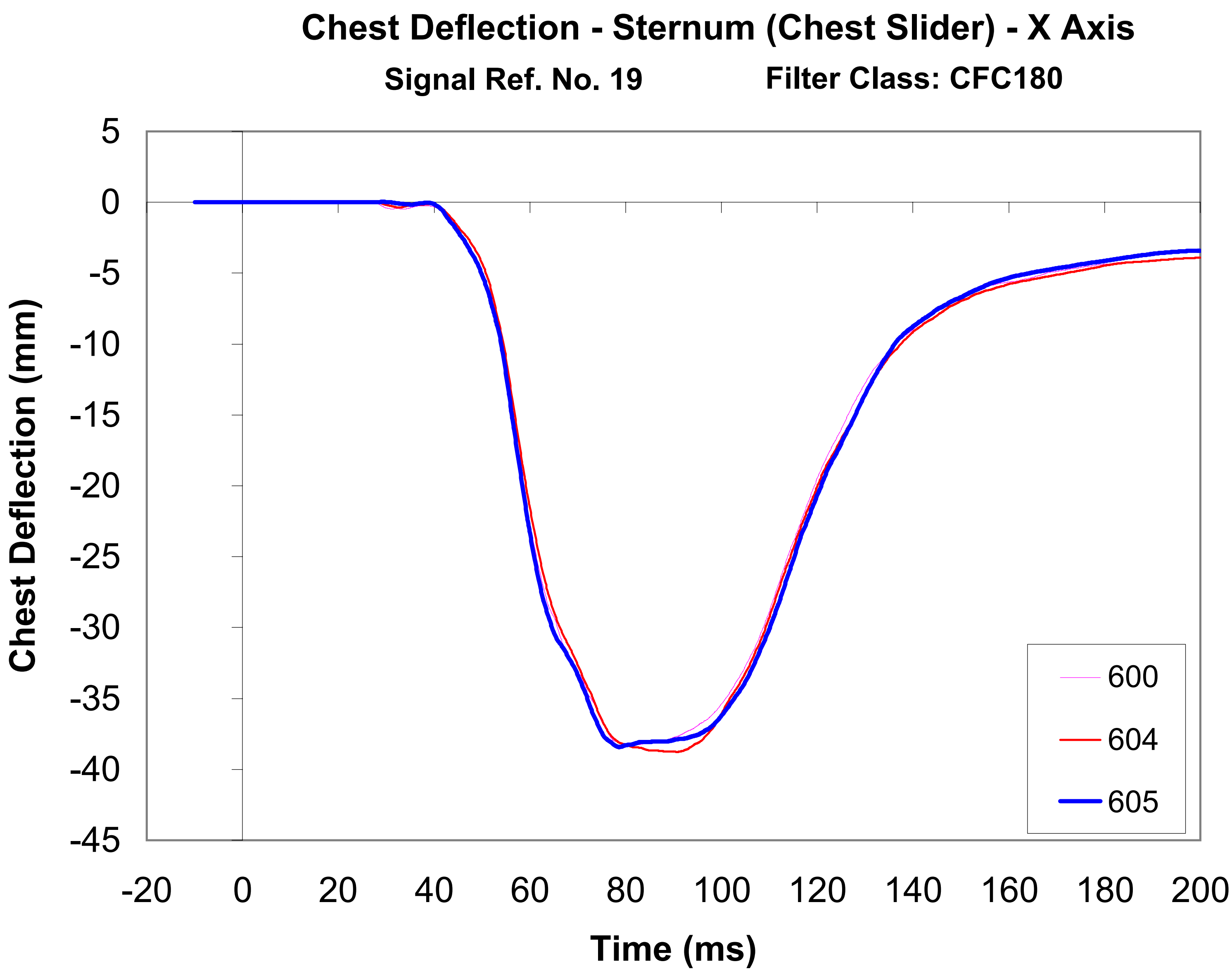


Maximum		
Test #	Value	Time
600	46	69
604	49	65
605	52	65



Minimum

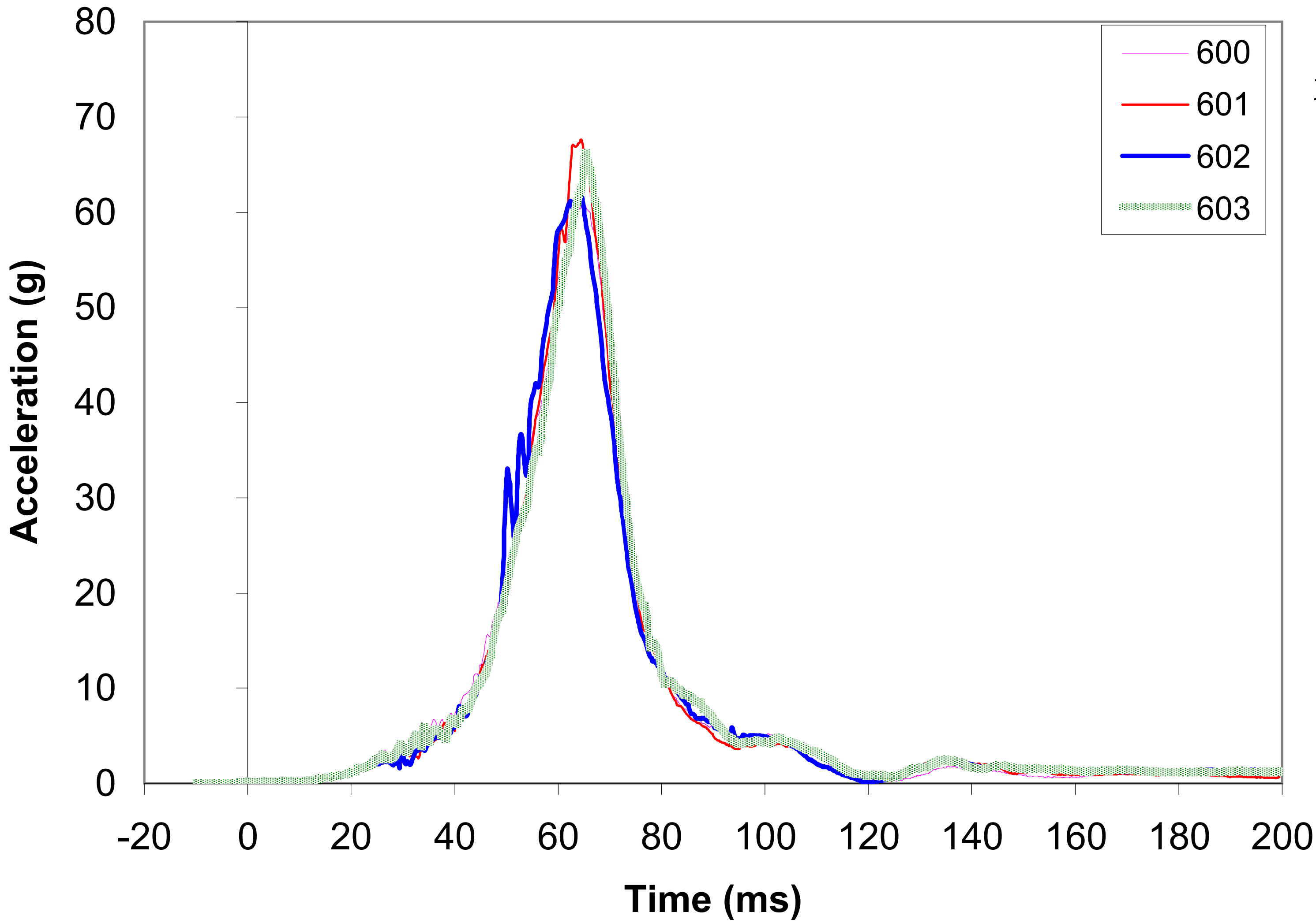
Test #	Value	Time
600	-38	80
601	-38	81
602	-35	91
603	-38	90



Minimum

Test #	Value	Time
600	-38	80
604	-39	91
605	-38	79

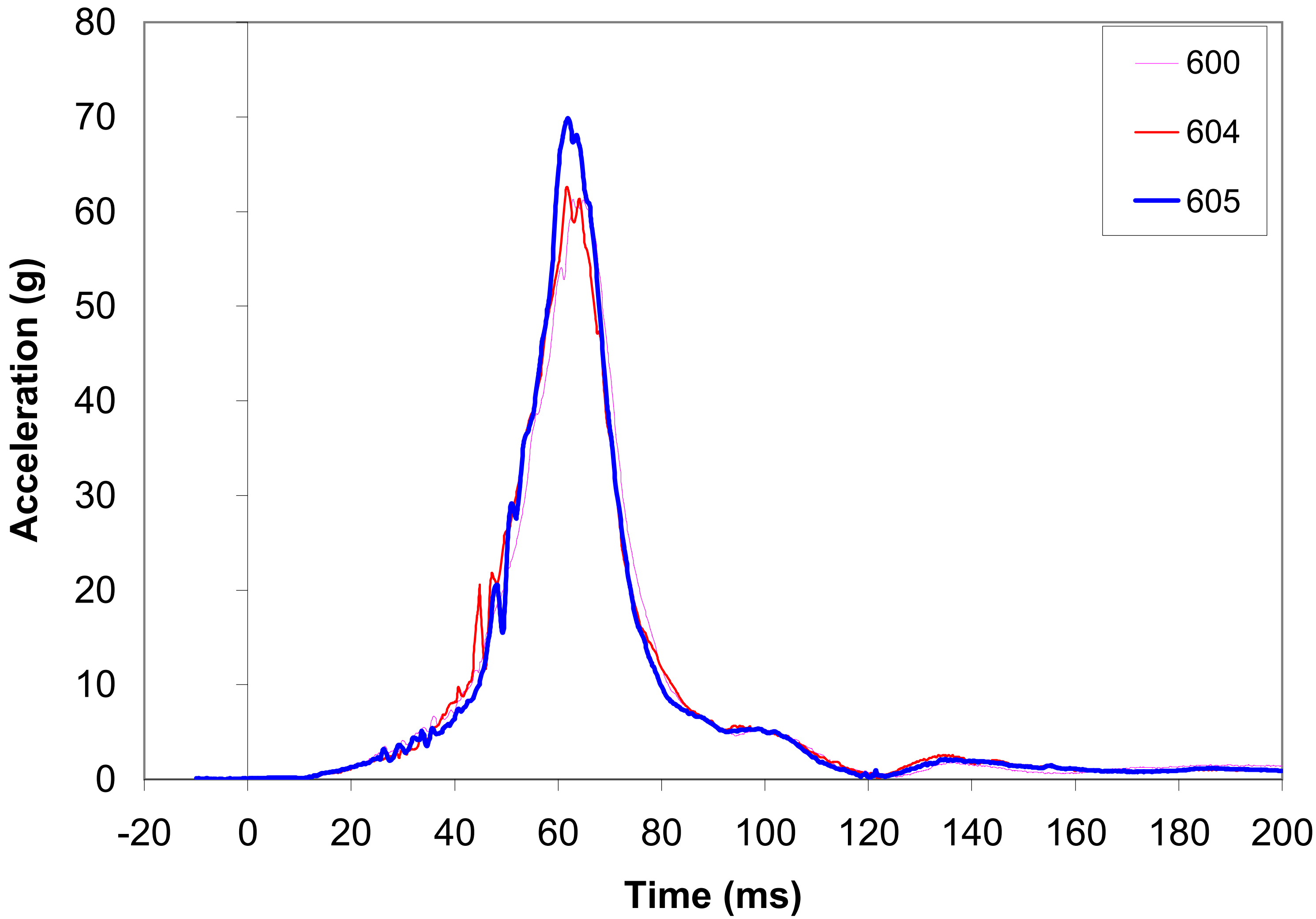
Pelvic CG Acceleration Resultant



Maximum

Test #	Value	Time
600	61	63
601	68	65
602	62	64
603	66	65

Pelvic CG Acceleration Resultant

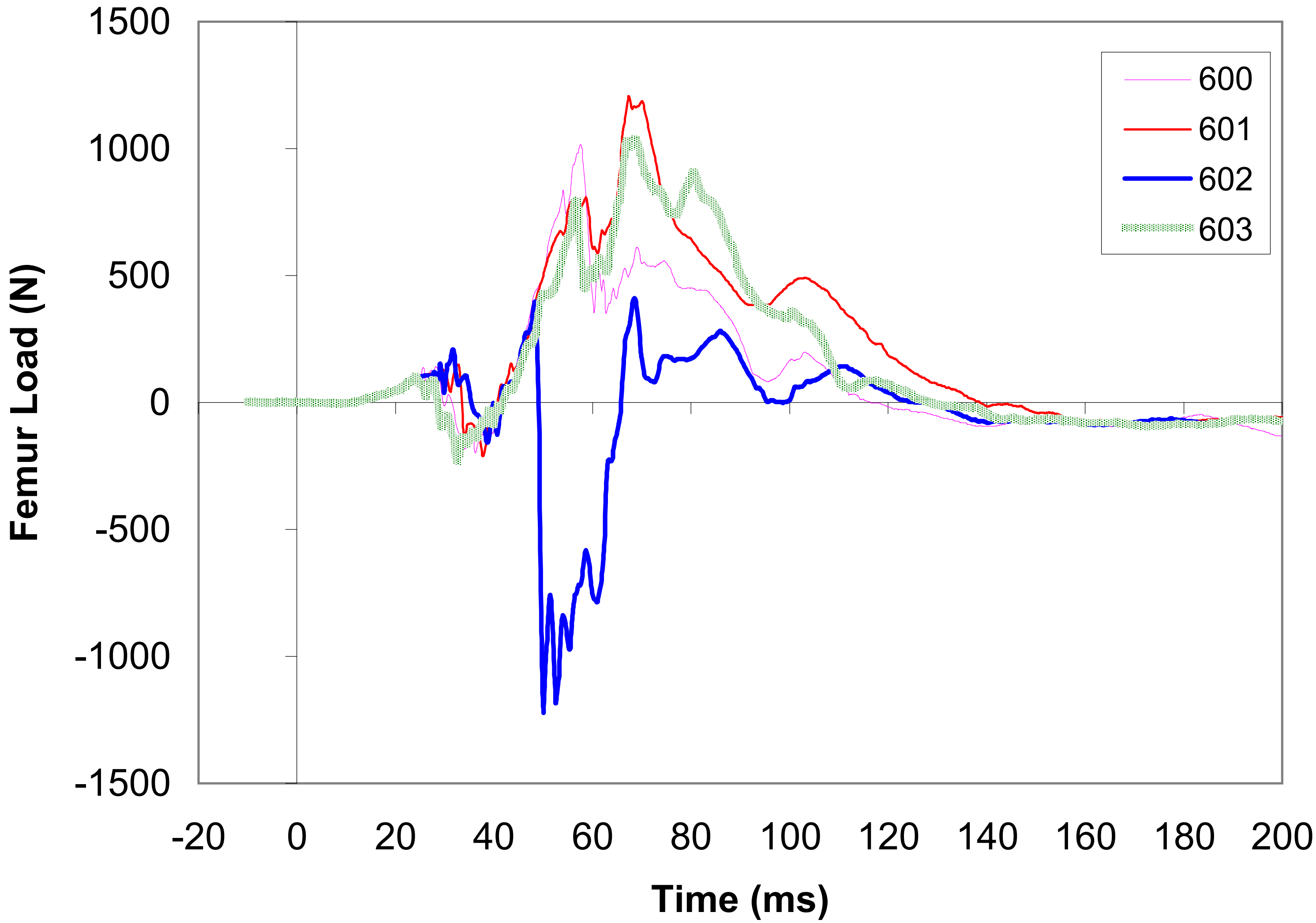


Maximum

Test #	Value	Time
600	61	63
604	63	62
605	70	62

Femur Load - Left Femur - Z Axis

Signal Ref. No. 23 **Filter Class: CFC600**



Maximum

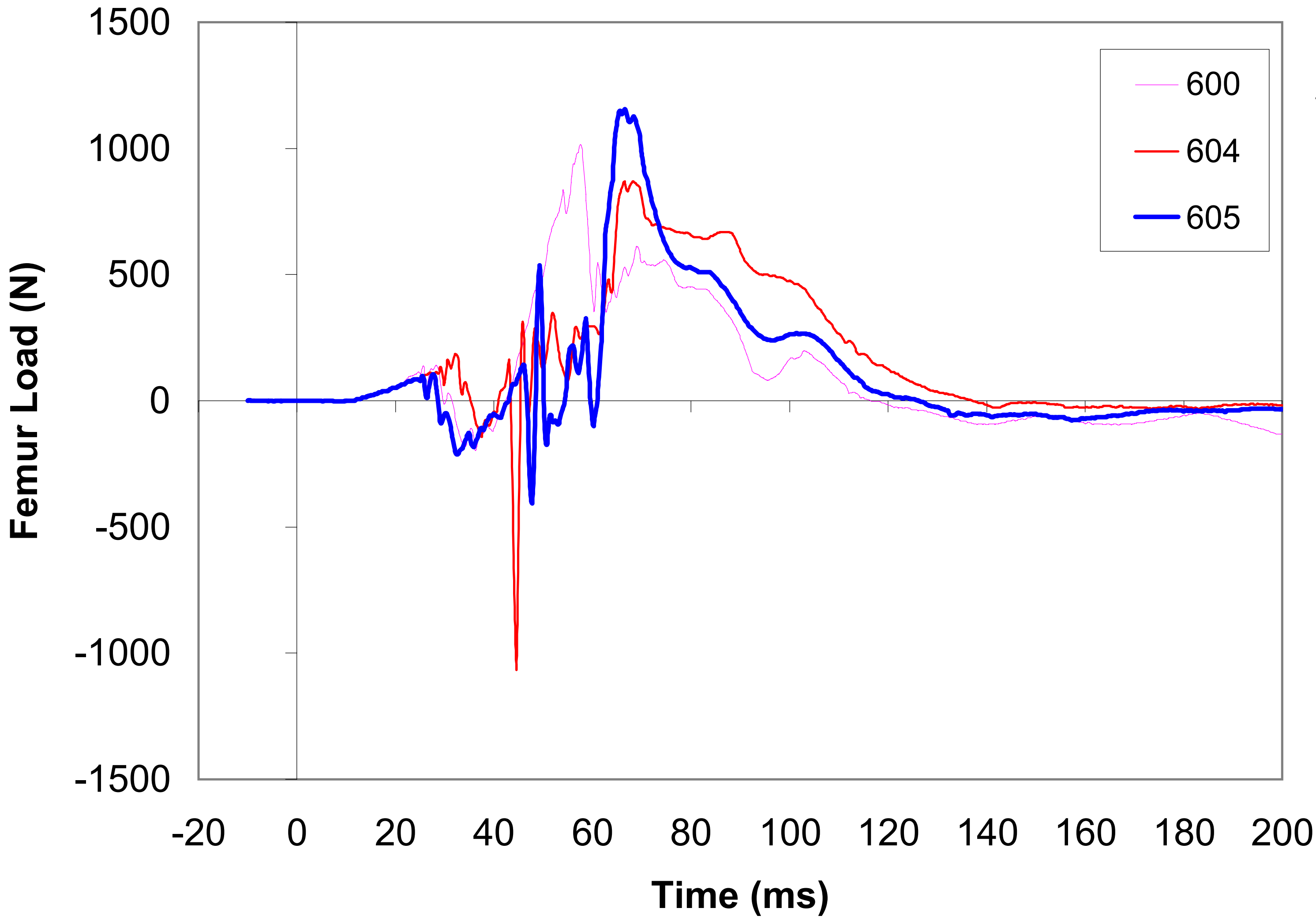
Test #	Value	Time
600	1015	58
601	1207	67
602	411	69
603	1036	69

Minimum

Test #	Value	Time
600	-198	36
601	-212	38
602	-1223	50
603	-231	33

Femur Load - Left Femur - Z Axis

Signal Ref. No. 23 **Filter Class: CFC600**



Maximum

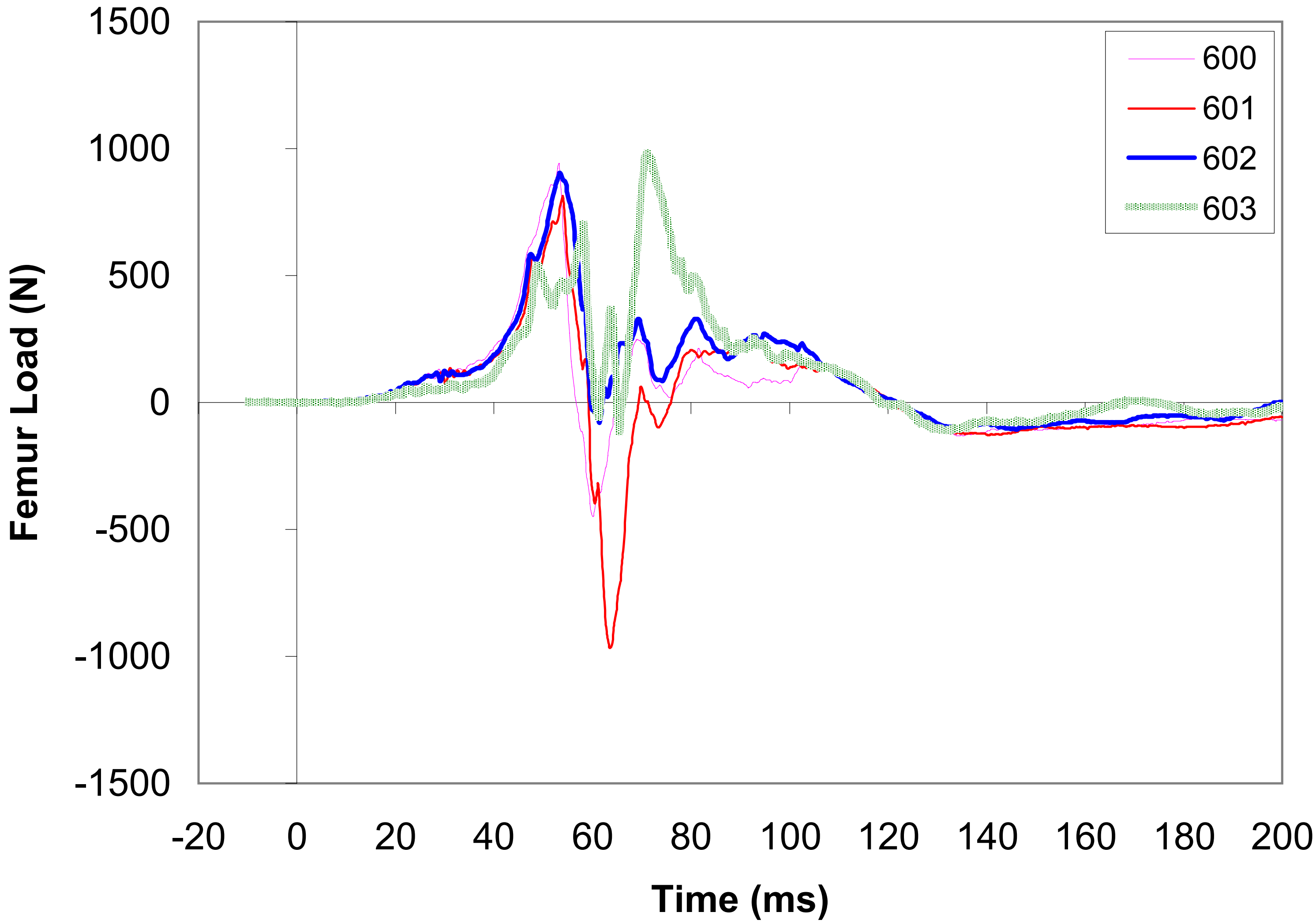
Test #	Value	Time
600	1015	58
604	869	68
605	1157	67

Minimum

Test #	Value	Time
600	-198	36
604	-1066	45
605	-407	48

Femur Load - Right Femur - Z Axis

Signal Ref. No. 24 **Filter Class: CFC600**

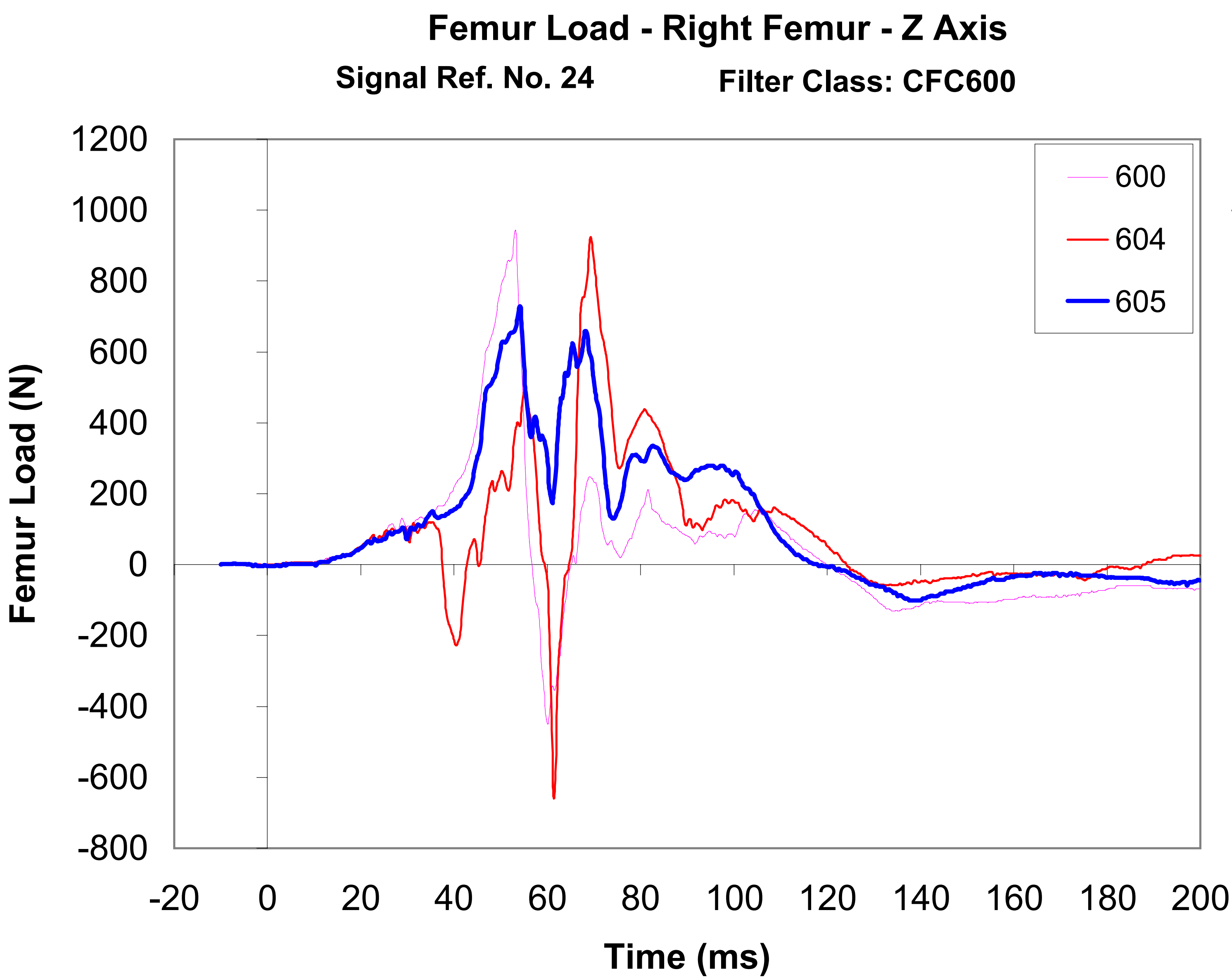


Maximum

Test #	Value	Time
600	943	53
601	813	54
602	905	53
603	980	71

Minimum

Test #	Value	Time
600	-450	60
601	-968	64
602	-107	146
603	-113	65



Maximum

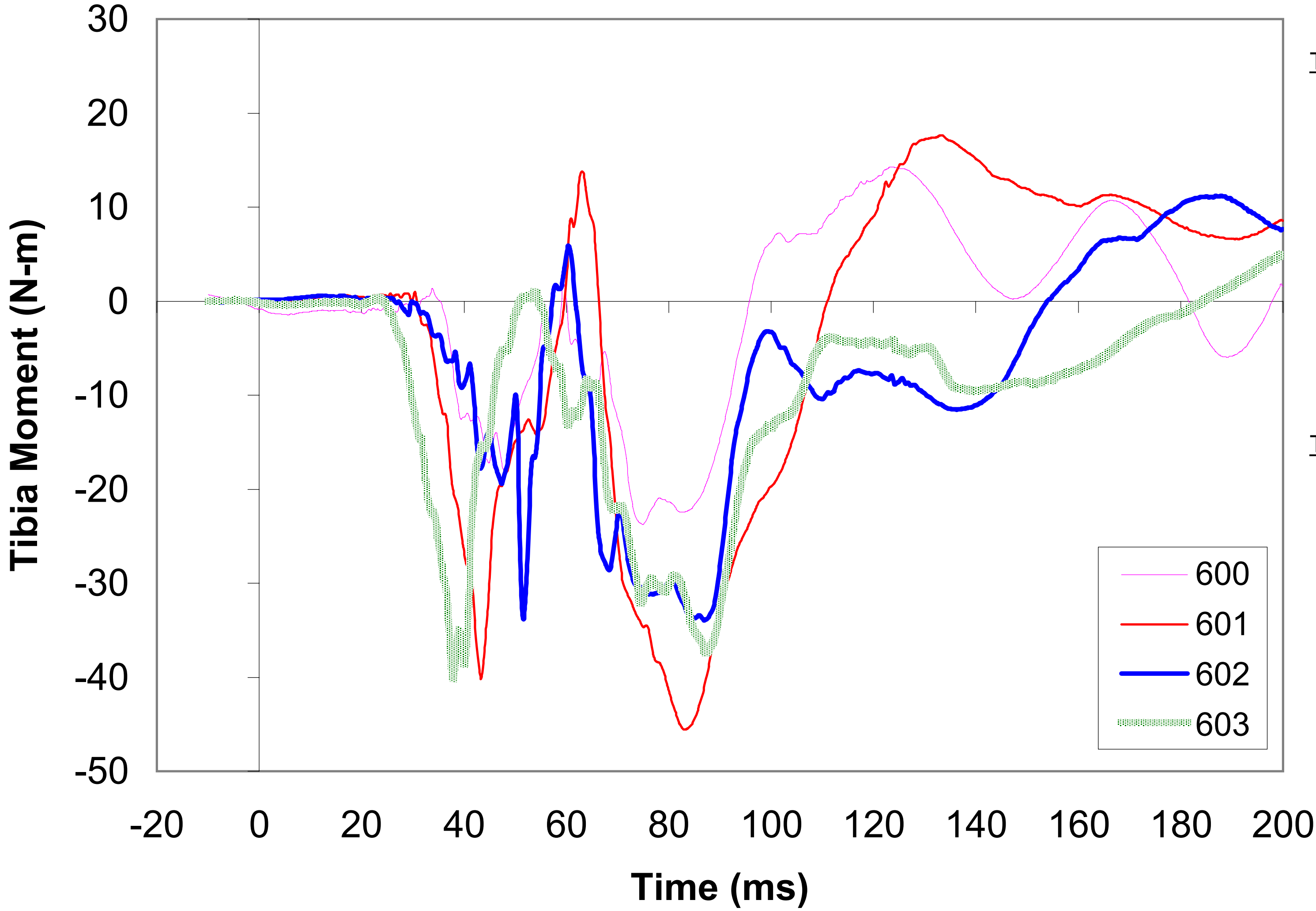
Test #	Value	Time
600	943	53
604	924	69
605	730	54

Minimum

Test #	Value	Time
600	-450	60
604	-660	61
605	-102	140

Tibia Moment - Upper Tibia Left - X Axis

Signal Ref. No. 25 Filter Class: CFC600



Maximum

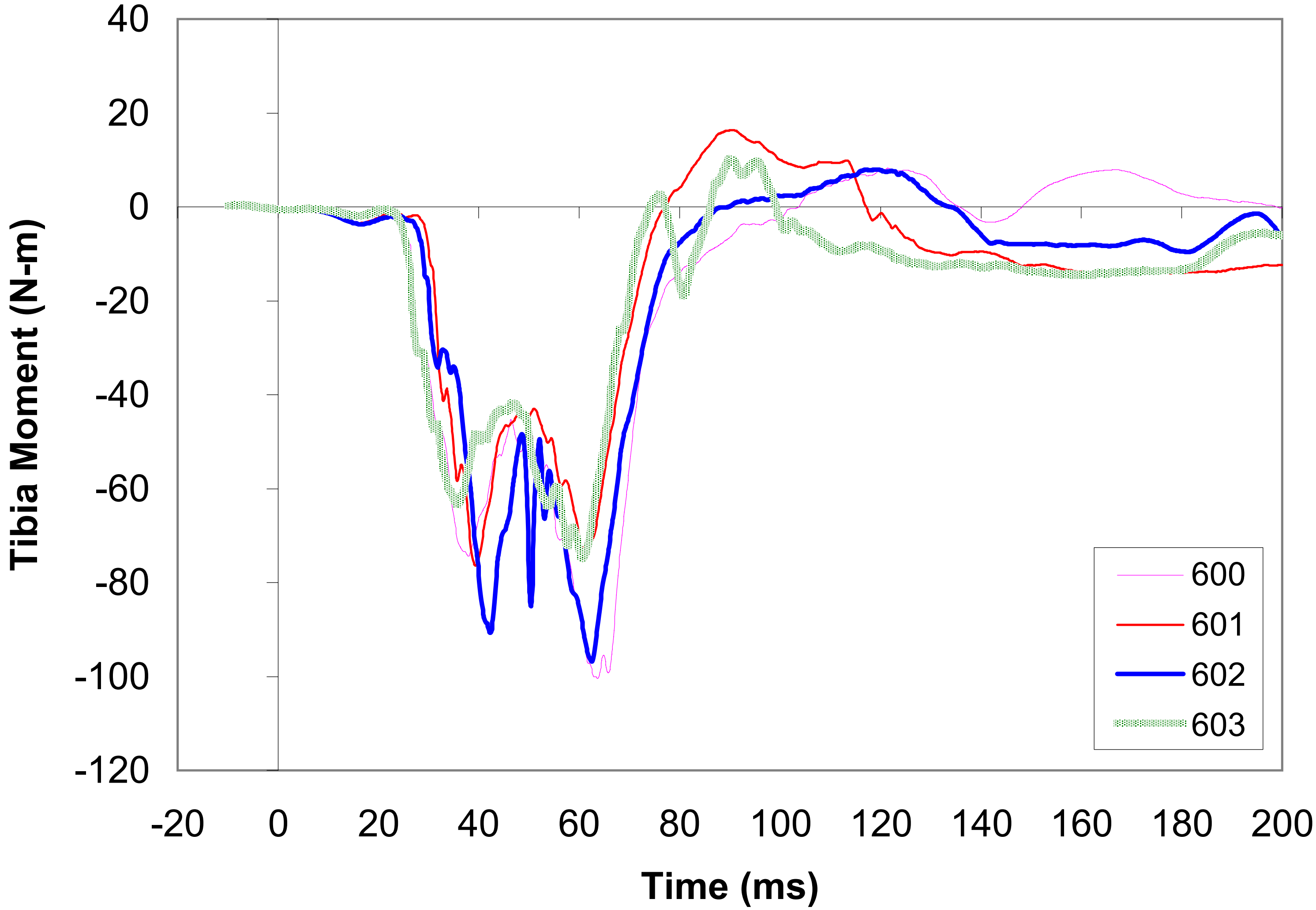
Test #	Value	Time
600	14	123
601	18	133
602	11	188
603	5	200

Minimum

Test #	Value	Time
600	-24	75
601	-46	83
602	-34	87
603	-40	38

Tibia Moment - Upper Tibia Left - Y Axis

Signal Ref. No. 26 **Filter Class: CFC600**



Maximum

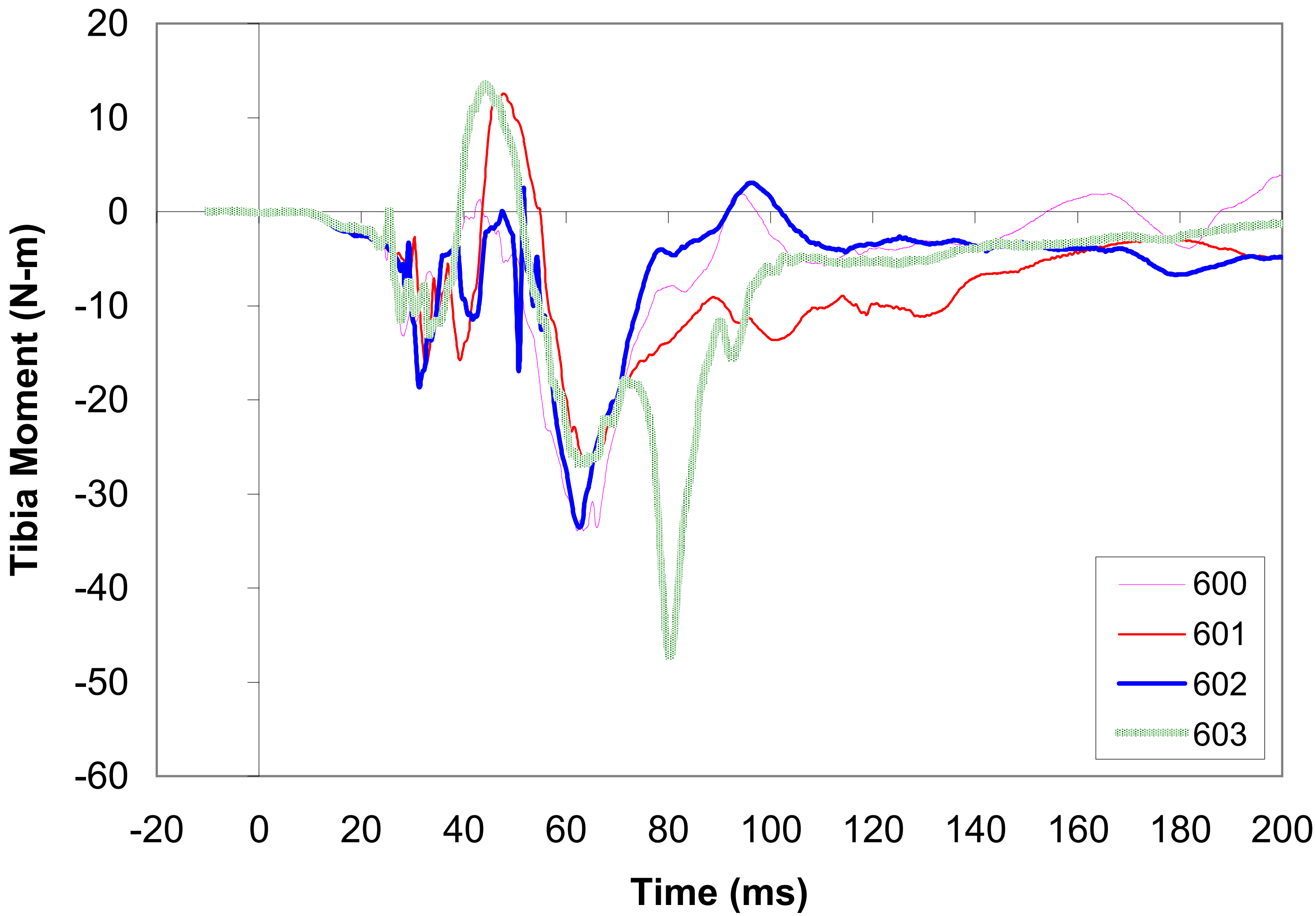
Test #	Value	Time
600	8	121
601	16	90
602	8	119
603	10	90

Minimum

Test #	Value	Time
600	-100	64
601	-76	39
602	-97	63
603	-75	61

Tibia Moment - Lower Tibia Left - Y Axis

Signal Ref. No. 29 **Filter Class: CFC600**



Maximum

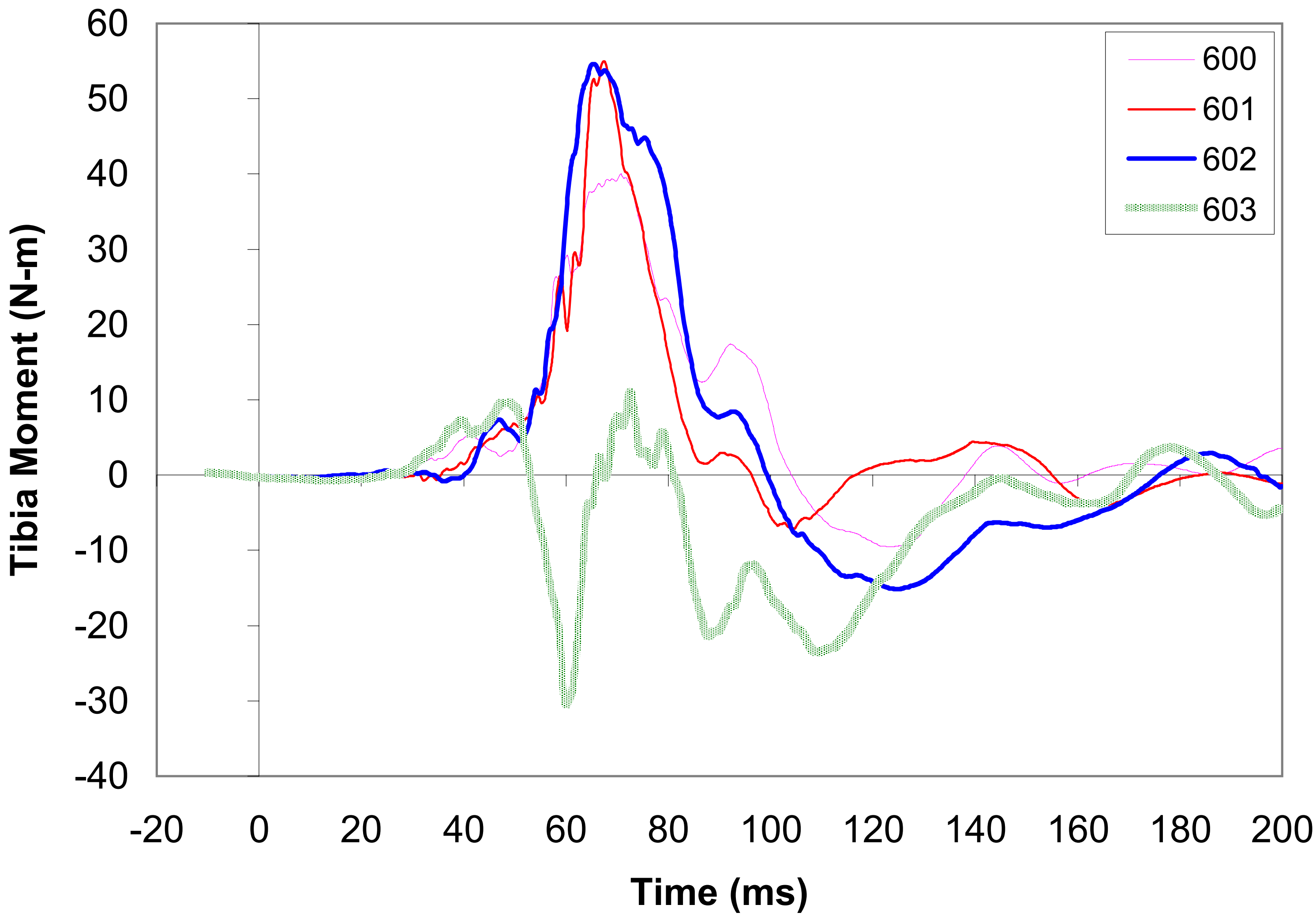
Test #	Value	Time
600	4	200
601	13	48
602	3	96
603	13	44

Minimum

Test #	Value	Time
600	-34	62
601	-27	64
602	-34	63
603	-47	80

Tibia Moment - Upper Tibia Right - X Axis

Signal Ref. No. 30 **Filter Class: CFC600**



Maximum

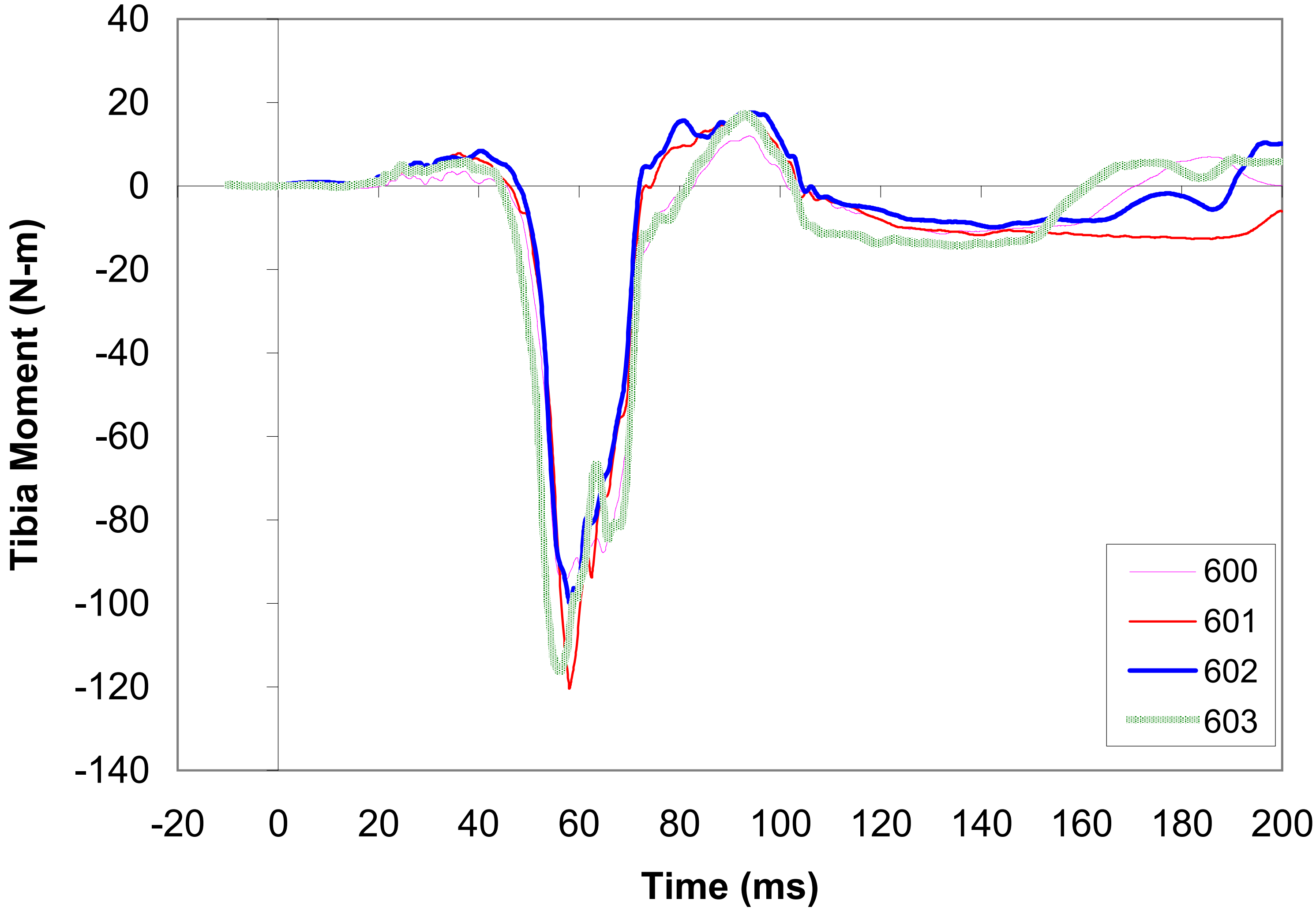
Test #	Value	Time
600	40	71
601	55	67
602	55	66
603	11	73

Minimum

Test #	Value	Time
600	-10	123
601	-7	105
602	-15	125
603	-30	60

Tibia Moment - Upper Tibia Right - Y Axis

Signal Ref. No. 31   Filter Class: CFC600



Maximum

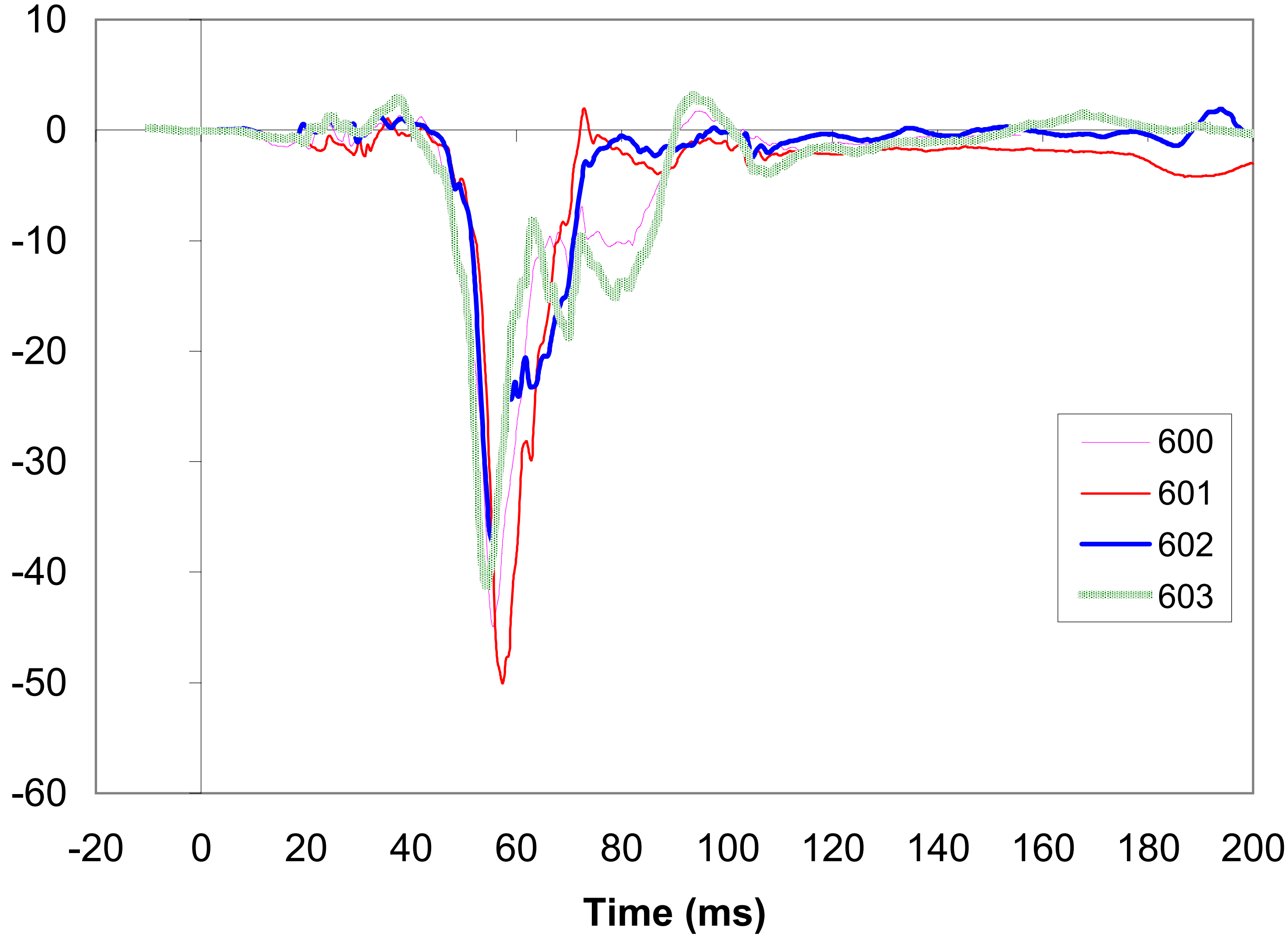
Test #	Value	Time
600	12	94
601	17	92
602	18	94
603	17	93

Minimum

Test #	Value	Time
600	-94	58
601	-120	58
602	-100	58
603	-116	56

Tibia Moment - Lower Tibia Right - Y Axis

Signal Ref. No. 34 **Filter Class: CFC600**



Maximum

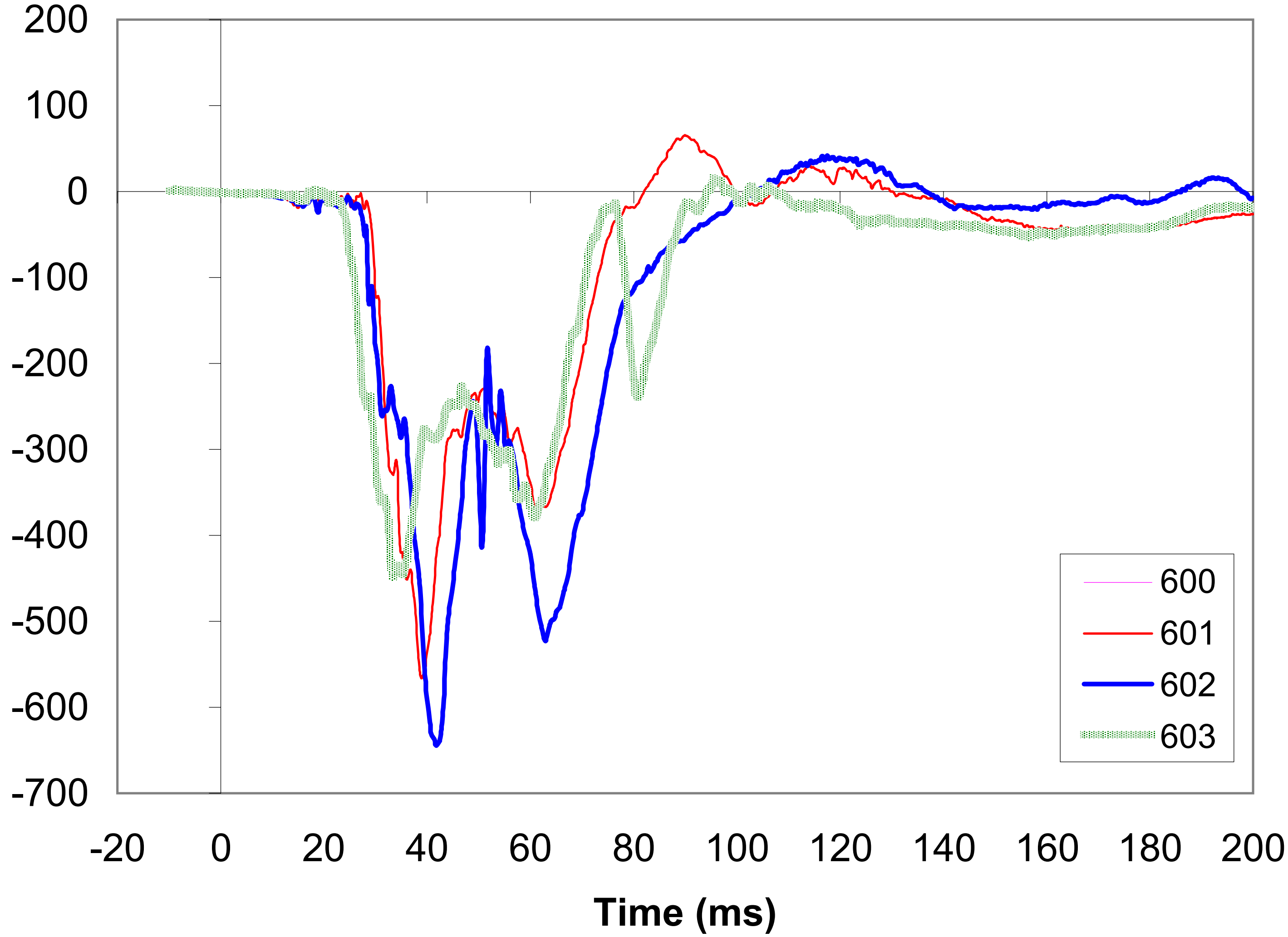
Test #	Value	Time
600	2	95
601	2	73
602	2	194
603	3	94

Minimum

Test #	Value	Time
600	-45	56
601	-50	57
602	-37	56
603	-41	54

Tibia Load - Lower Tibia Left - X Axis

Signal Ref. No. 27   Filter Class: CFC600



Maximum

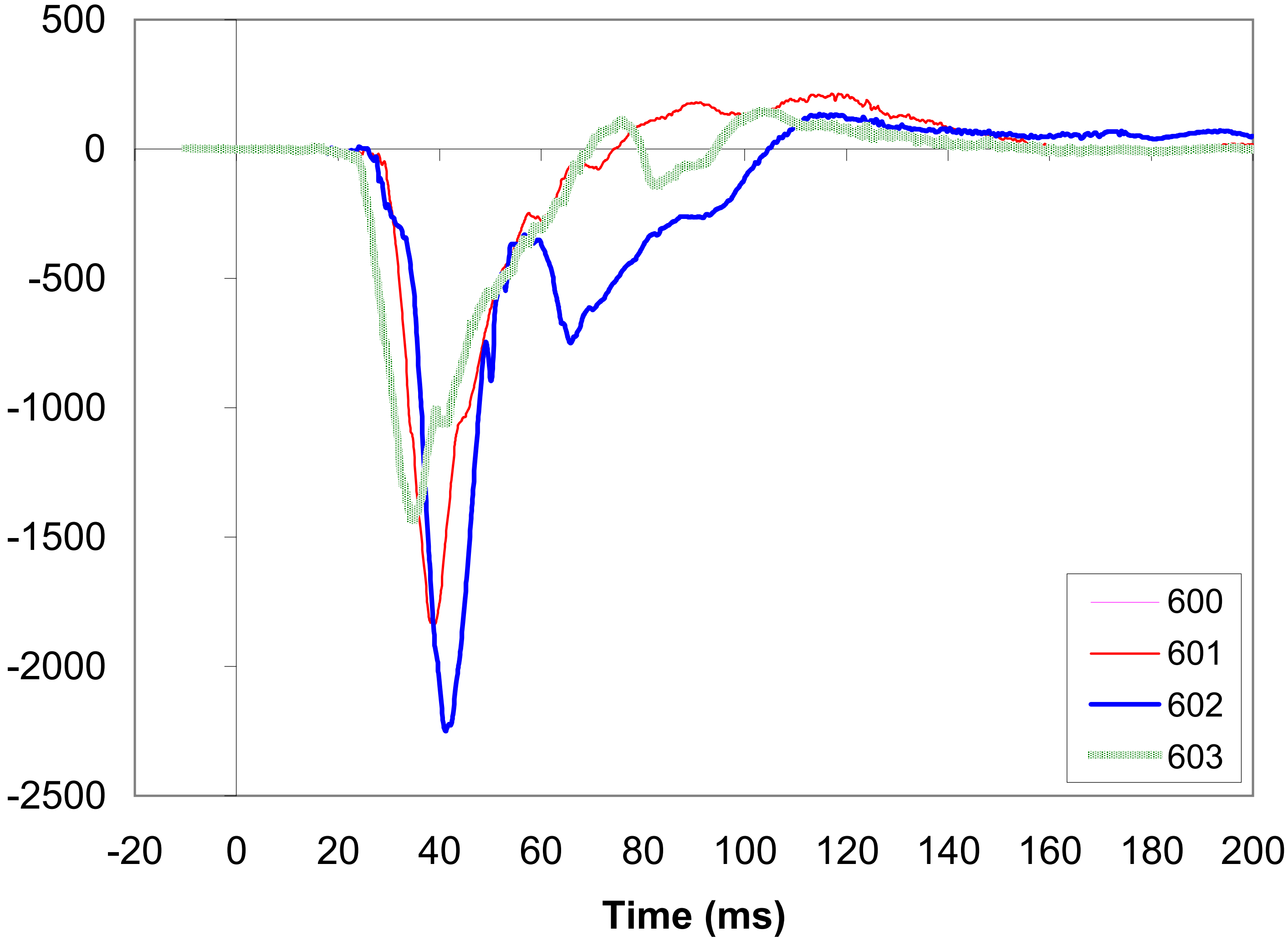
Test #	Value	Time
600	43	122
601	65	90
602	42	117
603	15	95

Minimum

Test #	Value	Time
600	-586	66
601	-567	39
602	-644	42
603	-449	33

Tibia Load - Lower Tibia Left - Z Axis

Signal Ref. No. 28 **Filter Class: CFC600**



Maximum

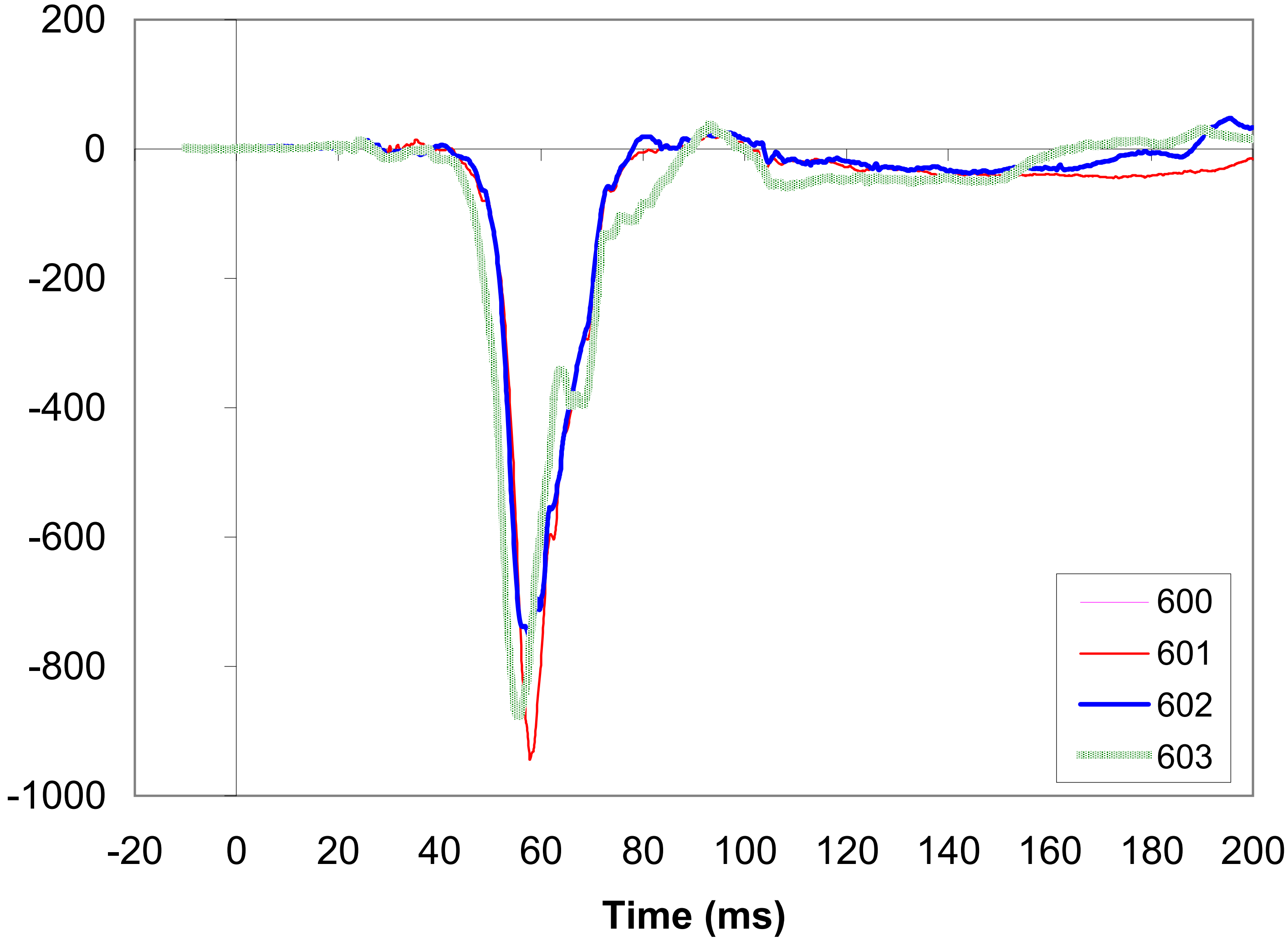
Test #	Value	Time
600	118	113
601	213	118
602	135	115
603	144	103

Minimum

Test #	Value	Time
600	-1881	38
601	-1836	39
602	-2250	41
603	-1436	35

Tibia Load - Lower Tibia Right - X Axis

Signal Ref. No. 32 **Filter Class: CFC600**



Maximum

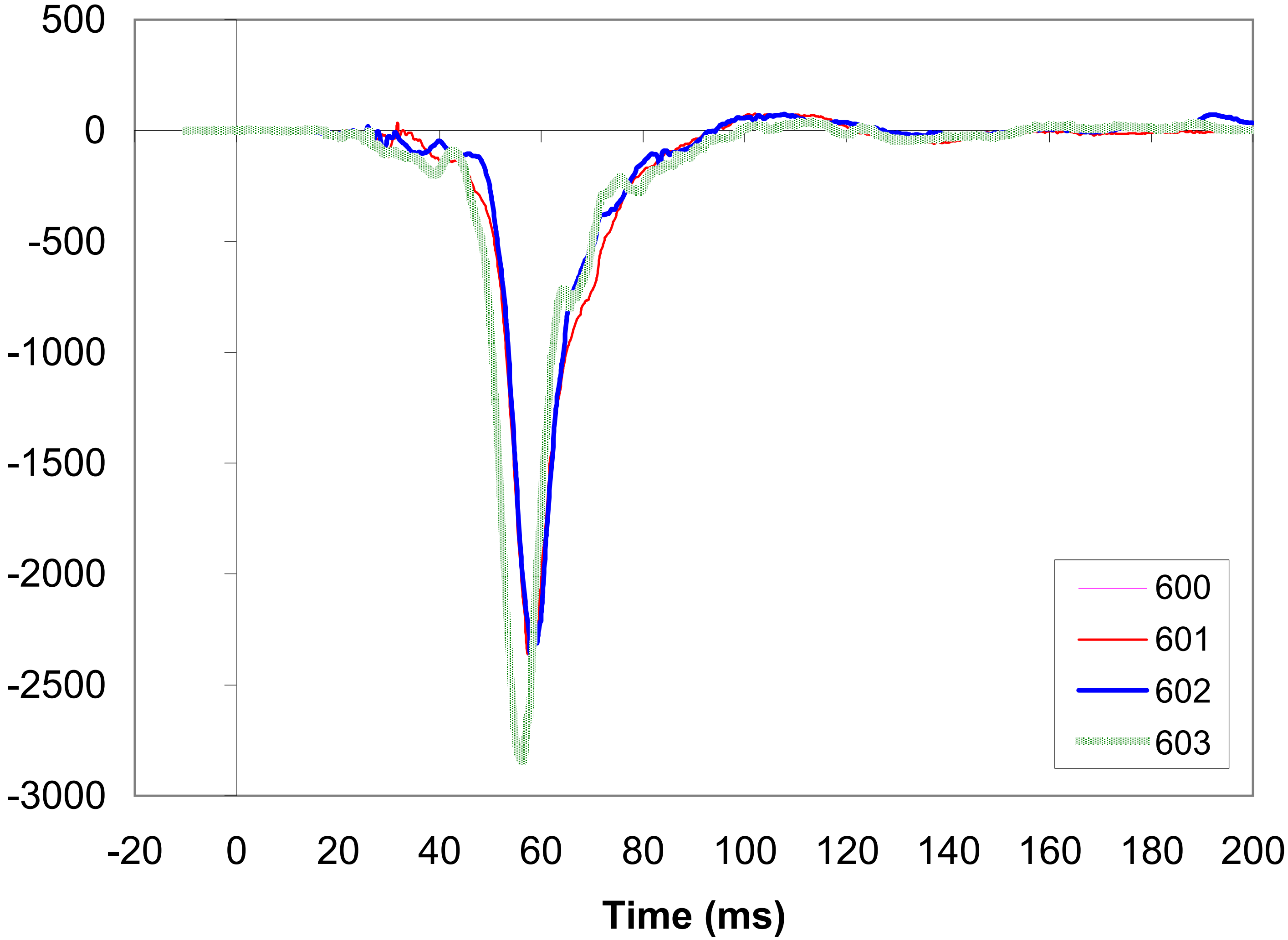
Test #	Value	Time
600	22	185
601	21	93
602	48	196
603	37	93

Minimum

Test #	Value	Time
600	-757	56
601	-944	58
602	-752	58
603	-877	56

Tibia Load - Lower Tibia Right - Z Axis

Signal Ref. No. 33 **Filter Class: CFC600**

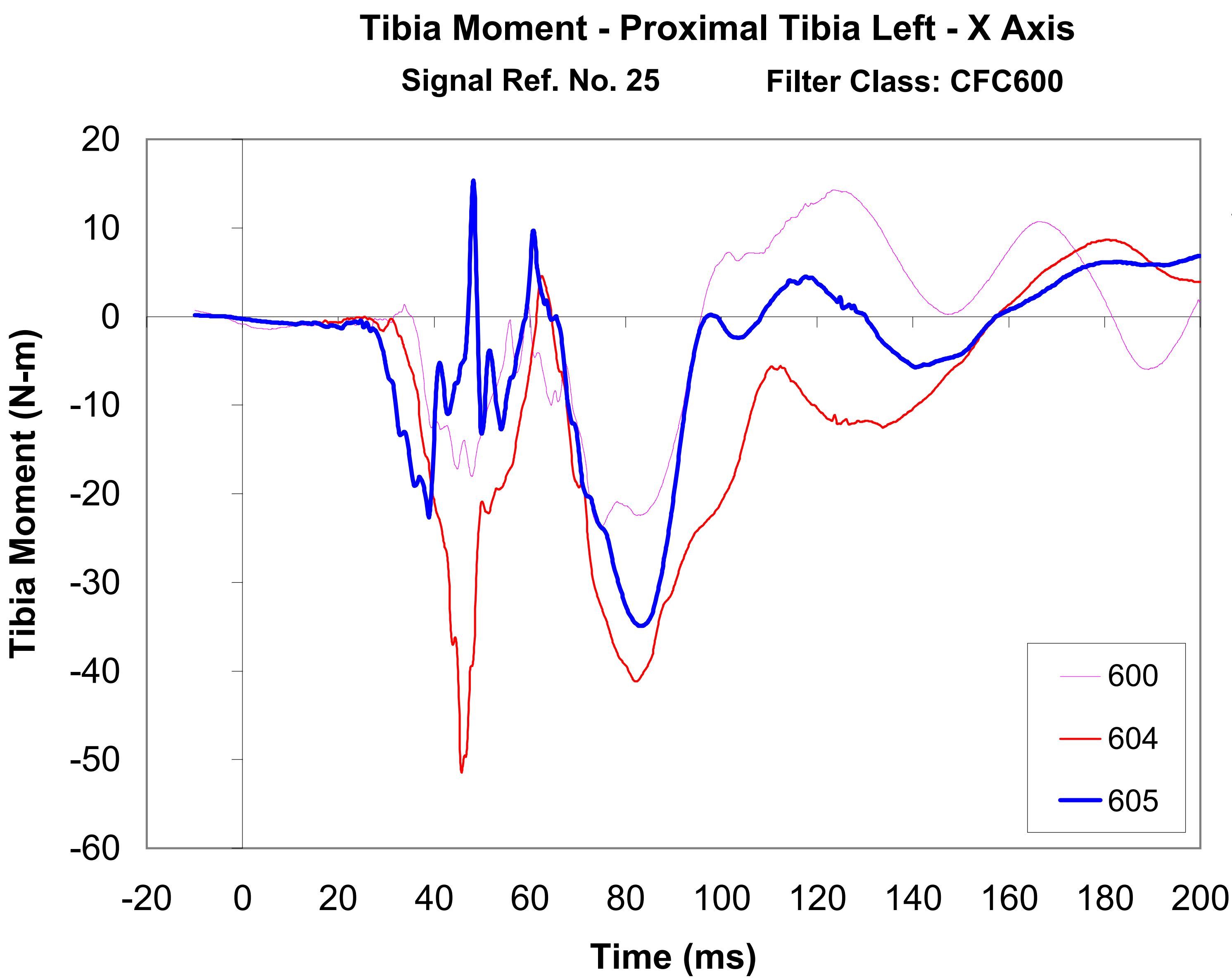


Maximum

Test #	Value	Time
600	46	116
601	76	102
602	74	108
603	39	113

Minimum

Test #	Value	Time
600	-1975	59
601	-2422	58
602	-2379	58
603	-2846	56

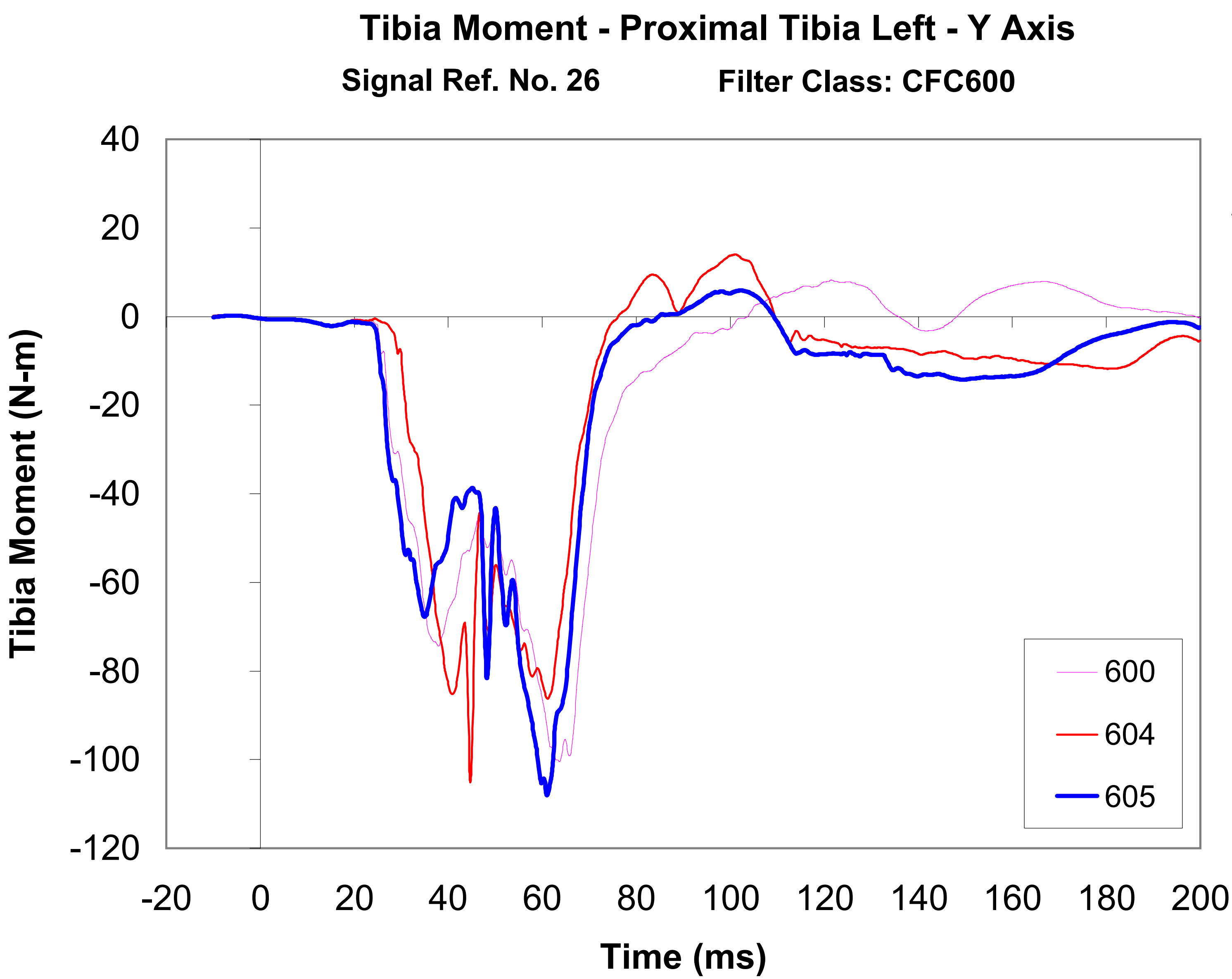


Maximum

Test #	Value	Time
600	14	123
604	9	181
605	15	48

Minimum

Test #	Value	Time
600	-24	75
604	-51	46
605	-35	83

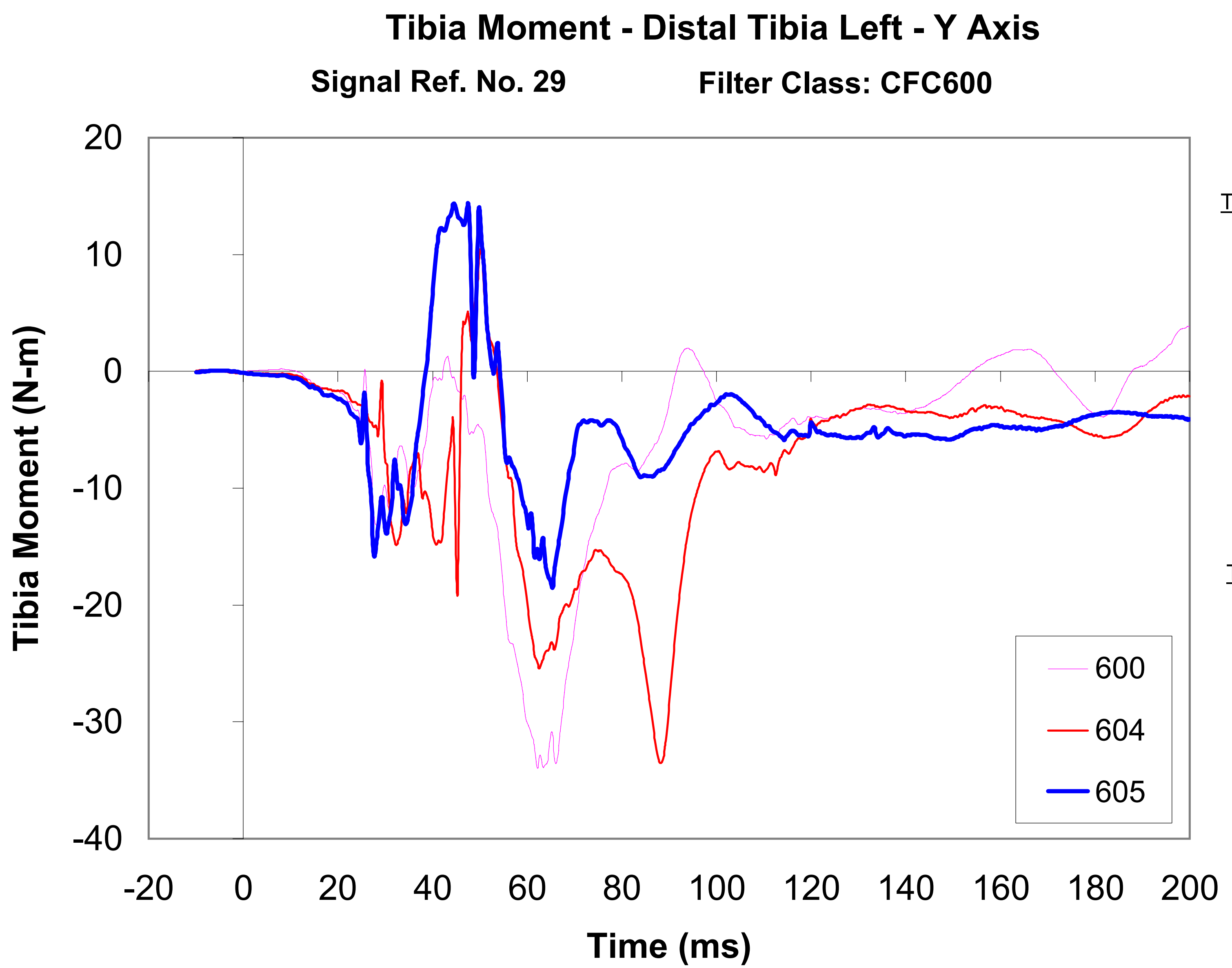


Maximum

Test #	Value	Time
600	8	121
604	14	101
605	6	102

Minimum

Test #	Value	Time
600	-100	64
604	-105	45
605	-108	61



Maximum

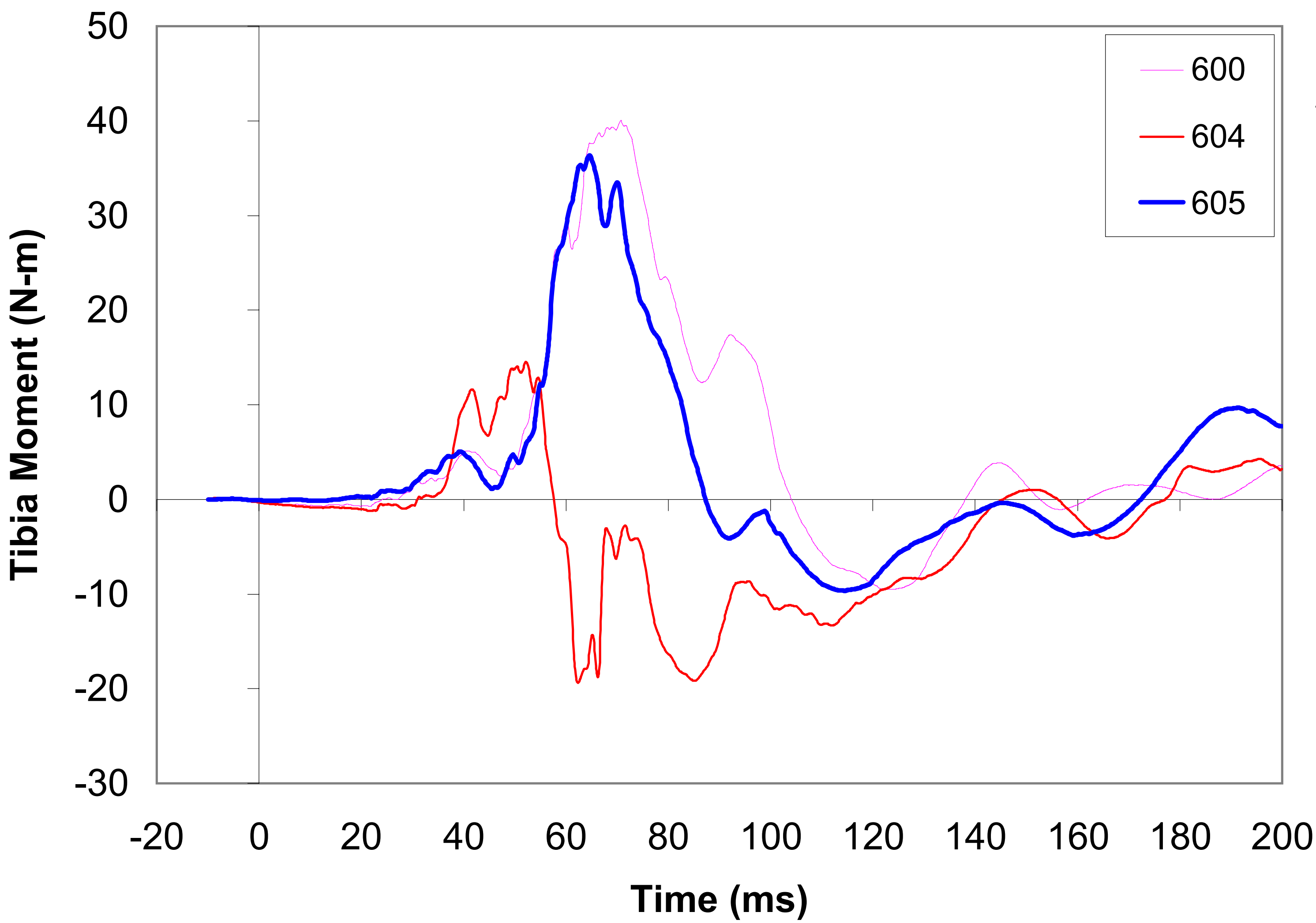
Test #	Value	Time
600	4	200
604	11	50
605	14	48

Minimum

Test #	Value	Time
600	-34	62
604	-34	88
605	-19	65

Tibia Moment - Proximal Tibia Right - X Axis

Signal Ref. No. 30 **Filter Class: CFC600**

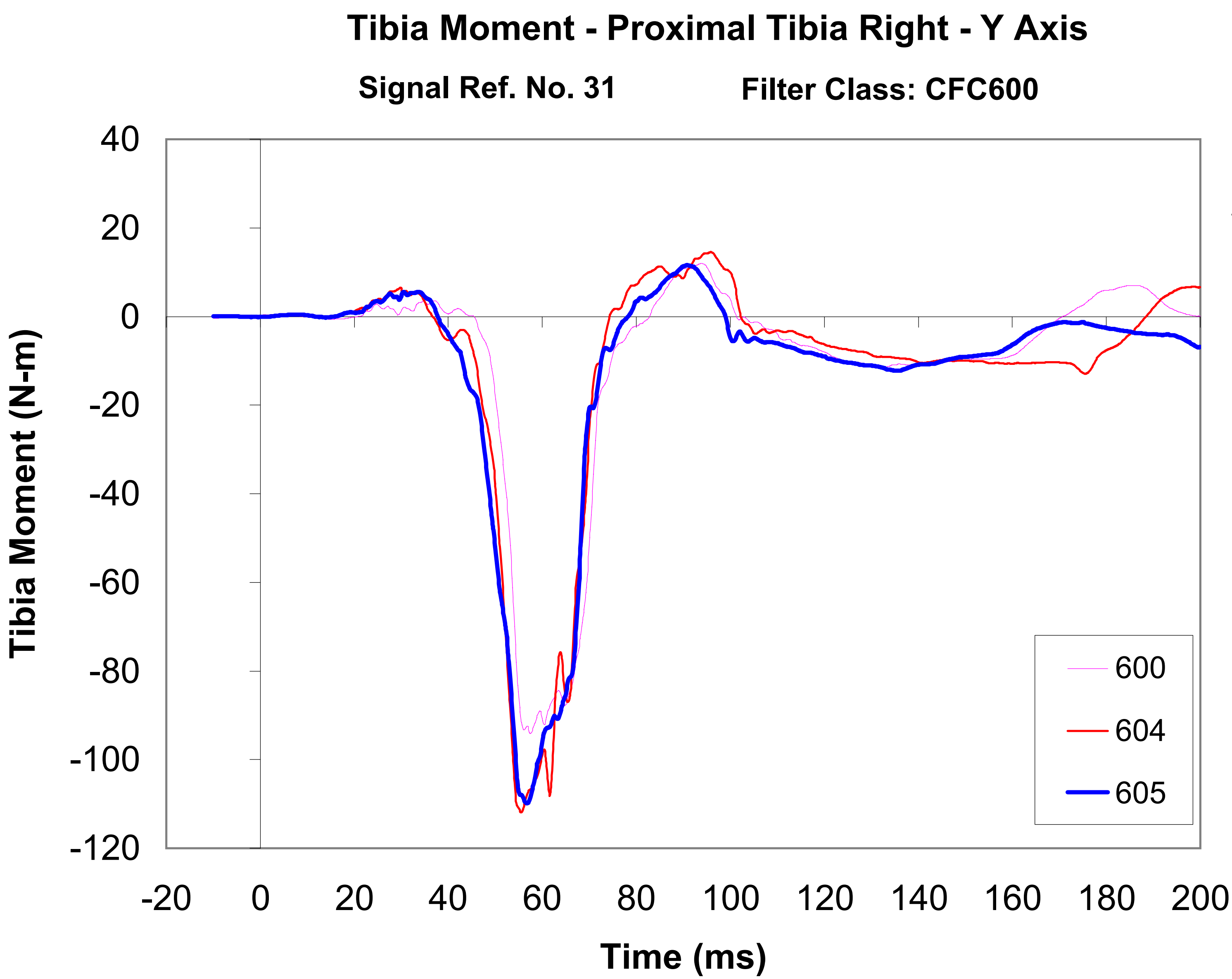


Maximum

Test #	Value	Time
600	40	71
604	15	52
605	36	65

Minimum

Test #	Value	Time
600	-10	123
604	-19	62
605	-10	114

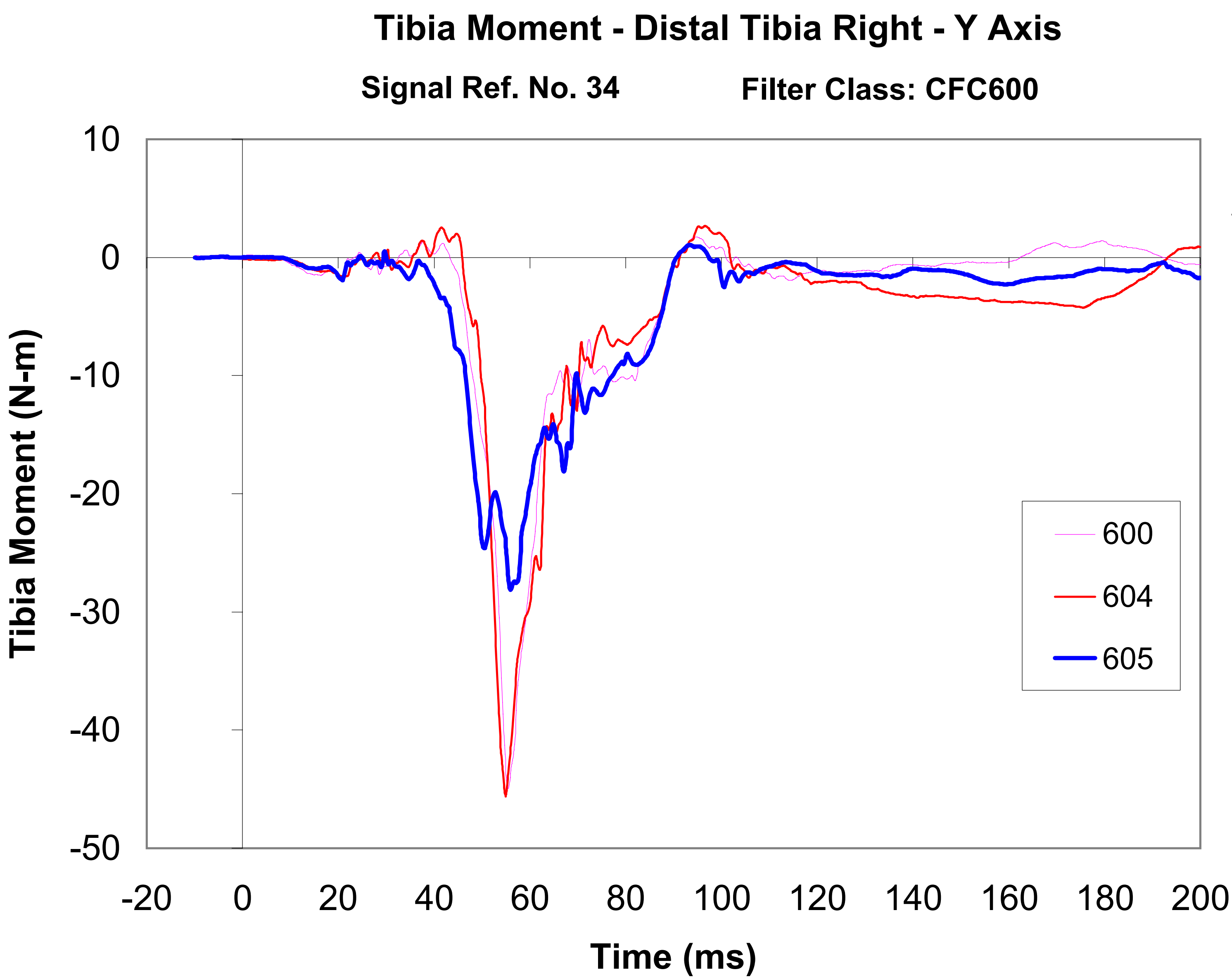


Maximum

Test #	Value	Time
600	12	94
604	15	96
605	12	91

Minimum

Test #	Value	Time
600	-94	58
604	-112	56
605	-110	57



Maximum

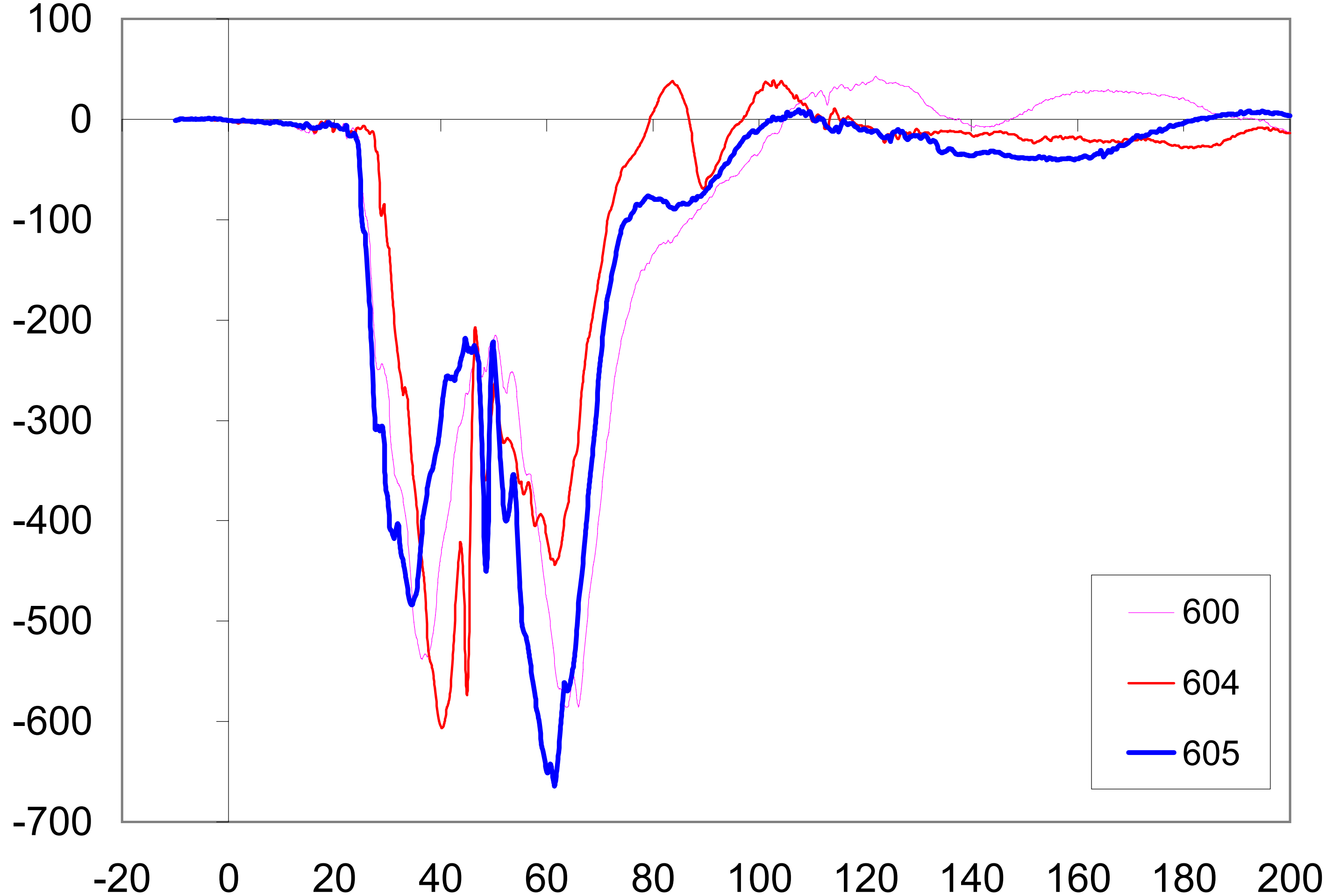
Test #	Value	Time
600	2	95
604	3	97
605	1	93

Minimum

Test #	Value	Time
600	-45	56
604	-46	55
605	-28	56

Tibia Load - Distal Tibia Left - X Axis

Signal Ref. No. 27 Filter Class: CFC600



Maximum

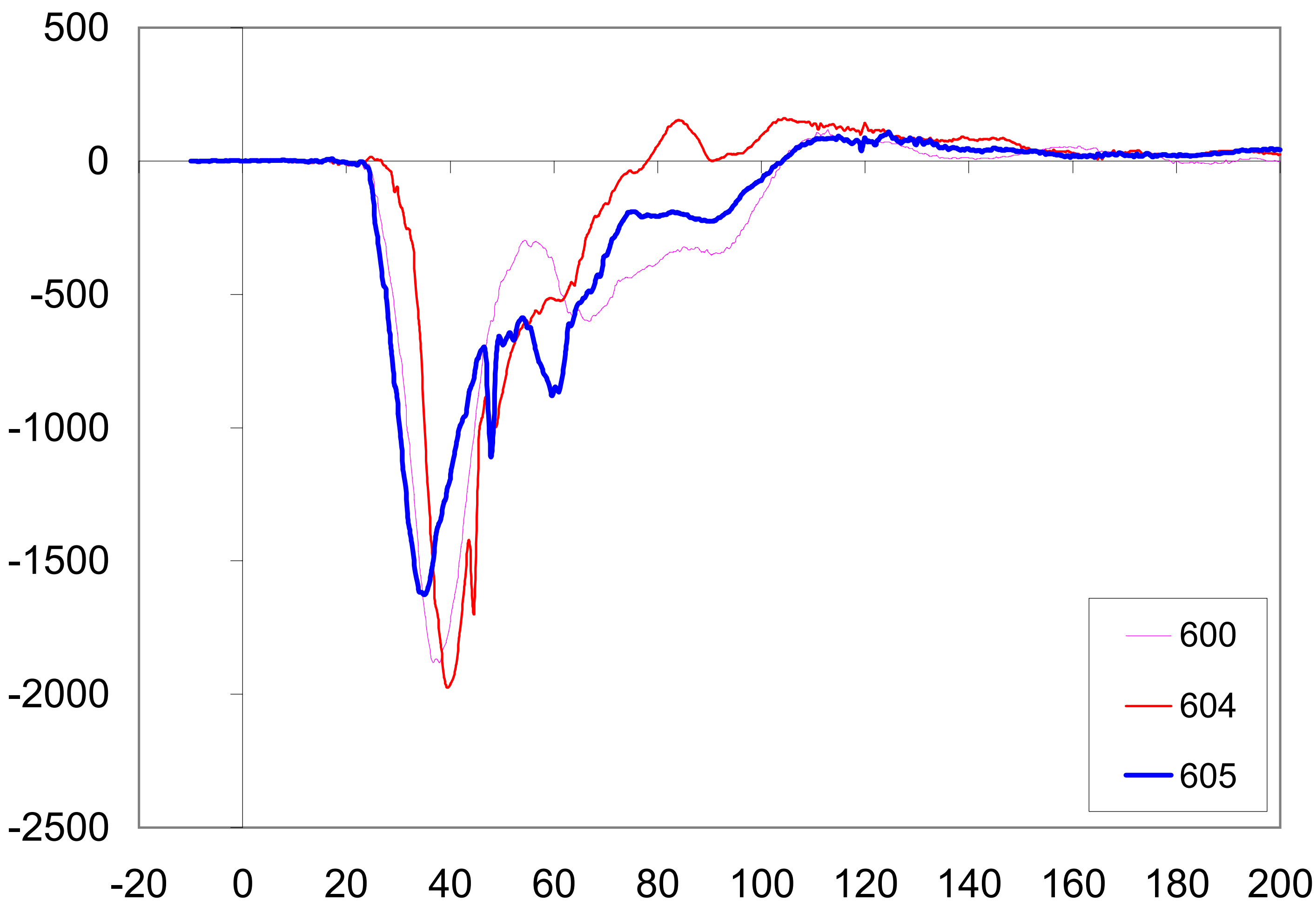
Test #	Value	Time
600	43	122
604	39	103
605	9	107

Minimum

Test #	Value	Time
600	-586	66
604	-606	40
605	-664	62

Tibia Load - Distal Tibia Left - Z Axis

Signal Ref. No. 28 Filter Class: CFC600

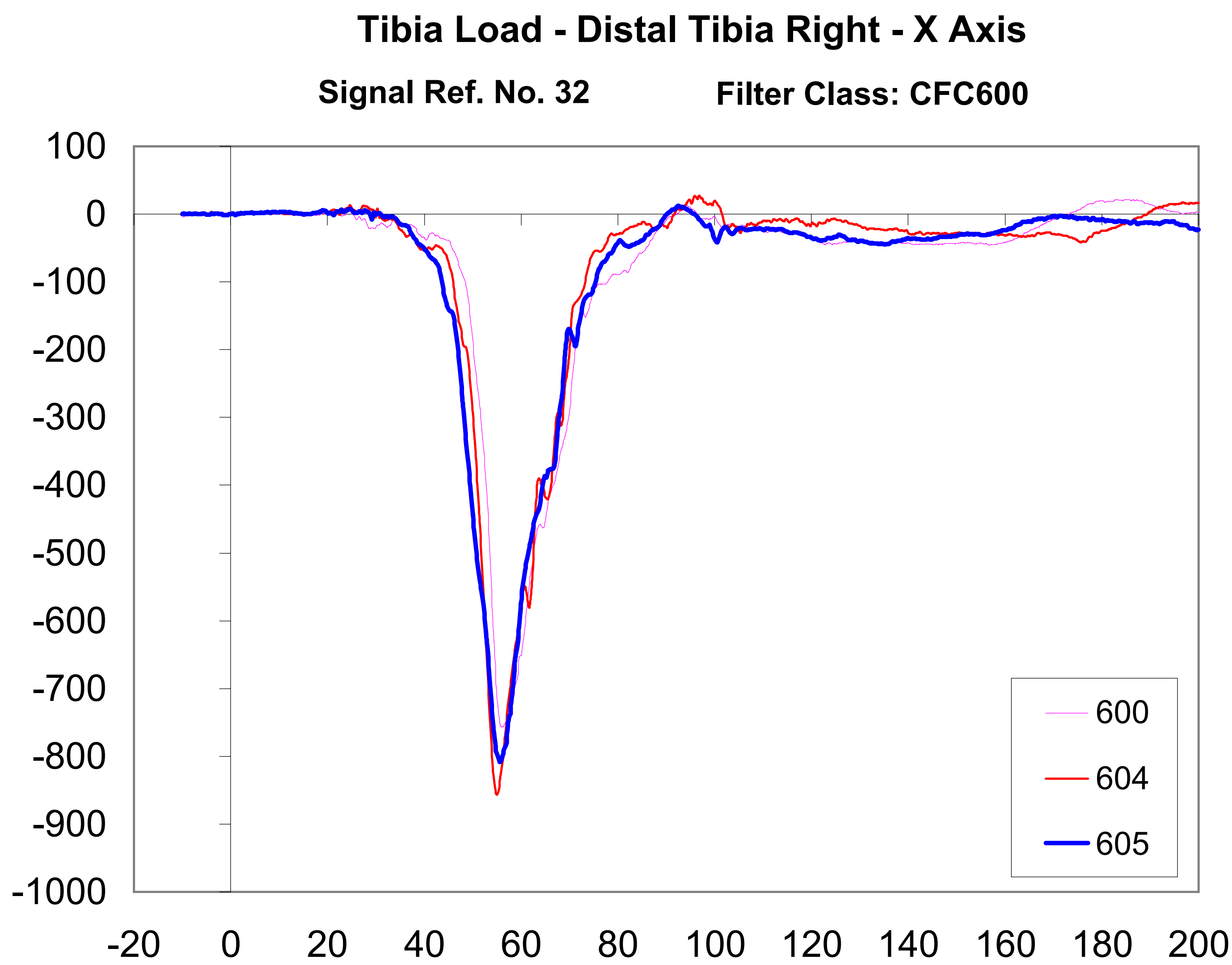


Maximum

Test #	Value	Time
600	118	113
604	161	104
605	108	125

Minimum

Test #	Value	Time
600	-1881	38
604	-1976	40
605	-1627	35

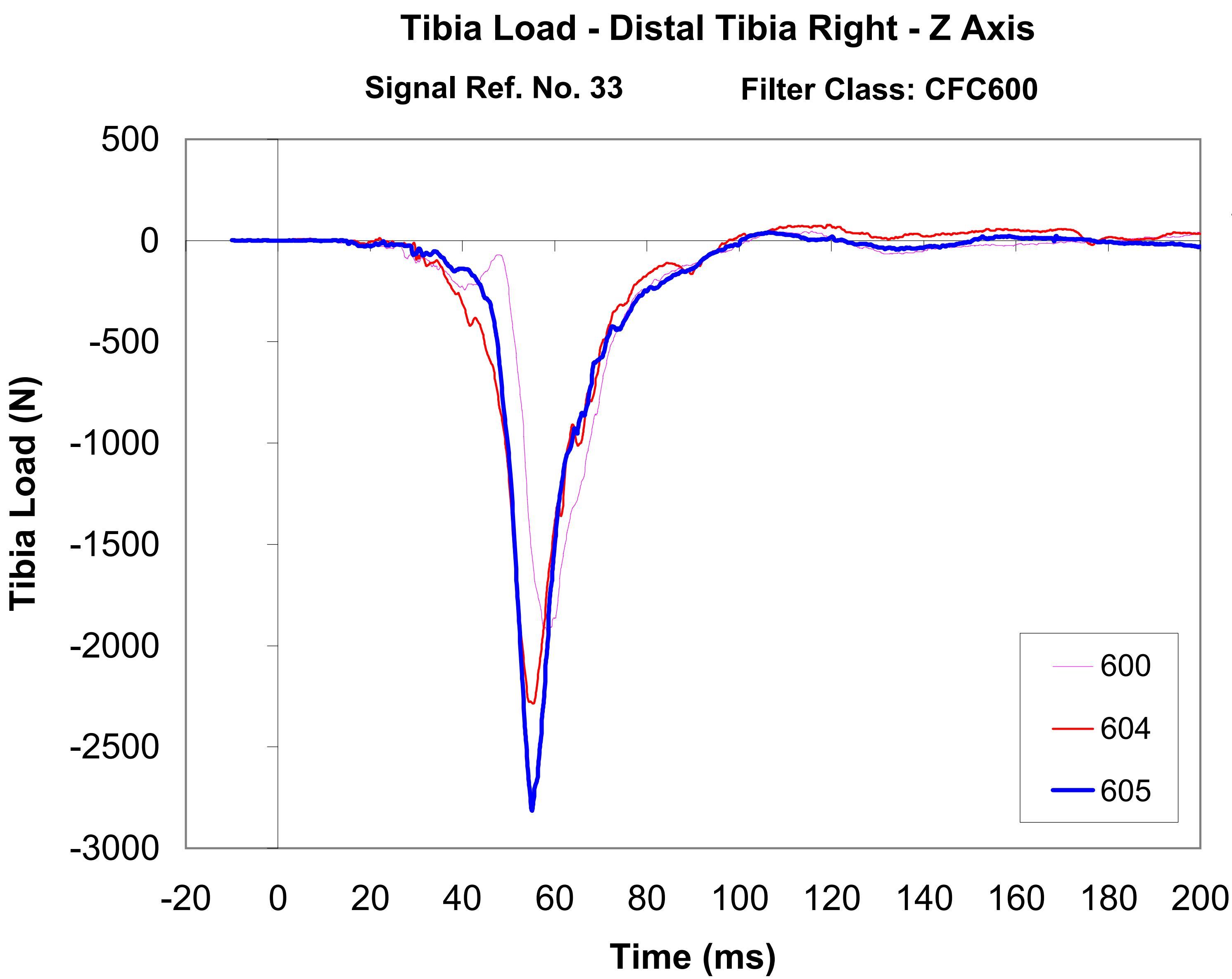


Maximum

Test #	Value	Time
600	22	185
604	27	97
605	12	92

Minimum

Test #	Value	Time
600	-757	56
604	-856	55
605	-808	56



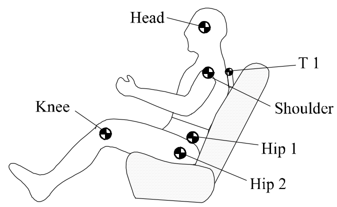
Maximum

Test #	Value	Time
600	46	116
604	79	120
605	40	106

Minimum

Test #	Value	Time
600	-1975	59
604	-2286	55
605	-2815	55

3.3: PHOTOGRAPHIC RESULTS



Neck1 Angle: Head to T1
Neck2 Angle: Head to Shoulder
Torso Angle: Shoulder to Hip1
Femur Angle: Hip2 to Knee

All Angles relative to 0 position
↶ Positive
↷ negative

Figure 3. Motion analysis points and angles**.**

Table 8. Test 600 Motion Picture Analysis Summary

Measurement	Axis	Unit	Minimum		Maximum	
			Value	Time (ms)	Value	Time (ms)
Head Displacement	x	cm	0	0	47	100
	z	cm	-10	100	0	10
T1 Displacement	x	cm	0	0	34	90
	z	cm	-2	90	0	30
Shoulder Displacement	x	cm	0	0	31	90
	z	cm	-4	150	0	0
Hip1 Displacement	x	cm	0	0	15	70
	z	cm	-2	90	0	0
Hip2 Displacement	x	cm	0	0	17	70
	z	cm	0	90	1	130
Knee Displacement	x	cm	0	0	14	70
	z	cm	0	0	5	60
Neck Rotation (T1-Head)	Abs.	deg	-1	30	54	110
Torso Rotation (T1-Hip1)	Abs.	deg	-1	50	25	90
Femur Rotation (Hip2-Knee)	Abs.	deg	-10	70	1	10

Table 9. Test 601 Motion Picture Analysis Summary

Measurement	Axis	Unit	Minimum		Maximum	
			Value	Time (ms)	Value	Time (ms)
Head Displacement	x	cm	0	0	49	100
	z	cm	-11	110	0	10
T1 Displacement	x	cm	0	0	33	90
	z	cm	-3	150	0	0
Shoulder Displacement	x	cm	0	0	30	80
	z	cm	-5	150	0	60
Hip1 Displacement	x	cm	0	0	17	60
	z	cm	-3	80	0	0
Hip2 Displacement	x	cm	0	0	19	70
	z	cm	-1	0	0	60
Knee Displacement	x	cm	0	0	16	70
	z	cm	0	40	4	60
Neck Rotation (T1-Head)	Abs.	deg	0	0	59	110
Torso Rotation (T1-Hip1)	Abs.	deg	-3	30	22	90
Femur Rotation (Hip2-Knee)	Abs.	deg	-7	60	1	30

Table 10. Test 602 Motion Picture Analysis Summary

Measurement	Axis	Unit	Minimum		Maximum	
			Value	Time (ms)	Value	Time (ms)
Head Displacement	x	cm	0	0	48	100
	z	cm	-10	110	0	0
T1 Displacement	x	cm	0	0	35	90
	z	cm	-2	150	0	0
Shoulder Displacement	x	cm	0	0	29	80
	z	cm	-5	150	0	60
Hip1 Displacement	x	cm	0	0	15	70
	z	cm	-3	150	0	0
Hip2 Displacement	x	cm	0	0	16	70
	z	cm	-1	0	0	10
Knee Displacement	x	cm	0	0	15	70
	z	cm	0	30	4	60
Neck Rotation (T1-Head)	Abs.	deg	0	20	53	110
Torso Rotation (T1-Hip1)	Abs.	deg	-1	30	27	90
Femur Rotation (Hip2-Knee)	Abs.	deg	-7	70	1	40

Table 11. Test 603 Motion Picture Analysis Summary

Measurement	Axis	Unit	Minimum		Maximum	
			Value	Time (ms)	Value	Time (ms)
Head Displacement	x	cm	0	10	48	100
	z	cm	-12	110	0	30
T1 Displacement	x	cm	0	0	35	90
	z	cm	-2	140	0	20
Shoulder Displacement	x	cm	0	0	30	80
	z	cm	-5	150	1	20
Hip1 Displacement	x	cm	0	0	16	70
	z	cm	-3	80	0	10
Hip2 Displacement	x	cm	0	0	17	70
	z	cm	-1	0	0	20
Knee Displacement	x	cm	0	0	15	80
	z	cm	0	10	5	60
Neck Rotation (T1-Head)	Abs.	deg	-1	10	56	110
Torso Rotation (T1-Hip1)	Abs.	deg	-1	30	25	90
Femur Rotation (Hip2-Knee)	Abs.	deg	-8	60	0	0

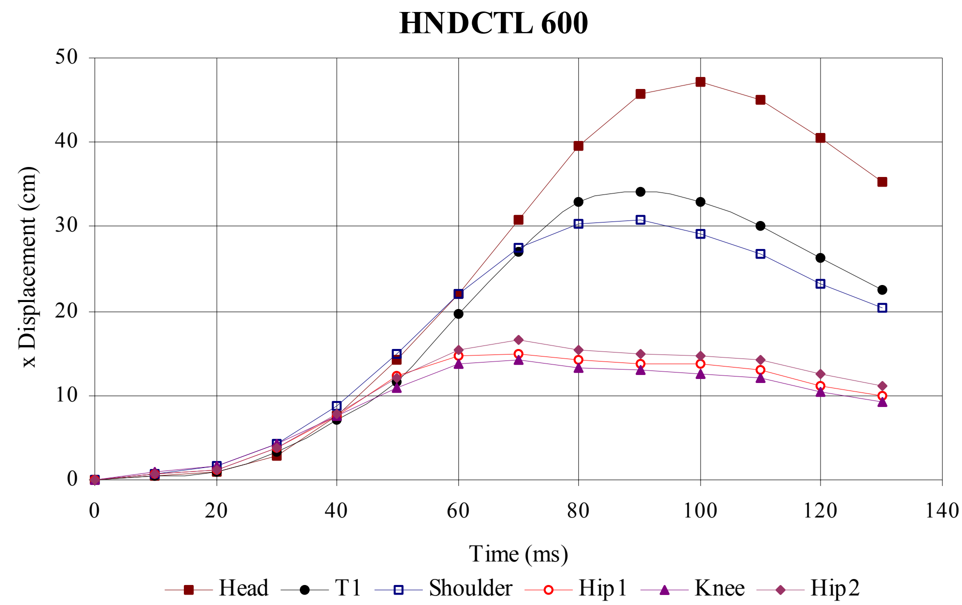
Table 12. Test 604 Motion Picture Analysis Summary

Measurement	Axis	Unit	Minimum		Maximum	
			Value	Time (ms)	Value	Time (ms)
Head Displacement	x	cm	0	0	46	90
	z	cm	-8	100	0	10
T1 Displacement	x	cm	0	0	35	90
	z	cm	-1	40	1	60
Shoulder Displacement	x	cm	0	0	28	80
	z	cm	-3	150	1	60
Hip1 Displacement	x	cm	0	0	15	60
	z	cm	-2	150	0	0
Hip2 Displacement	x	cm	0	0	17	70
	z	cm	-1	0	1	110
Knee Displacement	x	cm	0	0	16	70
	z	cm	0	100	4	60
Neck Rotation (T1-Head)	Abs.	deg	-2	40	49	110
Torso Rotation (T1-Hip1)	Abs.	deg	-1	30	25	90
Femur Rotation (Hip2-Knee)	Abs.	deg	-6	60	1	100

Table 13. Test 605 Motion Picture Analysis Summary

Measurement	Axis	Unit	Minimum		Maximum	
			Value	Time (ms)	Value	Time (ms)
Head Displacement	x	cm	0	0	48	100
	z	cm	-9	110	0	10
T1 Displacement	x	cm	0	0	36	90
	z	cm	-2	150	0	0
Shoulder Displacement	x	cm	0	0	30	80
	z	cm	-4	150	0	60
Hip1 Displacement	x	cm	0	0	16	70
	z	cm	-2	150	0	10
Hip2 Displacement	x	cm	0	0	17	70
	z	cm	-1	0	1	60
Knee Displacement	x	cm	0	0	15	70
	z	cm	0	10	5	60
Neck Rotation (T1-Head)	Abs.	deg	-2	10	53	110
Torso Rotation (T1-Hip1)	Abs.	deg	-1	30	25	90
Femur Rotation (Hip2-Knee)	Abs.	deg	-8	60	0	10

3.3.1: MOTION PICTURE ANALYSIS PLOTS



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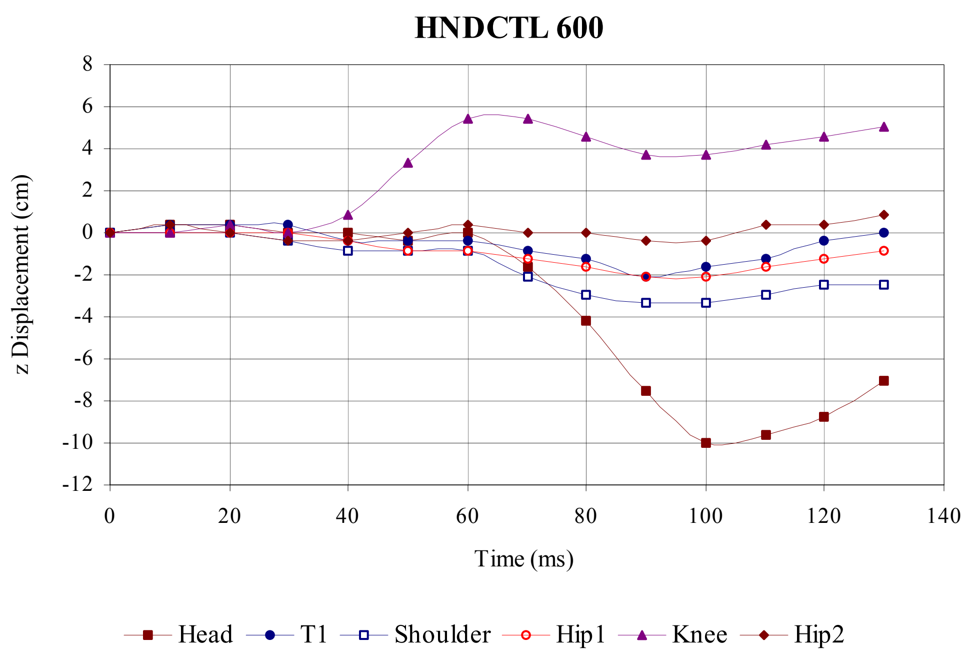
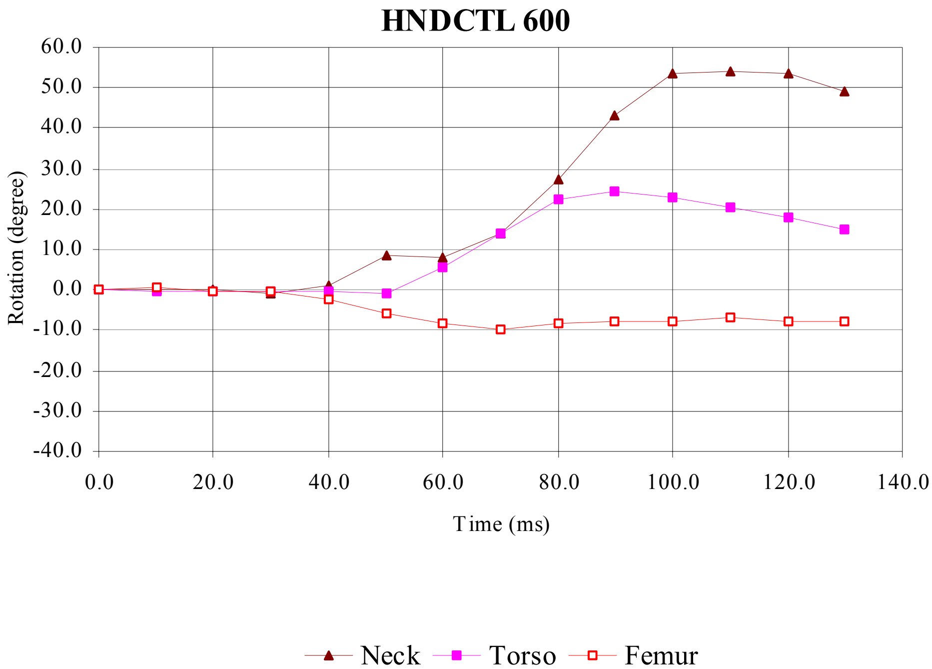
x Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2



HNDCTL 600
z Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2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50.0
40.0
30.0
20.0
10.0
0.0
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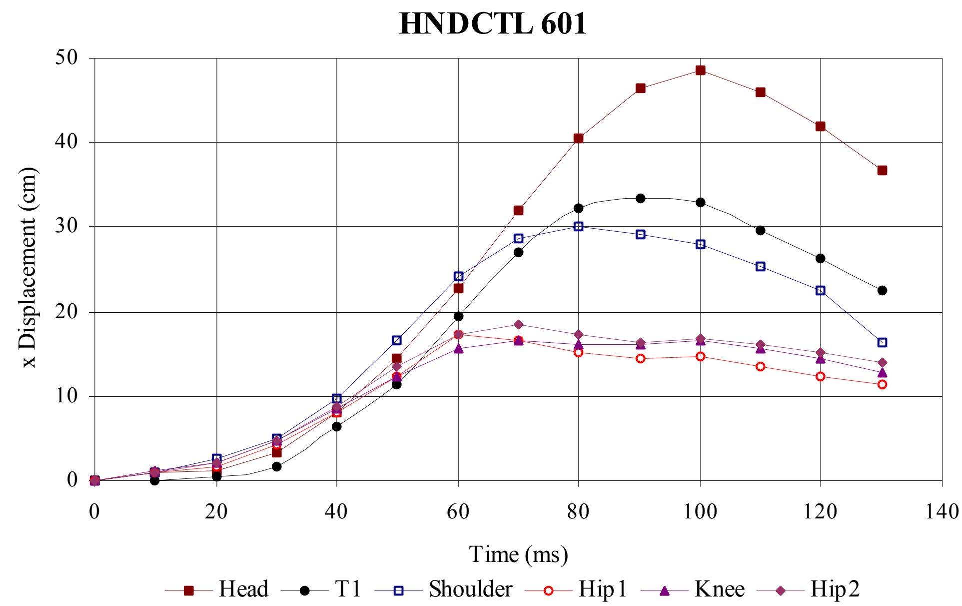
-20.0
-30.0
-40.0
Rotation (degree)
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
Time (ms)
Neck
Torso
Femur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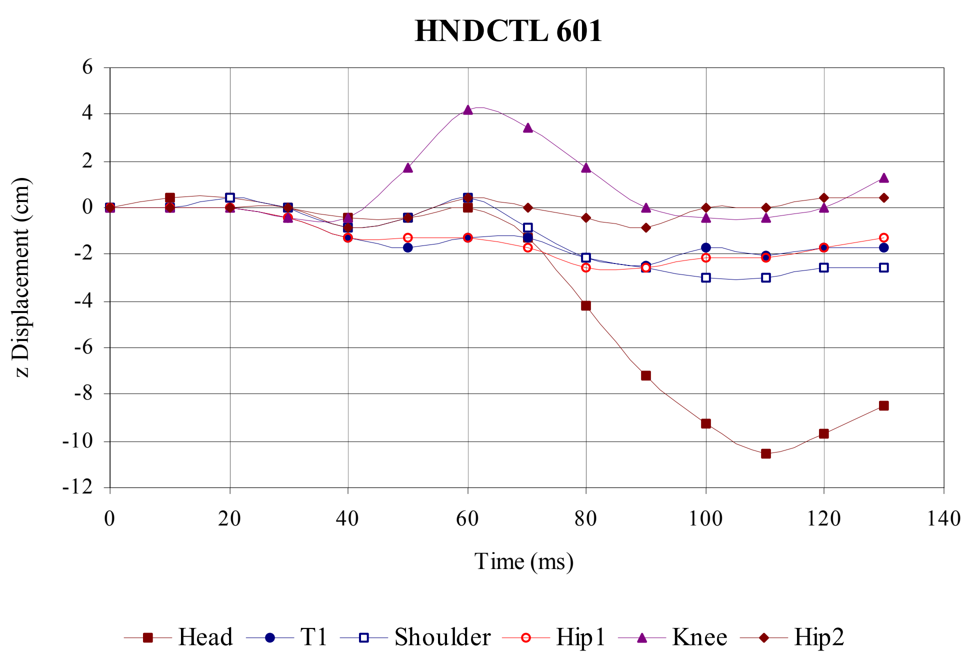
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2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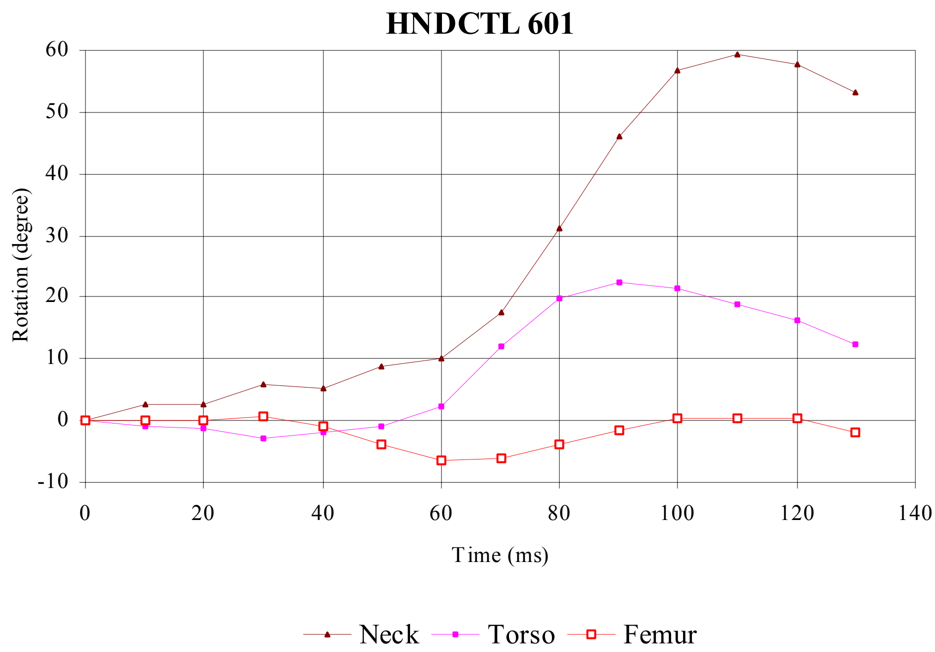
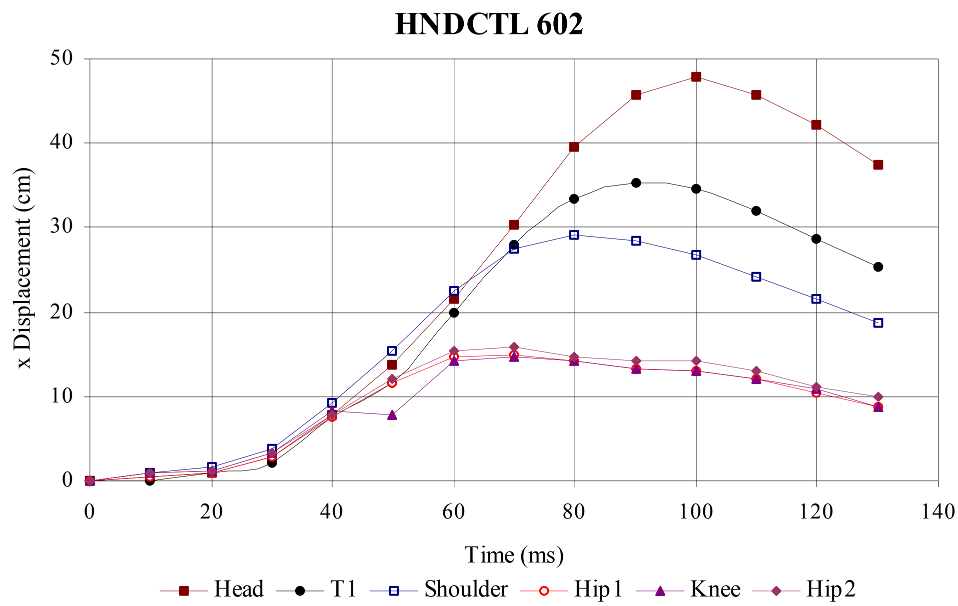
z Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2


HNDCTL 601
60
50
40
30
20
10
0
-10
Rotation (degree)
0
20
40
60
80
100
120
140
Time (ms)
Neck
Torso
Femur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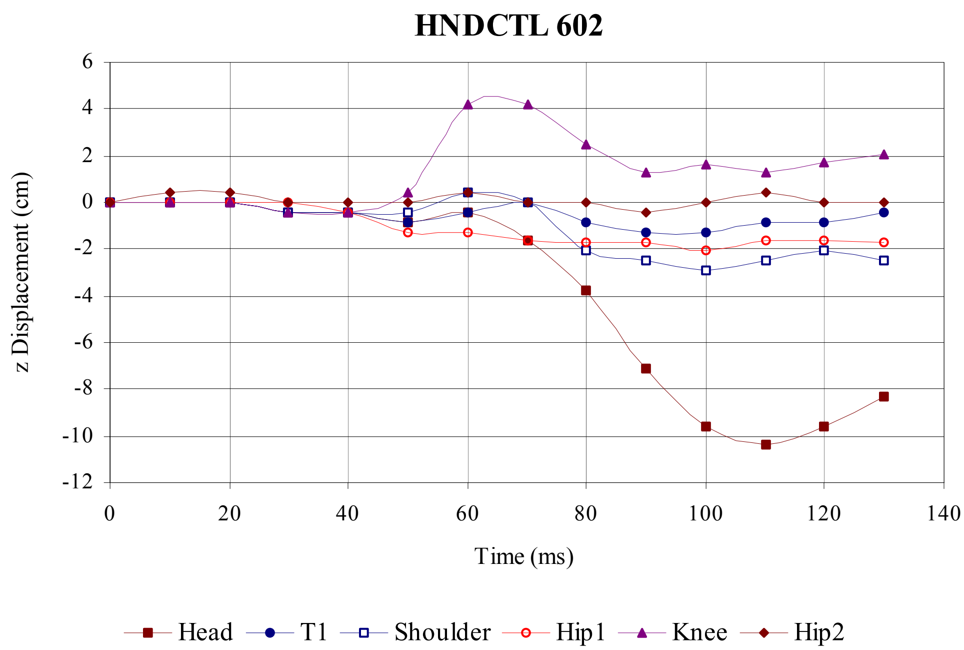
x Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2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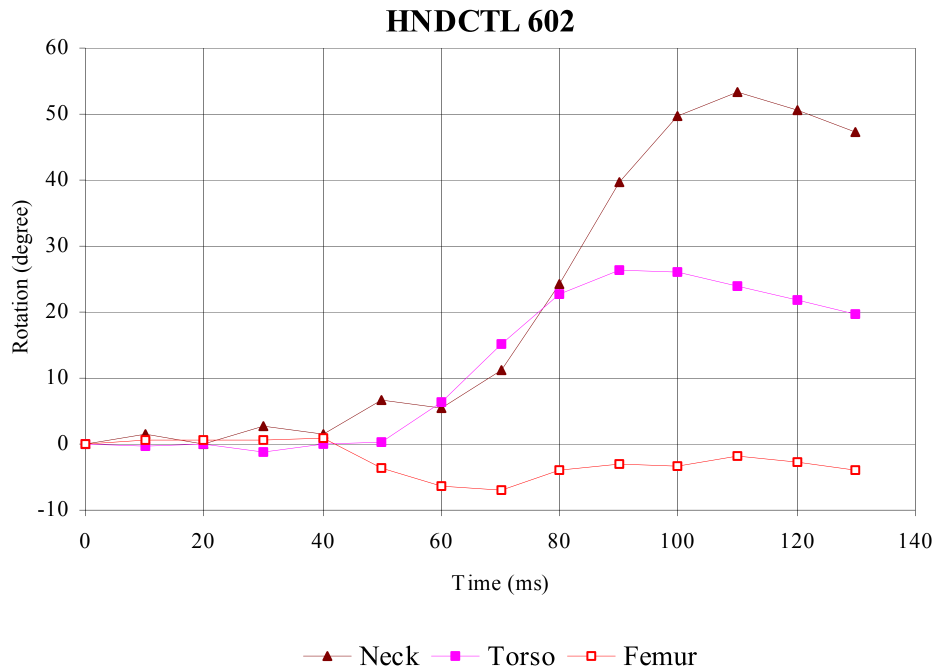
z Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2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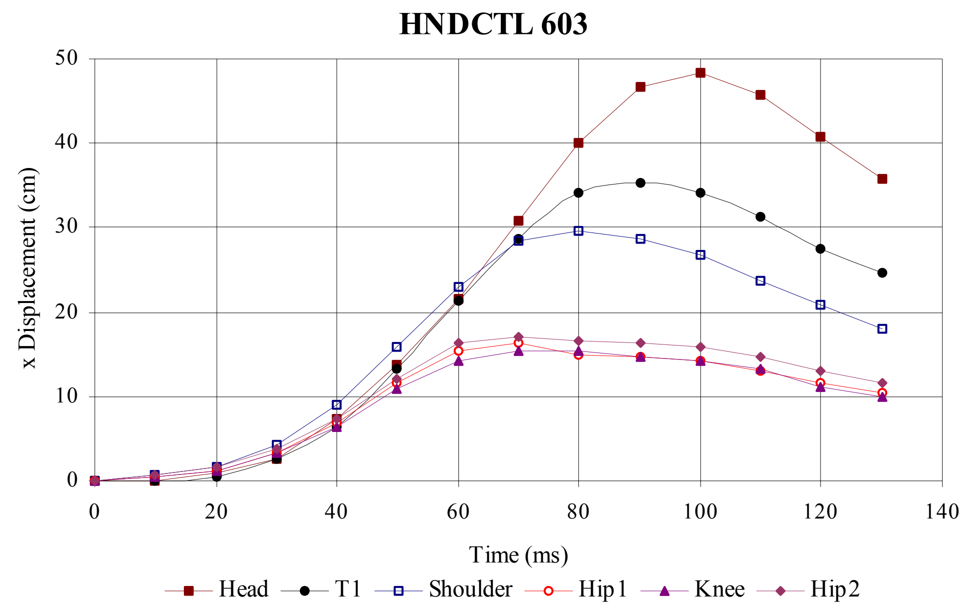
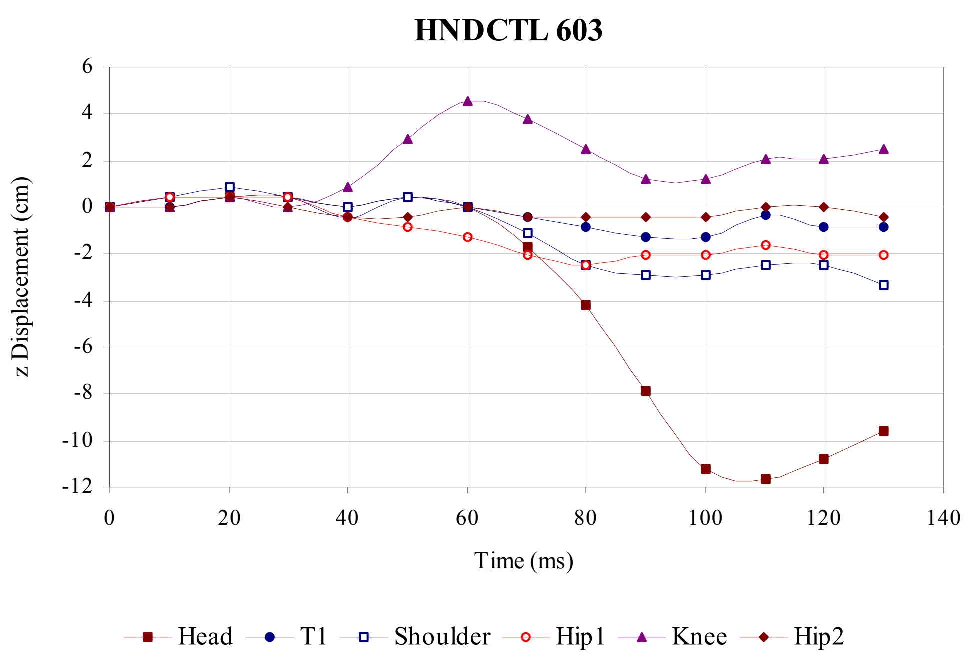
Rotation (degree)
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
Time (ms)
Neck
Torso
Femur


HNDCTL 603
x Displacement (cm)
Time (ms)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
Head
T1
Shoulder
Hip1
Knee
Hip2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z Displacement (cm)
Time (ms)
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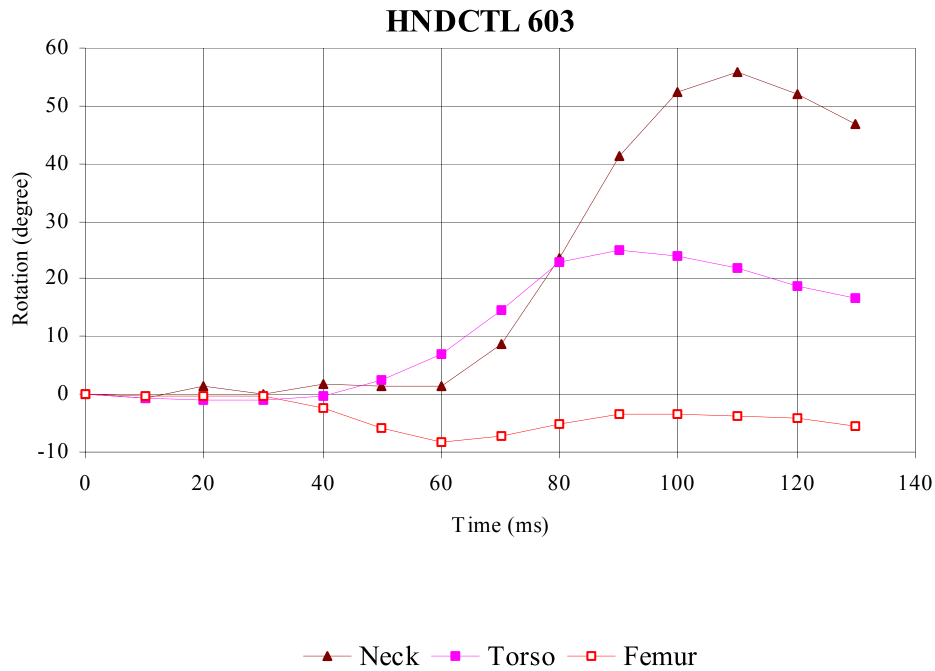
4
2
0
-2
-4
-6
-8
-10
-12
0
20
40
60
80
100
120
140
Head
T1
Shoulder
Hip1
Knee
Hip2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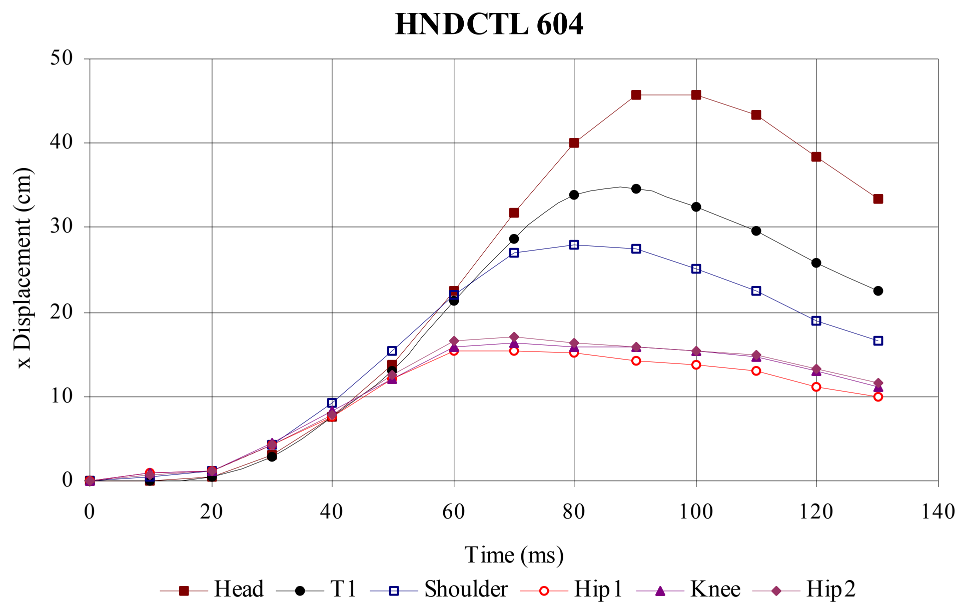
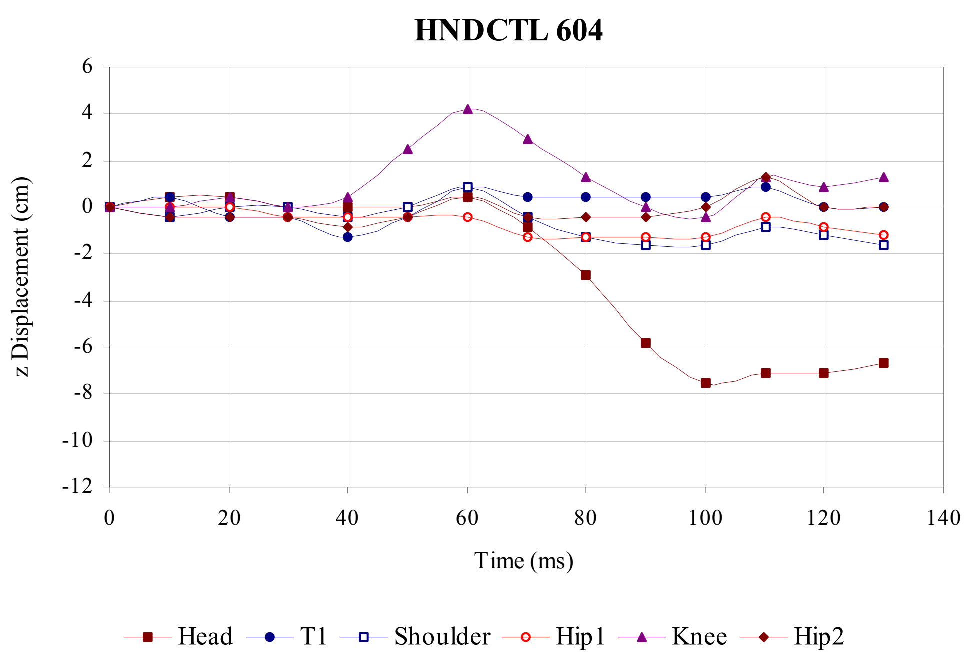
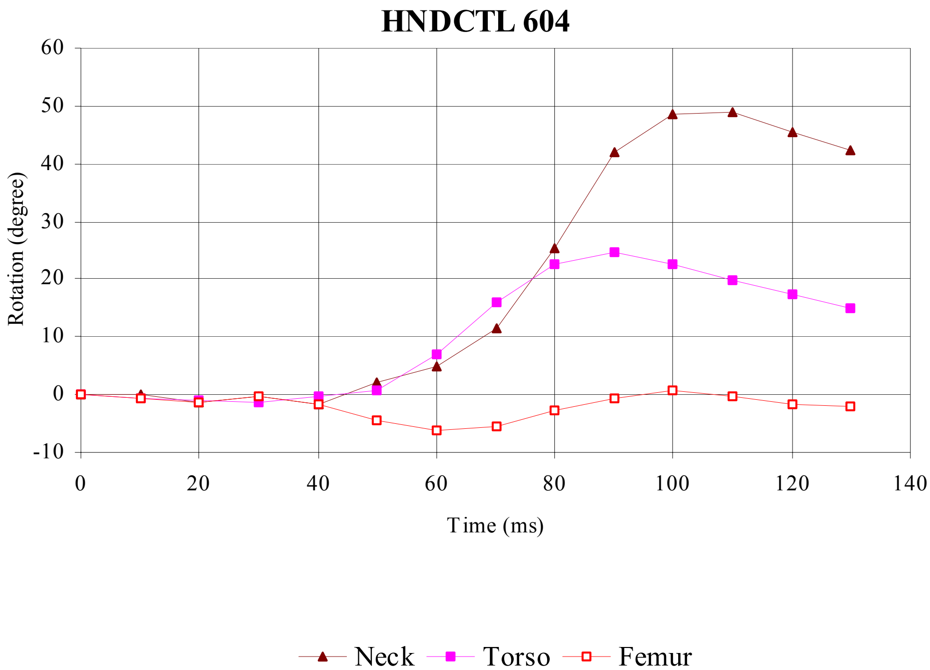
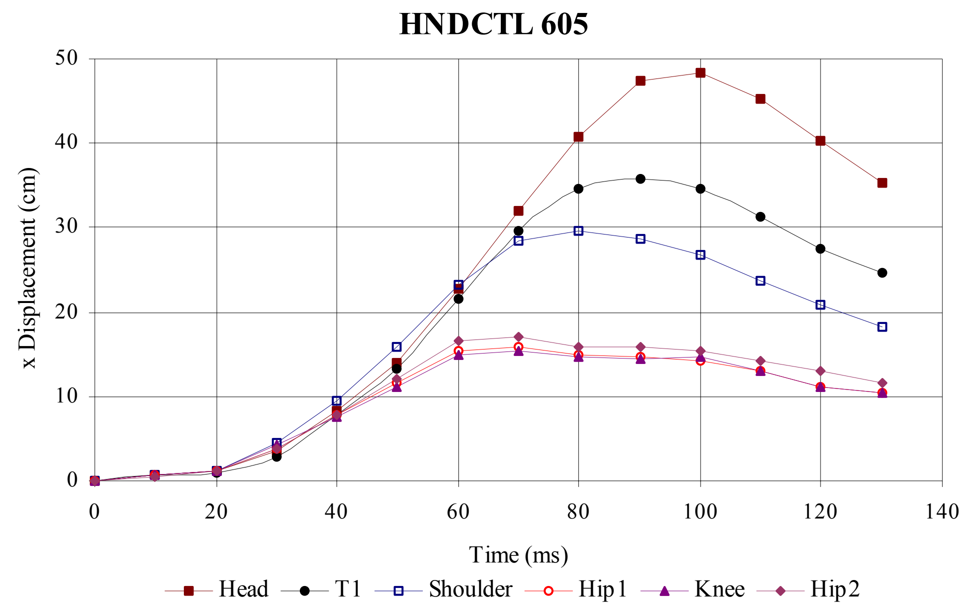
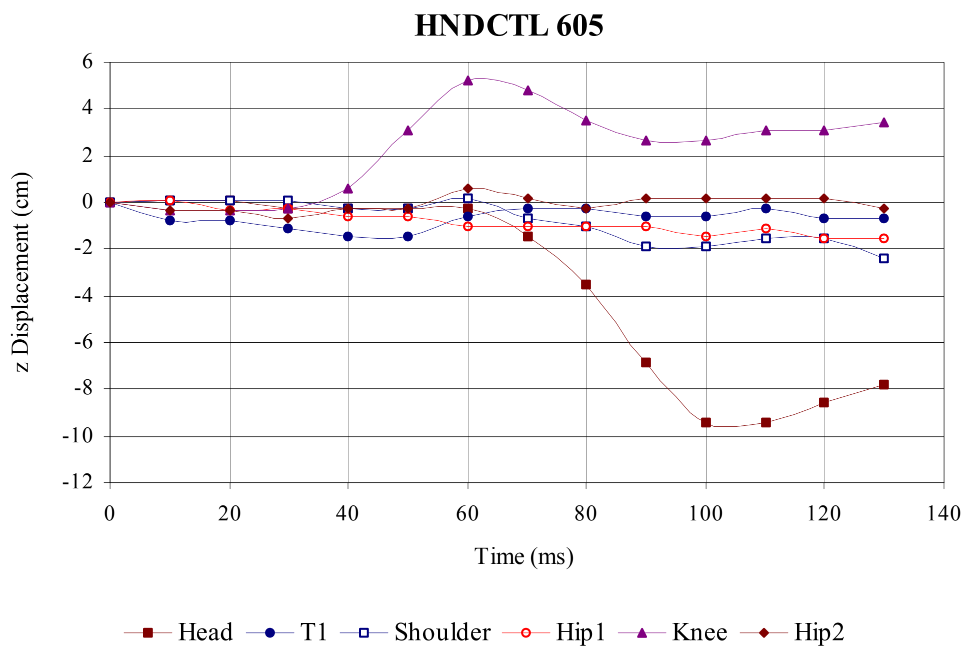
Rotation (degree)
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
Time (ms)
Neck
Torso
Femur


HNDCTL 604
x Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2

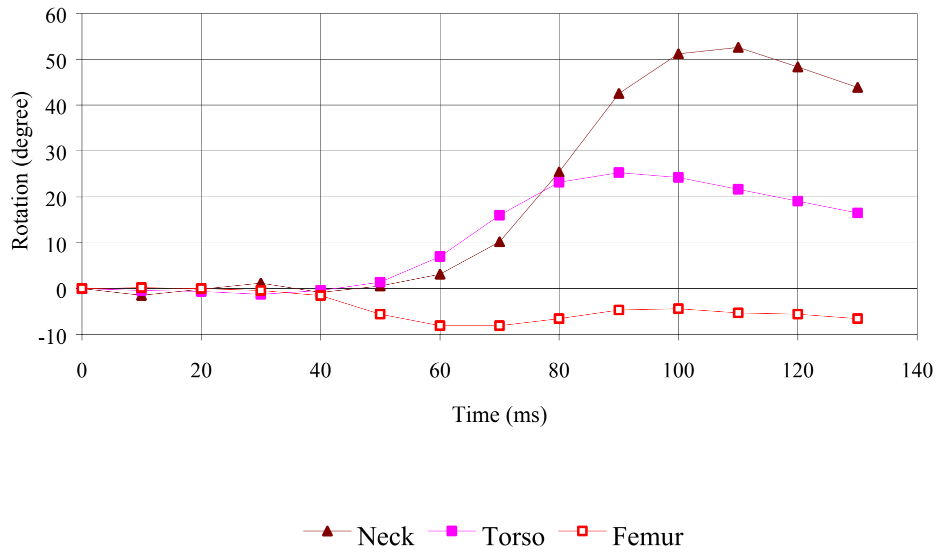

HNDCTL 604
z Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2


HNDCTL 604
60
50
40
30
20
10
0
-10
Rotation (degree)
0
20
40
60
80
100
120
140
Time (ms)
Neck
Torso
Femur


HNDCTL 605
x Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2


HNDCTL 605
z Displacement (cm)
Time (ms)
Head
T1
Shoulder
Hip1
Knee
Hip2

HNDCTL 605



60
50
40
30
20
10
0
-10
Rotation (degree)
0
20
40
60
80
100
120
140
Time (ms)
Neck
Torso
Femur

3.4: DISCUSSION OF RESULTS

In general, test-to-test repeatability for both dummy kinematics and instrument values was very good. Peak sled deceleration varied no more than 1.0 g; impact velocity varied no more than 0.5 km/h. The tests involved no mechanical failures. The upper shoulder belt load cell failed in tests 600 and 602.

The baseline test produced unremarkable results. The knees contacted the knee bolster. The contact registered on the femur load cell force-time history at approximately 60 ms after T_0. The change in load on the left femur was approximately 650 N (146 lbf). On the right, the change was 1390 N (312 lbs). Both values are much below the injury threshold of 10,000 N (2250 lbf). The minor impacts did not damage the knee bolster fascia nor permanently deform the stamped steel backing plate.

Contacts with the Hand Controls

In tests conducted with a hand control installed, the knees contacted the hand control hardware in all cases (Table 14). The left knee hit in all cases, but the contact with the hand control did not change the trajectory of the knee substantially (Fig 4). For most of the controls, the majority of the hardware was located nearer to the left knee. The hardest hit involved the Monarch Mark in test 602. Both layers of chamois were cut 1.5 cm medial of the knee centerline indicating a moderate laceration (Fig 5). Cuts in both layers of chamois suggested that both the epidermis and dermis of an actual driver may have been lacerated. Injury to the deeper dermal layer is associated with a greater chance of infection and scarring *(Pike, J. Automotive Safety, SAE Publications, 1990, p 74).* Chalk marks on the knee and the hand control suggested that the cut was made by the lower edge of a nut (Fig 6). There were no exposed screw threads. Table 15 summarizes the laceration index calculation. In terms of the Abbreviated Injury Scale (AIS), lacerations are assigned a "1- minor injury" classification. The minor knee contact with the hand control in the other tests typically involved the top of the knee rubbing against the underside of the horizontal member to which the handle was attached. The right knee contacted the hand control in the Drive-master (603) and the Sure Grip (604) tests. In test 603, the top of the knee suffered a minor abrasion and cut due to sliding contact with the underside of a linkage joint. The lower edge of the cylindrical joint was finished with a small radius.

Some of the hand control brake rods bent during the impacts. This was caused by the hand pushing the control handle into the dash and the knee contact with the control linkage. The observed deformation was minimal and there were no indications of breakage or separation.

Table 14. Knee Contacts

Test #	601	602	603	604	605
Manufacturer and Model	Wells Engberg	MPS Monarch Mark 1-A	Drive-master Ultralite XL	Howell Ventures Sure Grip	MPD 3500
Operation: Brake/Gas	Push/Twist	Push/Right Angle	Push/Pull	Push/Pull	Push/Right Angle
Left Knee	Contact	Moderate **CUT**	Contact	Contact	Contact
Right Knee			Minor Abrasion + **CUT**	Minor Abrasion	

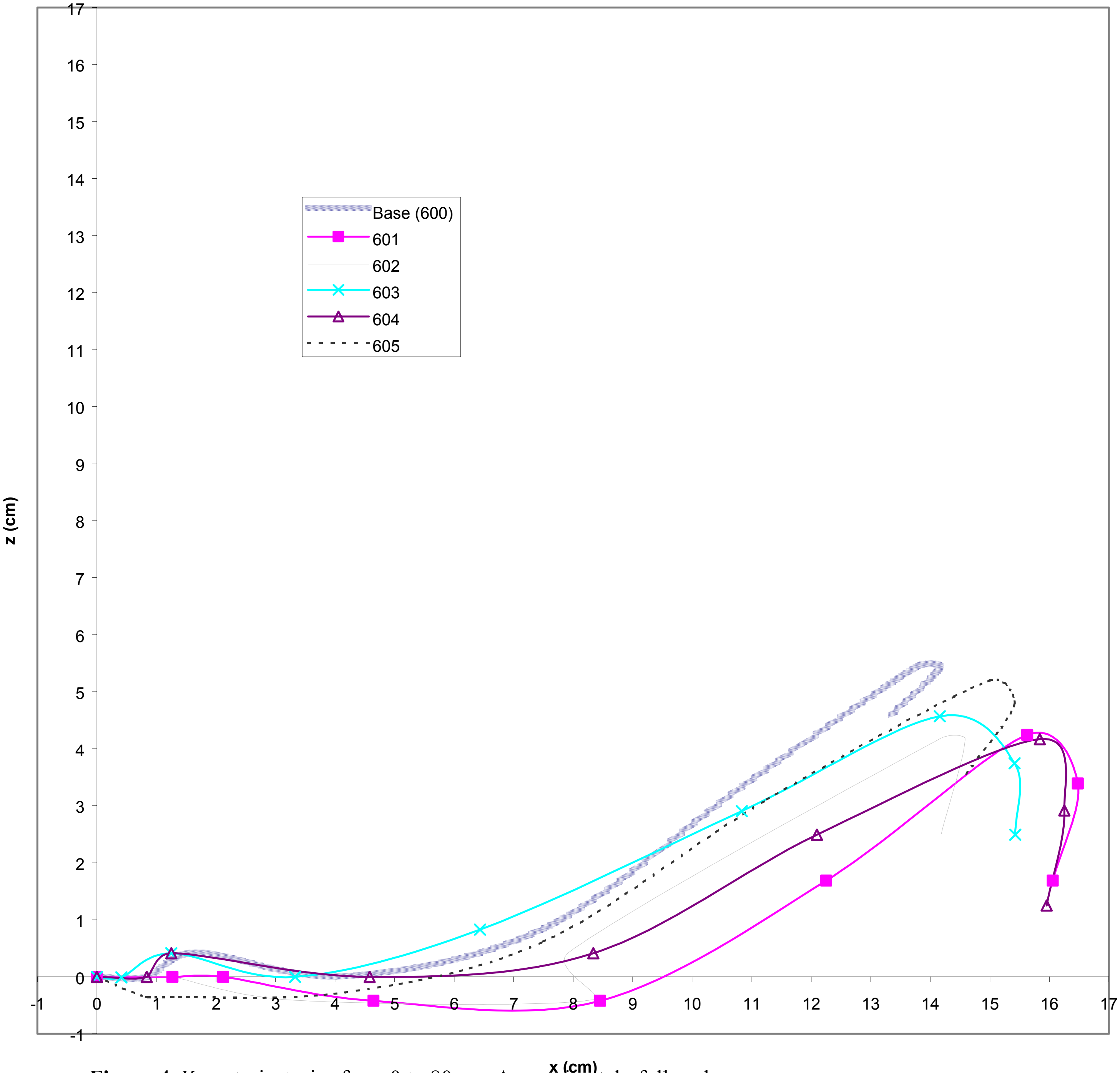


Figure 4. Knee trajectories from 0 to 80 ms. Approximately full scale.

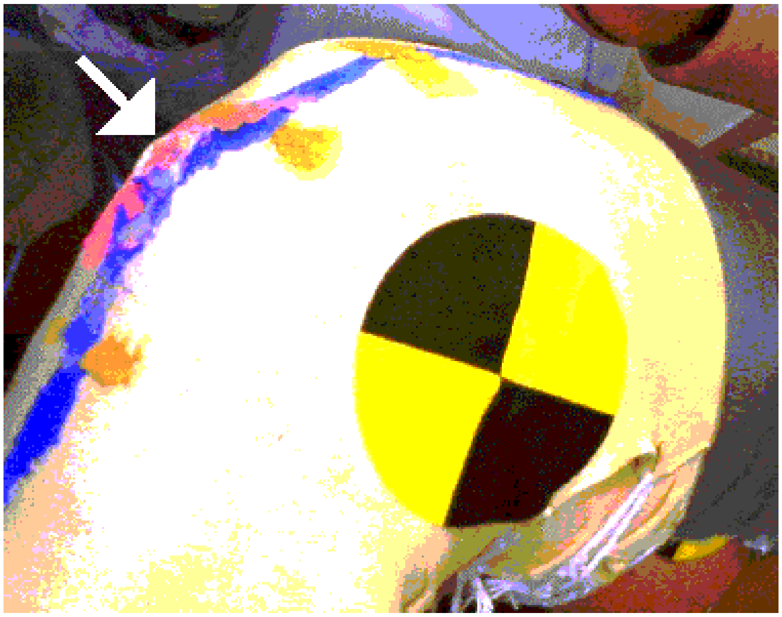


Figure 5. Knee cut in test 602 indicated by arrow.

Figure 6. Edge of nut that caused knee cut on the underside of the hand control.

Table 15. Facial Laceration Index

Test 602 MPS Monarch Mark 1-A Left Knee

Cuts Through Leathers						Cuts in PVC			
Outer Leather			Inner Leather						
# of cuts (N)	Length (S) mm	NS^2	# of cuts (N)	Length (S) mm	NS^2	# of cuts (N)	Length (S) mm	Depth (d) mm	NS^2 d^3
1	13		1	8		0			
A = 169			B = 64			C = 0			

Laceration Index (TLI) = 1 + $\log_{10}$ [1 + 1.16 (A) + 50.8 (B) + 16500 (C)] = **4.54**[A]

Test 603 Drive-master Ultralite XL Right Knee

Cuts Through Leathers						Cuts in PVC			
Outer Leather			Inner Leather						
# of cuts (N)	Length (S) mm	NS^2	# of cuts (N)	Length (S) mm	NS^2	# of cuts (N)	Length (S) mm	Depth (d) mm	NS^2 d^3
1	10		0			0			
A = 100			B = 0			C = 0			

Laceration Index (TLI) = 1 + $\log_{10}$ [1 + 1.16 (A) + 50.8 (B) + 16500 (C)] = **3.07** [A]

Notes: A - The TLI index has a minimum possible value of "1" – no cuts in the outer leather. The upper bound is numerically unlimited. The Wayne State and Corning rating scales suggest a moderate laceration for test 602 and a minor laceration for test 603. See *Jettner E and Hiltner E Facial laceration measurements, SAE Paper No. 860198.*

Injury Criteria

Dummy sensor values and corresponding injury threshold values were affected little by the presence of a hand control. In test 602, the left femur axial load (z-axis) recorded a –1223 N peak attributed to the knee impact with the hand control linkage/knee bolster. In test 604, a negative peak of much shorter duration occurred. The baseline and other tests did not record negative values in the time period in which these peaks occurred (40 – 50 ms after T_0). In test 603, the left distal tibia moment (y-axis) minimum was approximately 15 ms delayed with respect to the moments recorded in the other tests.

Figure 7 illustrates that the injury metrics were below the threshold values. The variation in peak values was not usually related to the presence of a hand control but attributed to expected test-to-test variability. A $\pm$ 30% variation in the tibia index was observed in repeated barrier crash tests *(Crandall, J.R., Funk, J.R., Rudd, R.W., and Tourret, L.J., The tibia index: a step in the right direction, Proceedings of the Toyota International Symposium on Human Life Support Biomechanics, Nagoya, Japan, December 1999)*.

Interpretation of the Study

This study and its conclusions are based on a single crash condition, namely, a 48 km/h (30 mph) simulated frontal crash with a belted driver. Without a lap belt, the standard configuration for an FMVSS 208 barrier test, the knees would have moved forward until restrained by deformation of the knee bolster. We do not know how much the knee bolster modifications would degrade its restraint performance in this test condition. Alternative positioning of the legs and crashes that were not squarely into a barrier would change the movement of knees and their contact with hand control components.

3.5: CONCLUSIONS AND RECOMMENDATIONS

The test results indicate that hand controls and the knee bolster modifications necessary for their installation minimally affected crash safety. The most severe injury was a moderate knee laceration. More generous radiuses on components mounted near the knees would reduce the risk and severity of lacerations. Injury criteria values such as HIC, chest g's, femur load, and the tibia index, were unaffected by the presence of the hand control. The results and conclusions of this study are based on a single crash condition. Hand controls and structurally compromised knee bolsters may perform differently in other crash environments. Modifications to the knee bolster structure should be minimized.

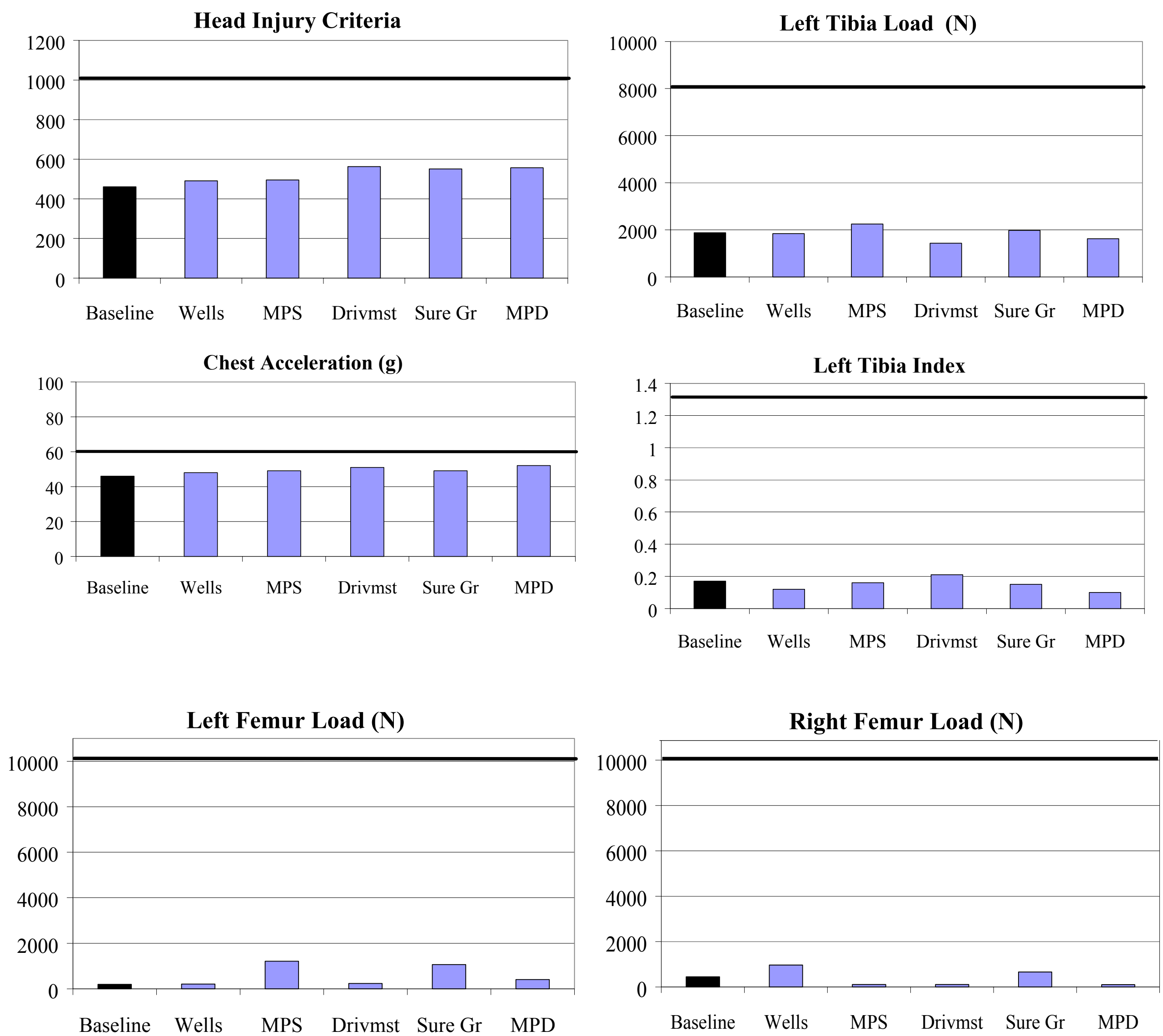


Figure 7. Injury criteria charts. The bold horizontal line indicates the injury threshold value.