PATTERNS OF WHEELCHAIR RESPONSE AND SEATING-SYSTEM FAILURES IN FRONTAL-IMPACT SLED TESTS

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ABSTRACT
Data from 259 frontal impact sled tests of commercial wheelchairs and seating systems were compiled and retrospectively analyzed. These data have general application to the development of additional design and performance requirements for transit wheelchair (WC) standards, and are specifically needed to guide the design and performance specifications of a reusable surrogate wheelchair base (SWCB) that can be used for frontal-impact testing of WC seating systems.

BACKGROUND
Section 19 of ANSI/RESNA WC/Vol.1 *Wheelchairs Used as Seats in Motor Vehicles* (WC/19), establishes performance standards for WCs that are used as seats in motor vehicles in an effort to improve the safety of WC riders in the event of a motor vehicle crash (1). WC/19 is a test of a complete WC, including the frame and seating system, but many WC users need to interchange WC frames and seating to meet their individual needs. Crash testing of each combination of WC frame and seating system is costly and time consuming. Therefore, a method of testing seating systems in isolation to verify their appropriateness for the transit environment is advantageous. Work by Ha, et al., (2) attempted to determine seating system integrity through low-cost, quasi-static testing but these methods do not simulate the dynamic interactions of the occupant/WC system and are not considered to be a suitable alternative to dynamic testing. Another approach is a reconfigurable, reusable surrogate wheelchair base (SWCB) that can accommodate a variety of WC seating systems. An initial prototype has been developed but in order to enhance the performance and the acceptability of the SCWB, it is desirable to match its features to the relevant performance characteristics of commercial WCs.

OBJECTIVES
The general objective was to quantify and document the kinematics, performance characteristics, and failure modes of different types of WCs and WC seating systems during frontal impact tests conducted at UMTRI since January 1998. An immediate objective was to use a subset of these data to guide the design and performance specifications of a SWCB that can be used for dynamic testing of WC seating systems independent of commercial WC bases.

METHODS
UMTRI sled test reports, photographs, and high-speed videos from WC/19 tests sponsored by seventeen WC and WC seating companies were reviewed to establish a set of over forty variables related to frontal-impact tests of WCs and WC seating systems. These variables include physical descriptors of the WC, the test setup geometry, and the size and weight of the anthropomorphic test device (ATD) used, peak ATD excursions, ATD accelerations, peak WC excursions, WC side-view rotational kinematics, WC frame deformation, seating-system failure modes, as well as peak tiedown and restraint forces. Seating system failures were of particular interest for validating the ability of the SWCB to produce similar types and levels of seating system loading as observed with commercial WC frames.

RESULTS

Table 1 summarizes the numbers of tests with specific WC and seating features, including seatback and seatpan failures, and different rotational kinematics. These data are divided into categories by WC type and show that the UMTRI database contains good representation of all three types of WCs: manual, power, and stroller. Seatback failures occurred at a similar but relatively low rate for all three types of WCs, but seatpan failures occurred primarily for the manual WCs. About half of the power WCs demonstrated counterclockwise rotation during impact loading, due to the fact that the WC and occupant combined center of mass was typically higher than the rear securement-point height. Manual and stroller-type WCs typically showed little rotation during impact loading.

Table 1. Summary of WC Database

Data Descriptors/Results		WC Category						All WCs	
		manual		power		stroller			
		#	%	#	%	#	%	#	%
	count (n)	92	35.5	75	35.5	92	29	259	100
user	adult	84	91	69	92	43	47	196	76
type	pediatric	8	9	6	8	49	53	63	24
does WC	yes	67	73	0	0	56	61	123	47
fold?	no	25	27	75	100	36	39	136	53
seatback	planar	71	77	41	55	66	72	178	69
type	sling	20	22	34	45	26	28	80	31
seatpan	planar	85	92	59	79	66	72	210	81
type	sling	6	7	16	21	26	28	48	19
seatback	yes	6	7	5	7	5	5	16	6
failure?	no	86	93	70	93	87	95	243	94
seatpan	yes	25	27	3	4	7	8	35	14
failure?	no	67	73	72	96	85	92	224	86
rotation	CCW	1	1	39	52	3	3	43	17
during	CW	1	1	0	0	2	2	3	1
impact	None	86	94	31	41	84	92	201	77
test	Missing	4	4	5	7	3	3	12	5

Table 2 summarizes the average WC mass in the three WC categories and also indicates the post-test seat width and height, and post-test seatback angle, relative to the original WC dimensions. The average mass of the manual and stroller WCs tested is between 45 and 50 lb, while the average mass of powered WCs is over 225 lb. Inward deformations tend to be small but are greatest for manual WCs, rearward seatback deflections from ATD rebound are largest for the powered WCs, and downward deformations are largest for the stroller-type WCs.

Table 2. Mean Values of WC Mass and Changes in Geometry from Test

Measure	WC type							
	manual		power		stroller		all	
	mean	(s.d.)	mean	(s.d.)	mean	(s.d.)	mean	(s.d.)
WC mass (lb)	50	(9)	229	(52)	45	(13)	100	(88)
Post-Test Geometry								
Seat width (% of pretest)	97.9	(7.9)	99.6	(6.6)	98.4	(5.7)	98.6	(6.8)
Seatback angle (degrees rearward)	2.0	(10.2)	10.7	(23.9)	-0.5	(15.0)	3.5	(17)
Seat height (%of pretest)	98.7	(7.5)	97.2	(7.2)	94.8	(12.8)	96.8	(9.7)

Table 3 lists the percentages of different types of seatpan failures and percentages of three factors that are suspected to have contributed to failures. Many WC seats had more than one failure mode and consequently were counted in more than one failure mode category. Most failures were of the seating attachment hardware rather than a failure of the actual seat surface, with the most common cause being detachment of non-positively locked hardware. Seating hardware that slid or popped off the frame rails during the test is the second most common cause of seatpan failure, while deflection of the seat or WC frame frequently contributed to seatpan failures.

Table 3. Summary of Seat Attachment Failures and Contributing Factors

Attachment Hardware Failure Mode ☐	Count n	Percent of Failures in Category
Detachment of non-positively locked seating	30	65%
Fracture of attachment hardware	7	15%
Hardware slid off or popped off frame rail	21	46%
Downward deflection of WC frame contributed to failure	6	13%
Rear deflection of WC seatback contributed to failure	3	7%
Inward deflection of WC frame contributed to failure	14	30%

DISCUSSION AND CONCLUSIONS

Although the WCs in the UMTRI database are not a representative sample of today's WC fleet, they represent nearly all of the WC/19-compliant WCs available in the North American marketplace. A basic analysis of these data indicate that:

- Seating failures are relatively rare and usually result from attachment hardware failures.
- Much of the attachment hardware that fails is not positively locked to the frame, suggesting that simple design changes could improve seat system crashworthiness.
- Power WCs, that usually have high CGs and low WC securement points, tend to rotate counter-clockwise while non-power WCs tend not to rotate during impact.
- Non-power WCs experience little rotation but account for the majority of WC seatpan failures, suggesting that shear loading is the worst-case scenario.
- Modest WC deformation characteristics that fall between the mean and maximum response levels, such as 10 degrees of seatback deflection, 5% inward deflection, and 5% downward deflection, are sufficient to represent the data.

REFERENCES

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