SAE INTERNATIONAL

Government/Industry Meeting

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The Intersection of Engineering and Policy.

Protecting Vulnerable Populations

Tools for Improving Wheelchair Transportation Safety

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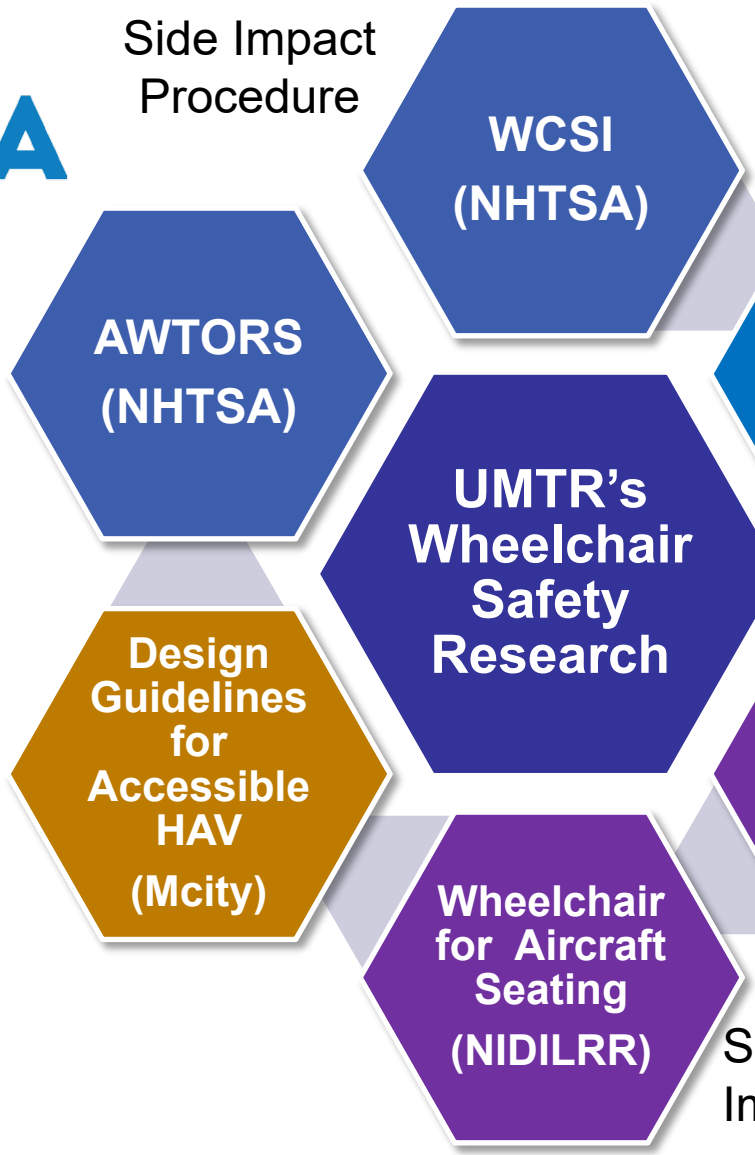
Background

- Approximately 3.6 million people in the United States use wheelchairs (Brault, 2012)
- Majority (87%) have access to a privately owned vehicle (Brinkey et al., 2009) that has been modified for use by occupants seated in wheelchairs.
- Modified vehicles are exempt from many safety standards.
- Highly automated vehicles (HAVs) present an opportunity to design integrated wheelchair seating stations with equivalent level of safety.
- RESNA[1] and ISO[2] include test protocols of wheelchairs and WTORS[3] for frontal crashworthiness at similar conditions to FMVSS No. 213 (20g, 48 km/h)

[1] RESNA: The Rehabilitation Engineering Association of North America
[2] ISO: The International Organization for Standardization
[3] WTORS: Wheelchair Tiedown and Occupant Restraint System

Overview of UMTRI's Wheelchair Projects



Wheel Chair Side Impact Procedure

Automated Wheelchair Tiedown and Occupant Restraint System

Integration of standards, research, and practice

AWTORS prototypes and additional volunteer testing on electric vehicles

Parametric wheelchair geometry and FE model

Safety designs in aircraft Impact conditions

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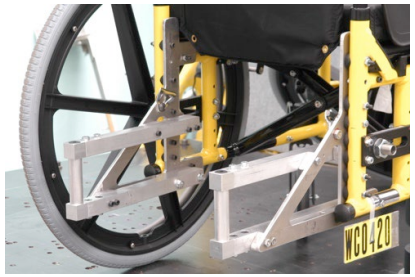
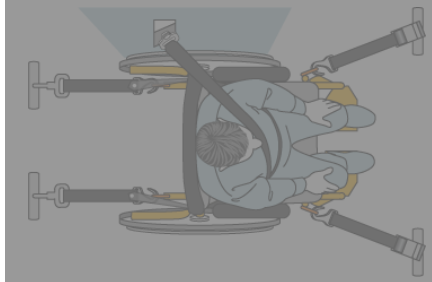
Development of AWTORS

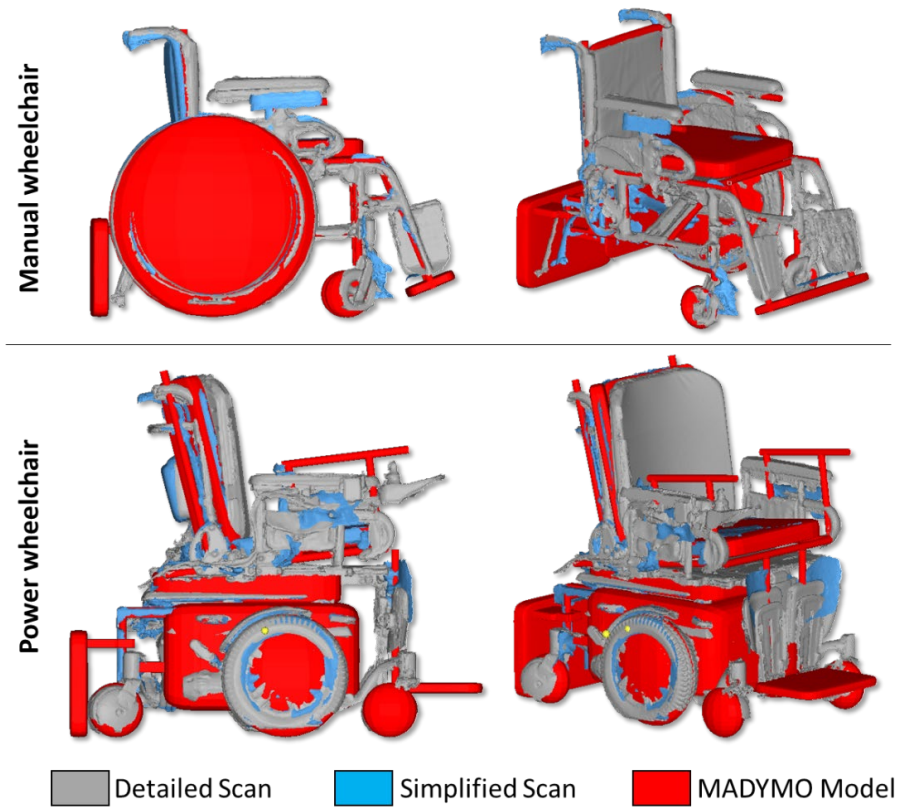
Automated Wheelchair Tiedown and Occupant Restraint System

- Develop an automated WC docking station that would allow safe, independent docking of occupants seated in WCs
- Develop an automated belt-donning system WC users
- Computational modeling, sled testing, and volunteer evaluation
- Both frontal and side impacts

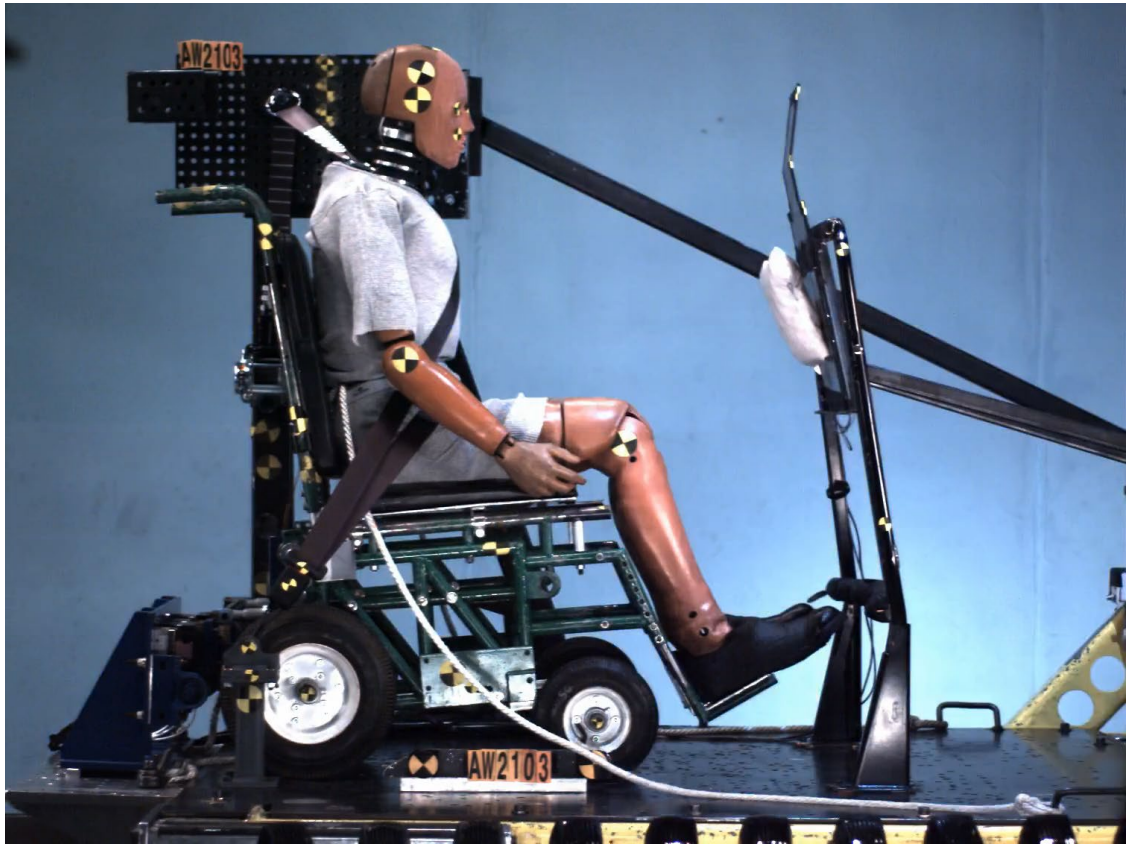
UDIG	4-pt Strap Tiedown	Traditional Docking
Independent	Not Independent	Independent
		
		

Frontal Crashes

- MADYMO Wheelchair Models



- SCaRAB airbag reduces frontal injury risk, particularly with suboptimal geometry



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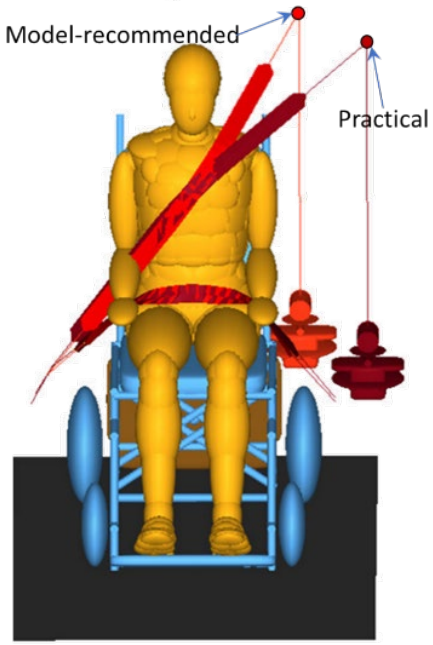
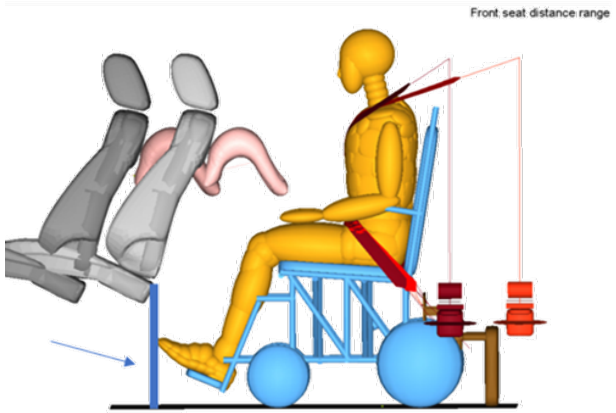
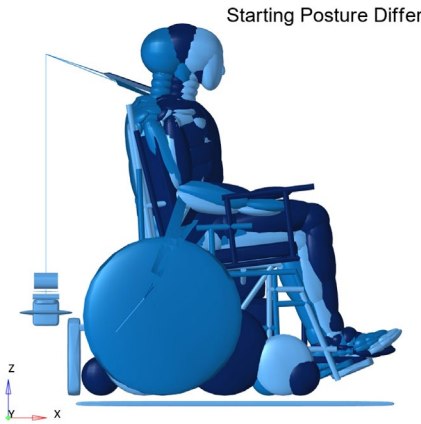
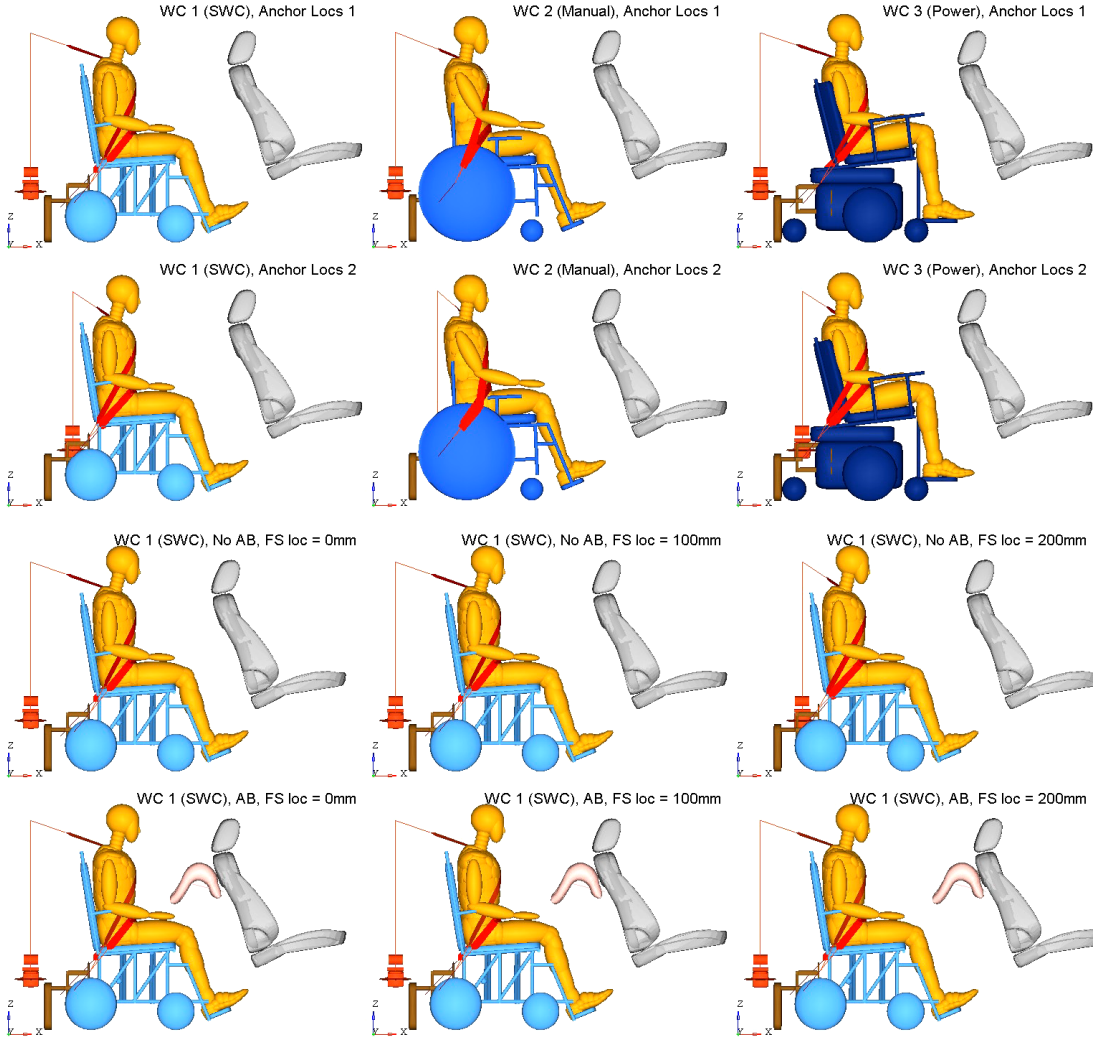
Frontal Crashes (Continued)

- Parametric studies with hundreds of simulations









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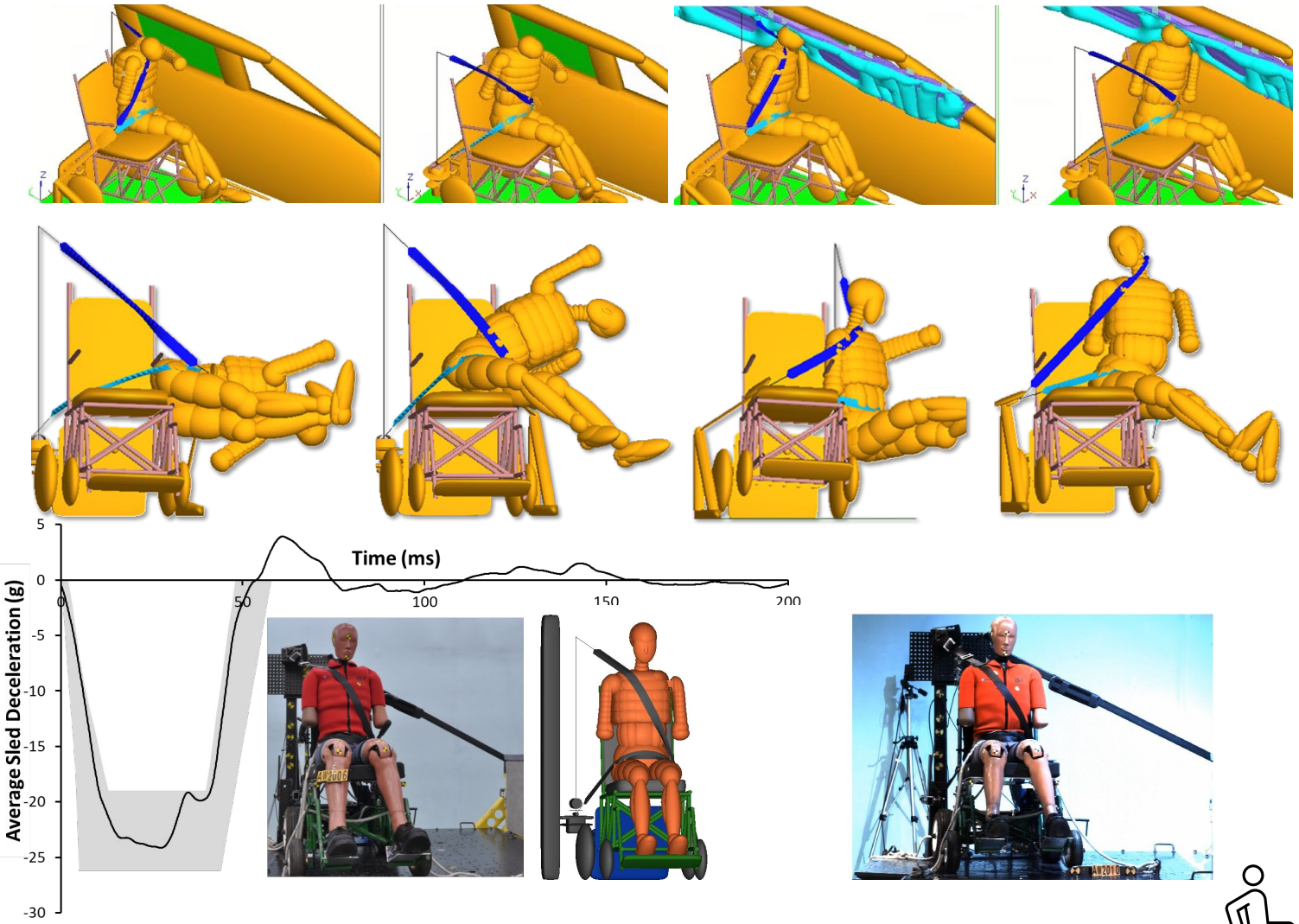
Side Impact Crashes

- Traditional belt and curtain airbag provide reasonable protection in nearside impact without intrusion
- Far-side impacts pose design challenges for wheelchair-seated occupants
- New CATCH (Center Airbag To Contain Humans) design provides containment in farside impacts

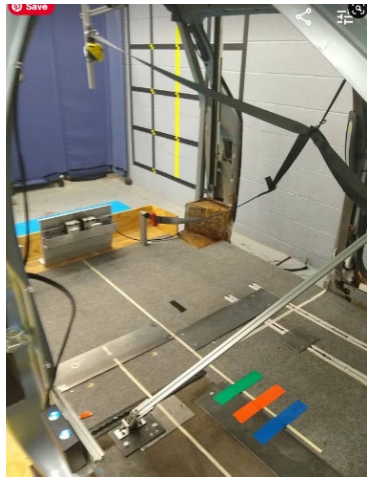


CATCH: Center Airbag To Contain Humans

AW2107	AW2108	AW2110	AW2116	AW2117	AW2118
CATCH-V / Wide tether attachment / Long tether	CATCH-H / Wide tether attachment / Long tether	CATCH-V / Wide tether attachment / Shorter tether	CATCH-V' / small tether attachment / Shorter tether	CATCH-V'-window small tether attachment / Shorter tether	CATCH-V' / small tether attachment / Shorter tether
					
					

Volunteer Evaluation

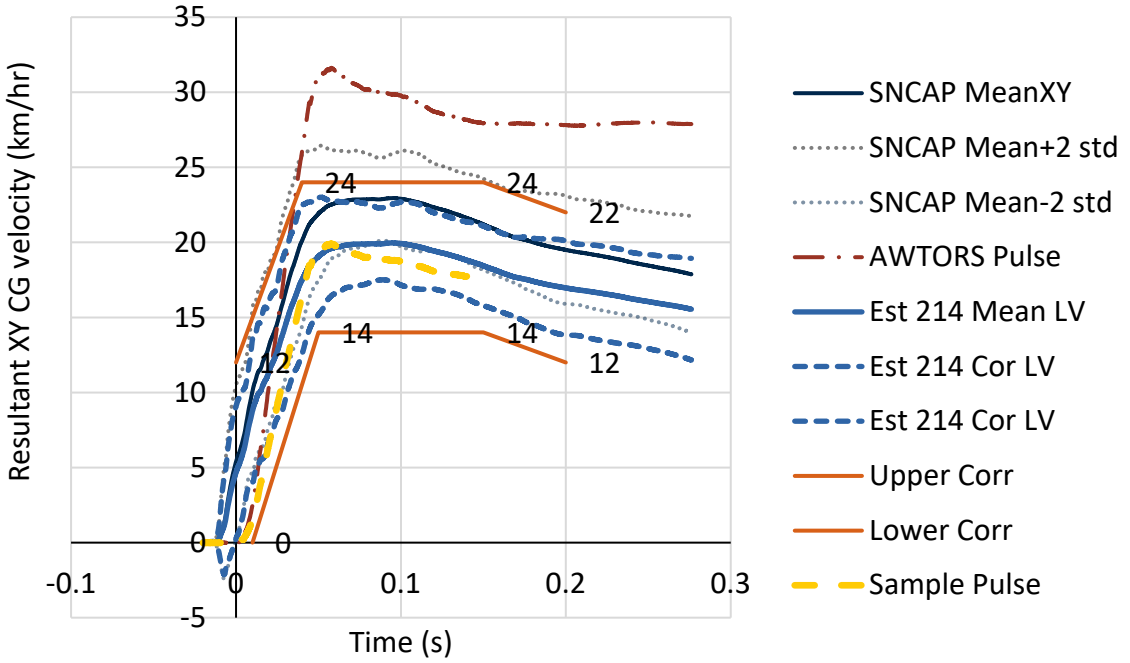
- 8 volunteers who were regular WC users
- 2 vehicles, each with 2 stations x 2 seatbelt geometries
- Manual and power WCs equipped with UDIG
- Automated belt donning system
- Post-trial surveys and video analysis to assess belt fit, usability

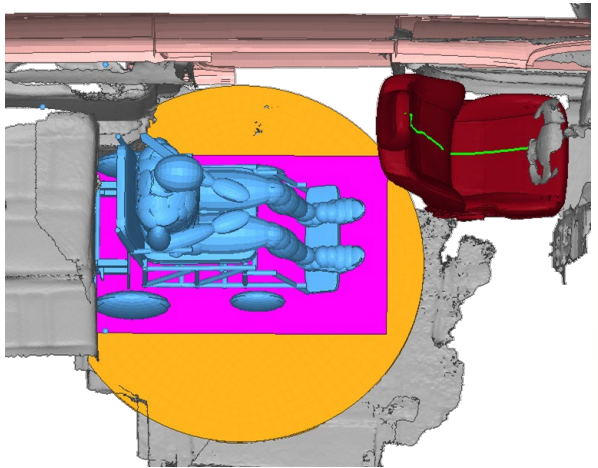


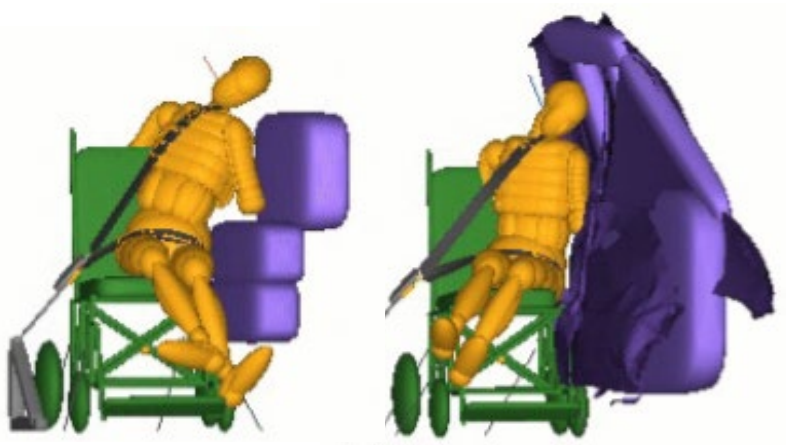
Development of WCSI Test Procedures

Wheelchair Side Impact Test Procedures

- Develop relevant crash pulse
- Locate wheelchair station
- Identify seatbelt conditions
- Simulate vehicle intrusion
- Modify SWCB test fixture for side impact
- Write test protocols
- Create performance criteria





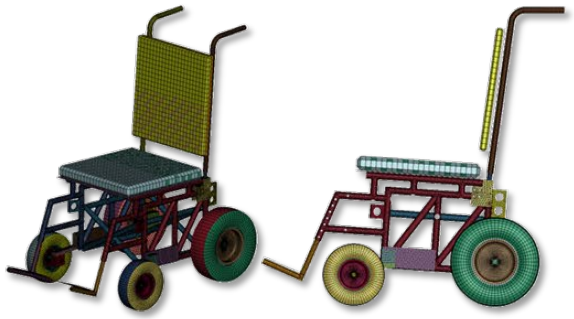
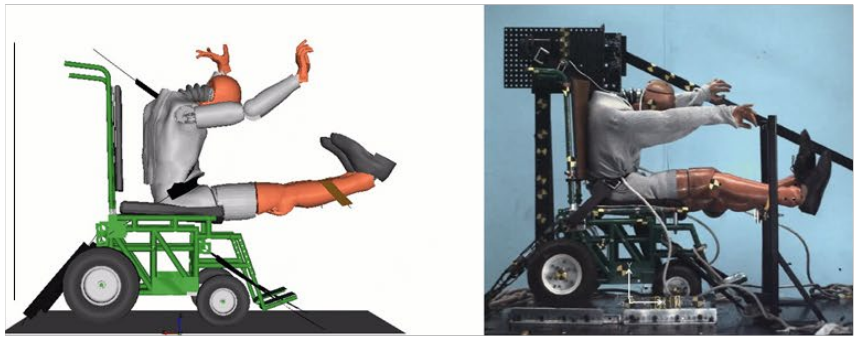
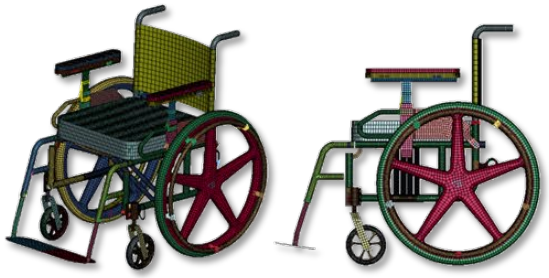
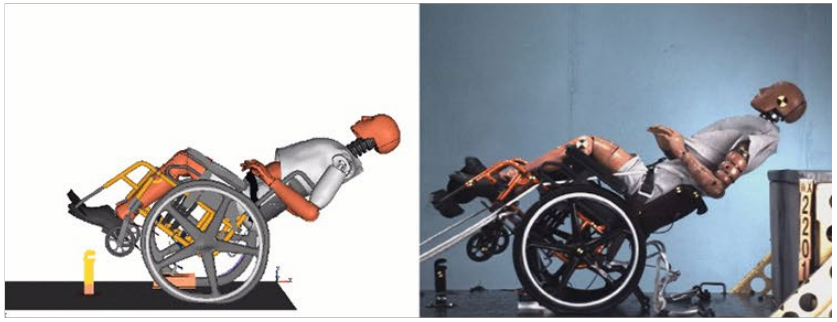
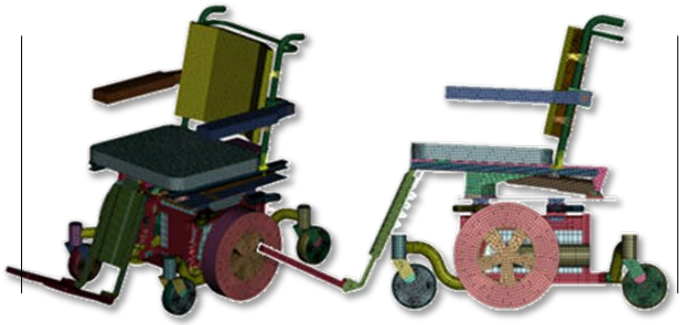
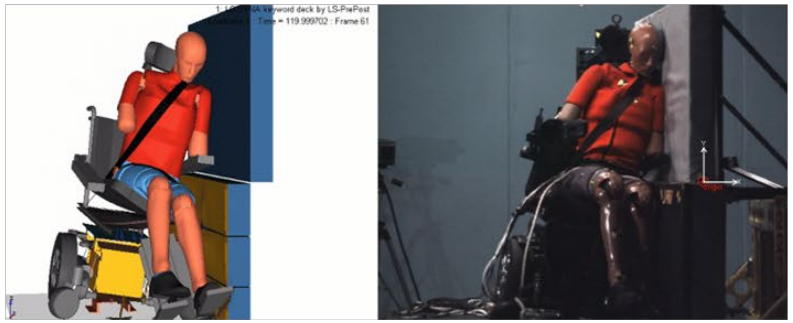


Development of WCSI Test Procedures

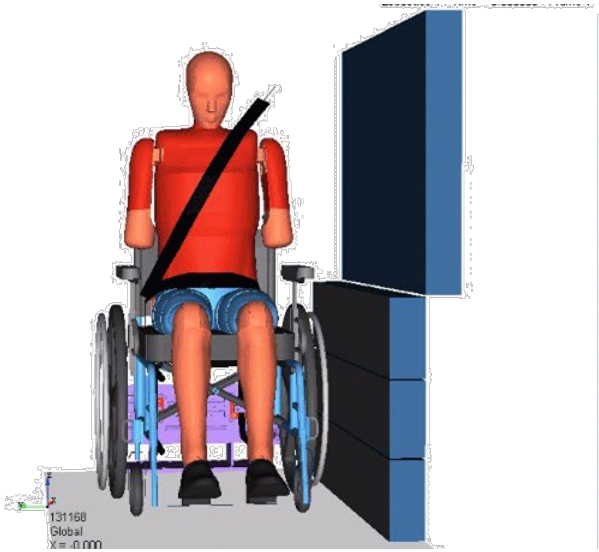
Wheelchair Side Impact Test Procedures

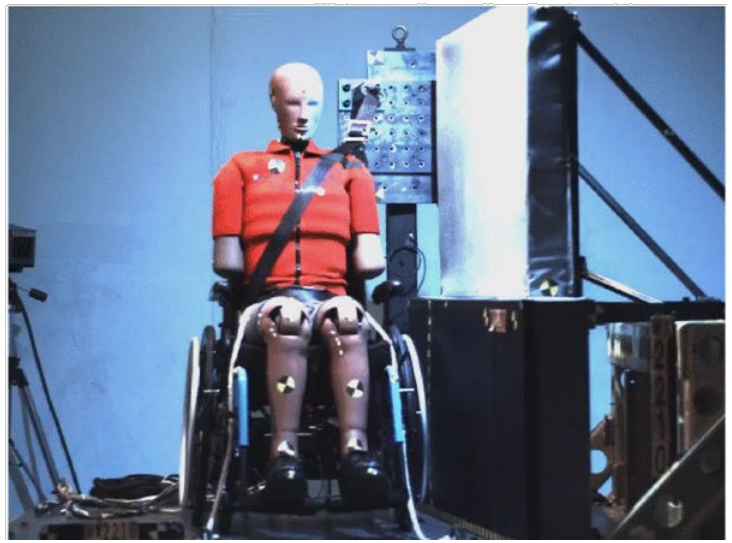
- **Elements needed:**
  - Wheelchairs that retain structural integrity during lateral impact and keep the occupant positioned appropriately relative to vehicle side structures, seatbelt systems and/or airbags
  - Tiedowns that secure wheelchairs under lateral loading and limit lateral excursion
  - Occupant protection systems for nearside and farside impact
- **Consider needs of consumers, wheelchair manufacturers, WTORS manufacturers, and vehicle manufacturers**
  - Wheelchair standards are voluntary
  - No established method of simulating side impact on a sled
  - Minimizing mass a high priority for manual wheelchair users

FE Wheelchair Models

	Physical Chair	FE Model	Validation Example
Surrogate Wheelchair Base SWCB			
Manual Chair Ki Mobility Catalyst 5			
Power Chair Quantum Rehab Q6 Edge 2.0			

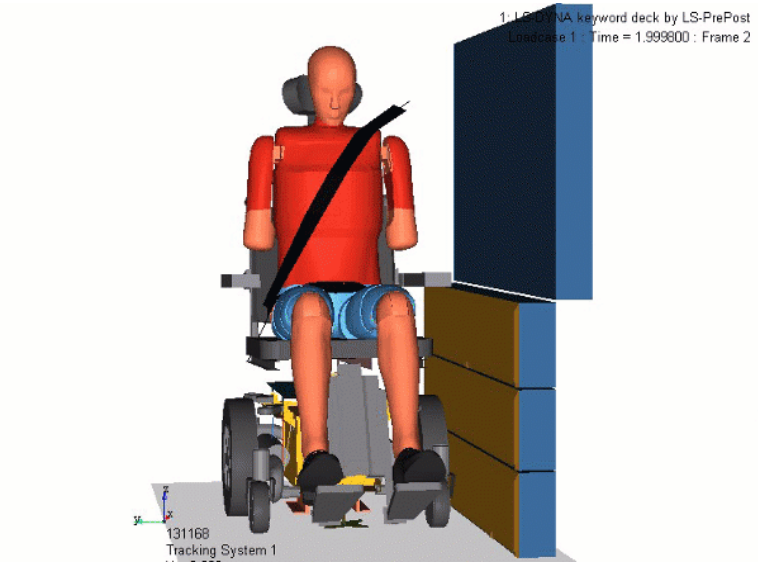
Wheelchair Model and Side Impact Test Validations

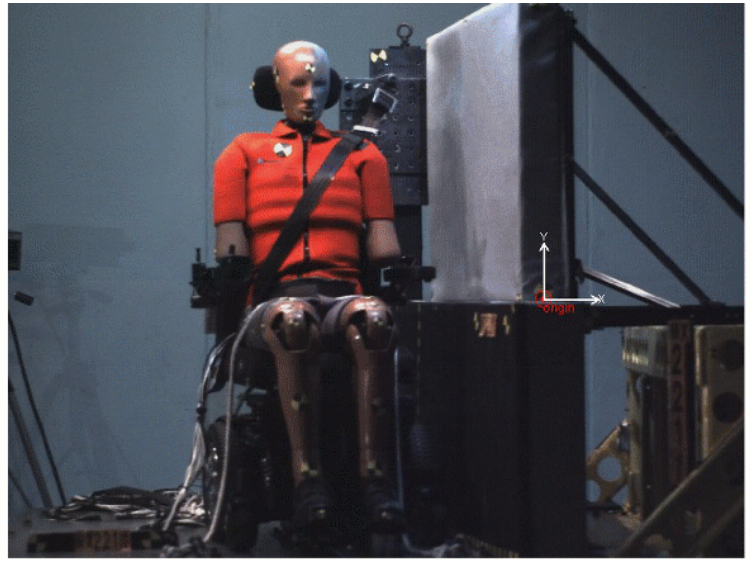




Manual Chair
Ki Mobility
Catalyst 5

Power Chair
Quantum Rehab
Q6 Edge 2.0





Inclusive Design Challenge

- UMTRI+May Mobility selected as one of 10 finalists in DOT Inclusive Design Challenge; iterated on AWTORS prototypes and additional volunteer testing on electric vehicles

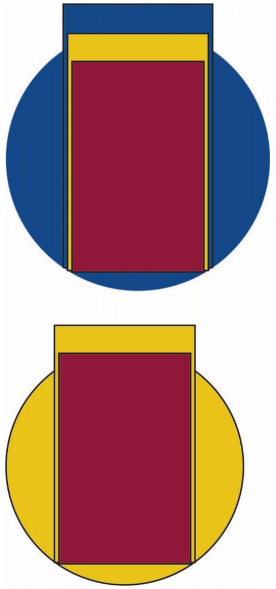
Design Guidelines for Accessible Automated Vehicles

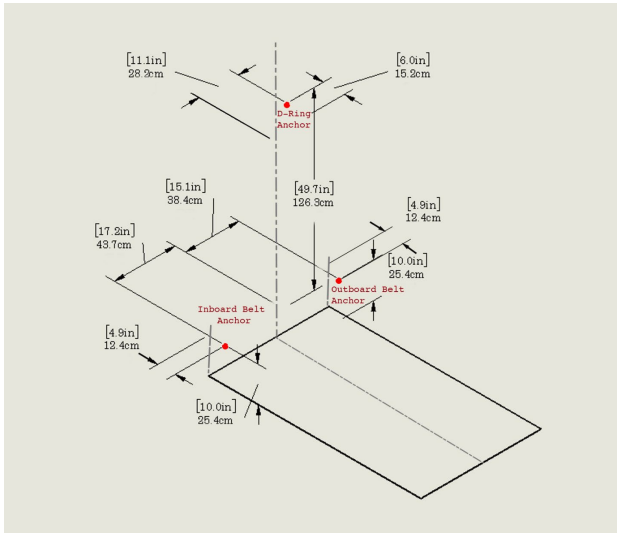
- **Develop design guidelines to ensure that HAVs are accessible for people with mobility disabilities**
  - Reference relevant information from existing regulations and recommended practices
  - Add clarifying material (such as illustrations) where helpful
  - Develop new procedures where needed

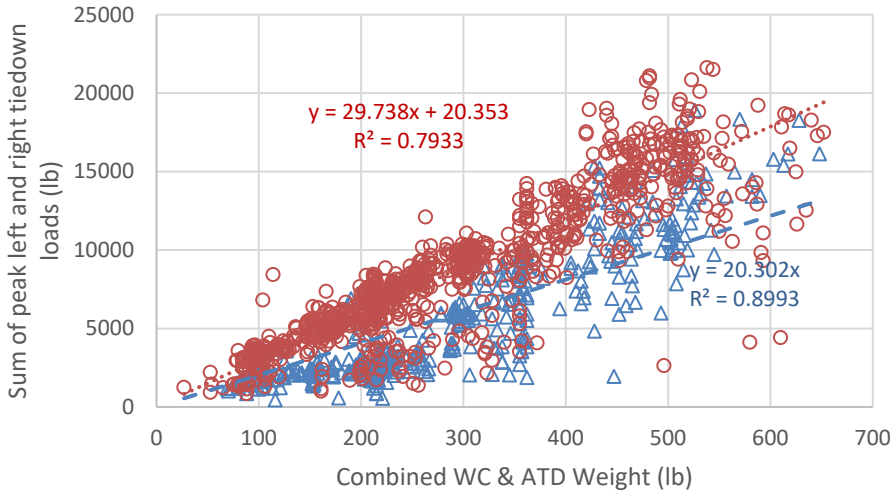
- **Topics**
  - Doors, ramps, lifts, access routes
  - Wheelchair station location, dimensions
  - Wheelchair securement
  - Occupant protection systems
- **Strategy**
  - Good, Better, Best recommendations for each topic
  - Good-our interpretation of minimum ADAAG requirements
  - Better, Best from recent research, requirements for buildings

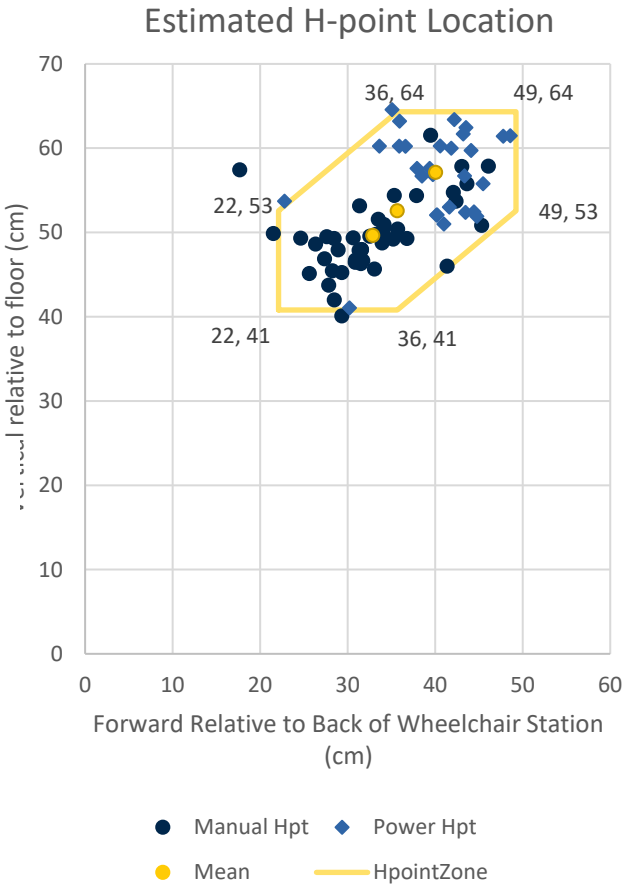
Design Guidelines Highlights

- **People strongly prefer ramps to lifts!**
  - Sill height needs to be <10 in to allow feasible, legal ramps
- **Link to CVS Simulator app that simulates color blindness to check your communication**









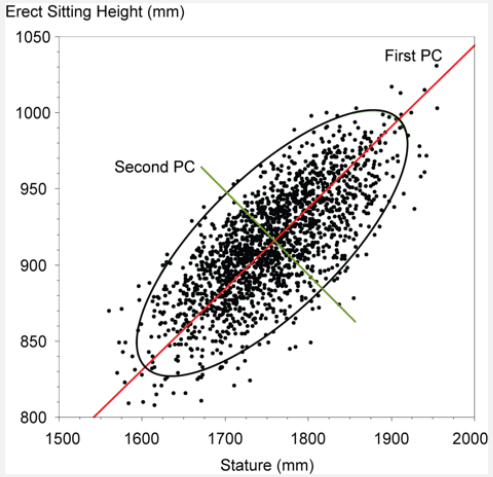
Wheelchair Tools: Parametric Wheelchair Models

Data Collection

- Three dimensional measurements of wheelchairs with/without participants
- Key dimensions extraction
- Key points (landmarks) digitization

Statistical Analysis

- Statistical analysis on extracted dimensions using a principal component analysis
- Representative dimensions determination

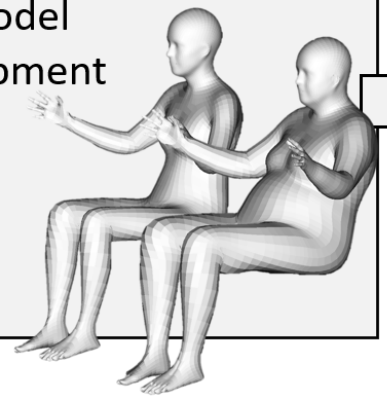


Virtual Models

- Baseline wheelchair model development
  - Representative model generation by modifying baseline model

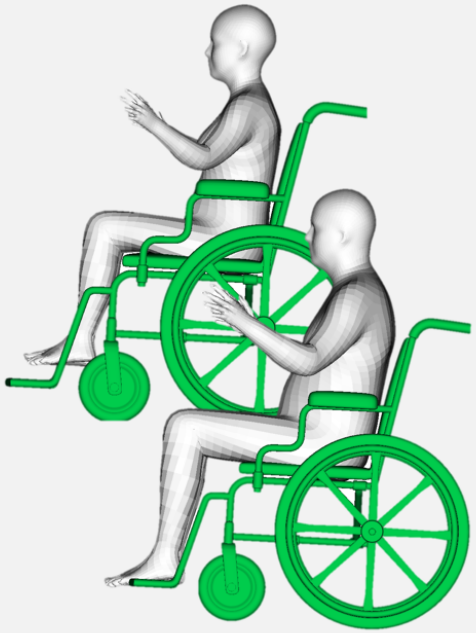
User Models

- Parametric wheelchair user model development



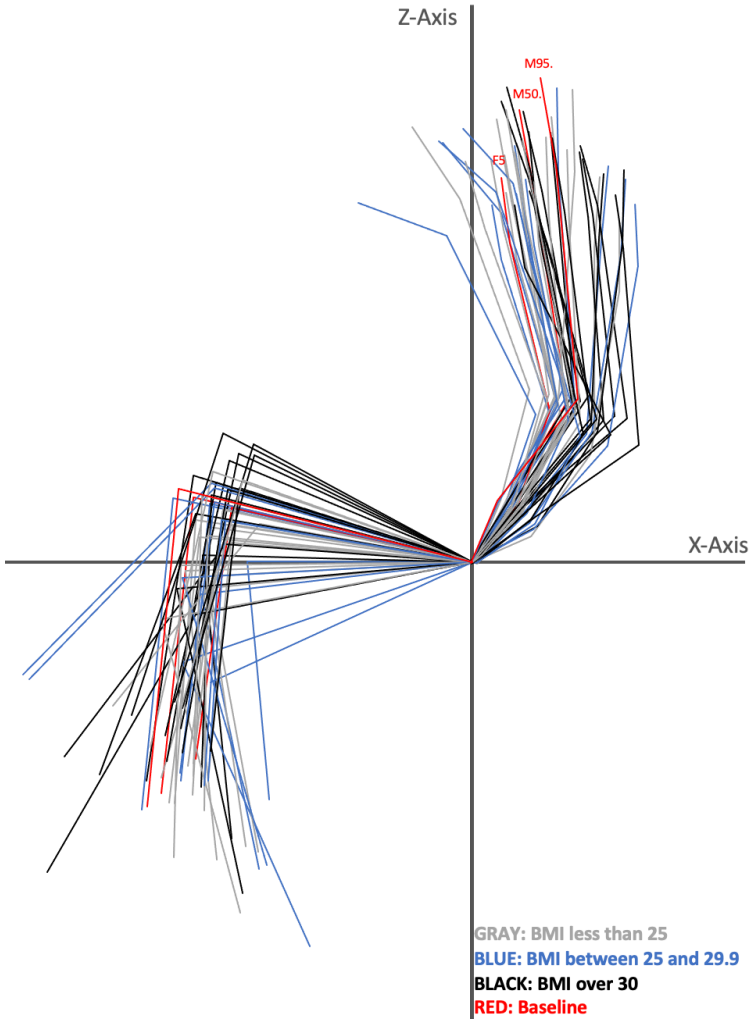
Final Model

- Combined statistical wheelchair and user model development
- Publish the models on a website

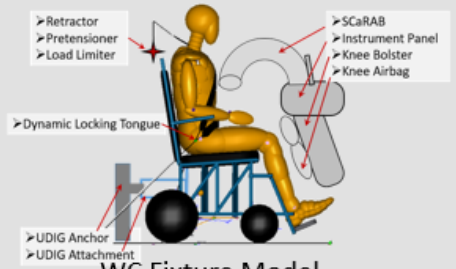


Wheelchair Tools: Occupant Posture in Wheelchairs

	Male	Female
n	21	27
Manual Chairs	19	14
Power Chairs	2	12
Scooters	0	1
Age	54.4 ± 20.0	55.0 ± 15.9
Height (cm)	170.8 ± 15.5	158.8 ± 12.2
BMI	27.3 ± 6.1	32.6 ± 12.7



Wheelchair Tools: Finite Element Models



WC Fixture Model


Manual WC Model


Power WC Model

Model Development

New MADYMO Models

- Make current UMTRI WC models parametric based on the statistical geometry models developed in Task 2.

New FE Models

- Develop new parametric FE WC models considering WC geometry and weight variations.

Model Validation

Frontal and Side Impact Tests

- Validate a sub-set of the WC models against frontal and side impact tests with varied WC size and occupant size.
- Sled tests from current NHTSA projects with varied WC sizes.
- Sled tests from Task 1 with varied WC fixture sizes.

Model Demonstration

Parametric Simulations

- Consider a WC design through the parametric MAYDMO WC model
- Consider human size and shape variations
- Consider AV design variations
- Conduct crash simulations in frontal and side impacts
- Evaluate the benefit of using diverse wheelchair models for safety designs


Wheelchair Variations in Task 2


Crash Tests in Task 1 & Past


Human Diversity & Vehicle Variation

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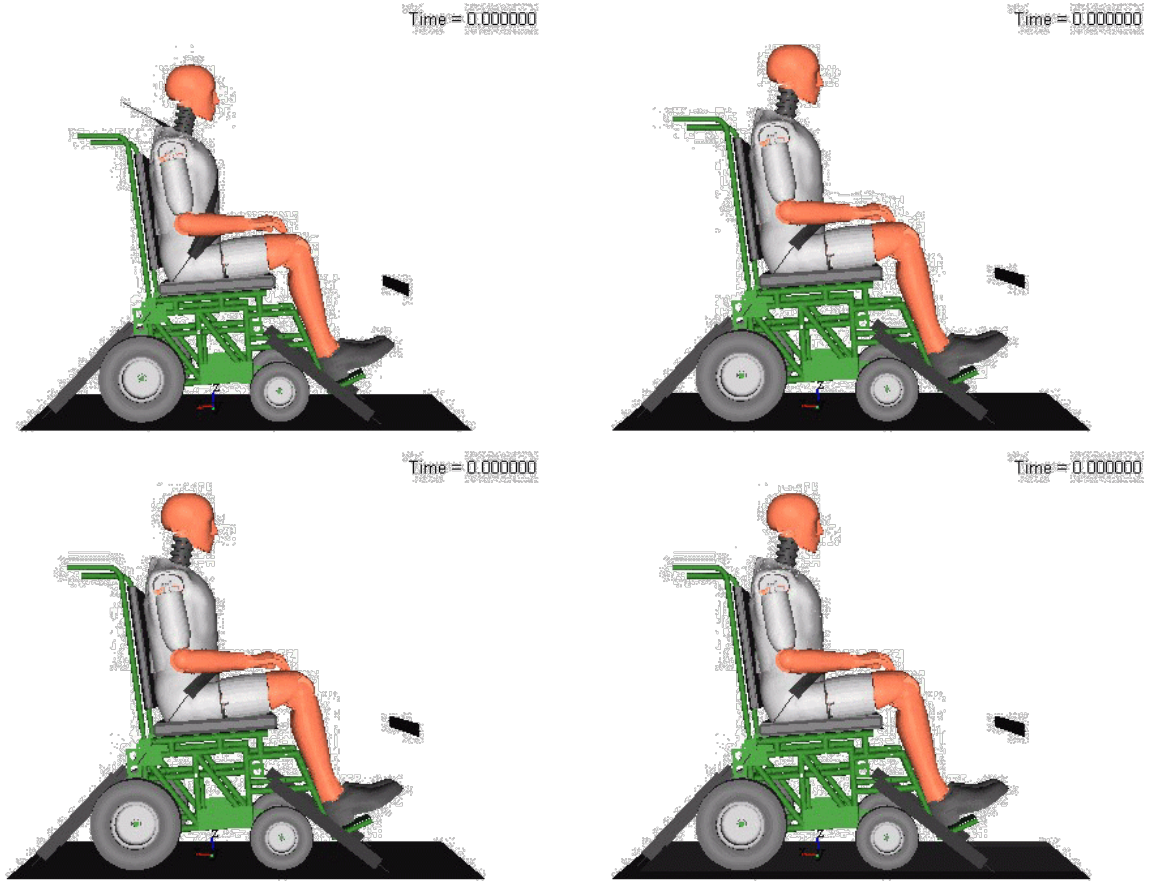
Evaluating Crashworthiness of Wheelchairs for Potential Use as Aircraft Seating

- A 2021 National Academy of Sciences (NAS) consensus document determined that it should be technically feasible on most commercial aircraft to allow passengers to use their wheelchairs.
- Next step: determine if wheelchairs meeting current RESNA standards for use as seats in motor vehicles (WC19-compliant wheelchairs) can meet the FAA crashworthiness requirements for airline seats.
- Adapt FAA test procedures to evaluate wheelchairs under frontal, vertical, and static test conditions



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More Information

- Travelsafer.org
- Standards, publications, research
- Info about UDIG

Recent Research

Evaluating Wheelchair Crashworthiness for Potential Use as Aircraft Seating

Developing Tools to Assess Vehicle Crash Safety for Occupants in Wheelchairs

Development of Wheelchair Side Impact Test Procedures

Inclusive Design Challenge

Design Guidelines for Accessible Automated Vehicles: Mobility Focus

Evaluation of Wheelchair Tiedown Loads

Volunteer Evaluation of AWTORS

Development of Automated Wheelchair Tiedown and Occupant Restraint System

Wheelchair Occupant Studies

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