Wheelchair Tiedown and Restraint System Simulations and Standards

Lauren M. Graffeo[1] and Beth A. Todd[2]

Abstract

The increasing number of wheelchair users that are accessing both public and private transportation has led to a large increase in the need for research and standards associated with the safety of wheelchair structure, tiedowns and restraint systems for use in motor vehicles. This has prompted a number of organizations and educational institutions to begin testing various aspects of the transportable wheelchair and securement configurations using sled test and Articulated Total Body (ATB) simulations. These methods provide a means for referencing typical loading constraints and assessing occupant safety. This project has been established as an integration of current biomechanics technology and software with educational knowledge of mechanical and dynamic systems in an effort to validate and test various wheelchair tiedown and occupant restraint system configurations.

Introduction

Transportation is an integral part of an individual's independence and participation in society. Since the advent of the Americans with Disabilities Act (ADA) in 1990, an increasing number of wheelchair users are seeking public and personal transportation as a means of accessing employment, recreation, and other daily activities. Many of these individuals are not able to transfer from their wheelchairs to regular vehicle seats and, therefore must remain seated in their wheeled mobility device (WMD) during transport. Regular vehicle seats and restraint systems are required to uphold a particular level of safety and crashworthiness as dictated by the Federal Motor Vehicle Safety Standards (FMVSS). The securement, placement and design of these components are carefully considered to maximize occupant safety and reduce injury. For those passengers that remain in their wheelchairs during transit, the wheelchair and the wheelchair tiedown and occupant restraint system (WTORS) must serve in the place of these regular components, and therefore must provide the passenger with the same level of occupant safety. [4,5] For this reason, the need for standards governing WMD transportability, crashworthiness, and securement has increased.

Much of the research in recent years has focused on determining the effects of various types of wheelchair tiedown and restraint systems on WMD stability and occupant safety. [2] There are currently two main types of wheelchair tiedown systems in use: the belt type and the auto-docking system. Belt systems employ three or four belts that attach to the wheelchair frame and require an attendant to help secure the wheelchair in place. Auto-docking devices employ two mating parts, one of which is attached to the wheelchair frame, and the other that is located in the vehicle. This type is perhaps more desirable for wheelchair users because they do not

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[1] Undergraduate student, Department of Mechanical Engineering, Box 870276, The University of Alabama, Tuscaloosa, AL 35487-0276.

[2] Assistant Professor, Department of Mechanical Engineering, Box 870276, The University of Alabama, Tuscaloosa, AL 35487-0276.

require additional assistance from an attendant. Both systems, however, are problematic, especially for public transportation, because of the lack of a universal method of attachment and securement location points. Other methods, such as wheel and frame clamps, are also sometimes used, but have been found ineffective in meeting crash protection requirements. Voluntary standards for wheelchair tiedowns began appearing in the 1980's; however, uniform standards have only recently been adopted by such organizations as ISO and SAE. [4,5]

The current standards associated with wheelchair tiedowns are a culmination of the research of many organizations over the past decade. Research in this area has, for the most part, been based on crash test evaluations similar to those already used in vehicle safety testing. In lieu of expensive full vehicle crash tests, a laboratory impact sled is accelerated along rails to simulate actual crash situations. [3] In general, the sled is equipped with an SAE J2249 WTORS surrogate wheelchair and 50th percentile male hybrid III anthropomorphic test dummy. The surrogate wheelchair is a structurally enhanced model, particularly designed to withstand repeated sled tests, and is meant to provide a reference point for testing load capacities of tiedown and restraint systems. This wheelchair can be fastened to the sled in various ways to approximate securement configurations of different WTORS. In compliance with the SAE J2249 testing standards, most tests simulate a 20g/30 mph frontal crash, with side and rear impact testing given secondary priority. Furthermore, these crash situations can be replicated using mathematical computer simulation models, which were developed as a means of predicting and analyzing 3-D dynamic responses. These programs have been continually updated and validated against actual testing results.

Methods

Mathematical computer simulations provide useful and comparatively inexpensive ways to model dynamic system responses of vehicle, WMD, and occupant interactions. The software used in this application, known as the Articulated Total Body (ATB) Model, is used by the Air Force Research Laboratory and many other institutions to predict gross human body response to dynamic environments, such as automobile crashes and aircraft ejections. [1] This software is capable of simulating models made up of a number of rigid or deformable segments, any of which may be coupled by joints to form bodies. Although the software was originally created to model the response of crash test dummies, and subsequently, similar human responses, the model is quite general in nature, and can accommodate simulations of a wide range of interactions, including approximations of vehicle and restraint system response. Body segments are represented as ellipsoids, which are numbered and oriented in relation to the lower torso, designated as the reference segment. Bodies may then be formed from chains of segments connected by joints and/or spring-damper combinations, and segments are also allowed to interact with the environment. The ATB program is written in Fortran, and retains the old language of Fortran cards to specify the location of information, such as the weight, semi-axis, and principal moment of inertia for each segment, as well as similar information recorded for each joint. This requires that data for the ATB program be organized properly in the input file to be read. Often, this organization is accomplished using GEBOD—GEnerator of BOdy Data. GEBOD was developed in conjunction with ATB to generate information on human body segments. GEBOD creates B cards for the segment and joint information, and saves the files with *.ain* extensions, which are required for all ATB input files. GEBOD output is formatted for direct input into ATB. Similarly, GEBOD requires a particular input format, depending on the type of simulation being produced. For this reason, a simplifying Fortran program, referred to as ENGLISH, was created to condition measured anthropomorphic data. [6] This program allows the user simply to enter measured values, which are then formatted for GEBOD. Once all parameters have been successfully input into the ATB program, a number of output files with three separate types of extensions are produced. These files contain clearly labeled input values, run-time information, tabular time history outputs of user-chosen simulations, and input data files for the VIEW and IMAGE programs. These programs create graphical image generations of the simulations run in the ATB program.

The Fortran language was chosen for its compatibility with any number of computer interfaces, including personal computers and UNIX workstations. The ATB model has been through a number of revisions to correct problems and to include new functional capabilities. The current version, ATBV1-3, was revised and released in

1998. [1] The software is also continually tested against actual sled testing to retain accuracy of ATB models. While the frequent updates are necessary to produce results consistent with current technology, these revisions can result in new computer language and linking errors between various parts of the Fortran executable files. Inconsistencies may also result in the serial input/output linkage from ENGLISH into GEBOD and finally into the ATB program itself.

Results

This project was created as an educational integration of the updated biomechanics software and research with classroom knowledge of mechanical and dynamic systems. The main focus of the first phase of this project was to research recent developments in wheelchair tiedown and restraint systems, and to learn the methods associated with their testing. This phase included an extensive literature search of current rehabilitation engineering publications, WTORS and transportable wheelchair standards, and applicable computer software manuals. [1-5] This information provided a broad base of knowledge on the types of wheeled mobility devices currently on the market, as well as the types and locations of various WTORS devices used. In addition, this literature review provided insight into the development of current ANSI/RESNA, SAE, and ISO standards associated with wheelchair transport by providing a number of research methods and results. These results, which can be found in full text in appropriate RESNA and IEEE publications, have culminated in a number of voluntary wheelchair standards and common four belt type restraint system devices. Computer program information for the ATB and GEBOD software, as well as a general review of basic Fortran and DOS commands were essential to understanding and replicating these research methods.

A significant amount of time was spent learning the computer software and working out problems in the Fortran code. Once these problems were resolved, additional time was spent evaluating example input and output files in order to become familiar with the format and location of valuable user defined and computer-generated information. Subsequently, small example files were created from approximate anthropomorphic data to begin learning the methods of inputting data into the ENGLISH and GEBOD programs, and to link these output files into the ATB simulations to produce model results. This allowed a significant opportunity for familiarization with the software and experience with creating user-defined models.

Future Work

Current standards and testing procedures are based on research done mainly with the SAE surrogate wheelchair and 50^{th} percentile male anthropomorphic test dummy in a 20g/30 mph frontal crash. [3] The next step in the continuation of this project will be to recreate the models and research results obtained by using this test configuration and the GEBOD/ATB software. Verification of these models will help further understanding of the effects of various crash and WTORS parameters, and allow for additional familiarization with the extensive Fortran input, output, and executable files. In addition to this model verification, new extensions in WTORS testing can be performed. This could include modeling effects of special wheelchair types, such as smaller children's models, or assessing the effects of secondary crash concerns such as rear or side impact collisions.

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Lauren M. Graffeo

Lauren Graffeo is a senior in mechanical engineering at The University of Alabama. She is working on this project in fulfillment of the requirements of the University Honors Program. Lauren is interested in engineering problems related to the human body, and her future career plans include medical school.

Beth A. Todd

Dr. Beth Todd graduated from Penn State University with a BS degree in engineering science in 1981. Before attending graduate school, she worked in nuclear reactor core performance at Bettis Atomic Power Laboratory. She earned an MS degree in applied mechanics in 1986 and a Ph.D. in mechanical and aerospace engineering in 1992 from the University of Virginia. She is interested in applying mechanical analysis to problems of the human body. She has completed research projects for both the US Air Force and for NASA. Prior to her current position as Assistant Professor and Undergraduate Program Coordinator in Mechanical Engineering at The University of Alabama, Dr. Todd was an instructor at Kettering University (formerly GMI Engineering & Management Institute) in Flint, Michigan.