Occupant Kinematics in Forensics:

Evaluating the Appropriateness and Applicability of an ATB Application

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Background on ATB/CVS

In 1963 the U.S. Public Health Service and the Automobile Manufacturer's Association, Inc. funded research at Calspan performed by Raymond R. McHenry to develop a mathematical model of an automobile occupant in a longitudinal collision. The resulting computer program was called the CAL-2D (**i**,**ii**,**iii**). The research was aimed at the development of a response to a Consumer Reports issue (**iv**) and related reports (**vvi**) that included the assertion that American belts failed under the Swedish test conditions and "the major points of failure of the belts tested were the webbing…and the floor brackets themselves".

The CAL-2D model was created "in order to help improve understanding of the complex relationships of force-acceleration-time-position-velocity that occur in the impact and energy-absorbing cycle of automobile passenger restraint systems". The study was performed to provide guidance concerning "(1) fundamental differences in the results obtained by static and dynamic testing and (2) the possible need for dynamic acceptance testing of seat belts.

One of the results of the study was the conclusion that "the use of a very short stopping distance in a cart test of lap belts can produce a distorted comparison of the strength (when belt loads are not measured) and the performance of webbing materials with different load-elongation characteristics. A short (3") cart-stopping distance, from 25 mph, produces increases in the magnitudes of both primary and secondary belt loading cycles over those obtained a more "realistic" (17") stopping distance, as encountered in automobile crashes".

A subsequent follow-up contract for a 3 dimensional crash victim simulation at Calspan was directed by Dr. John Fleck and resulted in the creation of the Crash Victim Simulator (CVS) (**vii**, **viii**). In the 1980's, the CVS was adapted for use by the Armstrong Aerospace Medical Research Laboratory Wright Patterson Air Force Base and was re-named the Articulated Total Body (ATB). The principal investigator of the CVS/ATB development at Calspan was Dr. John Fleck. (**ix**). The pioneering work by Dr. Fleck included extremely efficient integration routines for economical execution of the program and the addition of many extensions and refinements to move the mathematical model from 2 dimensions to 3 dimensions.

The Articulated Total Body (ATB) Model is a public domain computer program that is used to simulate the dynamic motion of jointed systems of rigid bodies The ATB program is a research tool which is used primarily to interpolate and extrapolate the results of full-scale vehicle crash tests with anthropomorphic test dummies. A typical input file for the ATB program can require anywhere from 500 to 7000 parameters The inputs for ATB require detailed definitions of the occupant, the vehicle interior, the interaction of the occupant with the vehicle interior and definition of the acceleration environment. The appropriate values for input parameters are not readily available and there are no recognized "default" or "typical" values. (**x**)

"The ATB model was developed to complement experimental research in automobile crash environments and to provide a functional instrument for parametric investigations" (viii)

Since the advent of the PC and the availability of PC versions of the ATB computer program, the ATB has been frequently encountered as an accident reconstruction tool used for demonstrative purposes in litigation matters. This presentation will include discussion and presentation of some of the types of applications encountered. The presentation will also include discussion of the appropriateness and applicability of the ATB to specific forensic investigations.

Validation of ATB

"The most common application of ATB is to model human or dummy occupant motion in vehicle crashes" (**xi**). "ATB can be a useful tool in the design process when used in conjunction with a series of full-scale tests" (**xii).** Validation of the ATB occupant simulation model consists of running full-scale tests and then comparing the predictions of the mathematical model with the full-scale test results.

"Generally good correlation was obtained with the results of the impact sled experiments. The results of full-scale car-to-car crash tests...did not correlate with the program predictions to the same degree of accuracy" (**xiii**)

“Assumptions are inherent in any mathematical model” and “a given model may yield better predictions for one situation than for another” (**xiv**, p 180) . “The Agreement achieved between predictions and observed responses of a system, (“validity”) is … user dependent” (xiv, p181). In view of variations of the use of the CVS program “the authors have drawn no conclusions concerning the validity of the CVS model that is demonstrated by the results obtained in this study” (xiv, p181).

The Human Biomechanics and Simulation Standards Committee of the Society of Automobile Engineers (SAE) created a proposed Validation Index which requires a quantitative comparison of output data generated by models or tests. (**xv**). Most attempts at validation of the ATB/CVS have been by comparing the responses of the ATB/CVS with sled tests of <u>adult</u> anthropomorphic dummies. A live human being has responses which differ substantially from an anthropomorphic dummy.

The use of the Articulated Total Body (ATB) Model for occupant simulation requires extensive data to describe human and dummy geometric and inertial properties (**xvi**). The modeling approach used in the ATB model considers the body as being divided into individual rigid segments, typically 15 or 17 segments. The segments are joined at locations representing the physical joints of the human body and have the mass of the body between body joints.

To satisfy the input requirement for definition of the occupant, the GEBOD (GEnerator of BODy Data) was developed to generate human and dummy data sets. (**xvii**, **xviii**). The data sets created by GEBOD include approximations of the body segments' geometric and mass properties, and approximations for the joints' locations and mechanical properties. Regression equations from anthropometric surveys and stereo photometric data are used in computing these data sets. (**xix**, **xx**). There are vast differences in the proportions, musculature and mass distribution of individuals, particularly children. Regression equations can only roughly approximate the properties of an occupant or dummy in vehicle crash tests. The properties created by Regression equations of GEBOD are for a ***passive*** occupant or anthropomorphic dummy to be used in modeling vehicle crash tests.

“The user should be cautioned, however, in the use and limitations of percentiles to describe an individual or class of individuals. As Daniels (**xxi**) has demonstrated it is virtually impossible to find an individual who is “average” in more than a few body measurements.” (xx) “Anthropometrically, while the human body is the same in qualitative appearance within the species, there are considerable differences in the quantitative measures of the body. In statistical terms, there are relatively few dimensions that are highly correlated (“r”>.70) which means that the system varies in dimensional description within the same body and population.”(xx)

“In the standard application of CVS or ATB, the kinematics of the occupant, as well as the occupant’s initial position and orientation, must be known beforehand in order to validate the program for its specific application” (**xxii**). “For real world accidents, actual observed kinematics are not available and there is thus no means to validate the accuracy of the input data used for the program”(**xxii).** “Even small deviations between input data and actual values may have significant effects on the reliability of the results” (**xxii**). “Force-deflection values which have been established for a specific contact area of a specific vehicle have substantial variations depending on the location of the loading, the angle of loading, and the rate of loading” (x). The “extreme variability” of force-deflection values “is one of the most significant problems with using ATB for accident reconstruction” (x). The ATB has never been validated as a general predictive occupant kinematics simulation model for any type of real-world accidents.

Force-Deflection Stiffness, Coefficient of Restitution

When two objects interact in a collision, a deformation or compression phase is followed by a restoration or restitution phase (**xxiii** (p346),**xxiv**.). The amount that the two objects deform during the initial deformation or compression phase is determined by the stiffness or hardness of the two objects interacting. The restitution phase is the time from the maximum deformation condition to the instant at which the bodies separate. (**xxv**). Restitution consists of two separate aspects: (1) a partial dimensional recovery and (2) a partial restoration of kinetic energy.(**xxvi**, **xxvii**). The amount of restoration or restitution is a separate property of each object with no direct relationship to the stiffness or hardness of an object. The coefficient of restitution depends on the impact velocity and can approach unity as the impact velocity approaches zero. (**xxiv)**. The coefficient of restitution depends on the types of materials, sizes, shapes and temperatures of both colliding bodies (**xxiii**).

Restitution in the ATB is modeled by the R & G factors which originated in the CAL-2D program. The R factor is the energy absorption function and it is used to specify the amount of energy recovered at the end of unloading. The R factor ranges from 0 to 1. The G factor it the permanent deflection function and it is used to model permanent deformation due to contact force. The G factor ranges from 0 to 1. The R & G factors in the ATB program are not a measure of the “the stiffness of the contacting surfaces when they impact"(**xxviii**).

ATB Inputs

Interactions between the occupant and the environment are accomplished by the creation of functions representing the force-deflection and frictional properties. Experimental and theoretical modeling of head impact concluded that the ‘choice of head modeling greatly influences the nature of the shock’ and demonstrates ‘the importance of a more realistic modeling of the head in the theoretical and experimental study of shock aggressiveness’ (**xxix**).

There exists a dataset of joint properties for a seated adult male subject in a sled test. (**xxx**). The ATB adult male joint properties may produce unrealistic oscillations of the arms and legs when used for simulations other than a seated adult male in a sled test.

Some Sample Applications/Areas of Investigation

ATB Model Version differences

- The current version of the ATB is ATBV.1-5. The latest revision date for the ATB V.1-5 is 9/20/00.
- Version updates to the ATB may include changes which may affect the results of the ATB.
- Some of the more recent changes are deformable segment capability and joint actuator capability, (**xxx).** Deformable segments have been demonstrated to improve correlation of head/neck responses (**xxxi**).
- In several cases we have found significant differences in predicted results between the versions.

Interior dimensions and properties

- There is no standardized dimensional measurement procedure
- There is no standardized force-deflection property measurement procedure
- When Force Deflection properties are used the sources and measurment techniques must be defined.

Use of the ATB to attempt to demonstrate "Mitigation" is arbitrary and misleading

- Examples include varying the force deflection properties w/o varying the dimensions of the objects,
  - "air-gap " padding
  - “Padded” deflection of 2” on sill, 1.5” on B-Pillar rear face (For baseline run deflection 0.9” on sill, 0.70” on rear face of sill) Can these deflections be accommodated? **Why did they not increase the dimensions of the B-pillar to accommodate the additional “padding” requirements?**
- Installation and creation of properties for components that include component movement –
  - Timing of movement
  - Rate of movement
  - arbitrary nature lends itself to sensitivities
  - extremely arbitrary and sensitive
  - For some runs, belt “anchor” points erroneously move forward and upward with the seat.
    - Arbitrary belt Anchor movements can produce arbitrary slack in the belt which may not have occurred in an actual crash.
  - For some other runs, outboard anchor points of lap and 3-point belt erroneously do not move inboard with intrusion
    - Anchors penetrate the front of striking car
  - For 3-point run, Upper anchor moves forward and upward with the seat movement.

- HIC discussion
  - HIC "predications" are extremely sensitive, especially when moving components contact the occupant
  - A moving component striking the occupant head produces wild variations in the predicted HIC

Conclusions and Recommendations

ATB should be used in forensics and accident reconstruction only as a tool to assist in understanding gross occupant kinematics. Any results or conclusions drawn from an ATB application related to detailed occupant kinematics involve so many approximations, estimates, and assumptions that they must be recognized as not being compatible with sound engineering practices and principles and, therefore, not scientifically supportable.

References

i McHenry "**Analysis of the Dynamics of Automobile Passenger-Restraint Systems**", 7th Stapp Car Conference Proceedings, SAE, 1966
ii McHenry, Naab "**Computer Simulation of the Crash Victim – A Validation Study**", SAE paper 660792, SAE 1966
iii Cheng, Sens, Weichel, Gunther "**An Overview of the Evolution of Computer Assisted Motor Vehicle Accident Reconstruction**", SAE paper 87-1881
iv Consumer Reports, October 1961, Articles by Michelson and Tourin
v Michelson, Torin, "**Consumer Union's Dynamic Tests of Seat Belts**", 5th Stapp Automotive Crash and Field Demonstration Conference, September 1961
vi Michelson, I., Aldman, B., Tourin, B. and Mitchel, J. "**Dynamic Tests of Automobile Passenger Restraining Devices**", Presentation to Committee No. 6, Department of Traffic and Operations, Annual Meeting of the Highway Research Board, Washington DC, January 7, 1963
vii Bartz "**Development and Validation of a Computer Simulation of a Crash Victim in Three Dimensions**", SAE Paper 720961, SAE, 1972
viii Fleck, "**An Improved 3-Dimensional Computer Simulation of Vehicle Crash Victims**", NHTSA, April 1975, NTIS PB-241 693, PB 241 694, PB-241 695
ix Fleck, "**Improvements in the ATB/CVS Body Dynamics Model**", 13th International Technical Conference on Experimental Safety Vehicles, S8-W-20, 1991
x James, Nordhagen, Warner, Allsop, Perl "**Limitations of ATB/CVS as an Accident Reconstruction Tool**", SAE paper 97-1045
xi http://www.orl.columbia.edu/~atbug/moreinfo.html (ATB users Group site)
xii Digges, "**Improvements in the Simulation of Unrestrained Passengers in Frontal Crashes Using Vehicle Test Data**", SAE Paper 860654
xiii Bartz, Butler, "A Three-Dimensional Computer Simulation of a Motor Vehicle Crash Victim", Phase 2, Validation Study of the Model, Contract FH-11-7592, December 1972
xiv Fleck, Butler, Deleys "**Validation of the Crash Victim Simulator, Volume 2, Engineering Manual, Part II – Validation Effort**", August 1982, PB86 212446/AS, DOT HS 6 01300
xv Robbins, "**Restraint Systems Computer Modeling and Simulation State of the Art and Correlation with Reality**", SAE paper 891976
xvi Cheng, Obergefell, Rizer "**Generator of Body Data (GEBOD) Manual**", AL/CF-TR-1994-0051, March 1994
xvii. Baughman, L.D., 1983, "**Development of an Interactive Computer Program to Produce Body Description Data**" AFAMRL-TR-83-058, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

xviii. Gross, M.E., 1991, "**The GEBODIII Program User's Guide and Description**" AL-TR-1991-0102, Armstrong Aerospace Research Laboratory, Wright-Patterson Air Force Base, Ohio.

xix. Clauser, Charles E., Pearl E. Tucker, John T. McConville, Edmund Churchill, Lloyd L. Laubach, Joan A. Reardon, April 1972, "**Anthropometry of Air Force Women**" AMRL-TR-70-5, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

xx Snyder, R.G., Schneider, L.W., Owings, C.L., Reynolds, H.M., Golomb, D.H., Sckork, M.A., May 1977, "**Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design**" UM-HSRI-77-17, Consumer Product Safety Commission, Bethesda, Maryland.

xxi Daniels, The "Average Man"?, Wright Air Development Center, WPAFB, Tec Note WCRD 53-7, Dec 1952

xxii Declaration of John Fleck, February 25, 1992, Miller, et al, v VW, US District Court, Eastern District of California, No. CVF-90-312 REC

xxiii Riley, Strurges "**Engineering Mechanics – Dynamics**", John Wiley and Sons, ISBN – 0-471-51242-7

xxiv Meriam, **Engineering Mechanics – Volume 2 – Dynamics**, John Wiley & Sons, ISBN-0-471-59461-X

xxv http://www.mchenrysoftware2.com/damrev.htm

xxvi http://www.mchenrysoftware2.com/TOPTEC.htm

xxvii McHenry, McHenry "**Effects of Restitution in the Application of Crush Coefficients**", SAE paper 97-0960

xxviii From Deposition testimony of Expert utilizing ATB.

xxix Guimberteau, McLean, Andersen, Farmer "**Experimental and Theoretical Modelling of Head Impact – Influence of Head Modelling**" , Proceedings of 1996 International IRCOBI Conference on the Biomechanics of Impact, 1996, Dublin, Ireland

xxx Cheng, Rizer "**Articulated Total Body Model V Users's Manual**", Veridian, Dayton, OH

xxxi Ashrafiuon, Colbert, "**Introduction of Deformable Segments in the ATB Model"** , Presentation at 1995 ATB Model Users' Colloquium