

**Internal Impact of Brain** 



by using BIONECHANICS

### INERTIA

# CENTRIFUGAL Force

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- A<sub>x</sub> = Linear Acceleration, Forward-Backward Direction
- A<sub>y</sub> = Linear Acceleration, Side to Side Direction
- A<sub>z</sub> = Linear Acceleration, Vertical Direction
- $\mathcal{A}_{x}$  = Rotational Acceleration, About Forward-Backward Direction
- $a_y$  = Rotational Acceleration, About Side to Side Direction
- $a_z$  = Rotational Acceleration, About Vertical Direction

# Linear Acceleration Rotational Acceleration

### $A_x$ = Linear Acceleration, Forward-Backward Direction

 $A_y = Linear Acceleration, Side to Side Direction$ 

 $A_z = Linear Acceleration, Vertical Direction$ 

*alx* = Rotational Acceleration, About Forward-Backward Direction

aly = Rotational Acceleration, About Side to Side Direction

*QLz* = Rotational Acceleration, About Vertical Direction



 $A_{x} = \text{Linear Acceleration, Forward-Backward Director}$   $A_{y} = \text{Linear Acceleration, Side to Side Direction}$   $A_{z} = \text{Linear Acceleration, Vertical Direction}$   $A_{z} = \text{Rotational Acceleration, About Forward-Backward Direction}$   $A_{y} = \text{Rotational Acceleration, About Side to Side Direction}$   $A_{z} = \text{Rotational Acceleration, About Vertical Direction}$ 

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# Linear Acceleration

 $A_x =$  Linear Acceleration, Forward-Backward Direction  $A_y =$  Linear Acceleration, Side to Side Direction

### A<sub>z</sub> = Linear Acceleration, Vertical Direction

 $Q_{Lx} = \text{Rotational Acceleration, About Forward-Backward Direction}$  $Q_{Ly} = \text{Rotational Acceleration, About Side to Side Direction}$  $Q_{Lz} = \text{Rotational Acceleration, About Vertical Direction}$ 



A<sub>x</sub> = Linear Acceleration, Forward-Backward Director
 A<sub>y</sub> = Linear Acceleration, Side to Side Direction
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+Z



 $A_x$ = Linear Acceleration, Forward-Backward Direction $A_y$ = Linear Acceleration, Side to Side Direction $A_z$ = Linear Acceleration, Vertical Direction $Q_{Lx}$ = Rotational Acceleration, About Forward-Backward Direction $Q_{Ly}$ = Rotational Acceleration, About Side to Side Direction $Q_{Lz}$ = Rotational Acceleration, About Vertical Direction

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# COLLISION SEVERITY Change in velocity (AV)





LAW OF PHYSICS: Newton's 2<sup>nd</sup> Law (force = mass \* acceleration)

## **COLLISION SEVERITY** Defined as:

**Change in velocity (\Delta V)** 

### **EXAMPLE:** • Weight of the Vehicle = 4,000lb

- Impact Duration = 0.12s
- Change in Velocity = 5mph (7.33 ft/s)



LAW OF PHYSICS: Newton's 2<sup>nd</sup> Law (force = mass \* acceleration)

#### AFRL-HE-WP-TR-1998-0015



#### UNITED STATES AIR FORCE RESEARCH LABORATORY

Articulated Total Body Model Version V

**User's Manual** 

Huaining Cheng Annette L. Rizer

VERIDIAN 5200 Springfield Pike Suite 200 Dayton OH 45431-1289

Louise A. Obergefell

Crew Survivability and Logistics Human Effectiveness Direct Air Force Research Labora

February 1998

#### UNITED STATES AIR FORCE RESEARCH LABORATORY

#### Articulated Total Body Model Version V

**User's Manual** 

Approved for public release; distribution is unlimited.

Human Effectiveness Directorate Crew Survivability and Logistics Division 2610 Seventh Street Wright-Patterson AFB OH 45433-7901

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### "Report Date: February 1998"

"The Articulated Total Body (ATB) Model is used by the Air Force Research Laboratory (AFRL) and other organizations, companies and educational institutions for predicting gross *human body response* in various dynamic environments, *especially automobile crashes* 

"ATB – V version"

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AIR FORCE MATERIEL COMMAND WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

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"...Generator of Body Data (GEBOD) Manual of March, 1994...produces the human...body description data..." "data may be computed for ... **adult human males**..." "...improvements have been supported by both the Armstrong Laboratory and the National Highway Traffic Safety Administration."

# WHO IS USING ATB?

- Government
- Major Automotive Industries
- University Professors
- Collision Reconstruction
  - Case specific analysis
  - Teaching manuals

 Wide application computer software or accident reconstruction only 2000-01-0469

SAE TECHNICAL PAPER SERIES

#### Simulations of Large School Bus Crashes

Kristin Bolte, Lawrence Jackson, Barbara Czech and Shane Lack National Transportation Safety Board

> Aida Barsan Information Systems and Services, Inc.

Stephen Summers National Highway Traffic Safety Administration

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Time = 0.12 seconds



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Figure 14. A time history of the unrestrained occupant kinematics in the Holmdel, New Jersey simulation.

Pellman, E., D. Viano, A. Tucker, et.al. "Simulation of Large School Bus Crashes." *Society of Automotive Engineers 2000* SAE #2000k-01-0469. 15-Passenger Van Single-Vehicle Rollover Accidents, Henrietta, Texas, May 8, 2001, and Randleman, North Carolina, July 1, 2001



Highway

PB2003-91620 Notation 7507 Highway Accident Report NTSB/HAR-03/03

PB2003-916203 Notation 7567

National Transportation Safety Board Washington, D.C.



National Transportation Safety Board Waitington, D.C.



Time = 0.4 seconds (~40° rotation)



Time = 0.8 seconds (~110° rotation)

Figure 6. A series of still images illustrating the occupant kinematics in the lap/shoulderbelted condition at various stages of the rollover.

15: Parsonger Van Gingto Wohane Roflever Accidents, Bernstey, Heast, May 5, 2001, and Upothetics, North Cartalina, July 1, 2001



"National Transportation Safety Board (NTSB) (2003). 15-Passenger Van Single-Vehicle Rollover Accidents, Henrietta, Texas, May 8, 2001, and Randleman, North Carolina, July 1, 2001. Retrieved October 15, 2004, from http://www.ntsb.gov/publictn/2003/HAR0303.pdf.

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### **Resultant Linear Acceleration**

$$\mathbf{Q} = \sqrt{\mathbf{Q}_{x}^{2} + \mathbf{Q}_{y}^{2} + \mathbf{Q}_{z}^{2}}$$

### **Resultant Angular Acceleration**

# $\mathcal{X} = \sqrt{\mathcal{X}_{x}^{2}} + \mathcal{X}_{y}^{2} + \mathcal{X}_{z}^{2}$

# BRAIN INJURY TOLERANCE (Head Angular Acceleration)



National Highway Traffic Safety Administration (NHTSA)



### **Numerical Injury Identifier**

A framework for constructing an impairment scale has recently been proposed by States,<sup>10</sup> and work on its development has been undertaken by the AAAM Committee on Injury Scaling. The criteria for such an impairment scale are being deliberated. In anticipation of this new scale, the list of injuries in the AIS has been expanded to accommodate the addition of an impairment severity code. Even when the AIS code is the same for a number of different injuries to an organ, the relative impairment of these injuries may be quite different; thus the need for more definitive injury diagnoses.

#### Numerical Injury Identifier

AIS 85 introduced a unique 6-digit code for each injury diagnosis to assist in computerization of data. To addition of injury descriptions in AIS 90, especially in the brain and extremities, has required a more flexib numerical system than that used in 1985.

In AIS 90, each injury description is assigned a unique 6-digit numerical code in addition to the AIS severi score. As summarized in the diagram below, the first digit identifies the body region; the second digit ident fies the type of anatomic structure; the third and fourth digits identify the specific anatomic structure or, in the case of injuries to the external region, the specific nature of the injury; the fifth and sixth digits identify the level of injury within a specific body region and anatomic structure. The digit to the right of the decimal point in the AIS score.



Body Region

The following conventions are used in assigning the numerics to specific injury decriptions:

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Type of Anatomic Structu Specific Anatomic Structu Level Als



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140634.5	bilateral
1406365	large ( >50cc adult; >25cc if $\leq$ 10 years old; >1cm thick; massive; extensive)

### LENGTH OF UNCONSCIOUSNESS

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#### 1997 FORD F250 HD CREW CAB 4DR 4X4 PICKUP

## **1997 Ford Pickup Mitchell Data**

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# 1997 Ford F250

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## **1997 Ford F250**

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## **1997 Ford Pickup Repairs**

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1		REAR BUMPER					
2		O/H rear bumper w/cushions				1.3	
3	Repl	Step bumper w/o Lightning chrome	1	316.	00	Incl.	
4	Repl	Pad upper	1	63.	95	Incl.	
5	Repl	Pad lower	1	31.	18	Incl.	
6#	Rpr	REAR HITCH OPEN					
7 SO	1 Repl	RT Step bumper mount bracket inner w/o dual wheels	1	15.	30		
8 SO	1 Repl	LT Step bumper mount bracket inner w/o dual wheels	1	15.	30		
9# SO	1	Retainer bolt	2	12.	10		
10# 50	2	FINAL BILL AUTHORIZED TO PAY	1				

### PENDIX A - TEST VEHICLE BUMPER DESCRIPTIONS

A new argent rear bumper assembly which is common to

#### PPENDIX A - TEST VEHICLE BUMPER DESCRIPTIONS

Each burger tested is described below. All burger heights given are to the top of the area engaged in the test.

All diagrams are taken from Mitchel<sup>®</sup>. All bumpers tested had the same replacement part numbers for both the US and Canada. Although the opti are shown in some diagrams, no bu finds with bumpereites.

FORD F150

All of the bumper parts used on the For OEM parts purchased from a local Ford

#### Froot Bumper

A new chrome front bumper face 1 before each test. This bumper is con 1966 model. Ford pickup trucks. T consisted of a steel face bar bolted de with two bolts to each traver rail. The b 60 cm.





Rear Bumper A new argent rear bumper assembly which is common to 1992 to 1996 F150, F250, F350 and 1997 to 1998 F250H0, F350 was substep for to each each This is now the replacement bumper for this 1980 bruck as the

Rear Bumper



right box side.

#### GMC C1500

195

All of the bumper parts used on the GMC C1500 were new CEM parts purchased from a local General Motors dealership.



Heinrichs, B., J. Lawrence, B. Allin, J. Bowler, C. Wilkinson, K. Ising and D. King. *Low-Speed Impact Testing of Pickup Truck Bumpers* Society of Automotive Engineers, Inc. 2001.

#### Vehicle 1 – 1980 Ford F150 rear bumper tests



Heinrichs, B., J. Lawrence, B. Allin, J. Bowler, C. Wilkinson, K. Ising and D. King. *Low-Speed Impact Testing of Pickup Truck Bumpers* Society of Automotive Engineers, Inc. 2001.

## **1999 Dodge Durango AUTOSTATS**

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## **1999 Dodge Durango Mitchell Data**





## **1999 Dodge Durango Repairs**

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## **1999 Dodge Durango**

VE



## **COLLISION SEVERITY**

# $\Delta V = 7 - 10$ mph (10.3 - 14.7 ft/s)

## COLLISION SEVERITY Minimum



- Weight of the Vehicle = 5,730lb
- Impact Duration ( $\Delta t$ ) = 0.12s
- Change in Velocity = 7 mph (10.3 ft/s)

### **Equations**

 $\mathbf{F} = \mathbf{m} \cdot \mathbf{a}$ 





F<sub>peak</sub> = 30,000lb

## COLLISION SEVERITY Maximum



- Weight of the Vehicle = 5,730lb
- Impact Duration ( $\Delta t$ ) = 0.12s
- Change in Velocity = 10 mph (14.7 ft/s)

### **Equations**

 $\mathbf{F} = \mathbf{m} \cdot \mathbf{a}$ 



F<sub>average</sub> = 21,000lb

F<sub>peak</sub> = 42,000lb

#### AFRL-HE-WP-TR-1998-0015



#### UNITED STATES AIR FORCE RESEARCH LABORATORY

Articulated Total Body Model Version V

**User's Manual** 

Huaining Cheng Annette L. Rizer

VERIDIAN 5200 Springfield Pike Suite 200 Dayton OH 45431-1289

Louise A. Obergefell

Crew Survivability and Logistics Human Effectiveness Direct Air Force Research Labora

February 1998

#### UNITED STATES AIR FORCE RESEARCH LABORATORY

#### Articulated Total Body Model Version V

**User's Manual** 

Approved for public release; distribution is unlimited.

Human Effectiveness Directorate Crew Survivability and Logistics Division 2610 Seventh Street Wright-Patterson AFB OH 45433-7901

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#### "Report Date: February 1998"

"The Articulated Total Body (ATB) Model is used by the Air Force Research Laboratory (AFRL) and other organizations, companies and educational institutions for predicting gross *human body response* in various dynamic environments, *especially automobile crashes* 

"ATB – V version"

# **Body Position**

ALC: NOT

## **Body Position**

Page 1 of 1

head restraint

backeet [cm]

distance from

top of head (cm)

height is

backset [om]

acceptable margina

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#### PASSENGER CARS, PICKUPS, AND UTILITY VEHICLES

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#### Head restraint geometry explained

The necessary first attribute of an effective head restraint is good geometry. If a head restraint isn't behind and close to the back of an occupant's head, it can't prevent a "whiplash" injury in a rear-end collision. Institute researchers regularly evaluate the geometry of head restraints in passenger vehicles based on the height and backset relative to an average-size male. A restraint should be at least as high as the head's center of gravity, or about 9 cardimeters (3.5 inches) below the top. The backset, or distance behind the head, should be as small as possible. Backsets of more than 10 cantimeters (about 4 inches) have been associated with increased symptoms of neck injury in crashes.

Institute ratings are good predictors of how well people will be protected in rear-end crashes — drivers with restraints rated good are less likely than those with poor restraints to daim neck injuries. Head restraint ratings for hundreds of passenger vehicles are listed by, whicle make and series. Various head/sect combinations are rated (not every available seat option in every series has been measured). The restraints are measured with the angle of the borso at about 25 degrees, a typical seathack angle. Each restraint is classified according

to its height and backset into one of four geometric zones - good, acceptable, marginal, or poor.

#### How they are rated

Since 1995, the Institute has been publishing model-by-model ratings of been restraint geometry, based on a procedure for taking geometric measurements. The rating for a fixed head restraint is straightforward — the zone into which its height and backest place: It also defines its rating. The rating for a head nestmint that adjusts in height and/or backset depends on whether it tooks in the adjusted position. If it doesn't lock, its rating is defined by its height and backset in the down and/or rear position. If it doesn't lock, its rating is defined by its height and backset in the adjusted and locked position. The final rating is the better of the two, except that if the rating as adjusted is used, it's downgraded one category because so few motorists adjust their restraints. Many vehicle models have more than one seat option — if seat differences affect the head restraint zat more than one rating is shown. This procedure is used to rate the head restraints in 1995-99 models.

A modification of the above procedure has become an international standard evailable from the Research Council Automobile Repairs (RCAR), Ratings for fixed head restreints and adjustable restraints that don't lock is unchange under the international RCAR protocol. For adjustable restraints that lock in position when adjusted, the rating is based on the midpoint of the best (highest and closest) and worst (lowest and farthest) positions in relation to an average-size male. Active head restraints that move into position on impact are rated good. The Institute rates har restraints in 2000 and later models according to the RCAR procedure.

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(22001, insurance institute for Highway Safety, Highway Loss Data Institute Last modified: 23-Jan-2002



### **Case Specific Computer Analysis** (Articulated Total Body – ATB Computer Output)

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BARS ANTIDA. STRE TOTAL BODY LATES HEREL

## BRAIN INJURY TOLERANCE (Head Angular Acceleration)



National Highway Traffic Safety Administration (NHTSA)

## Collision



## **Body Motion – Real Time**



## **Body Motion – Slow Motion**



## Impact – Real Time

### **Internal Impact of Brain**



## Impact – Slow Motion

#### **Internal Impact of Brain**



CAVITATION : FORMATION AND DESTRUCTION OF VAPOR FILLED MICRO-BUBBLES

### Cavitation







## **Brain Dynamic Testing**

## Equipment



### **High Speed Camera**

- MotionScope®, Redlake Imaging
- Model: PCI 2000
- Model Number: 1108-0004
- Serial Number: 98P-0095

#### Accelerometer

- Type: ICSensors 3028
- Range: +/- 100g
- Serial Number: 0021-029

#### **Skull/Gel Model**

- Skull: A20/1 (Anatomical Chart Company; Hagerstown, MD)
- Gel: Sylgard 527 A&B Silicon Dielectric Gel (Dow Corning Corporation; Midland, MI)

### **Subject Seat**

• 1997 Ford F250 (VIN: 1FT HW26F 8 VE A67707)

### **Skull: A20/1**

Equipment

#### (Anatomical Chart Company; Hagerstown, MD)



#### Equipment

### **Silicon Gel Properties** Sylgard 5-27 A&B Silicon Dielectric Gel (Dow Corning Corporation; Midland, MI)



#### 9hr cure



#### 14hr cure



## 12hr cure



## **Properties Comparison Silicon Gel & Brain Tissue**

parameters, might exist in post-mortern time, amplitude of applied strain and different donors.

Figure 4: Stonge modules G' (apper) and loss modules G' (losser) of measured models (frain insue (n = 4) and discree get [p-10]), and linear out (1, a more write moter (1, 2, a more construmt (1, 2, a portine braintern ( $\chi$ =2.0%) [18]. 4 portine construmt ( $\chi$ =2.0%) [19]. 5. cult construmt ( $\chi$ =2.0%) [19]. 6. portine construmt ( $\chi$ =2.0%) [10].

MODEL MATERIALS

The applicability of the model materials in a mechanical head model is predominantly determined by the minicking qualities of the model materials, but also by their experimental manageability. The latter includes factors such as aging, temperature sensitivity and ease of preparation, which are important in every day laboratory practice. Both considerations will be discussed.

For the Sylgard 527 A&B silcone gel a frequency range up to 280 Hz could be obtained by applying TTS in the chosen temperature range of 25 to -50°C. It is believed that the frequency range can be expanded to higher frequencies, without any problem temperatures below -50°C. Our res with the thindings of Arbogast et al., the dynamic shear modulus of the tasting their high frequency shear i they did not report the phase angle compared with our data.

The dynamic medulus of sticone ge tissue in a range up to 10 Hz. For hi to 250 Hz, the sticone gel become tissue. Thus, when applied in a his the sticone gel are expected to be brah tissue, for those frequendes. It frequency strains will be demped at get than in brain tissue, since the hence the toos modulus, of the get brah tissue.

The experimental manageability of the begod. The effect of material repeating a frequency sweep test, a after the material had been in the in three days at 25°C. The dynamic increase of approximately 10% in frequency range. The phase angle of 2.5 degrees. Repeating the experiths, did not reveal additional different it can be concluded that the influence low.

The dynamic modulus of the gelatin decades higher than the modulus factor of 50 for the 4% gelatin sol 2000 for the 20% solution). The p almost zero (0-2°). Both quantities frequency. This indicates that, range tested (0.1-16 Hz), the ge nearly periect elastic solid that is it brain tissue. In theory, the stiffness lowered by using lower percentage mixture. However, in practice because of the high damage sensi causing it to break up at very low the material behaviour of the gelati to aging (parameters change preparation) and mechanical failure. can be concluded that getatin is not material for brain tissue

#### ACCURACY ANALYSIS

The accuracy of the measurement accuracy with which the shear can collisiting plate, and the measuring on the fixed plate. The rotation o applied with discrete slopes of 511 diameters and thickness' used, the



Brands, D., P. Bovendeered, G. Peter, et al. "Comparison of the Dynamic Behaviour of Brain Tissue and Two Model Materials", SAE 99C21, Society of Automotive Engineers, Inc. 1999.

### **Test Conditions (per ATB Simulation)**

#### **A. SEVERITY OF IMPACT**







#### **B. POSITION OF HEAD**



50 **Experimental** 


## **Skull/Gel Model Testing**

## **Test Conditions (per ATB Simulation) :**

Severity of Impact (X = 10.10g, Y = 14.09g, Z = 4.02)
Tested at Y = 10.55g
Position of Head (Yaw 75°, Pitch 7°, Roll 6°)

Video Parameters:

- Capture rate: 10,000 frames/sec
- Slow motion (1/60th of actual velocity)



## **Skull/Gel Model Testing**

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- Position of Head (Yaw 75°, Pitch 7°, Roll 6°)

#### Video Parameters:

- Capture rate: 10,000 frames/sec
- Slow motion (1/60th of actual velocity)

## **Transformed MRI Data**

Source of Original Data:

• Dr. Orrison, Nevada Imaging Centers



## **Skull/Gel Model Testing**

### **Test Conditions (per ATB Simulation) :**

- Severity of Impact (X = 10.10g, Y = 14.09g, Z = 4.02) •Tested at Y = 10.55g
- Position of Head (Yaw 75°, Pitch 7°, Roll 6°)

Right

*left* 

#### **Video Parameters:**

- Capture rate: 10,000 frames/sec
- Slow motion (1/60th of actual velocity)

## **Transformed MRI Data**

Source of Original Data:

• Dr. Orrison, Nevada Imaging Centers



# Limitation of Dr. Ravani's Hand Calculations

• Dr. Ravani uses average not the peak values

# Average VS. Peak



## The peak acceleration is twice the average

## acceleration.

SAE TECHNICAL PAPER SERIES 2002-0	1-0540	system, and all data. The pition type obsorber data was over-represented and lends to put the all data curve obse to the pition type absorber zone. As expected, the fund illustrates realitation har piece based and decreases. The form one by per tumper systems lend to produce a higher realitation than the pition type absorbers. The correlation contributi, it, for the all data curve it is 0.005, for the form care data 5.011, and for the pitch higher absorber 1066.	Crown Energy $E = L(AC + \frac{BC^2}{2} + \frac{A^2}{2B})$ Targer Vehicle Defa-V $(1 + c) \frac{D(E_r + E_R)(m_r + m_r)}{2}$
Low Speed Collinear Impact Seve Comparison between Full Scale T and Analytical Prediction Too Restitution Ar	erity: A Festing Is with nalysis	In general, the data continued the overall curve fit whether in exponential or logarithmic fits, produced by Anheniti [1]. Additionally, the logarithmic fit for the foram core data produce a good correlation to the available data. The following three equations were obtained from the besist curves: Plateon Composete (Plateon to Plateon) c= 0.44871 = 0.24963 log(r) + 0.04988 log(r) <sup>2</sup> = 0.12660 log(r) <sup>2</sup>	$\Delta v_r = \frac{m_r}{1 + \frac{m_r}{m_g}} \sqrt{\frac{(1 - e^2)m_r m_g}{(1 - e^2)m_r m_g}}$ Crush Force $F = AL + BLC$ Relative Approach Velocity $v_r = \frac{m_r}{m_g}$
A. L. Cipriani, F. P. Bayan, M. L. Woodhouse, A. D. Cometto, A C. B. Tanner and T. A FTISE Quan, Smith	L. P. Dalton, A. Timbario E. Consulting E. S. Deyerl & Associates	Feam Core Composite (Feam Core to Feam Core) $e = 0.5391 - 0.31654 \log(r) + 0.22723 \log(r)^2 - 0.28915 \log(r)^3$ All Data Composite $e = 0.47447 - 0.36139 \log(r) + 0.03842 \log(r)^2 - 0.11639 \log(r)^3$	$\label{eq:rescaled} \begin{split} & l+-\frac{1}{m_{e}}\Delta\nu_{T}\\ & \nu_{ee}=\frac{m_{e}}{(l+e)}\Delta\nu_{T}\\ Tris motiles MER processure was used for each crash iset and compared to the data cochected aim ing the size of control of the size control of an ing the size of th$
Reprinted From: Accident Reconst	truction 2002 (SP-1666)	MER METHOD COMPARISON The MER method is a method usad in reconstructing low- speed collevar collectors. The data from the 30 staged collectors using pholographically collectors without densities and the MER equations shown below. Conservation of Momentum $m_F v_F + m_F v_F = m_F v_F + m_F v_F$ Conservation of Energy $\frac{1}{2}$ $m_F v_F + m_F v_F + m_F v_F + F$	Several methods can be used to calculate the peek occeleration experienced by the vehicles in a low-speed onlike. The film mithod singly utilizes the peak force and divides by the weight of the vehicle in posterior. In the third methods assume the singles of the impact public as weights and the venue on the links of the peak to a start weight of the second of the links of the second second second second second second second to the venue on the links of second second to the venue on the links of second second to the venue on the links of second to the venue on the links of second second second second second second to the venue of the comparison to the second links were. The peak acceleration is hits the second second second second second second second second second second second second second and the predicted motified MEV second secon
SAE The Engineering Society For Advancing Wobility IN T E R N A T I O N A L 400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (	rld Congress oit, Michigan rch 4-7, 2002 (724) 776-5760	$\frac{1}{2} \frac{1}{2} \frac{1}$	prediction in velocity change, average acceleration, and peak acceleration by the motified MER mathed as can be seen in Appendix C. Accordingly, this data writtes that the motified MER method can be used as a loo in determining the upper timt of velocity change, average acceleration; and peak acceleration in low-speed collisions under these conditions. Predicting the precise velocity change, average acceleration; and peak acceleration in low-speed

Cipriani, A., F. Bayan, M. Woodhouse, et.al. "Low Speed Collinear Impact Severity: A Comparison between Full Scale Testing and Analytical Prediction Tools with Restitution Analysis." *Society of Automotive Engineers 2002* SAE #2002-01-0540.



West, D. Low Speed Rear-End Collision Resting Using Human Subjects, Accident Reconstruction Journal, May/June 1993.

## A. Peak Vehicle Acceleration (using a multiplier of 2)



## **B. Peak Occupant Head Linear Acceleration** (using multiplier of 3)



## C. Peak Occupant Head Angular Acceleration (using multiplier of 2)

TSR 7809  
- Using anthrop. data  

$$F \cong \frac{14.5-5.1}{69.1} \times 71 = 9.66^{\circ} \approx 0.8^{\circ}$$

$$k \cong 2.75^{\circ} \approx .229^{\circ}$$

$$\chi \cong \frac{(5 \pm 5.5 \times 2) \times 32.2 \times .9}{.229^{2} \pm .8^{2}} = 372 \pm 409$$

$$rad/sec$$
Even if we use  $r = .58$  ft then  

$$\chi = 1.49 = a_{head} = 1.49 \times \frac{105011 \times 32.2}{105011 \times 32.2} = \frac{1}{2} 480 \pm 527$$
For  $a_{head}^{\circ} = 7 - 8g's$   $rad/sec$   

$$\chi = 670-770 \quad rad/sec$$
Average Value  
(as used by Dr. Ravani)

X 2 = 1,340 – 1,540 rad/s<sup>2</sup>

# **Peak Value** (calculated maximum value)

# Limitation of Dr. Ravani's Computer model

- •2 dimensional (2D)
- Validation with only 2 studies
- •Not capable of including head rotation around the vertical axis (looking to the left)
- Not capable of modeling contact with the headrest
- Not the entire necessary time period was evaluated

we of the improvement accords of these data findings. Note experi-nate statistics, how that up arough conditioned the data and used to collater a statistical according of the finite statistics which can be excluded a function and the statistics. adaption over The is because proper subscreeted public along the difficult of int in bounded tomog formula relations, in addition, the ad double, once occurrented and relations for a range

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## Methods

The multi-body model developed is a four-segment model and consists of three rigid rods connected by four revolute/pin pivots and connected to the head at its center of mass (as shown in Fig. 1). The model combines the body and spine into segments, which are connected with rotational springs and dampers at each pivot. The model is constrained to 2-D motion in the sagittal plane.

Garcia, T., B. Ravani. A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model Journal of Biomechanical Engineering APRIL 2003, Vol. 125, pp254-265.

## Results

a Comparison to Other Experimental Data. It has been concluded in recent studies that whiplash injuries/symptoms can occur in the initial extension motion of the head (before the head contacts the headrest) approximately when the cervical spine takes on an S-shape formation [3,4,6,9,10,12]. Because of this the model simulations were run until the time when the head would contact the headrest. This was determined from the kinematics and a 15° seatback angle.



Garcia, T., B. Ravani. *A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model* Journal of Biomechanical Engineering APRIL 2003, Vol. 125, pp254-265.

## Conclusions

Conversity of

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The first objective of this study was to achieve a design of a relatively simple and efficient multi-body linkage model that can be used to simulate the biomechanics of whiplash. It is shown that a two dimensional four segment model in the sagittal plane can capture the peak loads as well as the kinematics of the cervical spine observed in experimental studies. Data from two experimental human studies are used to validate the model. Simulation runs with the model are shown to produce peak accelerations and forces as well as the kinematics that agree with other existing experimental data. Much of the data from the model was seen to lie in between experimental data from human volunteers and cadavers. This is implies that the model best simulates the dynamics of an unaware human subjected to rear-end impact. Therefore the first objective is met.

Garcia, T., B. Ravani. *A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model* Journal of Biomechanical Engineering APRIL 2003, Vol. 125, pp254-265.

## Not the entire necessary time period was evaluated

## Dr. Ravani's Case Analysis



## **Dr. Ravani's Publication**

colonials in the interTS or W descines (Interstable in descripted in the optimization sector below). The local value of QL was deter minud away involved dispress of the same in the second you tion [21]. The rules of the antisi ingles of the serviced spine 022 and (21) were determined from rulesgraphs of horses voluments inform for Obus, et al. [10] and Transgueirs, et al. [28]. The arights Q2 and Q3 are the angles of the segments with respect to [9220 whenever fixmus A and H respectively, which are bacd in the tody infation to it. The angle knowes that CE-CH to OC link-front Barra "2" and the Head reference former to constant at 39 do prote This was taileded become the book senies of ges supervise and papersor to the OC Operable distances more estimated trues data loose Reise et al. [20] The angle Q4 is the angle of the init fram the OC pixel to the head UG, w.r.t. the flatter "Head" (tas) Fig. 7). The initial starts O4 may not so that the famil is resulted It degrees with the vertical). In other words, the CS-CP to OC link angle (watching version) plus the "Mend" frame angle Orient at 33 (by) plus Q4 too), the Head Noris) equals 13 sligens. The Hea turns is send to find the staffeess and damping characteristics

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# the seat/lumbar spine. Because it has been indicated that injury mechanisms occur during the first 200 ms following the rear-end collision, the muscles in an unwarned subject do not have enough

The model, formers in the order of a few ord reconstant to the angle of the second sec

As invariant bodies, exploration of the result is understanding constructions (regular) of the average between a shown werk mackets (right extracted beams of supposing relations and native into its models into the structure of the structure of the data masket and the random size from the constructive integrations structures in the 1 structure for maskets with the product the structure the structure for maskets and masket with ( $T/T_{\rm e}$  structure the structure for maskets with the structure the structure of these source postant density with the masket of the structure of the structure for maskets with the structure of the structure of the structure of the strucsting trappends between the structure the mask.

Journal of Biomechanical Engineering

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APRK 2003, Vol. 125 / 287

# **ATB Issue: Dr. Ravani's**

 In his paper published in 2003 he refers to ATB papers that were published between 1976-1985 (old ATB versions)

•Not aware of studies in the last 20 years



There have also been detailed multi-body dynamic models of the head/cervical spine for simulating pilot ejections (see, for example, [19,20–22]). These models however have only been used to simulate flexion and lateral bending of the neck and have not been used or validated for extension motion of the head/neck observed in rear end collisions.



Garcia, T., B. Ravani. *A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model* Journal of Biomechanical Engineering APRIL 2003, Vol. 125, pp254-265.

- [19] Willams, J., and Belytscho, T. (1981) "A Dynamic Model of the Cervial Spine and Head," Air Force Aerospace Medical Research Lab-Technical Report, AFAMRL-TR-81-5, Wright-Patterson AFB, OH.
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- [21] Eddy, W. C., 1976 "Non-linear Biomechanical Model of the Cervical-Thoracic Transregional Joint," Aerospace Medical Research Lab-Technical Report, AMRL-TR-76-90, Wright-Patterson AFB, OH.
- [22] Belytschoko, T., Rencis, M., and Willes, J. "Head-Spine Structure Modeling: Enhancements to Secondary Loading Path: Model and Validation of Headcervical Spine Model," Aerospace Medical Research Lab-Technical Report, AAMRL-TR-85-019, Wright-Patterson AFB, OH.



Garcia, T., B. Ravani. *A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model* Journal of Biomechanical Engineering APRIL 2003, Vol. 125, pp254-265.



## "Report Date: January 1988"

"The Articulated Total Body (ATB) Model is used at the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) to study human body biomechanics in various dynamic environments, especially aircraft ejection with windblast exposure."

"ATB – IV version"

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## "Report Date: February 1998"

"The Articulated Total Body (ATB) Model is used by the Air Force Research Laboratory (AFRL) and other organizations, companies and educational institutions for predicting gross *human body response* in various dynamic environments, *especially automobile crashes* 

"ATB – V version"

2000-01-0469

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#### Simulations of Large School Bus Crashes

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Figure 14. A time history of the unrestrained occupant kinematics in the Holmdel, New Jersey simulation.

Pellman, E., D. Viano, A. Tucker, et.al. "Simulation of Large School Bus Crashes." *Society of Automotive Engineers 2000* SAE #2000k-01-0469. 15-Passenger Van Single-Vehicle Rollover Accidents, Henrietta, Texas, May 8, 2001, and Randleman, North Carolina, July 1, 2001



Highway

PB2003-91620 Notation 7507 Highway Accident Report NTSB/HAR-03/03

PB2003-916203 Notation 7567

National Transportation Safety Board Washington, D.C.



National Transportation Safety Board Waitington, D.C.



Time = 0.4 seconds (~40° rotation)



Time = 0.8 seconds (~110° rotation)

Figure 6. A series of still images illustrating the occupant kinematics in the lap/shoulderbelted condition at various stages of the rollover.

15: Parsonger Van Gingto Wohane Roflever Accidents, Bernstey, Heast, May 5, 2001, and Upothetics, North Cartalina, July 1, 2001



"National Transportation Safety Board (NTSB) (2003). 15-Passenger Van Single-Vehicle Rollover Accidents, Henrietta, Texas, May 8, 2001, and Randleman, North Carolina, July 1, 2001. Retrieved October 15, 2004, from http://www.ntsb.gov/publictn/2003/HAR0303.pdf.