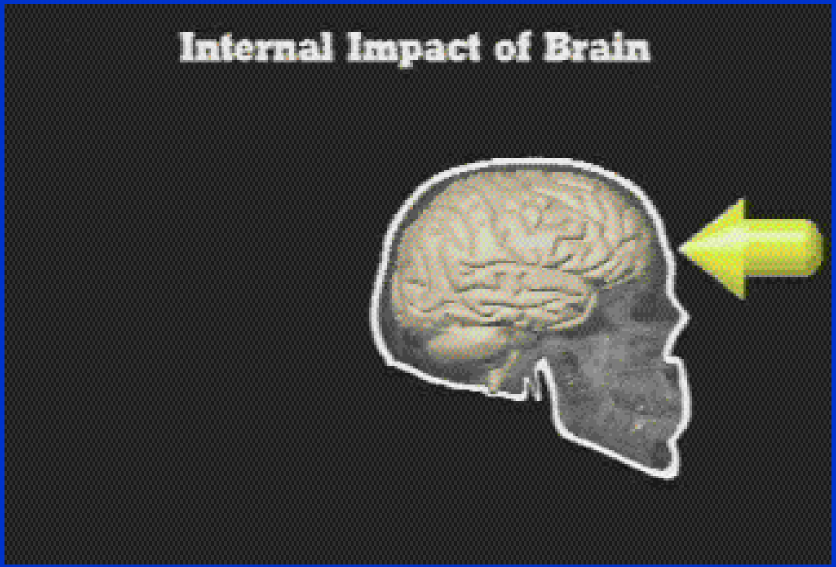
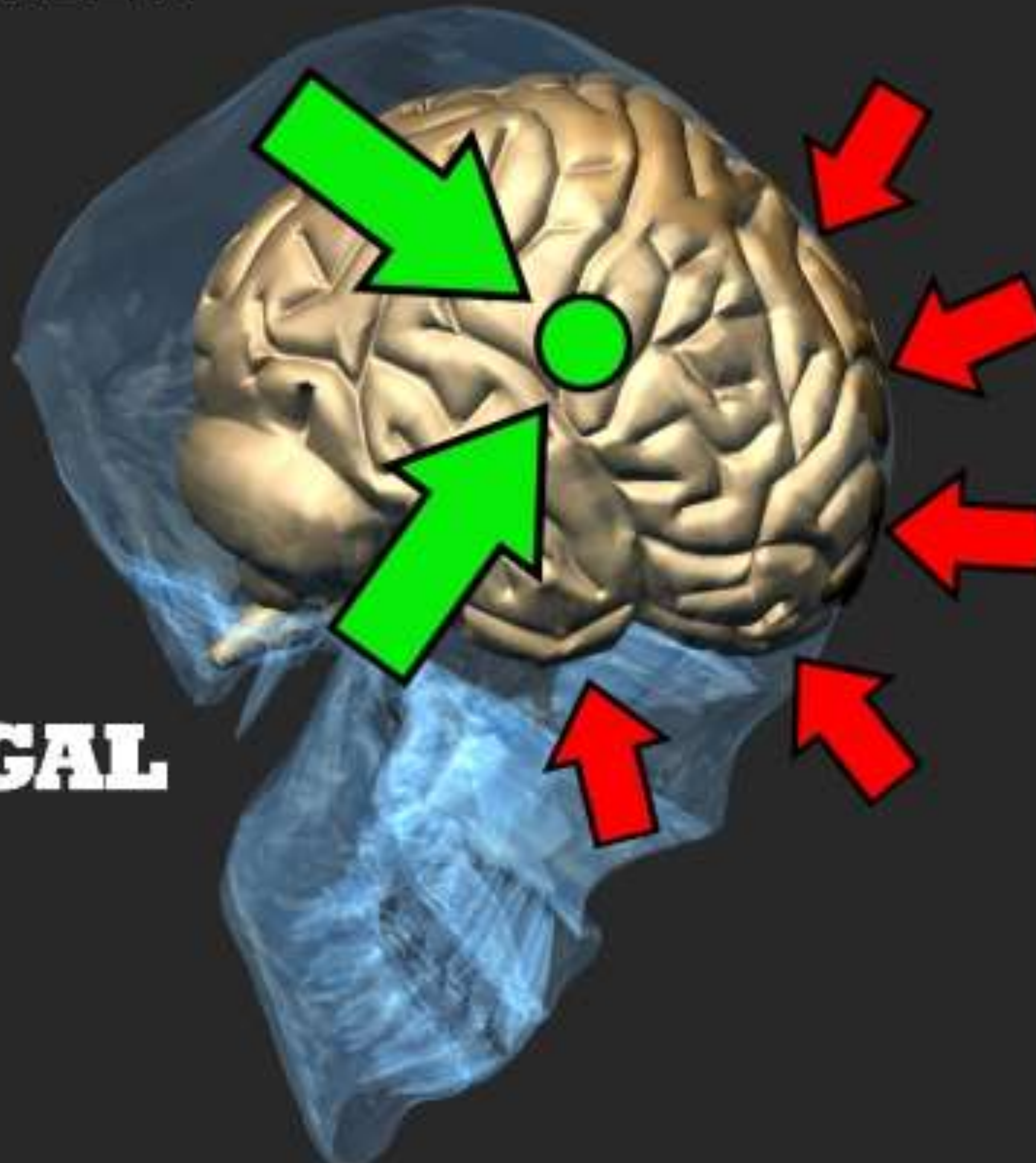


LINKED

by using

BIOMECHANICS

INERTIA

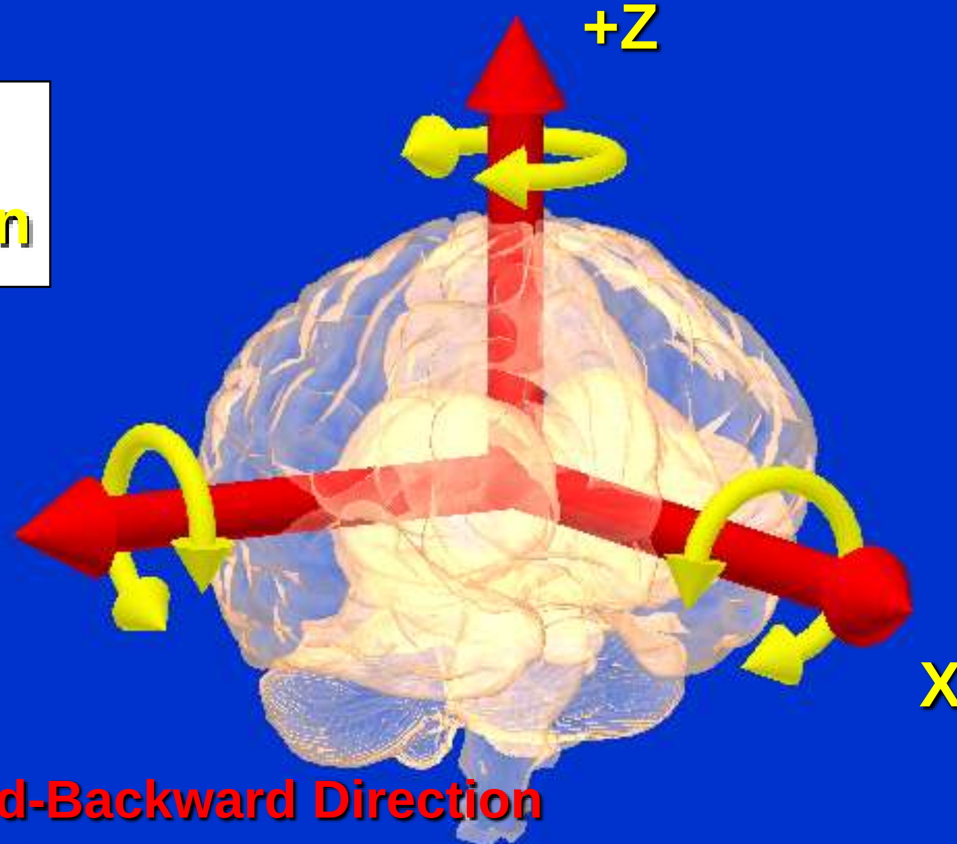


CENTRIFUGAL
FORCE

TYPES OF ACCELERATION

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

a_x = Rotational Acceleration, About Forward-Backward Direction

a_y = Rotational Acceleration, About Side to Side Direction

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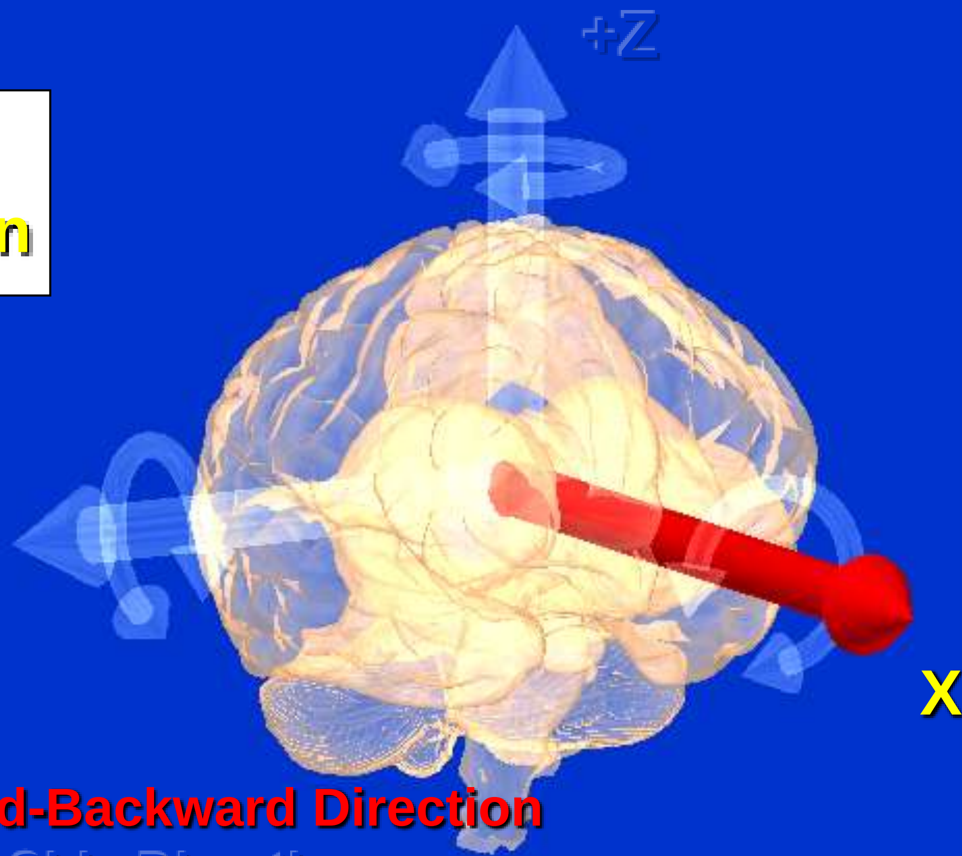
TYPES OF ACCELERATION

Linear Acceleration
Rotational Acceleration



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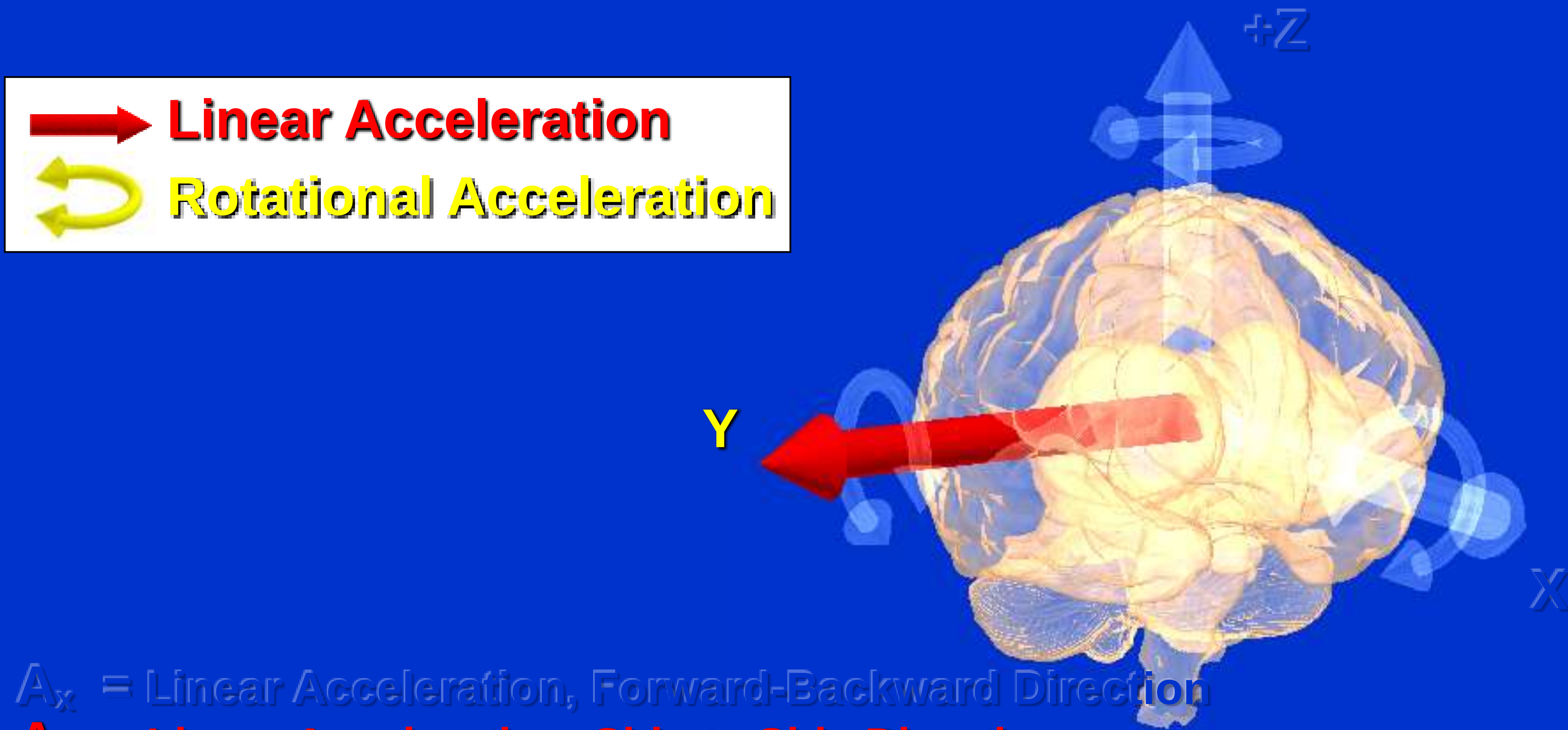

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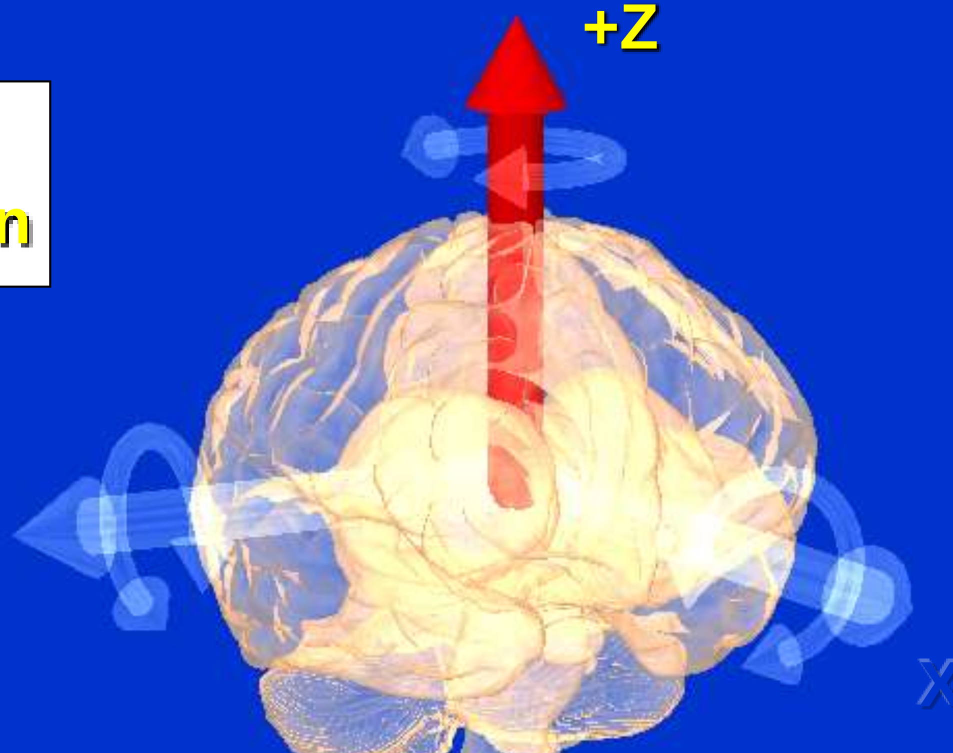
Rotational Acceleration



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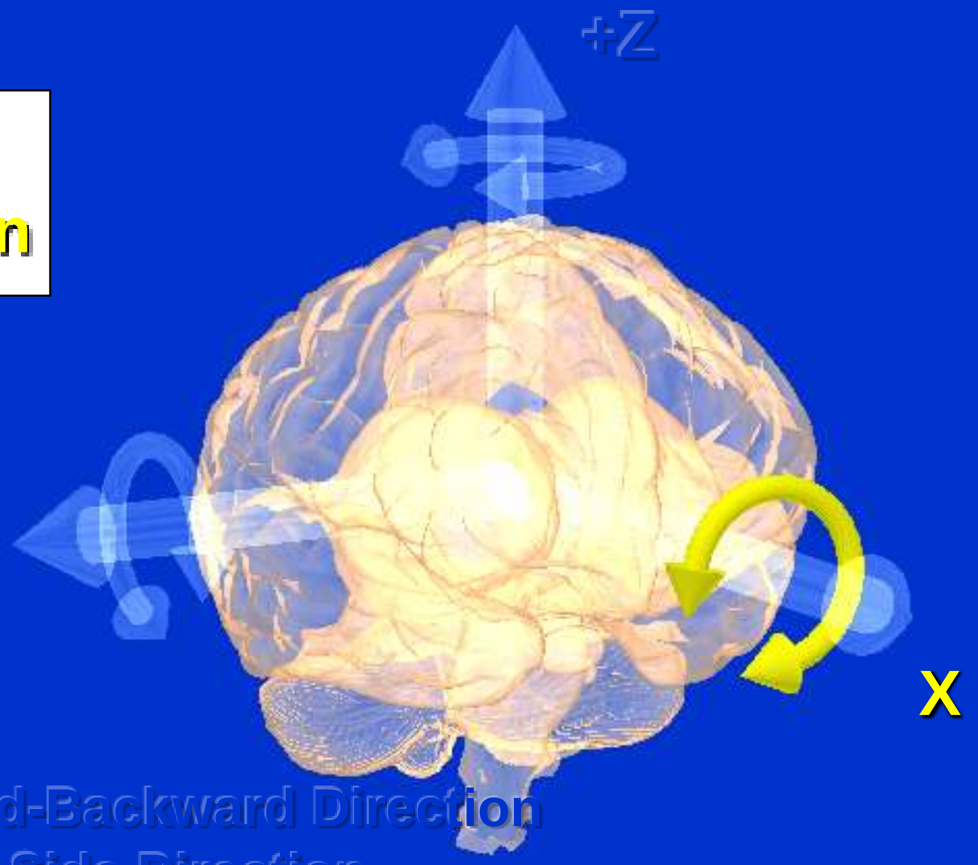

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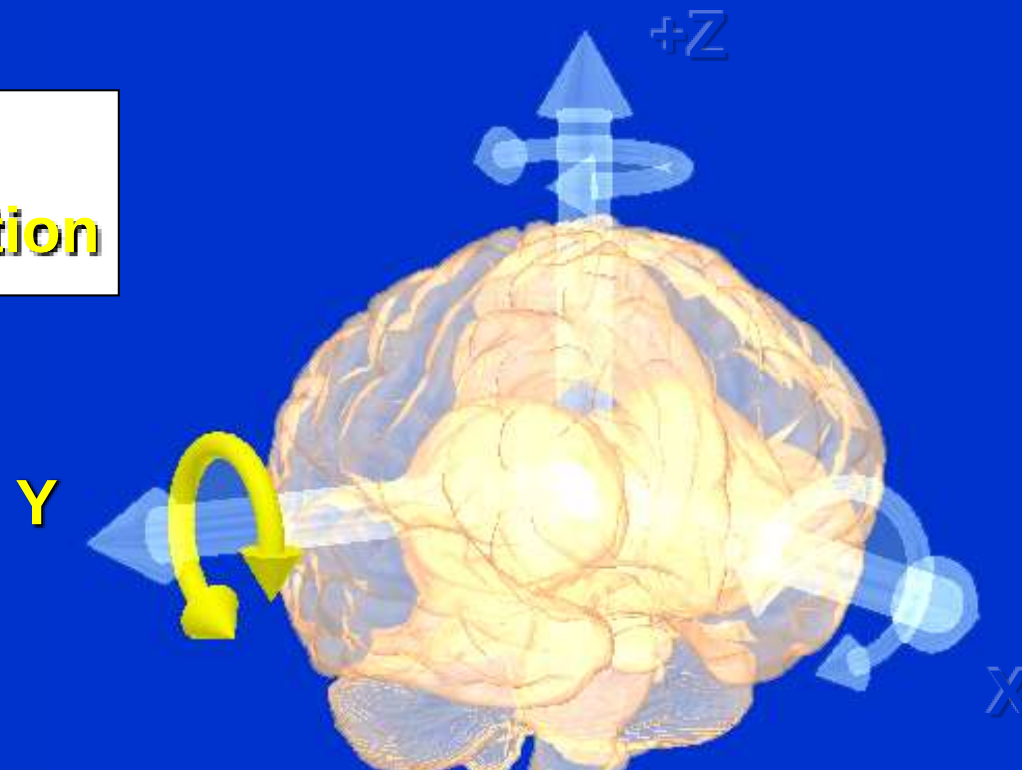
Rotational Acceleration



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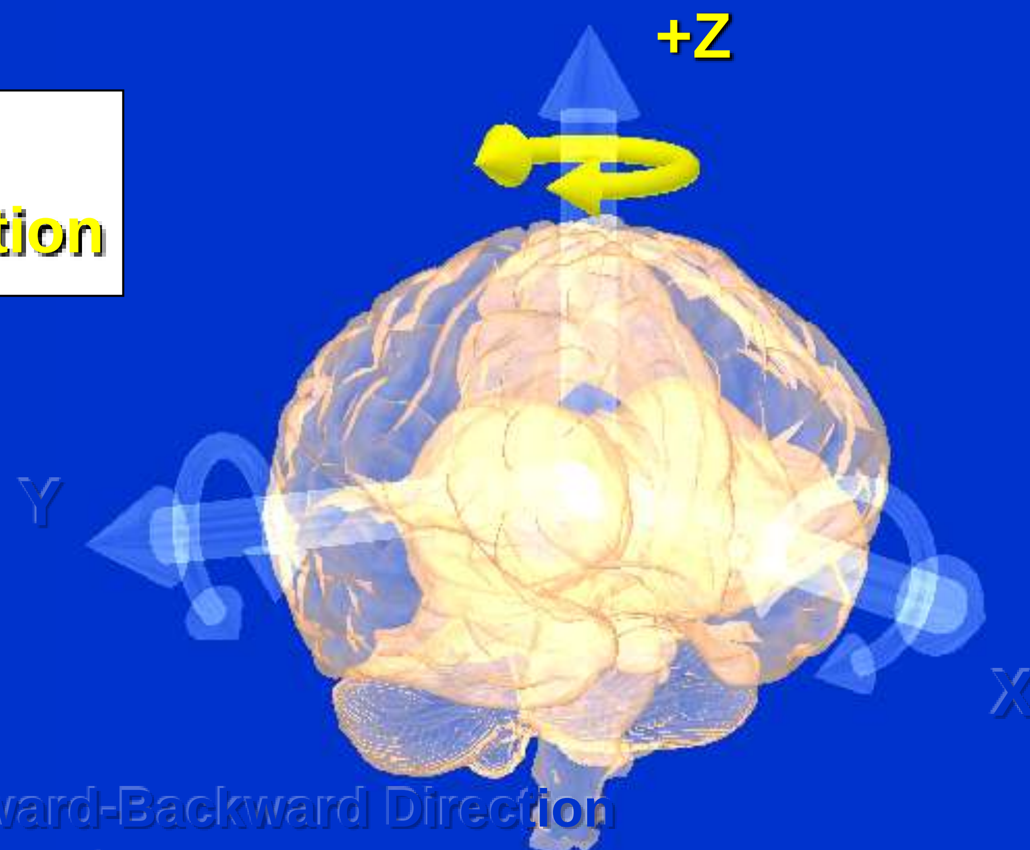

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TYPES OF ACCELERATION

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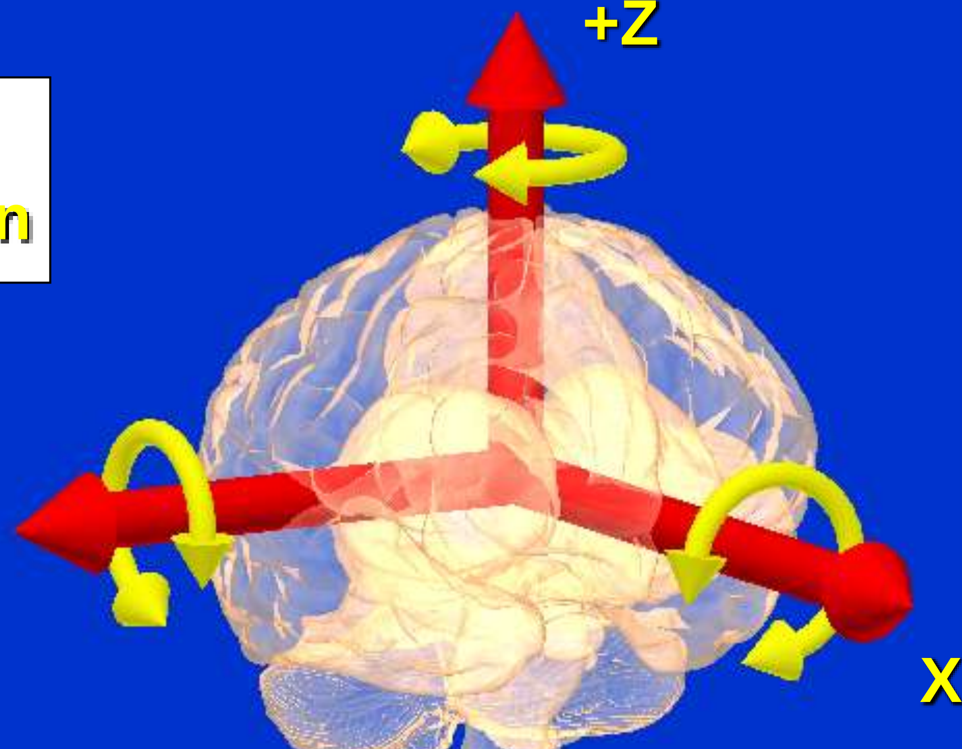

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VEHICLE DYNAMICS ANALYSIS

↓

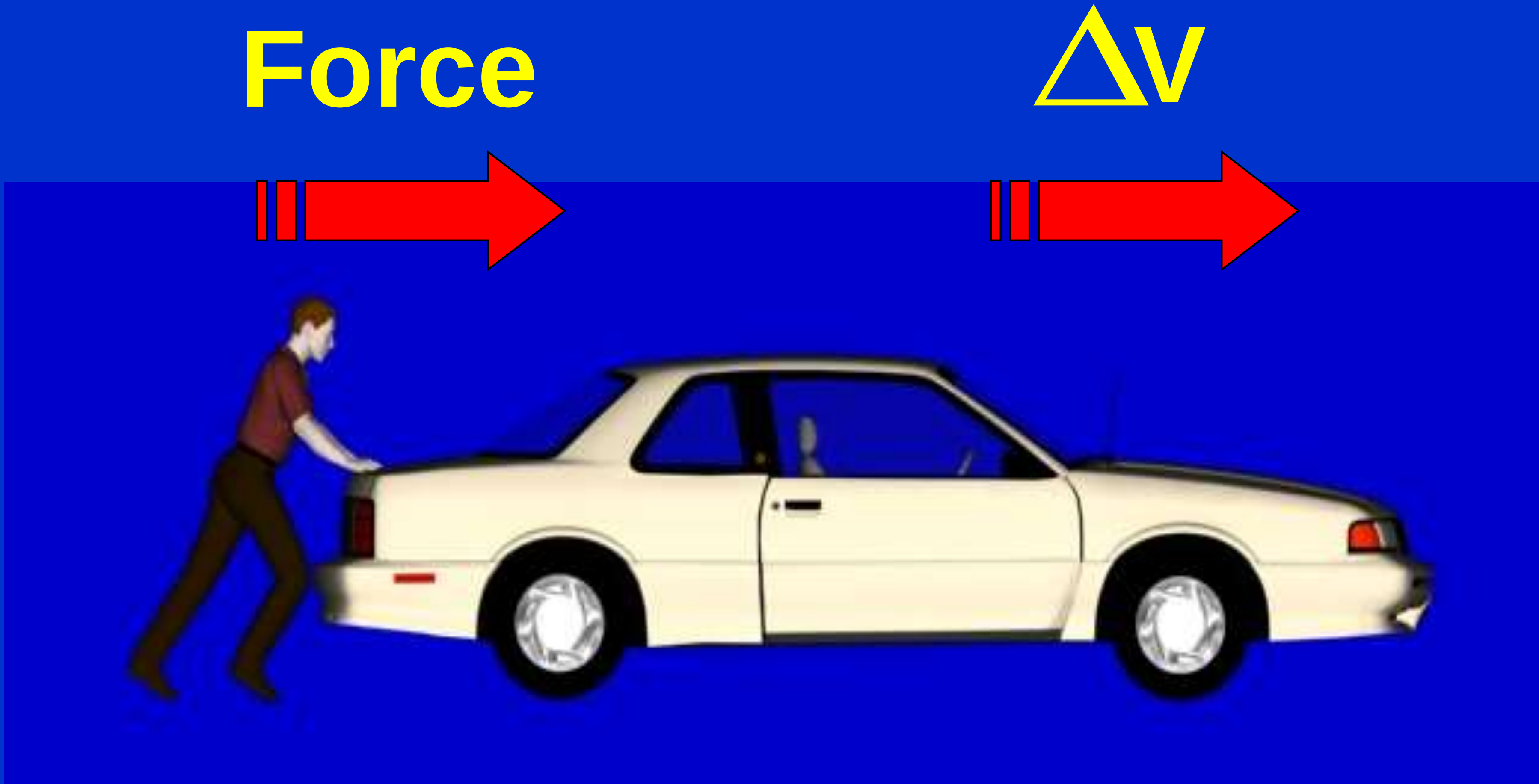
HUMAN BODY DYNAMICS ANALYSIS

↓

HUMAN TOLERANCE LIMITS ANALYSIS

COLLISION SEVERITY

Change in velocity (ΔV)



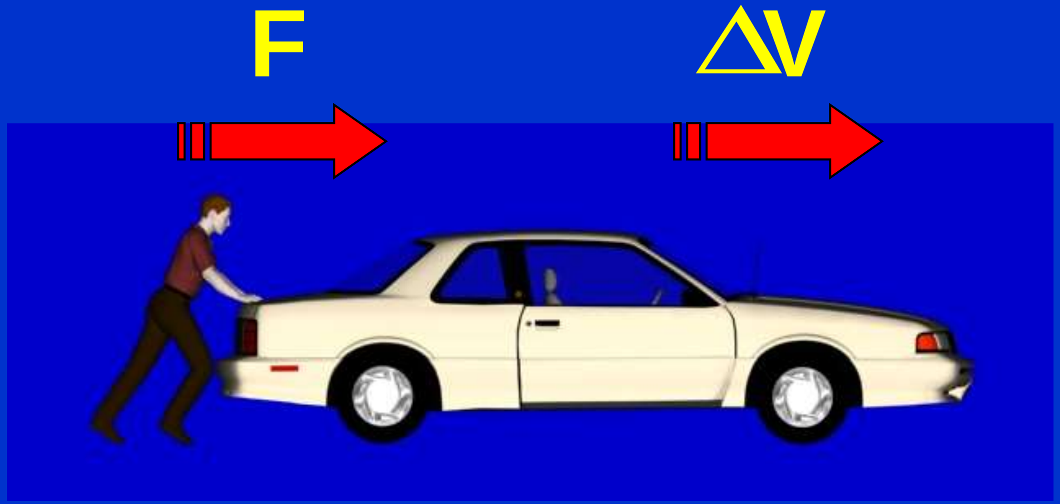
COLLISION SEVERITY

Defined as:

Change in velocity (ΔV)

$$F = m \cdot \frac{\Delta V \text{ (change in velocity)}}{\Delta T \text{ (change in time)}}$$

(Force) (mass)



LAW OF PHYSICS: Newton's 2nd Law (force = mass * acceleration)

COLLISION SEVERITY

Defined as:

Change in velocity (ΔV)

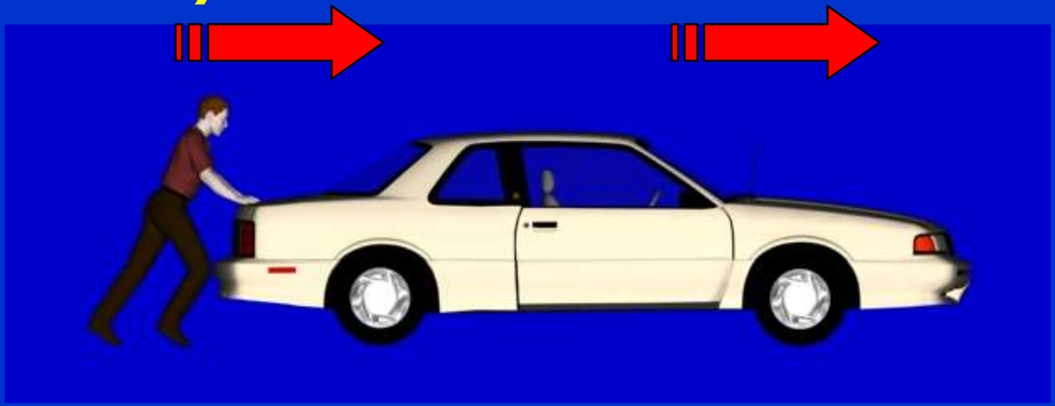
EXAMPLE:

- Weight of the Vehicle = 4,000lb
- Impact Duration = 0.12s
- Change in Velocity = 5mph (7.33 ft/s)

$F_{average}$ = 7,500 lb

F_{peak} = 15,000 lb

ΔV = 5.0 mph



LAW OF PHYSICS: Newton's 2nd 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

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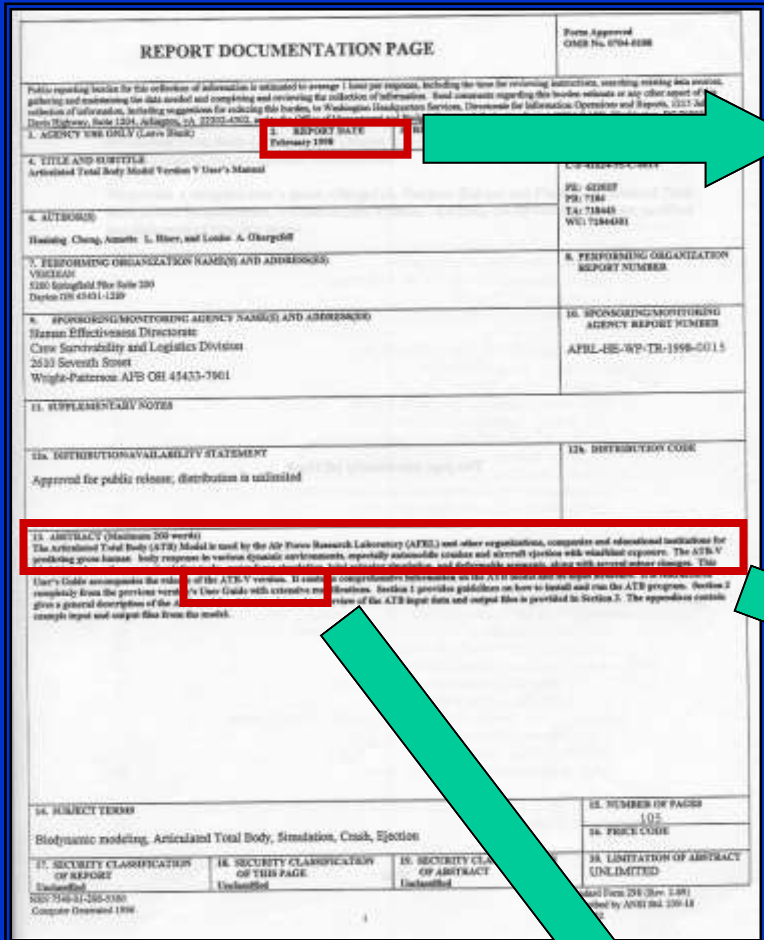
Human Effectiveness Directorate
Crew Survivability and Logistics Division
2610 Seventh Street
Wright-Patterson AFB OH 45433-7901



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4. TITLE AND SUBTITLE Articulated Total Body Model Version V User's Manual	PE: 62202F PR: 7184 TA: 718445 WU: 71844501
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13. ABSTRACT (Maximum 200 words)
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 and aircraft ejection with windblast exposure. The ATB-V ... User's Guide accompanies the release of the ATB-V version. It contains comprehensive information on the ATB model ... completely from the previous version's User Guide with extensive modifications. Section 1 provides guidelines on how to install and run the ATB program. Section 2 gives a general description of the A... review of the ATB input data and output files is provided in Section 3. The appendices contain example input and output files from the model.

14. SUBJECT TERMS Biodynamic modeling, Articulated Total Body, Simulation, Crash, Ejection			15. NUMBER OF PAGES 105
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Computer Generated 1998

“Report Date: February 1998”

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“ATB – V version”

ARMSTRONG LABORATORY

AL/CF-TR-1994-0051

GENERATOR OF BODY DATA (GEBOD) MANUAL

Huaining Cheng

SYSTEMS RESEARCH LABORATORIES, INC.
2800 INDIAN RIPPLE RD.
DAYTON OH 45440

GENERATOR OF BODY DATA (GEBOD) MANUAL

2800 INDIAN RIPPLE RD.
DAYTON OH 45440

MARCH 1994

MANUAL FOR THE PERIOD APRIL 1991 TO MARCH 1994

Approved for public release; distribution is unlimited.

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

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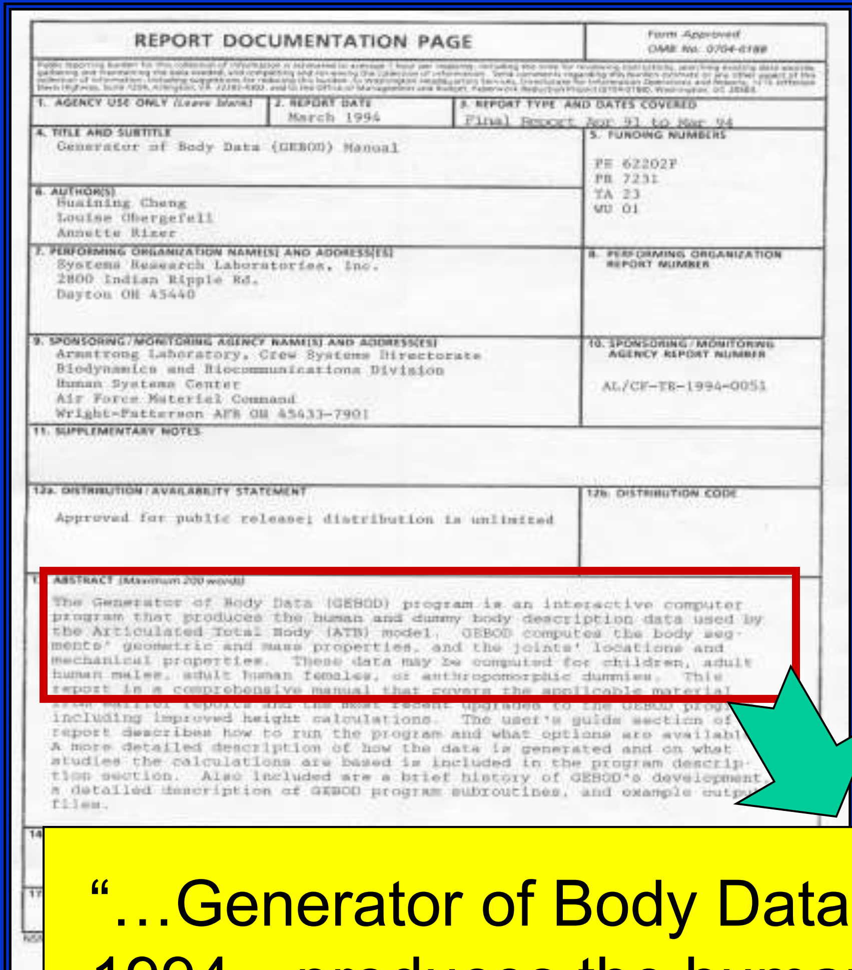
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2800 Indian Ripple Rd.
Dayton OH 45440

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The Generator of Body Data (GEBOD) program is an interactive computer program that produces the human and dummy body description data used by the Articulated Total Body (ATB) model. GEBOD computes the body segments' geometric and mass properties, and the joints' locations and mechanical properties. These data may be computed for children, adult human males, adult human females, or anthropomorphic dummies. This report is a comprehensive manual that covers the applicable material from earlier reports and the most recent upgrades to the GEBOD program including improved height calculations. The user's guide section of report describes how to run the program and what options are available. A more detailed description of how the data is generated and on what studies the calculations are based is included in the program description section. Also included are a brief history of GEBOD's development, a detailed description of GEBOD program subroutines, and example output files.

"…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

SAE TECHNICAL
PAPER SERIES

2000-01-0469

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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Stephen Summers
National Highway Traffic Safety Administration

Time = 0.12 seconds

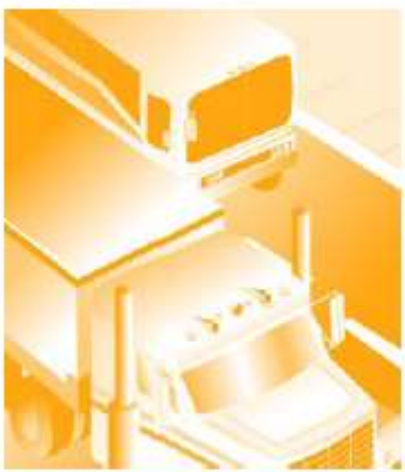
Time = 0.25 seconds

Simulations of Large School Bus Crashes

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 Accident Report

NTSB/HAR-03/03

PB2003-916203
Notation 7567

National Transportation Safety Board
Washington, D.C.

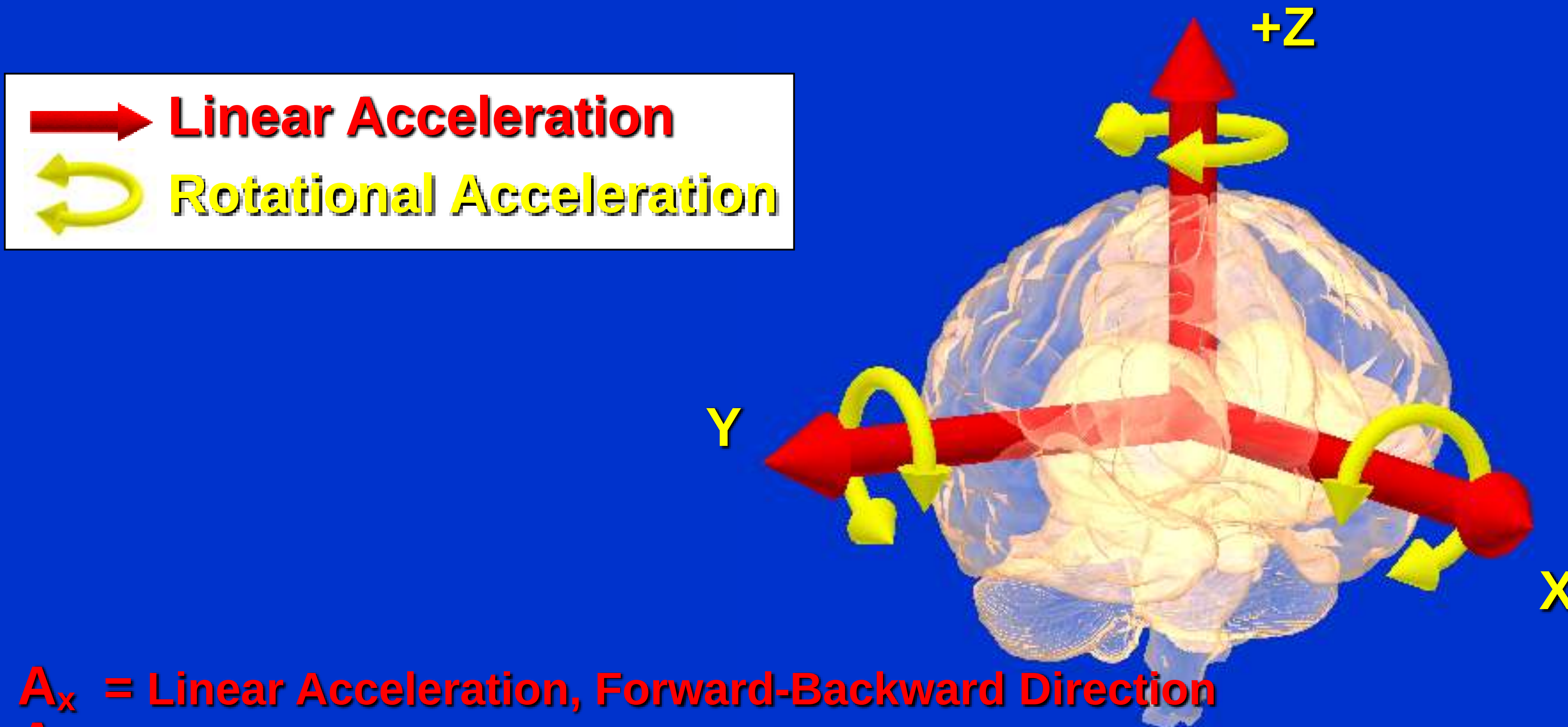
Time = 0.4 seconds (~40° rotation)

Time = 0.8 seconds (~110° rotation)

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

"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.

TYPES OF ACCELERATION



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A_z = Linear Acceleration, Vertical Direction

a_x = Rotational Acceleration, About Forward-Backward Direction

a_y = Rotational Acceleration, About Side to Side Direction

a_z = Rotational Acceleration, About Vertical Direction

Resultant Linear Acceleration

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Resultant Angular Acceleration

$$\alpha = \sqrt{\alpha_x^2 + \alpha_y^2 + \alpha_z^2}$$

BRAIN INJURY TOLERANCE
(Head Angular Acceleration)

$1{,}700 \ rad/s^2$

National Highway Traffic Safety Administration (NHTSA)

The Abbreviated Injury Scale

1990 Revision

Update 98

Founded 1957

Association for the Advancement of Automotive Medicine

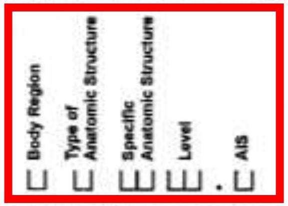
Numerical Injury Identifier

A framework for constructing an impairment scale has recently been proposed by States,[19] 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. Th 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 t case of injuries to the external region, the specific nature of the injury; the fifth and sixth digits identify t level of injury within a specific body region and anatomic structure. The digit to the right of the decimal poi is the AIS score:



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

1. Body Region

1	Head
2	Face
3	Neck
4	Thorax
5	Abdomen
6	Spine
7	Upper Extremity
8	Lower Extremity
9	Unspecified

2. Type of Anatomic Structure

1	Whole Area
2	Vessels
3	Nerves
4	Organs (incl. muscles/lig.)
5	Skeletal (incl. joints)
6	Head - LOC

3. Specific Anatomic Structure or Nature

Whole Area

02	Skin - Abrasion
04	- Contusion
06	- Laceration
08	- Avulsion
10	Amputation
20	Burn
30	Crush
40	Degloving
50	Injury - NFS
60	Penetrating
90	Trauma, other than mechanical

Head - LOC

02	Length of LOC
04, 06, 08	Level of Consciousness
10	Concussion

Spine

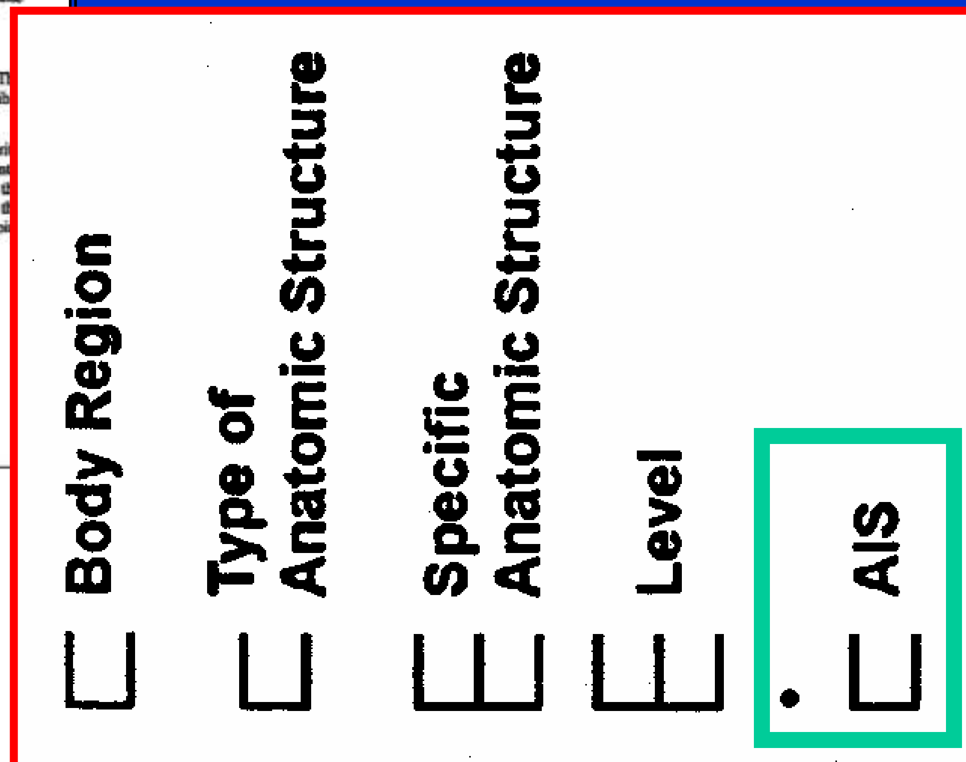
02	Cervical
04	Thoracic
06	Lumbar

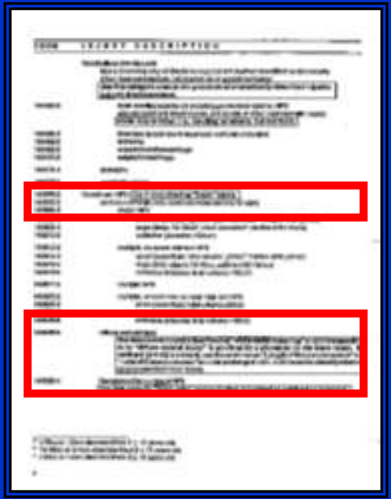
Vessels, Nerves, Organs, Bones, Joints are assigned consecutive two digit numbers beginning with 02.

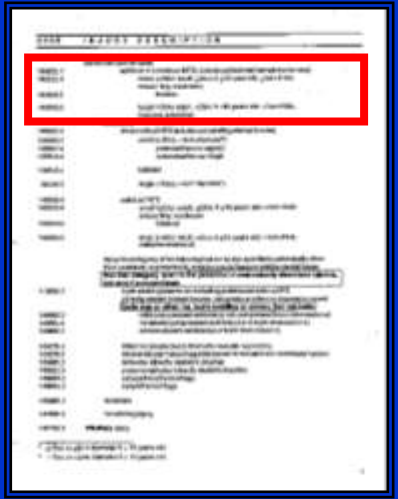
4. Level

Specific injuries are assigned consecutive two-digit numbers beginning with 02.

To the extent possible, within the organizational framework of the AIS, 00 is assigned to an injury NFS as to severity or where only one injury is given in the dictionary for that anatomic structure. 99 is assigned to an injury NFS as to lesion or severity.







140699.3 Cerebrum NFS **Use if described as "brain" injury**

140602.3 contusion NFS [include pericontusional edema for size]

140628.5 diffuse axonal injury

Use this code if (1) DAI is described as "white matter shearing" or (2) if the specific term "diffuse axonal injury" is ascribed by a physician to the brain injury. If neither (1) nor (2) is present, use the sections on "Length of Unconsciousness" or "Loss of Consciousness" to code prolonged LOC. LOC must be directly related to documented head injury.

140629.4 hematoma (hemorrhage) NFS

Use this code for "extra axial" unless further described as epidural or subdural.

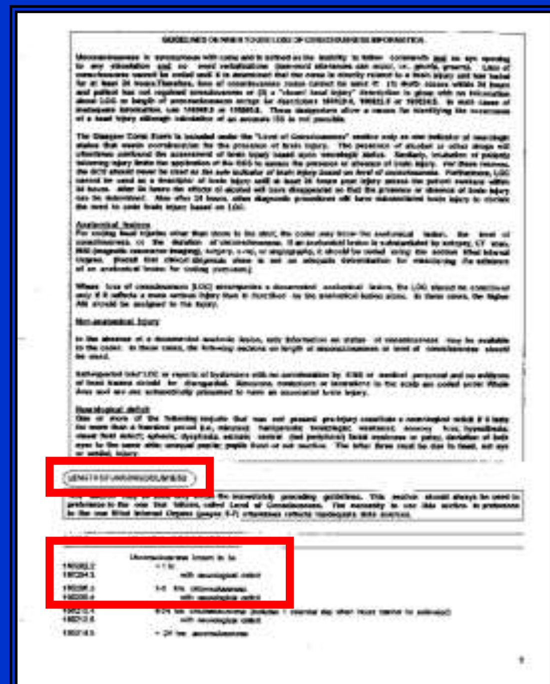
140630.4 epidural or extradural NFS (include perilesional hematoma for size)

140632.4 small (≤50cc adult; ≤25cc if ≤10 year old; ≤1cm thick; smear; tiny; moderate)

140634.5 bilateral

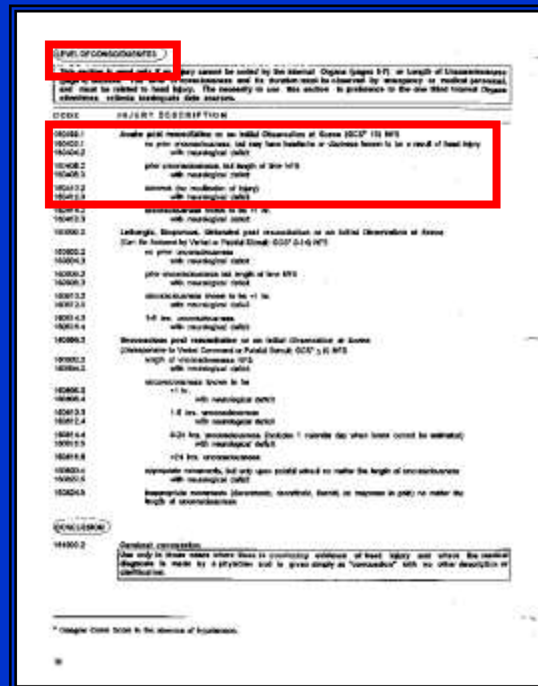
140636.5 large (>50cc adult; >25cc if ≤10 years old; >1cm thick; massive; extensive)

LENGTH OF UNCONSCIOUSNESS



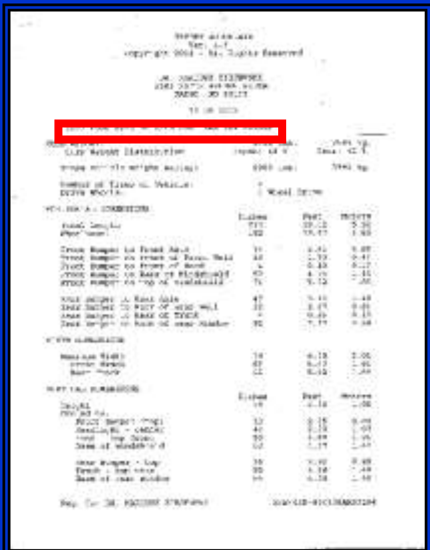
	Unconsciousness known to be
160202.2	< 1 hr.
160204.3	with neurological deficit
160206.3	1-6 hrs. unconsciousness
160208.4	with neurological deficit

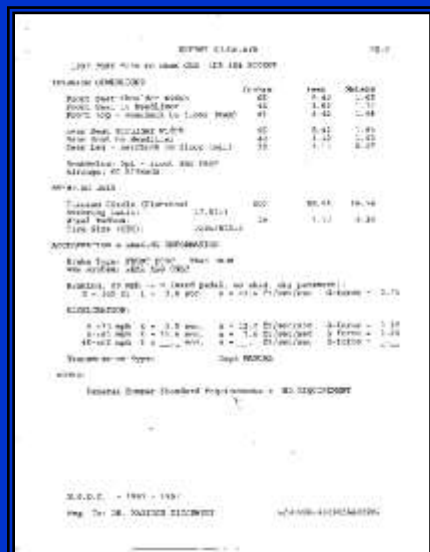
LEVEL OF CONSCIOUSNESS



160499.1	Awake post resuscitation or on Initial Observation at Scene (GCS* 15) NFS
16040 .1	no prior unconsciousness, but may have headache or dizziness known to be a result of head injury
160404.	with neurological deficit
160406.2	prior unconsciousness, but length of time NFS
160408.3	with neurological deficit
16041 .2	amnesia (no recollection of injury)
160412.3	with neurological deficit

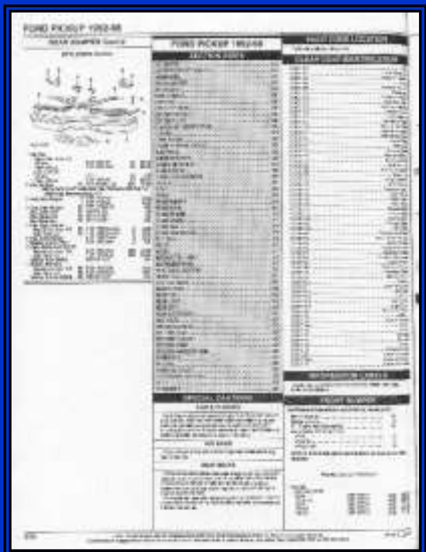
1997 Ford F250 AUTOSTATS

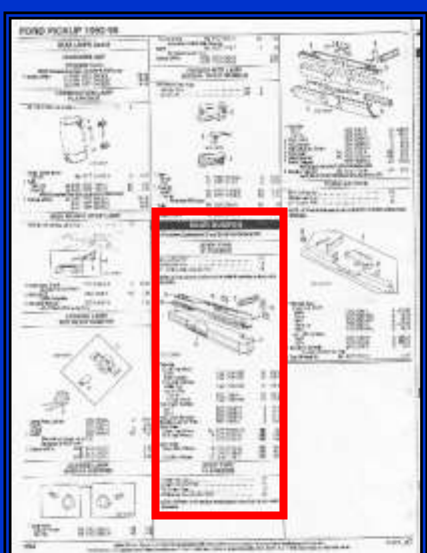




1997 FORD F250 HD CREW CAB 4DR 4X4 PICKUP

1997 Ford Pickup Mitchell Data





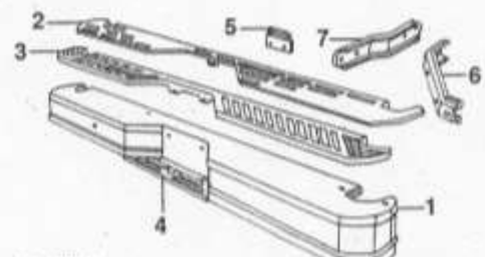
REAR BUMPER

Use Procedure Explanations 27 and 28 with the following text.

STEP TYPE STYLESIDE

Refinish Face Bar	1.7
R&I Bumper Assy	.4
O/H Bumper Assy (Includes R&I)	1.0

NOTE: All Parts in this section are included in overhaul unless noted otherwise.



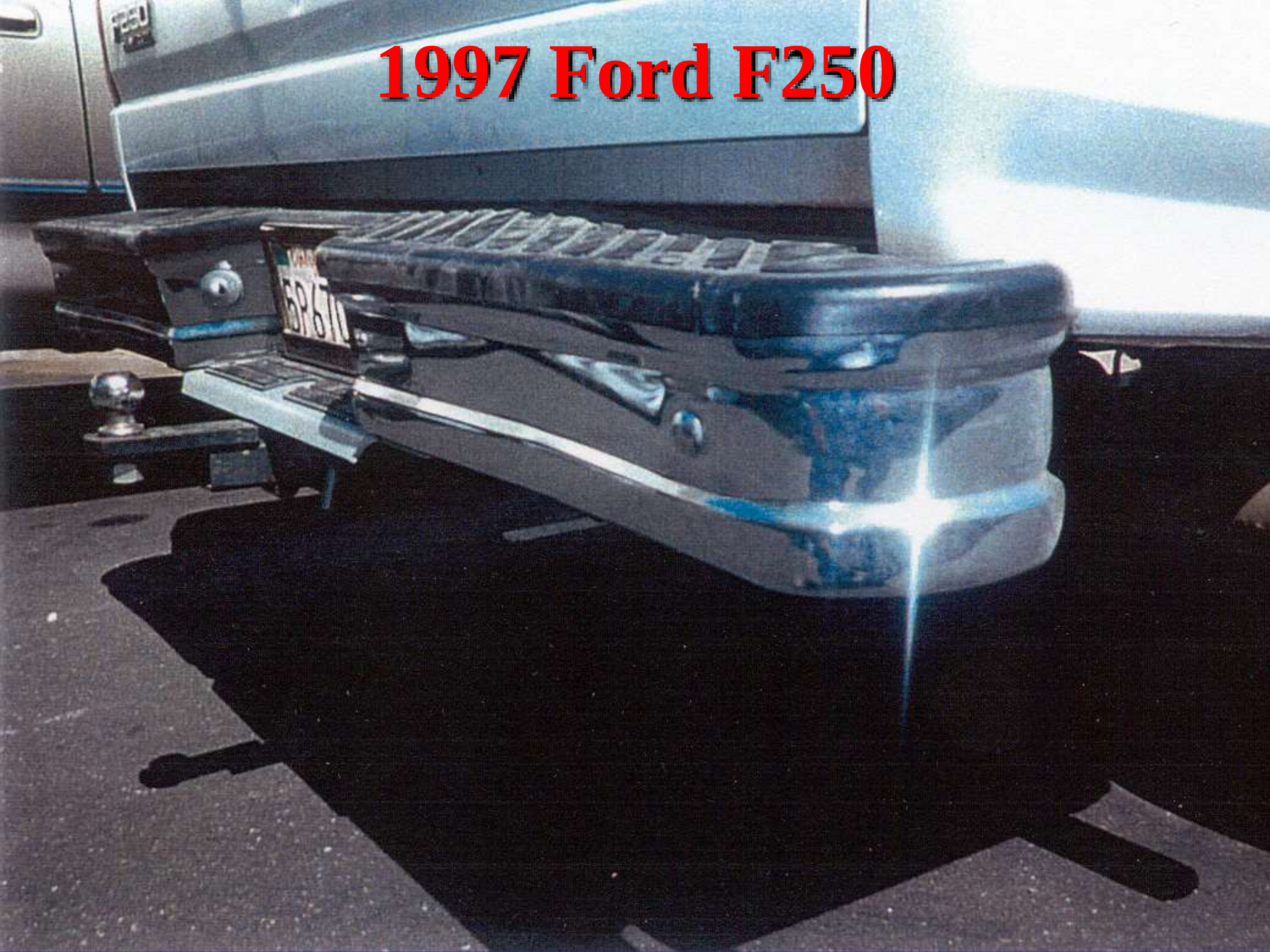
002-09386

1 **Face Bar**				
w/Lightning Model				
Black		YL3Z 17906 AAE	1.0	150.0
Paint to Match		YL3Z 17906 AAE	1.0	150.0
w/o Lightning Model				
w/Nite Pkg		YL3Z 17906 AAE	1.0	150.0
w/o Nite Pkg				
Chrome		F2TZ 17906 A	1.0	316.01
Paint to Match		YL3Z 17906 AAE	1.0	150.0
Pad, Upper Bumper				
2 Type 1		F2TZ 17B807 E	.3	66.1
3 Type 2		E7TZ 17B807 A	.3	44.7
4 **Pad, Lower Bumper**		E7TZ 17B807 B	.2	31.1
5 **Bracket, License Plate**		E8TZ 13406 A	.2	26.5
6 **Arm, Outer**				
Single Rear Wheels	R/L	F7TZ 17795-6 BA	IOH	6.9
Dual Rear Wheels	R	F7TZ 17795 AA	IOH	19.8
	L	F7TZ 17796 AA	IOH	14.6
7 **Arm, Inner**				
Single Rear Wheels	R	F7TZ 17787 AA	IOH	29.0
	L	F7TZ 17788 AA	IOH	28.3
Dual Rear Wheels	R/L	E0TZ 17787 D	IOH	33.9

STEP TYPE FLARESIDE

Refinish Face Bar	1.7
Refinish Valance Panel	1.4
R&I Bumper Assy	.4
O/H Bumper Assy (Includes R&I)	1.2

NOTE: All Parts in this section are included in overhaul unless noted otherwise.

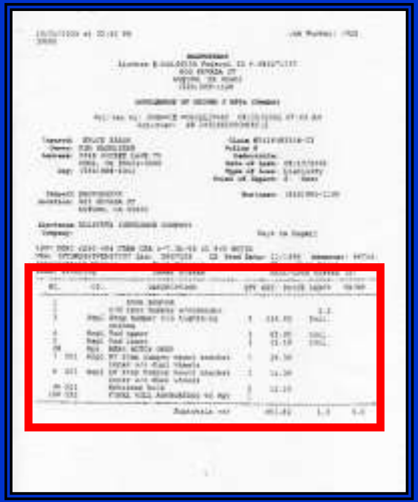

1997 Ford F250

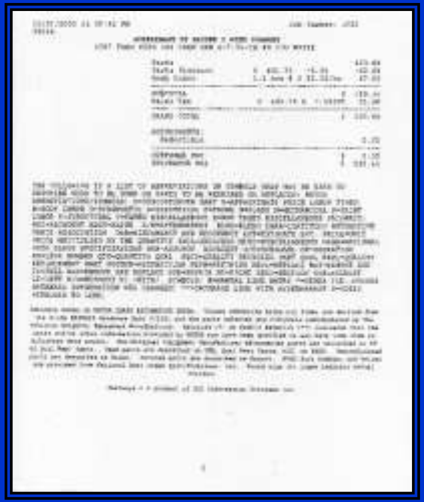
1997 Ford F250

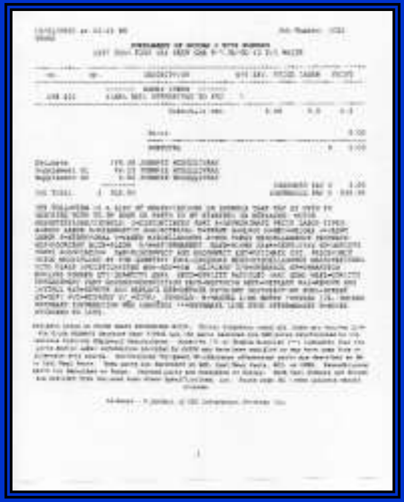

1997 Ford F250


1997 Ford F250
5P67026

1997 Ford Pickup Repairs

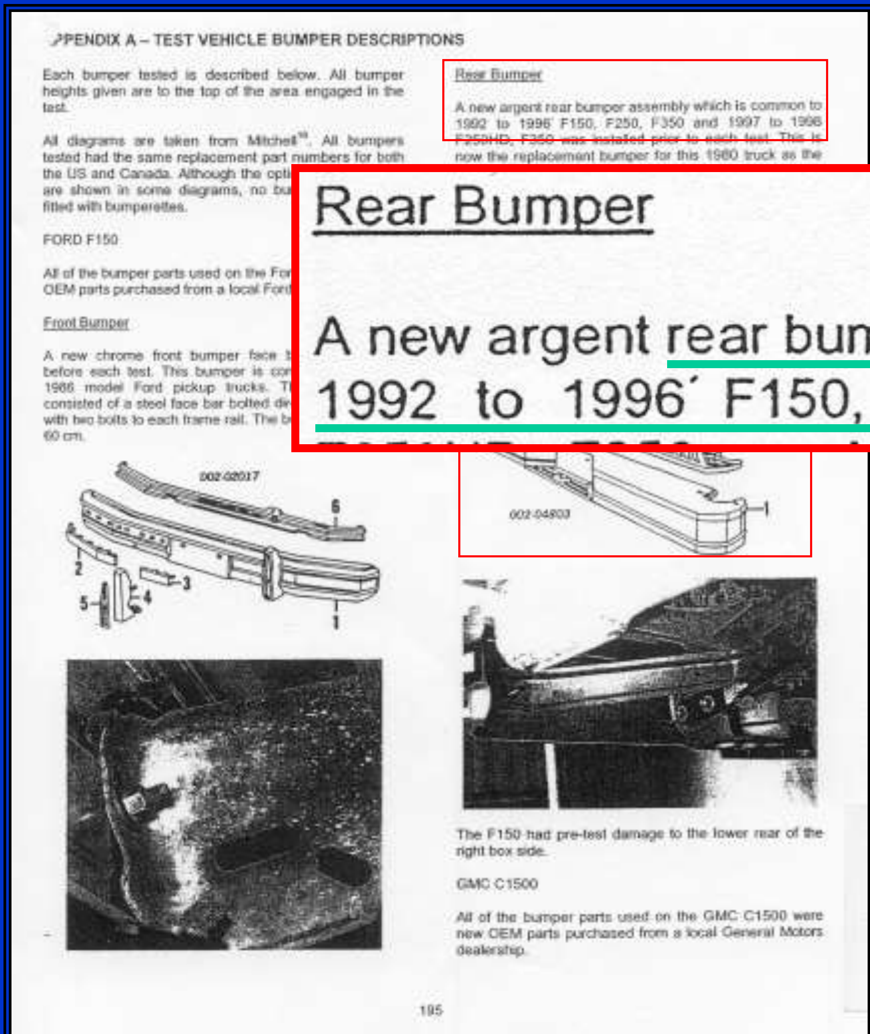






NO.	OP.	DESCRIPTION	QTY	EXT. PRICE	LABOR	PAINT
1		REAR BUMPER				
2		O/H rear bumper w/cushions			1.3	
3		Repl Step bumper w/o Lightning chrome	1	316.00	Incl.	
4		Repl Pad upper	1	63.95	Incl.	
5		Repl Pad lower	1	31.18	Incl.	
6#		Rpr REAR HITCH OPEN				
7	S01	Repl RT Step bumper mount bracket inner w/o dual wheels	1	15.30		
8	S01	Repl LT Step bumper mount bracket inner w/o dual wheels	1	15.30		
9#	S01	Retainer bolt	2	12.10		
10#	S02	FINAL BILL AUTHORIZED TO PAY	1			
		Subtotals ==>		453.83	1.3	0.0

.PPENDIX A – TEST VEHICLE BUMPER DESCRIPTIONS


.PPENDIX A – TEST VEHICLE BUMPER DESCRIPTIONS

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

All diagrams are taken from Mitchell™. 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… fitted with bumperettes.

FORD F150

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

Front Bumper

A new chrome front bumper face b… before each test. This bumper is co… 1986 model Ford pickup trucks. T… consisted of a steel face bar bolted di… with two bolts to each frame 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 F250HD, F350 was installed prior to each test. This is now the replacement bumper for this 1980 truck as the…

The F150 had pre-test damage to the lower rear of the right box side.

GMC C1500

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

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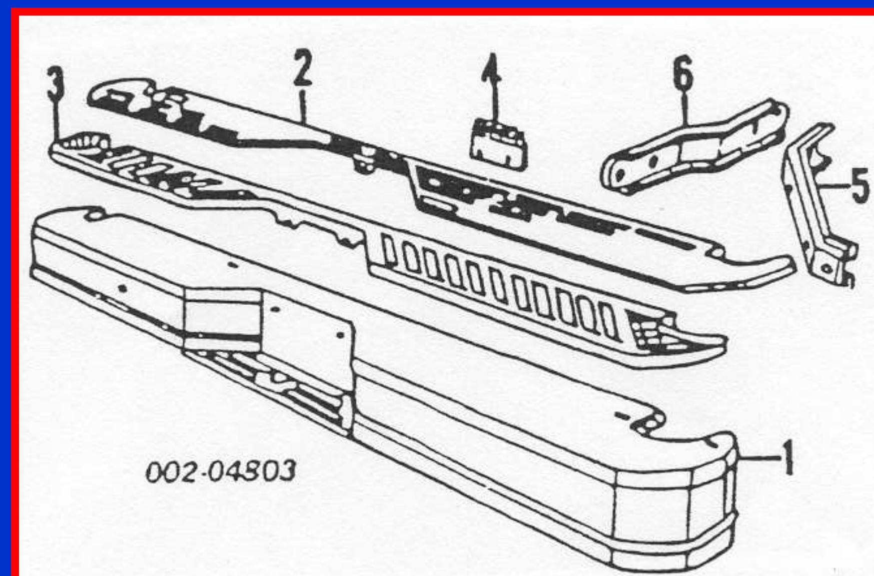
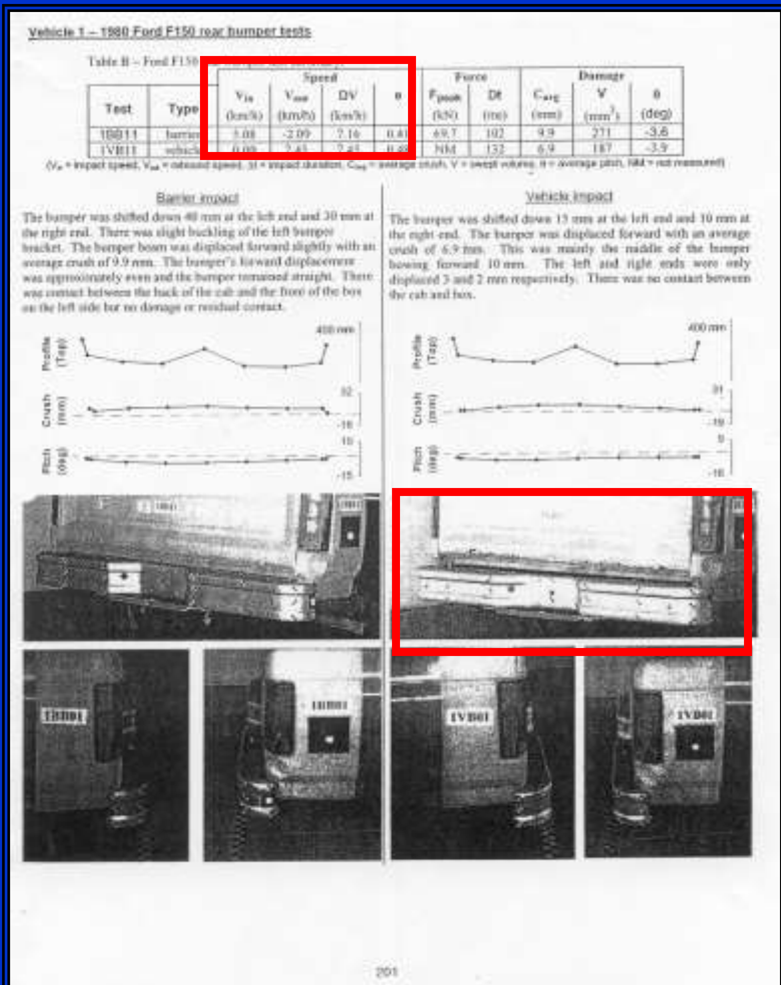
Rear Bumper

A new argent rear bumper assembly which is common to 1992 to 1996´ F150, F250, F350 and 1997 to 1998



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



Vehicle 1 – 1980 Ford F150 rear bumper tests

Table B – Ford F150

Test	Type	Speed V_{in} (km/h)	V_{out} (km/h)	DV (km/h)	e	Force F_{peak} (kN)	Dt (ms)	Damage C_{avg} (mm)	V (mm^3)	θ (deg)
1BB11	barrier	5.08	-2.09	7.16	0.41	69.7	102	9.9	271	-3.6
1VB11	vehicle	0.00	7.45	7.45	0.48	NM	132	6.9	187	-3.9

(V_{in} = impact speed, V_{out} = outbound speed, Δt = impact duration, C_{avg} = average crush, V = swept volume, θ = average pitch, NM = not measured)

Barrier impact

The bumper was shifted down 40 mm at the left end and 30 mm at the right end. There was slight buckling of the left bumper bracket. The bumper beam was displaced forward slightly with an average crush of 9.9 mm. The bumper's forward displacement was approximately even and the bumper remained straight. There was contact between the back of the cab and the front of the box on the left side but no damage or residual contact.

Vehicle impact

The bumper was shifted down 15 mm at the left end and 10 mm at the right end. The bumper was displaced forward with an average crush of 6.9 mm. This was mainly the middle of the bumper bowing forward 10 mm. The left and right ends were only displaced 3 and 2 mm respectively. There was no contact between the cab and box.

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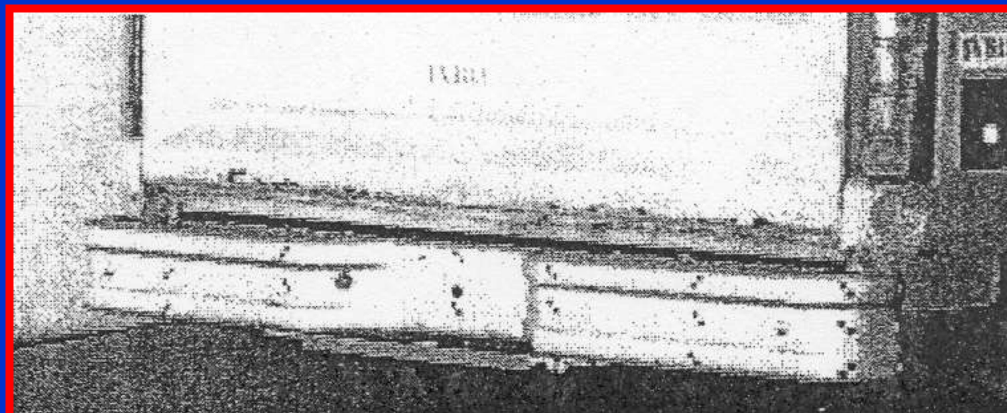
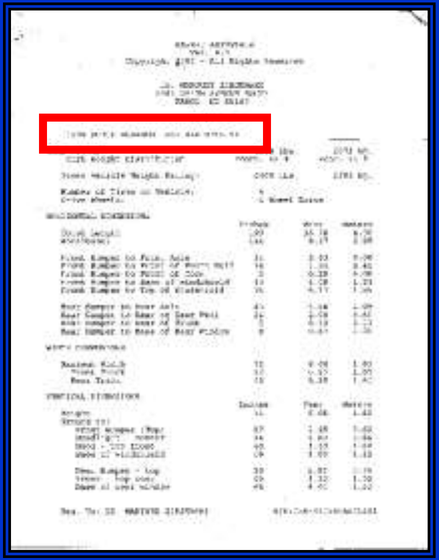
Speed V_{in} (km/h)	V_{out} (km/h)	DV (km/h)	e
5.08	-2.09	7.16	0.41
0.00	7.45	7.45	0.48



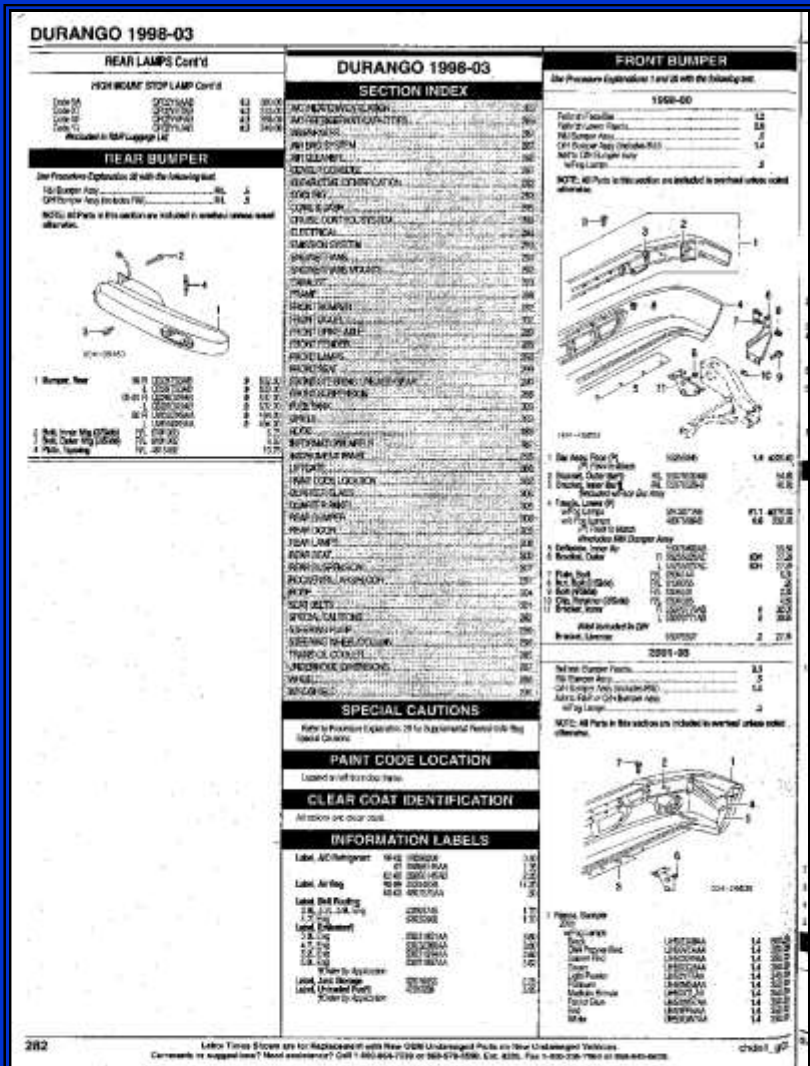
Heinrichs, B., J. Lawrence, B. Allin, J. Bowler, C. Wilkinson, K. Ising and D. King. *Low-Speed Impact Testing of Pickup Truck Bumpers* Society of Automotive Engineers, Inc. 2001.

1999 Dodge Durango AUTOSTATS



1999 DODGE DURANGO 4DR 4X4 UTILITY

1999 Dodge Durango Mitchell Data


DURANGO 1998-03

REAR LAMPS Cont'd

REAR BUMPER

DURANGO 1998-03

SECTION INDEX

SPECIAL CAUTIONS

PAINT CODE LOCATION

CLEAR COAT IDENTIFICATION

INFORMATION LABELS

FRONT BUMPER

1998-00

2001-03

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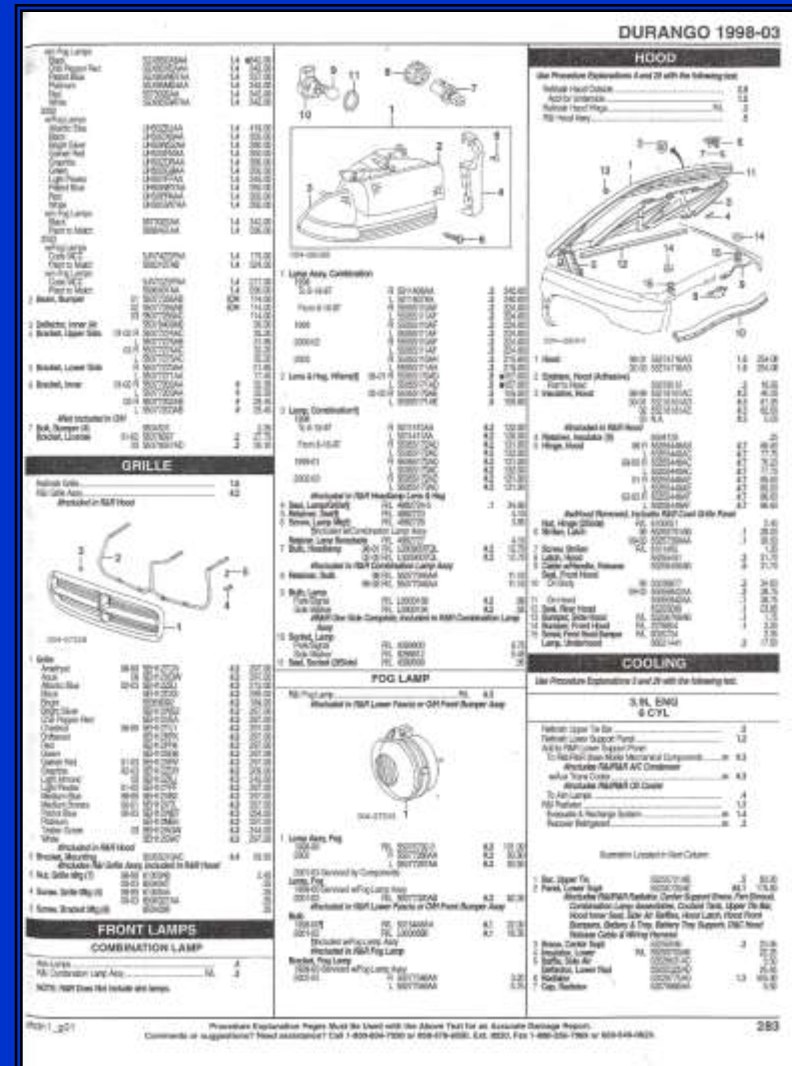

DURANGO 1998-03

GRILLE

FRONT LAMPS

COMBINATION LAMP

FOG LAMP

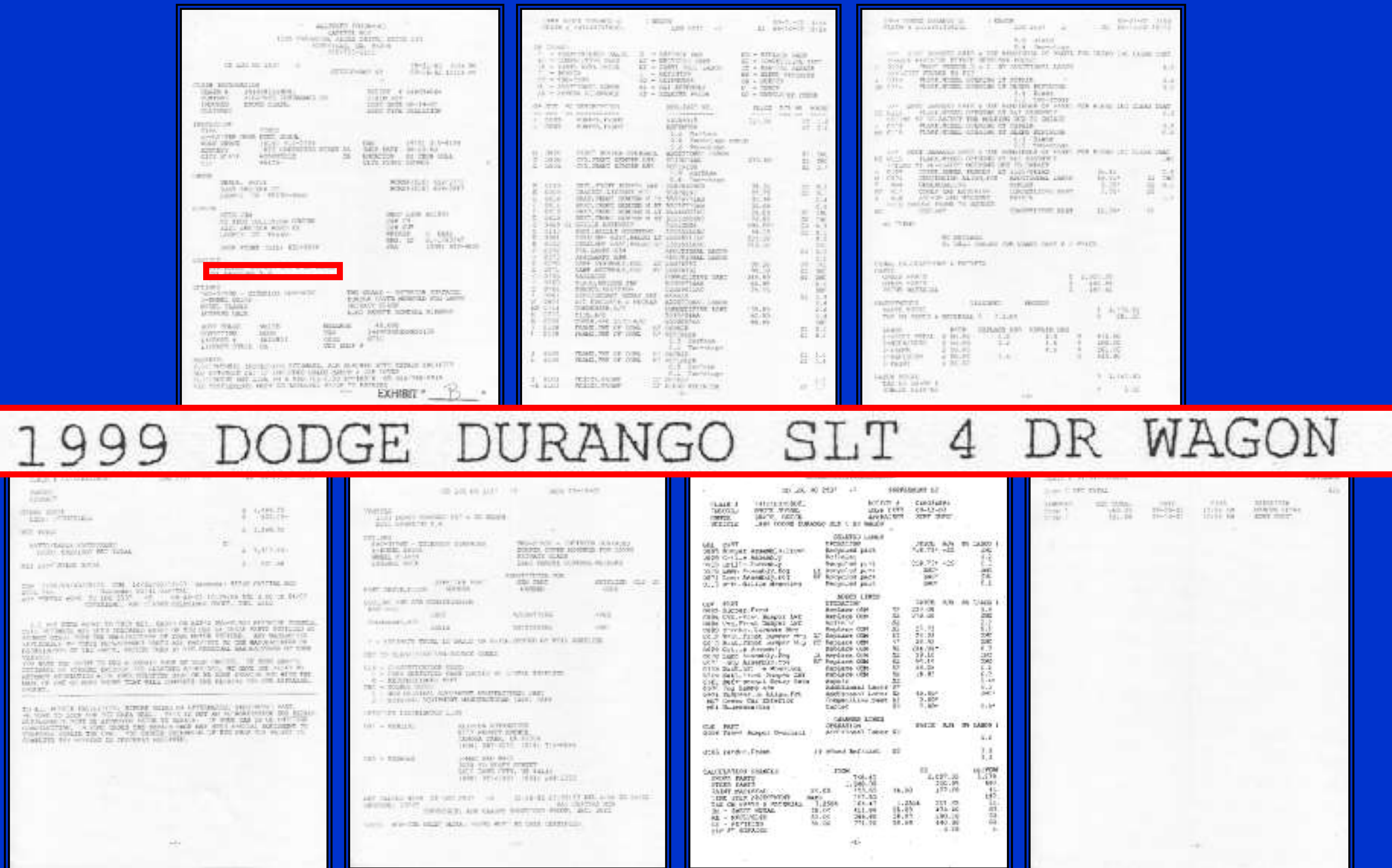
HOOD

COOLING

3.9L ENG
6 CYL

283

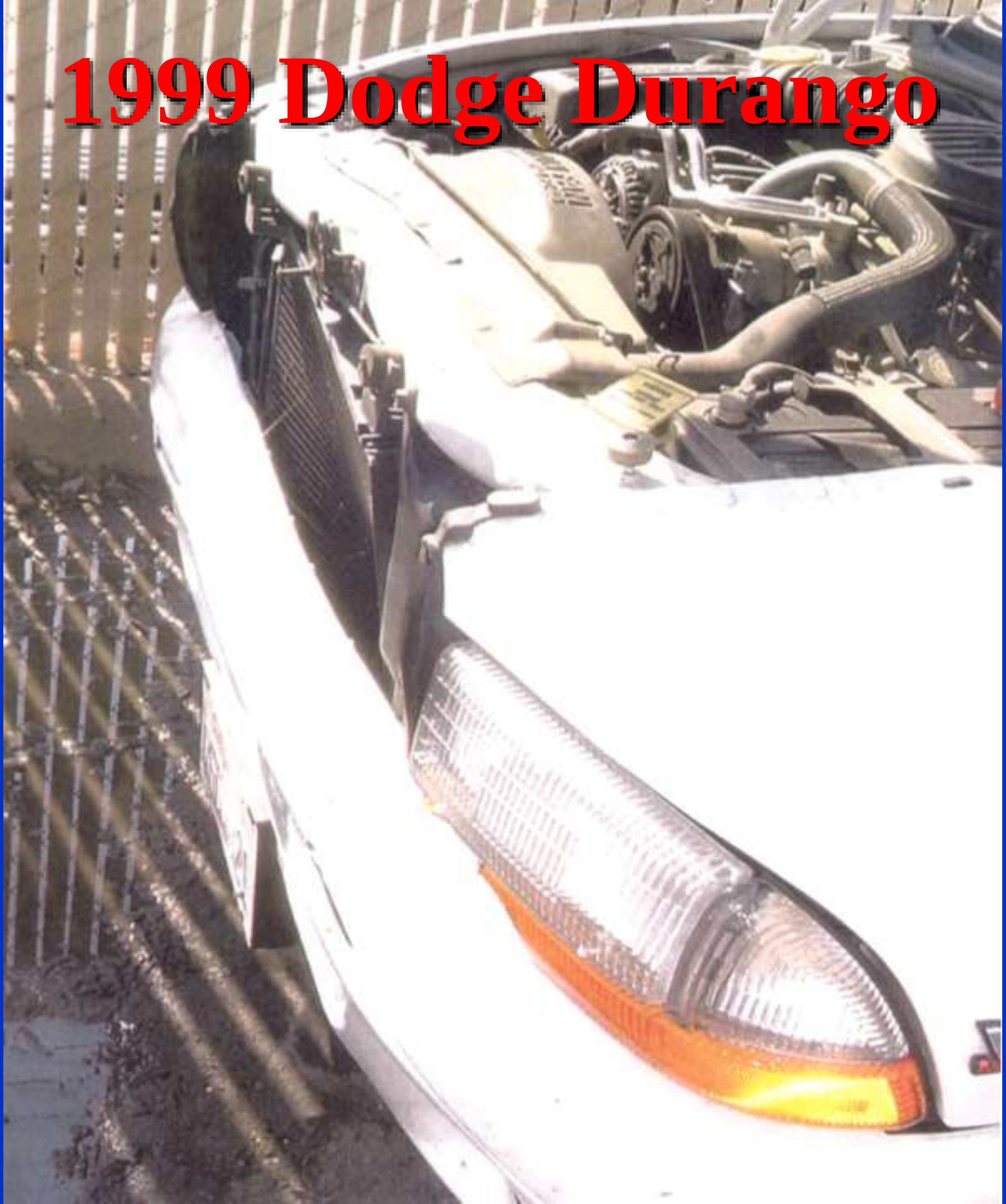
1999 Dodge Durango Repairs



1999 Dodge Durango

1999 Dodge Durango

1999 Dodge Durango



COLLISION SEVERITY

$\Delta V = 7 - 10$ mph

(10.3 – 14.7 ft/s)

COLLISION SEVERITY

Minimum

Data

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

Equations

$$F = m \bullet a$$

Analysis

$F_{average}$ = 15,000lb

F_{peak} = 30,000lb

COLLISION SEVERITY

Maximum

Data

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

Equations

$$F = m \cdot a$$

Analysis

$F_{average}$ = 21,000lb

F_{peak} = 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

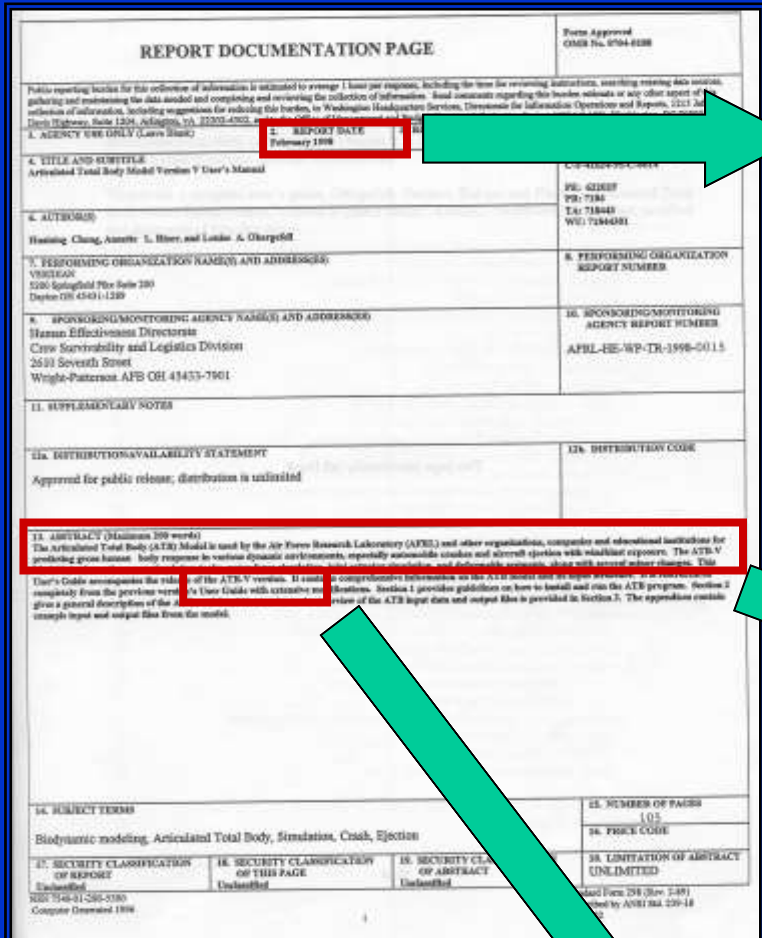
UNITED STATES AIR FORCE RESEARCH LABORATORY

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



REPORT DOCUMENTATION PAGE

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6. AUTHOR(S) Huaining Cheng, Annette L. Rizer, and Louise A. Obergefell

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) VERIDIAN 5200 Springfield Pike Suite 200 Dayton OH 45431-1289

8. PERFORMING ORGANIZATION REPORT NUMBER

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11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words) 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 and aircraft ejection with windblast exposure. The ATB-V User's Guide accompanies the release of the ATB-V version. It contains comprehensive information on the ATB model and its application. ... User's Guide with extensive modifications. Section 1 provides guidelines on how to install and run the ATB program. Section 2 gives a general description of the ATB ... of the ATB input data and output files is provided in Section 3. The appendices contain example input and output files from the model.

14. SUBJECT TERMS Biodynamic modeling, Articulated Total Body, Simulation, Crash, Ejection

15. NUMBER OF PAGES 105

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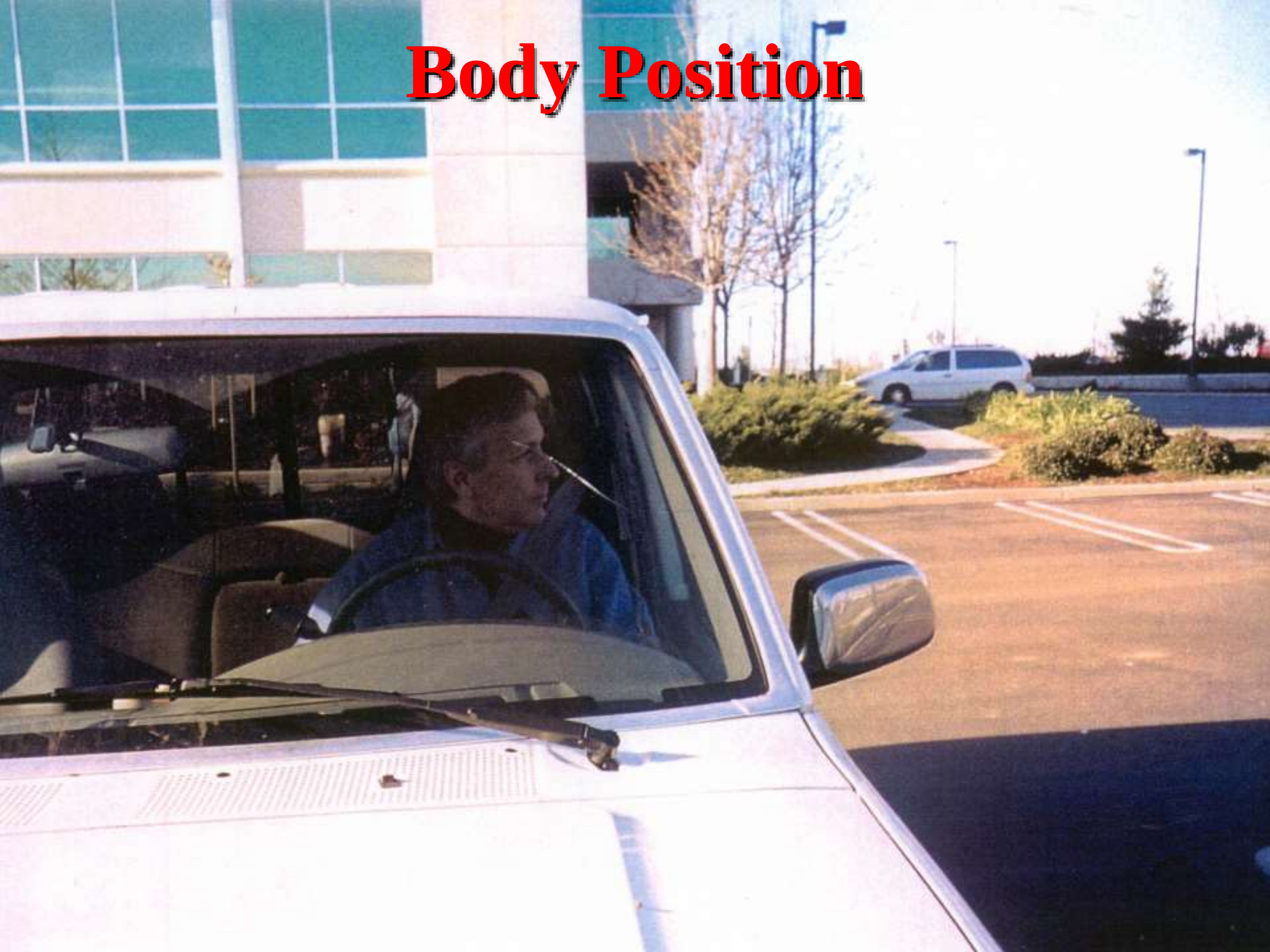
Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

“Report Date: February 1998”

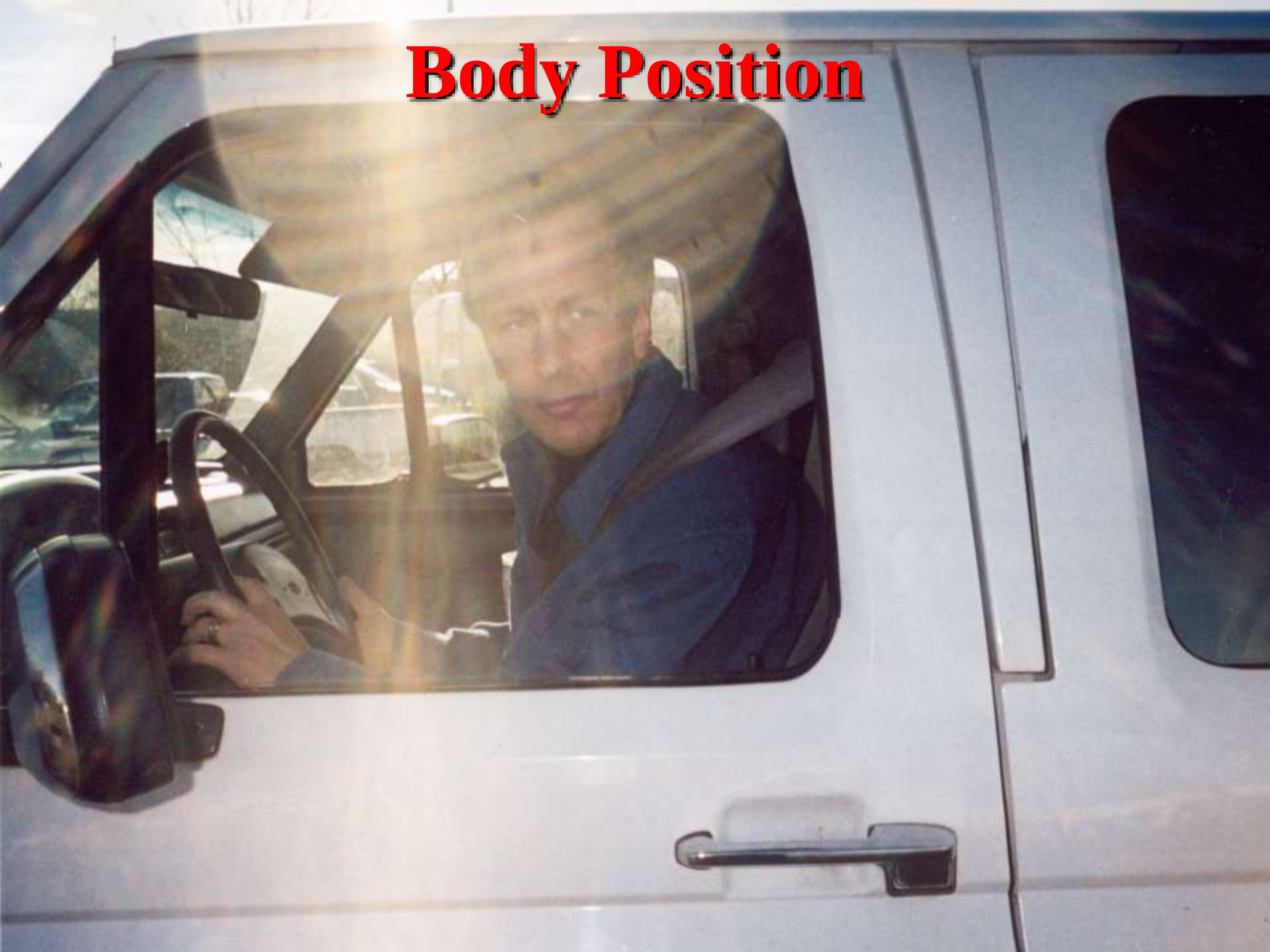
“The Articulated Total Body (ATB) Model is used by the Air Force Research Laboratory (AFRL) and other organizations, companies and educational institutions for predicting gross ***human body response*** in various dynamic environments, ***especially automobile crashes***

“ATB – V version”

Body Position

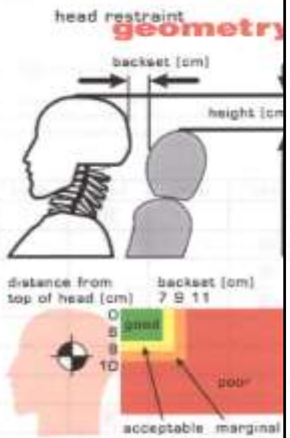


Body Position



PASSENGER CARS, PICKUPS, AND UTILITY VEHICLES

Choose manufacturer:



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 centimeters (3.5 inches) below the top. The backset, or distance behind the head, should be as small as possible. Backsets of more than 10 centimeters (about 4 inches) have been associated with increased symptoms of neck injury in crashes.

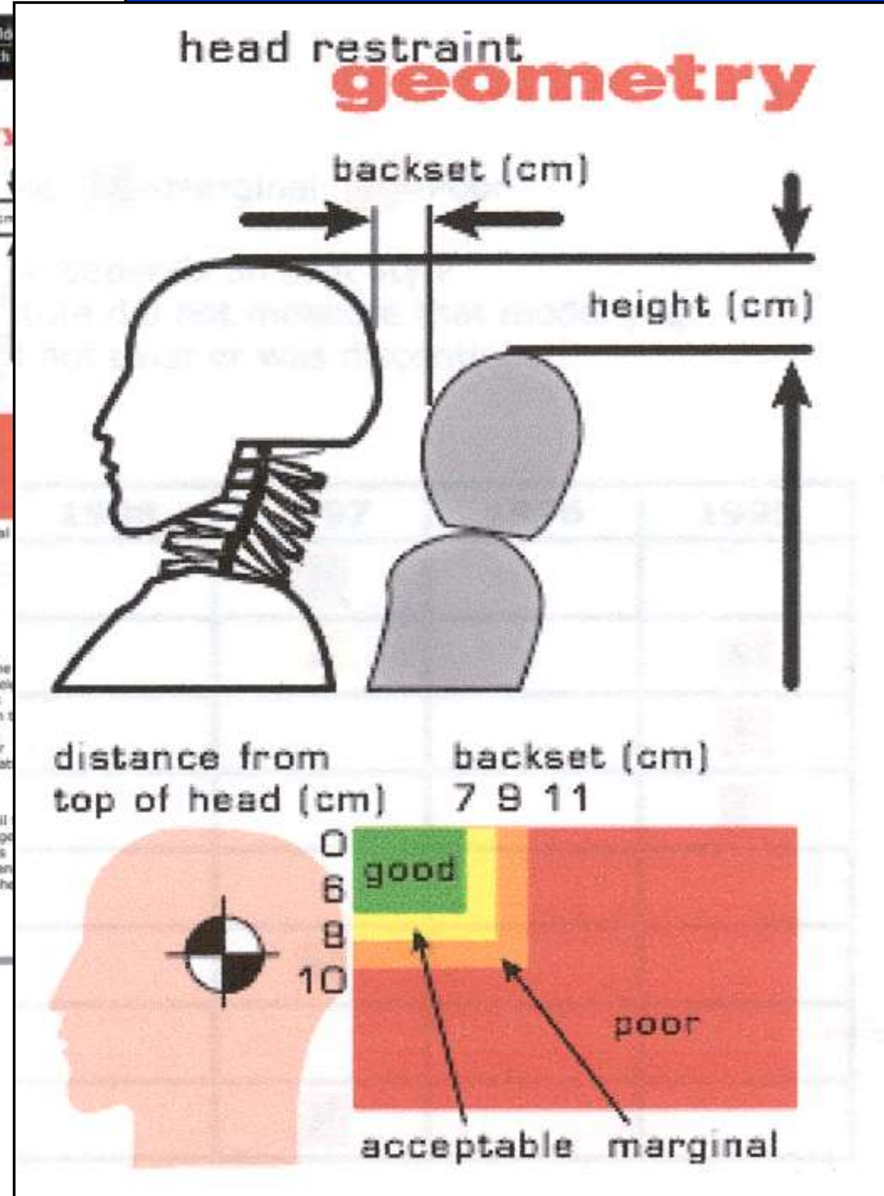
Institute ratings are good predictors of how well people will be protected in rear-end crashes -- drivers with restraints rated good are less likely than those with poor restraints to claim neck injuries. Head restraint ratings for hundreds of passenger vehicles are listed by vehicle make and series. Various head/seat combinations are rated (not every available seat option in every series has been measured). The restraints are measured with the angle of the torso at about 25 degrees, a typical seatback 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 head 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 backset place it also defines its rating. The rating for a head restraint that adjusts in hei and/or backset depends on whether it locks 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 does lock, height and backset are measured twice -- in t down position, and in the most favorable 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 rat more than one rating is shown. This procedure is used to rate the head restraints in 1995-99 models.

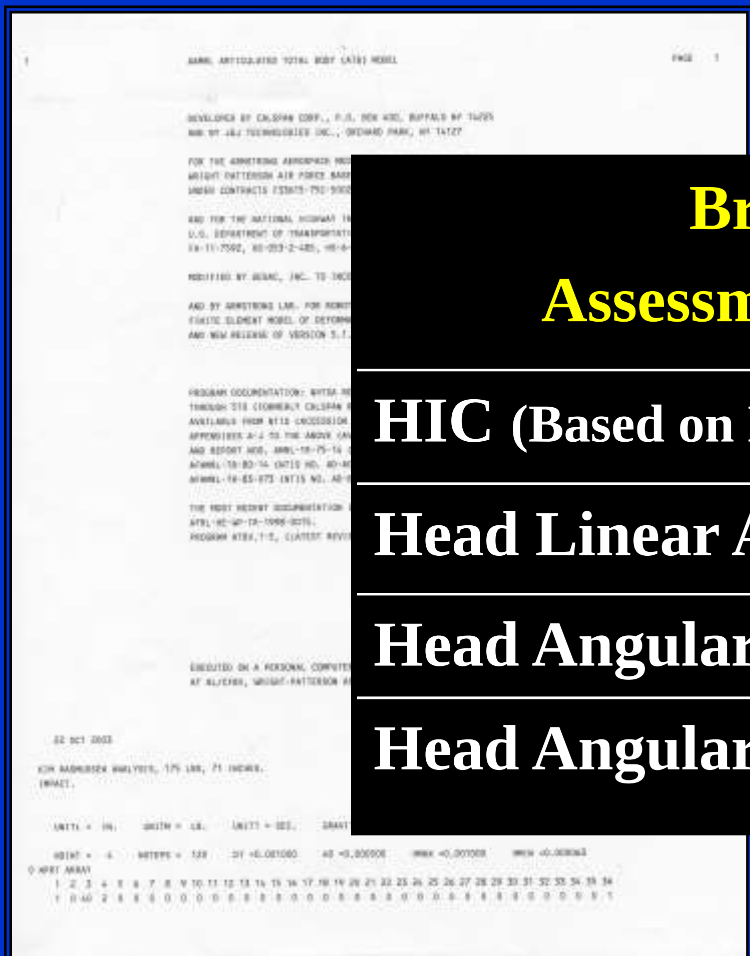
A modification of the above procedure has become an international standard available from the Research Council Automobile Repairs (RCAR). Ratings for fixed head restraints and adjustable restraints that don't lock is unchange under the international RCAR protocol. For adjustable restraints that lock 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 he restraints in 2000 and later models according to the RCAR procedure.

Last modified: 23-Jan-2002



Case Specific Computer Analysis

(Articulated Total Body – ATB Computer Output)



Brain Injury Assessment Parameters	Results*
HIC (Based on Head Linear Acceleration)	**8.3**
Head Linear Acceleration (g)	**17.7**
Head Angular Velocity (rad/s)	**12.1**
Head Angular Acceleration (rad/s^2)	**1,633**

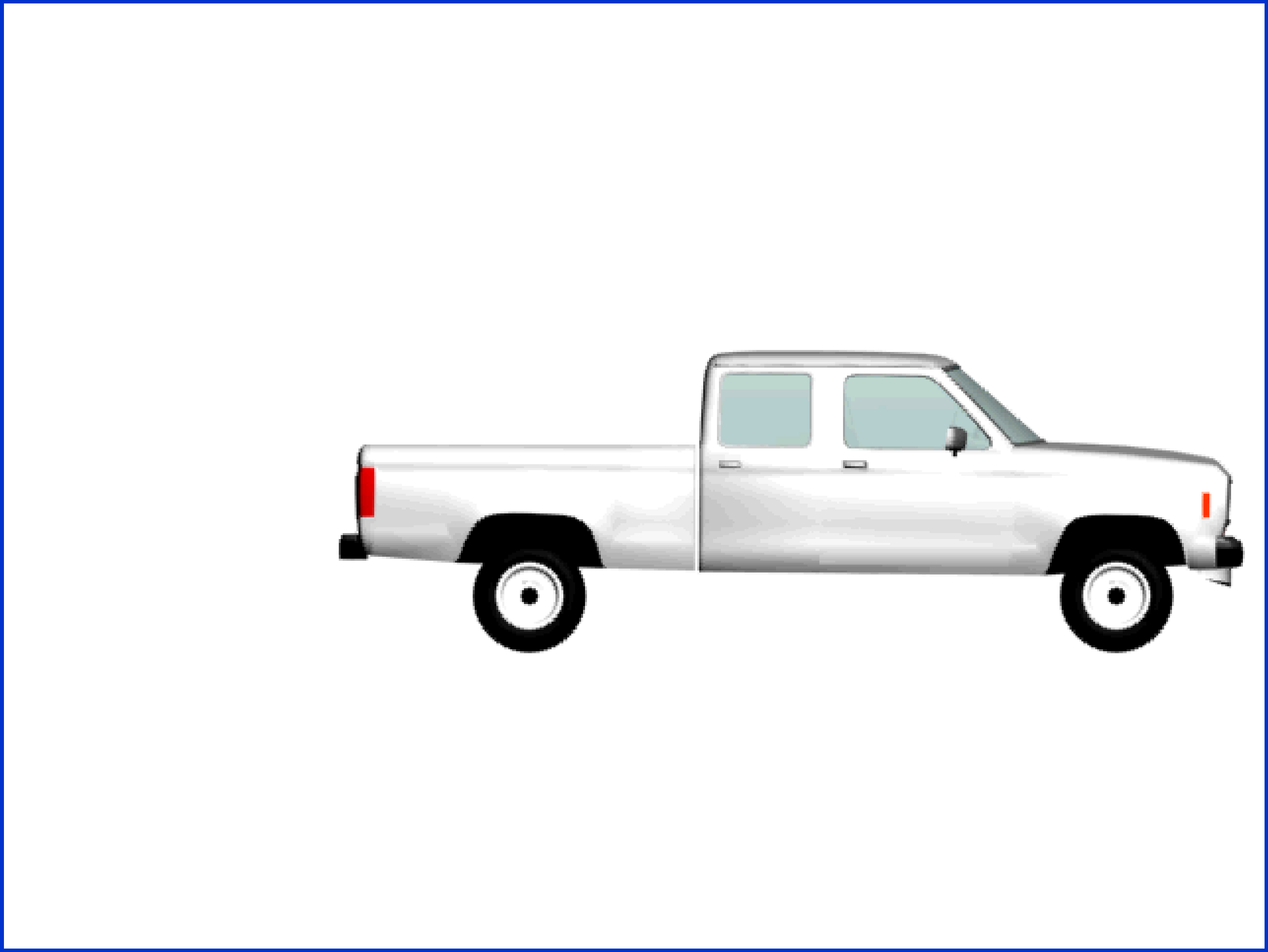
* ATB Output

BRAIN INJURY TOLERANCE
(Head Angular Acceleration)

$1{,}700\ rad/s^2$

National Highway Traffic Safety Administration (NHTSA)

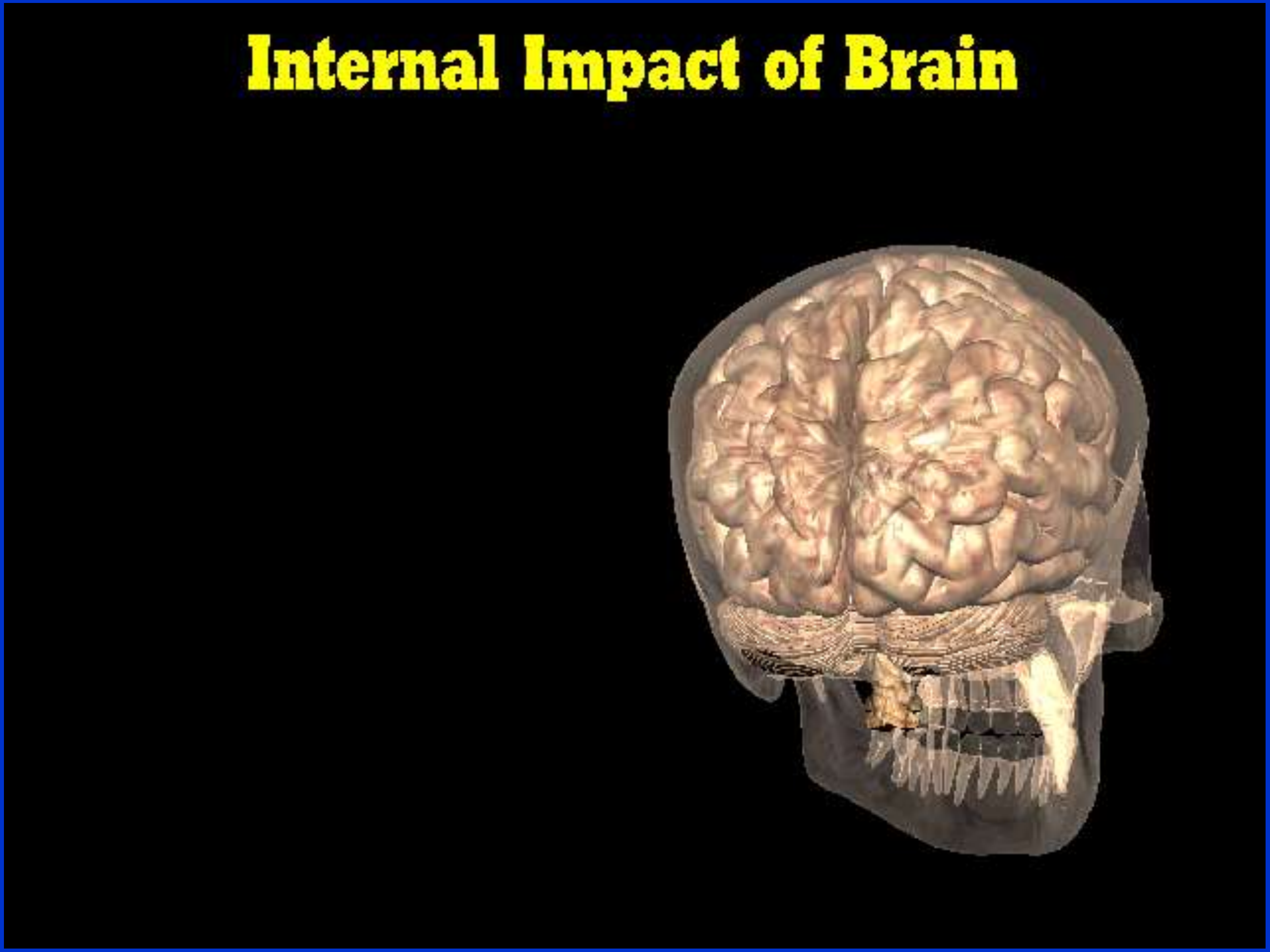
Collision



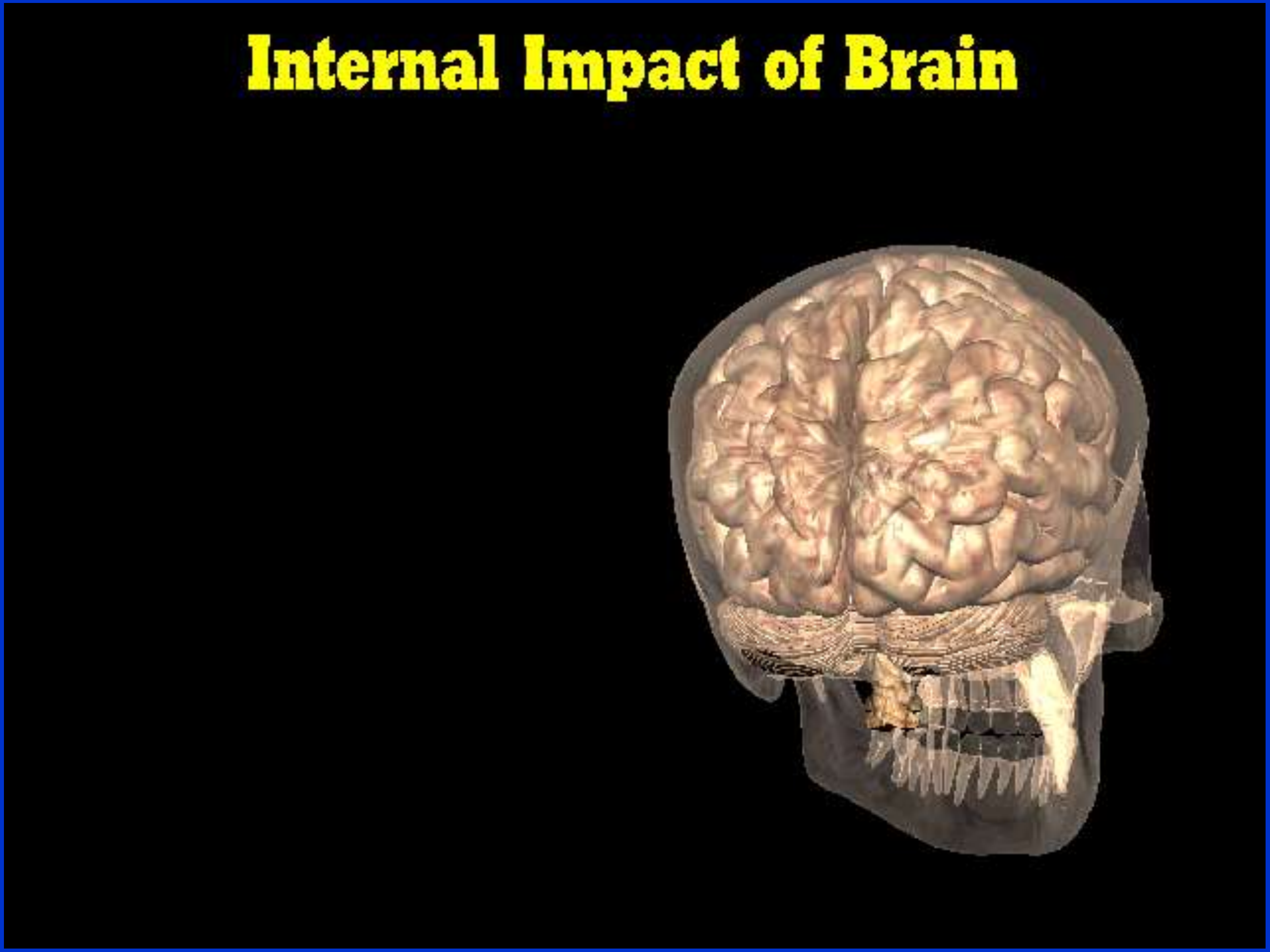
Body Motion – Real Time

Body Motion – Slow Motion

Impact – Real Time



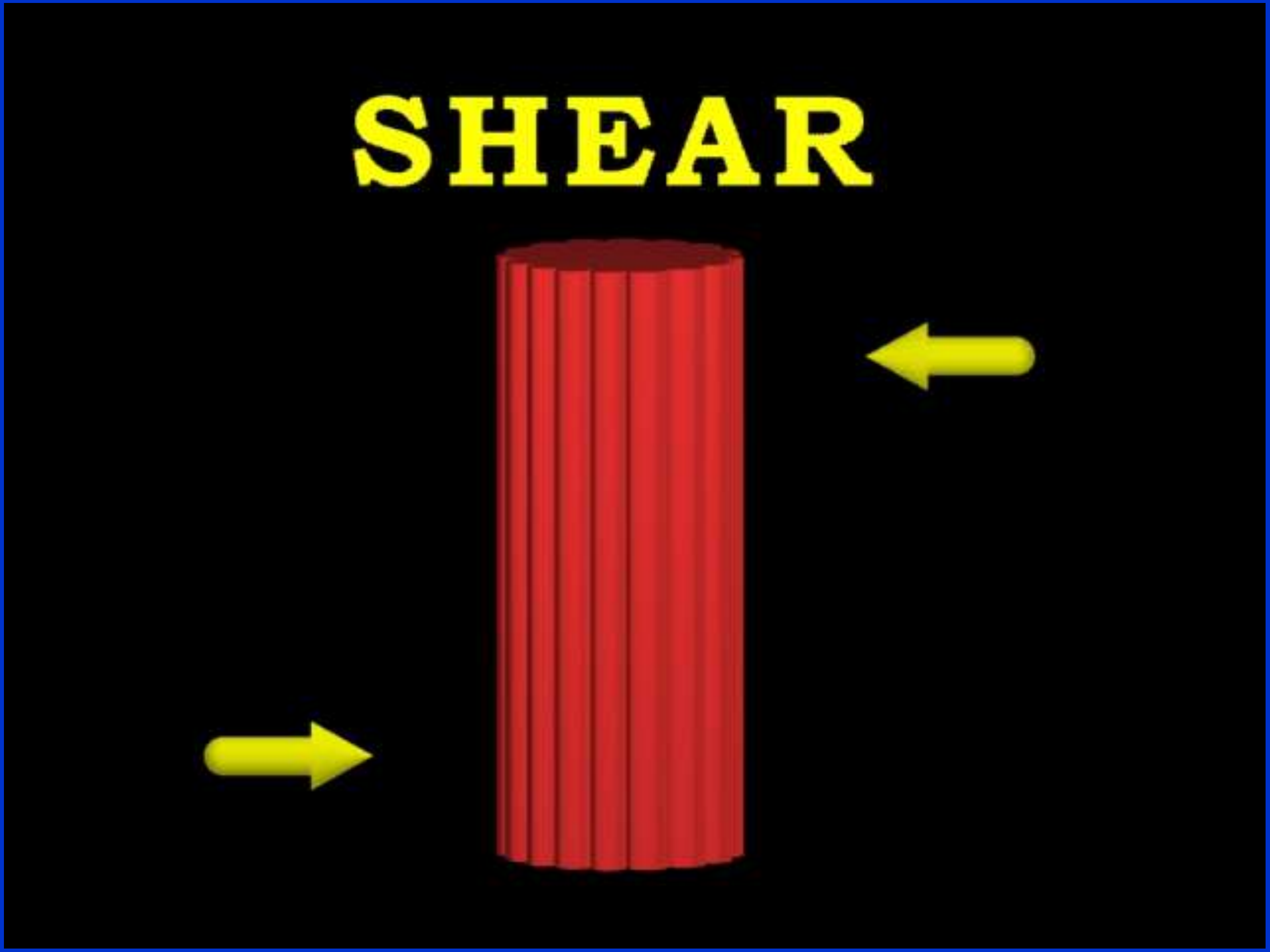
Impact – Slow Motion

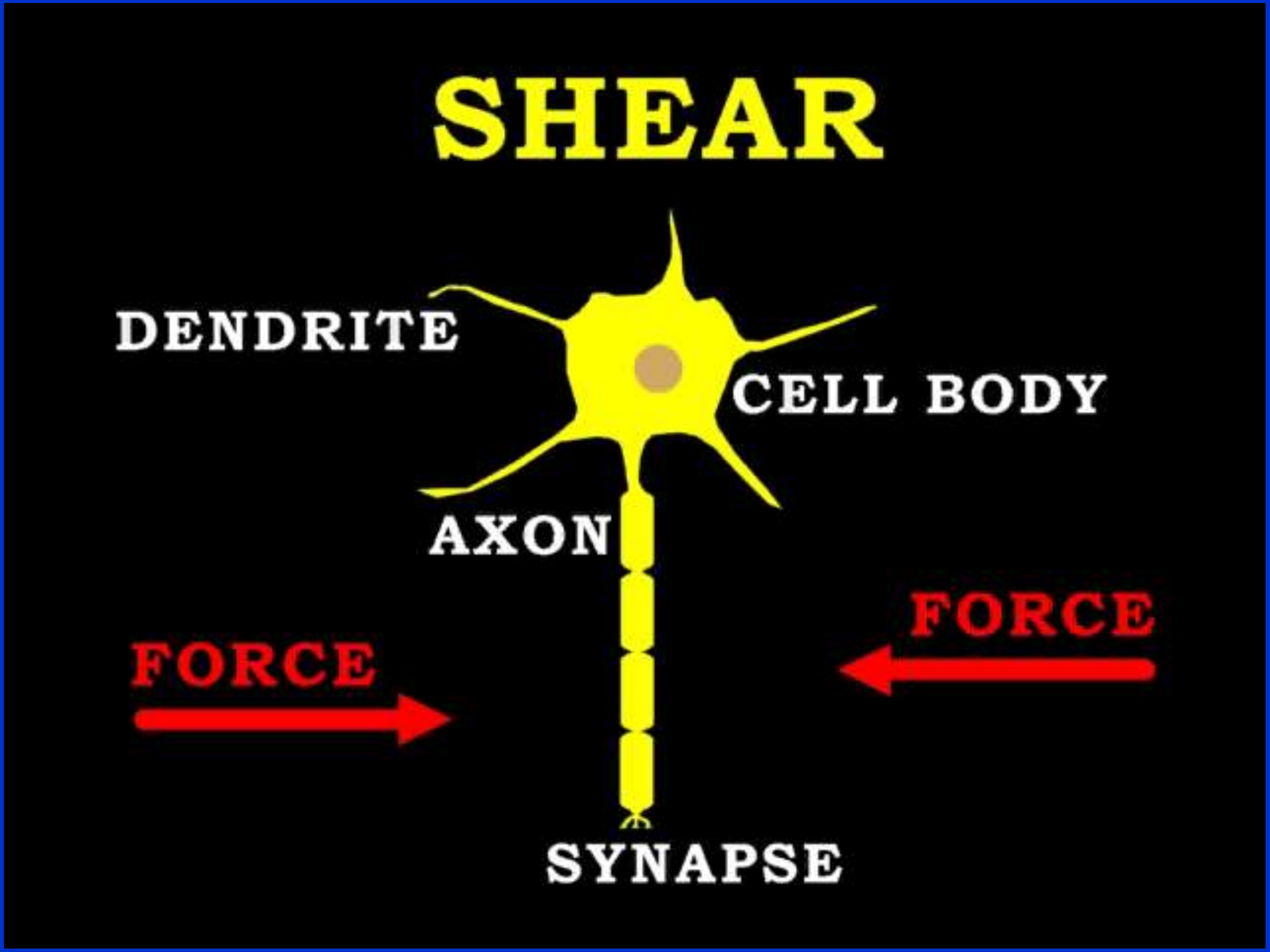


CAVITATION

: FORMATION AND DESTRUCTION OF VAPOR FILLED MICRO-BUBBLES

Cavitation


SHEAR

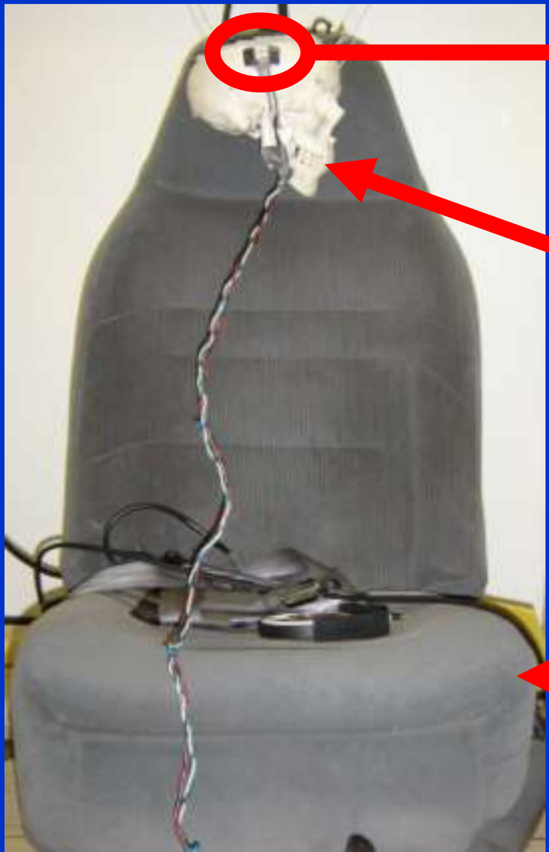

SHEAR
DENDRITE
CELL BODY
AXON
FORCE
FORCE
SYNAPSE

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

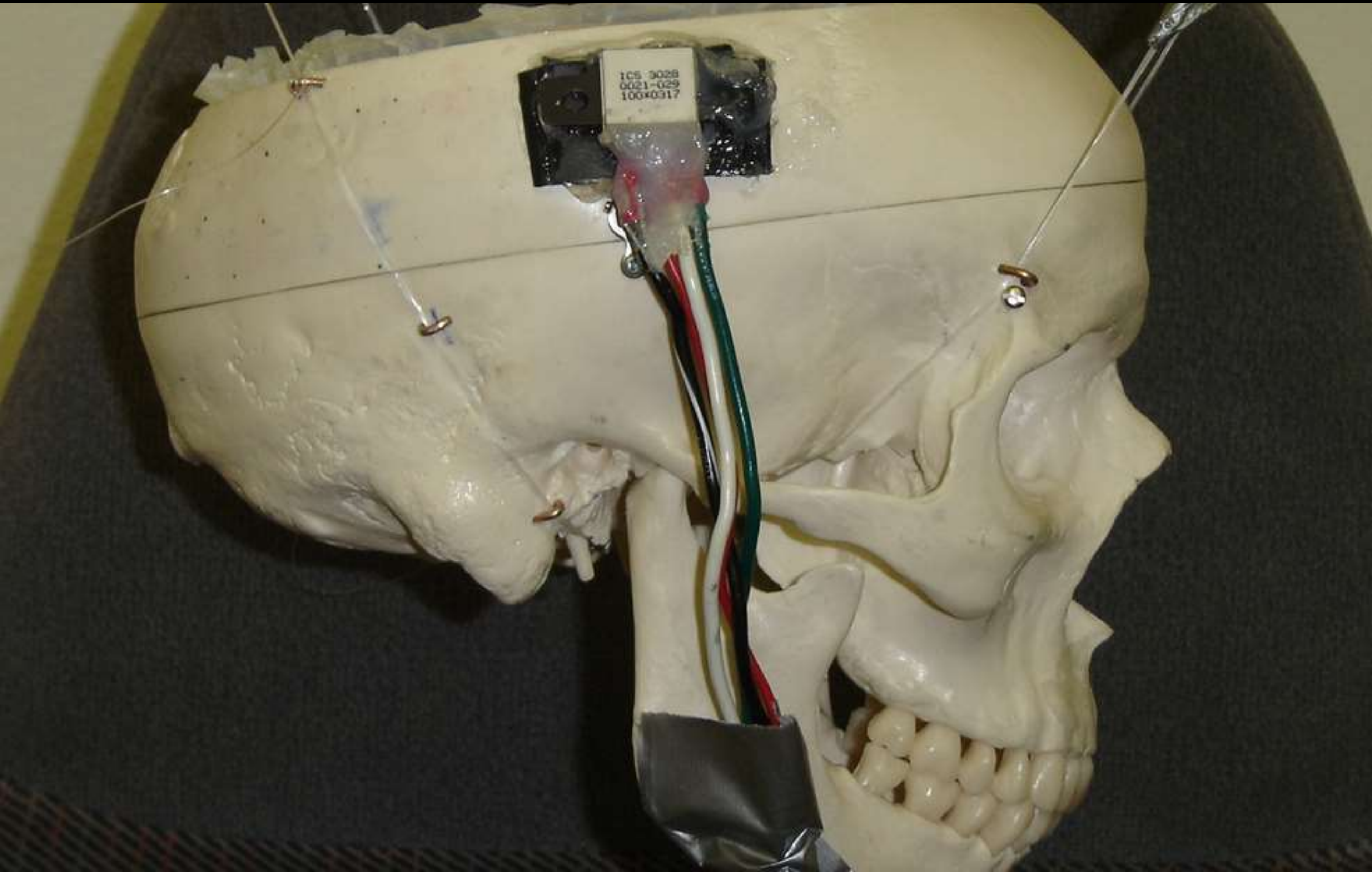
- Skull: A20/1
  (Anatomical Chart Company; Hagerstown, MD)
- Gel: Sylgard 527 A&B Silicon Dielectric Gel
  (Dow Corning Corporation; Midland, MI)

Subject Seat

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

Skull: A20/1

(Anatomical Chart Company; Hagerstown, MD)

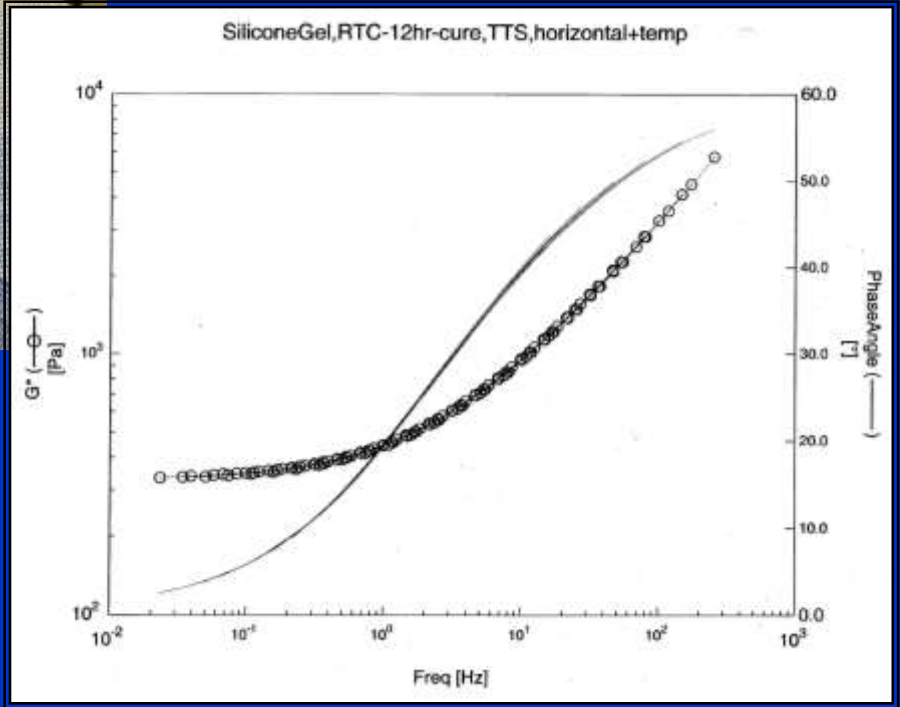


Equipment

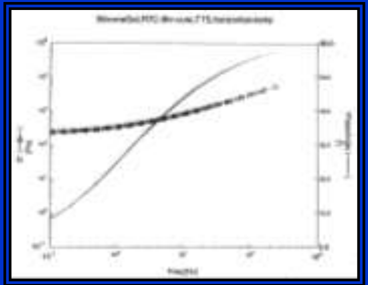
Silicon Gel Properties

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

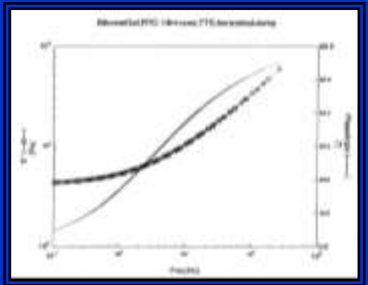
12hr cure



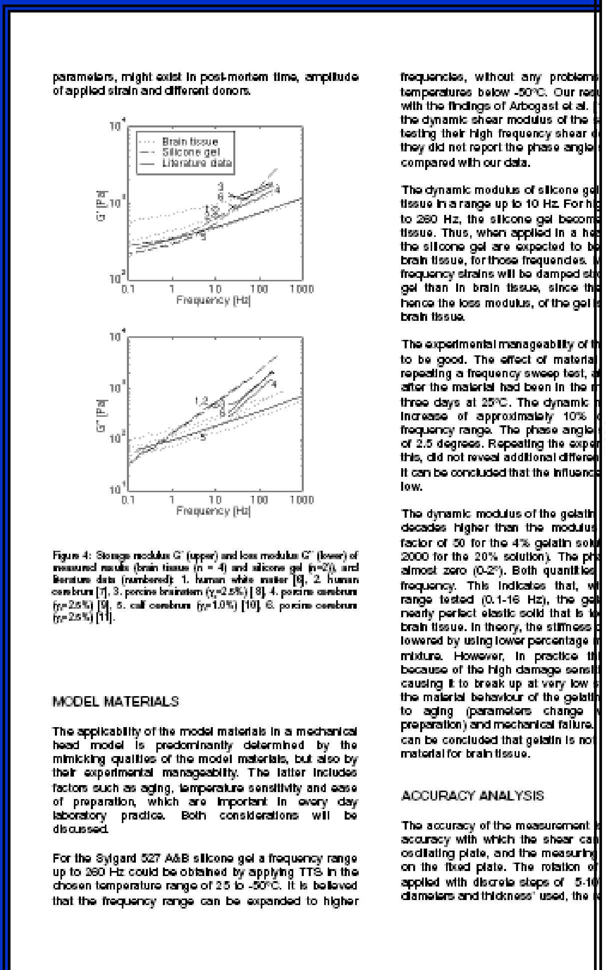
9hr cure



14hr cure



Properties Comparison
Silicon Gel & Brain Tissue



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

Figure 4: Storage modulus G' (upper) and loss modulus G'' (lower) of measured results (brain tissue (n = 4) and silicone gel (n=2)), and literature data (numbered): 1. human white matter [6], 2. human cerebrum [7], 3. porcine brainstem (γ_s=2.5%) [8], 4. porcine cerebrum (γ_s=2.5%) [9], 5. calf cerebrum (γ_s=1.0%) [10], 6. porcine cerebrum (γ_s=2.5%) [11].

MODEL MATERIALS

The applicability of the model materials in a mechanical head model is predominantly determined by the mimicking 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 silicone gel a frequency range up to 260 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 findings of Arbogast et al.
the dynamic shear modulus of the
testing their high frequency shear
they did not report the phase angle
compared with our data.

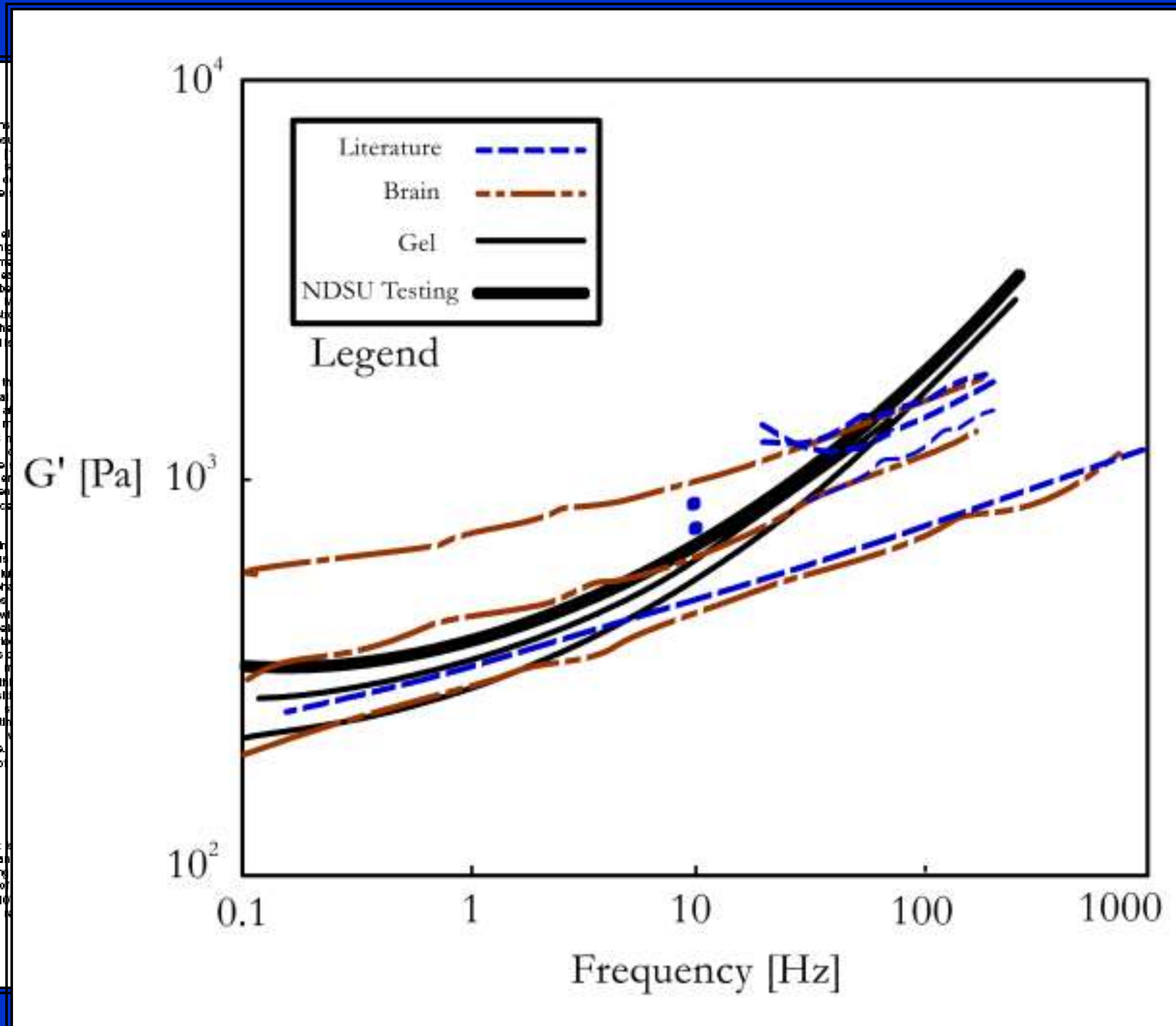
The dynamic modulus of silicone gel
tissue in a range up to 10 Hz. For hi
to 260 Hz, the silicone gel becom
tissue. Thus, when applied in a he
the silicone gel are expected to b
brain tissue, for those frequencies.
frequency strains will be damped st
gel than in brain tissue, since th
hence the loss modulus, of the gel
brain tissue.

The experimental manageability of t
to be good. The effect of material
repeating a frequency sweep test,
after the material had been in the
three days at 25°C. The dynamic
increase of approximately 10%
frequency range. The phase angle
of 2.5 degrees. Repeating the expe
this, did not reveal additional differe
It can be concluded that the influenc
low.

The dynamic modulus of the gelati
decades higher than the modulus
factor of 50 for the 4% gelatin sol
2000 for the 20% solution). The ph
almost zero (0-2°). Both quantities
frequency. This indicates that, w
range tested (0.1-16 Hz), the ge
nearly perfect elastic solid that is
brain tissue. In theory, the stiffness
lowered by using lower percentage
mixture. However, in practice th
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 gelatin is not
material for brain tissue.

ACCURACY ANALYSIS

The accuracy of the measurement
accuracy with which the shear ca
oscillating plate, and the measurin
on the fixed plate. The rotation o
applied with discrete steps of 5-1
diameters and thickness' used, the



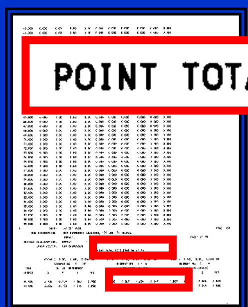
Brands, D., P. Bovendeered, G. Peter, et al. "Comparison of the Dynamic Behaviour of Brain Tissue and Two Model Materials", *SAE 99C21*, Society of Automotive Engineers, Inc. 1999.

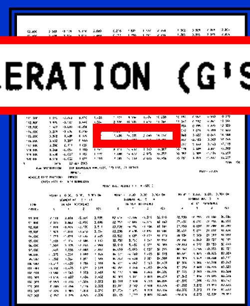
Test Conditions (per ATB Simulation)

A. SEVERITY OF IMPACT

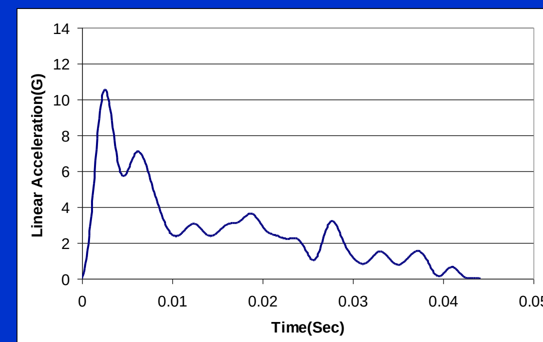
Simulation **14.09g**

Experimental **10.55g**





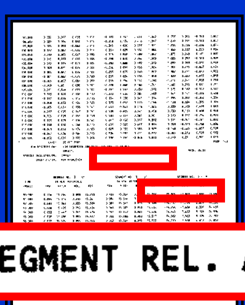
POINT TOTAL ACCELERATION (G'S)

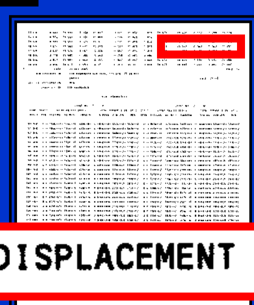


B. POSITION OF HEAD

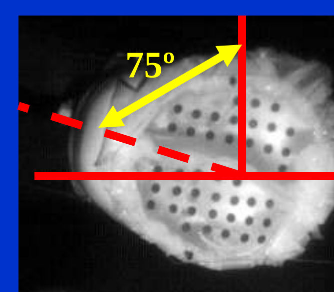
Simulation **75°**

Experimental **75°**





SEGMENT REL. ANGULAR DISPLACEMENT (DEG)



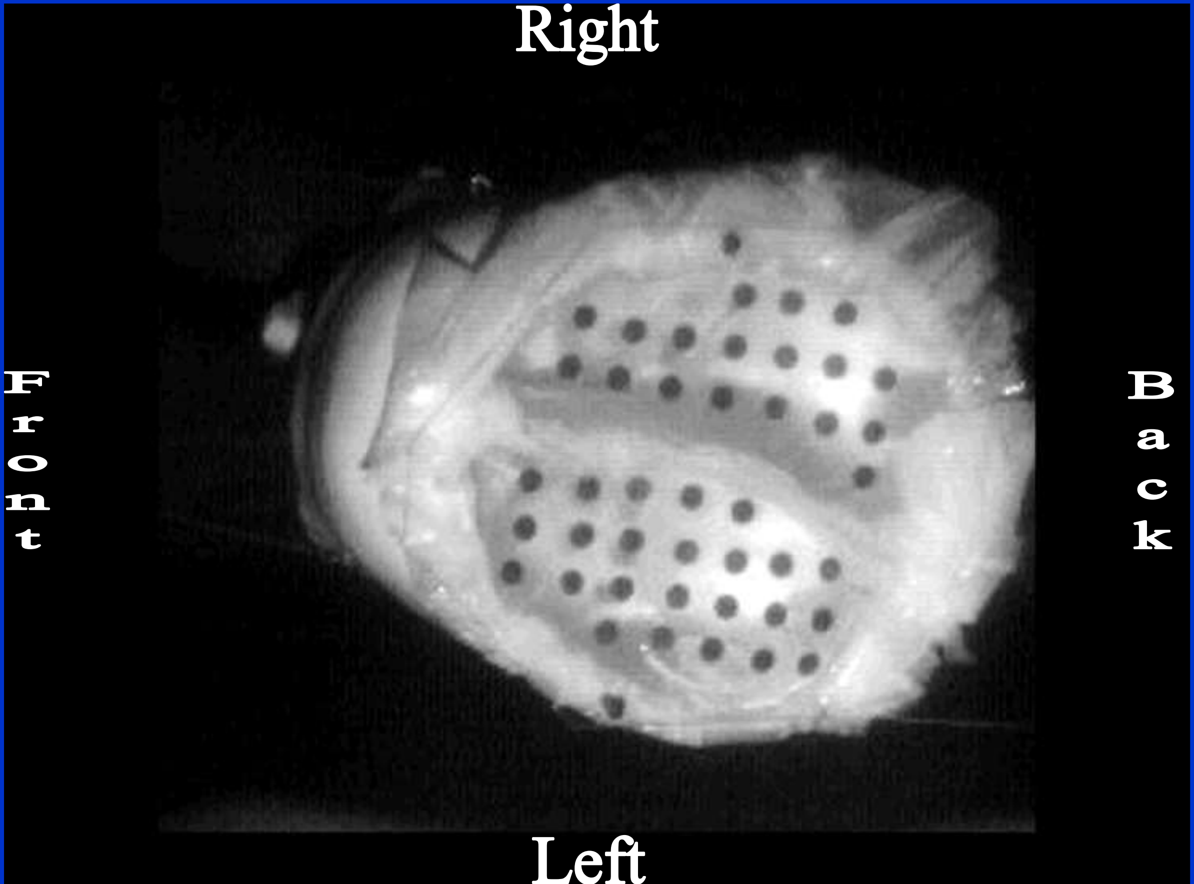
Skull/Gel Model Testing

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 75º, Pitch 7º, Roll 6º)

Video Parameters:

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



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 75º, Pitch 7º, Roll 6º)

Video Parameters:

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

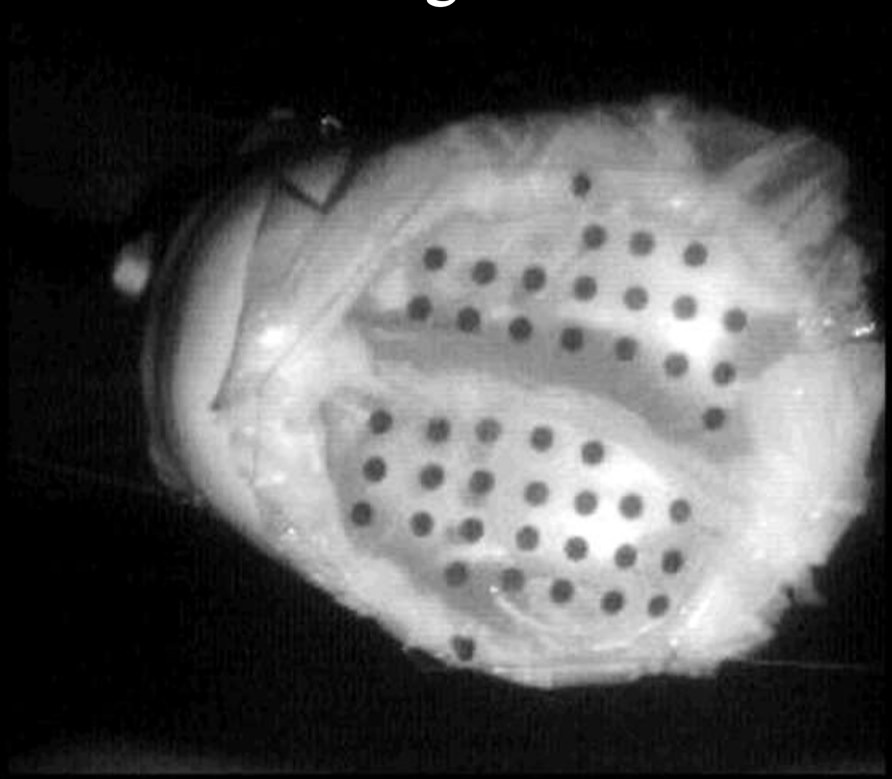
Transformed MRI Data

Source of Original Data:

- Dr. Orrison, Nevada Imaging Centers

Right

Front



Back

Left

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 75º, Pitch 7º, Roll 6º)

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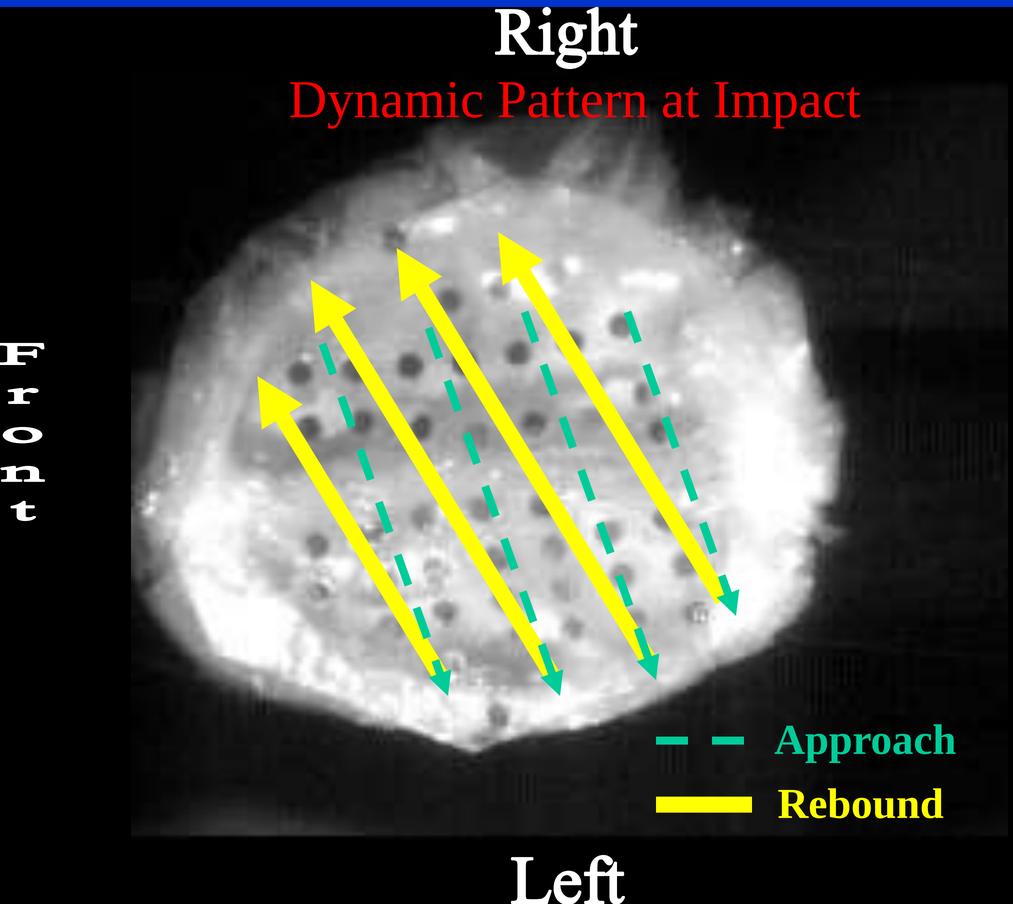
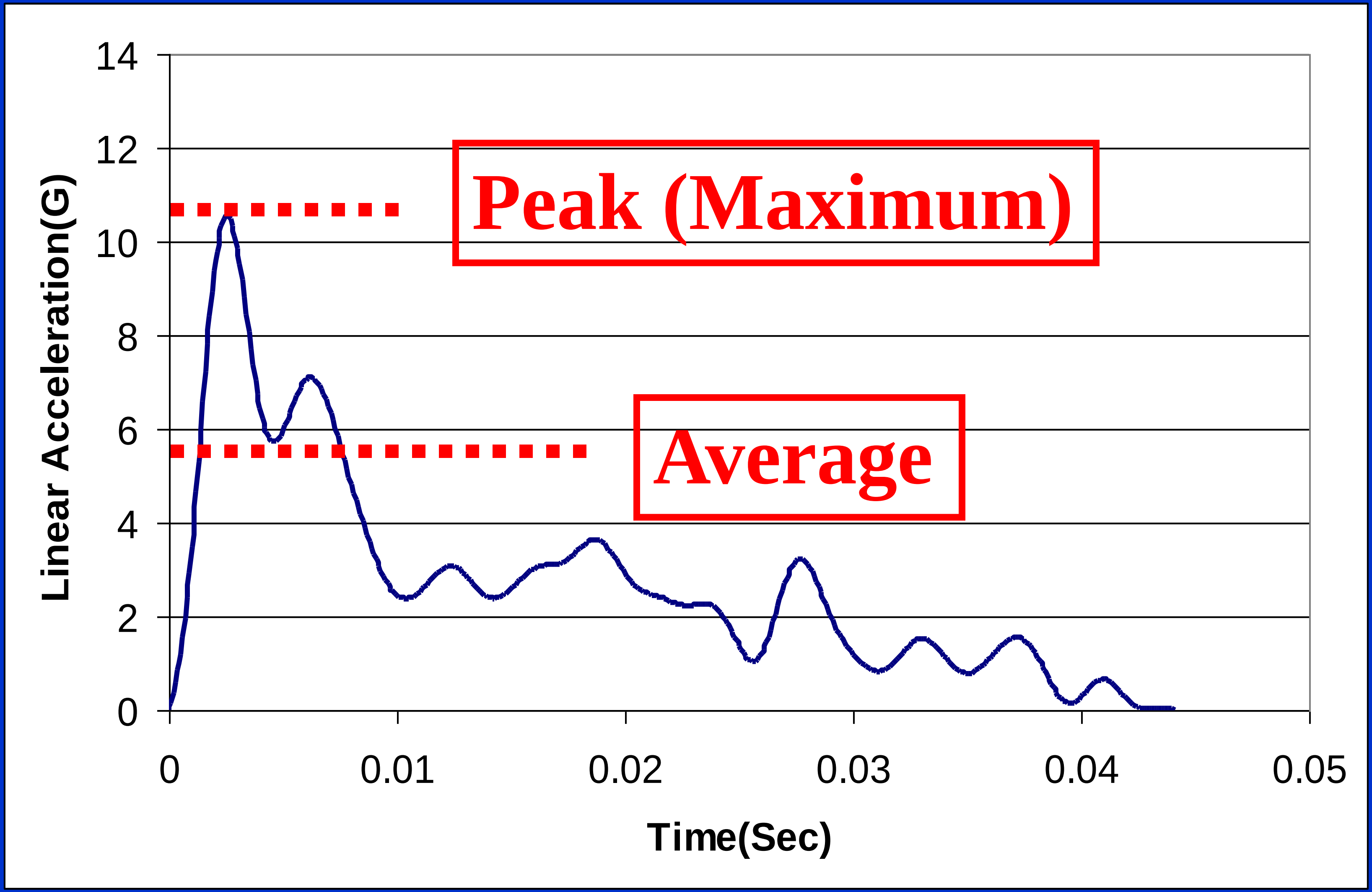


Back

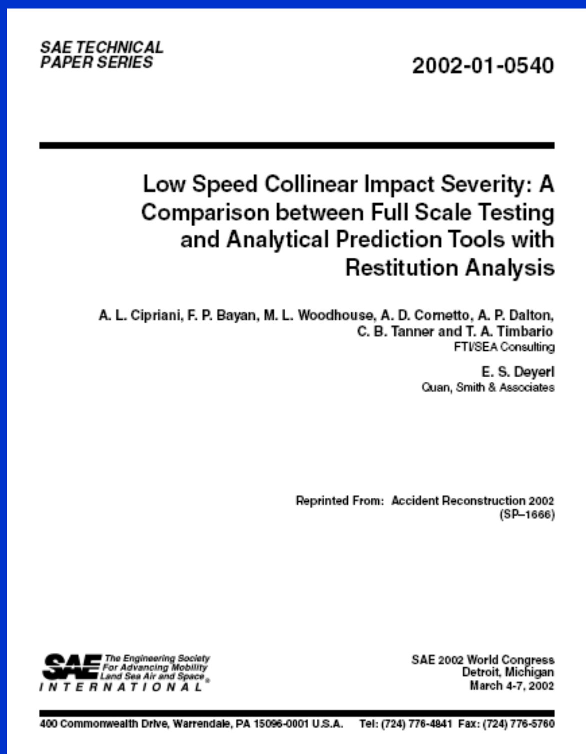
Limitation of Dr. Ravani's Hand Calculations

- Dr. Ravani uses average not the peak values

Average VS. Peak



The peak acceleration is twice the average acceleration.



SAE TECHNICAL PAPER SERIES

2002-01-0540

Low Speed Collinear Impact Severity: A Comparison between Full Scale Testing and Analytical Prediction Tools with Restitution Analysis

A. L. Cipriani, F. P. Bayan, M. L. Woodhouse, A. D. Cornetto, A. P. Dalton, C. B. Tanner and T. A. Timbario
FTI/SEA Consulting

E. S. Deyerl
Quan, Smith & Associates

Reprinted From: Accident Reconstruction 2002 (SP–1666)

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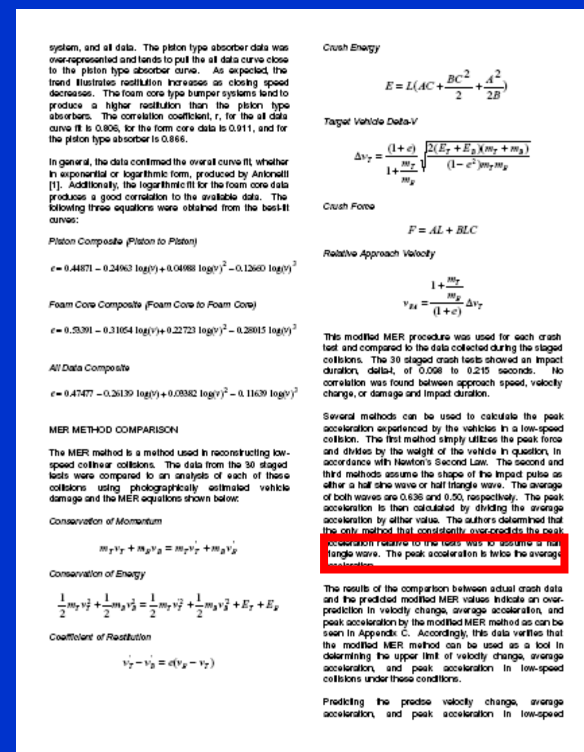


system, and all data. The piston type absorber data was over-represented and tends to pull the all data curve close to the piston type absorber curve. As expected, the trend illustrates restitution increases as closing speed decreases. The foam core type bumper systems tend to produce a higher restitution than the piston type absorbers. The correlation coefficient, r, for the all data curve fit is 0.806, for the form core data is 0.911, and for the piston type absorber is 0.866.

In general, the data confirmed the overall curve fit, whether in exponential or logarithmic form, produced by Antonetti [1]. Additionally, the logarithmic fit for the foam core data produces a good correlation to the available data. The following three equations were obtained from the best-fit curves:

Piston Composite (Piston to Piston)

$$e = 0.44871 - 0.24963\log(V) + 0.04988\log(V)^2 - 0.12660\log(V)^3$$

Foam Core Composite (Foam Core to Foam Core)

$$e = 0.53391 - 0.31054\log(V) + 0.22723\log(V)^2 - 0.28015\log(V)^3$$

All Data Composite

$$e = 0.47477 - 0.26139\log(V) + 0.08382\log(V)^2 - 0.11639\log(V)^3$$

MER METHOD COMPARISON

The MER method is a method used in reconstructing low-speed collinear collisions. The data from the 30 staged tests were compared to an analysis of each of these collisions using photographically estimated vehicle damage and the MER equations shown below:

Conservation of Momentum

$$m_T v_T + m_B v_B = m_T v_T' + m_B v_B'$$

Conservation of Energy

$$\frac{1}{2}m_T v_T^2 + \frac{1}{2}m_B v_B^2 = \frac{1}{2}m_T v_T'^2 + \frac{1}{2}m_B v_B'^2 + E_T + E_B$$

Coefficient of Restitution

$$v_T' - v_B' = e(v_B - v_T)$$

Crush Energy

$$E = L(AC + \frac{BC^2}{2} + \frac{A^2}{2B})$$

Target Vehicle Delta-V

$$\Delta v_T = \frac{(1+e)}{1+\frac{m_T}{m_B}}\sqrt{\frac{2(E_T + E_B)(m_T + m_B)}{(1-e^2)m_T m_B}}$$

Crush Force

$$F = AL + BLC$$

Relative Approach Velocity

$$v_{RA} = \frac{1+\frac{m_T}{m_B}}{(1+e)}\Delta v_T$$

This modified MER procedure was used for each crash test and compared to the data collected during the staged collisions. The 30 staged crash tests showed an impact duration, delta-t, of 0.098 to 0.215 seconds. No correlation was found between approach speed, velocity change, or damage and impact duration.

Several methods can be used to calculate the peak acceleration experienced by the vehicles in a low-speed collision. The first method simply utilizes the peak force and divides by the weight of the vehicle in question, in accordance with Newton's Second Law. The second and third methods assume the shape of the impact pulse as either a half sine wave or half triangle wave. The average of both waves are 0.636 and 0.50, respectively. The peak acceleration is then calculated by dividing the average acceleration by either value. The authors determined that the only method that consistently over-predicts the peak acceleration relative to the tests was to assume a half triangle wave. The peak acceleration is twice the average acceleration.

The results of the comparison between actual crash data and the predicted modified MER values indicate an over-prediction in velocity change, average acceleration, and peak acceleration by the modified MER method as can be seen in Appendix C. Accordingly, this data verifies that the modified MER method can be used as a tool in determining the upper limit 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.

A B

Striking Speed (km/h)	Vehicle Peak Acceleration (g)	Occupant Peak Head Acceleration x (g)	y (g)	z (g)	Vehicle Displacement (cm)	Isolator Compression Left (mm)	Isolator Compression Right (mm)
1.8	0.9	•	•	•	13	13	13
2.9	0.9	1.5	1.1	0.5	13	22	29
3.2	1.0	1.2	1.7	0.5	14	22	29
4.7	1.5	2.3	1.8	0.5	96	48	44
5.5	1.5	1.9	1.0	1.0	31	48	44
6.1	1.7	2.3	1.3	1.8	46	48	44
7.2	1.9	4.5	2.0	1.8	•	full	full
7.2	2.4	3.8	1.8	1.8	•	full	full
8.0	3.0	4.8	3.0	2.8			
8.7	2.8	7.5	3.3	2.9			
9.8	2.9	7.0	3.4	2.8			
11.6	3.1	8.3	3.4	2.8	152	full	full

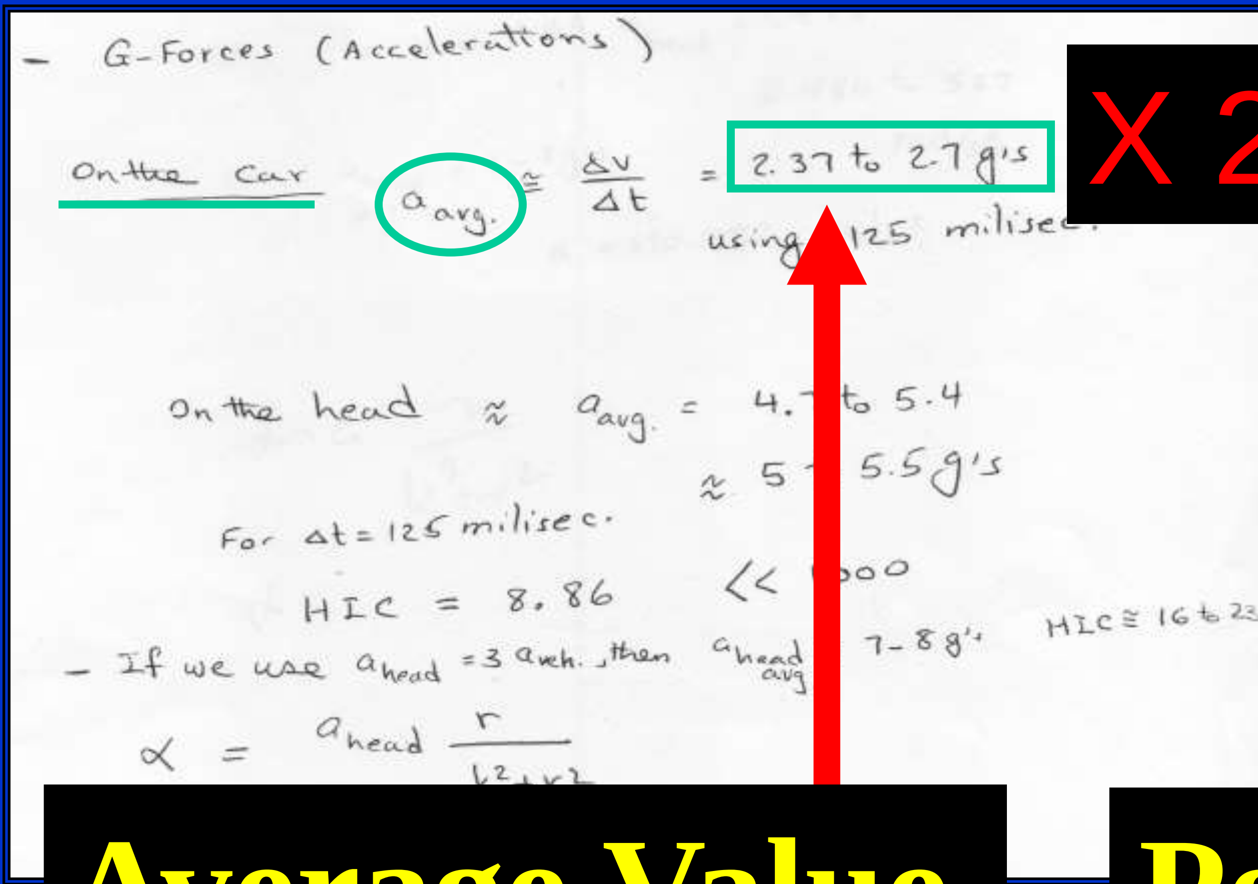
$$\sqrt{8.3^2 + 3.4^2 + 2.8^2} = 9.4g$$

$$\frac{9.4}{3.1} = 3.0$$

3.0 Multiplier for Occupant's Head

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)



X 2 = 4.7 to 5.4g

Average Value
(as used by Dr. Ravani)

Peak Value
(calculated maximum value)

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

– G-Forces (Accelerations)

On the Car $\quad a_{avg.} \cong \frac{\Delta v}{\Delta t} = 2.37$ to 2.7 g's

using 125 milisec

On the head $\approx a_{avg.} = 4.7$ to 5.4

$\approx \boxed{5 \text{ to } 5.5 \text{ g's}}$

For $\Delta t = 125$ milisec.

HIC = 8.86 $\ll$ 1000

– If we use $a_{head} = 3\, a_{veh.}$, then $a_{head\ avg}$ 7–8 g's

$\alpha = a_{head} \frac{r}{l^2+r^2}$

X 2 = 4.7 to 5.4g

X 3

14.1 to 16.2g

Average Value

(as used by Dr. Ravani)

Peak Value

(calculated maximum value)

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

TSR 7809

– Using anthrop. data

$$r \cong \frac{14.5-5.1}{69.1} \times 71 = 9.66'' \approx 0.8'$$

$$k \cong 2.75'' \approx .229'$$

$$\alpha \cong \frac{(5 \text{ to } 5.5 \times 2) \times 32.2 \times .8}{.229^2 + .8^2} = 372 \text{ to } 409 \text{ rad/sec}^2$$

Even if we use $r = .58$ ft then

$$\alpha = 1.49\, a_{head} = 1.49 \times 10 \text{ to } 11 \times 32.2 = \cong 480 \text{ to } 527 \text{ rad/sec}^2$$

For a_{head} avg. $= 7-8$ g's

$$\boxed{\alpha = 670-770 \text{ rad/sec}^2}$$

X 2 = 1,340 – 1,540 rad/s²

Average Value

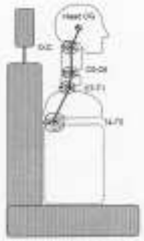
(as used by Dr. Ravani)

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



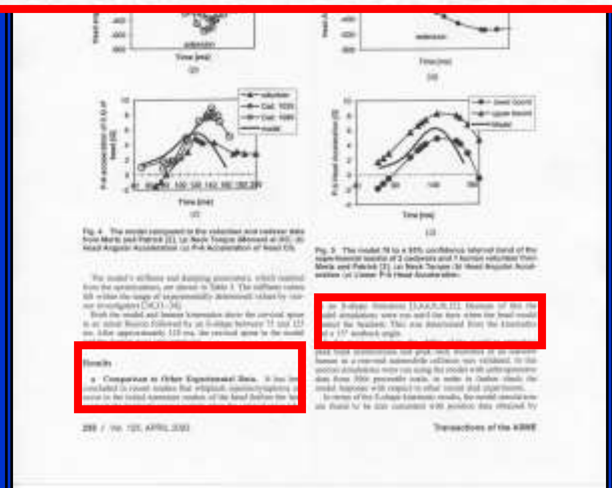
Methods

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

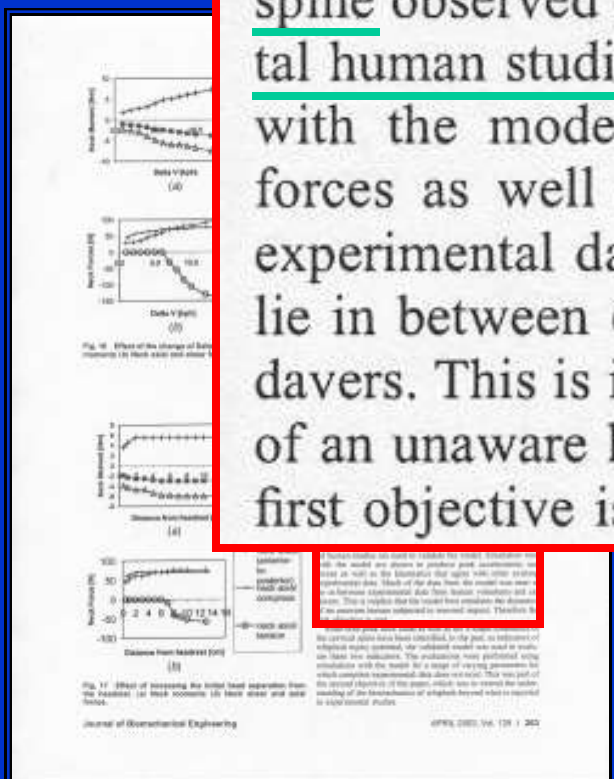
a Comparison to Other Experimental Data. It has been concluded in recent studies that whiplash injuries/symptoms can occur in the initial extension motion of the head (before the head contacts the headrest) approximately when the cervical spine takes on an S-shape formation [3,4,6,9,10,12]. Because of 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

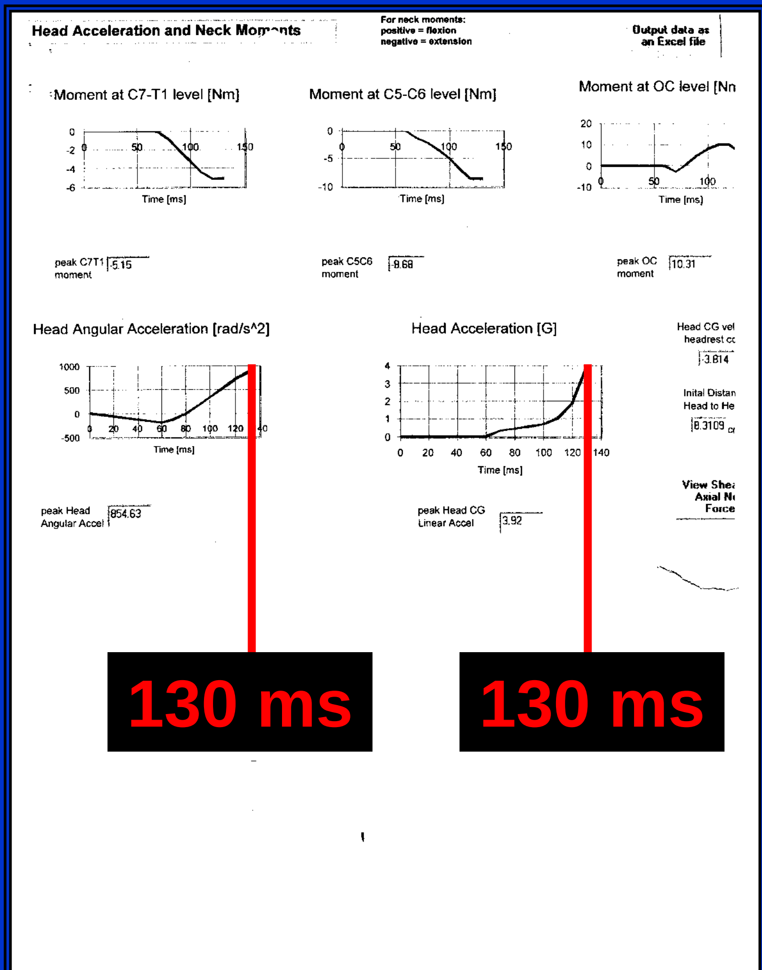
The first objective of this study was to achieve a design of a relatively simple and efficient multi-body linkage model that can be used to simulate the biomechanics of whiplash. It is shown that a two dimensional four segment model in the sagittal plane can capture the peak loads as well as the kinematics 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.



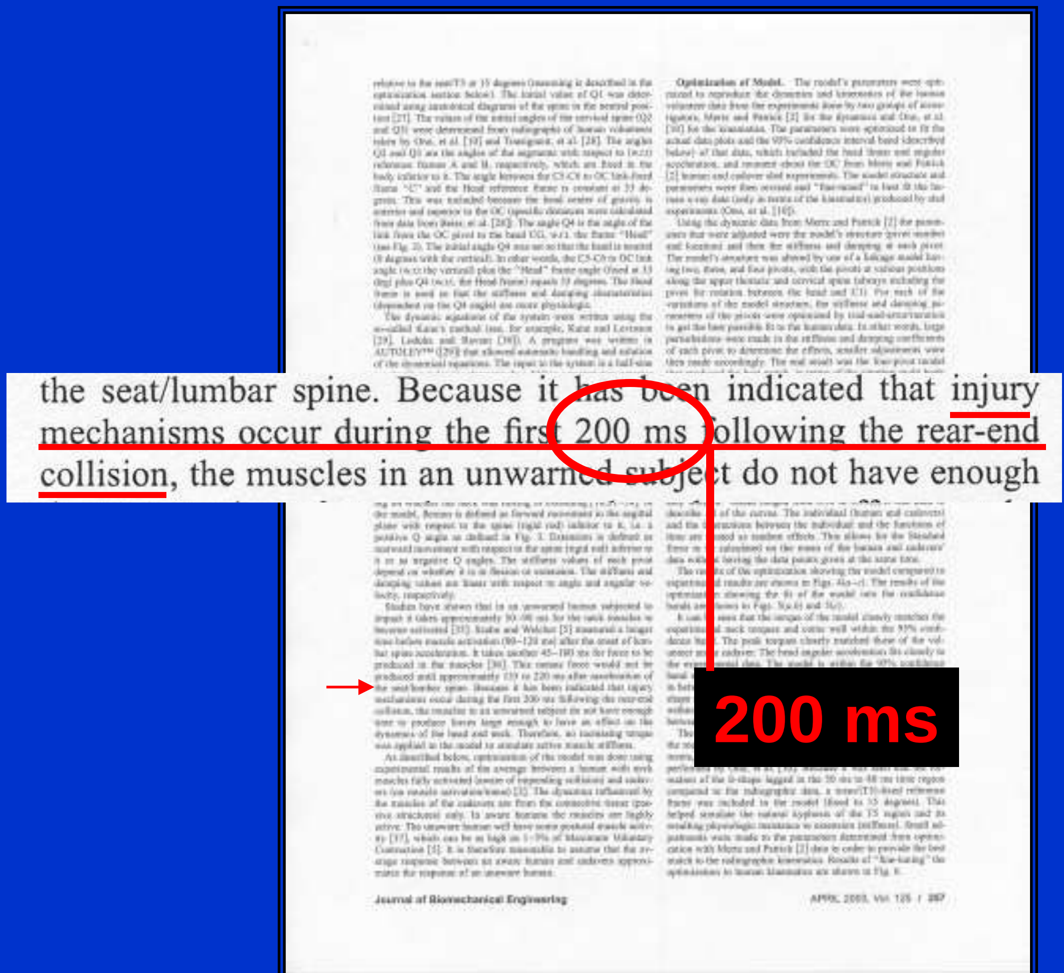
Garcia, T., B. Ravani. *A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model* Journal of Biomechanical Engineering APRIL 2003, Vol. 125, pp254-265.

•Not the entire necessary time period was evaluated

Dr. Ravani's Case Analysis



Dr. Ravani's Publication



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

A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model

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.

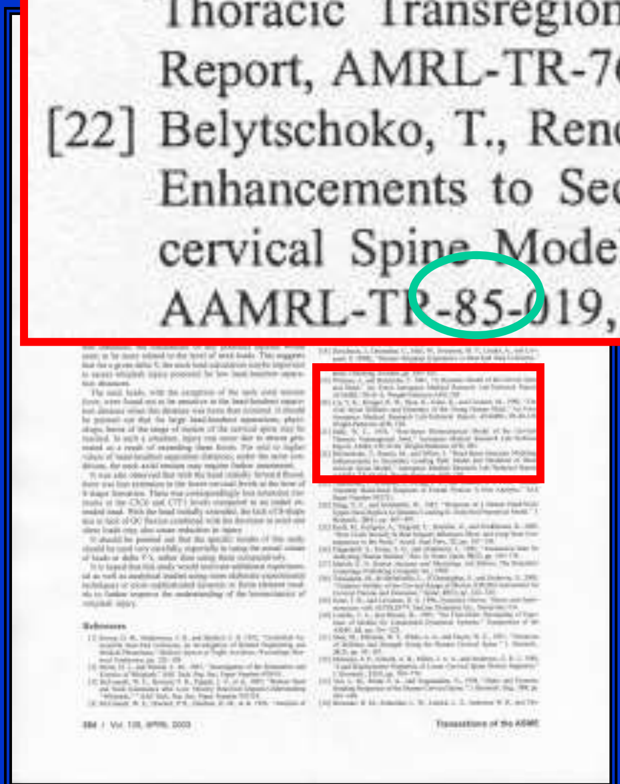
Garcia, T., B. Ravani. *A Biomechanical Evaluation of Whiplash Using a Multi-Body Dynamic Model* Journal of Biomechanical Engineering APRIL 2003, Vol. 125, pp254-265.

[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.

[20] Liu, Y. K., Krieger, K. W., Njus, G., Ueno, K., and Connors, M., 1980, "Cervical Spine Stiffness and Geometry of the Young Human Male," Air Force Aerospace Medical Research Lab-Technical Report, AFAMRL-TR-80-138, Wright-Patterson AFB, OH.

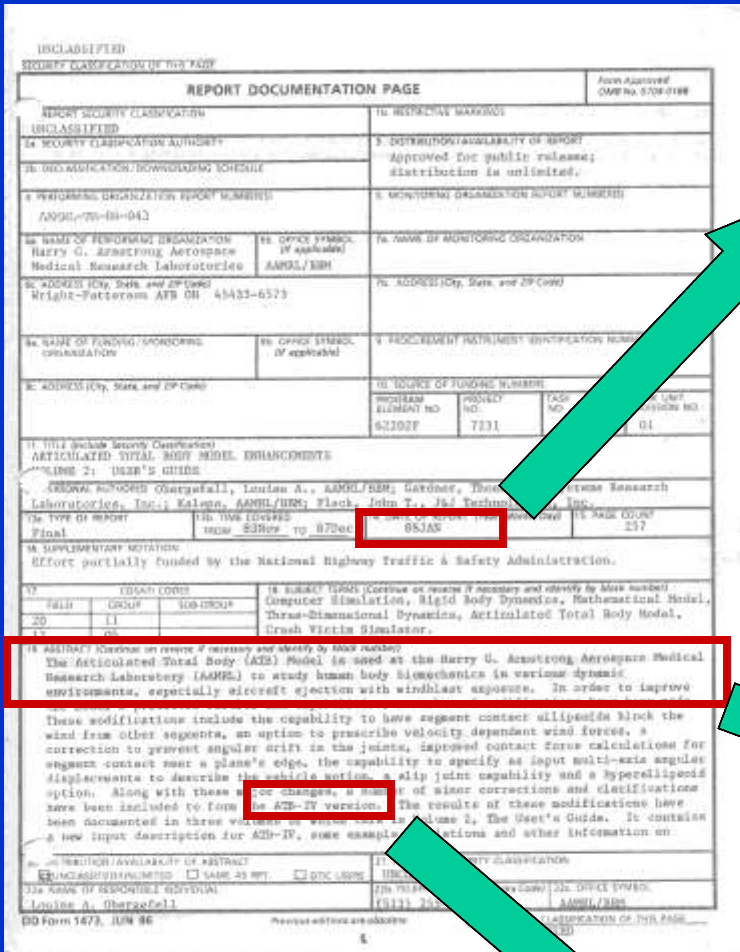
[21] Eddy, W. C., 1976, "Non-linear Biomechanical Model of the Cervical-Thoracic Transregional Joint," Aerospace Medical Research Lab-Technical Report, AMRL-TR-76-90, Wright-Patterson AFB, OH.

[22] Belytschoko, T., Rencis, M., and Willes, J. "Head-Spine Structure Modeling: Enhancements to Secondary Loading Path: Model and Validation of Head-cervical Spine Model," Aerospace Medical Research Lab-Technical Report, AAMRL-TR-85-019, Wright-Patterson AFB, OH.



1976 - 1985

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.



UNCLASSIFIED

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12. PERSONAL AUTHOR(S) Obergefell, Louise A., AAMRL/BBM; Gardner, Thomas R., Systems Research Laboratories, Inc.; Kaleps, AAMRL/BBM; Fleck, John T., J&J Technologies, Inc.

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19. ABSTRACT 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. In order to improve ... These modifications include the capability to have segment contact ellipsoids block the wind from other segments, an option to prescribe velocity dependent wind forces, a correction to prevent angular drift in the joints, improved contact force calculations for segment contact near a plane's edge, the capability to specify as input multi-axis angular displacements to describe the vehicle motion, a slip joint capability and a hyperellipsoid option. Along with these major changes, a number of minor corrections and clarifications have been included to form the ATB-IV version. The results of these modifications have been documented in three volumes of which this is Volume 2, The User's Guide. It contains a new input description for ATB-IV, some example ... and other information on

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED

22a. NAME OF RESPONSIBLE INDIVIDUAL Louise A. Obergefell

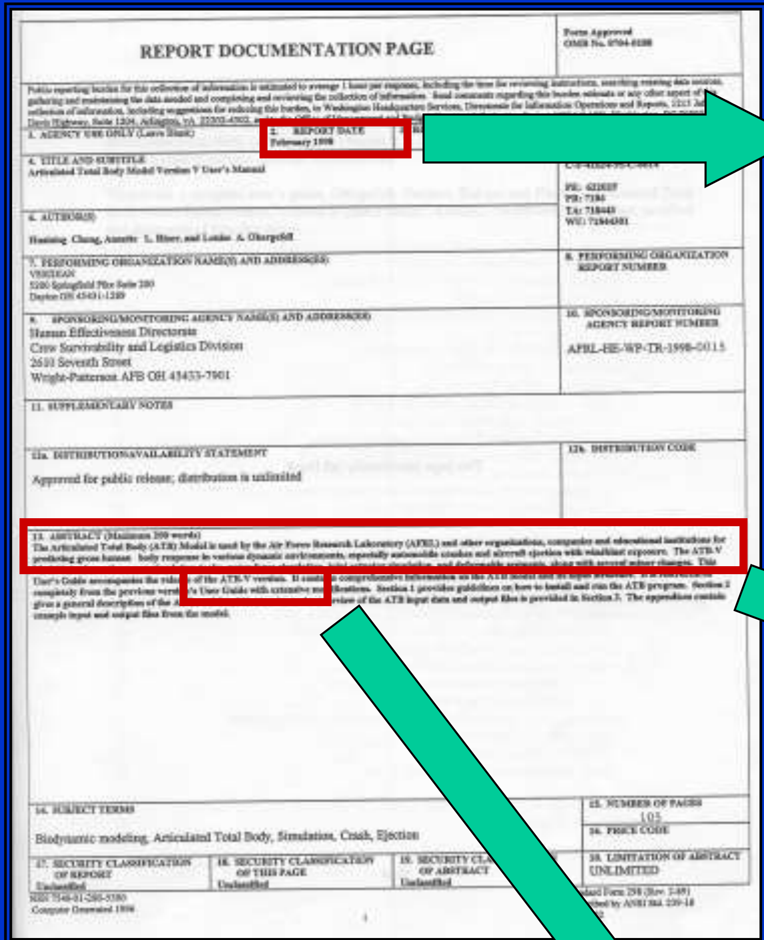
22c. OFFICE SYMBOL AAMRL/BBM

DD Form 1473, JUN 86 Previous editions are obsolete.

"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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13. ABSTRACT (Maximum 200 words)

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 and aircraft ejection with windblast exposure. The ATB-V ... User's Guide accompanies the release of the ATB-V version. ... User's Guide with extensive modifications. Section 1 provides guidelines on how to install and run the ATB program. ... review of the ATB input data and output files is provided in Section 3. The appendices contain example input and output files from the model.

14. SUBJECT TERMS Biodynamic modeling, Articulated Total Body, Simulation, Crash, Ejection	15. NUMBER OF PAGES 105
	16. PRICE CODE

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Unclassified	Unclassified	Unclassified	UNLIMITED

Computer Generated 1998

"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"

SAE TECHNICAL PAPER SERIES

2000-01-0469

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

400 Com

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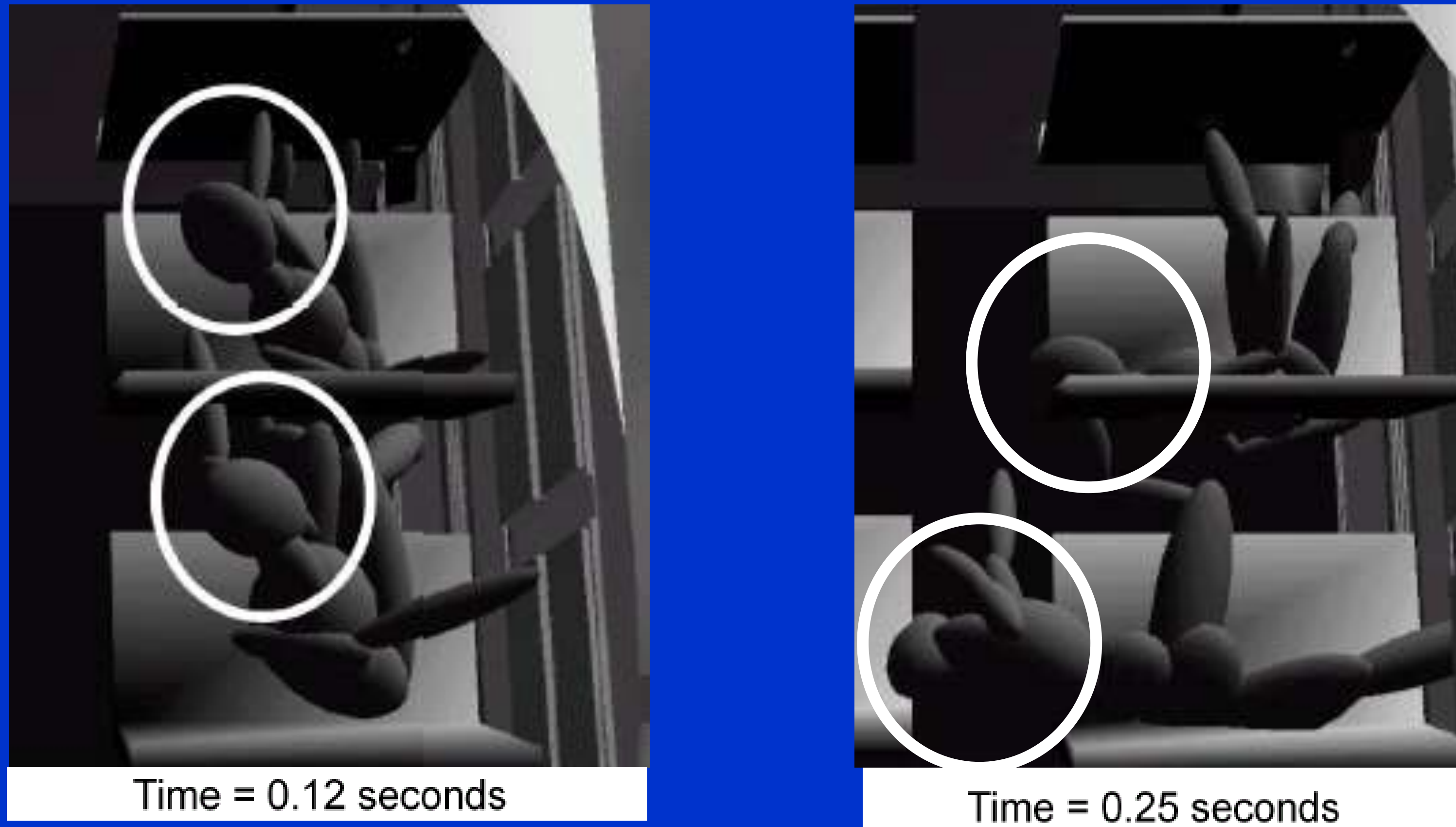
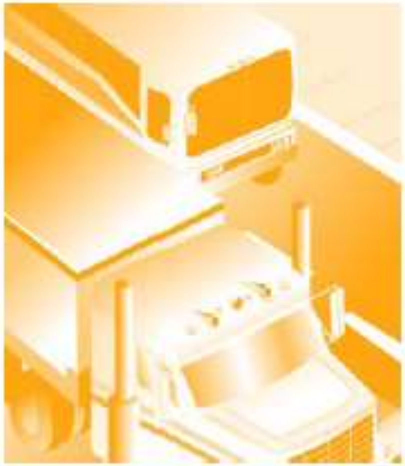


Figure 14. A time history of the unrestrained occupant kinematics in the Holmdel, New Jersey simulation.

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 Accident Report

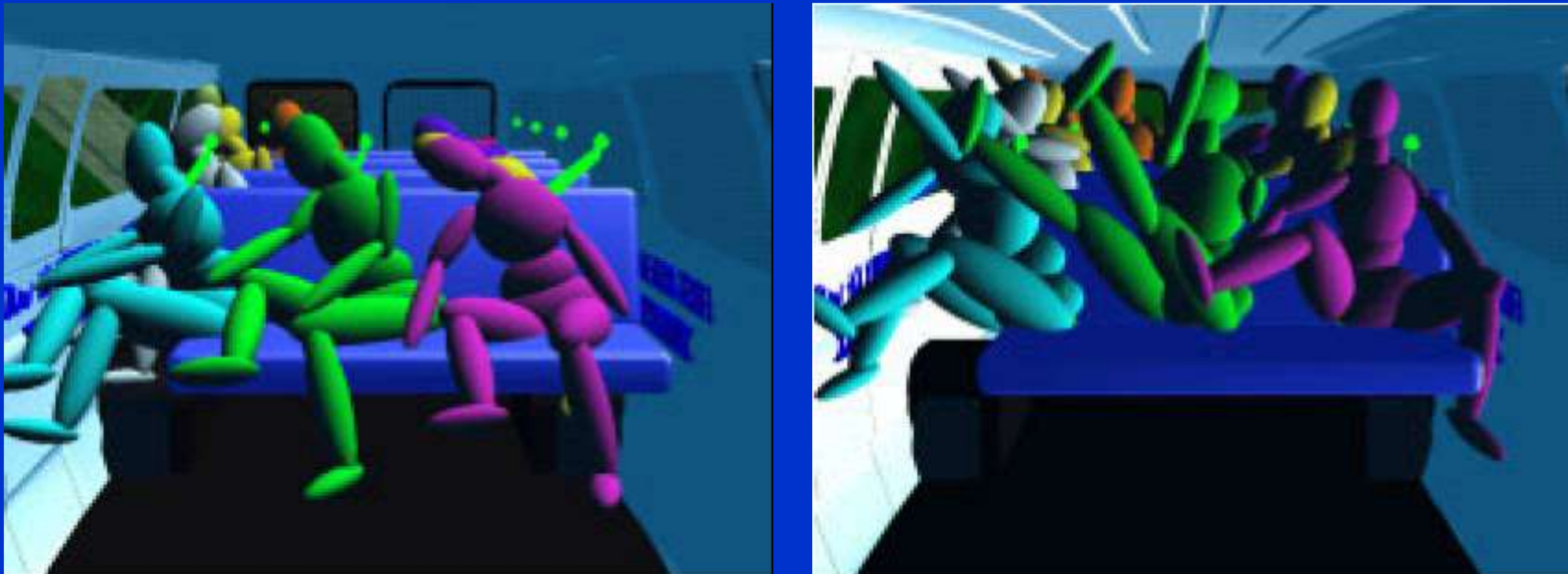
NTSB/HAR-03/03

PB2003-916203
Notation 7567

National Transportation Safety Board
Washington, D.C.

Highway Accident Report
NTSB/HAR-03/03
PB2003-916203
Notation 7567

National Transportation Safety Board
Washington, 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/shoulder-belted condition at various stages of the rollover.

"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.