Vehicle Safety

Automotive collisions

Nicolas Joseph Cugnot, 1769 First self propelled road vehicle

http://inventors.about.com/library/weekly/aacarssteama.htm

The first fatality: Mary Ward fell under a steam car in Ireland , 31 August 1869

Head-on collisions
Rear-end collisions
Side collisions
Rollovers

Single-vehicle collisions
Multi-vehicle collisions
Backup accidents
Level crossing accidents

Bicycles
Pedestrians

trucks,
large animals

Trees, poles or road signs

Why do we need Vehicle Safety ?

United states of America

1999	6,289,000	3,200,004	42,116
2000	6,356,000	3,200,000	41,821
2002	6,316,000	2,900,000	42,815
2003	6,328,000	2,900,000	42,643
2005	6,420,000	2,900,000	42,636

$230 billion

http://www.unitedjustice.com/death-statistics.html

India

http://timesofindia.indiatimes.com/india/India-leads-world-in-road-deaths-WHO/articleshow/4900415.cms

2006			89,455
2007			1,14,000

3,00,000 accidents every year

820 accidents every day

34 accidents every hour

An accident every two minutes

MOTORINDIA, March 2004

Why do we need Vehicle Safety ?

- European Union is the largest car producing area in the world & the largest car market
- In the 15 Member States of the European Union there are appr. 42000 reported deaths & 1.5 million casualties
- The annual costs to the European Society due to these accidents are more than 160 billion Euro, which is twice the entire budget of the EU
- For society & for individual the loss of health is the most serious effect of crashes
- It leads to huge losses both in monetary terms to society & in personal suffering to the individual

ROAD SAFETY:
A Developmental Challenge for South Asia

Country	Vehicles/ 1,000	Injuries/ 100,000	Deaths/ 100,000	Deaths/ 10,000 vehicles
Bangladesh	3.8	2.7	1.7	44
Bhutan	19.6	2.0	0.8	4
India	31.2	32.5	6.3	20
Pakistan	18.0	6.7	3.2	17
Sri Lanka	42.0	91.9	10.5	25
United Kingdom	408.0	538.8	6.1	1.2
United States	787.0	1,281.3	14.8	1.9

Source: Estimating Global Road fatalities. Department for International Development, 2000

Birth of Motor Vehicle Safety

- First motor vehicle fatality occurred in 1889 in New York City
- From the turn of the century to 1935 was a period of genesis, growth & development to understand the extremely complex process of vehicle collisions
- During this period focus was laid on basic improvements such as:

  a) reduction of tire blowouts;

  b) introduction of self-starter;

  c) incorporation of headlamps; &

  d) adopting an all-steel body structure for better occupant safety
- Second Period from 1936 to 1965 was an intermediate safety period
- During this period auto manufacturers introduced many crash avoidance devices like:

Birth of Motor Vehicle Safety

a) turn signals;

b) dual windshield wipers;

c) improved headlamps;

d) high penetration-resistant windshield glass;

- GM conducted the first car-to-barrier frontal crash test
- Seat belts were introduced as an option in 1956
- Third period started in 1966: President Lyndon Johnson signed a law called Highway Safety Act & National Highway Traffic Safety Administration (NHTSA) was formed
- During this period more focus was laid on crash avoidance technology, structural crashworthiness & occupant protection devices

Birth of Motor Vehicle Safety

- In 1994, the National Safety Council estimated that 20 million vehicle crashes occurred on roads in US, resulting in 43,000 fatalities & 2.1 million injuries requiring hospitalization
- From a public health perspective, motor vehicle crashes are the fourth leading cause of death after disease, cancer & stroke
- Hence 'vehicle crashworthiness' is currently ranked at equal level to quality, styling, ride and handling, and fuel economy
- Auto manufacturers, govt. agencies, insurance underwriters, & the media provide consumers with assessments of automotive safety

Motor Vehicle Safety
Prevent/Minimise injury and fatality rate

- Avoidance
- Prevention
- Safety Systems
- Design for Safety
- Testing for Safety Design
  - Structural
  - Dummies
- Simulation for Safety Design
  - Software
  - Dummies

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Impact and Crash

Impact:

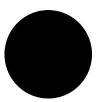
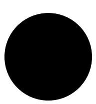
the striking of one thing against another; forceful contact; collision

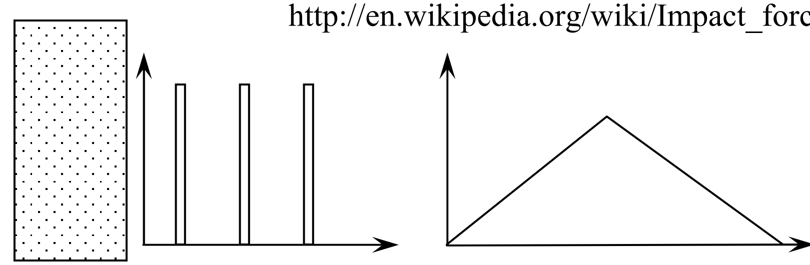
Crash:

to make a loud, clattering noise, as of something dashed to pieces; to break or fall to pieces with noise; to collide, esp. violently and noisily;

An **impact force** is a high force applied over a short time period. Such a force can have a greater effect than a lower force applied over a proportionally longer time period.

http://en.wikipedia.org/wiki/Impact_force

* 
* 



Impact and Crash

Impact: Collision between two bodies

Short interval of time

Large contact forces

*

Momentum is conserved

(assumed)

Kinetic energy

KE is conserved	Elastic collision
KE is not conserved	Inelastic collision
Bodies stick together	Completely inelastic collision

Collision in One Dimension

*

Momentum: $m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$

KE: $\frac{1}{2} m_1 v_{1i}^{\ 2} + \frac{1}{2} m_2 v_{2i}^{\ 2} = \frac{1}{2} m_1 v_{1f}^{\ 2} + \frac{1}{2} m_2 v_{2f}^{\ 2}$

$$\boxed{v_{1i} - v_{2i} = v_{1f} - v_{2f}}$$

$$v_{1f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v_{1i} + \left(\frac{2m_2}{m_1 + m_2}\right) v_{2i} \qquad v_{2f} = \left(\frac{2m_2}{m_1 + m_2}\right) v_{1i} + \left(\frac{m_2 - m_1}{m_1 + m_2}\right) v_{2i}$$

Collision in One Dimension

If $m_1 = m_2$

$$v_{1f} = v_{2i} \quad \& \quad v_{2f} = v_{1i}$$

If $v_{2i} = 0$

$$v_{1f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v_{1i} \qquad v_{2f} = \left(\frac{2m_2}{m_1 + m_2}\right) v_{1i}$$

If $m_1 = m_2$

$$v_{1f} = 0 \quad \& \quad v_{2f} = v_{1i}$$

If $m_1 << m_2$

$$v_{1f} \cong -v_{1i} \quad \& \quad v_{2f} \cong 0$$

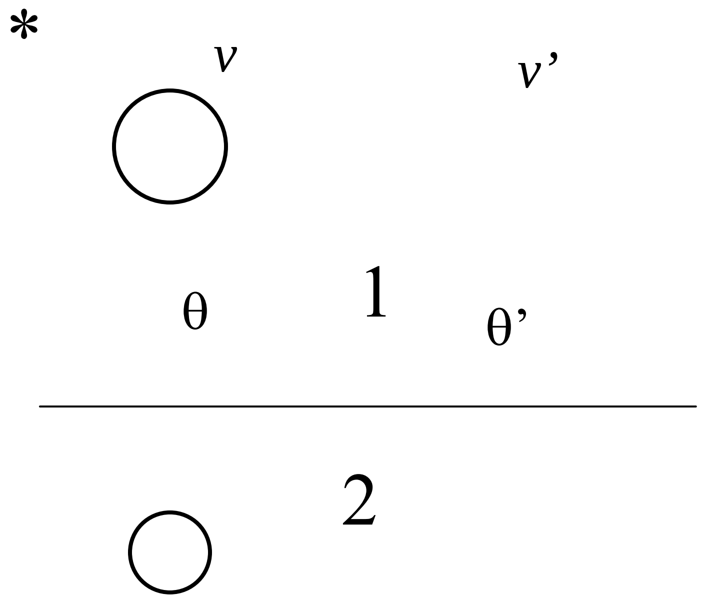
If $m_1 >> m_2$

$$v_{1f} \cong v_{1i} \quad \& \quad v_{2f} \cong 2v_{1i}$$

Collision in Two and Three Dimensions

Number of unknowns > Number of equations

(For 2D case, four components of velocities and only three equations)



$$-m_1 v_1 \sin\theta_1 + m_2 v_2 \sin\theta_2 = m_1 v_1' \sin\theta_1' - m_2 v_2' \sin\theta_2'$$

$$v_1 \cos\theta_1 = v_1' \cos\theta_1' \quad \& \quad v_2 \cos\theta_2 = v_2' \cos\theta_2'$$

Fourth relation

- shape of the body
- Material properties

Coefficient of restitution 'e'

$$e = \left(\frac{\int_{t_1}^{t} F_r \, dt}{\int_0^{t_1} F_d \, dt} \right)$$

$$e = \frac{m_1 (v_1' \sin\theta_1' - v_0)}{m_1 (v_0 + v_1 \sin\theta_1)}$$

$$e = \frac{m_2 (v_2' \sin\theta_2' - v_0)}{m_2 (-v_0 + v_2 \sin\theta_2)}$$

$$\boxed{e = \frac{(v_1' \sin\theta_1' + v_2' \sin\theta_2')}{(v_1 \sin\theta_1 + v_2 \sin\theta_2)}}$$

Little bit of Physics

Newton's First Law of Motion

Inertia

Newton's Second Law of Motion

$$\vec{F} = \frac{d(m\vec{v})}{dt} = \frac{\Delta(m\vec{v})}{\Delta t} = \frac{m\Delta(\vec{v})}{\Delta t}$$

$$\vec{F} * \Delta t \quad = \quad m * \Delta\vec{v}$$

$$Impulse \quad = \quad Momentum$$

Little bit of Physics

Law of Conservation of Momentum

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

Heavier Car vs Lighter Car

Kinetic Energy

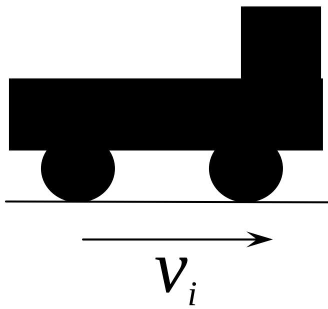
$$KE = \frac{1}{2} m v^2$$

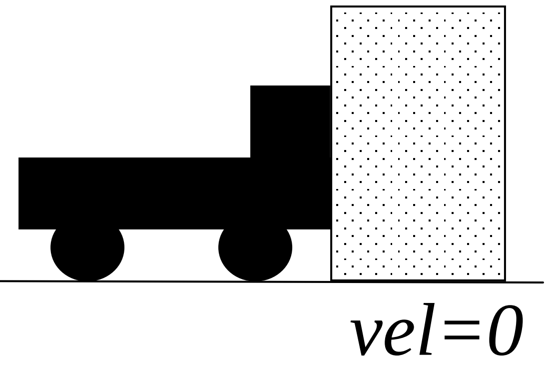
Work and Energy

Force and Work

Force in a Crash

- Mass of the vehicle
- Velocity
- Stopping distance
- Force on the structure
- Forces on the occupant

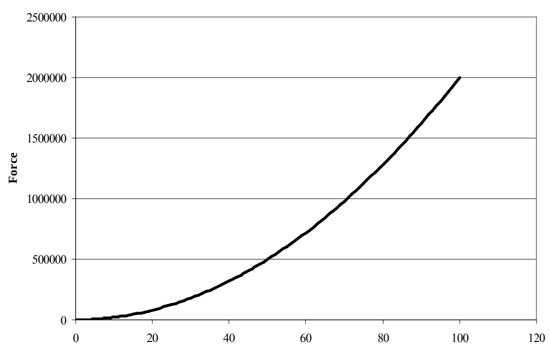




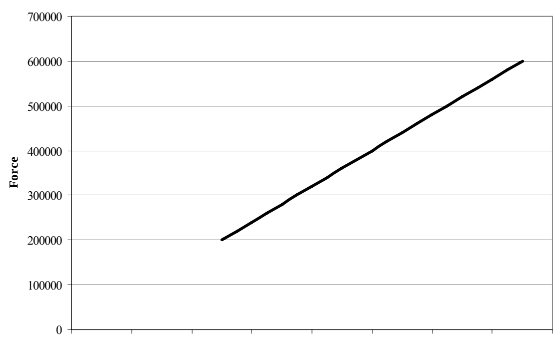
$KE=0.5*m*v_i^2$

$KE=0, Work=F_{avg}*d$

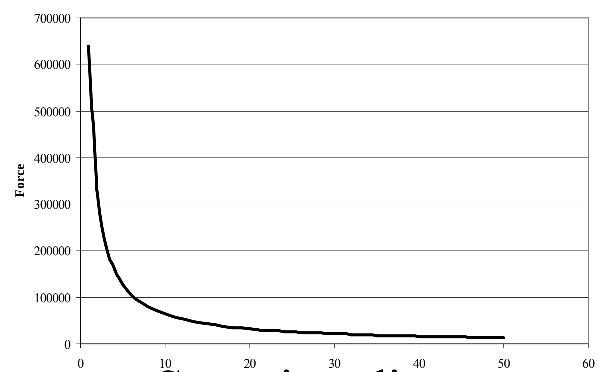
$$F_{avg} = (0.5*m*v_i^2)/d$$



Velocity



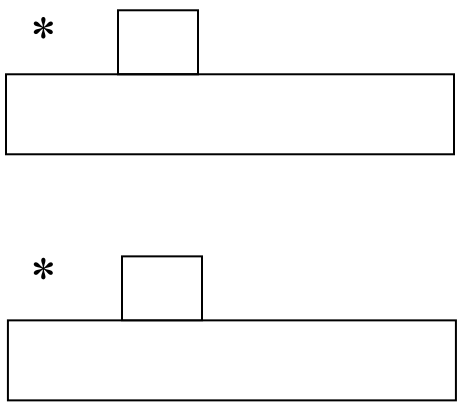
Weight



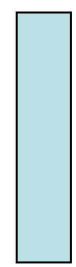
Stopping distance

The Three Stages of Collision

- Vehicle to Vehicle of Vehicle to Object Collision
  - ➢ Deceleration of the vehicle
  - ➢ Inertia of Occupant



- Occupant to Interior of the vehicle
  - ➢ Deceleration of the Occupant
  - ➢ Inertia of the internal organs



- Internal organs to the body interior
  - ➢ Deceleration of internal organs

Vehicle -- Occupant Interaction

Simplifying assumptions:

- Rigid Body Dynamics
- Relative motion leading to injury is not considered

'g' loading: Force resulting from acceleration of a mass

If acceleration of a body is expressed in terms of multiple of acceleration due to gravity ($n*g$), the force acting on the mass is ($n*W$), where w is the weight of the body.

What does a safety criteria "a human can withstand 10g loading" mean?

(Safe if 10 times the weight is applied on the person)

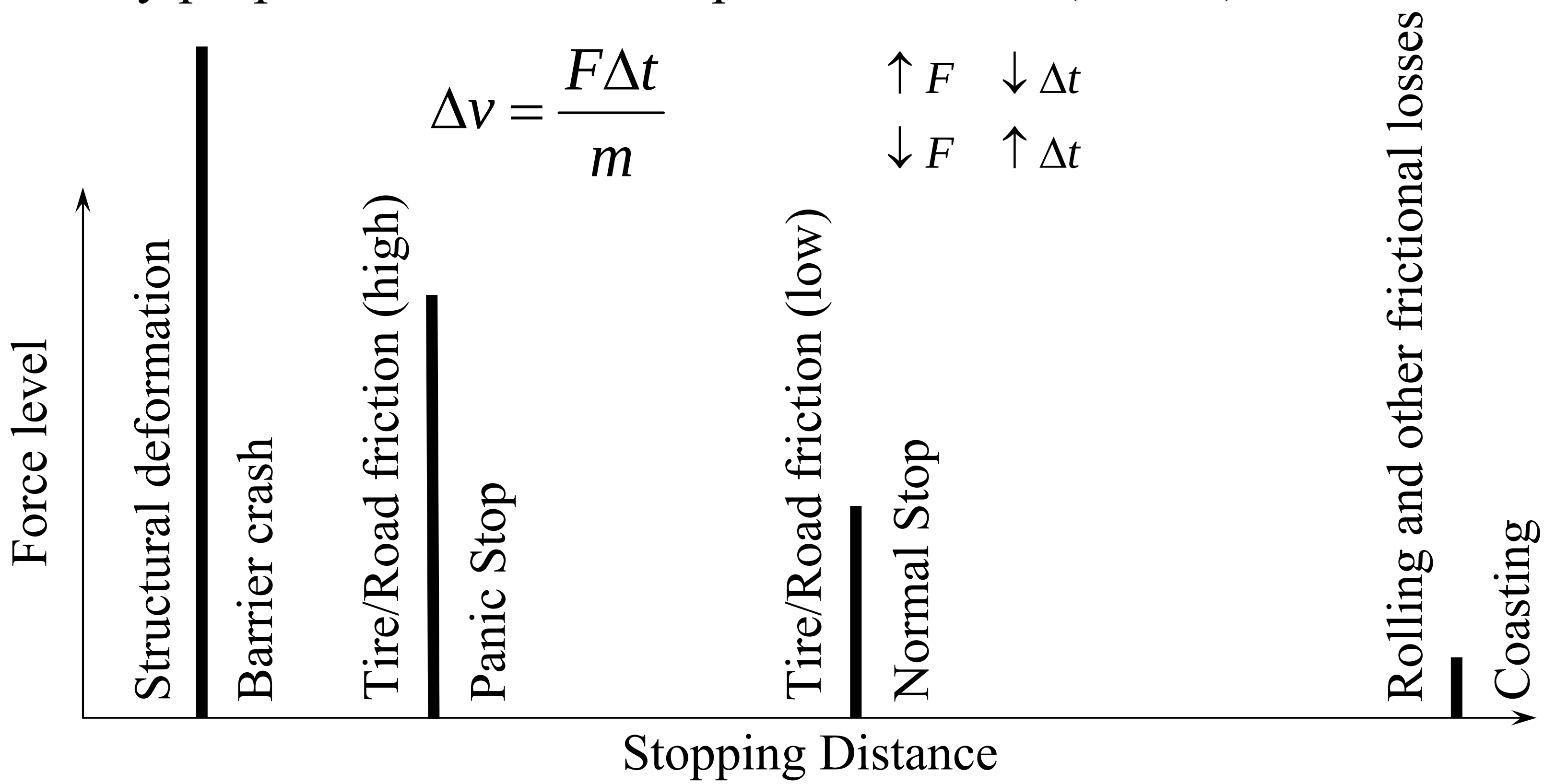
Vehicle -- Occupant Interaction

- Deceleration of the vehicle and occupant, generates forces on them (1st law)
- Increase/decrease of the velocity of the vehicle and occupant is proportional to the applied force and the duration of its application and inversely proportional to their respective masses (2nd law)

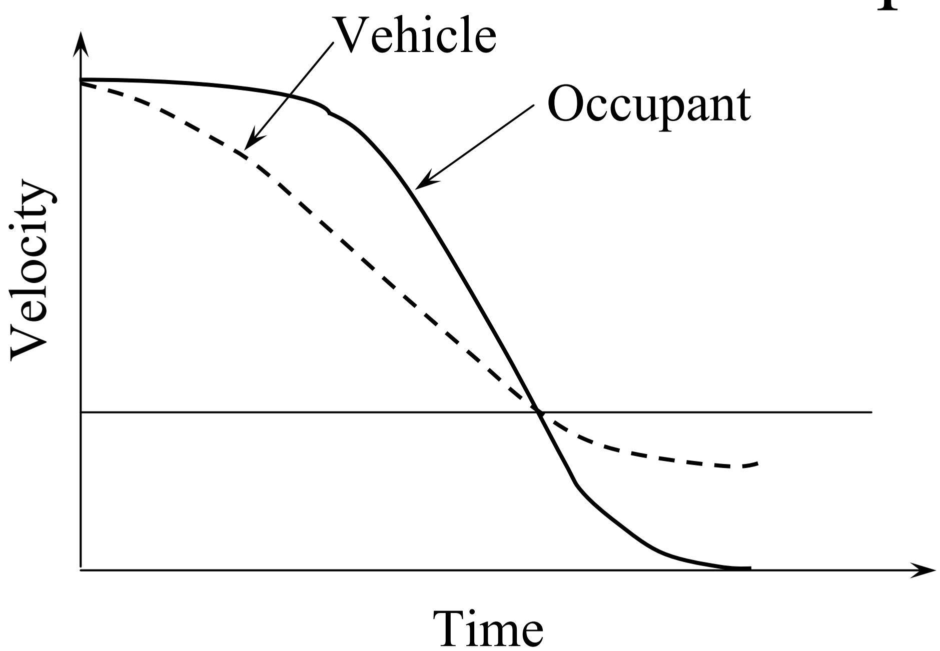
$$\Delta v = \frac{F\Delta t}{m}$$

$\uparrow F \quad \downarrow \Delta t$

$\downarrow F \quad \uparrow \Delta t$

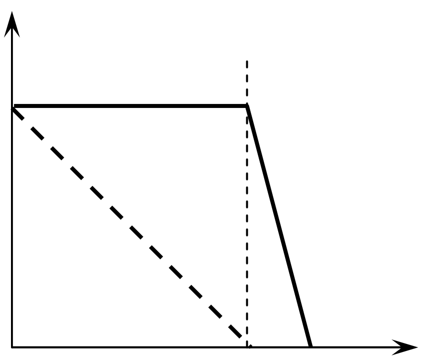


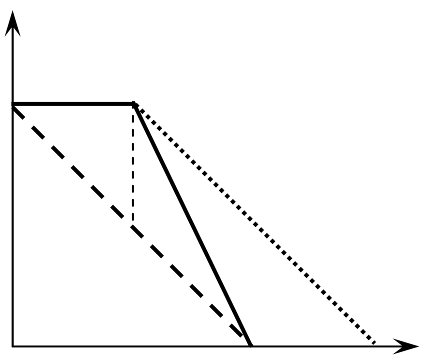
Vehicle -- Occupant Interaction



More the difference between the time of start of vehicle deceleration and application of restraint forces, more is relative travel of the occupant

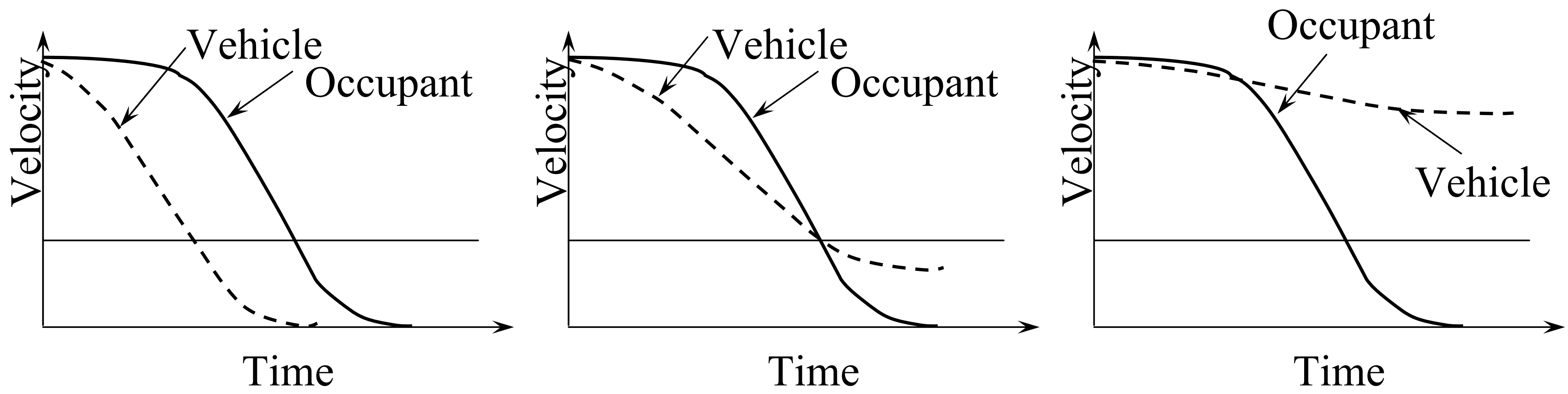
Unrestrained occupant continues to move at the initial velocity of the vehicle and is stopped by the impact over a very short time (depending on the stiffness of the structure)

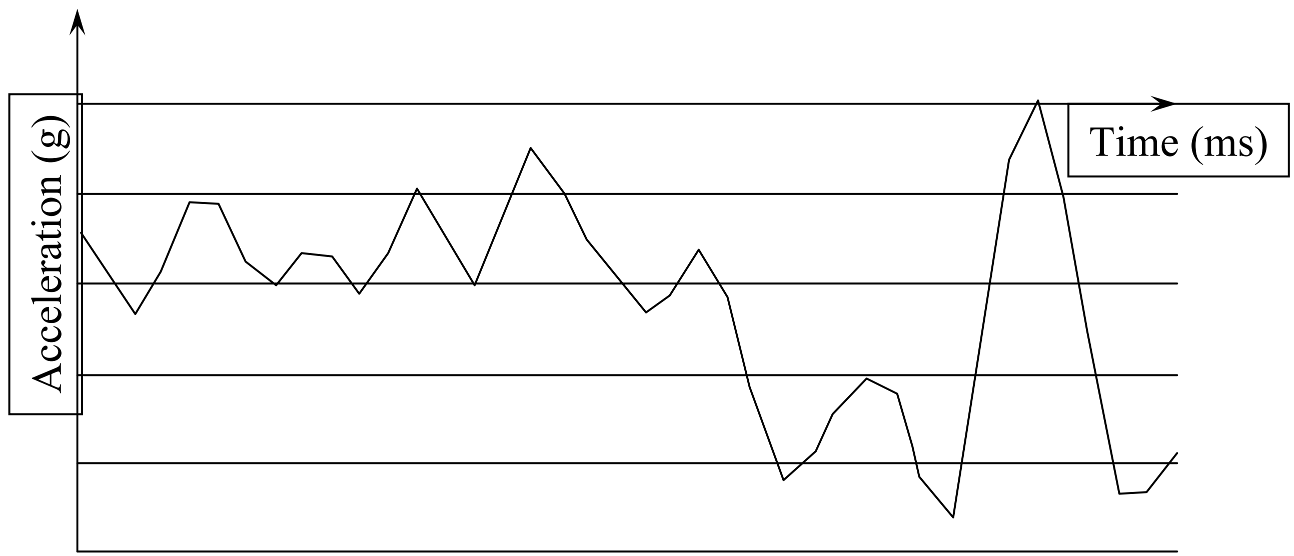




Time available to bring the restrained occupant, compared to unrestrained occupant, is much higher. Relative travel is much lower for constrained occupant.

Vehicle -- Occupant Interaction

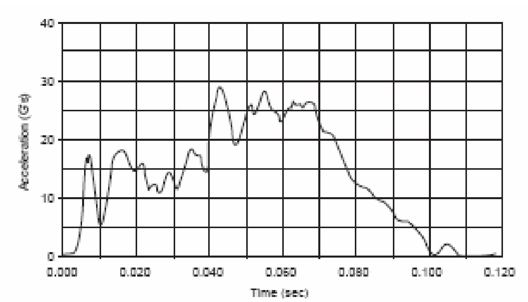




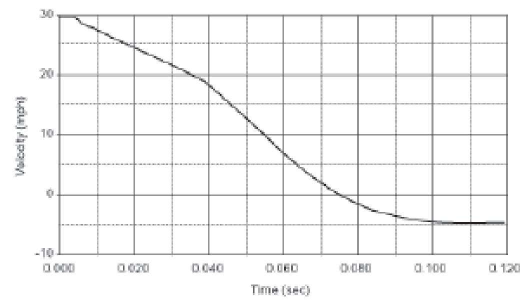
Safety related Vehicle Characteristics

Crash Pulse: Signature of vehicle deceleration measured in the non-crash zone in the passenger compartment

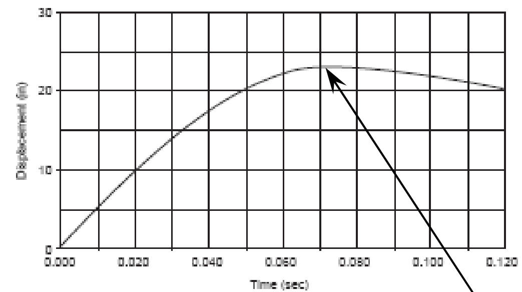
(function of dynamic crush phenomena)



Acc^n vs Time

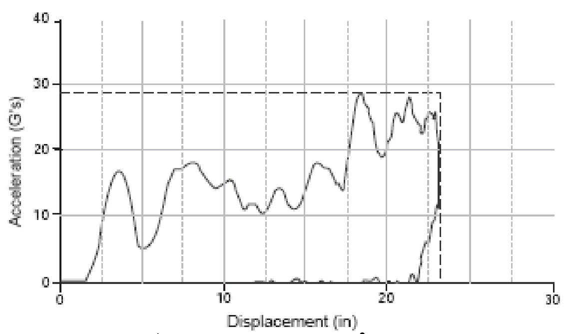


Vel. vs Time



Disp. vs Time

Vehicle Dynamic Crush Length

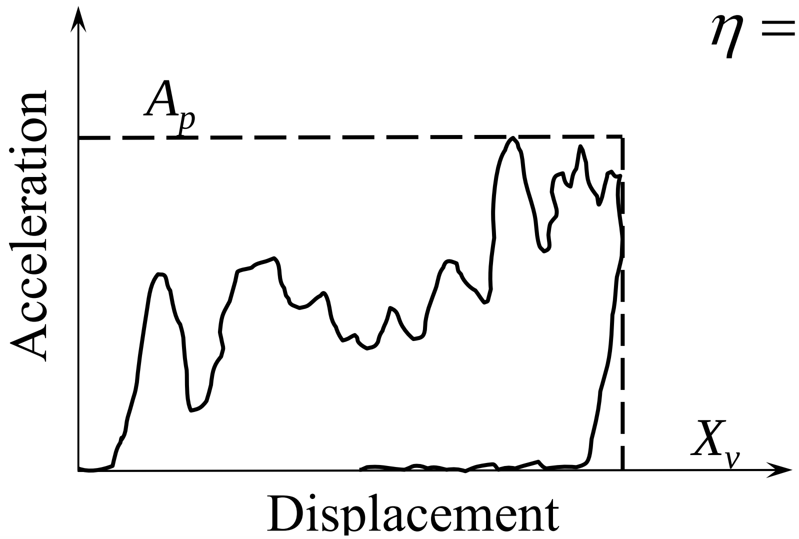


Acc^n vs Disp

$$\frac{1}{2}mv^2 \cong \int_0^v madx$$

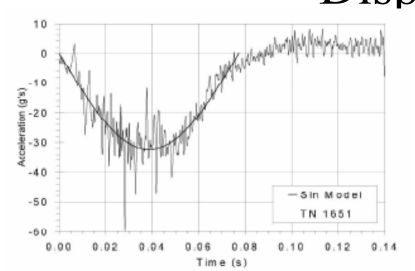
Safety related Vehicle Characteristics

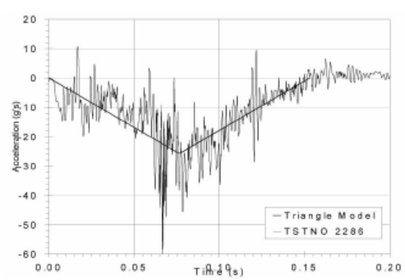
Idealisation:



$$\eta = \frac{Area\ under\ original\ curve}{Area\ under\ idealised\ curve} = \frac{0.5mv^2}{mX_v A_p}$$

$$F_{avg} = \frac{0.5mv^2}{X_v}$$





$$Equivalent\ Square\ Wave\ (ESW) = \frac{F_{avg}}{mg} = \frac{0.5v^2}{X_v}$$

A square pulse results in lower "peak" deceleration force

Result is lower force on the occupant

Lower restraint forces are required

Non-square pulse – extra crush distance

Occupant Safety

Prevent relative motion between the slowing vehicle and moving occupant

Force

(Interior of the vehicle)

Restraint System

- Deployment time
- Magnitude
- Time of application
- Mode of application
- Stiffness

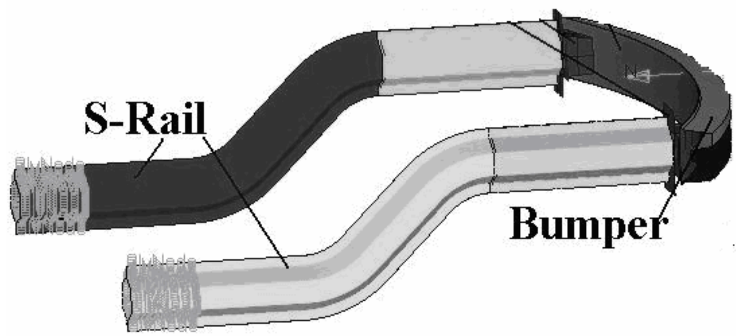
Structural Design Considerations

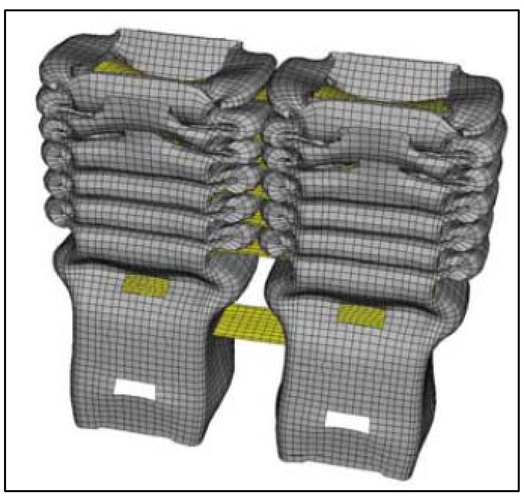
Structural Design for Occupant safety

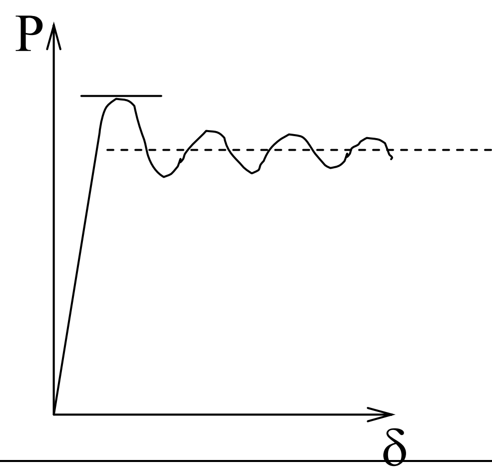
Control the Acceleration Pulse Characteristics

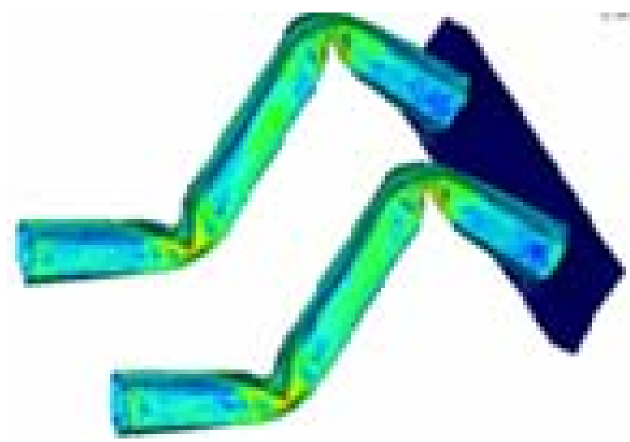
Controlled Energy Extraction

Soft? Hard?









Structural Design for Occupant safety

- Front end Stiffness
  - Materials
  - Geometry
  - Layout
  - Local Stiffness
- Interior design
  - Critical areas
  - Materials
  - Geometric details
  - Distances
  - Stiffness

Movement of bulky items

Pedestrian Safety

Automobiles/Accidents/Safety

The First Accident: Cugnot's steam tractor hits a low wall in the grounds of the Paris arsenal (1797)

http://inventors.about.com/library/weekly/aacarssteama.htm

http://en.wikipedia.org/wiki/Automobile

http://www.delhitrafficpolice.nic.in/traffic-history.htm

First documented fatalities: Mary Ward, Parsontown, Ireland (August 31, 1869)
Henry Bliss, New York City, NY (September 13, 1899)

First occupant fatality: First motor-car accident resulting in the death of the driver Grove Hill, Harrow-on-the-Hill, London (February 25, 1899)

The First Act: The Locomotives and Highway Act was the first piece of British motoring legislation. This was also known as the Red Flag Act of 1865. The act required three persons in attendance one to steer, one to stoke and one to walk 60 yards ahead with a red flag to warn the oncoming traffic.

20 million and counting

Traffic fatalities – Some Statistics

1 in 50 deaths caused by traffic accident

Yearly toll approximately 1.2 million

#2 killer in 5-29 yr age group

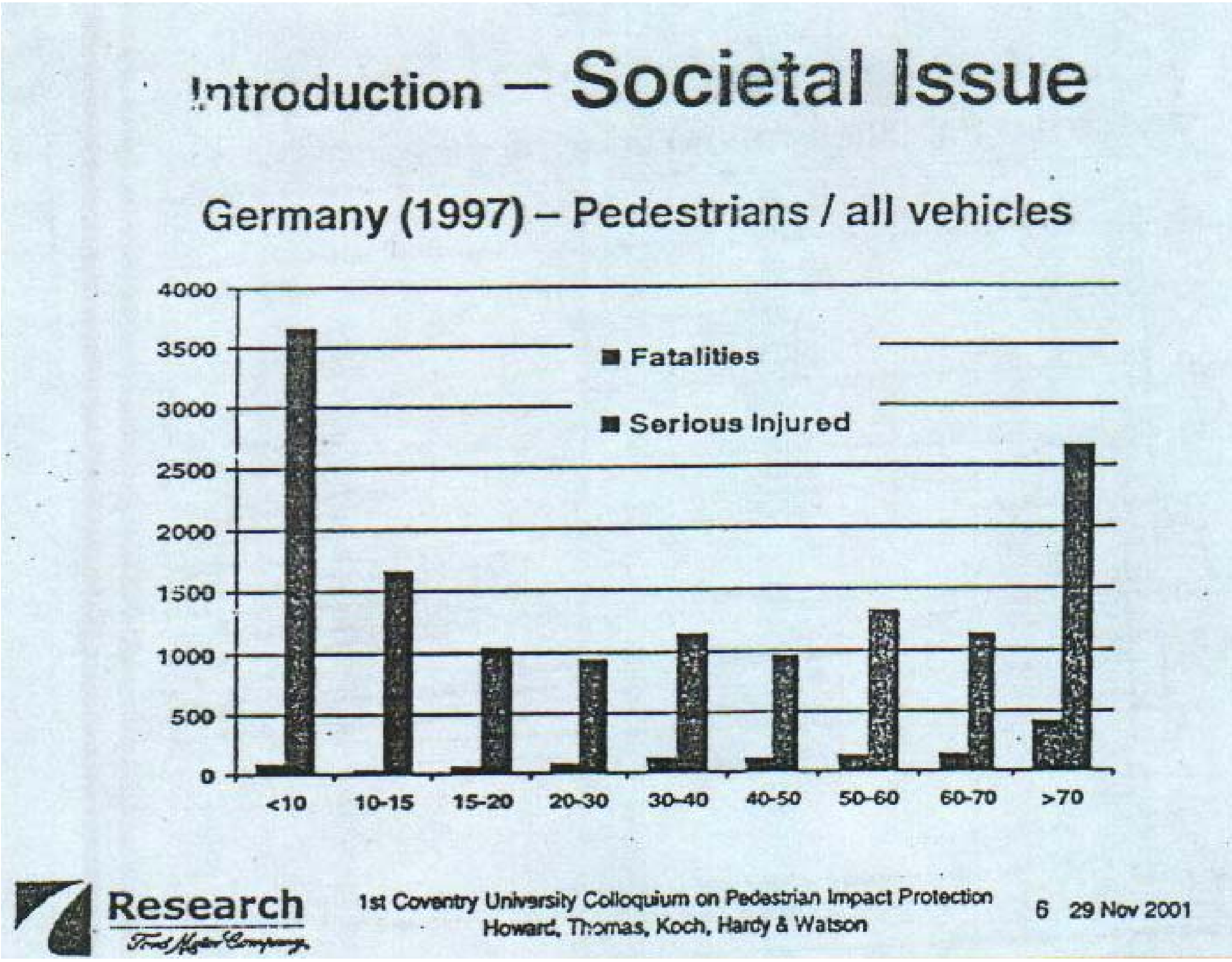
3rd largest health problem by 2020

US:	5000 fatalities	70000 injuries
Europe:	8000 fatalities	30000 injuries
India:	~100000 fatalities	(~ 270/day)

~ 40% involve pedestrians
(~80% in Mumbai, ~55% in Delhi)

Socio-economic cost: Rs. 55000 crores (~3% of GDP)

Traffic fatalities – Some Statistics



Children and Elderly are more vulnerable

Pedestrian protection solutions must cater to all the age groups

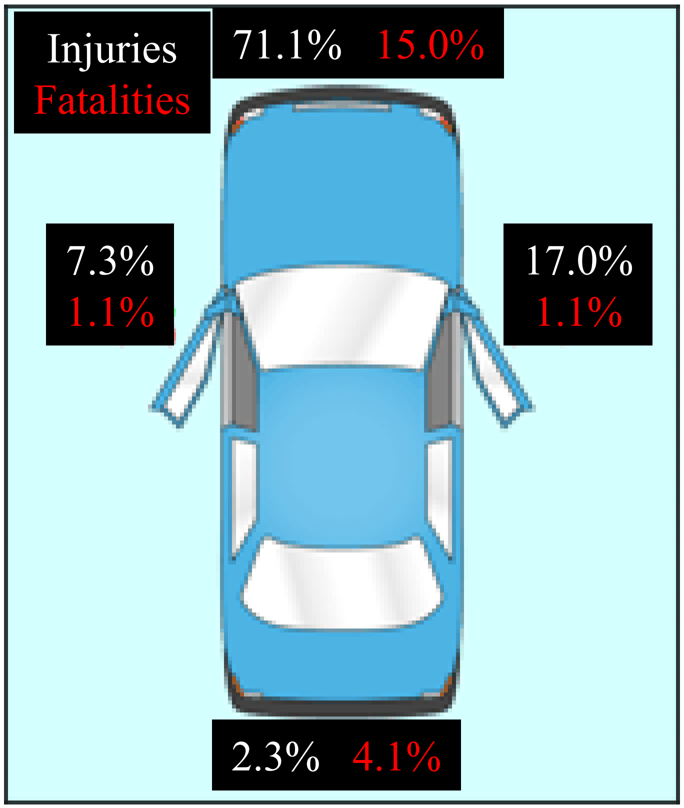
Age Gender

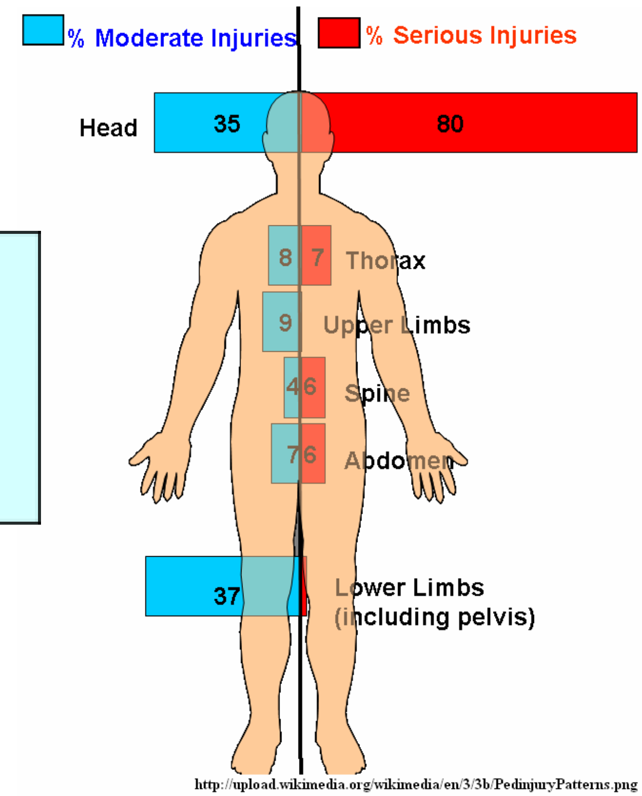
Types of injuries?

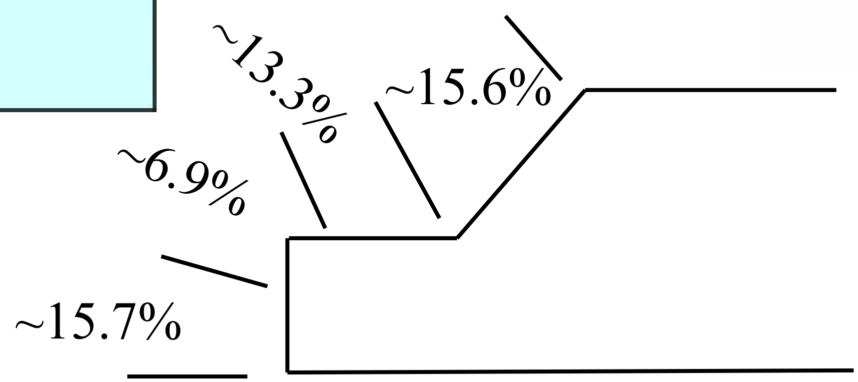
Body response?

Human body kinematics and human body injury indices
(simulation and testing)

Pedestrian Injury Statistics

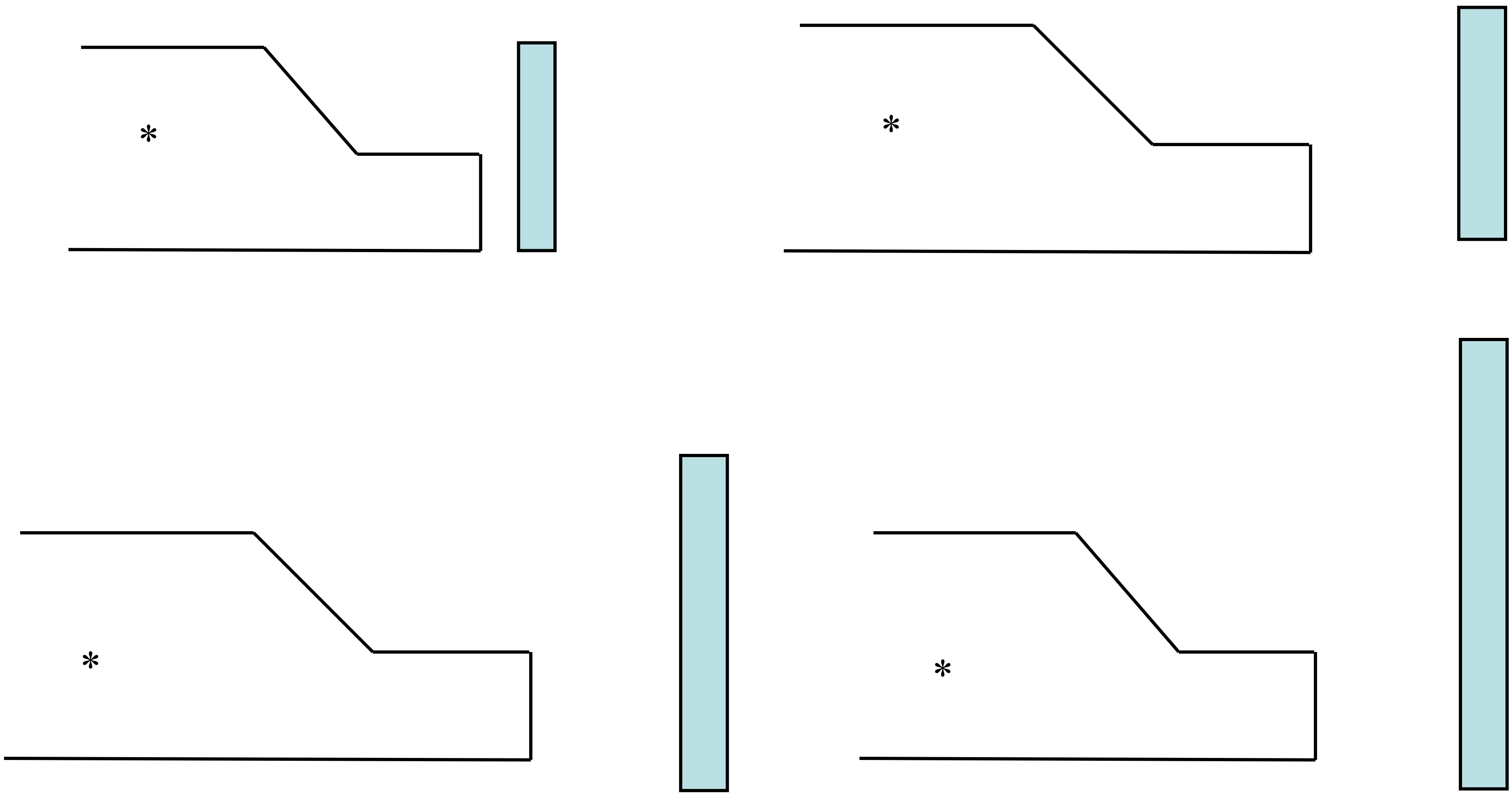




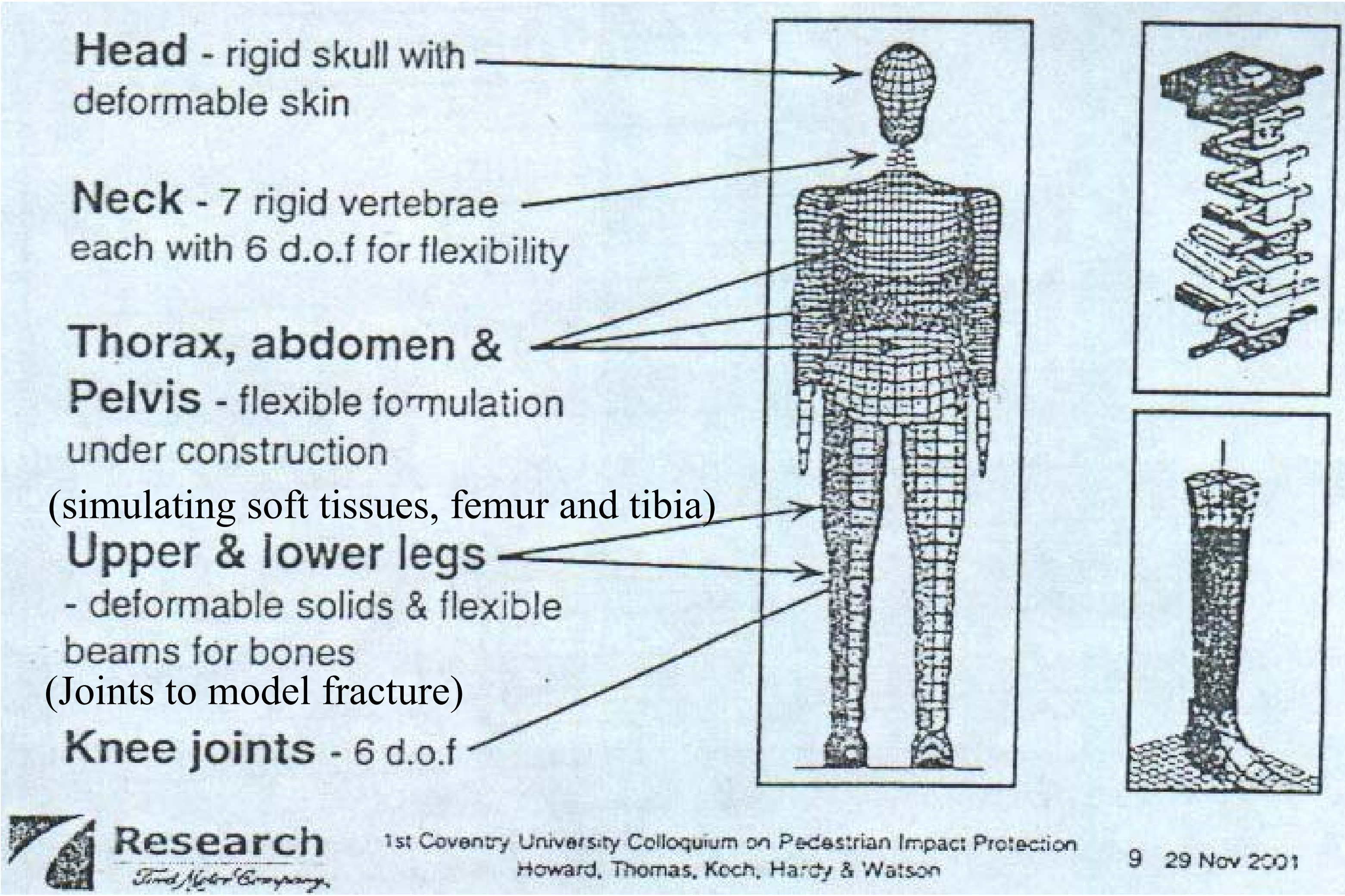


Nature of Vehicle-Pedestrian collision

Cause of automotive accidents Speed or Speed differential?



Humanoid Model -- Formulation

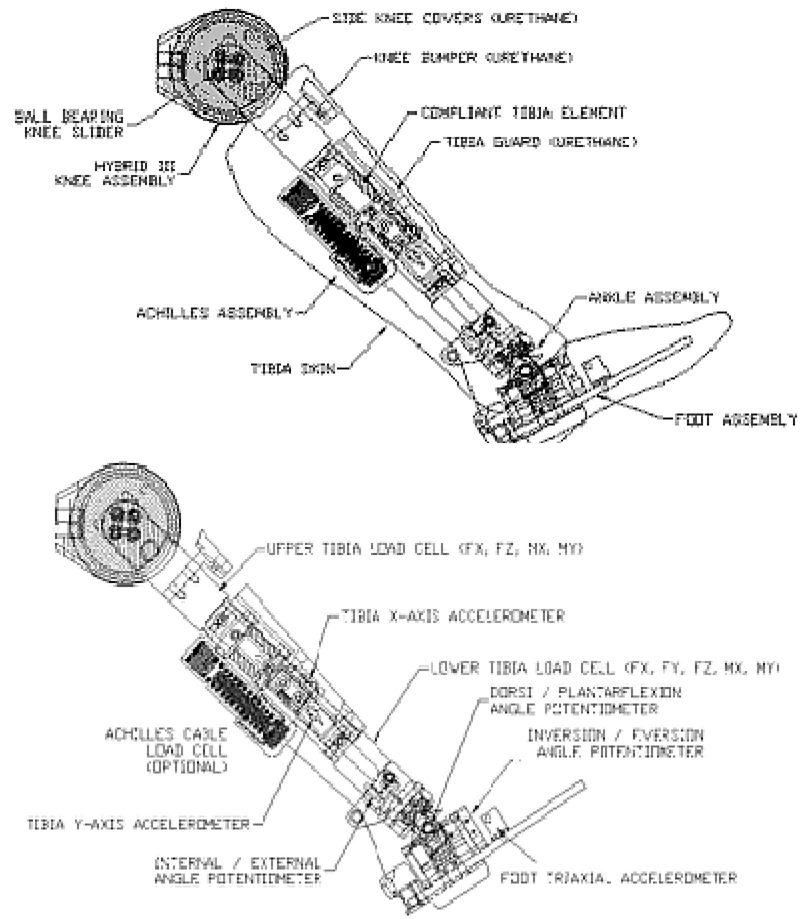


Features and mechanisms for improved model biofidelity and injury prediction

Humanoid Model (~ 7000 elements) in LS-DYNA3D for Pedestrian Accident simulation

Accident Simulation Model

National Transportation Biomechanics Research Center (NTBRC) of the NHTSA Research and Development Office



http://www-nrd.nhtsa.dot.gov/departments/nrd-51/thor_LX/Thorlxweb.html

Accident Simulation Model

First of its kind (pedestrian dummy) developed in 1998

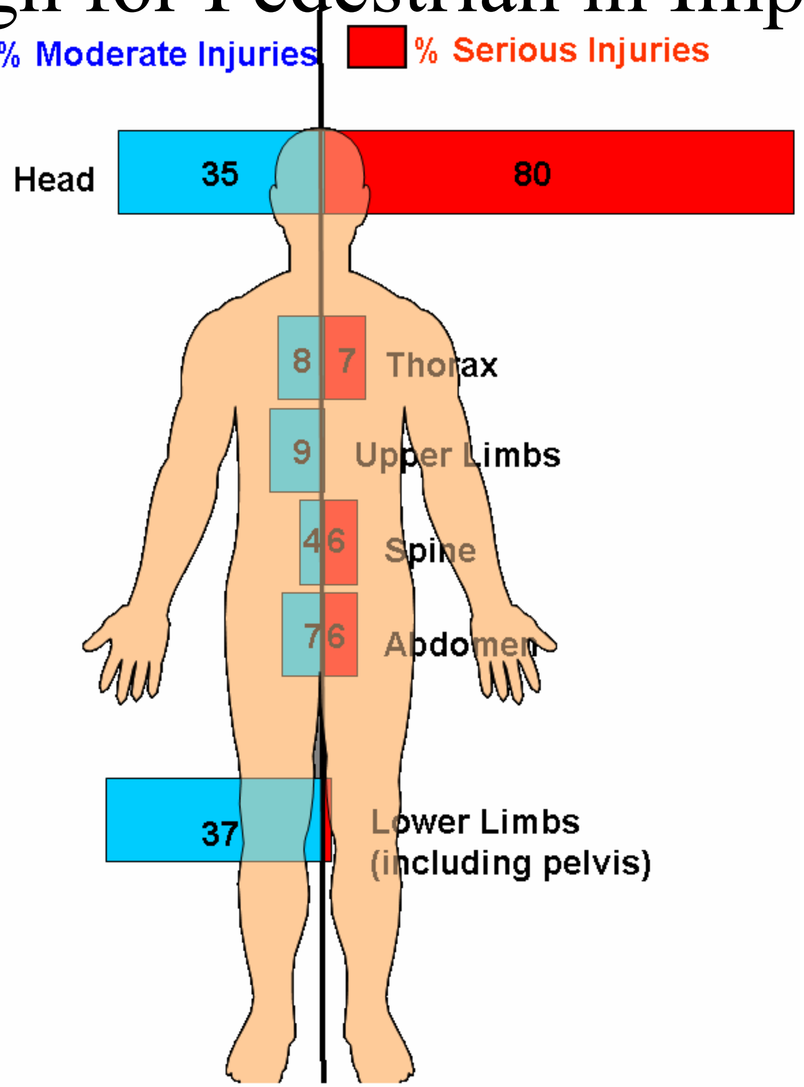
Used in the development of HR-V and Odessey

In 2001 Civic, 75 mm gap was provided between the hood and the engine

Investigating Pedestrian Kinematics with the Polar-II Finite Element Model
Document Number: 2007-01-0756
Jaeho Shin, Costin Untaroiu, Jason Kerrigan, Jeff Crandall, Damien Subit - Univ. of Virginia
Yukou Takahashi, Akihiko Akiyama, Yuji Kikuchi, Douglas Longhitano - Honda R&D Co., Ltd.

Design for Pedestrian in Impact

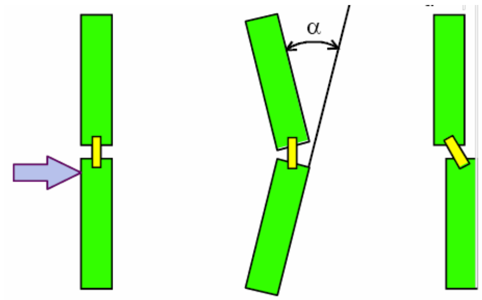
Bumper
Front end profile
Pedestrian physique



http://upload.wikimedia.org/wikimedia/en/3/3b/PedinjuryPatterns.png

Absorption of impact energy without undue deformation or acceleration

Absorption of impact energy with controlled deceleration



Front end profile
Pedestrian physique
Hood design
W/s X-mbr

Design for Pedestrian in Impact

Front Bumper:

Deeper profile/Secondary support bar below bumper/Bumper height

Reduced pitching of leg form and bending of knee joint

Localised compliance and efficient energy absorption

Reduced forces on the leg form

Headlamps:

Material (plastic vs glass)

Mounting location (below upper leg crush zone, back)

Mounting compliance (contradicting requirements)

Bonnet Leading edge:

Reduced stiffness at the front end

(moving the latch and stiffeners to side and back)

Increase crush depth

(contradicting requirements)

Design for Pedestrian in Impact

Bonnet and Fender tops:

Increase in low stiffness region

Fewer hard seams (generally at the edges)

Alternative design and material
(is opening the bonnet necessary?)
(can bonnet be a structural member?)

Increase under bonnet clearance (75 mm)

Placing softer components on the top

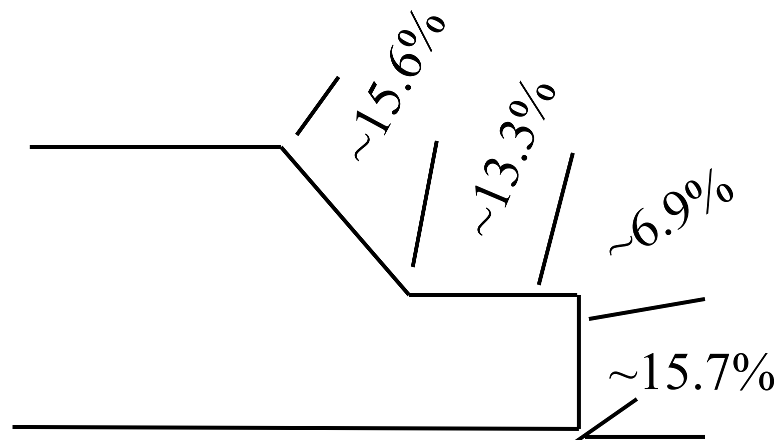
Bonnet that wraps around the sides

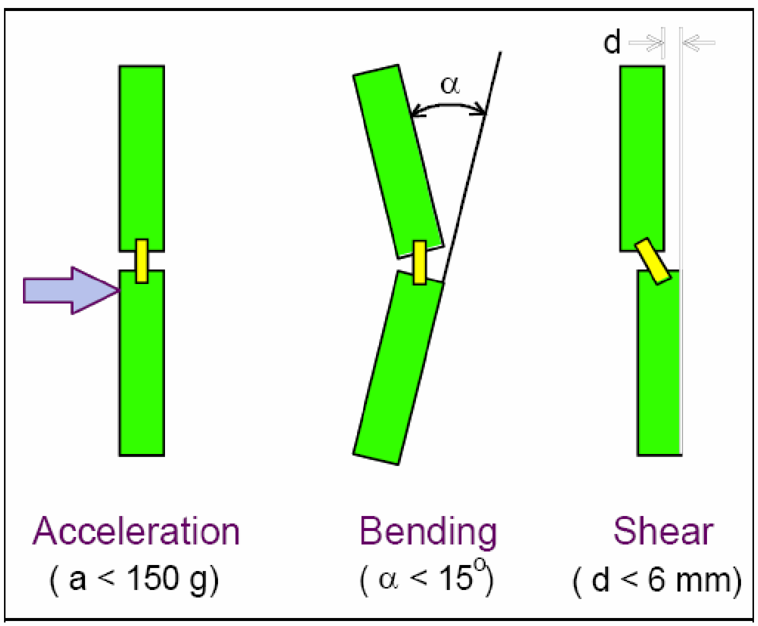
Bonnet with modified inner structure

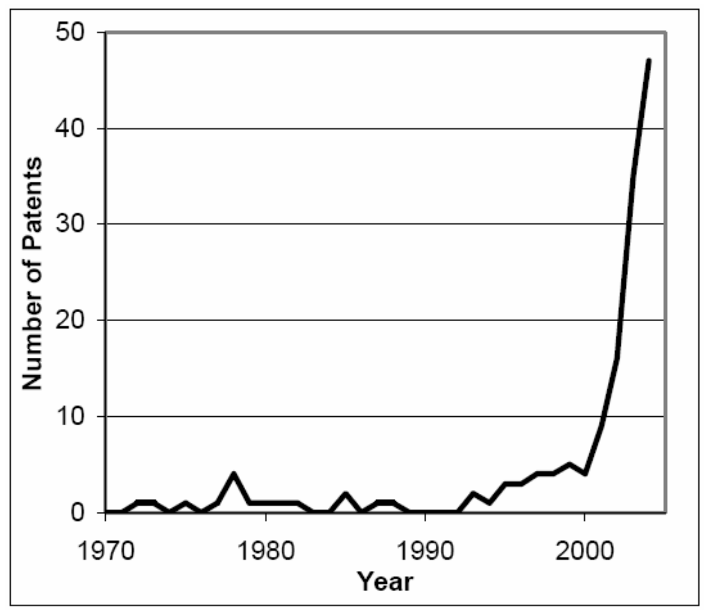
Systems for avoiding/softening collision with Pedestrian

- Over the hood air bag – 54”x22” deployed in 50-75 ms
  requires pre-impact sensor
- Base of the windshield air bag – two air bags deployed in 100 ms
  sensing initial impact with the pedestrian
  A-pillar to A-pillar
  Low enough not to block driver’s view
- Daytime running lights – Headlights whenever the car is running
  Increased visibility (resulted in 9% reduction)
- Laser Radar – For detecting pedestrians unto 50 yds in front
  Driver warning (visual and aural)
  Apply brakes in case of imminent collision
- Pop-up bonnet – Increases clearance between hood hard components underneath
  triggered by the initial impact (styling remains intact)
- Night vision technology – Infrared system identifies a pedestrians and warns
  triggered by the initial impact

Trends in Bumper Design



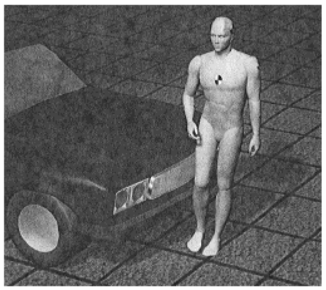


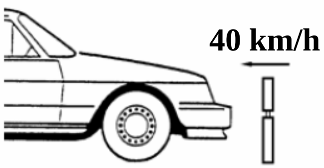


Peter J. Schuster, "Current Trends in Bumper Design for Pedestrian Impact", SAE Paper 2006-01-0464

Trends in Bumper Design

Leg
to Bumper





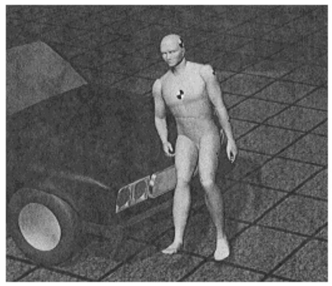
Directive 2003/105/EC

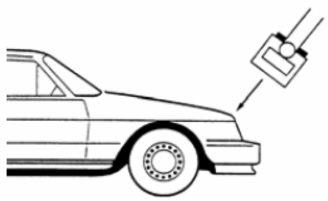
Knee bending	< 21°
Knee shear	< 6 mm
Tibia acceleration	< 200 g

EuroNCAP

Knee bending	< 15°
Knee shear	< 6 mm
Tibia acceleration	< 150 g

Upper Leg
to Hood Edge





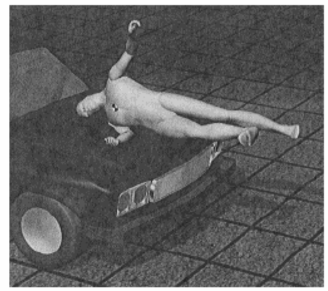
Directive 2003/105/EC

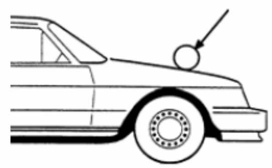
(Monitor Only)

EuroNCAP

Total load	< 5 kN
Bending moment	< 300 Nm

Head
to Hood Top





Directive 2003/105/EC

HPC	< 1000	(2/3 of area)
HPC	< 2000	(1/3 of area)

EuroNCAP

HPC < 1000

Peter J. Schuster, "Current Trends in Bumper Design for Pedestrian Impact", SAE Paper 2006-01-0464

M.P.Paine and C.G.Coxon, "Assessment of Pedestrian Protection Afforded by Vehicles in Australia", *Presented at Impact Biomechanics & Neck Injury 2000, Institution of Engineers Australia ,Sydney, March 2000*

Trends in Bumper Design

1. Cushion the impact and provide support to limbs to limit bending of the knee
2. Active systems triggered by the impact

Cushion the Impact:

Main purpose of the bumper system – for vehicle impact

For pedestrian impact, impact energy density is mush lower (~50%)

Performance criteria (e.g. allowable peak load) is different

Bumper system for pedestrian safety sacrifice vehicle damageability and increase depth of the bumper system

- Foam energy absorbers: Improve efficiency of existing foam absorbers with minimal increase in the vehicle length
  - Design of contacting shape (use some energy for rotation)
  - Use of multiple density foams
  - Use of fluid filled foam
  - Provide more space for foam (depression in the beam)
  - Coring of foam (removing material on the backside of the foam)

(Preferable with recovery char.)

Trends in Bumper Design

- Molded plastic energy absorbers: Molded plastic structure to absorb energy

  - ‘Egg-crate’ shapes
  - Structure with variable stiffness (changing thickness)
  - Open shells with no foam (for pedestrians only)

- Air filled energy absorbers: Constant or variable stiffness for different impacts
- Flexible or Plastic beam: Changing the structural member of the bumper
- Deploying bumper: Push out system when impact is predicted (vehicle length is not increased)
- Crush cans: Attached to the bumper beam – provide lower peak load
- Add-ons: Separate deformable structure added outside of the vehicle
- Foam encapsulated metal: Balance the two materials to achieve the goal
- Steel energy absorber: Use steel springs (with or independent of foam)

Trends in Bumper Design

Support: Distribute the load to minimise bending moment on the knee

Constrained by Ground clearance requirement
Vehicle damageability requirement

- Fixed lower stiffeners: Additional stationary component below the bumper preventing intrusion of lower leg form (metal beam, plastic tray, engine under tray etc.)

- Deploying lower stiffeners: Deployed based on object detection or speed

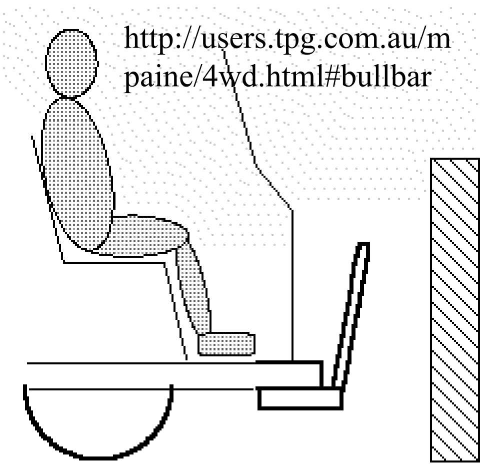
- Mechanical Linkages: Deployed by pressure on the bumper through linkage

- Deploying Upper Structure: Structure to prevent upper leg form movement

- Broad Face Bumpers: Tall bumpers for additional support

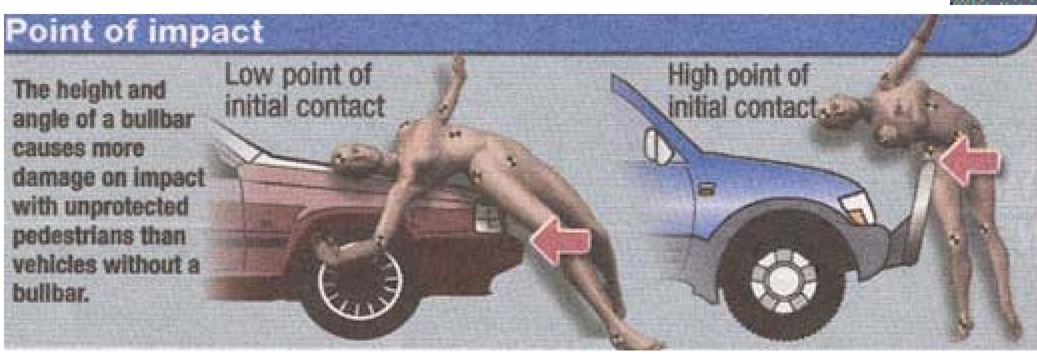
How not to design/modify the front end

*



*

Sequence from the Video "The Physics of Car Crashes“ by the Roads and Traffic Authority of NSW.

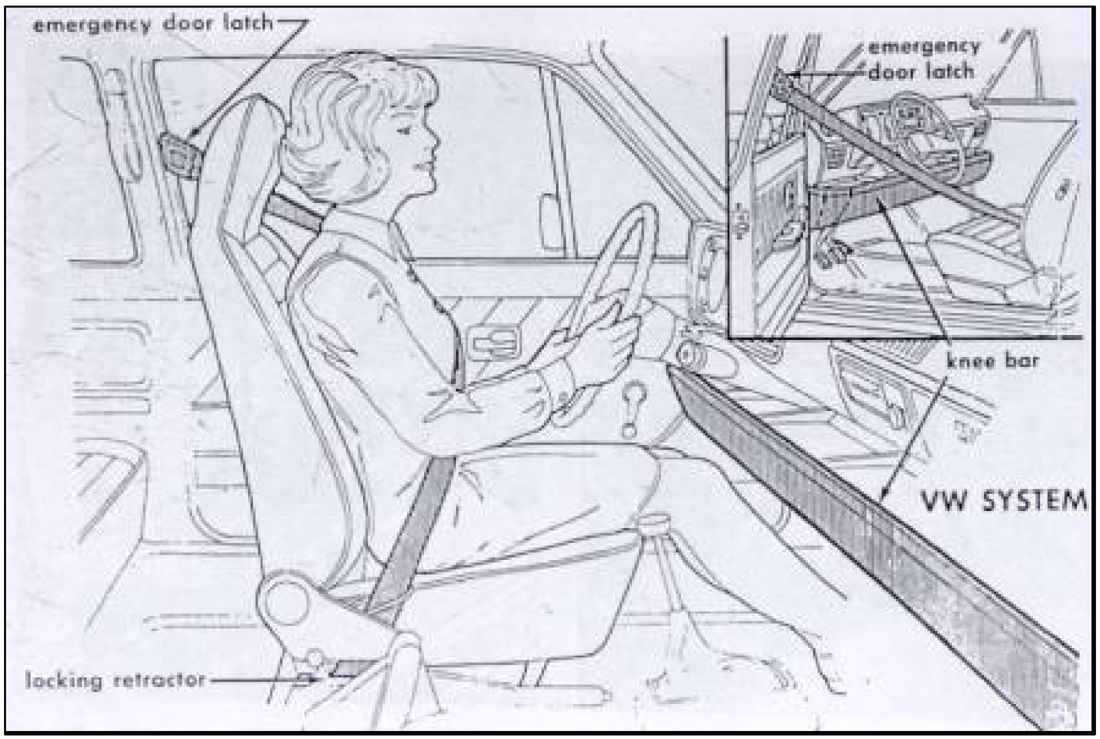


http://www.walk.com.au/pedestriancouncil /Page.asp?PageID=791

Passive Restraint Systems Seatbelts & Airbags

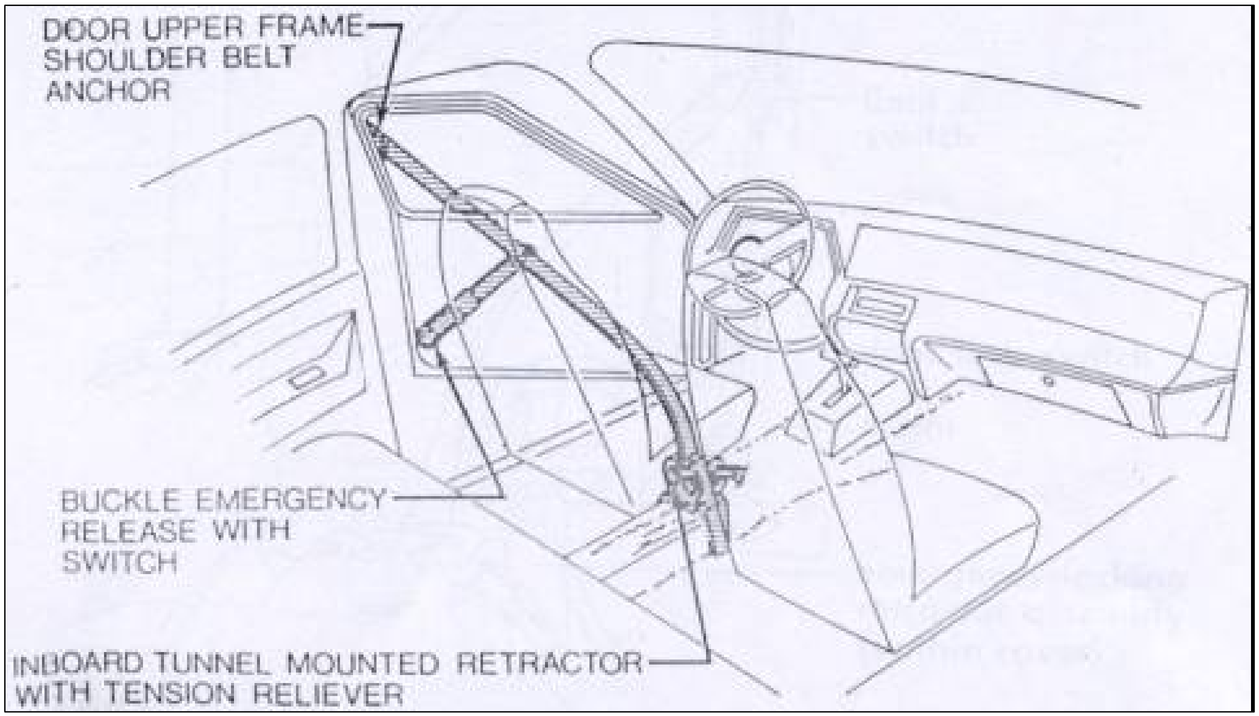
Historical Development

- Volvo 1959
- First production model to appear was a 2-point system in Volkswagen Rabbit - 1975



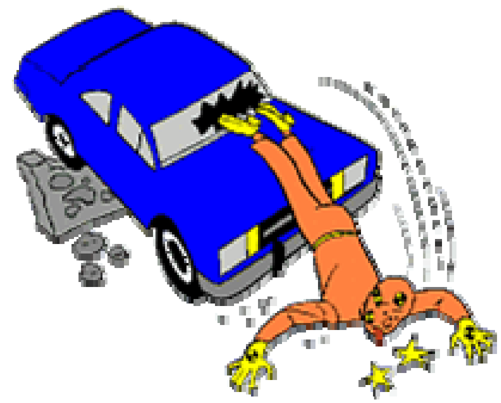
Historical Development

- 1980 - GM introduced 3-Point System in Chevette



Seat Belt Action

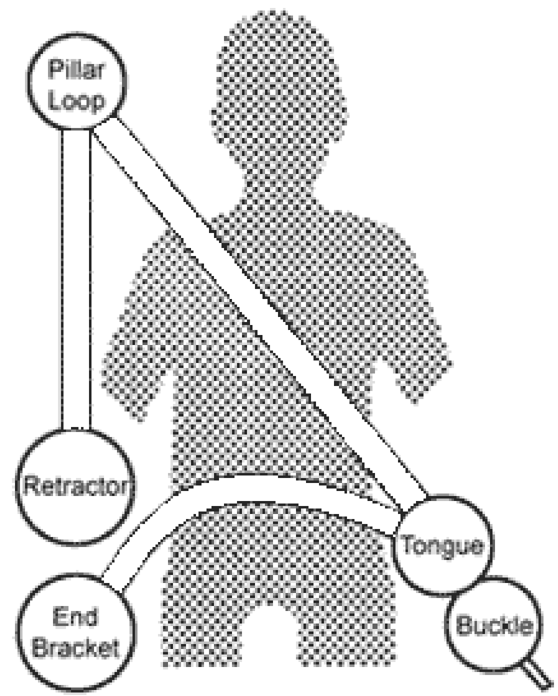
- Restraint forward movement of the occupant under sudden deceleration of the car through controlled application of force
- Distribute the forces of rapid deceleration over larger and stronger parts of the body - shoulder, chest & hip



- It reduce fatalities by 45 percent and serious injury by 50 percent.

3 Point Seat Belt System

- Lap Belt, Shoulder Belt, D-ring, Buckle, Retractor



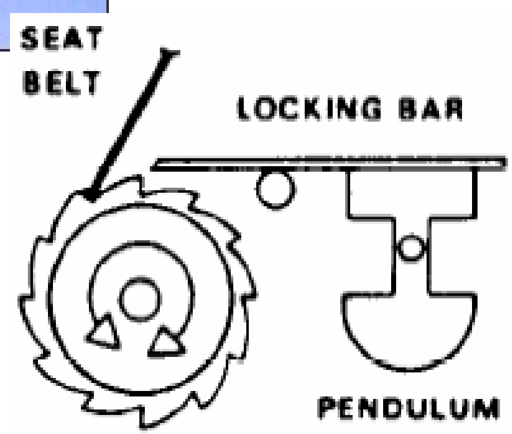
Seat Belt Webbing

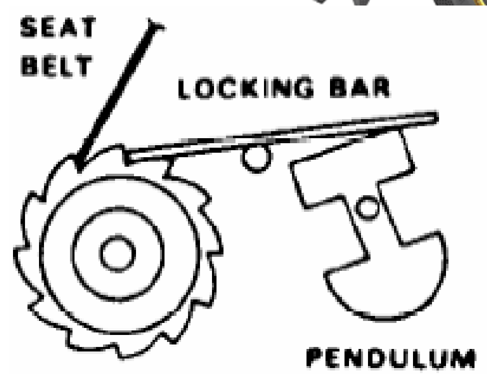
- Flexible Material
- Tensile Strength- 27kN
- Elongation of 10-15 % at 11.1kN

www.autotrends.org/images/inflatable-seat-belt-1.jpg

Retractor

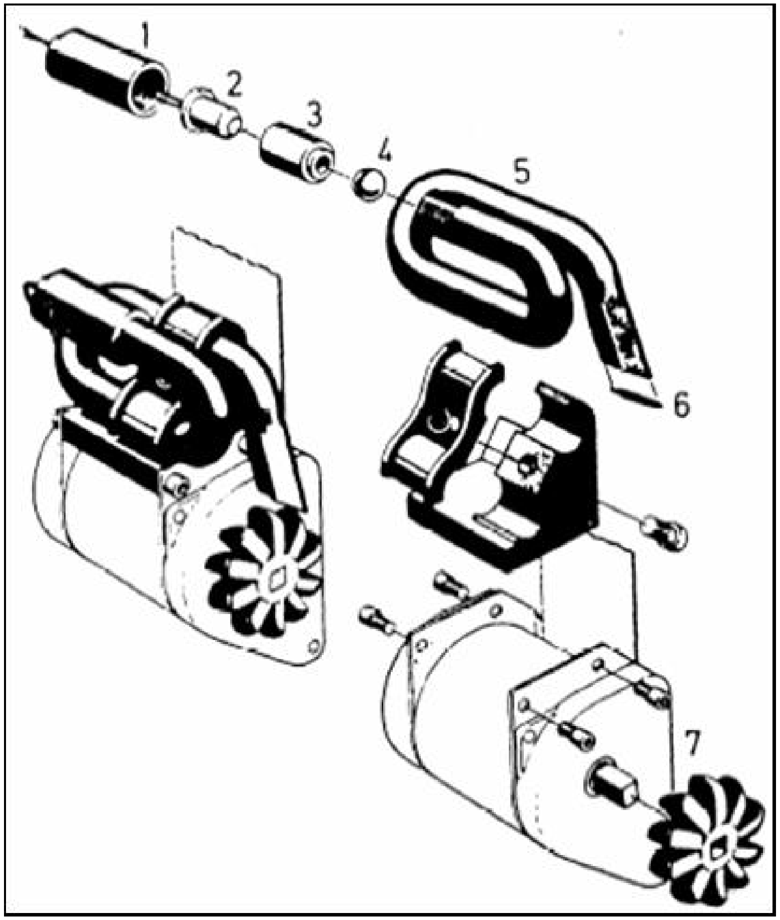
- Stores and Release the webbing
- During emergency it locks the Spindle
- Equipped by multiple sensing mechanism - Vehicle Deceleration or Rate at which webbing is pulled out





RATCHET MECHANISM

Retractor



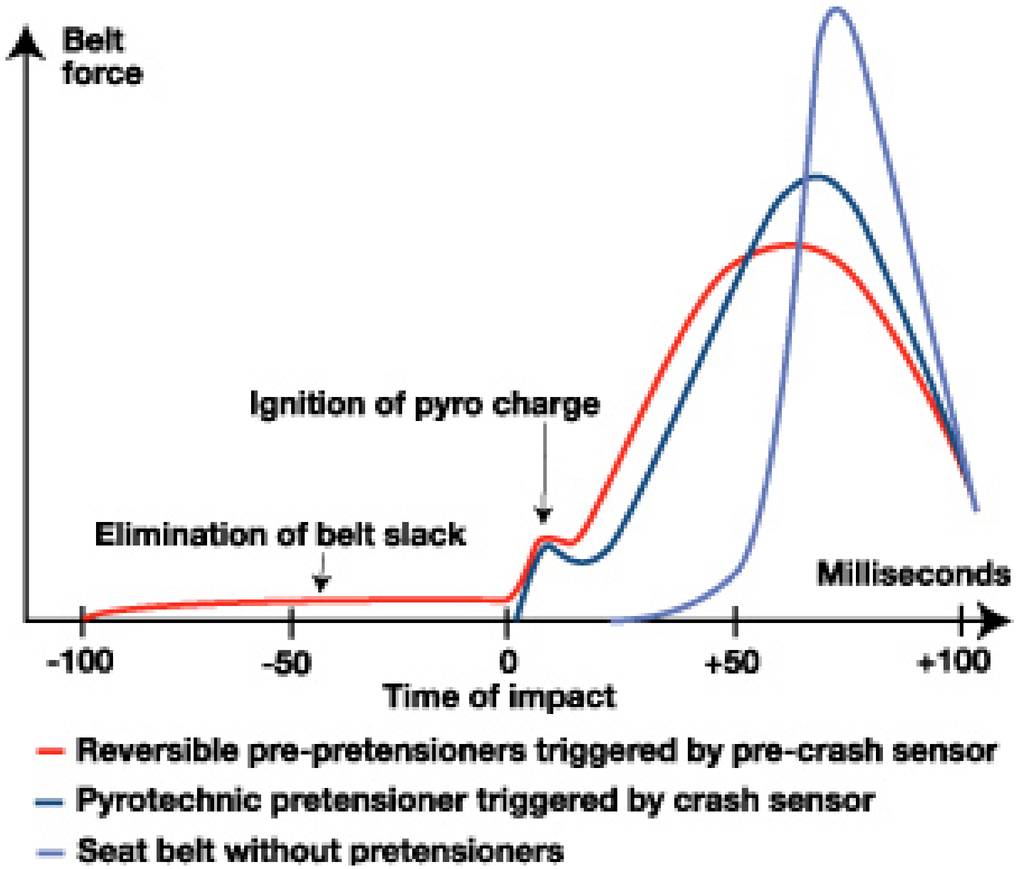
1.Clamping Nut, 2.Solid Propellant Capsule,

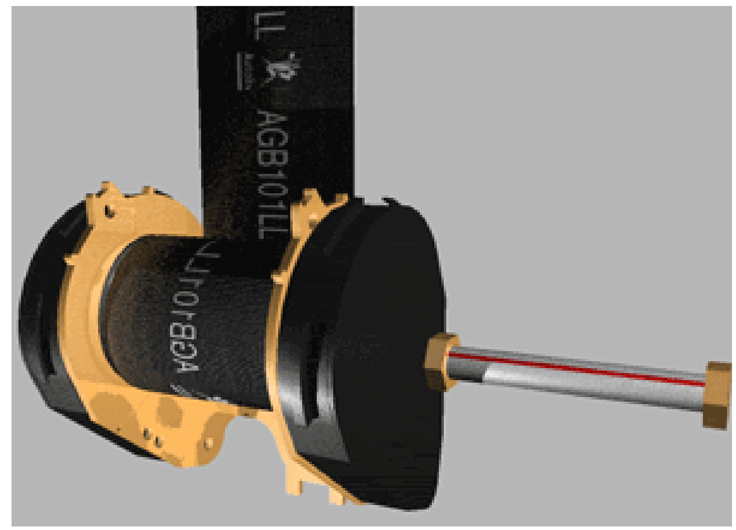
3.Gas Generator Housing, 4.Flying Piston,

5.Fluid Filled Tube, 6.Foil Plug, 7.Turbine Wheel

Roto - Pretensioner

Retractor





Load Limiter

Performance of Retractor with Pretensioner

To wear or not to wear, that is the question

A Fatal Crash – A Timeline

0:00.1: Front bumper & grill collapse as the vehicle makes contact with stationary solid object

0:00.2: Hood crumples, striking windshield, rear wheels lift from the ground. Car frame has halted, but your unrestrained body is still going 55mph. Legs stiffen against the crash & snap at the knee joint

0:00.3: Steering wheel starts to disintegrate as your chest is propelled toward the steering column

0:00.4: Two feet of the car's front end is wrecked. The rear end still moves at 35mph, & your body continues traveling at 55mph

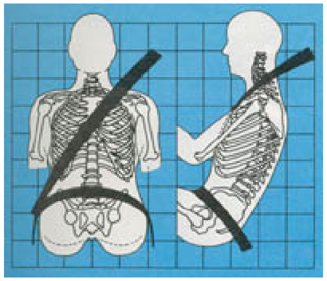
0:00.5: You are impaled on the steering column, & blood rushes to your lungs

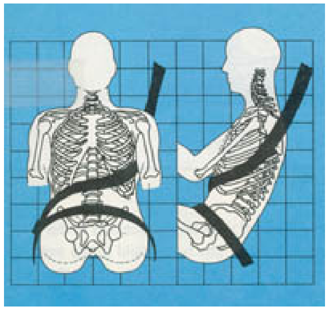
0:00.6: Impact builds, ripping your feet from tightly laced shoes, brake pedals come off, car frame buckles in the middle, your head smashes into the windshield as the rear wheels, still spinning, fall back to earth.

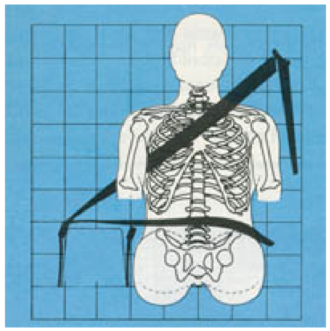
A Fatal Crash – A Timeline

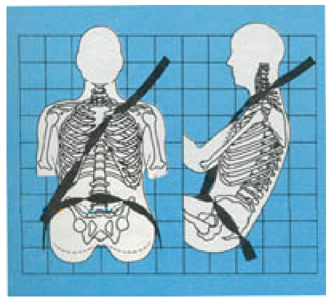
0:00.7: Hinges rip loose, doors open & the seat breaks free, striking you from behind and the last three tenths of a second mean nothing to you because you are now **DEAD !**

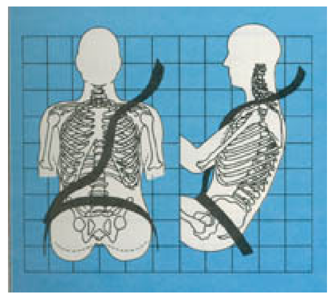
Dos and Don’ts of Seat Belts











Usage Precautions for Vehicles Equipped with Airbags

4 Point Seat Belt

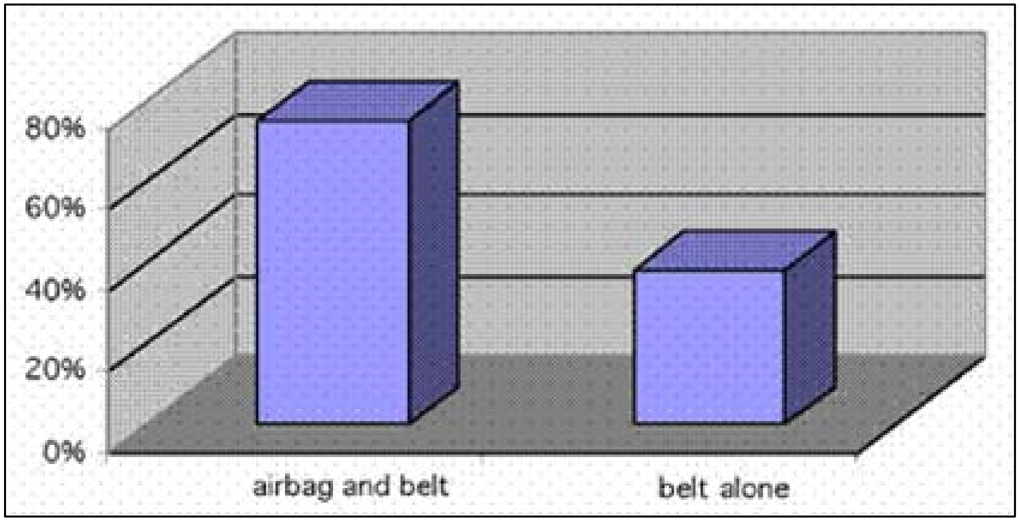
5 Point Seat Belt

https://www.autoloandaily.com/images/stories/28006_proper_child_safety_5.jpg

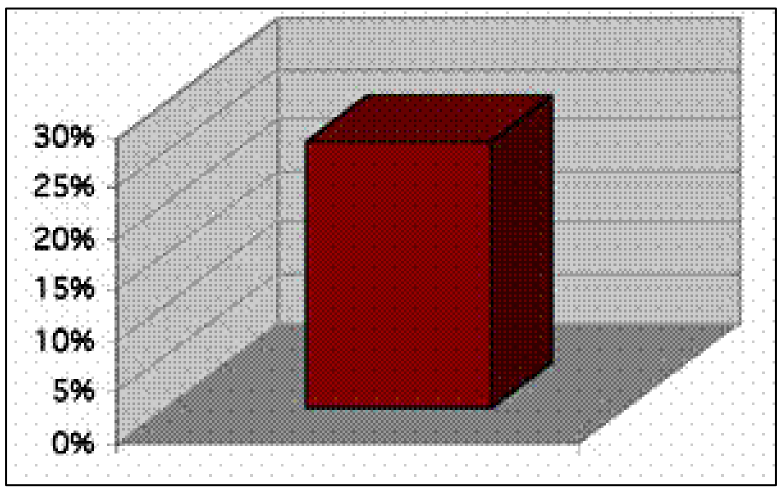
Airbags

The Safety Advantage of Airbag:

- SRS
- Restrains drivers & Passengers in an accident
- Designed to act as a supplemental safety device in addition to a seat belt
- Patented in 1953 / Available since late 1980's
- Deploy and inflate within 40 milliseconds
- US passed a law which was effective from 1998
- Reduce risk of dying in a direct frontal crash by about 30 %

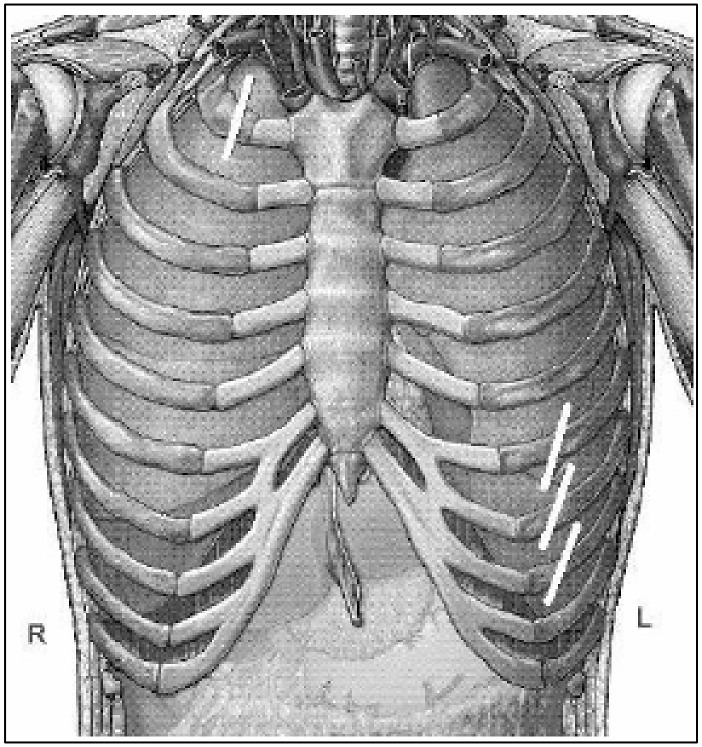


Percent Reduction in Moderate to Serious Head Injuries
(Compared to Drivers Using No Restraining Safety Equipment)



Percent Reduction in Driver Deaths Attributable to Airbags Among Drivers Using Seat Belts

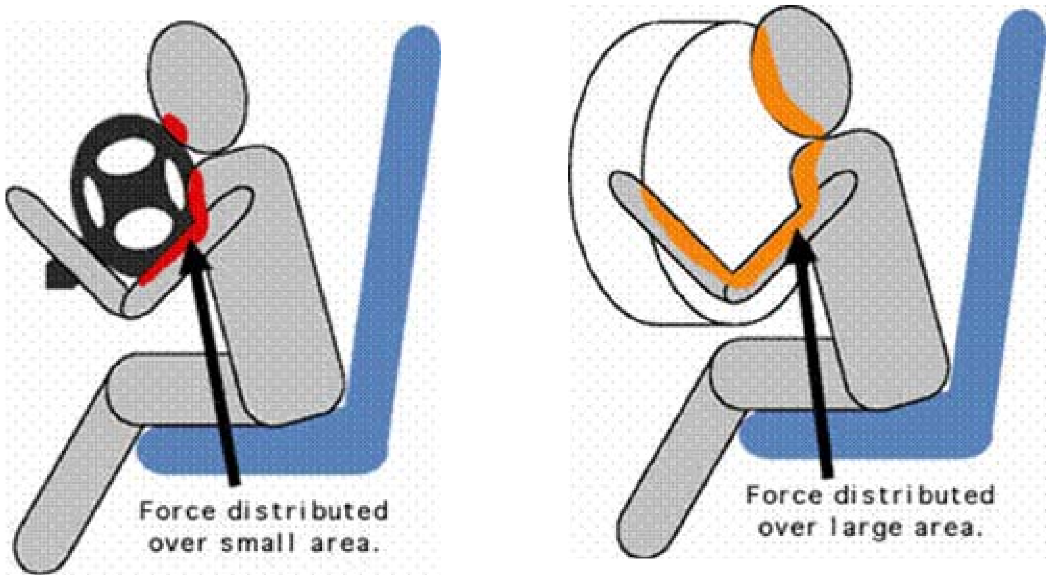
CASE #92-017

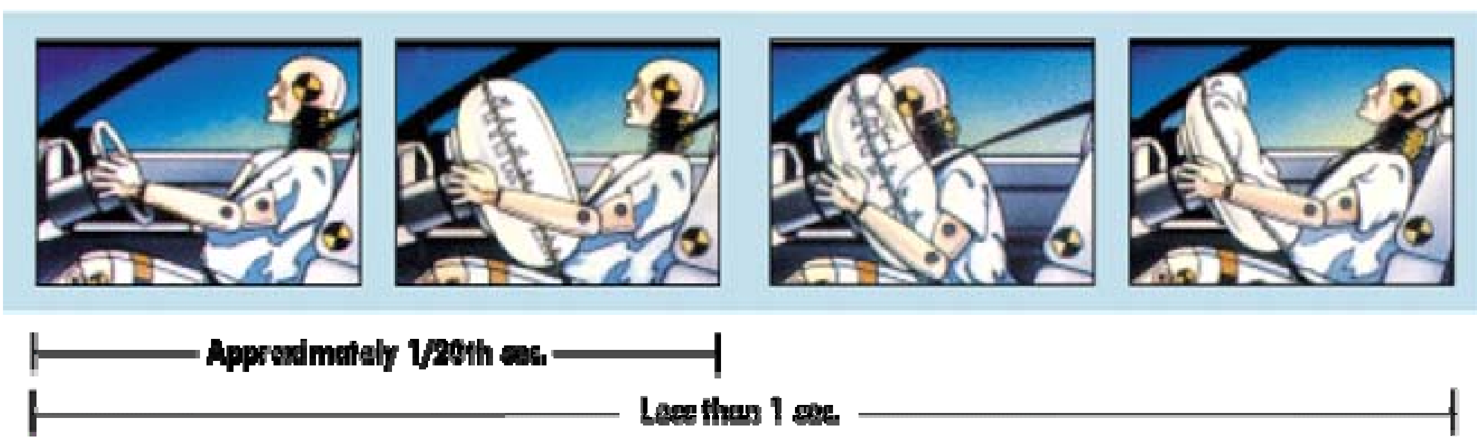


AIS 3 Rib Fracture, Left
AIS 3 Heart Contusion
AIS 3 Lung Contusion, Left
AIS 2 Calcaneus Fracture, Right

- 1991 Mercury Marquis, impacted a 1992 Ford Mustang with a delta-V of 37 mph
- Impact was full frontal & driver was a 63-year-old male, 70” tall, weighing 175 lbs
- He was protected by a lap & shoulder belt & an airbag
- There was 5 inches of toepan intrusion & 2 inches of steering wheel deformation

How Does the Presence of an Airbag Actually Protect You ?





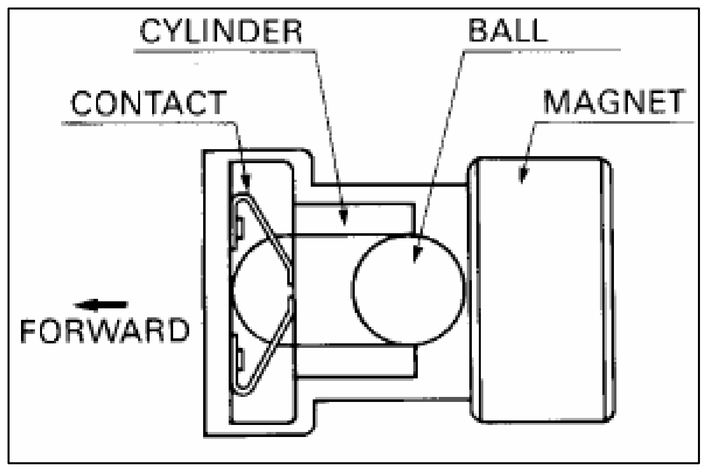
Distribution of forces without and with airbag

The components of an Airbag System:

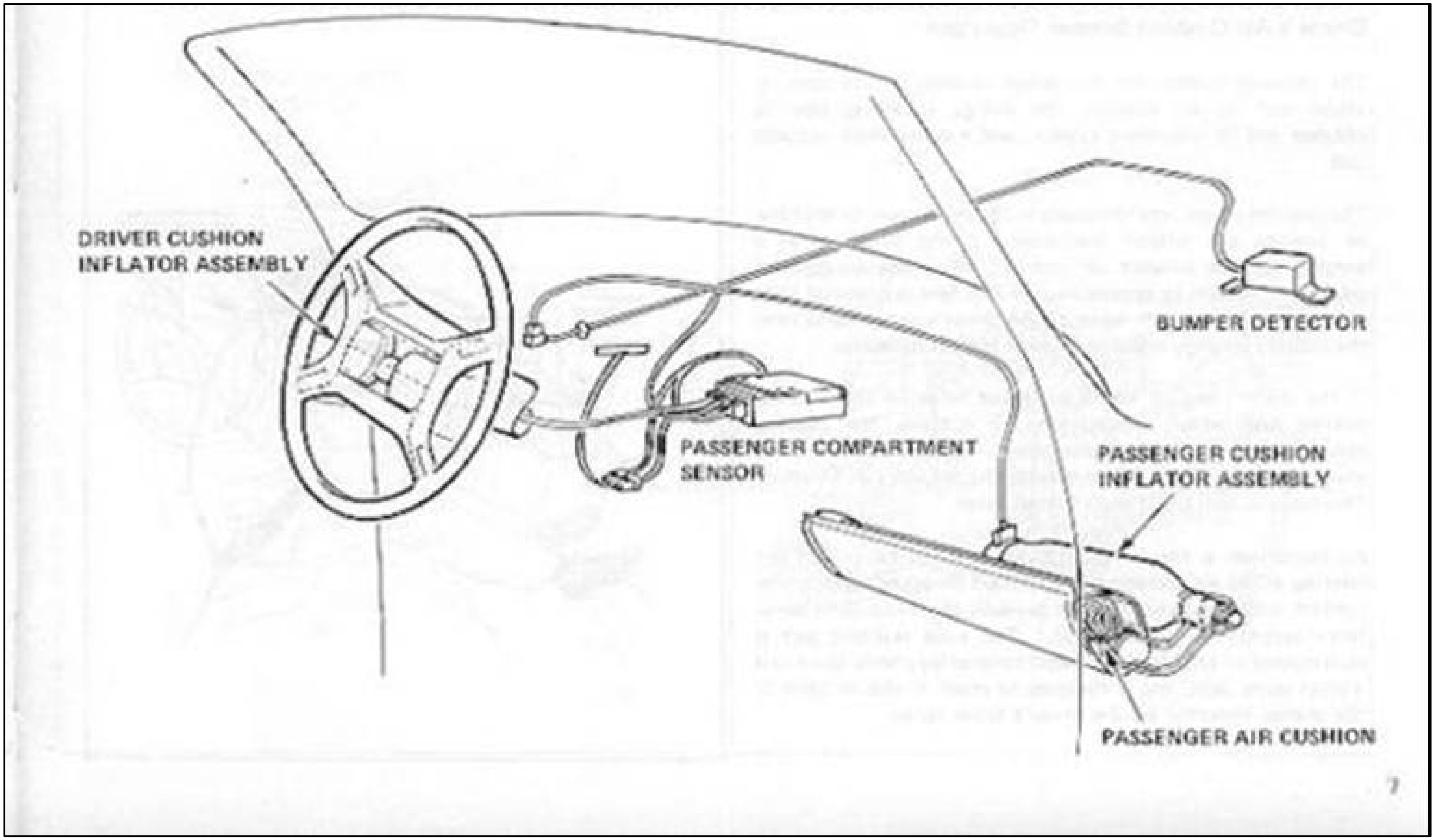
• 'Bag' – thin, nylon fabric / steering wheel, dashboard, seat or door

• 'Sensor' – tells the bag to inflate / 10 to 15 miles per hour / 40 milliseconds / steel ball sliding inside a smooth bore

• 'Inflation System' – sodium azide react with potassium nitrate to produce nitrogen gas



COMPONENTS OF THE AIR CUSHION RESTRAINT SYSTEM



Chemical Reactions Used to Generate the Nitrogen Gas

Gas-Generator Reaction	**Reactants**	**Products**
Initial Reaction Triggered by Sensor.	NaN_3	Na N_2 (g)
Second Reaction.	Na KNO_3	K_2O Na_2O N_2 (g)
Final Reaction.	K_2O Na_2O SiO_2	alkaline silicate (glass)

Amount of Gas & Pressure required to fill the Airbag

Variety of Airbags

Head – Thorax Side Impact Airbag:

• Developed Ford & Renault in 1998

• Inflated at 12 thousands of a second – four times faster than the frontal airbags

Inflatable Curtain (IC):

• Introduced in 1998 by Mercedes and Volvo

• Inflated at 25 thousands of a second – four times faster than the blink of an eye

Inflatable Tubular Structure (ITS):

• Introduced in 1997 by BMW

• Nylon tube, installed in the head-liner & inflates to a diameter of about 15 centimeters

Pedestrain Airbag:

- To reduce the head injuries to the pedestrian

Injury Criteria

Injury Criteria

- Biomechanical Properties

  Physical construction, parts involved, mechanics of the configuration

- Potential Injuries

  Fracture, Concussion, Lacerations, Dislocations, Over-stretching, Over-compression

- Injury Mechanism

  Relative movement (impact, stretch, crush), Direct force, Overextension

- Injury Criteria

  Limits on forces, deformations, acceleration/time, movements (absolute and relative) etc.

Injury Criteria

Head Biomechanics Injuries and Injury Criteria

- **Biomechanical Properties**

  Rigid Bone sphere with thin compliant skin containing viscous/plasticelastic brain

- **Potential Injuries**

  Concussion

  Skull Fracture

- **Injury Mechanism**

  Relative displacements to brain

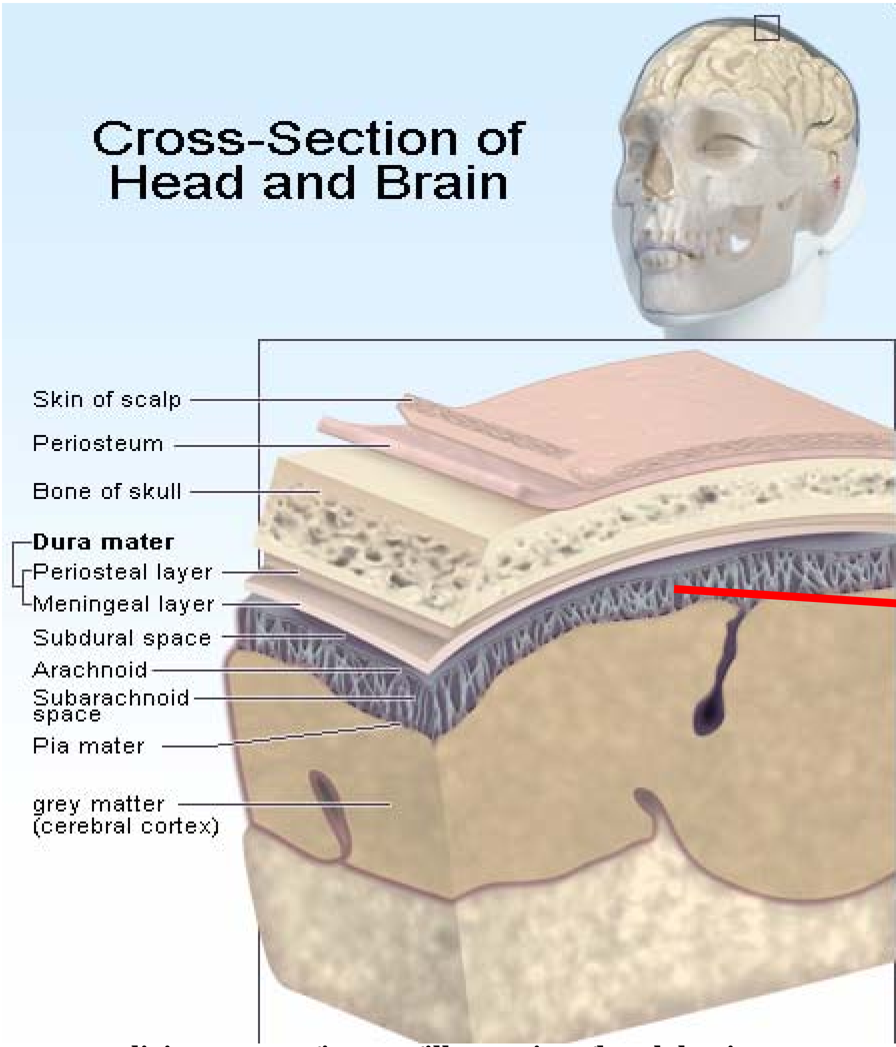
  Direct force to skull = Sitting or standing head impact to rigid flat or blunt object

- **Injury Criteria**

  Acceleration/Time based criteria (HIC)

  Force (acceleration) based criteria

Structure of Head and Brain

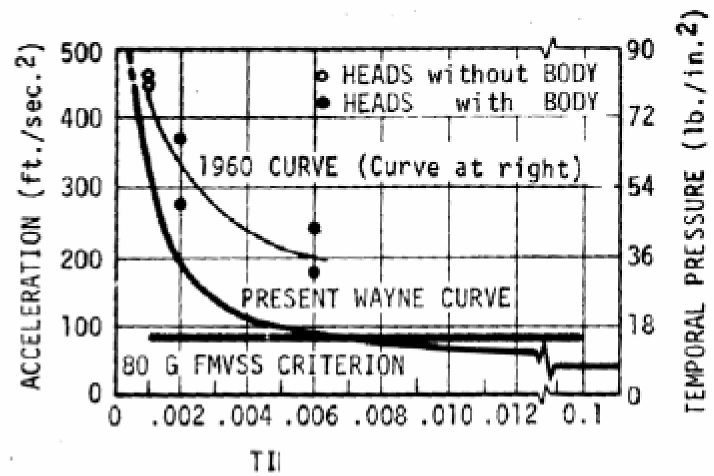


http://images.medicinenet.com/images/illustrations/head_brain_cross_section.jpg

1. Skin and soft tissues covering the skull
2. Bony skull (facial and cranial)
3. Contents of skull

spongy tissue and intercommunicating channels filled with cerebrospinal fluid (prone to deceleration injuries)

Heade Injury Criteria



$$HSI = \int [a(t)]^{2.5} dt$$

Head Severity Index

$$HIC = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a dt \right]^{2.5} (t_2 - t_1)$$

Where

a is a resultant head acceleration

t_2-t_2 $\leq$36 ms

t_2, t_1 selected so as to maximize HIC (2)

Brian G. McHenry, "Head Injury Criterion and the ATB," McHenry Software Inc.
http://www.mchenrysoftware.com/HIC%20and%20the%20ATB.htm

Injury Criteria

Head	Concussion (HIC) Skull Fracture (Force/HIC)
Neck	Force, Bending moment
Face	Fracture (Force), Lacerations
Thorax	Rib Fracture (Deflection)
Abdomen	Internal injuries (Deflection)
Pelvis	Fracture and/or dislocation (Force)
Arms	Fracture (Force) Laceration (Impact velocity)
Leg	Fracture (Force)
Knee	Fracture (Force, Bending, Shear)

Simulation Software

Simulation Software

Model a transient dynamic phenomena involving large deformation and rotation of the structure including modelling of contact between different parts of the structure

LS-Dyna

1987 – LSTC formed by Dr. John Hallquist to commercialise DYNA3D, a public domain code developed by Lawrence Livermore National Laboratory

Automotive Crashworthiness & Occupant Safety, Sheet Metal Forming With LS-DYNA, Military and Defense Applications
Aerospace Industry Applications
Drop testing, Can and shipping container design, Electronic component design, Glass forming, Plastics, mold, and blow forming, Biomedical, Metal cutting, Earthquake engineering
Failure analysis, Sports equipment (golf clubs, golf balls, baseball bats, helmets), Civil engineering (offshore platforms, pavement design)

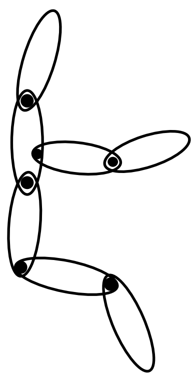
Simulation Software

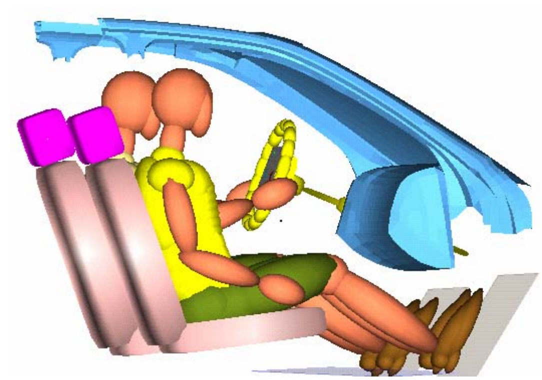
MAthematical DYnamic Models (MADYMO)

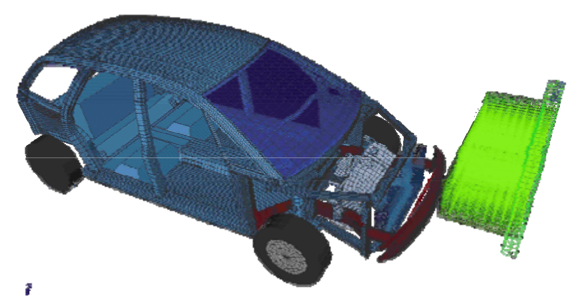
Developed by TNO Automotive, Delft, The Netherlands

Rigid Body Dynamics

Finite Element Model







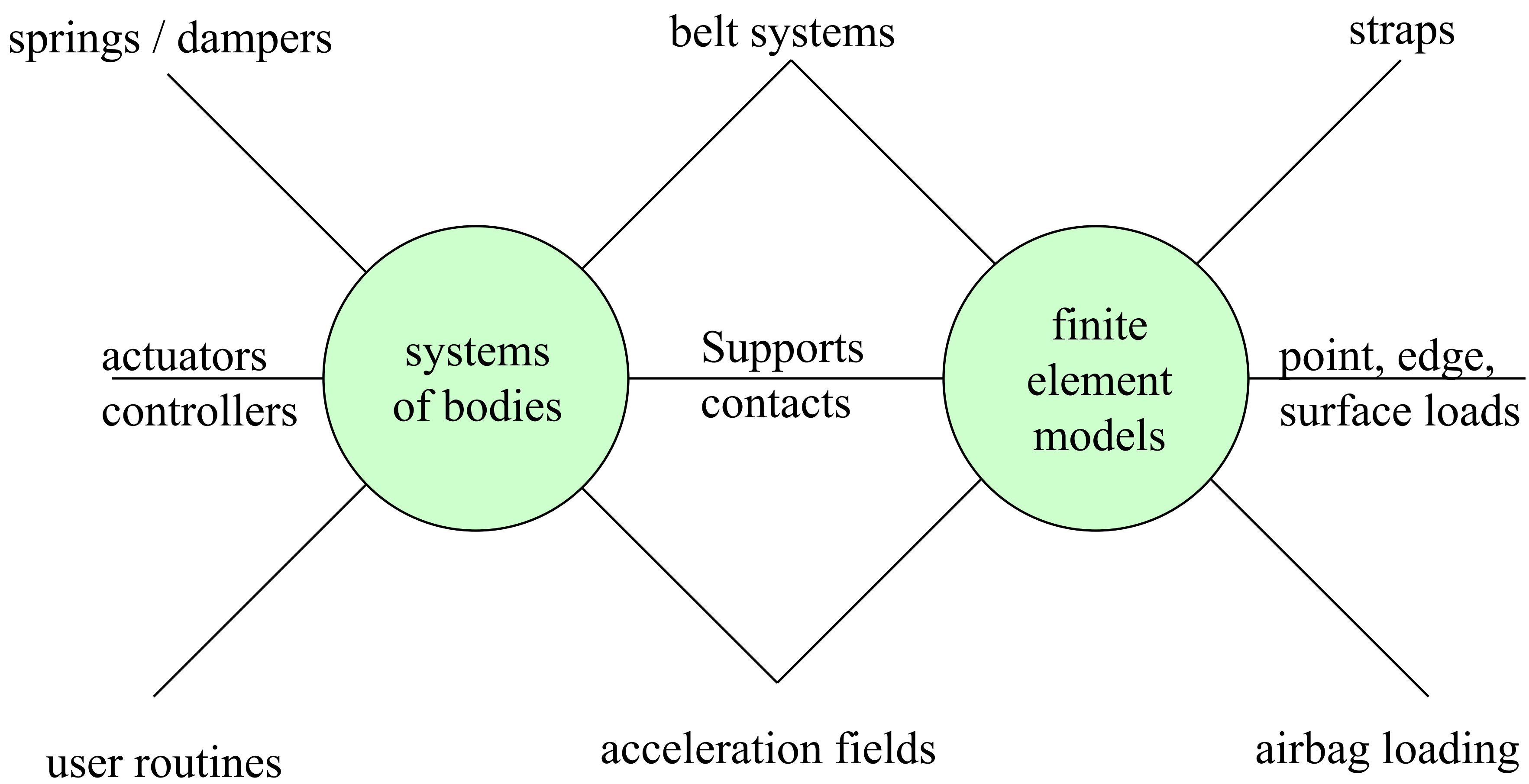
Multiple Rigid Bodies
connected at joints
Motions/Contacts/Forces

Traditional FEA

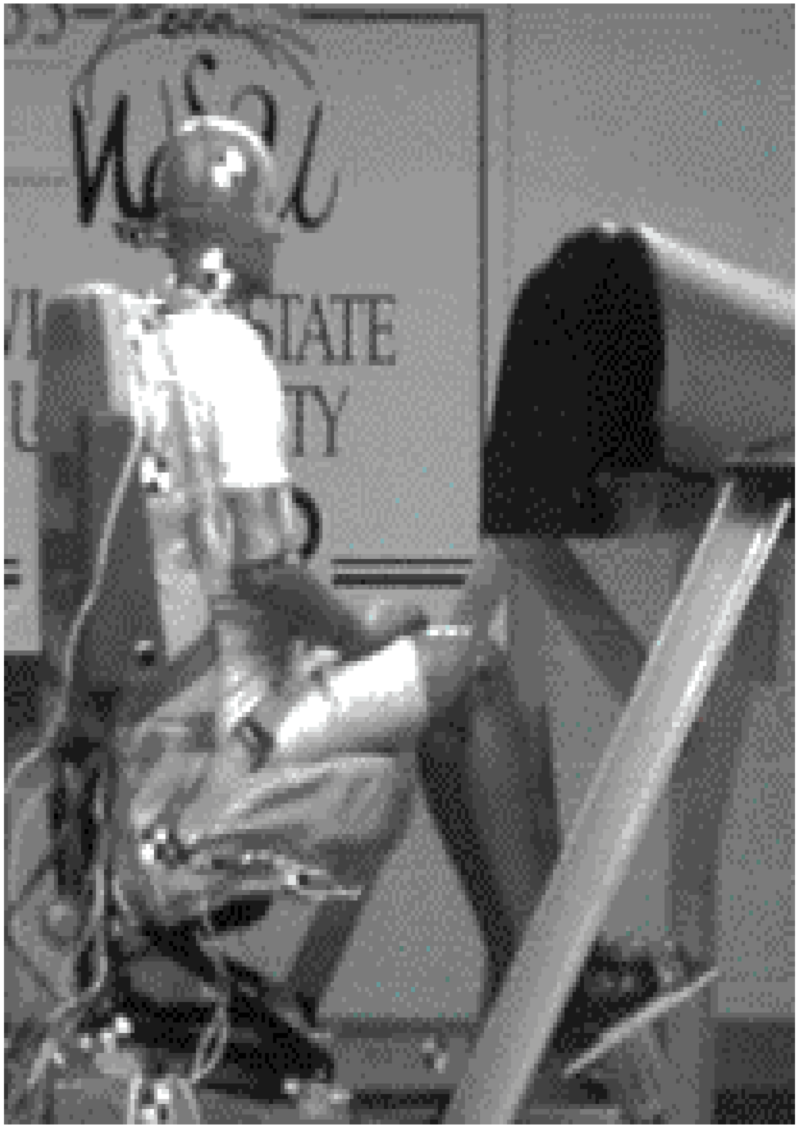
Displacements/Stresses

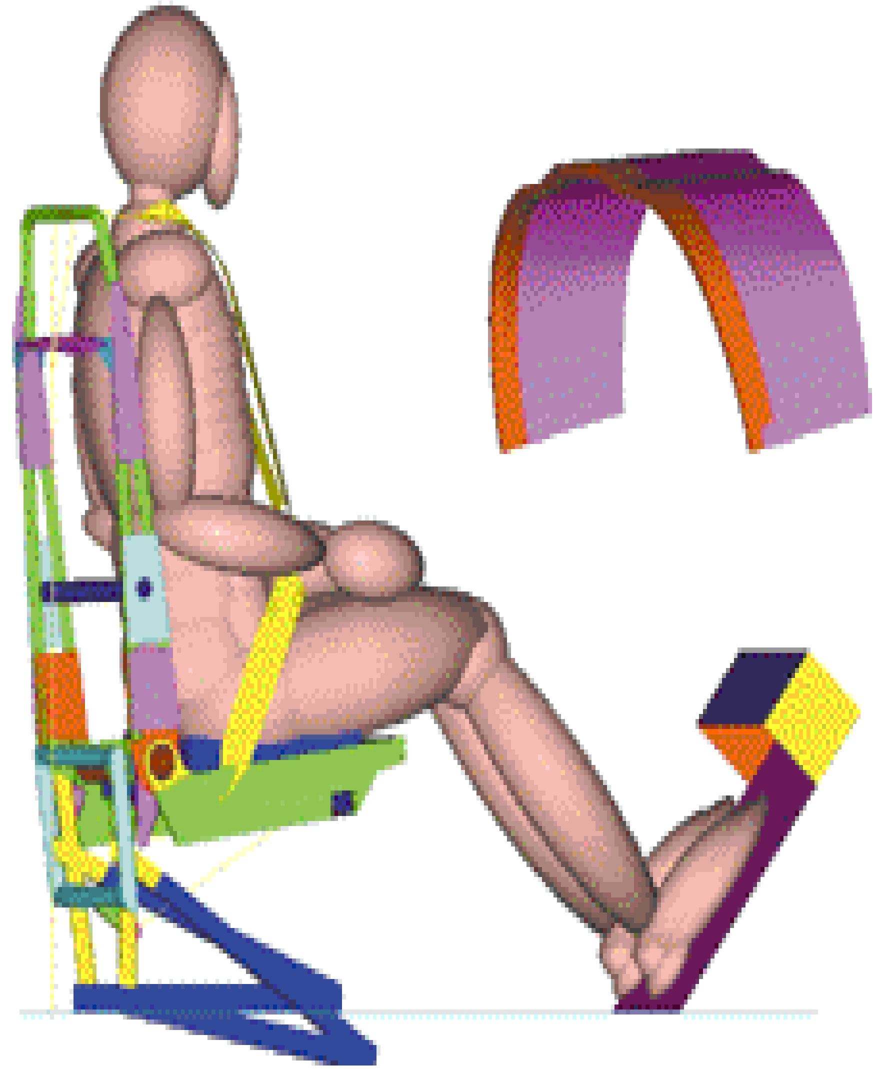
Simulation Software

MAthematical DYnamic Models (MADYMO)



MADYMO 6.0.1, Introduction Course, Multibody Module, TNO Automotive UK





Simulation of Sled Test For Automotive Seat Belt Using MADYMO

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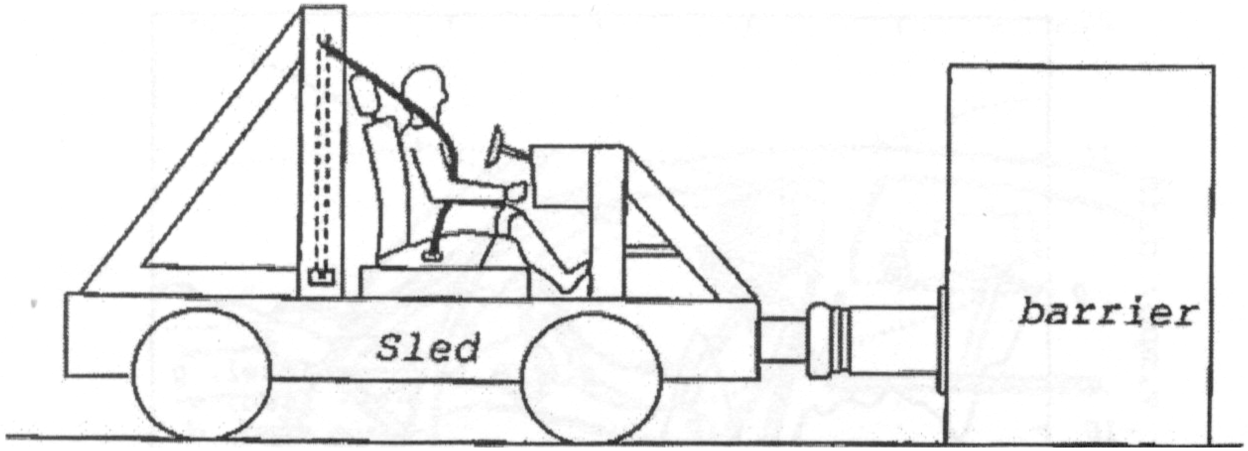
3. Dr.Vinod Kumar Banthia
4. Ramachandra Rao M R

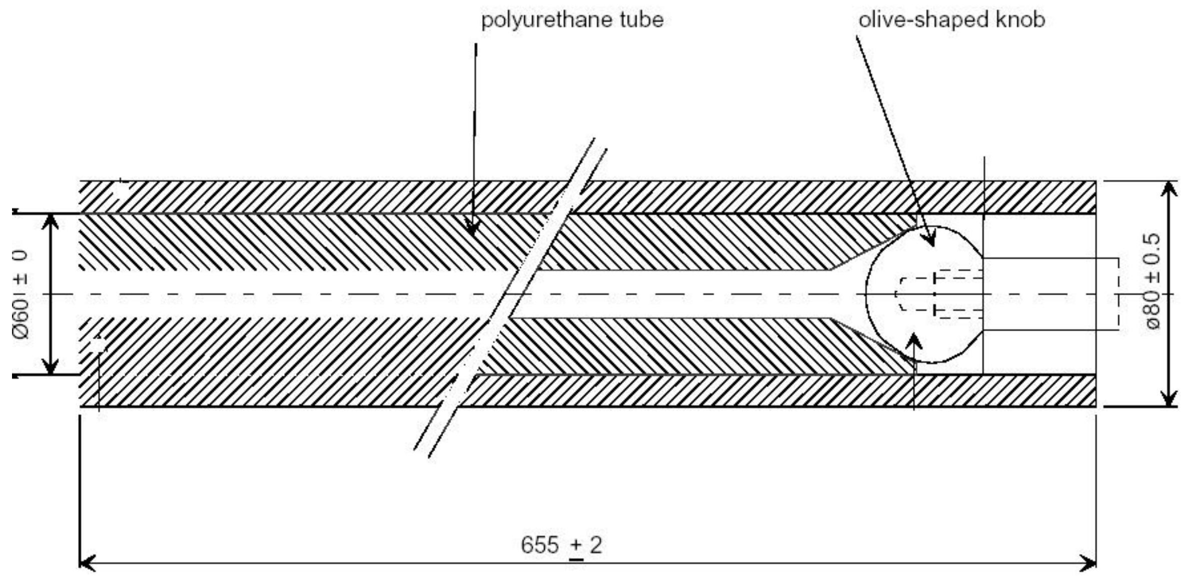
Problem Statement

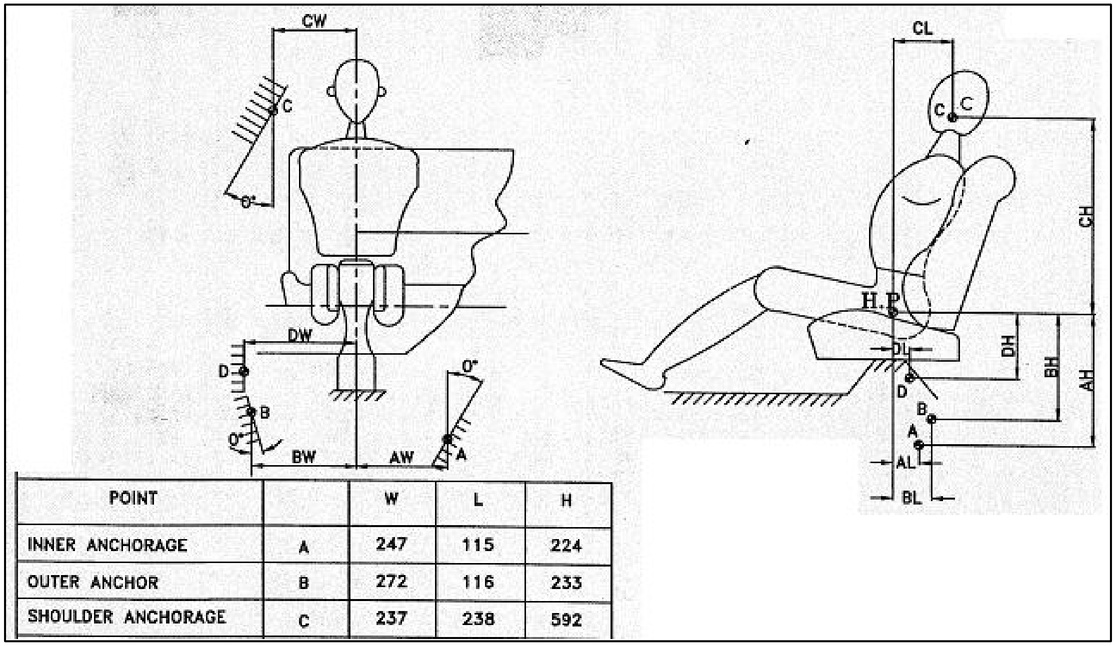
"Simulation of Sled Test for Automotive Application using MADYMO and Correlation of the Seat Belt Performance & Response with Actual Sled Test Results"

Sled Test

- Sled Test is carried out by placing Dummy as per ECE Regulation No.16
- Trolley, Seat, Anchorages & Stopping Device


Sled
barrier


polyurethane tube
olive-shaped knob
Ø60 ± 0
ø80 ± 0.5
655 ± 2



POINT		W	L	H
INNER ANCHORAGE	A	247	115	224
OUTER ANCHOR	B	272	116	233
SHOULDER ANCHORAGE	C	237	238	592

TNO-10 Dummy

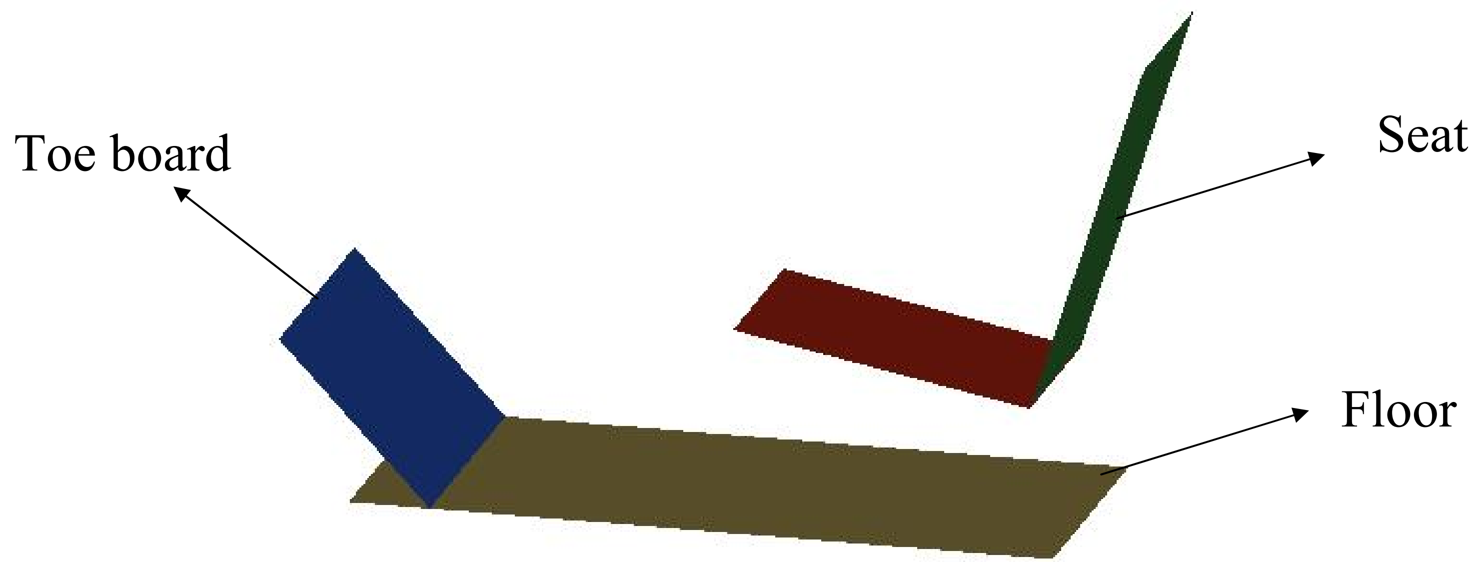
- Loading device for testing safety belts according to ECE-R16
- Weighs 75.5 kg
- Consists of Head, Neck, Torso, Two Upper Legs & Lower Leg
- Chest Cushion - ‘Polyethylene Foam’

Objectives

- Developing a methodology for sled test simulation using MADYMO and assessing the performance & response of seat belt by determining:
- Retractor, Shoulder & Lap Belt Forces
- Forces at the Retractor, D-Ring & Buckle Point
- Chest Forward Displacement
- Head Injury Criteria (HIC)

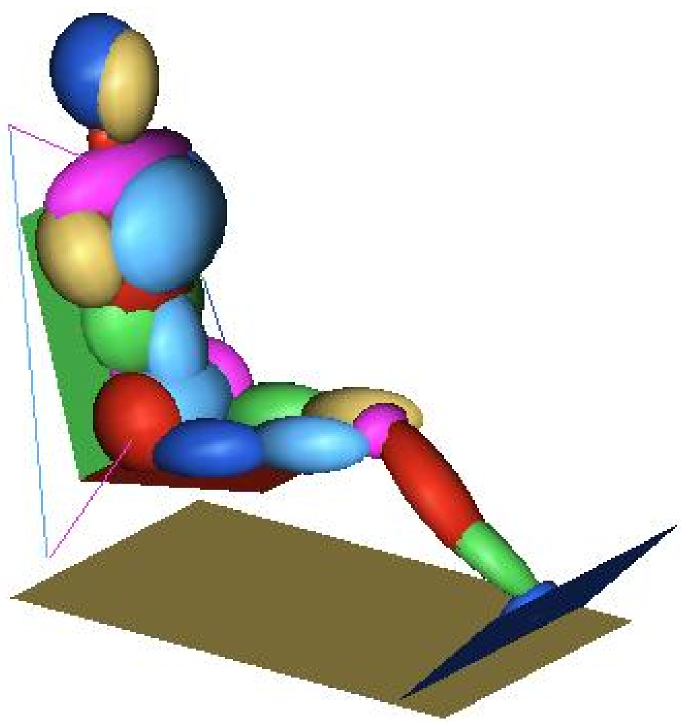
Methodology

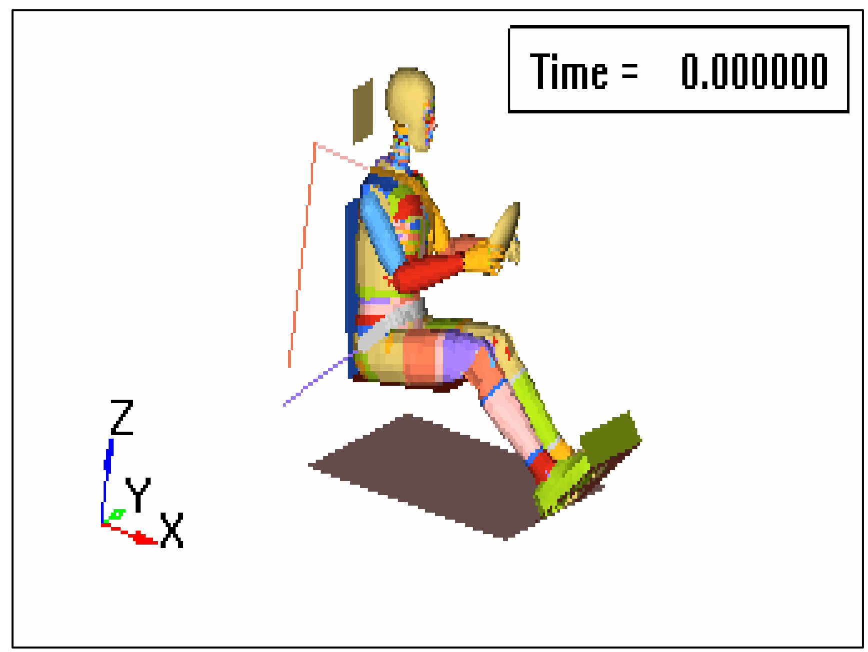
- Building-up of TNO-10 Dummy user file
- Defining Floor, Toe board, Seat & Anchorage Points as per ECE-R16



Methodology

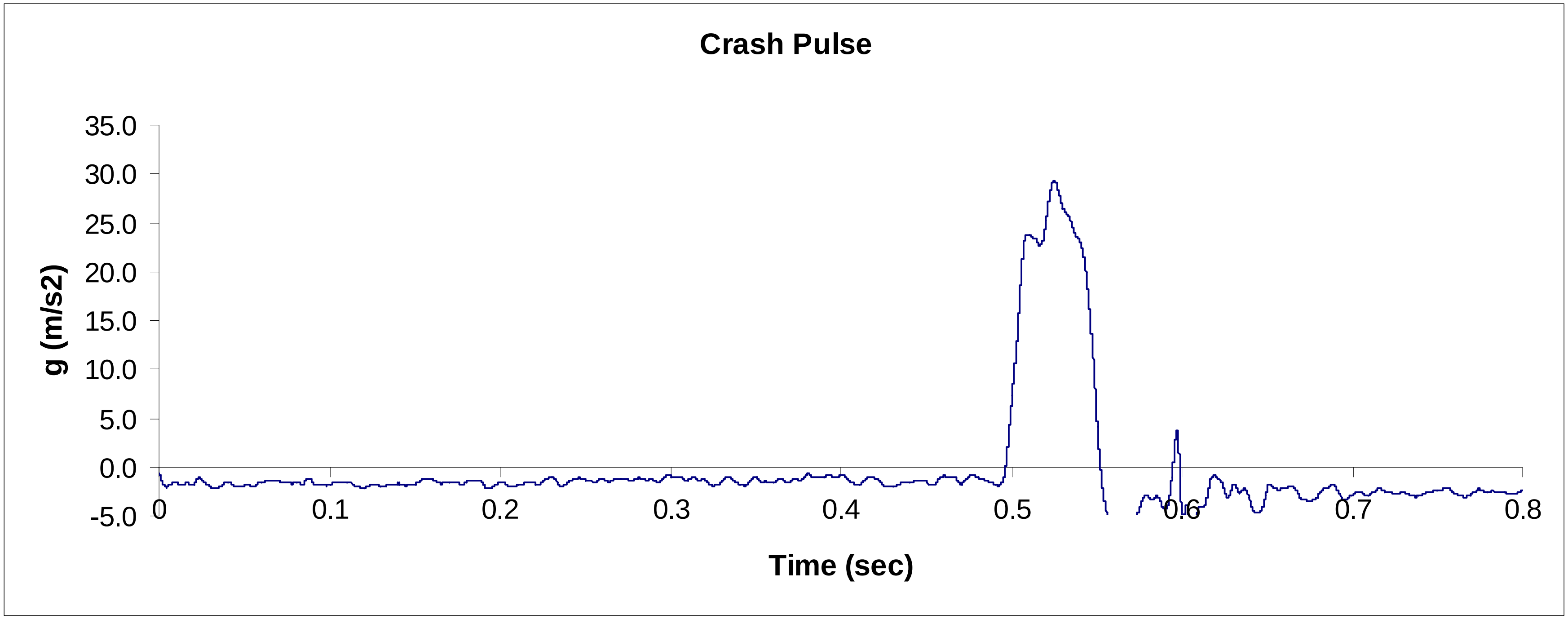
- Proper positioning of Dummy
- Conventional Belt Modeling
- Defining contacts





Methodology

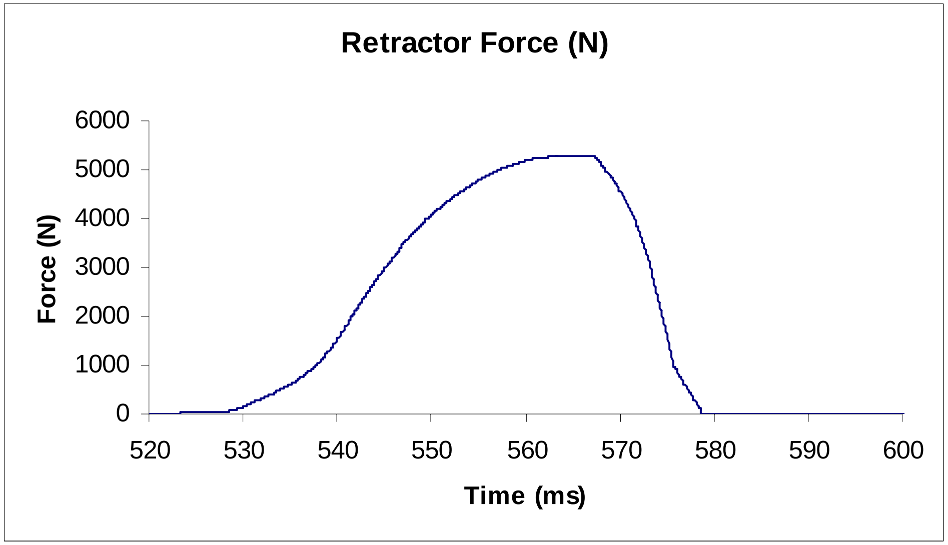
- Applying Crash Pulse

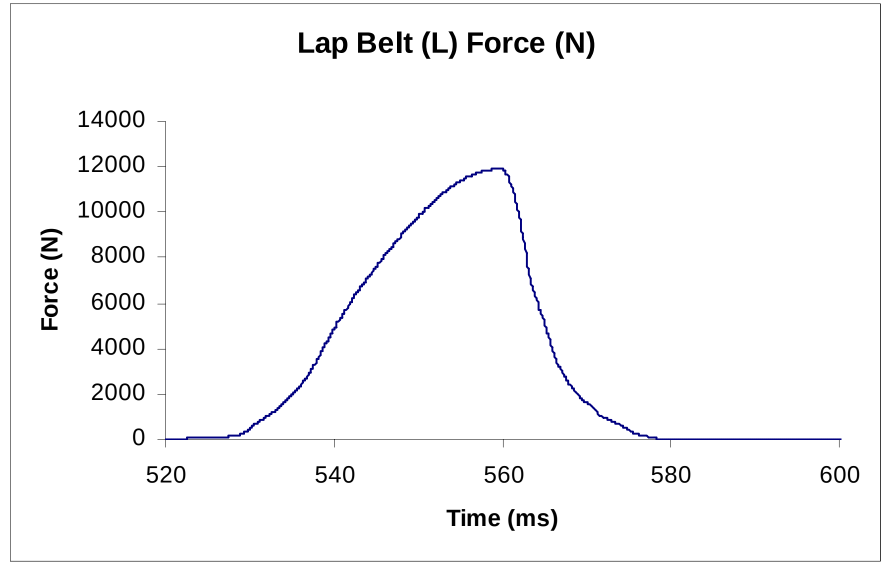


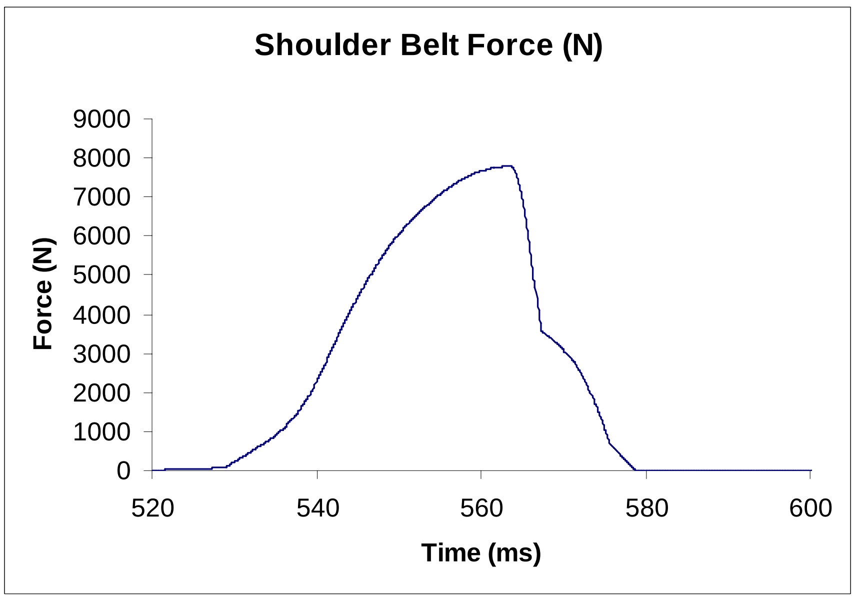
Methodology

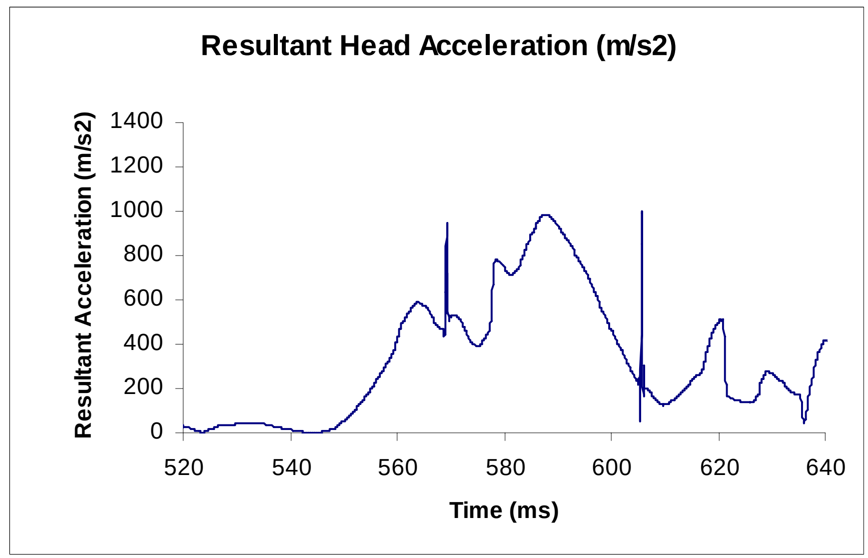
- Defining outputs to be taken from Dummy Model, Belt Model & Anchorage Points
- Calculating Injury Criteria
- Conducting actual sled test at Autoliv-IFB
- Correlating MADYMO simulation results with actual sled test results

Results


Retractor Force (N)
Force (N)
6000
5000
4000
3000
2000
1000
0
520
530
540
550
560
570
580
590
600
Time (ms)


Lap Belt (L) Force (N)
Force (N)
14000
12000
10000
8000
6000
4000
2000
0
520
540
560
580
600
Time (ms)


Shoulder Belt Force (N)
Force (N)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
520
540
560
580
600
Time (ms)


Resultant Head Acceleration (m/s2)
Resultant Acceleration (m/s2)
1400
1200
1000
800
600
400
200
0
520
540
560
580
600
620
640
Time (ms)

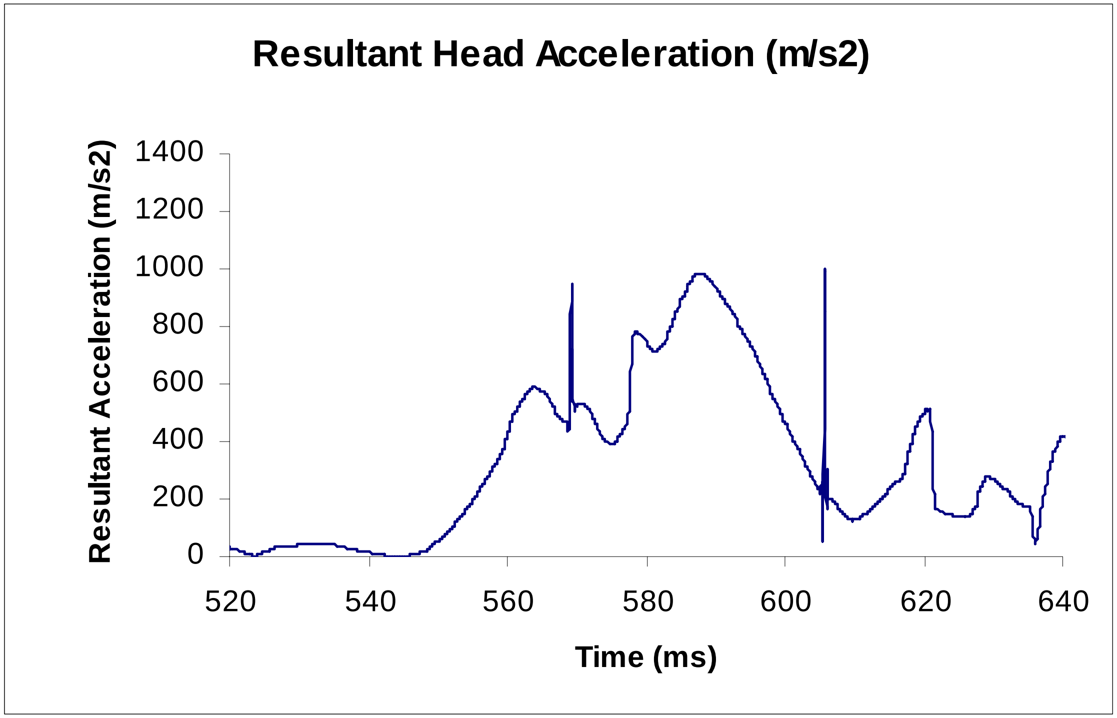
Results

- Forward Chest Displacement = *274.9 mm*
- Resultant Constraint Force at Retractor Point = *5.27 kN*
- Resultant Constraint Force at D-Ring Point = *10.9 kN*
- Resultant Constraint Force at Buckle Point = *18.4 kN*

Results

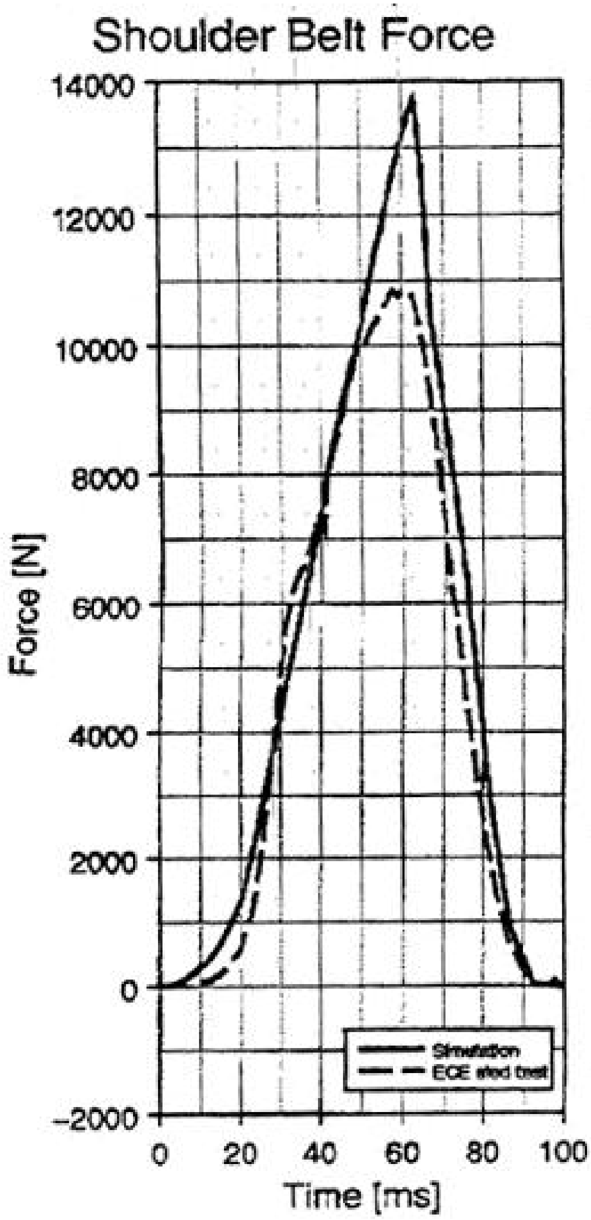
Injury Criteria

- H I C = 707.907

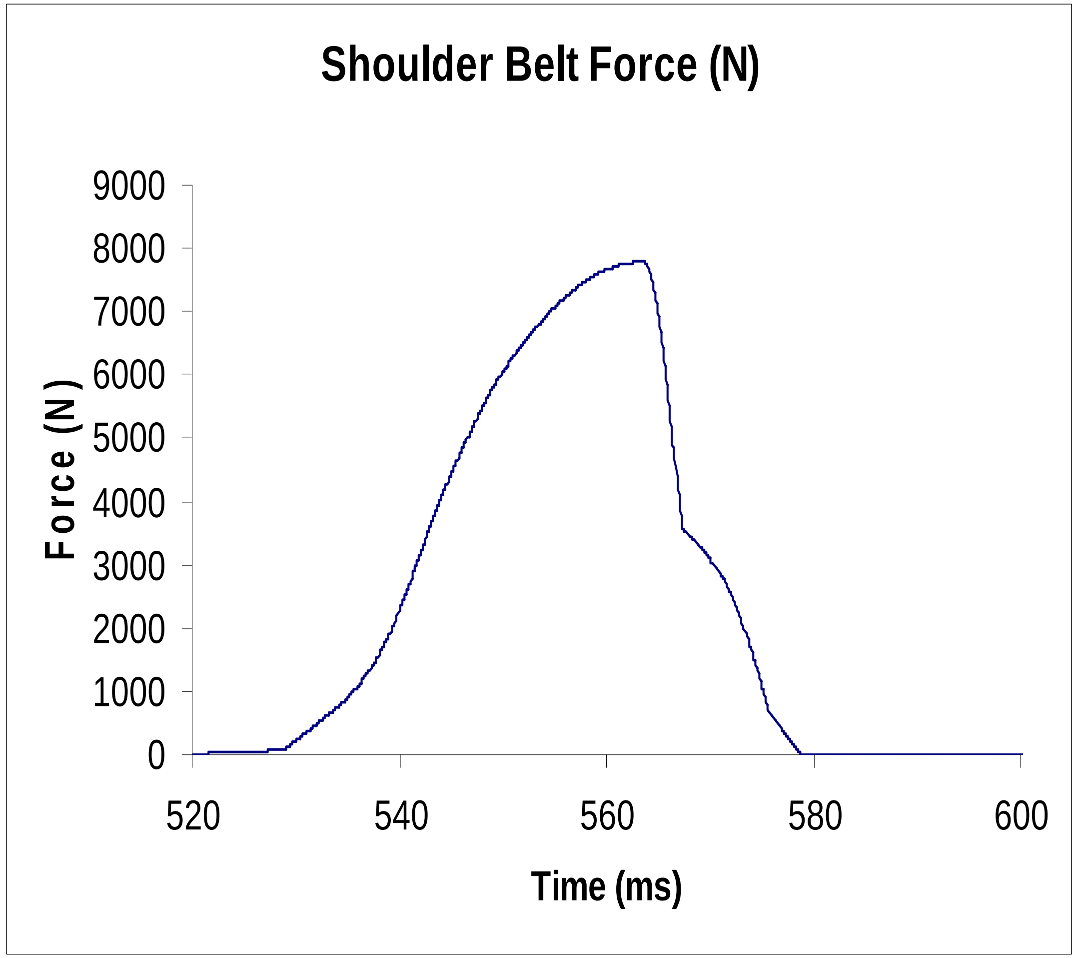


$$HIC = 0.303\ A_P^{2.5}\ T$$

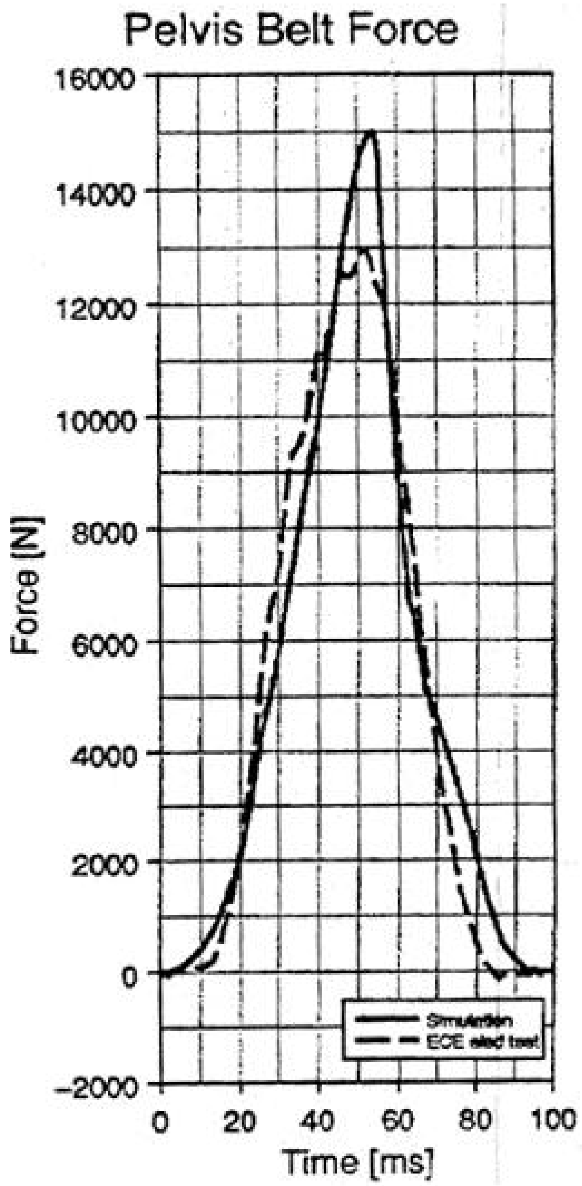
[Matthew Huang, Vehicle Crash Mechanics, CRC Press, New York, P.No.141]

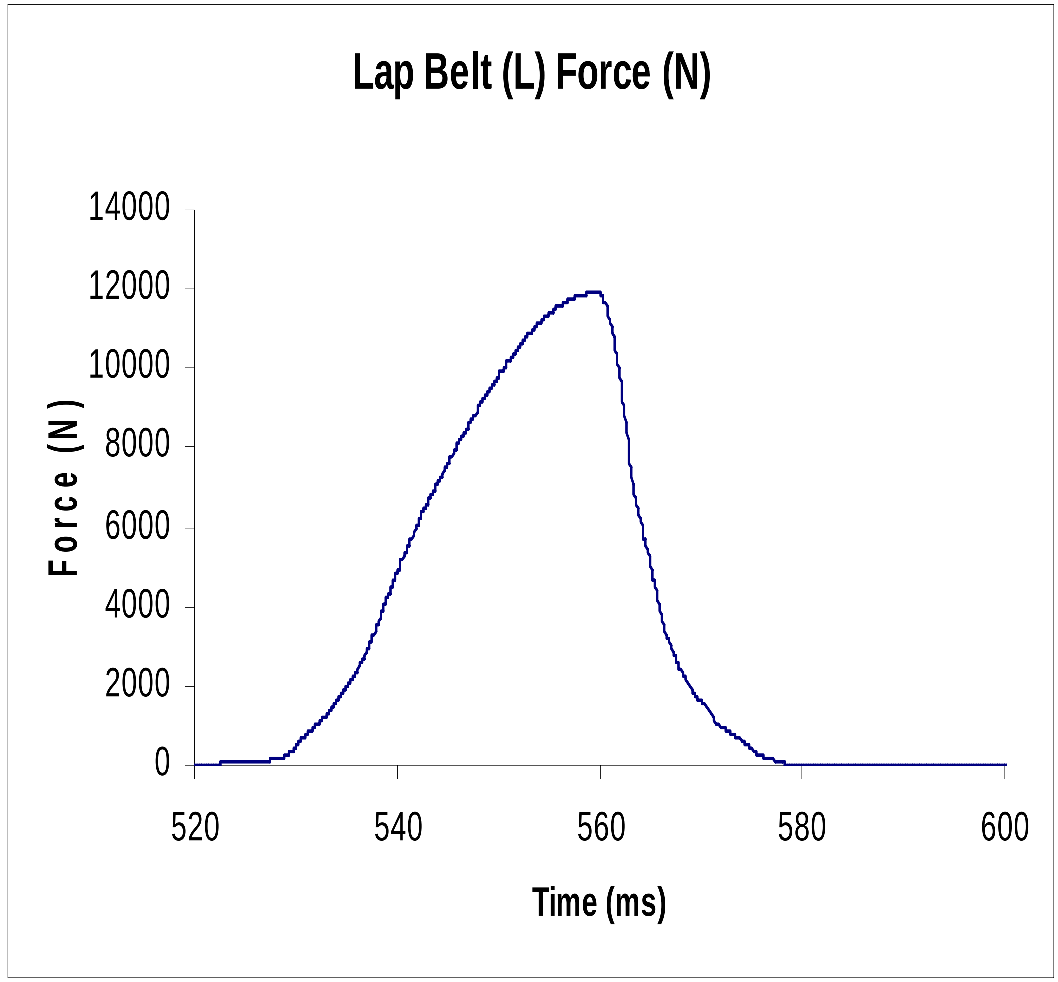


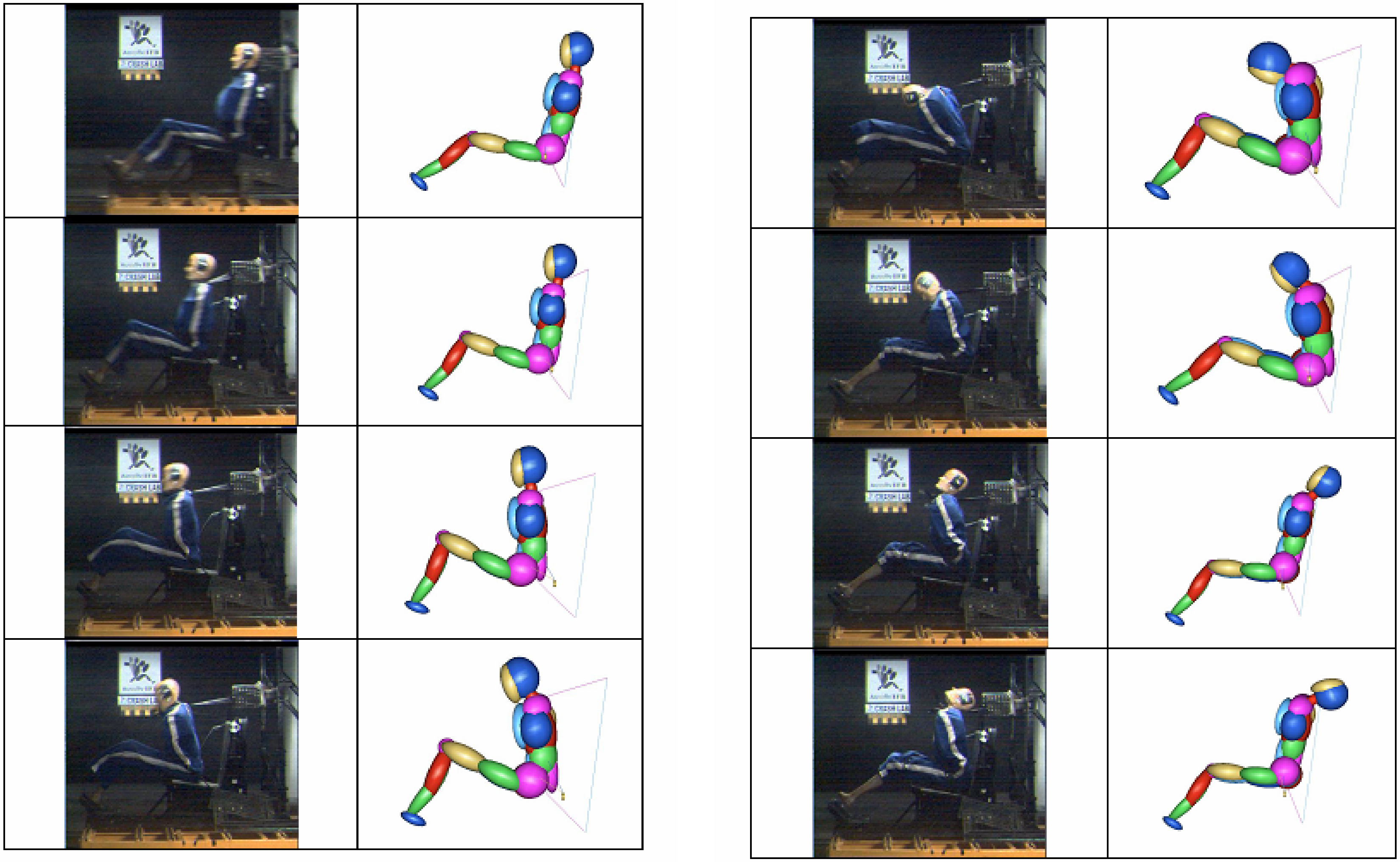
Shoulder Belt Force
14000
12000
10000
8000
6000
4000
2000
0
-2000
Force [N]
0
20
40
60
80
100
Time [ms]
Simulation
ECE sled test



Shoulder Belt Force (N)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Force (N)
520
540
560
580
600
Time (ms)


Pelvis Belt Force
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
Force [N]
0
20
40
60
80
100
Time [ms]

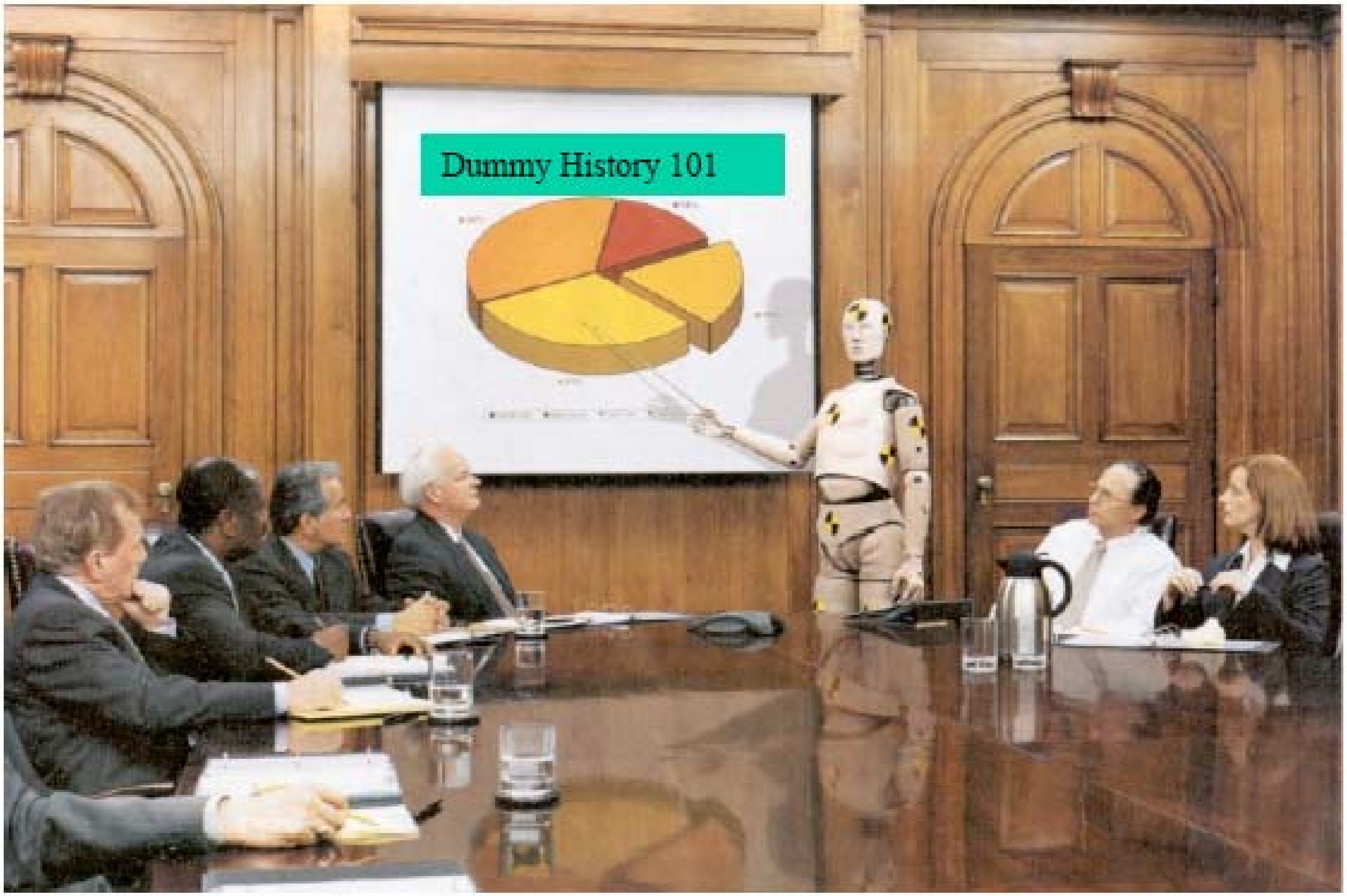

Lap Belt (L) Force (N)
14000
12000
10000
8000
6000
4000
2000
0
Force (N)
520
540
560
580
600
Time (ms)



Correlation of the actual test and the simulation

Testing and its Aids

History of Anthropomorphic Test Devices

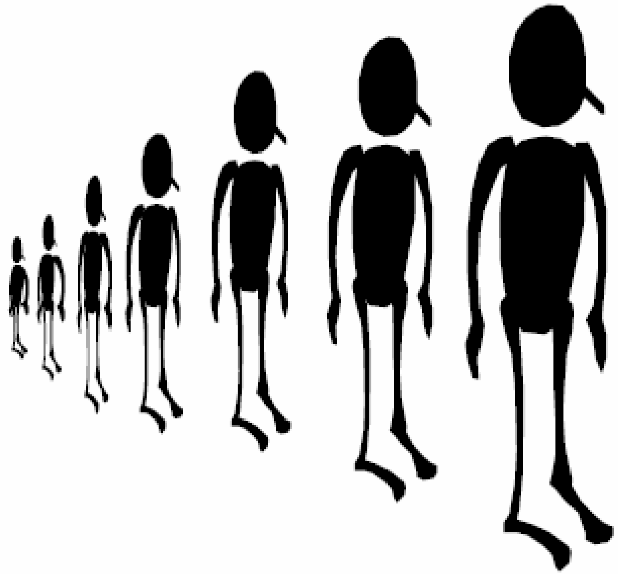


History of Anthropomorphic Test Devices

- Anthopomorphic Test Devices (ATDs) are mechanical surrogates of humans
- Are used to evaluate the occupant protection potential of various types of restraint systems in simulated collisons of new vehicle designs
- Current ATDs are designed to be ‘biofidelic’
- Equipped with transducers that measure accelerations, deformations and loading of various body parts
- Analyses of these mearuements are used to assess the efficiency of restraint system design

History of Anthropomorphic Test Devices

- 1950's The Journey Begins
- 1960's Multiple Developments
- 1970's Refinement of Crash Dummies
- 1980's The Great Expansion
- 1990's Specialty Dummies
- 2000 and Beyond………

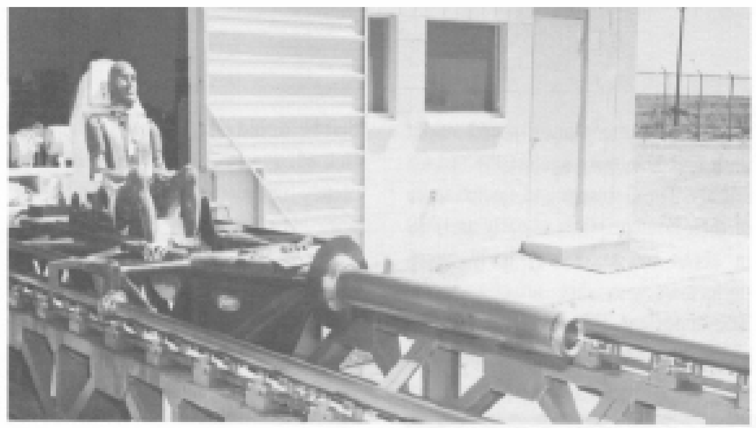


Dummies in Space

Early Dummies in Action

Pierre the dummy gives the Aircraft Rescue Crew a chance to polish up their quick rescue techniques

OFFICIAL U.S. NAVY PHOTO



A new seat is tested on the horizontal rocket sled

The copper man wears his "sweating skin"

Ejection starts as sled reaches 550 mph (bottom photo)

First dummies developed:
(Aerospace)

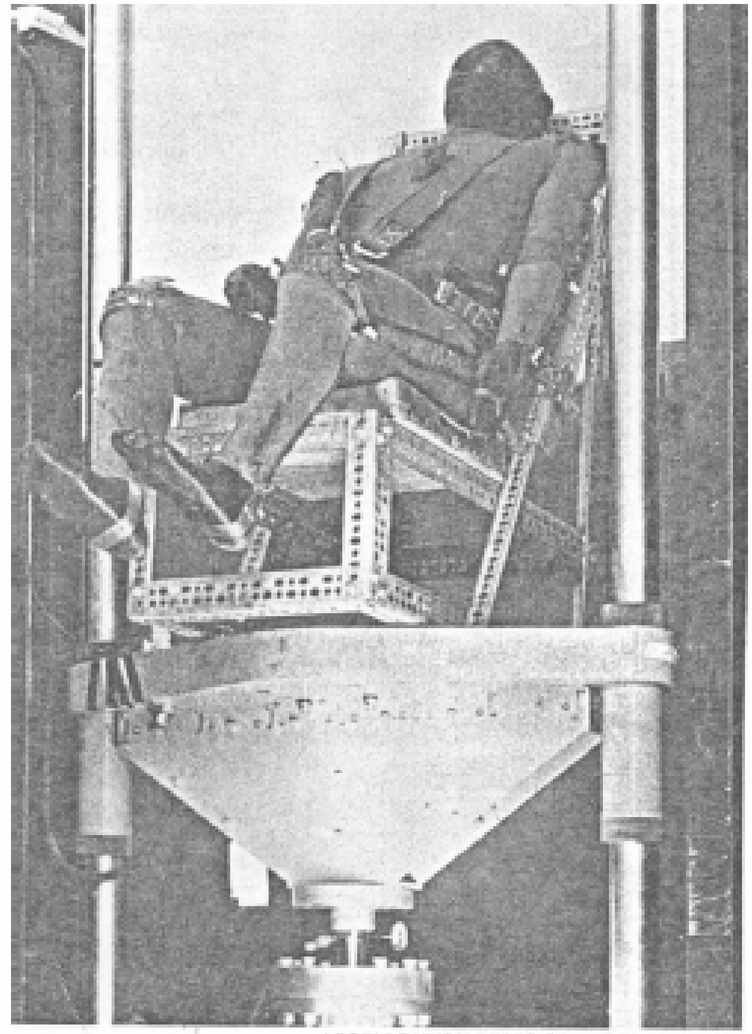
- Sierra Sam - 1949 (95th%)
- Sierra Engineering Co.
- Human shape & weight
- Acceleration measurements (Centrifuge
- U.S. Air Force contract

"OSCAR"

- 1949
- Aviation Research
- 120 lbs.
- Decompression test in aircraft
- Rocket sleds
- Atomic bomb tests

Dummies to Evaluate Radiation

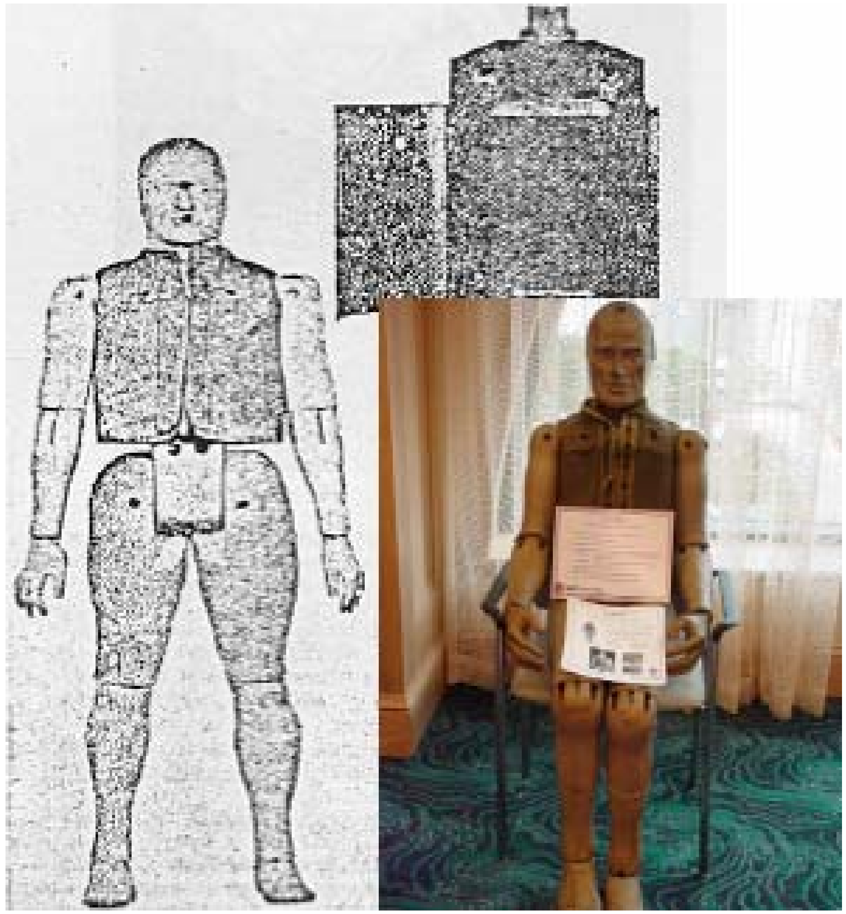
Plastinaut was a 50^{th} percentile dummy designed to evaluate absorption of space radiations.



ACCELERATION TESTS OF THE PLASTINAUT

1950's The Journey Begins

- Aerospace dummies are the grandfather of all dummies
- Aircraft Ejection Seats
- Some parts still used today along with manufacturing techniques



1^{st} Dummy produced in Japan

- Developed by Tokyo Institute of Technology (Dr. Kondo) - 1952
- Wooden dummy developed for motorcycle running stability
- Size of dummy similar to technician who performed the test
- Weight & center of gravity based on anthropometrics data from the U.S.A.

1960’s Multiple Developments

- Medical Dummies
- Rescue Training Dummies
- Space Program
- Automotive Crash Dummies

1960's Con't…….

- Sierra Sam – 50th % (1967)
- Aluminum castings
- Vinyl skin & polyurethane foam
- Ball & socket design for neck & lumbar
- Seat belt interactions studies
- Chest deflection data
- Acceleration & force measurements

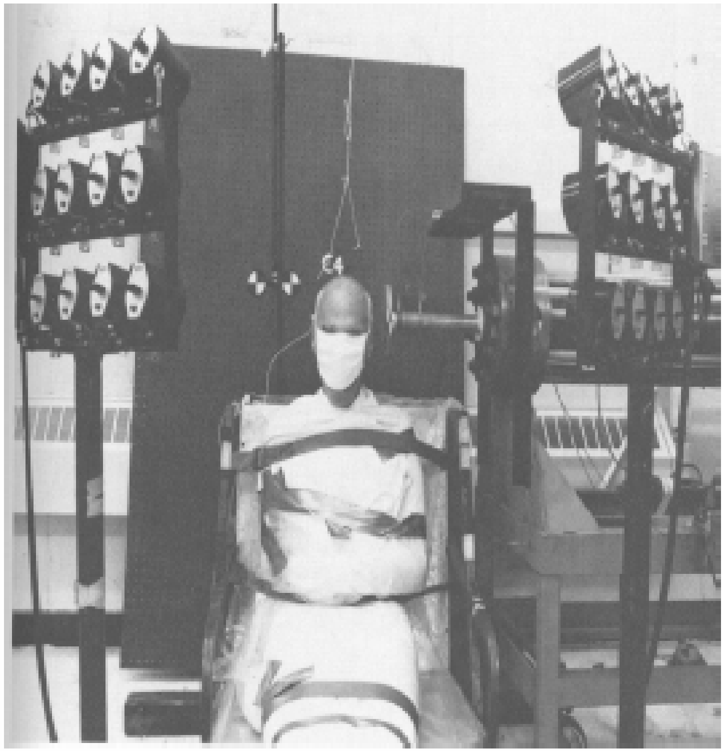
Grumman Alderson Research Dummy (GARD)

New Requirements for Dummies

- Biofidelity requirements need to include more than just weight and shape.
- New biofidelity requirements include dynamic impact performance.

Human response is measured

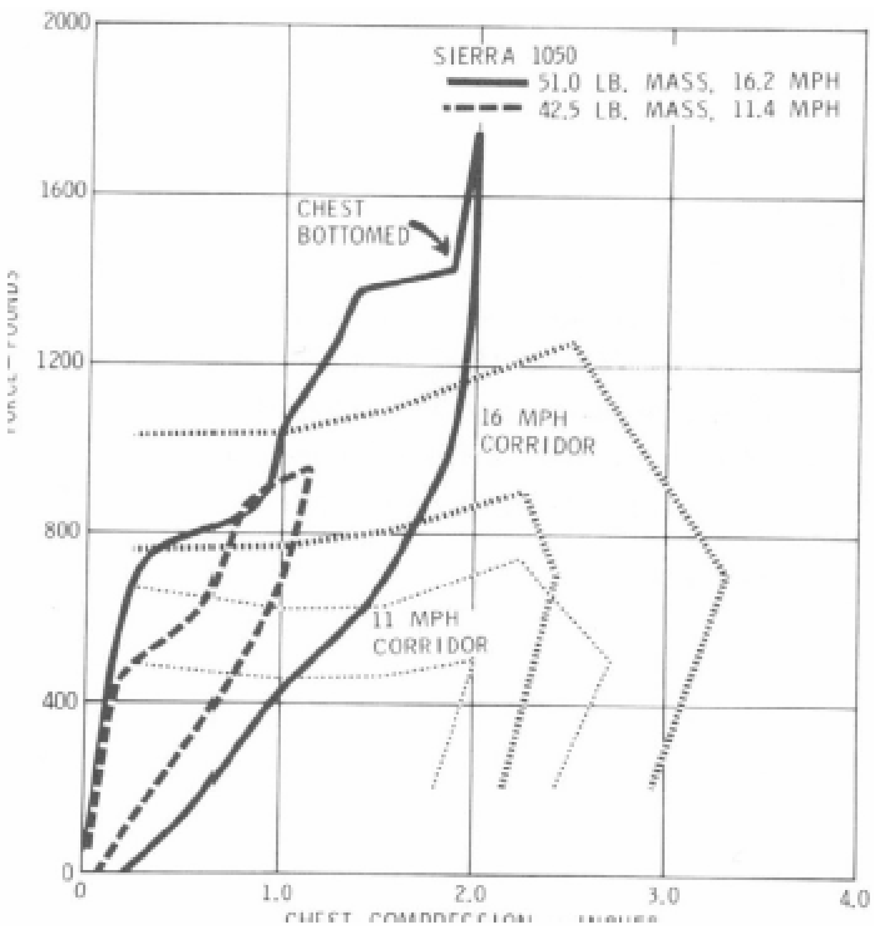
- **Head, Thorax, spine vertical response, knee, abdomen, pelvis, etc…. Was measured to determine dynamic response.**
- **Engineers went back to the drawing board and developed new dummies.**

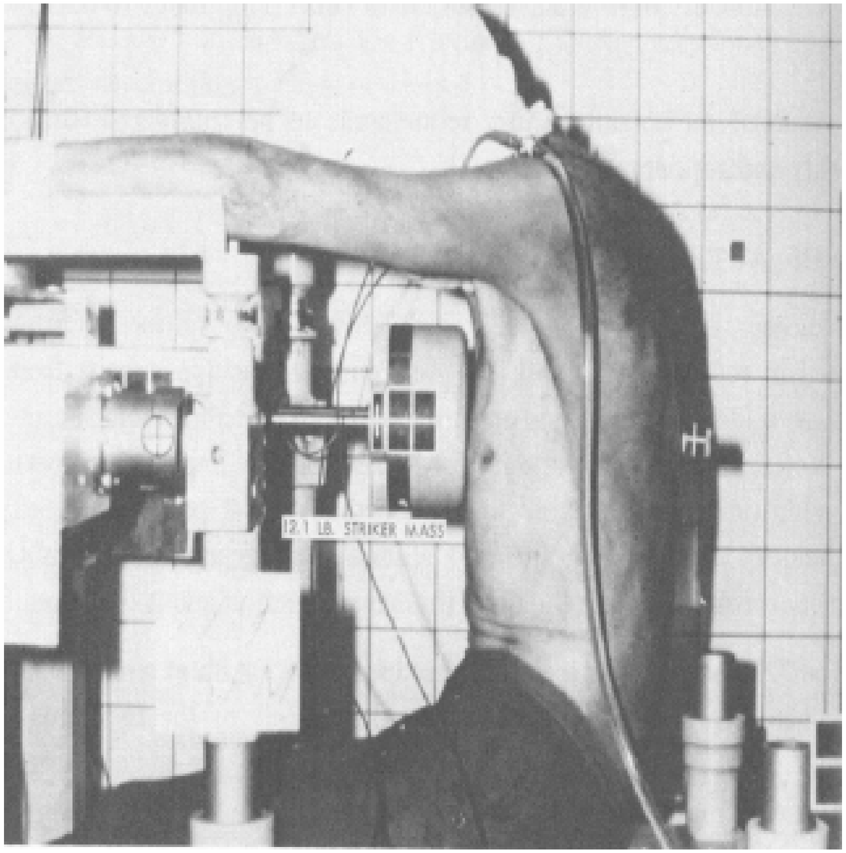


Measurement of Human Response

Human response

More Human Testing & Establishment of Biofidelic Corridors





Chest Compression (Inches) vs. Force (Pounds)

1970's Crash Dummy Refinements

Hybrid II Dummy Family

- Developed by GM in 1972 / 50th % male
- To assess the integrity of lap/shoulder belt systems
- Was specified in FMVSS 208 for testing vehicle equipped with passive restraint systems

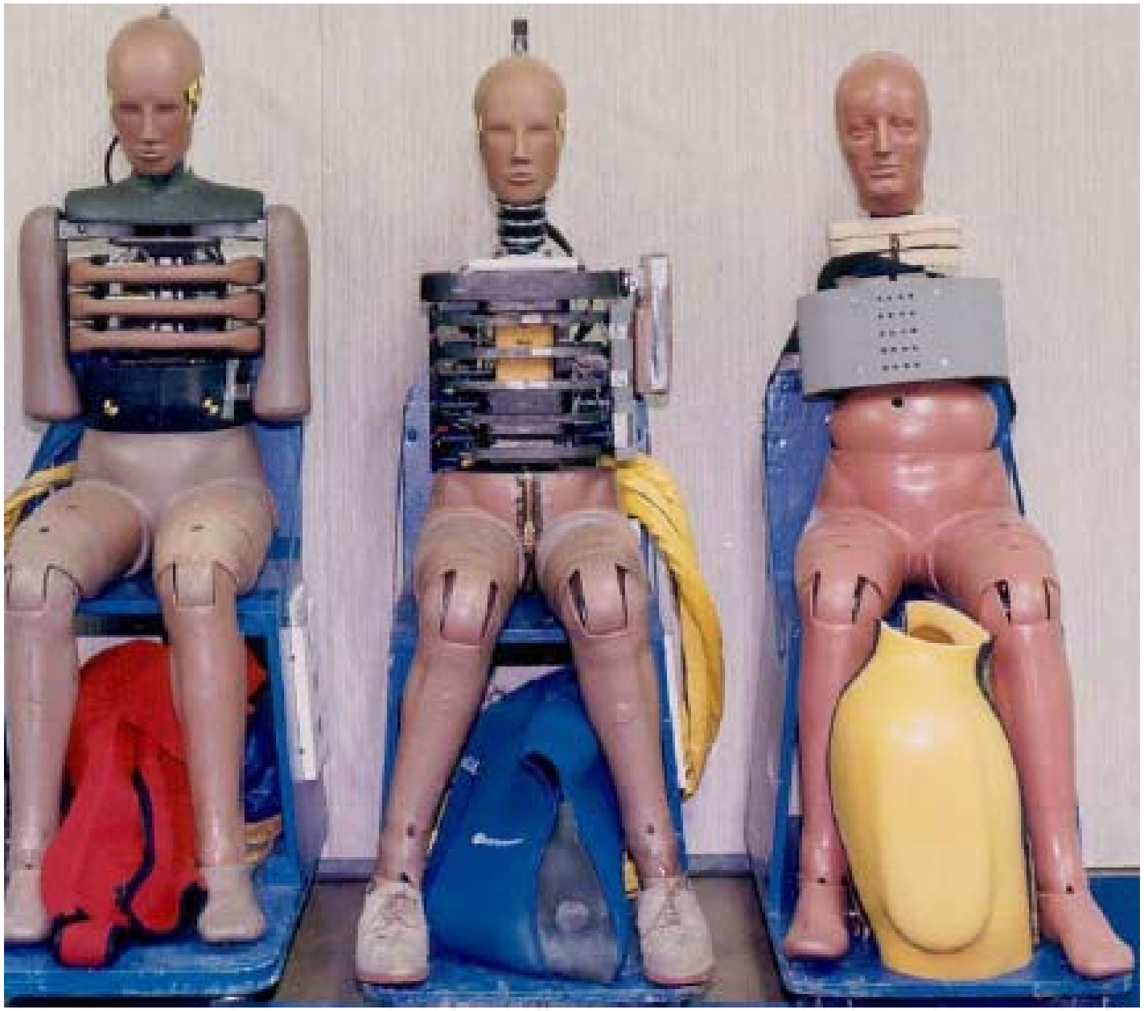
Hybrid III Dummy Family

- Developed by GM in 1976 / regulated by NHTSA in 1986
- Size & weight of the dummy represent an "average" of the USA adult male population
- Evaluation of automotive safety restraint systems

Hybrid III Dummy Family
(Frontal Impact Applications)

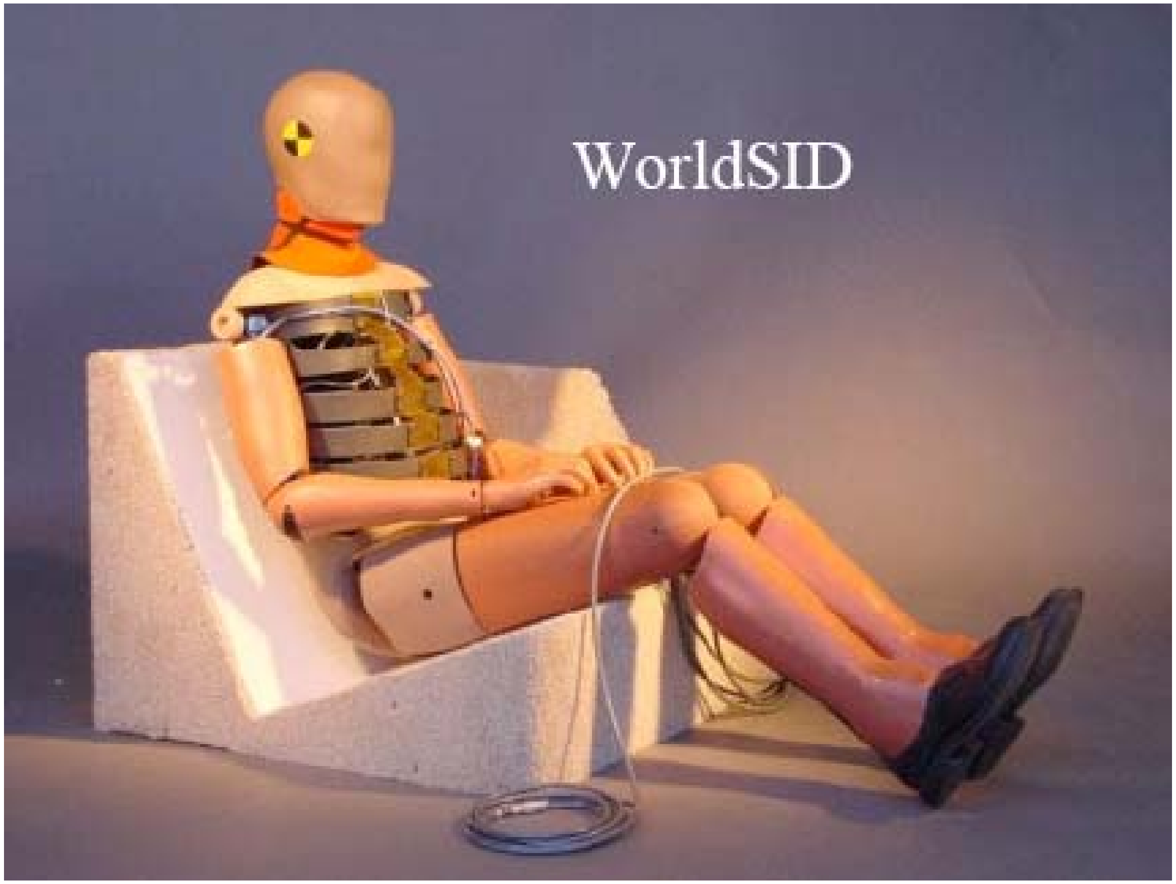
Small Female, Mid-Size Male, Large Male, 3 yr old, 6yr old and CRABI 12-month

Side Impact Dummies



EUROSID, BIOSID & SID

World Side Impact Dummies



Pedestrain Dummies – Why do we need them?

- 5,549 pedestrians were killed in 1992
- 71,000 pedestrian injured in traffic crashes and 4,808 were killed in 2002
- On average, a pedestrian is killed in a traffic crash every 109 minutes
- A pedestrian is injured in a traffic crash every 7 minutes

Pedestrain Dummies


H-III6C


Polar-II

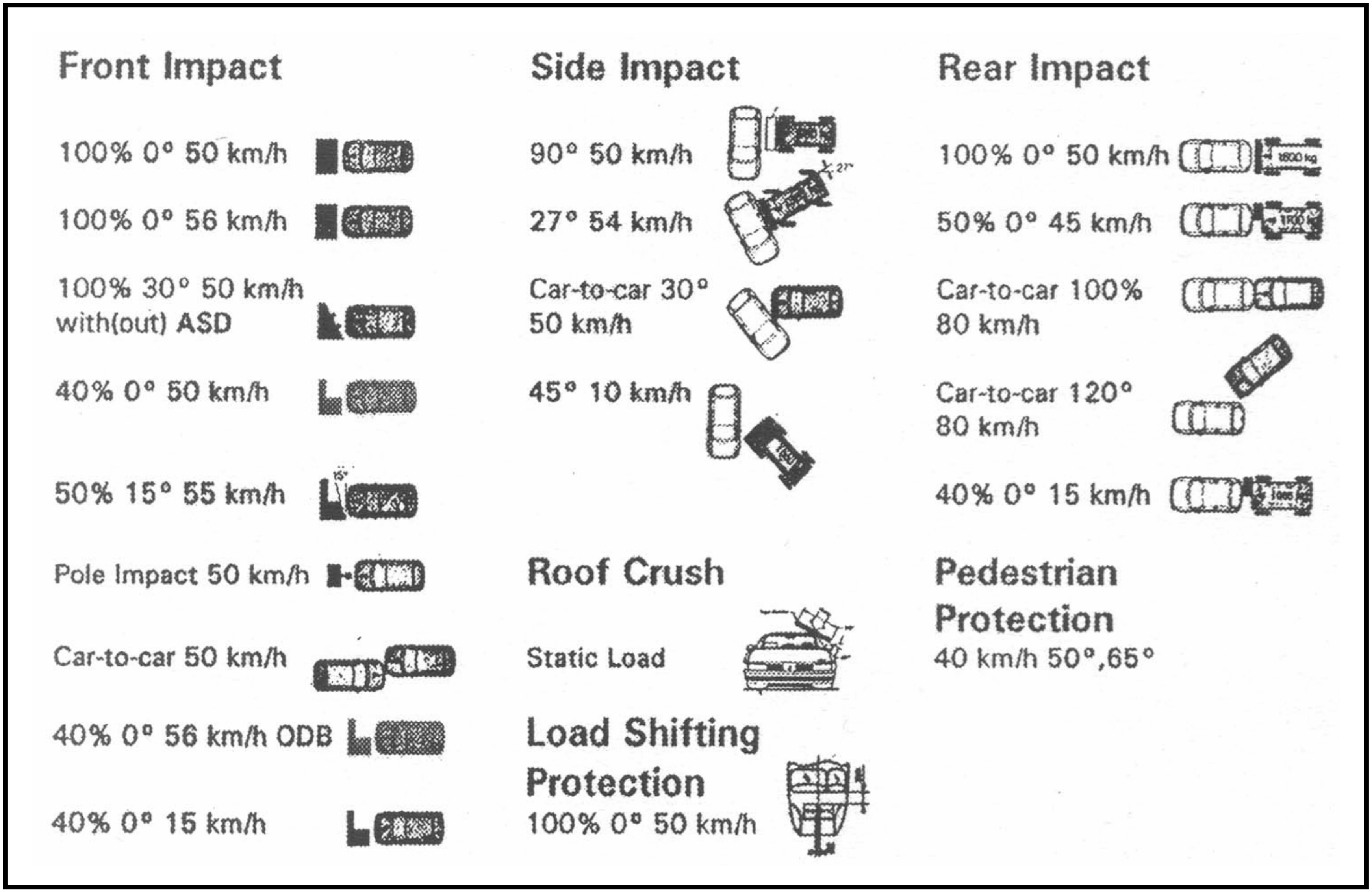

H-III50M

2000 and beyond……?

- School Bus Safety
- Railway Safety Studies
- Seating Comfort
- Motorcycle Safety
- Recreational
- Medical

Safety Regulations

Loadcases for Crash Simulations



Safety Standards and Norms

National Highway Traffic Safety Administration (NHSTA)

"Save lives, prevent injuries and reduce economic costs due to road traffic crashes, through education, research, safety standards and enforcement activity."

http://www.nhtsa.dot.gov/

Federal Motor Vehicle Safety Standards and Regulations (FMVSS) *

*

Crash avoidance, crashworthiness, Post crash standards and others

www.nhtsa.dot.gov/cars/rules/import/**FMVSS**/index.html

Insurance Institute for Highway Safety (IIHS)

http://www.iihs.org/

New Car Assessment Program (NCAP)

http://www.nasva.go.jp/

http://www.mynrma.com.au/cps/rde/xchg/mynrma/hs.xsl/motoring.htm

Safety Standards and Norms

*

European NCAP

"Euro NCAP provides motoring consumers with a realistic and independent assessment of the safety performance of some of the most popular cars sold in Europe."

www.euroncap.com

European Commission

"Every EU citizen has the right to live and work in safety. So, when you are walking, cycling, biking or driving a car or a truck, you should do so with a minimum risk to be hurt or killed. Likewise, other road users should not be damaged by your own participation in traffic."

europa.eu.int/comm/dgs/energy_transport

International Research Council on Biomechanics of Injury

http://www.ircobi.org/index.htm

EC Regulations

http://www.crash-network.com/Regulations/ECE_Regulations/ece_regulations.html