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RESEARCH REGARDING THE VEHICLE SHAPE AS DESIGN FACTOR INFLUENCING COLLISION MECHANICS FOR A FRONT-END CAR-PEDESTRIAN COLLISION

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Abstract
The paper is aimed to the area of simulation and virtual reality in engineering design in the transport safety. It is mainly a study of the level of influence of the vehicle design parameters for the front-end car-pedestrian collision.

1. PROBLEM DEFINITION

The kinematics of pedestrian in collision depends on vehicle shape, initial position of pedestrian and collision velocity.
When a car hits a pedestrian the movement of the pedestrian due to the impact can be divided into three phases:
· Contact phase
· Flight phase
· Sliding phase (ground contact phase)
The first phase is the contact phase, where one or more bodies of the pedestrian have contact with the vehicle and the pedestrian is accelerated. High contact forces can be seen during this phase, forming the main cause of injury
The second cause of injury is the ground contact phase. Both phases contribute to the injuries. Although contribution of the last phase to total injury is appeared to be very significant, the primary phase is studied above all.
The research regarding this problem came up with the existence of four main injury mechanism types. Each type is typical for different shape of the vehicle front end, velocity and initial pedestrian position. The most frequent kinematics of the contact phase is the following: the front bumper hits the pedestrian's leg in the area of calf and knee, after which the pedestrian's thigh or pelvis is hit by the bonnet leading edge. At this point, the pedestrian rotates about the leading edge until arms, head and chest hit the bonnet top or windscreen.

2. VEHICLE SHAPE

The main design factor regarding the influence over the injury degree sustained by the pedestrian in an actual impact with a vehicle is represented by the vehicle shape type. This factor dictates the main impact contact zones on the vehicle, and thus, the behavior of the impact mechanics.

Depending on the shape of the vehicle different accelerations for the pedestrian body may result. The six different most common vehicle shapes are shown below; the exact geometrical conditions are given in the following table.

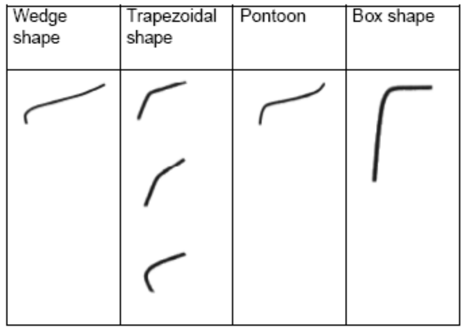
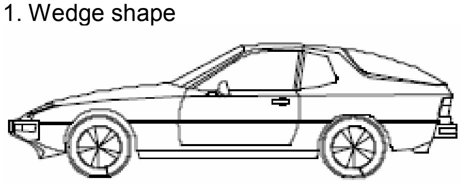


Fig. 1: Geometrical front shape classifications [4]

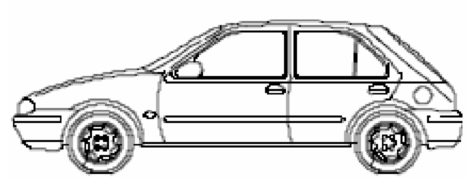
Table 1: Geometrical front shape classifications [4]

	Bonnet height	Bonnet angle	Front angle
Wedge shape	≤ 0.7 m	≤ 20 °	
Trapezoidal shape			
shallow bonnet		≤ 20 °	≤ 70 °
steep bonnet		> 20°	≤ 70 °
ellipsoidal front	Front vehicle edge R > 0,25 m		
Pontoon shape			> 70°
Box shape	Upright contact plane		

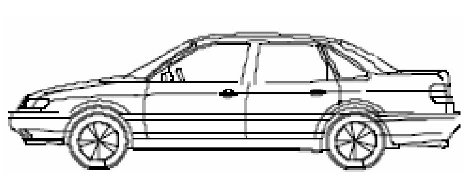
1. Wedge shape



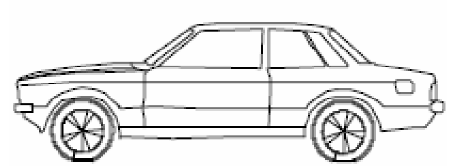
4. Trapezoidal shape with ellipsoid front



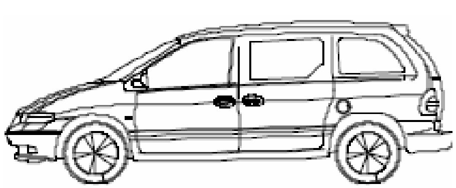
2. Trapezoidal shape with shallow bonnet



5. Pontoon shape



3. Trapezoidal shape with steep bonnet



6. Box shape

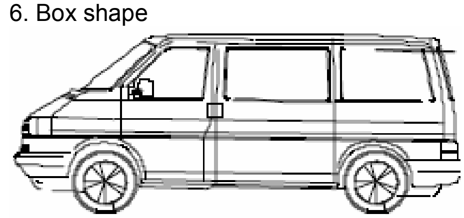


Fig. 2: Geometrical front shape classifications [4]

When considering pedestrian impact mechanics, the frontal vehicle shape is determided by several main parameters such as the

- upper and lower bumper reference lines and hights,
- bonnet leading edge refernce line and hight,

- bonnet and windshield angles,
- surface curvatures relative to the median plane.

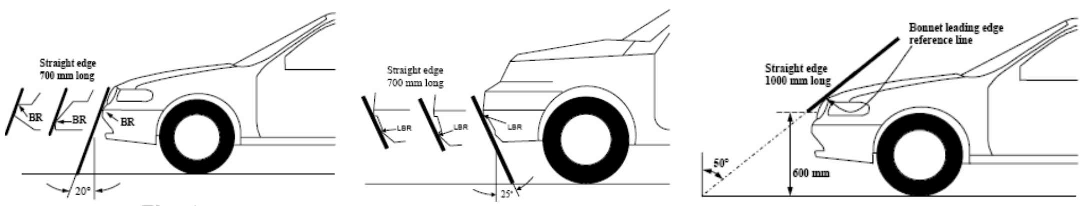


Fig. 3: BR - Upper Bumper Reference Line, LBR - Lower Bumper Reference Line, Bonnet Leading Edge Reference Line [6]

3. SIMULATION. THE MULTIBODY PEDESTRIAN MODEL

PC-Crash 8.0 has been used for simulating the impact behavior and collision mechanics.

Most simulation programs used for accident reconstruction to calculate the movement of the vehicles during and after the impact consider each vehicle as one rigid body. This simplification can be used for vehicle to vehicle collisions as well as for collisions with rigid objects. If impacts between vehicles and pedestrians have to be simulated, the pedestrians have to be modeled as a system of rigid bodies interconnected by joints.

The pedestrian model in PC-Crash uses a multi-body system consisting of several rigid bodies to simulate the movement. The different bodies, which represent the different parts of the pedestrian like head, torso, pelvis etc., are interconnected by joints. For each body different properties like geometry, mass, contact stiffness and coefficients of friction can be specified. The geometry for each body can be specified by defining a general ellipsoid of degree n.

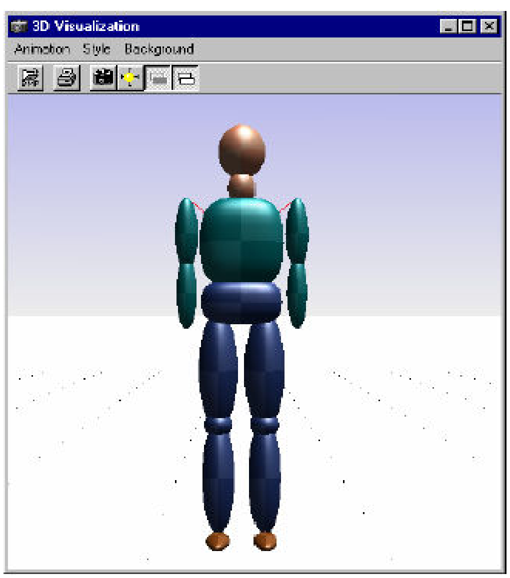


Fig. 4: PC-Crash Multi-body model [3]

Body properties: – For each body of the multi-body system the following properties can be specified independently.

- Geometry: Each body is represented by a general ellipsoid, the length of the semi-axes a, b, c and the degree of the ellipsoid can be specified.
- Mass and Moments of Inertia: For each body of the multi-body system the mass and the moments of inertia have to be specified.
- Stiffness coefficients: A body stiffness coefficient has to be specified, which is used when calculating contacts.
- The stiffness coefficients for different body parts can be determined experimentally.
- Coefficients of friction: Two coefficients of friction can be specified. One is used for ellipsoid to vehicle contacts, the other one is used for ellipsoid to ellipsoid or for ellipsoid to ground contacts. These coefficients of friction are assumed to be independent of the amount of penetration.

4. THE VEHICLE MODEL

The vehicle model can be imported from the existent PC-Crash database and then altered in order to configure the needed impact parameters.
The software offers the possibility to change the vehicle shape parameters, as seen in the picture. Frontal shape parameters from a) to d) and from 1 to 4 are of particular interest.

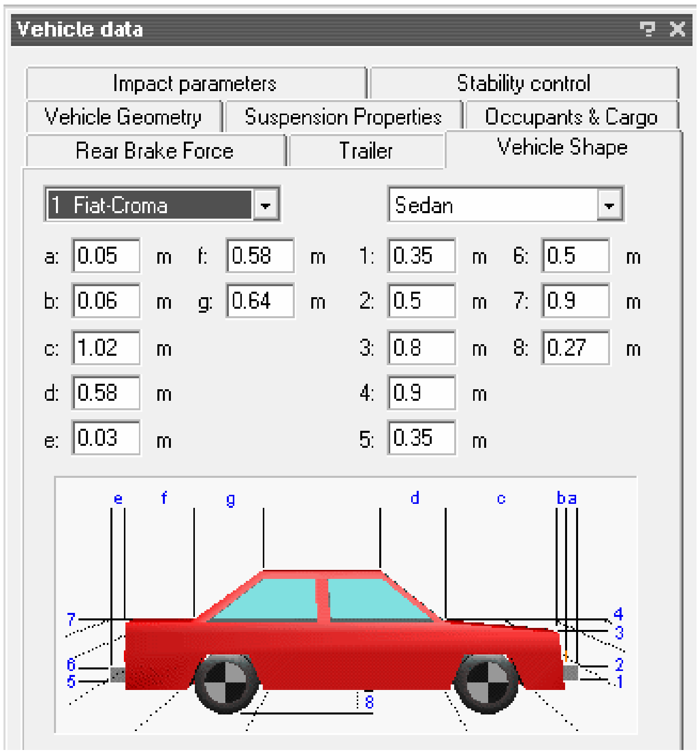


Fig. 5: PC-Crash Vehicle shape parameters

5. TESTING PARAMETERS

Several tests have been conducted in order to determine the influence of vehicle shape for impact mechanics. The resulted acceleration graphs of the multi-body system components simulate for the real human body parts movement.

First test. Testing the influence of the pedestrian distance towards the median plane when considering the shape of frontal structure of the same vehicle.

Parameters:
- initial car speed: 40km/h;
- steering: no steering;
- braking: pedal position: 100%, brake factors: 101.9 on both axles;
- vehicle shape: one vehicle used for a selected shape type;
- pedestrian position: four positions have been used, as it can be seen below;
- pedestrian parameters: default PC-Crash pedestrian values;
- pedestrian regions analyzed: torso, hip, femur, lower left leg, head, left knee.

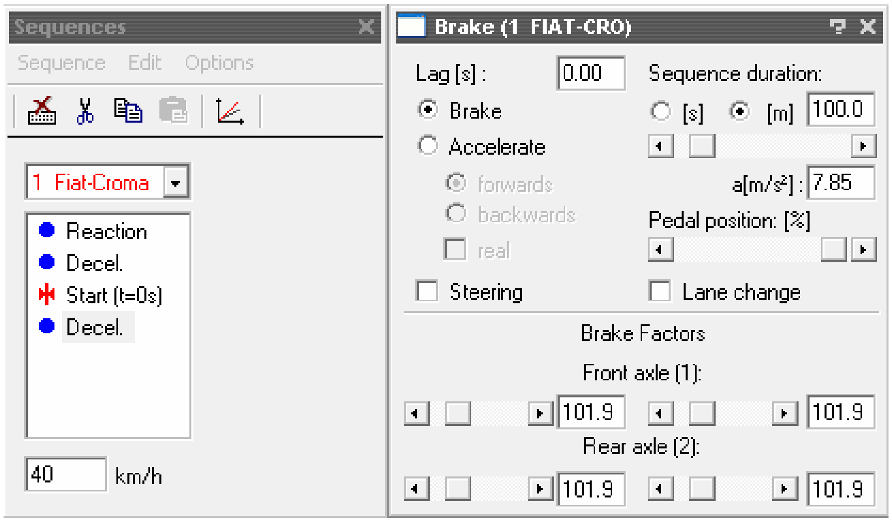
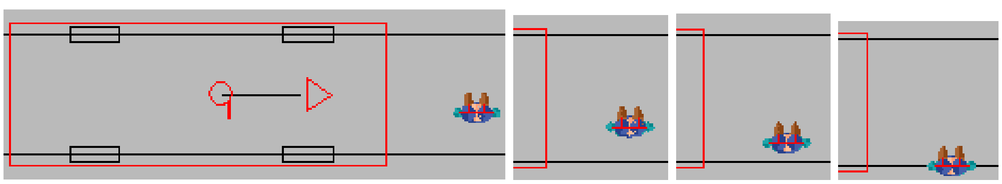


Fig. 6: Setting up the impact sequences and parameters



a) near the center b) intermediate 1 c) intermediate 2 d) centered on the wheels
Fig. 7: pedestrian position used

Second test. Testing the influence of the shape type for different shape types.

Parameters:
- initial car speed: 40km/h;
- steering: no steering;
- braking: pedal position: 100%, brake factors: 101.9 on both axles;
- vehicle shape: vehicles used for the 6 different shape types;
- pedestrian position: the second pedestrian position of the previous test was used;
- pedestrian parameters: default PC-Crash pedestrian values;
- pedestrian regions analyzed: torso, hip, femur, lower left leg, head, left knee.

Third test. Testing the influence of the shape for different vehicles of the same shape type.

Parameters:
- initial car speed: 40km/h;
- steering: no steering;
- braking: pedal position: 100%, brake factors: 101.9 on both axles;
- vehicle shape: different vehicles used for the most common shape type;
- pedestrian position: same as above;
- pedestrian parameters: default PC-Crash pedestrian values;
- pedestrian regions analyzed: torso, hip, femur, lower left leg, head, left knee.

6. CONCLUSION

As the tests show, it can be seen that the the pedestrian distance towards the median plane has a clear impact on the event mechanics. Thus an impact that takes place near the center or the margins of the front-end has milder consequences, while an intermediate point of impact greatly increases the acceleration of the lower body parts.

The second test shows the influence of the shape type for different shape types. Different values and numbers for maximal values for the different body parts evolved clearly illustrate the difference of influence each shape type has on the car-pedestrian impact.

The third test shows the influence of the shape type for different vehicles, of the same shape type: trapezoidal shape with shallow bonnet, usual to be encountered in Romanian traffic.

For most graphs, it can be seen that the head acceleration maximal values are between 40 [g] and 60 [g], while the lower body parts accelerations maximal values go anywhere from 100[g] to 250[g], depending on the vehicle shape and manufacturer.

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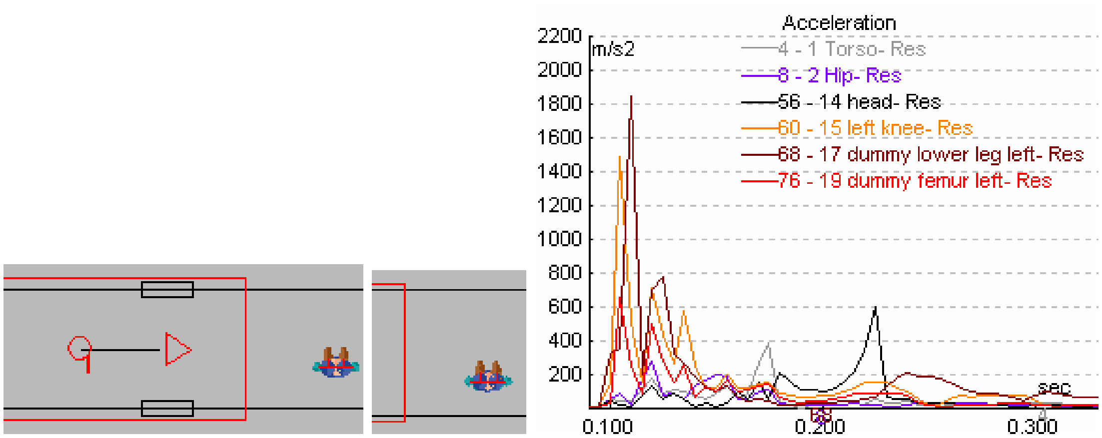
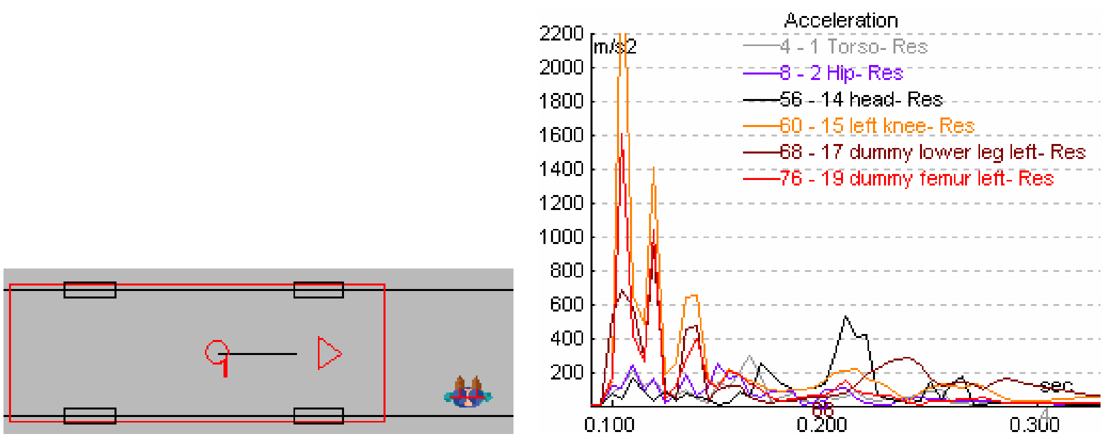
APPENDIX: VIRTUAL TESTING RESULTS

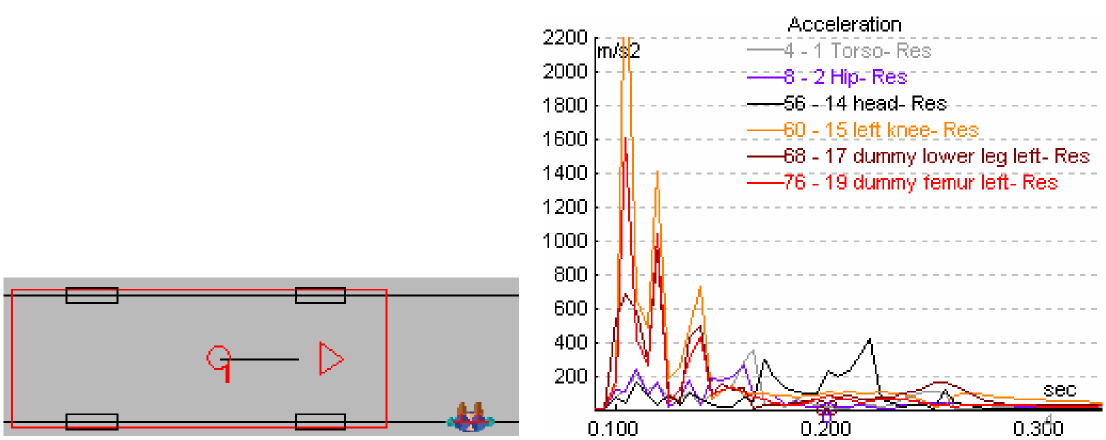
First test. Testing the influence of the pedestrian distance towards the median plane when considering the shape of frontal structure of the same vehicle. Trapezoidal shape with steep bonnet.



a) acceleration graph for the first and second pedestrian position

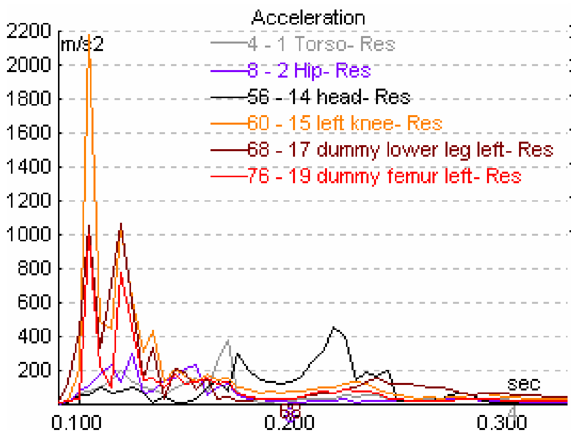


b) acceleration graph for the third pedestrian position

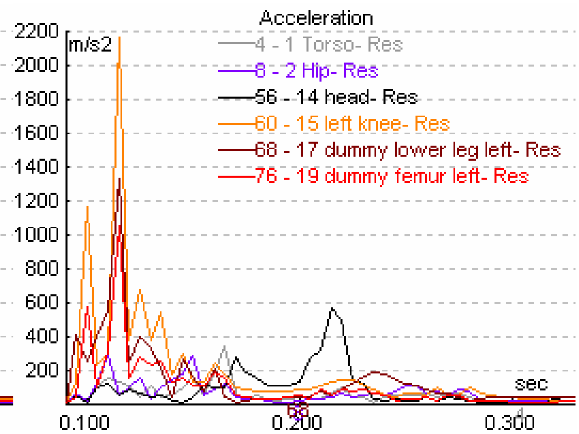


c) acceleration graph for the fourth pedestrian position

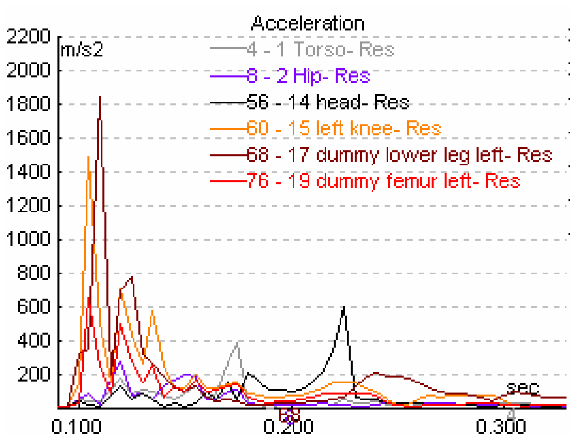
Second test. Testing the influence of the shape type for different shape types.



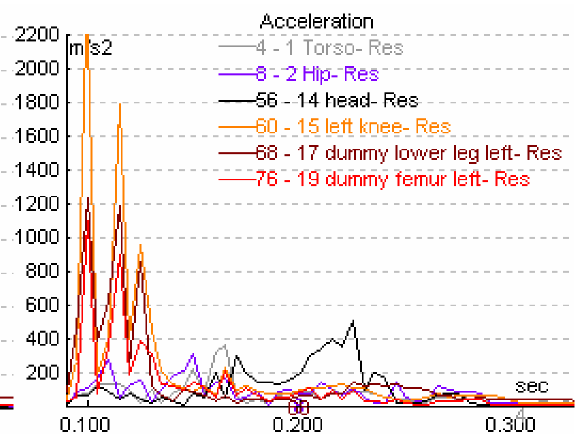
a) Wedge shape



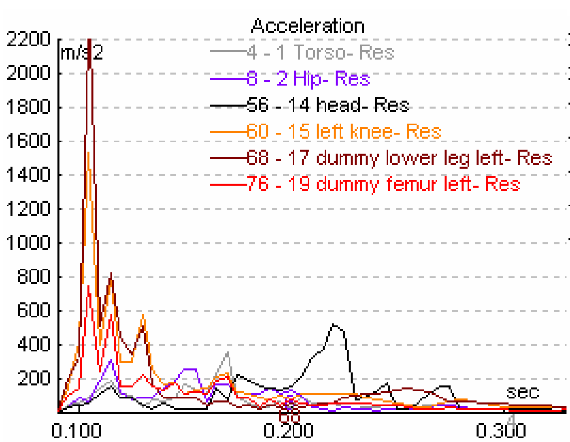
b) Trapezoidal shape with ellipsoid front



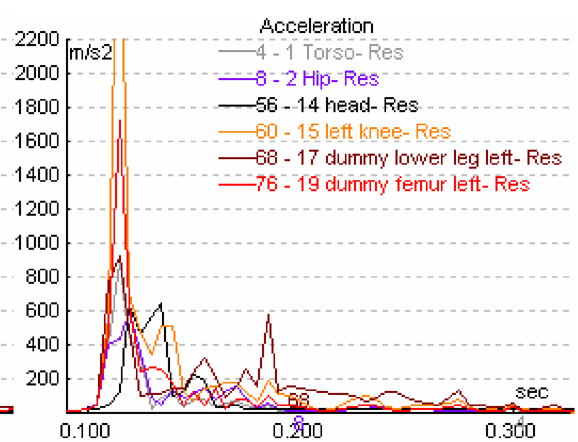
c) Trapezoidal shape with shallow bonnet



d) Pontoon shape



e) Trapezoidal shape with stepped bonnet



f) box shape