BEHAVIOUR OF RESTRAINED DUMMIES AND CADAVERS IN FRONTAL IMPACTS

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Many studies using cadavers as restrained occupants in frontal impacts have been reported previously (1,2,3,4,5,6). Some of these papers tried to compare the results of cadaver tests with the results of dummy tests, but none can associate the results of cadaver and dummy tests under the same crash conditions. To make this comparison, we performed 12 sled using at the same time one human cadaver and 2 different types of dummies, whose results are described in this study.

1. TESTS CONDITIONS

Three models of human living were simultaneously used :
- 1 Alderson VIP 50 dummy
- 1 Hybrid II dummy (Part 572)
- 1 fresh human cadaver

placed at the same time on a structure that offers three driver seats and a model of a VW Passat passenger compartment whole placed on a dynamic test sled turned to the left of a 15° angle. Each human model is restrained by a three points automatic belt.

The tests are conducted at four different speeds : 24, 34 and 48km/h and three impacts are performed for each speed.

Dummies are fitted with tri-axial accelerometers screwed in the head and the thorax. On the cadaver, a setting enables to place three tri-axial accelerometers which are necessary to calculate the resultant acceleration at the theoretical head gravity center.

It supports, at the fourth back vertebra, a triaxial accelerometer that gives the thoracic acceleration.

At the safety belt level, three force-transducers are placed near the anchorage points and enable to know the efforts on each strap.

On the sled, two accelerometers jointed to the tower state the sled acceleration ; one is orientated in the movement axis, the other turned of 15°. The cinematographic cover (5 high speed cameras) enables to study the kinematic of the entirety and of each model.

Cadavers using first require a choice (age, height, weight, nature of death). The used cadavers are fresh. When the different accelerometers have been placed, a catheter is pushed through sub clavian artery to fill in the systemic circulation system. An intra-tracheal tube enables to maintain a pulmonary pressure close to a normal breathing.

After the test, X ray pictures of cadavers are taken and a complete autopsy is done.

2. CADAVERS INJURIES

We notice an only thoraco-abdominal localization of the lesions on the cadavers used in the 12 sled tests.

2.1. Thoracic injuries

At the thoracic level, lesions are very diversified from a simple lesion from strap rasping on a large bilateral flailchest with, in that case, a breaking of the aortic isthmus associated with a great bony decay.

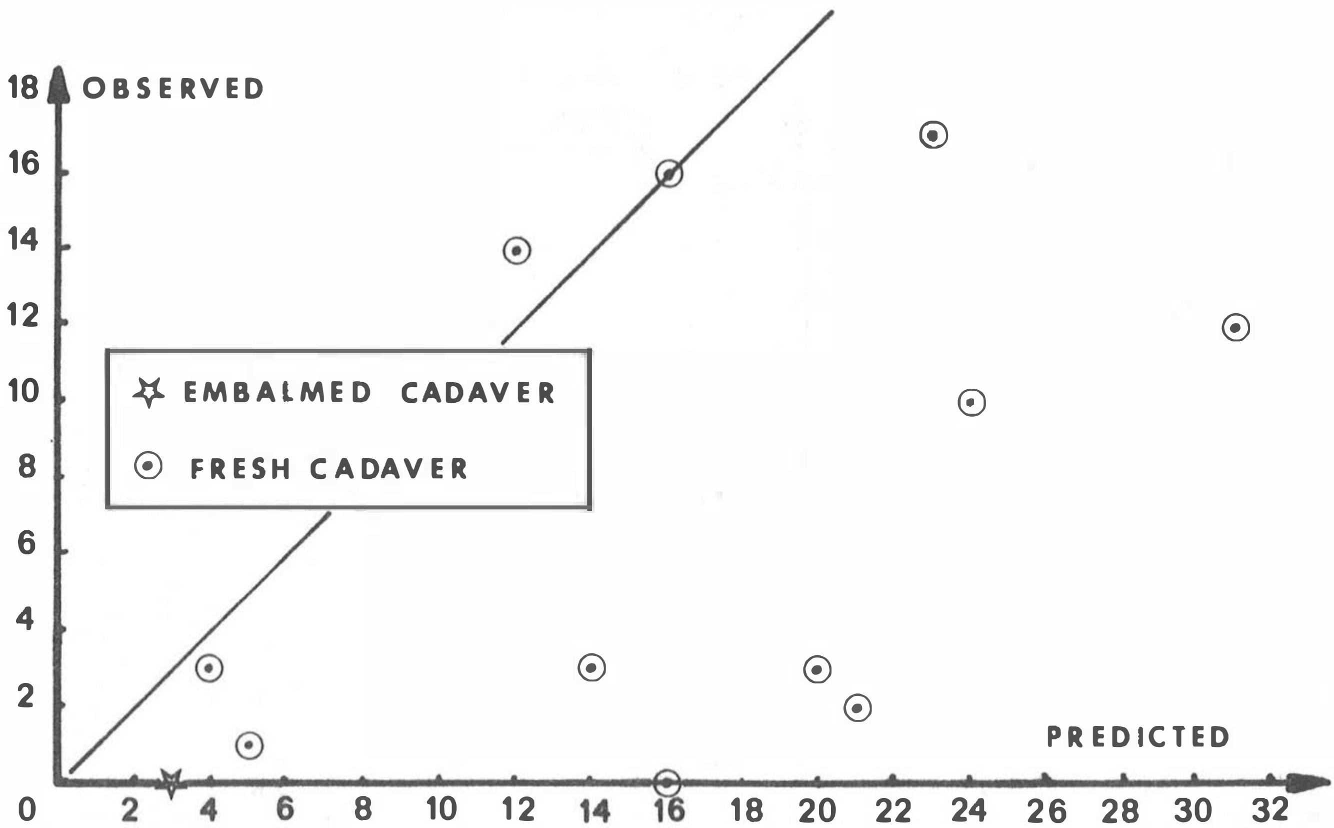
One case of spitting of the right auricle by the only second fractured rib appears to be more as an unfavourable hazard than a typical lesion.

As for lung parenchyma level, we notice liquid extravasations which traumatic origin is difficult to precise. We can only ascertain that they are always associated with important bony lesions.

In two cases, we note a cross fracture in middle of the sternum, nearly at the same level, situated under the thoracic strap passage.

In one case, we notice a left clavicle fracture, in the middle part of it, and there again, under the strap passage.

The injuries sustained by cadavers during the sled tests seem extensive. However, if we compare the numbers of chest fractures observed in the tests with the number of same injuries predicted by a statistical relation established by Eppinger ( ), it is noticeable that most cadavers sustained less injuries than predicted, as indicated in fig. 1



2.2. Abdominal injuries

Most of the lesions we observed concern the spleen and the liver. No hepatic lesion was important. In two cases, hepato-spleenic lesions are associated with middle-thoracic fractures and correspond in all probability to lesions by shoulder strap passage.

In two cases, we notice a rupture of mesentere with on case associated with a spleen rupture and left low rib fractures. Lesions seem to be associated with sub-marining and by the way, to a raising under iliac crests of the abdominal strap, worsened by the trunk bending, that make the low rib leaning on the abdominal content.

3. ANALYSIS OF INJURY CRITERION VALUES

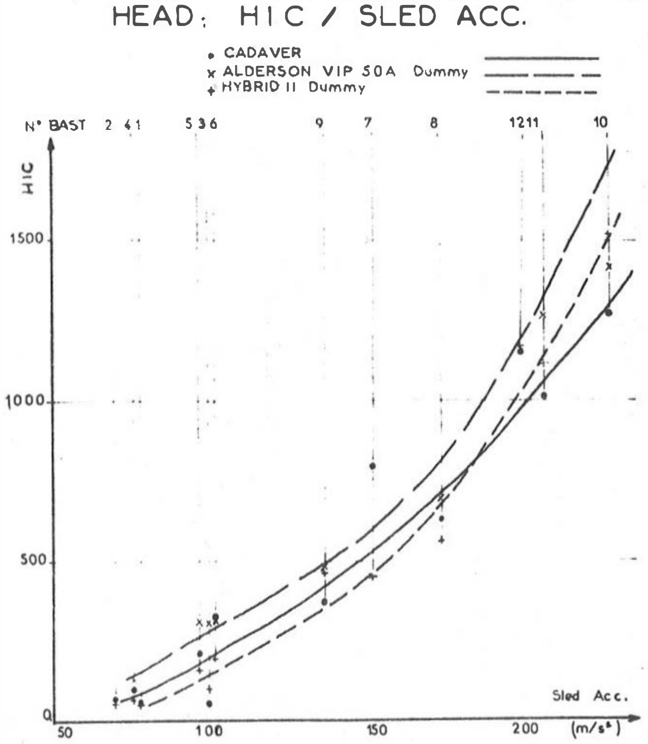
In the analysis of results are considered the HIC values of the three models in the 12 tests, and for the chest, the maximal acceleration and the shoulder belt force in the same tests.

3.1. Head injury criterion

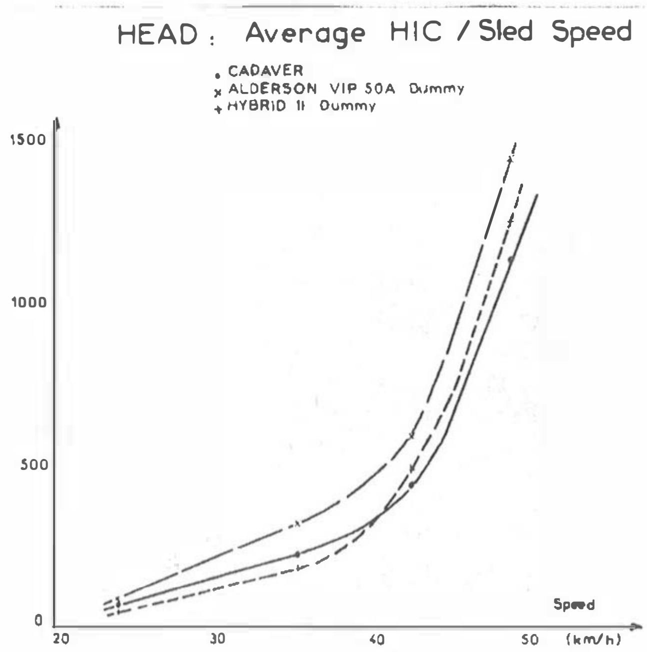
In the same way, the HIC increases rapidly with the test speed. We can explain this variation by the fact that part of the acceleration graph we consider is raised to the 2.5 power and that all test occuring without prime impact, the shapes of graphs are similar.

Between 42 and 48 km/h, we notice that average HIC values doubled for each model.

Drawn in regard to test speed, HIC graph increases with an exponential manner. The graphs that correspond to cadavers and Hybrid II dummies are very close to each other while those of the Alderson VIP 50 are always situated upper (fig. 2)



The average value of HIC calculated for the cadaver is higher than that of the Hybrid II for both lowest test speeds (24 km/h and 34 km/h) while they are lower in the 2 other configurations (fig. 3).



At 48 km/h, all the HIC values for the 3 models are higher than 1000 (average value of 1000, considered as acceptable limit must be near a 46 km/h speed of test).

Head acceleration of dummy head was recorded at the center of gravity. On cadavers we used the data of one external accelerometer. However this accelerometer was located near the ear, at the center of gravity level in vertical and antero-posterior components.

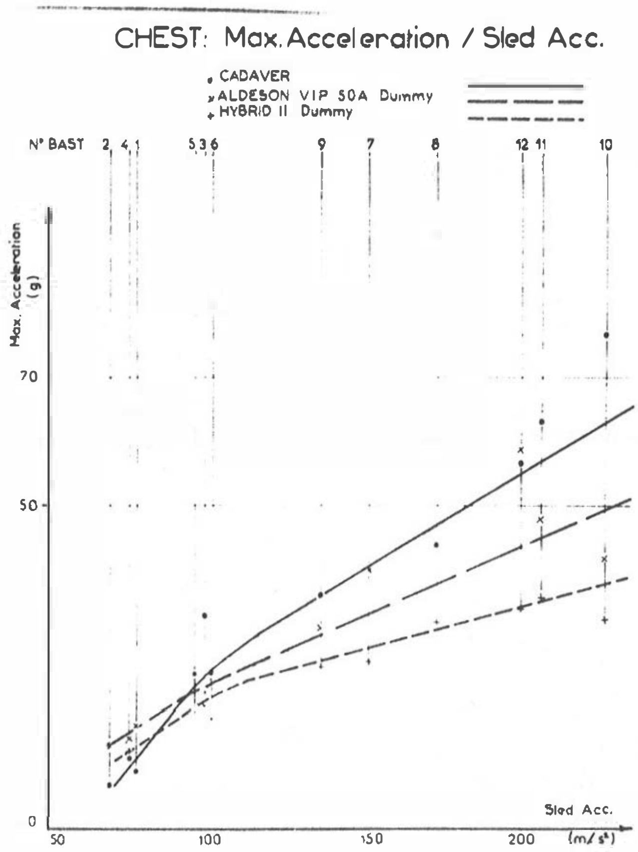
In such a frontal sled test and with an approximately symmetrical head motion, the data recorded on the external accelerometer would be in the same order of magnitude as the center of gravity head acceleration.

3.2. Thoracic injury criterion

Triaxial acceleration is measured at the center of gravity of dummies by a transducer jointed to the back of the thorax. On the cadaver, the triaxial accelerometer is external and bound at the 4th thoracic vertebrae level. From the accelerometers, we calculated the resultant acceleration. At the same time, we measured forces exerted on the belt near the 3 anchorage points.

3.2.1. Chest acceleration

The resultant acceleration of the thorax increases with a nearly linear manner with regards to average acceleration we noticed on the sled (fig. 4)

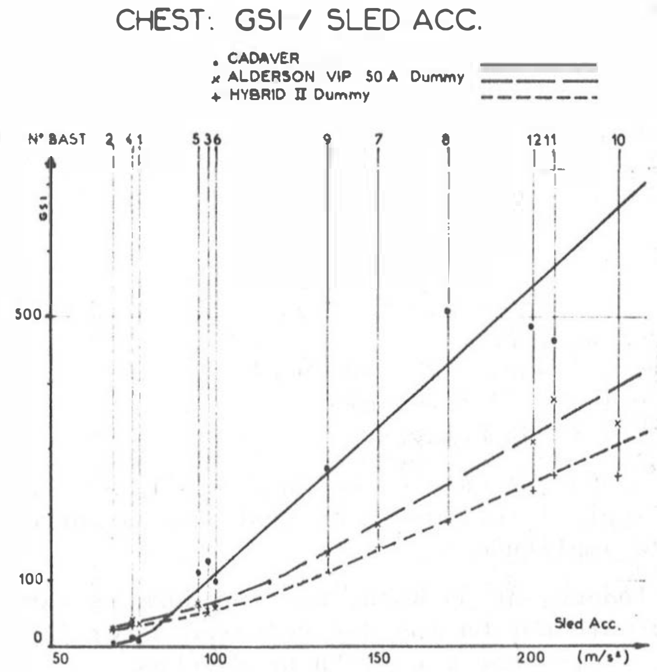


For each test range, we notice that the resultant acceleration increases from Hybrid II to Alderson and from Alderson to cadaver, i.e. the resultant acceleration is always higher on the cadaver than on dummies (fig. 5)

For the dummies, it is never over 60 g, even for 48 km/h tests. However, at such a speed, the Hybrid II always gives very low values, between 34 and 36 g.

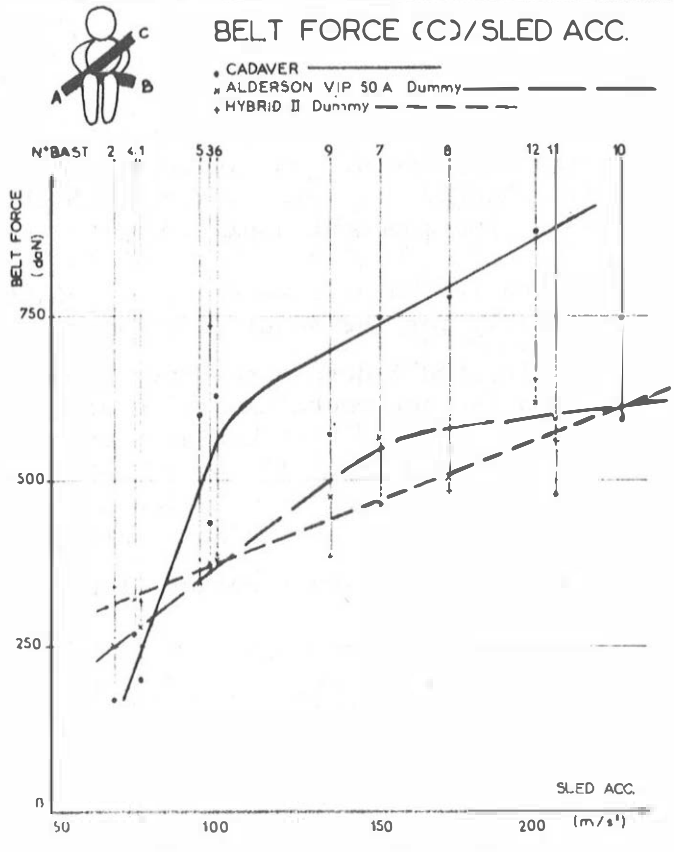
For the cadaver, in the same range of speed, we notice that, in two cases, the value exceeds 60 g (value normaly given as tolerance limit).

These high acceleration values however correspond to extensive lesions of bony thorax (AIS = 5) associated with abdominal lesions due to thoracic deformation (liver injury and/or spleen). Those 3 models did not sustain submarining during the test.



3.2.2. Belt force values

The forces are measured at 3 points, near the 3 anchorage points. The values we noticed increase for each point with the average speed of the sled. At the shoulder anchorage, (C. anchorage) the force exerted by the cadaver is higher than the one exerted by both different dummies (except in 2 cases of submarining) in spite of their weight practically always higher than the corpses we used (fig. 6).



On the contrary, effort values we pointed out on the abdominal strap (anchorage B) are always lower on the cadaver even when there is submarining.

In other words, we can see that the dummy behaves differently from the cadaver. Since it has a particular speed due to a modelisation of the spine not exactly realistic, the dummy moves in one piece and so first leans on the abdominal strap before the thoracic strap.

4. KINEMATICS

Different cinematographic views enable the study of each passenger of the structure, i.e.

- 1 Alderson VIP 50 dummy
- 1 Hybrid II dummy
- 1 fresh cadaver

Speed ranges are chosen (24, 34, 42 and 48 km/h) in order to represent a logical increasing of test speeds corresponding to areas of motion with varied amplitude.

Indeed, at 24 km/h, the two dummies have a perfectly similar behaviour : forward motion rapidly released after impact, "salute" very rigid of the trunk, rapid come back with head rebound.

The cadaver starts its movement later, and it lasts longer : motions are smoother, slope of the trunk is limited but rigid, with a detachment and a slight turning forward, on the right of left shoulder. The coming back is slower and, after the rebound, the head shows an incline with turning to left.

At 34 km/h, the behaviour of dummies is no more perfectly similar : the Alderson comes back faster than the Hybrid, with a very rigid trunk motion.

The cadaver has a slight turning motion round the shoulder strap. For the 5th test, the corpse (of small height) notably sank back. We can notice that, for this case, the shoulder strap is fixed much to high.

At 42 km/h, the Alderson dummy starts a submarining motion (which will increase at higher speed) and, in spite of it, comes back to first position sooner than Hybrid II, more flexible, which is nearer to human cadaver. The later increases the movement amplitude at 32 km/h but does not submarine at all.

The motion is sharper, suddenly braked by the crossing strap and the rebound (specially for the head) is cleaner.

At 48 km/h, the Alderson severely submarines after impact, we find it the back on the horizontal position of the seat. The Hybrid keeps a similar way to this of last test but at the rebound moment, the head knocks the model of middle leg. All the cadavers submarine specially the 10th which extremely submarines with a high abdominal raising of the strap and a sinking of the low part of the body on seat foundation.

The low weight and small height of the model are probably the cause of this movement.

The cadavers n° 10 and 12 which height and weight are much more "standard" begin a submarining but the strap stops when it is above the iliac crests. The lesions can come in part from this motion but also from important turning round the strap. That movement breaks the low ribs on upper abdominal content.

5. BEHAVIOUR OF RESTRAINT SYSTEMS

The used belts are similar for all the tests : mass production 3 points automatic belts (REPA) which strap is 50 mm large.

After each test, belts are removed and replaced by new belts, because the impact can modify the mechanical characteristics of the strap, with an irreversible manner.

We notice no failing of restraint system at any level. For each test, we determined, from high speed films, the unrolling of the strap at the run out of the drum of the belt worn by the cadaver and the Hybrid II support.

The determined values are not very important. They increase with the impact speed and vary between 2.5 and 6.8 cm.

This increase is always less important on the belt worn by the cadaver because its thorax begins to move later on. These increases are consistent with a correct restraint, even at the highest speed.

6. CONCLUSION

The aim of this study was to compare systematically the responses of human cadaver and of two different types of dummies, subjected to a same impact. In this purpose, 12 tests were performed at 4 different speeds.

These tests shown that an impact did not cause any injury on cadavers during test made at 24 km/h, meanwhile fastest test (48 km/h) always induces mortal or very severe lesions.

With regards to other test speeds, 5 from 6 cadavers supported typical injuries, but their severity enables a presumption of survival. The 6th model is indemn.

Those injuries are, over all, rib fractures, simple or flail chest sometimes associated with a crossing fracture of the sternum. In case of more violent impacts, we notice simultaneously hemothorax (sometimes two sided) and cardiac lesions (or large blood vessels).

Abdominal lesions are much less frequent than thoracic lesions. There are mostly fissures or rupture of spleen or liver, subjected either to submarining or deflection of low ribs with or without fracture. We also noticed a rupture of the mesentery, caused by an important submarining.

We did not find again lesions on others bodily segments specially no bony lesions of the spine. These tests seem to show that we observe lesions due to safety belts on the cadavers even at slow speed, but it is caused first to the oldness of used cadaver, secondly to the sled deceleration rule that makes the impact more severe.

A better selection of used cadavers, specially according to mechanical properties of their bones, should reduce the dispersion of results concerning the observed lesions.

In regard with kinematics, the difference between the three models increases with the speed. At low speed, the motions of both types of dummies are "in range" meanwhile the cadaver has a larger and longer movement. At higher speed, the Alderson VIP 50 dummy has a movement faster than the Hybrid II meanwhile the one of the cadaver is late.

Contrary to both other models, from 42 km/h the Alderson VIP 50 dummy submarines during the impact.

The cadaver always submarines during the test at 48 km/h meanwhile the Hybrid II dummy never does.

From the whole tests, it appears that the cadaver seems to have a realistic kinematics in spite of height and weight differences between the 12 subjects we used.

The kind of safety belts we used perfectly worked during all the tests.

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	Test n° 1			Test n° 2			Test n° 3		
SLED									
REAL SPEED	24 km/h			23,9 km/h			24,4 km/h		
Stopping distance	27 cm			32 cm			23,5 cm		
Maximal acceleration	12 g			10 g			19,5 g		
Average acceleration	8,1 g			6,9 g			9,8 g		
MEASUREMENTS	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.
- HEAD									
. HIC	55	101	53	71	61	47	50	300	93
. max	18	25	16	20	18	15	18	32	23
- CHEST									
. SI	8	26	35	5	25	26	131	51	55
. max	9	16	15	7	13	13	33	19	21
- BELTS									
. shoulder strap	200	280	320	170	250	290	400	375	406
. lap strap	150	220	220	160	170	160	248	340	285
. common strap	220	180	310	220	150	260	360	370	480
. strain		3,5		2,5	3,0	2,5	2,1		1,1
CADAVER PROPERTIES	Cause of death : cardiac infarct.			Cause of death : cerebral ictus			Cause of death : cerebral ictus		
- sex	male			female			female		
- height	1,70			1,62			1,53		
- weight	68			54			47		
- age	65			72			71		
- state	fresh			fresh			fresh		
CADAVER INJURIES	Chest : no injury - AIS = 0 no other injury OAIS = 0			Chest : medium arc fracture of 3, 4 and 10th right ribs with small hemothorax - AIS = 3 OAIS = 3			Chest : anterior fractures of 2, 3, 4th right ribs AIS = 3 OAIS = 3		

	Test n°4			Test n° 5			Test n° 6		
SLED REAL SPEED Stopping distance Maximal acceleration Average acceleration	33,6 km/h 58 cm 12,5 g 7,5 g			36,2 km/h 53 cm 13,5 g 9,5 g			33,7 km/h 44 cm 11,5 g 9,9 g		
MEASUREMENTS	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.
- HEAD									
. HIC	100	136	63	216	307	164	325	332	190
. max	29	29	18	43	42	24	64	44	23
- CHEST									
. SI	14	43	37	115	64	61	99	59	60
. max	11	14	12	24	19	18	24	17	23
- BELTS									
. shoulder strap	270	320		600	345	378	630	384	388
. lap strap	190	180		389	265	283	311	312	310
. common strap	380	370		593	329	432	812	391	500
. strain				2,7 cm		3 cm	3,8 cm		3,7 cm
CADAVER PROPERTIES	Cause of death : aneurysm rupt.			Cause of death : liver cancer			Cause of death :cardiac infarct.		
- sex	male			male			male		
- height	1,56			1,70			1,71		
- weight	56			70			78		
- age	58			69			70		
- state	fresh			fresh			fresh		
CADAVER INJURIES	Chest : 2nd fracture (anterior arc) - AIS = 2 Right auricle spit No other injury OAIS= 6			Chest : sternal fracture right flail chest (3rd to 7th rib) right rib fract.(2nd and 5th to 8th) bilateral hemothorax - AIS = 5 No other injury OAIS = 5			Chest : no injury - AIS = 0 No other injury OAIS = 0		

	Test n° 7			Test n° 8			Test n° 9		
SLED									
REAL SPEED	42,5 km/h			41,50 km/h			42,15 km/h		
Stopping distance	45,5 cm			39 cm			51 cm		
Maximal acceleration	17,5 g			20 g			17,5 g		
Average acceleration	14,9 g			17 g			13,4 g		
MEASUREMENTS	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.
- HEAD									
. HIC	795		445	625	695	557	370	481	460
. max	40		42	56	73	44	48	73	43
- CHEST									
. SI		185	125	508		189	270	142	114
. max		40	26	44		32	36	31	25
- BELTS									
. shoulder strap	750	562	464	780	506	486	570	475	383
. lap strap	311	407	391	347	485	483	262	381	405
. common strap	1000	417	658	318	645	723	606	499	592
. strain	3,2		3,8	3,2		4,7	2,8		3,6
CADAVER PROPERTIES	Cause of death : asphyxia			Cause of death : cerebral ictus			Cause of death : cerebral ictus		
- sex	female			male			female		
- height	1,60			1,74			1,52		
- weight	54			83			46		
- age	66			71			70		
- state	fresh			fresh			fresh		
CADAVER INJURIES	Chest : right rib fracture (2nd, 3rd, 6th, 7th) left rib fract (2nd to 6th) bilateral hemothorax - AIS=4 no other injury OAIS = 4			Chest : left rib fract (8th to 10th) - AIS = 3 splenic rupture, mesentery tears - AIS = 3 OAIS= 4			Chest : left rib fract (1st and 2nd) - AIS = 2 no other injury OAIS = 2		

	Test n° 10			Test n° 11			Test n° 12		
SLED									
REAL SPEED	48 km/h			46,9 km/h			48,6 km/h		
Stopping distance	42 cm			42 cm			46,5 cm		
Maximal acceleration	38 g			24 g			26 g		
Average acceleration	22,2 g			20,2 g			19,6 g		
MEASUREMENTS	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.	CAD.	ALD.	HYB.
- HEAD									
. HIC	1271	1411	1509	1014	1260	1106	1154	1682	1159
. max	98	89	68	79	86	71	87	93	80
- CHEST									
. SI	802	346	243	466	374	254	488	307	235
. max	77	42	35	66	48	36	57	59	34
- BELTS									
. shoulder strap	750	594	602	479	596	560	830	621	655
. lap strap	298	618	624	323	662	686	409	518	600
. common strap	700	965	949	926	896	879	926	965	761
. strain	4,4		6,8	3,6		5,7	4,9		5,3
CADAVER PROPERTIES	Cause of death : cerebral ictus			Cause of death : silicoosis			Cause of death : cardiac infarct.		
- sex	female			male			female		
- height	1,50			1,70			1,60		
- weight	46			69			57		
- age	74			68			59		
- state	fresh			fresh			fresh		
CADAVER INJURIES	Chest : right flail chest (5th to 8th) left rib fract (4th to 7th) AIS = 4; liver tear - AIS = 3; OAIS = 5			Chest : left clavicle fracture left flail chest (2nd to 6th) right rib fract (4th to 7th) AIS = 5; aortic isthmus rupture -AIS=5; splenic and hepatic tears AIS = 3; OAIS = 6			Chest : sternal fracture, left flail chest (2nd to 5th), right flail chest (3rd to 6th) small bilateral hemothorax AIS = 5; mesentery tear - AIS = 3; OAIS = 5		