



Description on female thorax protector development

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Description on female thorax protector development

Technical report

Appendix of Deliverable "D 4.3.3. A"

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Rev.	Issuing date	Pages	Written by	Visa	Verified by	Visa	Approved by	Visa
A.	17/12/2008	22	David Manzardo (Dainese) Aquilino Molinero Sergio Alonso David Garcia (Cidaut) Aline Delhayé (FEMA)	√	Aquilino Molinero (Cidaut)	√		
Modifications:								
B.								
C.								

Leading company: **Dainese S.p.A.**

Publishable summary

This document was written in the framework of Subproject 4 “Motorcycle Accidents” of APROSYS.

This report is a descriptive document of the deliverable 4.3.3 A (which is the female thorax protector prototype), and it helps the reader to understand the development process of the new passive protector for the rider’s breast body region.

After the development and the validation of the male thorax protector in previous activities of APROSYS (Deliverable 4.3.3 “New thorax protector”), an important rider’s cluster should not be forgotten; female motorcyclists. The male thorax protector has demonstrated to play an important role on the rider safety as the thorax is a often severely injured body region and this protector demonstrates its effectiveness on the injury prevention on this body area. The male thorax protector development showed through simulations carried out with ‘Humos model’, that the main mechanism of protection of this specific body area is the impact force distribution. This previous experience with male thorax protector has given important guidelines on the female thorax development, and also some of the previous activity has been used on the female thorax development, in particular:

- Materials selection.
- Concept design.
- Definition of the impact condition.
- Definition of the tests validation.
- Definition of the ergonomic test protocol.

As good performances on male thorax protector were achieved, it has no sense to change materials. Furthermore, as the conditions of use are the same for male and female motorcyclists, ergonomic and impact performance should be assessed in the same way.

In this project, a huge work was required to design this protector, to simulate its behaviour under impact condition and, after the protector’s development, to test it.

Simulations and real impact tests have demonstrated accordingly that female thorax protector developed inside APROSYS project protects this body region in case of thorax impacts.

Finally, prototypes manufactured within this Task D-4.3.3A of the APROSYS Project are archived c/o Dainese S.p.A. via dell’Artigianato, 35 I-36060 Molvena (VI) Italy.

Acknowledgement

Following participants contributed to this deliverable report.

Company	Representative	Chapters
CIDAUT	Aquilino Molinero Sergio Alonso David Garcia	Protector’s impact simulations – Impact tests
FEMA	Aline Delhaye	Ergonomic test
DAINESE	David Manzardo	Prototype manufacturing

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1 INTRODUCTION

APROSYS SP4 “Motorcycle accidents” aims to reduce the number and severity of powered two wheelers (motorcycle and moped) user injuries in the most relevant accident scenarios. A previous in depth study, identified the thorax body region as a critic area from the point of view of safety. For that reason, in the APROSYS deliverable 4.3.3 A, a new female thorax protector has been developed. This report shows the activities carried out during the project development, from validation tests set up, through the protector’s design till the final prototype validation, each activities, development and outcome are presented.

2 DEFINITION OF THE IMPACT CONDITION

2.1 Impact conditions for validation

As the condition of using this protective device is independent from the gender, same tests as for male thorax were foreseen to validate the female one. These conditions are indicated below.

2.1.1 Impact test condition

The validation tests were carried out with a Female Hybrid III Dummy. A series of impacts was carried out on the dummy with and without protective device, at two different velocities and with two different impactor geometries. Table 1 show the complete series impacts test.

	Impact velocity [m/s]	Impactor's geometry
Impact set 1	5	Cylindrical
Impact set 2	6,5	Cylindrical
Impact set 3	5	Kerbstone
Impact set 4	6,6	Kerbstone

Tab. 1
Impact test specification

The cylindrical impactor has a diameter of 6 inch (15.2 cm) and a weight of 23.4 kg. On the other hand, the Kerbstone impactor (Figure 1) meets the European Standard EN 1621.2/03 requirement on its geometry. It is usually used to test Back protectors and simulate the sharp impact opponent object.

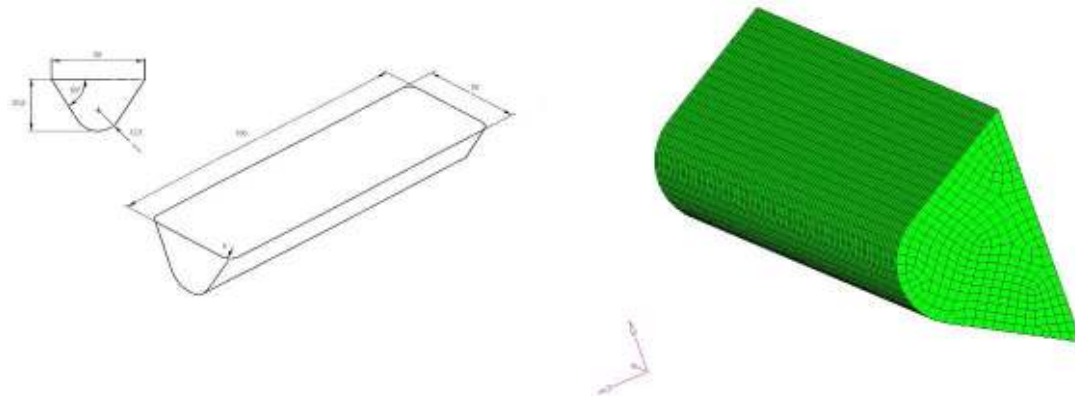


Fig. 1
Kerbstone impactor

The following data analysis was carried out analysing to the following criteria:

- The Thorax-Compression;
- The Viscous Criteria;
- Sternum acceleration.

3 DESIGN

3.1 INTRODUCTION

The design concept was driven by the previous experience that showed the need to achieve an impact energy distribution on a wider area and, at the same time, shift the forces from the central to the lateral area of the thorax in order to reduce the flexural momentum, thus fracture risk, on ribs.

Furthermore, as for male thorax protector, these safety requirements should be accomplished taking into account also ergonomic and comfort issues. Indeed, the female motorcyclists should have freedom of movements to be able to ride without impediments and this is an aspect related both ergonomics and safety. In addition, the protector should be thin enough to be worn under motorcyclist's garment without the necessity to increase the garment size, as this situation should lead to outplacements for the other protectors. As for male, breathability is also an aspect to be considered, therefore, if air is allowed to flow on the thorax area through the use of comfort materials or thanks to hole produced on the protector surface, the level of comfort can be significantly increased.

3.2 DESIGN PROCESS

The design process starts taking into account the guideline coming from the male thorax protector development and so, one piece shell in order to maximize the spread of the force was an immovable input for the designer. This bond made critical the protector's inner surface definition as it has to be as close as possible to the real female body. Therefore, two main aspects must be considered: to fulfil ergonomic aspects and to spread the impact force.

A female manikin model was identified and with reverse engineering methods, the surface was measured and transformed in a 3D CAD surface. Figures 2 and 3 show with different point of view the 3D CAD female surface.

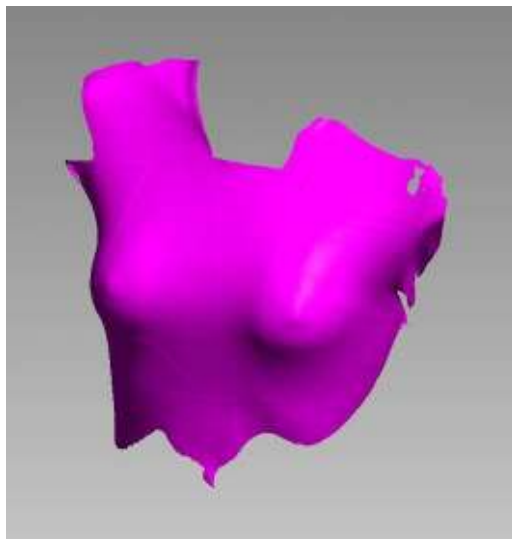


Fig. 2
3D - Manikin CAD surface front view

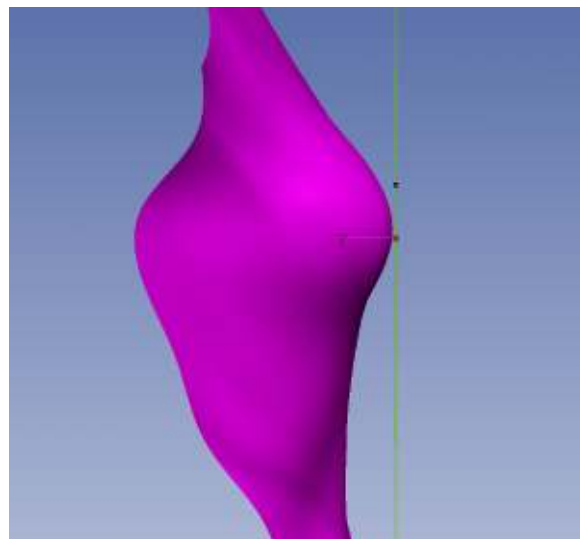


Fig. 3
3D - manikin CAD surface lateral view

Taking into account this surface and after the protector's perimeter definition (Figure 4 and 5), the protector's shape was prepared with rapid prototyping (Figure 6 and 7) and tested with a female human model in order to check the ergonomic fitting.

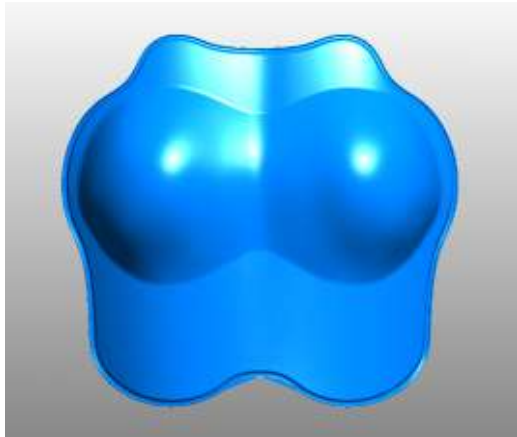


Fig. 4
Protector's basic shape front view

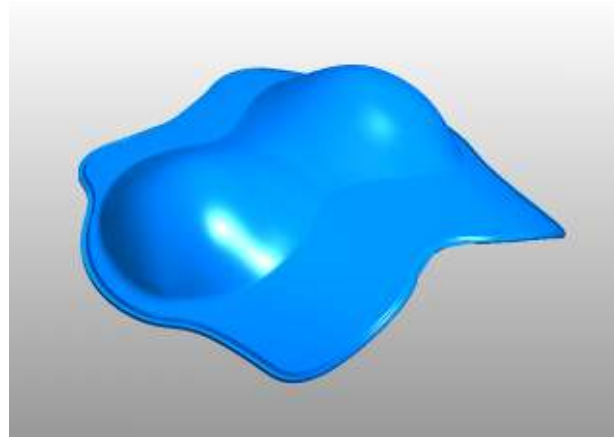


Fig. 5
Protector's basic shape lateral view



Fig. 6
Protector's prototype front view



Fig. 7
Protector's prototype lateral view

Some modifications on the shape and on the dimensions were necessary testing in real condition. The prototype was cut and detailed measures were recorded (Figure 8), as well as some adjustments on the protector perimeter became necessary.



Fig. 8
Protector's prototype with indication of modification

When the right shape was defined, the final protector's CAD design took in consideration also some inputs from stylists (Figure 9).

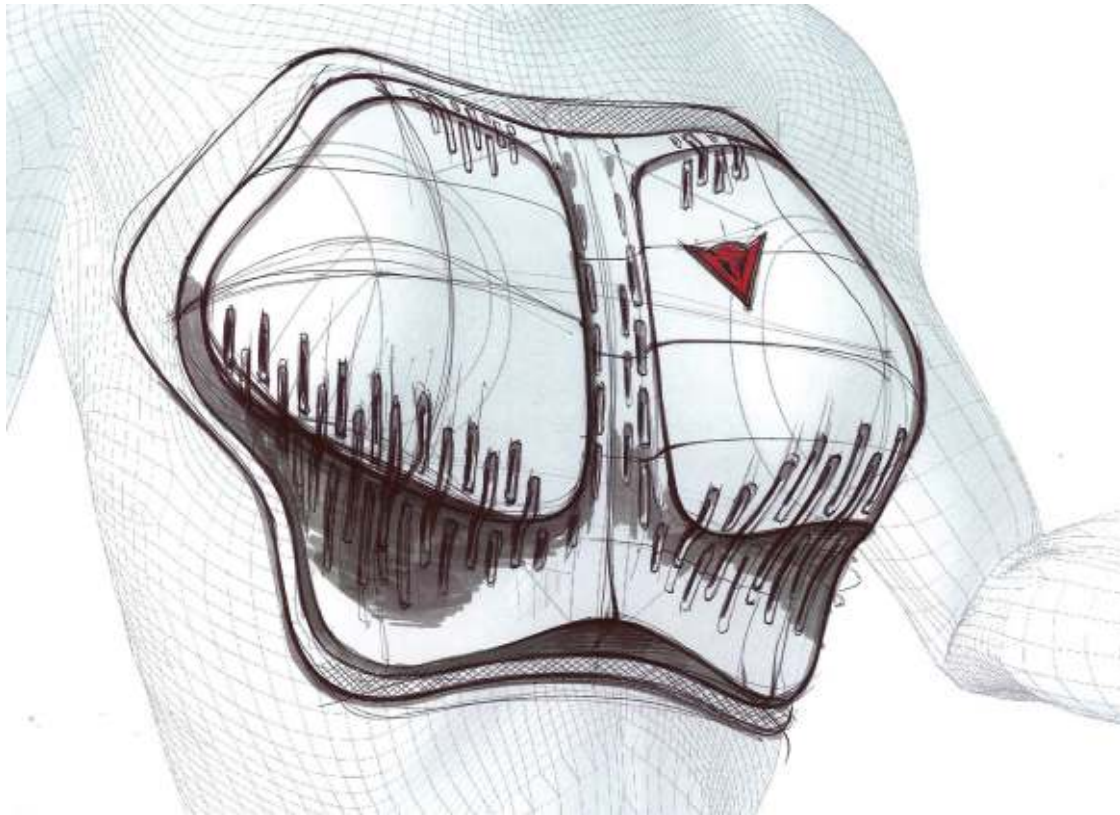


Fig. 9 – Protector's style

The last activity of the CAD design process was to create the holes for breathability. The shell's internal side was provided in some zones with a reticular structure, which give the shell both characteristics: lightness and the high rigidity (required for impact force distribution performance).

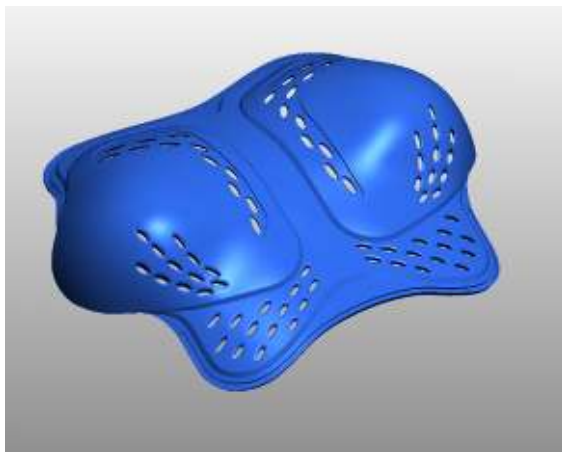


Fig. 10
Protector's definitive CAD surface

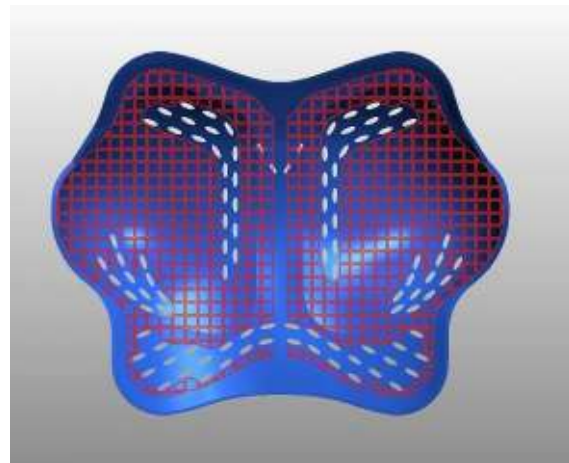


Fig. 11
Protector's reticular structure

Regarding the internal padding, a "3D" fabric was selected which allows an optimal perspiration.

4 PROTECTOR'S IMPACT SIMULATION

4.1 Introduction

The aim of the simulations done during this task (433 A) is to obtain the 'numeric model' of the female thorax protector developed. As every 'numeric model', it must be validated through the respective real tests. This validation has been also done in this task. Although this task could seem very similar to task 433 (in which the male thorax protector has been developed, prototyped and validated), it is a bit different. Whereas the male simulations were done using a finite elements model ('HUMOS'), the female simulations were done using a multibody model (Hybrid III in 'MADYMO').

4.2 Geometry of the female thorax protector

For the simulations, first of all it is necessary to know all the details related the geometry. These details were given by Dainese to Cidaut for preparing the numeric model.

4.3 Material characterization

Once the geometry was known, the next information needed was the physic characteristics of the material used in the female thorax protector. Because this material had not been used before in MADYMO, it was necessary to obtain the complete characterization of this material.

Several tests had to be done to determine the physic proprieties of the material. Through 'XMADGIX' software, a simulation model was made in MADYMO using these 'material characterization tests'. A later comparison between the results from this first model in MADYMO and the results from the 'material characterization tests' was done in order to adjust this first version of the 'simulation model'. Finally and subsequently after this adjustment, the simulation model is approved related to the 'material behaviour'.

4.4 Protector and impactor meshing

Using the geometry given by Dainese and through the geometries discretisation software 'ANSA', the protector was meshed correctly.

As well as the protector was meshed, the different impactors to be used were meshed (cylindrical impactor and Kerbstone impactor).

4.5 Model assembly

Again, using Xmadgic software, several numeric models were done in MADYMO and based on the frontal impact dummy (Hybrid III) given by this software. For the different tests to be done, both impactors (cylindrical and kerbstone ones) were located in the respective positions and distances with the aim of being thrown towards the thorax (with or without protector) at different impact speeds. Different models were obtained as follows:

Model Number	Thorax Protector	Impact Speed (m/s)	Impactor
1	No	5	Cylindrical
2	No	6,5	Cylindrical
3	Si	5	Cylindrical
4	Si	6,5	Cylindrical
5	No	5	Kerbstone
6	No	6,5	Kerbstone
7	Si	5	Kerbstone
8	Si	6,5	Kerbstone

Tab. 2 – Simulation tests

4.6 Simulation results

The simulation results demonstrated that the level of safety was increased by using the female thorax protector. Table 3 shows the ‘Viscous criteria’ peak recorded for Cylindrical impactor while figure 12 shows the ‘Chest deflection’ simulated with an impact speed of 5 m/s with a Cylindrical impactor. Figure 13 shows same results with an impact velocity of 6,5 m/s.

Cylindrical impactor	VC _{PEAK} [m/s]	
	Without thorax protector	With thorax protector
Impact velocity 5 [m/s]	0,49640	0,48016
Impact velocity 6,5 [m/s]	0,82725	0,80649

Tab. 3 – VC peak recorded at 5 m/s cylindrical impactor



Fig. 12 – Chest deflection at 5 m/s cylindrical impactor



Fig. 13 – Chest deflection at 6,5 m/s cylindrical impactor

Table 4 presents ‘Viscous Criteria’ peak measured with kerbstone impactor. Figure 14 and 15 show ‘Chest deflection’ obtained with same impactor.

Kerbstone impactor	VC PEAK [m/s]	
	Without thorax protector	With thorax protector
Impact velocity 5 [m/s]	0,54214	0,51209
Impact velocity 6,5 [m/s]	0,97516	0,82416

Tab. 4 -- VC peak recorded with kerbstone impactor



Fig. 14 – Chest deflection at 5 m/s kerbstone impactor



Fig. 15 – Chest deflection at 6,5 m/s kerbstone impactor

All the simulations accordingly have demonstrated that thorax protector is effective on injury reduction, in case of impact on the thorax area.

5 PROTOTYPE MANUFACTURING

5.1 Introduction

The first step of prototype development consisted of the preparation of a suitable CAD file for moulding the rigid shells. After that, with a shell prototype made with rapid prototyping methods, a sample was created and the pattern maker designed all the textile parts in order to allow protector's wearability.

5.2 Mould

From the Thorax CAD files, an aluminium mould was made. The manufacture of the mould was a very big task due to the shell's reticular structures and the curves presented in the breast area. The mould was around 600X600mm wide and 400mm high, liquid cooled with a hot single point of injection. Due the density of the reticular structures, number 6 (diameter 5 mm) and number 40 (diameter 3 mm), points of extraction were required. All these extractors were automatic. Figure 16 shows the mould.



Fig. 16 – Protector's mould

5.3 Prototypes

As it has been described above, a series of prototypes was manufactured in order to perform validation tests. The rigid shell was coupled with soft breathable fabric. Figures 17 and 18 show the protectors on its definitive aspect.



Fig. 17
Protector's front view



Fig. 18
Protector's side view

From the point of view of the retaining systems, the protector was provided with three adjustable belts, one on the waist line and two other for the shoulders that help also to define the right height of the protector respects the body. Figure 19 shows the reticular structure manufactured on the internal part of the shell in order to increase the shell rigidity.



Fig. 19 . Protector's inner view

6 Ergonomic test

An ergonomic test is crucial to ensure the motorcyclists feel free and comfortable while doing the movements which are necessary to control the motorcycle. These aspects have also an important impact on the active safety as the rider can control the bike and in case avoid dangerous situations.

An ergonomic test was performed, with the aim of knowing the feeling from the real users.

6.1 Results

Table 5 shows the test protocol established for the ergonomic evaluation of the thorax protector. The tester used must be able to do all the movements described in the list without any interference due to the protector. As the thorax protector is a prototype and not yet “CE” certified, the test had to be conducted in static way.

The following conclusions should be extracted:

- In terms of wearability/removal, the thorax protector was easy to put on and off:
- The protector was however not very comfortable to wear. The material is somehow too rigid (robot type) for the female bust/breasts. Unfortunately the choice of using one piece shell and select a rigid material to mould it was guided by the necessity to distribute the impact force in a wider area. This is the most effectiveness way to protect this body region and so it can not be changed. In order to solve this problem, in a future product development, high accuracy should be required in order to select a very soft and comfortable fabric material which should mitigate the discomfort effect created by the rigid shell.
- The most critical aspect of the project was to develop a range of sizes able to fit perfectly the thorax as well as the breast of all women. In fact, as it has been mentioned above, if the protector does not fit perfectly, the woman will experience little feeling of safety, and the protector might even hurt the breasts. Therefore, special attention had to be paid in the development of a complete range of sizes for a future product production.

A comment/conclusion made by the tester, and also by FEMA’s staff, is that it might actually be very difficult to find the right sizes fitting the different female morphologies. While this might not be an issue for a male thorax protector, the female morphology (importance of size/build + bust/cup size) makes it more complex. A small woman can have a very large breast, a tall woman no breast at all, etc.

Tester		Height 164cm; weight 56kg; Size EU 36; Bust 80	
Motorcycle		Not Applicable	
Distance covered (kilometers travelled)		Km - Not Applicable	
Time covered (hours of use - min. 6h)		h - Not Applicable	
Type of route covered (urban roads, extra urban roads, tracks, off-road)		Not Applicable	
Sizes available:		Thorax size 2 (Small - Medium)	
Wearability	Yes	No	Comments
Is it easy to be worn (please describe)?	Yes		Once the user clearly sees how the protector should be used, it can easily be put on and off.
Is it equipped with a set up system (such as suspenders) and adjustable? Is it easy to be used/operated/adjusted?	Yes	No	It is equipped with a set up system but it is difficult to adjust: not only is the size/build of the person important, but also her bust (cup size). For instance, the cup size was far too big and this part of the protector is not adjustable. The protector did move (went up when sitting; can easily move on the sides in case of shock)
Impediment/interference with normal ride (are some movements limited? Does it adversely affect normal riding);	Yes		If the wearer does not select the proper size, the protector becomes uncomfortable on the sides (arms touching the sides of the protective cups of the protector)
Position of the protective area (Does it lie precisely on the thorax?);	Yes		If well adjusted, no movement
Is the protector bulky/cumbersome to wear?		No	
Comfort			
Is the protector comfortable (is it flexible, is the foam rubber absorbent)?		No	Not very comfortable on the breasts and on the sides (rigid)
Does it prevent from breathing properly?		No	
Is it designed also taking into account female's morphology?	Yes	No	- Might be difficult to find proper sizes fitting all (need to take into account size + cup) - Robot-like design
Can it be integrated into the already existing jacket?		No	The protector tested can't be integrated in a jacket, it can be wear under it. The possibility to integrate it in a garment has to be taken into account by the manufacturer as this configuration can help the protector's diffusion
Is it comfortable and therefore be used in every single riding experience as well as on every kind of motorbikes (such as standard/naked, Multi-purpose, Touring, Sport-touring, Super-sport, off-roads)?		No	It is difficult to say within the range of the static test. The protector will probably suit standart/naked, Multi-purpose, Touring (upright position) but might be uncomfortable on supersport and chopper. The protector might go up, as well as hurt on the sides (arms) after a certain time.
Is it comfortable after prolonged riding (e.g. 6 hours or more?)			Not Applicable
Does it provide enough ventilation?			Not Applicable
Safety			
Does it give the user a certain degree of "safety" feeling [please indicate on a scale from 1 (not reassuring) to 5 very reassuring]	2		If the protector does not fit perfectly with the bust, it can move during an impact. This is very critical and important aspect to be considered
Removal			
Is it easy to be removed/taken off?	Yes		But need to open the adjusting parts on the sides
PRO		AGAINST	
- Relatively easy to put on/off		<ul style="list-style-type: none"> - Not very comfortable on the bust (rigid – robot type) - Difficult to find an appropriate size; - Little feeling of safety (if there is an inappropriate fit) in the case of inappropriate fit. - Protect thorax, but might hurt breasts in case of inappropriate fitting. - Additional piece of equipment 	

Tab. 5: Test protocol for the ergonomic test

7 Impact test

The validation tests were carried out with a Female Hybrid III Dummy with the purpose to define the protection level provided by the new female thorax protector. Impacts were carried out with and without the protector. The thorax compression and sternum accelerations in the frontal impact were measured and the peak 'Viscous response VC_{MAX} ' was calculated. No absolute limit has been set for measurements with the following evaluation criterion 'the highest possible difference between with and without protector should be reached'.

7.1 Impact test configuration

In order to perform the tests, the female instrumented HYBRID III test dummy was seated in a plane and an octofilar pendulum guided a cylinder probe with the impactor mounted on one side, to hit the female dummy in the sternum area. Impactor velocity was recorded immediately before the impact. Figure 20 and 21 show the female HYBRID III Dummy in test position. In this case, a kerbstone impactor has been mounted on the cylinder probe. Figure 22 and 23 show the flat impactor.

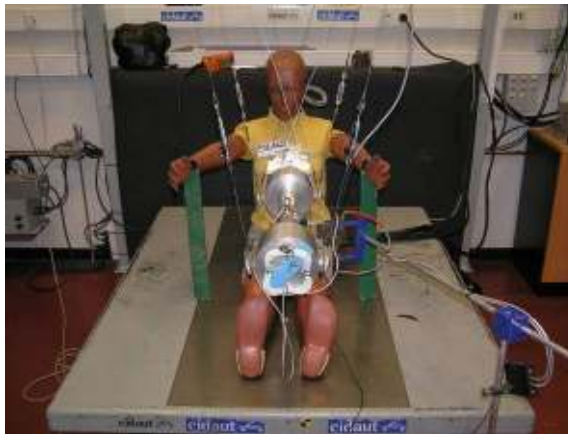


Fig. 20

Dummy kerbstone impactor front view



Fig. 21

Dummy Kerbstone impactor lateral view



Fig. 22

Dummy cylindrical impactor front view



Fig. 23

Dummy cylindrical impactor lateral view

Figure 24 and 25, show the female dummy with the protector and kerbstone impactor.



Fig. 24

Dummy with protector front view



Fig. 25

Dummy with protector lateral view

7.2 Impact test results

In Table 7, the matrix of tests is reported and peak recorded values are showed. Taking into account only these parameters, it can be easily observed that comparing data on the 'Chest compression', 'Viscous Criteria' recorded in the test (with and without protector) for each type of test set, there is a reduction on the recorded level in case of use of the protector.

Test N°	DATE	IMPACTOR	PROTECTIVE CLOTHING	TARGET PROBE VELOCITY (m/s)	MESURED PROBE VELOCITY (m/s)	Chest_S (mm)	Chest VC (m/s)	Sternum_ax (g)
E08-4427	15/12/2008	KERB	NO	5,00	4,79	41,2	0,57	-116,10
E08-4428	15/12/2008	KERB	NO	6,50	6,64	58,3	1,14	-306,70
E08-4429	15/12/2008	FLAT	NO	5,00	4,88	38,9	0,51	-119,00
E08-4430	15/12/2008	FLAT	NO	6,50	6,64	56,4	1,01	-216,10
E08-4431	15/12/2008	FLAT	YES	5,00	4,86	30,4	0,43	-67,10
E08-4432	15/12/2008	FLAT	YES	6,50	6,56	46,0	0,91	-170,70
E08-4433	15/12/2008	KERB	YES	5,00	4,86	35,1	0,43	-62,30
E08-4434	15/12/2008	KERB	YES	6,50	6,60	51,3	0,96	-119,70

Tab. 7: Results impact test

In figure 26, the chest compression is shown at 5 m/s recorded in the dummy 'with and without protector' using 'flat and kerbstone impactor'. A good improvement, in terms of safety, on the values has been recorded if the dummy wore a protector. Figure 27 shows the viscous criteria data in the same way. Still an important benefit on injuries reduction has been recorded:

'More effectiveness has been demonstrated by the protector, in case of sharp impact opponent'.

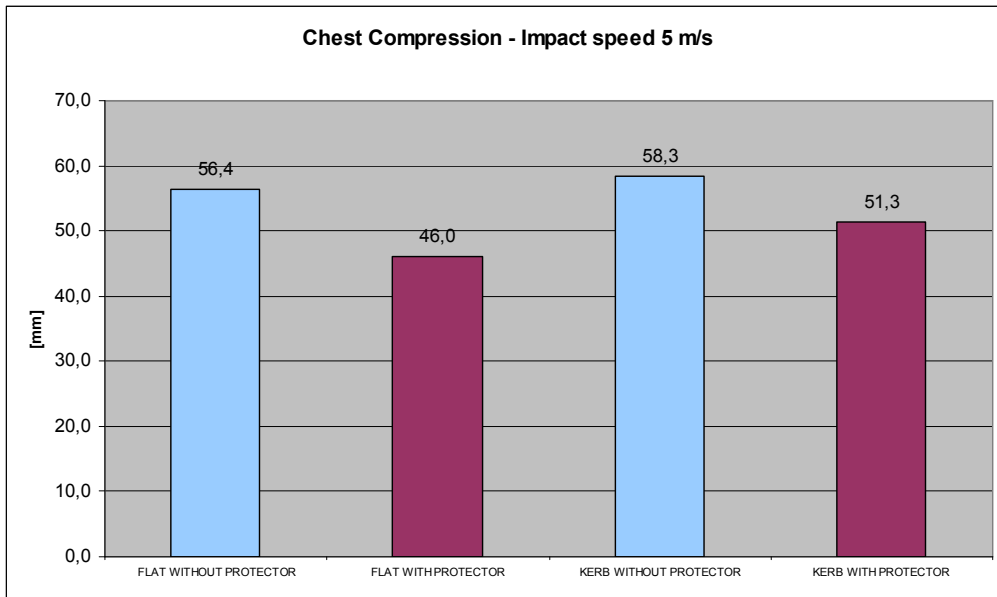


Fig. 26 – Chest compression at 5m/s

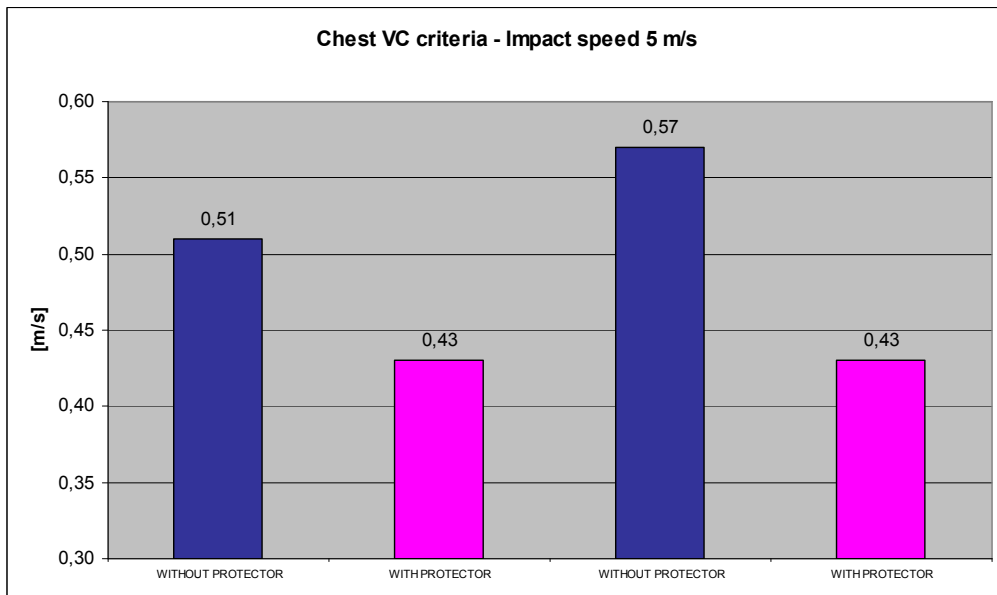


Fig. 27 – VC Criteria at 5 m/s

With reference to the acceleration, the peaks recorded conduct to the same conclusions: **‘Wear the protector reduces the level of sternum acceleration, particularly with kerbstone impactor where an acceleration reduction of around 43 – 46% is achieved’.**

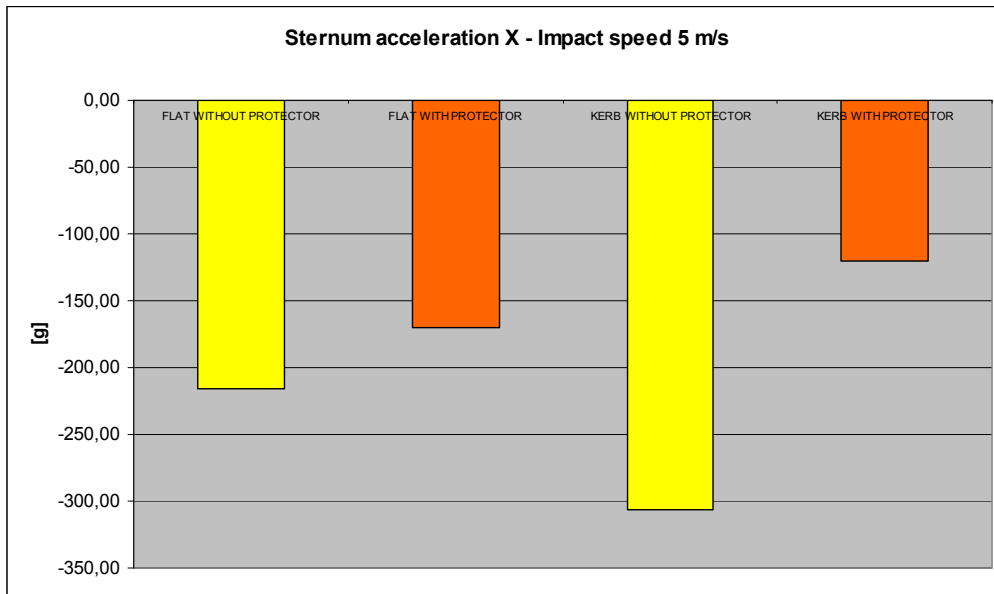


Fig. 28 – Acceleration peak at 5m/s

Figure 29 and 30 compare respectively the ‘Chest compression’ and the ‘Viscous criteria’ with different impactor shape at 6,5 m/s. Still data confirm that:
‘Wear the protector helps to reduce the risk to sustain injuries to the thorax area’.

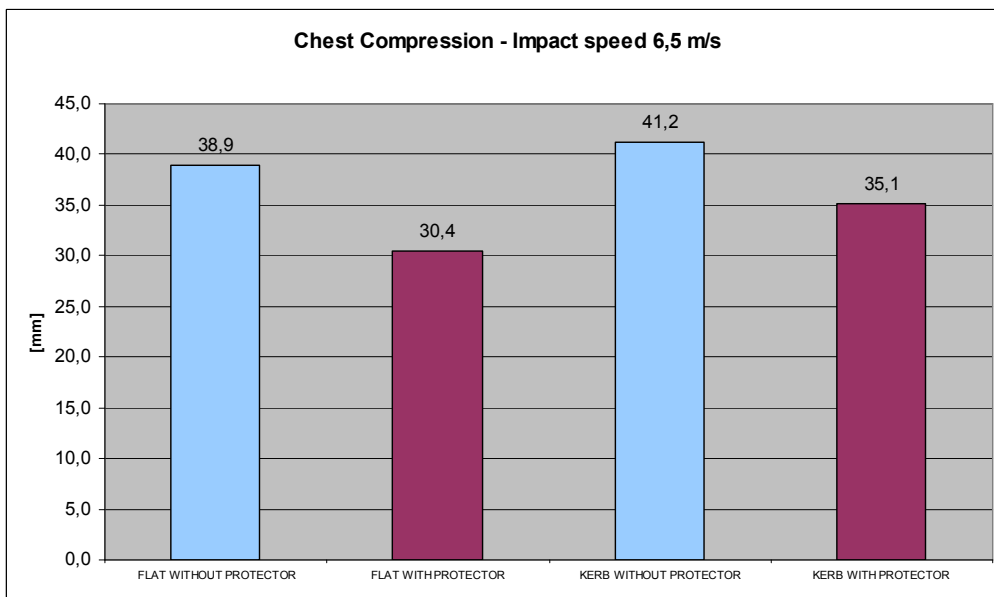


Fig. 29 Chest compression at 6,5m/s

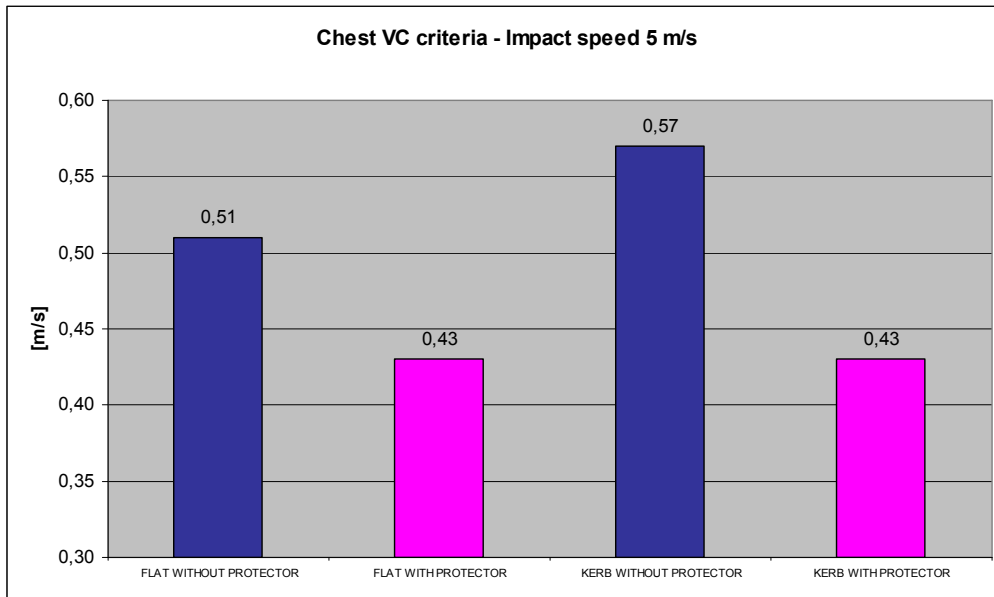


Fig. 30 – VC Criteria at 6,5 m/s

Figure 31 shows the Sternum acceleration peaks with an impact velocity of 6,5 m/s. Independently from the impactor' shape, **the protector reduce the accelerations level.**

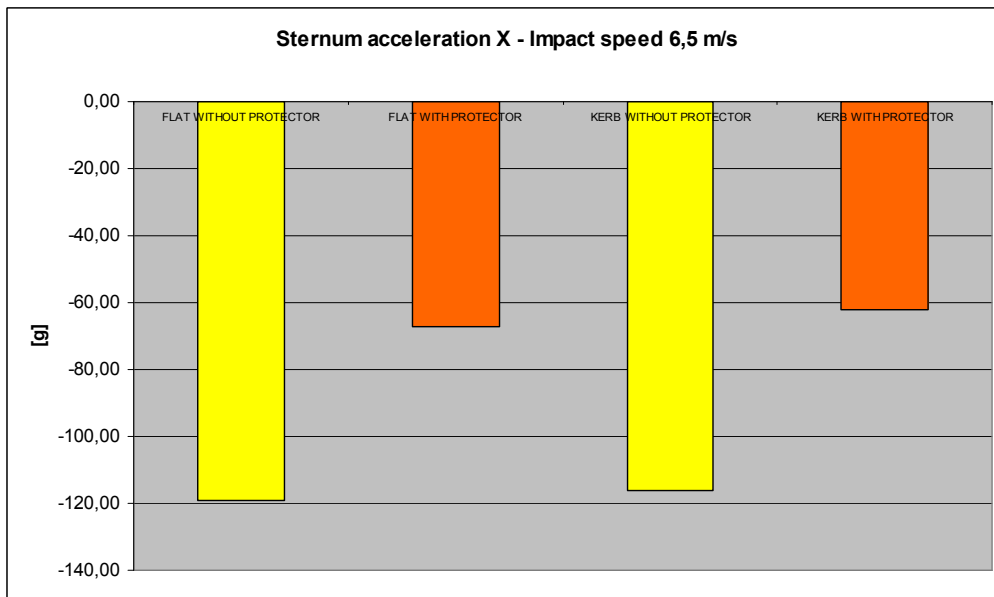


Fig. 31– Acceleration peak at 6,5m/s

8 CONCLUSIONS

From the simulation results and from the real impact tests done over the female thorax protector developed in APROSYS, it is shown that the female thorax protector improves the level of safety of a motorcyclist protecting the thoracic area.

This study confirms the outcome of the male thorax protector development, in particular that the rule of the spread of the force on the human protection is very important. This protective device can also play an important safety rule on other sports, like for instance skiing, cycling, fencing and in general where an impact on this critic area can produce injuries. Ergonomic tests though demonstrate that the protector's fitting is critic from the point of view of the wearability and of the protection as there should be in case of not right size a out of placement of the protector during an accidents. This aspect should be taken into account when the protector is industrialised and put on the market.