PROJECT FINAL REPORT

Grant Agreement N° 218259

Acronym: **RAPTOR**

Project title:

Rapid deployable, gas generator assisted inflatable mobile security kits for ballistic protection of European civilians against crime and terrorist attacks

Funding Scheme: SECURITY, Collaborative Project

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RAPTOR is co-funded by the European Commission, REA - Research Executive Agency

Project Coordinator: Dr. Jochen Neutz
Fraunhofer-Institut für Chemische Technologie ICT
Joseph-von-Fraunhofer-Str. 7
76327 Pfinztal, Germany
Tel +49 (0)721 4640 314
jochen.neutz@ict.fraunhofer.de

http://www.raptor-project.eu/

4.1 Final publishable summary report

4.1.1 Executive Summary

Raptor was a collaborative project funded by the European Commission. The project involved 5 partners from 3 European countries, and had a total funding budget of around 2 million €. It was carried out over a period of 48 months from January 2010 to December 2013.

The **aim** of the project was the development of innovative and integrated, mobile and rapid deployable, gas generator assisted inflatable structures for the ballistic protection of European civilians against security scenarios, such as crime and terroristic attacks. Tailored solutions have been developed based on the scope (e.g. the prevention of, or the response to security scenarios by European security forces, such as protection of special persons or general security of events), including inflatable ballistic structures for the protection of:

- Individuals
- Groups of 2 – 5 persons (carried in trolley, back pack, etc.)
- General security of events (transported in car boot, by pick-up, truck, etc.)

The **concept** was based on the fact, that not only heavy weight metal or light weight composites armouring, but also loose layers of aramid fibre fabrics can stop a bullet. The application area of the proposed protection device is strictly for civil application. Scenarios of European security forces contain threats from hand held guns or improvised explosive devices (IED), which have much lower ballistic performance than military equipment e.g. machine gun or mortar grenade. However, a fast response should enable a rapid deployment which should by the inflation of the gases from gas generator as used in airbags for cars.

The investigations included an outline of the threat scenarios which identified a list of situations where such a ballistic protection kit was urgently needed for improving security of individuals ending up with specifications. Predominantly, 2-3 persons have to be protected against the attack by hand guns and hand grenade and enable a counter attack from this safe area.

The ballistic protection was established by a multitude of textiles layers made out of aramide fibres. The fibre weaving applying various methods, treatment by lamination and their combination was optimized by measuring the energy reduction of various layers to achieve best resistance against the impact of the selected ammunition. The assumed effect of loose hanging fibres was disproved for this application ending with compacted textile layers. For the inflation of the ballistic package new approaches for the gas generator formulation and manufacturing techniques were needed. It combined pyrotechnic hot gas production with ablative cooling to provide cool gases for safely deploying the folded protecting shield stabilized by inflated tubular structure. Finally, all components were combined in a demonstrator which was tested on a shooting range. The results showed that the ballistic shield deployed in a short time and withstood the demanded impact of bullets, fragments and blasts according to the specifications.

The exploitation considers the innovative results of the developed components of the demonstrator, which will be individually used. The basic project concept was concluded, has been summarized on the demonstrator and its functionality has been successfully tested. The demonstrator is planned to be further developed to be a protection kit available for future law enforcement by security forces.

4.1.2 Summary description of project context and objectives

Research on security is a main issue in Europe to improve measures for protection of its inhabitants against manmade disasters or those induced by natural events. Specifically, terrorism has strongly threatened people at all scales of dimensions in the recent years. The context of the project concerns the protection of individuals or small groups against direct attack by weapons.

The overall objective of the project was the development of innovative and integrated, mobile and rapid deployable, gas generator assisted inflatable structures for the ballistic protection of European civilians against security scenarios, such as crime and terroristic attacks. Depending on the scope tailored solutions have been developed, including inflatable ballistic structures for the protection of:

- Individuals
- Groups of 2 – 5 persons (carried in trolley, back pack, etc.)
- General security of events (transported in car boot, by pick up truck, etc.)

The entire spectrum of personal protection gives rise to a large number of situations and sequences of actions which the relevant task forces of the BKA deem to be critical. A clear distinction has been drawn between situations of daily importance and special scenarios like public appointments, pre-election campaigns, state visits or conferences, as well as travel movements of the protected person both at home and abroad. Essentially, personal protection is influenced drastically and rendered more difficult by the following factors:

- Lack of material protection on the way from one secure area to another by foot
- Entry / exit of e.g. armoured vehicles
- Event locations (indoors and outdoors), where a huge audience is present and not every member of the audience can be completely inspected
- Spontaneous route changes of the protected person
- Speaker’s desks in the immediate vicinity of uncontrolled spectator masses
- Strict protocol regulations and / or limited resources
- Lack of suitable resources and partly different security standards for personal protection measures abroad

For this potential risks a solution has to be developed with respect to:

- Providing a shelter in case of an attack
- Attacking the aggressor from a covered position
- Ensuring safe evacuation of the protected person

Based on the listed scenarios, specifications for the development of the security kit were defined and criteria for the demonstration of their effective performance derived. The most flexible and realistic appearance of the security kit is a trolley-like housing.

The demands of the security kit were based on the requirements of ballistic protective vest level one. Blast-impeding properties were required to minimize the effects of a fragmentation hand grenade, i.e. the side of the security kit facing the blast must neither be penetrated by primary nor secondary fragments that could endanger any person behind the wall. The demonstrator proved the protecting performance of the shelter. Predominantly, 2-3 persons can to be protected against the attack by hand guns and hand grenade and enable a counter attack from this safe area.

Potential security scenarios included mobile security kits, such as:

- Briefcase/backpack for 1 person,
- trolley/suitcase for 1-5 persons (see Figure 1),

- tent (e.g. on pick-up truck or in a soccer stadium under the floor) for bigger crowds (see Figure 2)
- "red carpet" tunnels
- inflatable fences, and
- inflatable curtains

Figure 1: Scenario "trolley/suitcase"

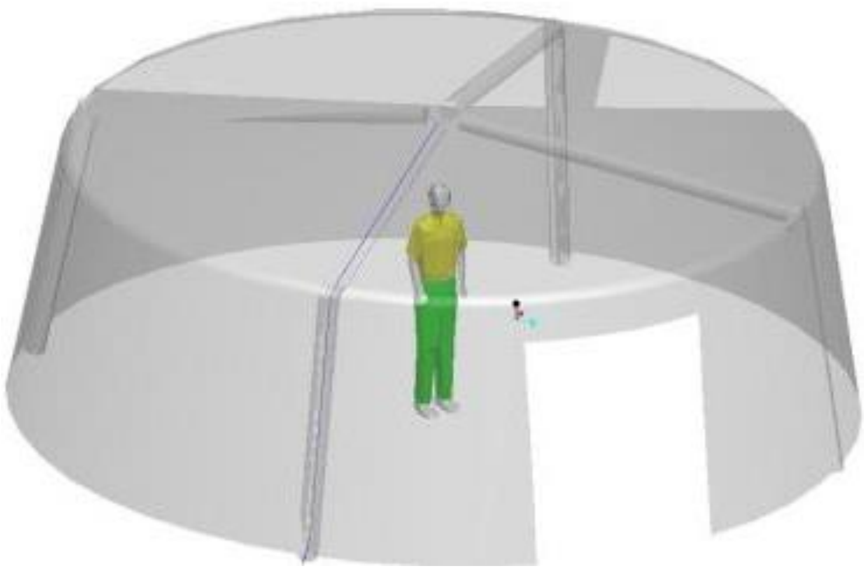


Figure 2: Scenario "pick-up truck based tent"

The application area of the proposed protection device is strictly for civil application. Scenarios of European security forces contain threats from hand held guns or improvised explosive devices (IED), which have much lower ballistic performance than military equipment e.g. machine gun or mortar grenade.

The **objectives** of the project were two fold – the **development** of the **high performance flexible ballistic textile systems** and the **gas generation for inflation a stable structure to deploy the protection unit in short time**.

The objectives of the ballistic textile system development included:

- selection of high performance textile yarns to characterize their strengths and drawbacks according to the specified scenarios and ballistic calibres
- development of fabric weaving / coating technology to end up with a high performance fabric to enable high ballistic protection in combination with a light weight structure to realize fast deployment times like in airbag systems
- development and design of the ballistic protection structure concerning the requirements, e.g. light weight by combination of different fabrics and special coatings, number of fabric layers etc., according to the selected ballistic calibres
- development of gas tight support structures of tube like form to enable on the one hand fast deployment and on the other hand long holding time (> 3 hours) of the structure
- design and testing of different folding pattern concerning reliable structure deployment and small package volume as in airbag systems

Pyrotechnic gas generator compositions used in airbag systems provide a huge amount of non-toxic gas within milliseconds. The solid compositions consist of a fuel and an oxidizer and are usually pressed in pellet shape. The gas is generated by a combustion reaction.

The objectives of the gas generator development were:

- selection of basic components of the pyrotechnic composition according to high gas yield above 400 dm^3 per kg composition, non-toxic gas composition and low combustion temperature (below 2000 °C)
- processing and shaping of compositions according to necessary gas production rate and safety parameters
- characterization of the combustion behaviour under pressure and the combustion temperature to select compositions with high combustion rates and low temperature
- design and development of the pellet shape to provide adjusted gas production enabling fast and reliable deployment of the fabric structure
- design and development of cooling agents reducing the gas temperature down to ambient conditions
- development and testing of the pyrotechnic gas generator combustion chamber in combination with the cooling agent to realize reaction times of the total system below 1 second

The development of both basic systems was performed in parallel based on the elaborated specifications.

Objectives for protection were based on results of current approaches of individuals against fire of hand guns (soft-ballistics) which use clothing like helmets, vests or movable bullet-proof shields. There have to be investigated effective ballistic fibres show high Young's modulus, tenacity and elongation at break consist of p-Aramides (Twaron®, Kevlar®) or UMHWPE (Dyneema®, Spectra®), an ultra-high molecular weight polyethylene. In some cases a special sort of fibreglass, so called S2-Glass is used. Some typical products for military or automotive industry personal protection are laminates (in most cases plates or soft-shaped preforms) to be taken into account consisting of ballistic fabrics and polymeric binders or multiple-ply packs with several layers of textiles stitched together. Standard textiles used for anti-ballistic applications were fabrics: Twaron®, for example, offers a variety of p-aramide fabrics with different weaves like plain, basket or twill.

In regard to official events, where outstanding persons have to be protected the concept of the mobile security kit follows the idea that a rapidly deployable unit leads to a surprising moment to the offender and that for a short period of time the single person or group to protect is hidden and counter measures by the security forces can come into action. Objective of the deployable kit was to complete the protection of persons that are wearing protective clothing because of the fact that strikes on bullet-proof vests can cause serious injuries to the wearer like blunt traumata. In opposition to mobile protection kits like shields, inflatable tents or tunnels can protect persons from bullets coming from more than one direction and the position of the victim still remains invisible for the shooter. Last but not least more than one person can be protected from gun shots. Because of the possibility to deploy curtain-like structures with several layers of loose anti-ballistic fabrics hanging down in defined distances, a so called towel-effect has been verified

With the additional specification of foldability - especially the ballistic textiles - havebeen constructed (stile of weave) and coated in that way that the single layers do not stick together and are resistant to creasing tendency. A second progress in textile modification beyond the state of the art was the development of textiles that meet the requirements of airbag application and that are stiff and airtight enough to maintain the specified shape desired time scales.

Finally, the gas generator for rapid inflation had to deploy the frame of the ballistic protecting device within its selected time scale. The security kit demonstrator was tested close to real conditions.

4.1.3 Description of main S & T results/foregrounds

Research on security in Europe is a follow-up manmade disaster or those induced by natural events. It has to improved measures for protection of European inhabitants by innovative approaches. Terrorisms evolved as threat strongly endangering people at all scales of dimensions in the past years. The project contributes to the need of protection of individuals or small groups against direct attack with weapons in exposed scenarios. It should develop a security kit which enabled a mobile and rapid deployable structure of a ballistic protection shield for European civilians against threat of a direct attack by weapons.

4.1.3.1 Scenarios and derived specification for the security kit

The entire spectrum of personal protection gives rise to a large number of situations and sequences of actions which the relevant task forces of the BKA deem to be critical. A clear distinction between situations of daily importance and special scenarios like public appointments, pre-election campaigns, state visits or conferences, as well as travel movements of the protected person both at home and abroad have been considered.

To close lacks of security, firstly a trolley-like solution with a ballistic protection and fast deployment was considered to be a potent possibility as an additional personal security resource. With aid of such a ballistic protection device, the possibilities to provide a short-time shelter and to evacuate the protected person would be largely enhanced. Furthermore, the aggressor can be fought off.

The device developed in the RAPTOR project has the potential to come to use in a multitude of situations to prevent terror and crime against European citizens and to increase their safety in many different threat scenarios.

Based on the above listed scenarios, specifications for the development of the security kit are defined and criteria for the demonstration of their effective performance derived. The most flexible and realistic appearance of the security kit is a trolley-like housing. Therefore, the needed technical requirements which were derived analysing the treats are listed below:

- Appearance: commercial travel trolley, divert attention
- Transportable on airlines, motor vehicles and ocean liners
- Total weight including ballistic package, support structure, gas generators and housing: maximum 15 kg
- Manual triggering (one-handed operation)
- Remote triggering with a max. reach of up to 10m
- Ballistic protection in accordance to specifications
- Protective space should be semi-circular
- Protection kit height: 170 cm, width: 200 cm
- Provides shelter for 2 – 3 persons
- Durable, fixed position after unfolding
- Possibility of shifting the deployed unit by carrying handles
- Minimum time in fixed position: 30 seconds
- Security package unfolds with the speed of an airbag
- Insensitive to extreme temperature fluctuations (-35°C to +85°C) and shocks
- Minimized danger during unfolding (brute force, burning, noise)

The guideline has to be interpreted flexibly. For instance, the set-up of ballistic measurements complying with the directives leads to higher bullet velocities compared to ballistic measurements performed with handguns. For the project certain deviations should be accepted concerning the bullet velocities defined by the VPAM guideline. Special emphasis will be put on the kinetic Energy on target. This energy should be as many as 500 Joule (see above listed ballistic requirements). This value can be achieved with handguns as well. Blast resistance should include stable protection against a hand grenade

4.1.3.2 Ballistic protection textiles

The main components of the protection kit are the ballistic protection textiles. Its development required the research, selection and modification of applicable fibres, yarns, fabric designs and fabric coatings for ballistic applications. A primary question in this context was about the protection level that best meets the threat scenario requirements.

Another important question was about which synthetic fibres could be applicable for ballistic protection. In several literature and product researches it was found that ideal antiballistic fibers for composite purpose have following profile (Cunniff[1], Auerbach, Vetter and Sikkema):

- high tensile and compressive modulus
- high tensile and compressive strength (in composite form),
- high damage tolerance,
- low specific weight,
- good adhesion to matrix materials (for structural composites only) and
- good temperature resistance.

As high degree of molecular orientation results in high tensile modulus and strengths but also in a loss of these properties transverse to the fibre axis bending or compression loading of high oriented fibres should be avoided and therefore they should be pulled parallel to their axis.

The research on applicable fibres and yarns for anti-ballistic purpose started with a general view of those types of fibres that are used in composites, most commercially available and, in terms of ballistic protection, interesting.

Following fibres E and S-Glass, Wire/Chain Mail, Wire/E-Glass, Aramid (Twaron/Kevlar), Aramid Auxetic, Aramid with wool, Carbon, UHMWPE (Dyneema/Spectra), PBO (Zylon) Poly(p-phenylen-2,6-benzobisoxazol), PIPD(M5 Poly {diimidazo pyridinylene (dihydroxy) phenylene}) for antiballistic purposes have been tested and established or are about to come into use. Some are listed in Table 1:

Table 1: Ballistic fibres.

Short name	Chemical formula	Product	Producer
p-Aramid	Poly(p-phenylenterephthalamide)	Kevlar®	DuPont
		Twaron®	Teijin Twaron
UHMWPE	High crystallin, ultradrawn Polyethylene fibre – UHMW-PE (Ultra High-Molecular-Weight polyehtylene Polyethylen)	Dyneema®	DSM
		Spectra®	Honeywell
PBO	Poly(p-phenylen-2,6-benzobisoxazol)	Zylon®	Toyobo
PIPD	poly{diimidazo pyridinylene (dihydroxy) phenylene}	M5®	Magellan Inc. (Today: DuPont; former: Akzo Nobel)
S-glass fibre		S-2 Glass®	S-2 Glass, from AGY (Aiken, S.C.)

[1] Cunniff, P.M. & Auerbach M.A. . High performance “M5” fiber for ballistics / structural composites Paper A0-04 at the 23rd Army Science Conference; Dezember 2002. WWW: http://web.mit.edu/course/3/3.91/OldFiles/www/slides/cunniff.pdf; 21-07-2010

There were experiments performed with all types listed in table 2 but aramid fibres are described in more detail:

Para-Aramid Fibres (Kevlar®, Twaron®, Technora ®)

Para-Aramid fibres are widely used in ballistic protection applications because of high properties and low density the values the sound velocities last from ca. 600 to 680 m/s. On the market of para-aramid fibres exist two leading companies: DuPont (Kevlar®) and Teijin (Twaron®). A further p-aramid fibre of Teijin Technora® is not used for antiballistic applications.The fibres are made by polymerising paraphenylene diamine and terephthaloyl dichloride in solvent. After the removal of the solvent a coagulated polymer is left. This polymer is called polyparaphenylene terephthalamide. In the next step the polymer is re-dissolved in sulphuric acid and spun a fibre into water. The process ends by stretching the fibres to align the molecules and by neutralizing the acid.

Properties of para-aramid fibre

Chain molecules longitudinally orientated with paracrystalline structure and covalent bonds give

- High tensile strength and modulus
- High thermal stability and glass transition temp. (Tg)
- High dimensional stability (low creep)
- Non-brittle and high impact resistance
- Good abrasion resistance
- High chemical resistance except strong mineral acids
- Low dielectric constant
- Poor resistance to UV radiation
- Poor compressive resistance due to defibrillation
- Absorbs up to 4,5 (5) % moisture by weight

For initial tests two different p-aramid yarns have been chosen:

- TWARON Type 2200; 405 dtex
- TWARON Type 1000; 3360 dtex

In the fibre selection process Mehler UK[2] stated that aramid fibre, either from DuPont or Teijin would be better than high molecular weight polyethylene because of the poor temperature resistance of Dyneema, limited to a maximum of 70ºC. Of the fibres from DuPont, Kevlar 29 would be his first choice and this is generally cheaper than Kevlar 49 although good results had also been achieved with both fibre types. The Twaron CT Microfilament yarn from Teijin introduced a few years ago was expected to give significant ballistic improvements however, this did not turn out to be the case and there is little to choose between the products from DuPont and Teijin.

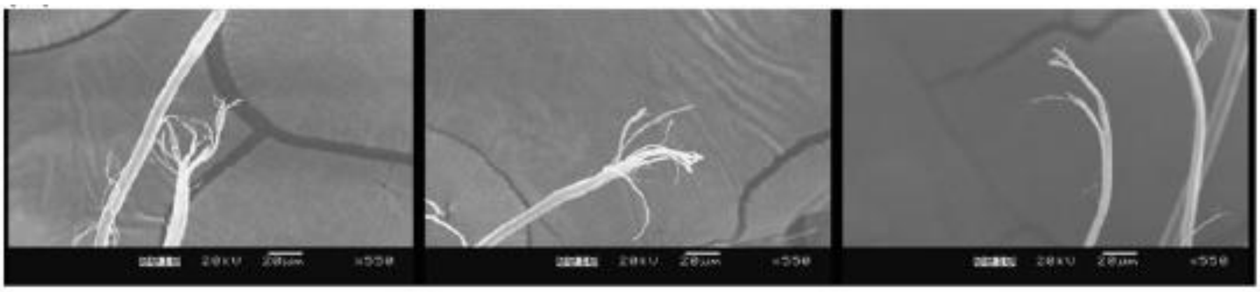


Figure 3: Fibrillation of aramid fibres

<u>Forms of fibres and yarns</u>

Beside the question about what materials were used for fibres and further for fabrics one should give a short overview about different fibre forms and the use these forms.

High performance fibres are generally used in one of four forms:

- Staple fibre, 1 to 15cm long, usually spun into yarn
- Chopped fibre, cut to short,specific length, often added to matrix
- Monofilament , a single, large, continuous filament
- Multifilament, extruded continuously with many filaments

Fibres were processed for use into one of four forms:

- Yarn or roving for further use
- Non-woven fabrics
- Woven fabric
- Knitted fabric

<u>Yarn or roving for further use</u>

Multifilament yarns are plied or twisted together and are used e.g. for sewing threads or ropes. Rovings are ".long and narrow bundles of fibres.." (http://en.wikipedia.org), obtained either directly in primary manufacturing or by combining multiple threads together without any twist. They are used for filament winding processes for pipes, pressure cylinders or to make unidirectional reinforcements, either as fibre or woven fabrics.

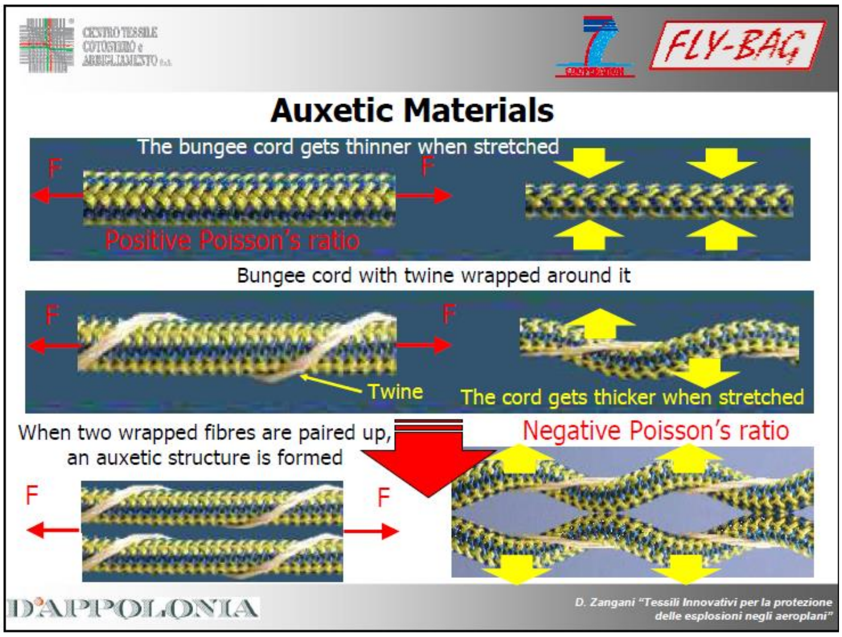
[2] These informations are provided by Derek Smith, UK Sales manager of Mehler GmbH, manufacturers of bullet-proof vests under the name Vario Systems in Germany, web-site at http://www.m-v-s.de/de/index.php

Yarns for anti-ballistic applications

An enhancement of the yarn strength can be achieved by increasing the twist .Yarns for anti-ballistic fabrics are slightly twisted because they consist of endless filaments and not of staple fibres and only have to be hold together by twisting.

Yarns for blast resistance - Auxetic Yarns

The use of auxetic yarns is being considered. Fabric woven with this yarn type was tested as part of the EU-funded **>>FlyBag project<<**[3] . This was a blast and fragmentation retaining device to protect aircraft from explosions in the cargo compartment. See below slides for explanation of the action of this type of yarn.



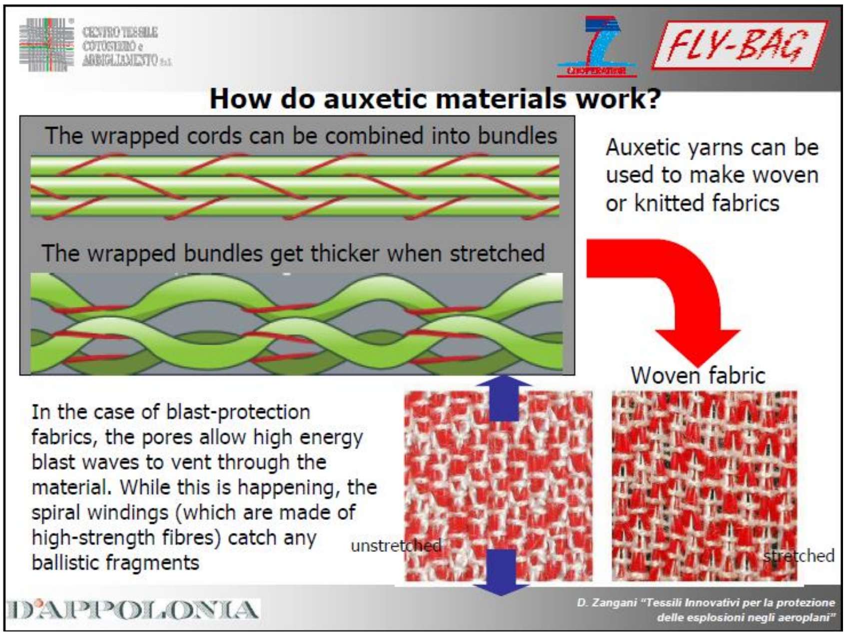


Figure 4: Auxetic yarns

[3] Zangani, D. (2010). Tessili Innovativi per la protezione delle esplosioni negli aeroplani. Centro Tessile Cotoniero e Abbigliamento S.p.A., WWW: http://www.centrocot.it/download/pub/ctc_3/DonatoZangani%20D%27Appolonia.pdf (2011-07-12)

Weaving has a strong impact on the ballistic performance. It involved the following types with the listed results:

- Weaving of auxetic yarn
  - Liaising with STFI for information on Fly-Bag project, blast control
  - Sourcing auxetic yarn from Dr. Hook of Auxetix
  - Setting up loom to weave auxetic yarns across a wire/glass warp
- Weaving and supplying mock leno fabric samples to test “chain-mail” effect
  - Novel fabric to simulate effect of chain mail in ballistic tests
  - Principle of “anisotropic” fabric could be developed further
- Weaving samples of fabric with Zylon HM and Dyneema SK65and SK90 weft yarn
  - Sourcing samples of the test yarns
  - Setting up loom to weave these high performance yarns not previously attempted
- Weaving and supplying 1,000m of 05471/170cm for manufacture of final demonstrators
  - Sourcing yarn and organising warp manufacture
  - Overcoming problems experienced weaving Panama construction at 170cm width

For ballistic tests there were panels woven supplied to Fraunhofer ICT:

- 50 x 2m panels 05471 woven at Sherborne
- 22 x 2m panels Dyneema SK 65 weft
- 22 x 2m panels Dyneema SK 90 weft
- 22 x 2m panels Zylon HM weft
- Approximately 150m warp yarn left on beam for weaving more of above fabrics or additional leno samples depending on results of ballistic tests.

Mock Leno **Plain Weave** **Panama Weave**

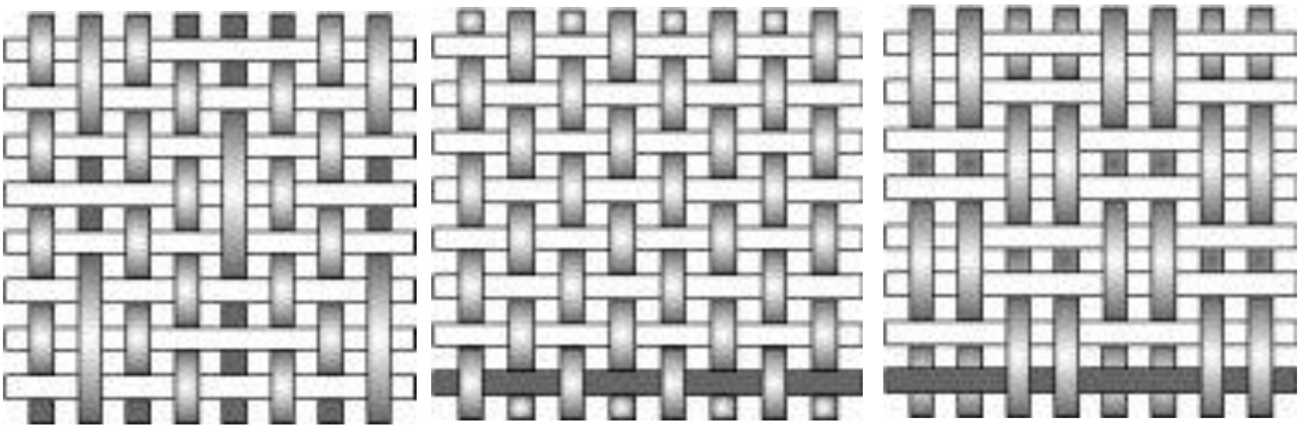


Figure 5: Weaving types which were investigated

Figure 6: Weaving machine- warp at rear of loom and the innovative Leno-locking mechanism solution

For the final demonstrator the following criteria were found using also the results of the next chapter:

- Fabric Type: Style 05471, aramid 1680dTex warp and weft, ends x picks 12.6 x 12.6/cm, Panama weave, weight 410g/m2
- Fabric Width: 170cm wide to remove requirement for seams in ballistic shield but giving sufficient height for protection
- Production Quantity: 1,000 linear metres woven will allow production of 10 to 12 demonstrators, each demonstrator requiring approximately 85lin.metres

“Panama” weave similar to “plain” weave but has two warp threads weaving in parallel together and two weft threads to be inserted side by side in each opening of warp threads.
Owing to increased width of 170cm, problems caused by first inserted thread being dragged out of position by “suction” of reed moving rapidly backwards since warp threads are held open to allow second weft thread to be inserted. Not a problem at narrower 107cm width
Problem overcome by use of leno-locking mechanism mounted in centre of loom.
Leno threads are crossed for each weft thread inserted thereby locking the centre of the pick in place. This prevents excessive movement of the first inserted pick as the reed returns to back position. First and second weft thread is held in place by the warp threads crossing past each other as the reed moves forward to push them into place.

- Fabric woven from Twaron aramid yarn gives the optimum combination of ballistic performance vs. cost and weight
- Ballistic fabric performance improvement by coating not worth increased weight penalty
- Optimum fabric design achieved with style 05471 to give flexibility with ballistic performance
- Weaving of 05471 at 170cm allowed ease of manufacture of final demonstrator by eliminating seams
- 170cm width sufficient for height requirements of demonstrator
- Elimination of seams allows easier packing and deployment of the RAPTOR shield

Coatings

It has been proposed that by coating the fabric, the energy can be transferred into adjacent threads to those which have been immediately impacted through the coating. The coating acts as a barrier to prevent the freedom of thread movement by locking threads together so that the kinetic energy is spread over a larger area than just that surrounding the point of impact.

The primary requirements for the coating to act as an energy dissipater are that the material selected should have:

1. High Ultimate Tensile Strength (UTS) High tensile strength should reduce the tendency for the coating to rupture between adjacent threads which would prevent the energy being transferred from thread to thread.
2. Excellent elasticity. The elongation of the coating compound at the point of break should be as high to allow the energy to be dissipated over as large an area as possible

Technical data sheets for both of these coating compounds are also attached to this report. A summary table of the significant technical data is shown below

Table 2: Coatings

Compound	Ultimate Tensile Strength N/mm²	Elongation at Break %
Polyurethane SU-10-108	43.6	720
Polyurethane SU-13-501	61.2	800
Silicone Elastosil 6250	5.0	350
Silicone Elastosil 3003/20	8.5	870

Laboratory testing at PD-ITS was carried out to determine the following characteristics of the coated fabric samples compared with the same tests on the uncoated 05471 material
1. Tensile strength warp and weft, kN/50mm. Test method DIN/ISO 4606
2. Coating add-on weight, g/m². Test method DIN 53-854/12127
3. Trapezoidal tear strength, kN. Test method ASTM 5733
4. Porosity at 2mbar pressure, litres/dm²/minute. Using Shirley porosity meter.

Table 3: Test Results Summary

Sample	Wt g/m²	Add-on g/m²	Trap Tear kN Warp	Weft	T/S kN Warp	Weft	Droop cm Warp	Weft	Porosity l/dm²/min
Loomstate	400.1		2.50	2.20	5.61	5.59	6.4	6.2	84.0
PU 108 1S	422.0	21.9	2.98	1.65	11.35	9.36	7.4	7.1	22.6
PU 108 2S	460.0	59.9	1.51	1.52	11.29	8.66	9.5+	9.5+	24.0
Sil 6250 1S	469.2	69.1	2.50	2.60	8.24	6.05	7.0	6.6	26.4
Sil 6250 2S	539.4	139.3	3.37	3.70	7.60	6.74	7.3	6.4	11.8
Sil 3003 1S	458.9	58.8	2.01	2.20	6.36	6.12	6.4	6.3	23.4
Sil 3003 2S	514.7	114.6	2.03	4.01	5.35	6.18	8.0	6.0	7.6

From the results it can be seen that:

- The add-on for silicone coating was much higher than for PU coating
- Coating the fabric increased the stiffness
- The fabric stiffness increase was much higher for PU than for either silicone
- The stiffer coating gave increased tensile strength values
- The stiffest fabric had the lowest tear resistance
- The fabric porosity decreased when coated
- The higher coat weights of the silicones gave the greatest porosity decrease

Stiffness – measured using droop angle method. Test method ASTM 5732.

Ballistic test series were performed to investigate the ballistic properties of coated fibre fabrics. Ballistic testing was performed by firing of a handgun with different types of ammunition on the fibre fabric. The layers were tested in different configurations. In the first configuration the fibre fabric is loosely hanging. In the second configuration the layers are fixed on top and on bottom on a wooden frame.

- Silicone type B, trade name "Silicone Elastosil 3003/20", is the best of the tested coatings. Aramid fibre fabric coated with Si B shows a continuously higher performance in reducing the energy of any tested bullet.
- The results for single side or double side coated material are close together – for deformation bullets (type I and II) no significant difference can be spotted, FMJs are influenced more by double sided coating.
- For environmental protection a single side coating is enough. But to have the best efficiency it is better to keep weight down.

Fabric roll unwind station	Coating roller and knife in KOA position
	
Coated fabric after coating knife	Coated fabric batch-up
	

Figure 7: Photographs of Coating Line

4.1.3.3 Ballistic tests

Fh-ICT performed ballistic test series to investigate the protecting performance of the textiles provided, including the proposed “Handtuch-Effekt” (“towel effect”) and the ballistic properties of different types of fibre fabrics. As a side effect an experimental setup was designed and evaluated, as well as the measuring methods most suitable for the characterisation of the experimental data. Ballistic testing was performed by firing of a handgun with different types of ammunition at loosely hanging layers of fibre fabric. Figure 8 and figure 9 show the experimental set-up at Fh-ICT.

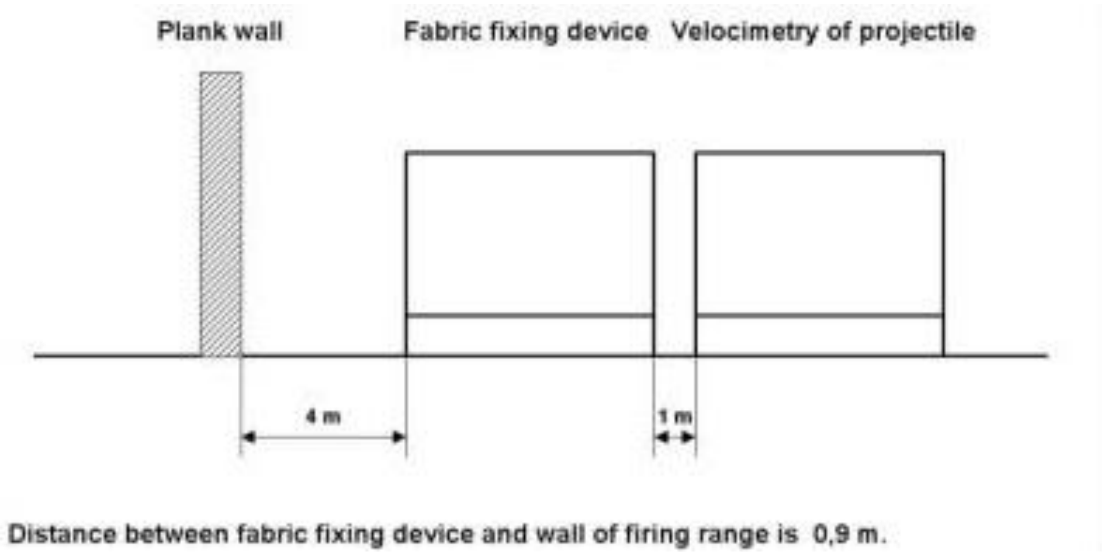


Figure 8: ***Experimental set-up - side view***

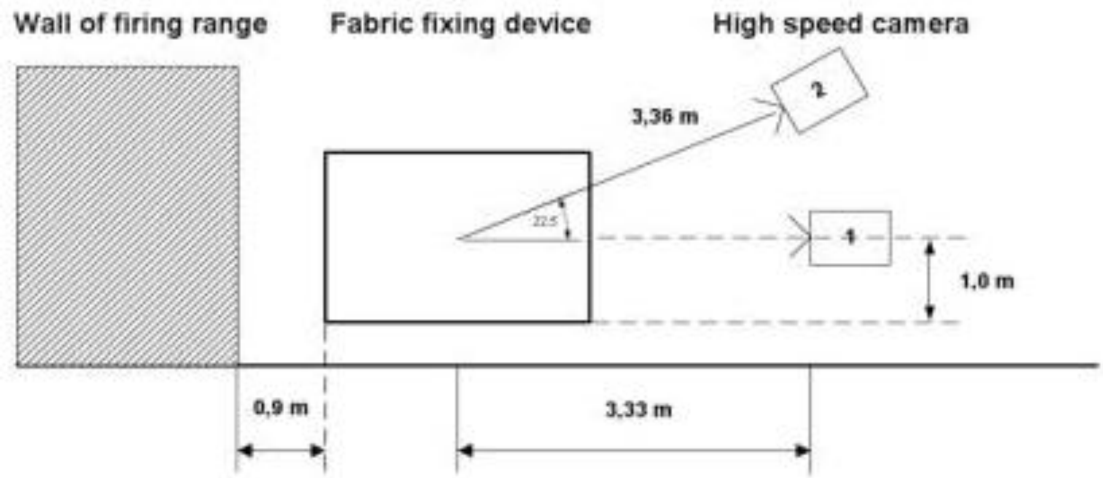


Figure 9: ***Experimental set-up - top view***

Figure 10: Experimental set-up at Fh-ICT firing range, including testing racks and high speed cameras and infrared light barrier to detect the bullet velocity

Some frames from a high speed video sequence are shown in Figure 11:

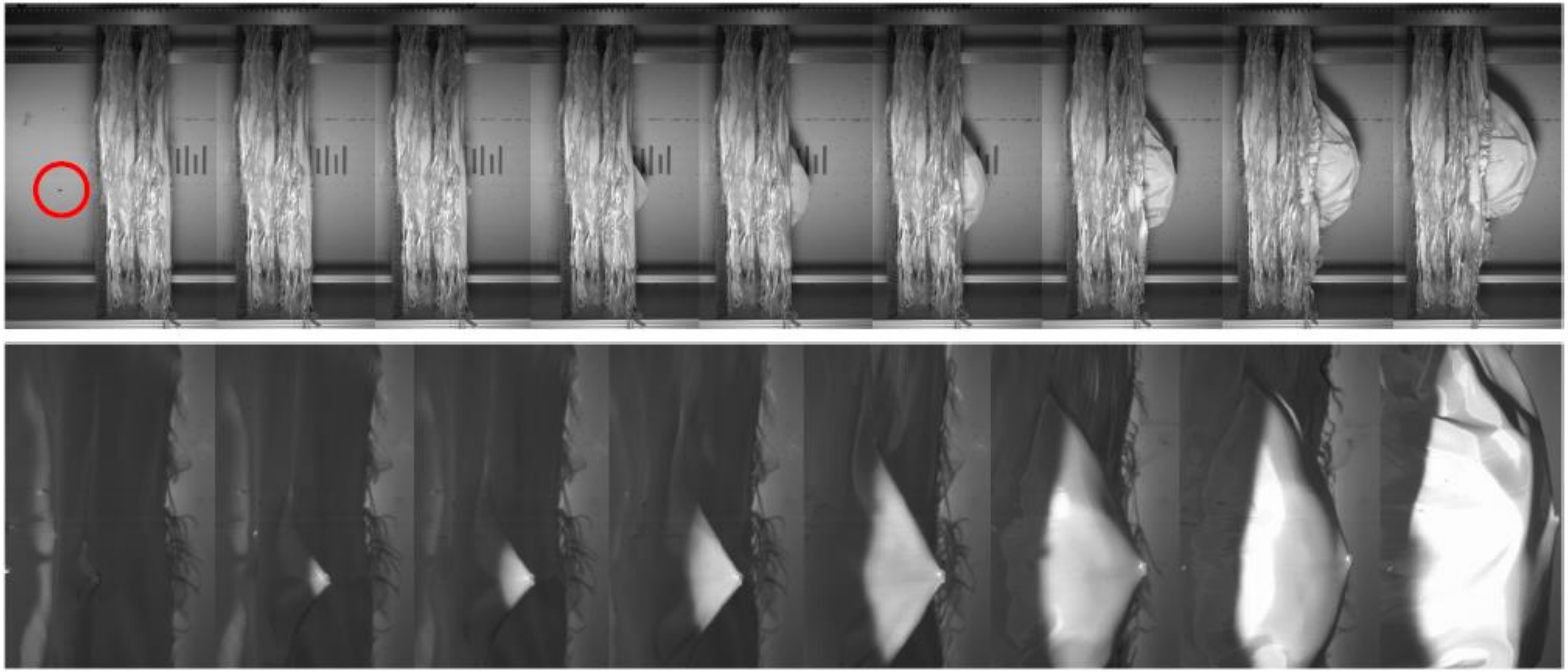


Figure 11: Sequence of a ballistic package (with chain mail) hit by a projectile, which is stopped, lower sequence (pictures enlarged)

Figures 12- 17 show the tested configuration of the tested ballistic packs. In addition, penetration of the projectiles is illustrated as well as extracted projected when it was stopped by the pack. The projectiles are strongly damaged by the ballistic textiles; especially Dyneema broadens strongly the head of FMJPs.

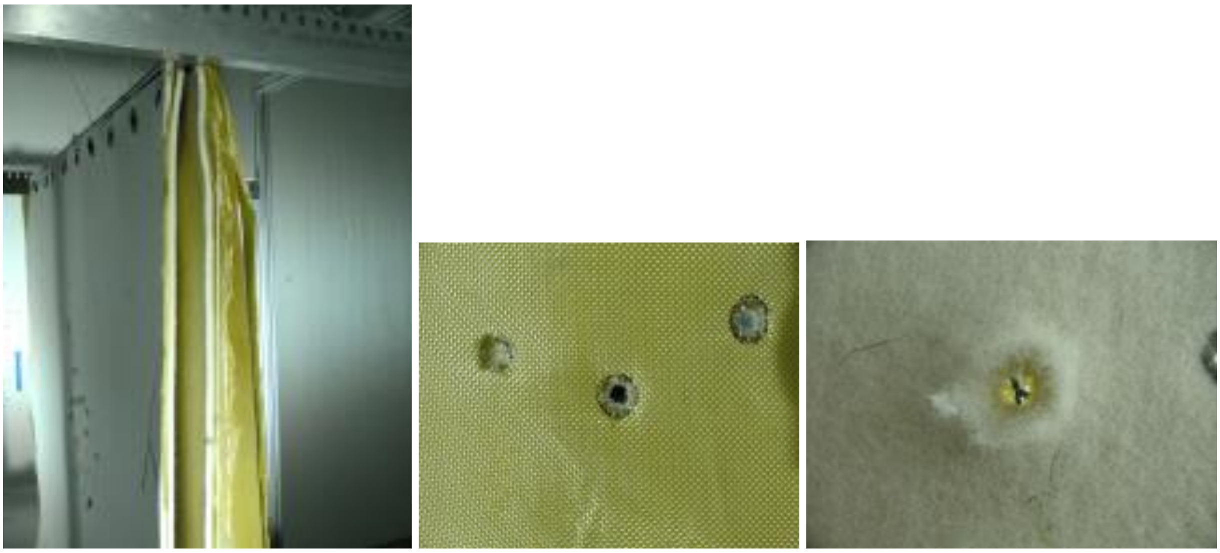


Figure 12: Felt/Aramid laminate

Figure 13: Dyneema

Figure 14: Security vest- inlay by "Mehler"

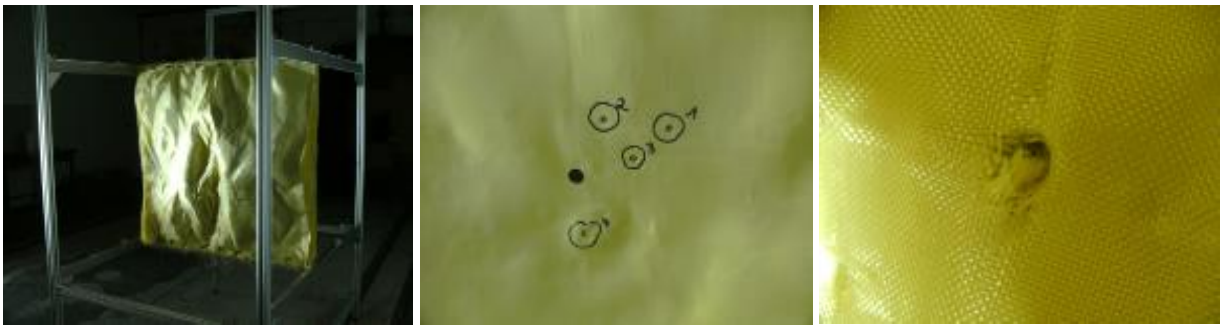


Figure 15: Aramid loose hanging right hand panama weave

Figure 16: Aramid loose hanging right hand panama weaved Aramid which stopped a projectile

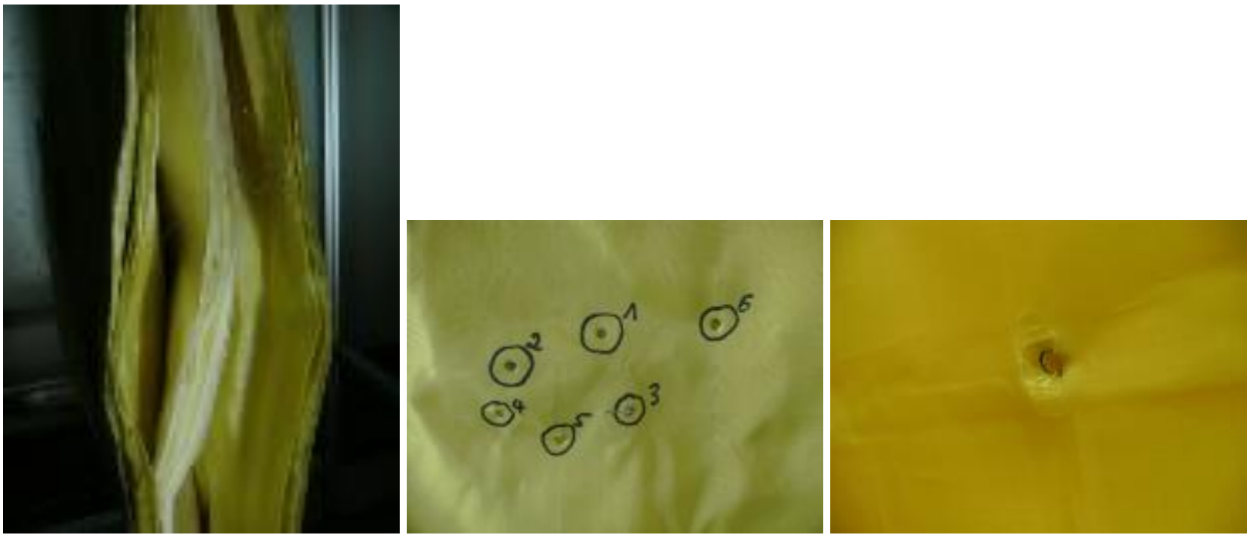


Figure 17: Aramid Dyneema Aramid combination

The provided ballistic packs were tested in various configurations, layers of 6 and 25 textile panels to study the energy reduction performance of the various textiles.

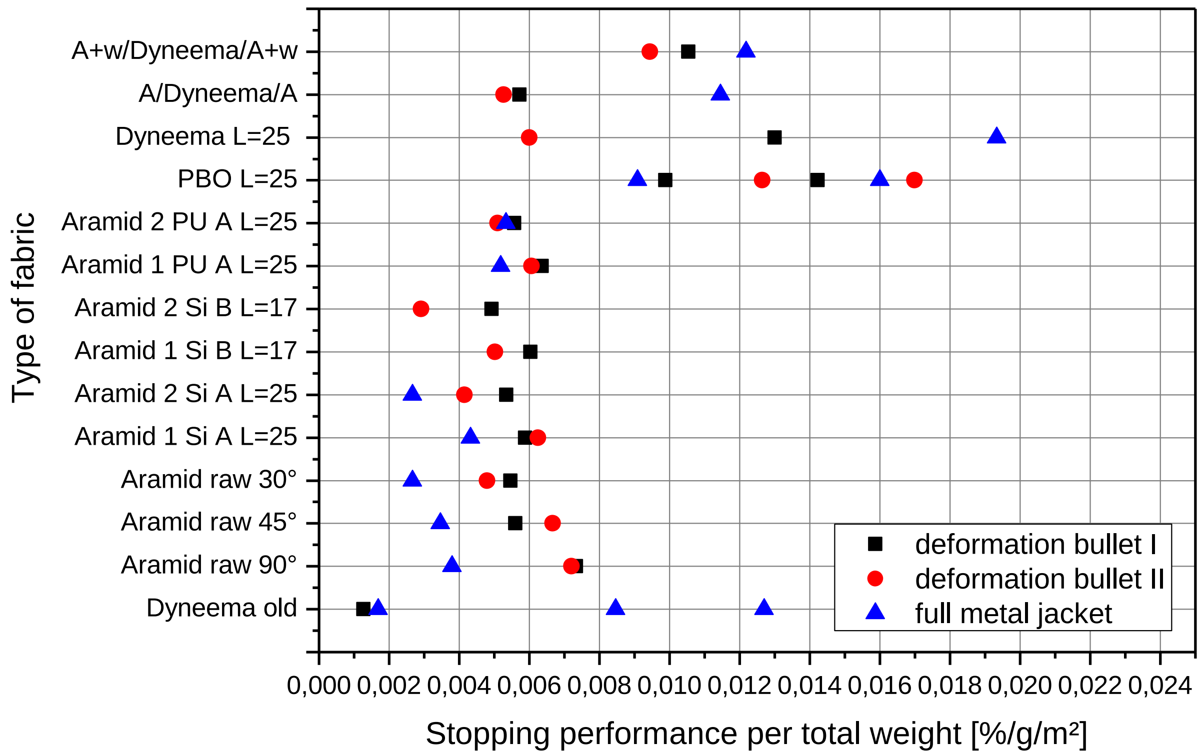


Figure 18: Comprised results from the various materials on the performance of the textiles with ranges in the 25 layer set-up

The key findings of the ballistic tests are:

- No significant enhancement of performance due to angle variation
- **No towel effect detectable**
- Set-up with close hanging layers, fixed on top and bottom is most goal-oriented
- PBO fibre fabric and Polyurethane coated Aramid have the lowest number of stopping layers for full metal jacket projectiles
- Raw Aramid fibre fabrics and Silicone coated Aramid fibre fabrics have the lowest number of stopping layers for deformation bullets
- Still a problem: wide scattering between different ammunition types
- Standardization shows:
  - PBO fibre fabric is highly effective with regard to its light weight! But is dismissed by the end user BKA due to negative experiences with security vest containing PBO fibres (fast aging due to UV and moisture)
  - Combined textiles are very effective and have a good strength-to-weight-ratio
  - Favourite materials are Aramid and the combination of wire reinforced Aramid with Dyneema (layer set-up: 3 A+w/20 Dyneema/3 A+w)

The protecting shield of the demonstrator

The ballistic pack has been produced and supplied by Valmiera Glass in its final configuration, a fabric of 170cm height (style 05471, aramid 1680dTex warp and weft, ends per picks 12.6 x 12.6/cm, Panama weave, weight 410g/m^2). 170 cm was the final height due diverse factors like the limitation on the manufacturing (the manufacturing has achieved its large limit) and not to high total weight (each cm increased the total weight due the number of layers) as well.

•

The fabric is fixed to the inflatable structure instead of mounted in a frame by Lanco (see ballistic tests procedure described in previous deliverables).Worst conditions have been used for the experiments, with a distance between the fabric and the shooter not exceeding 5 m and with an impact angle of 90°, where the fibres receive the shot in the optimum geometry for the bullet to pass through them. The described set up is illustrated in Figure 19.

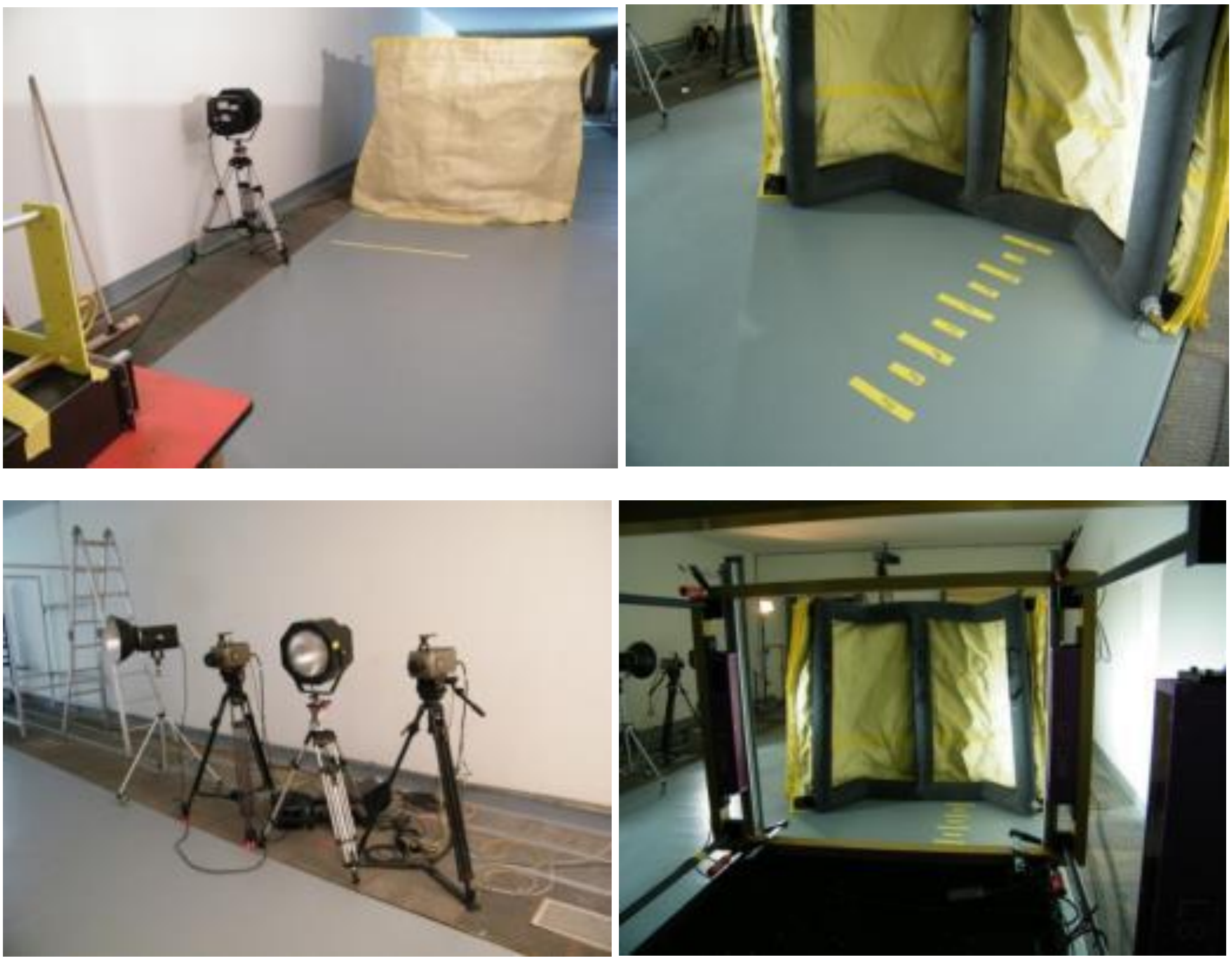


Figure 19: Experimental set-up, including testing fabrics, high speed cameras and infrared light.

Various tests were performed improving the interaction of the various layers. The selected RAPTOR demonstrator shows an excellent protective behaviour against all types of bullets and the blast and fragments from a hand grenade, even at short distances. The structure remains in its position, and the ballistic package (with a 10 cm sewing pattern) is able to stop the entirety of the fragments received from the hand grenade.

4.1.3.4 Gas generator development

For a rapid erection and stable standing of the ballistic shield there had to be developed a suitable gas generator (GG) propellant composition to inflate reliably the protection kit or parts of its supporting structure. The general scientific steps needed for gas generator composition development with energetic components are illustrated in Figure 20:

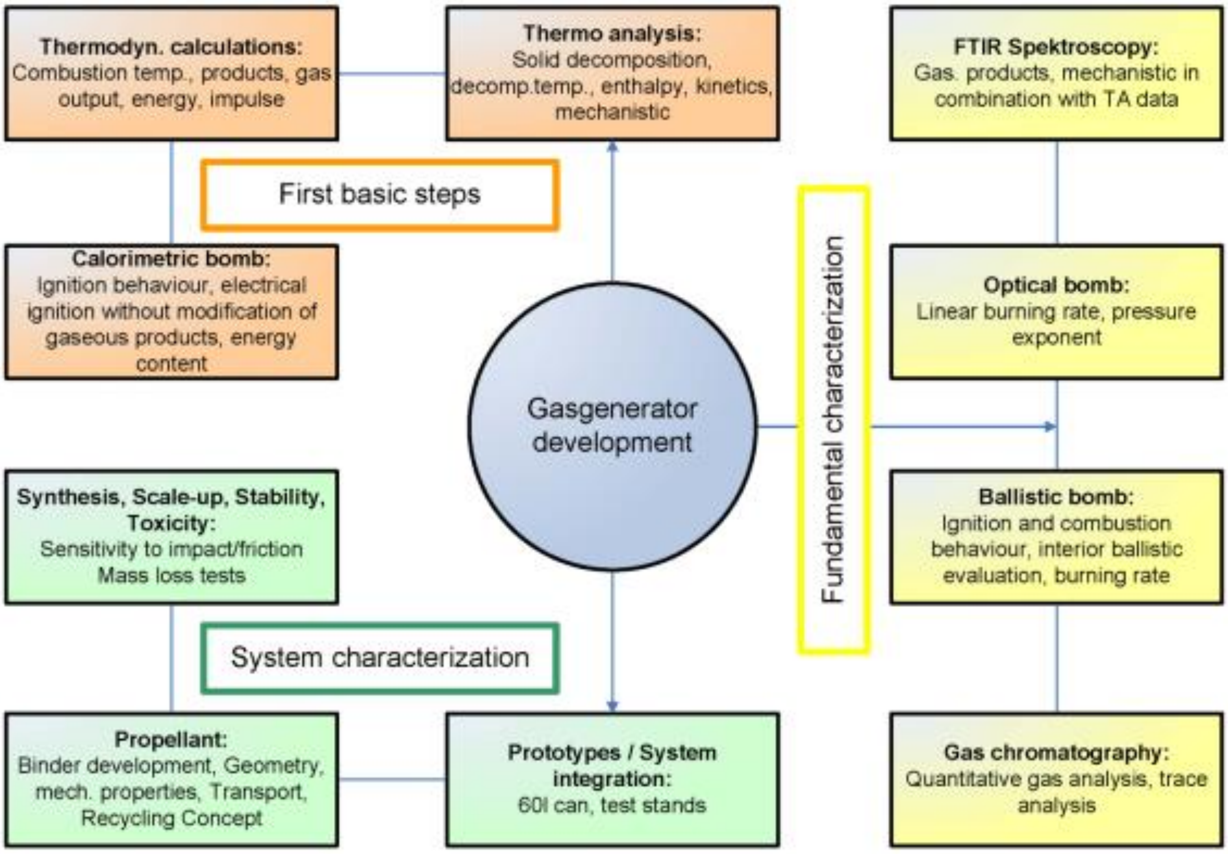


Figure 20: Steps in gas generator composition development – overview

At Fh-ICT there are certain tools to conduct thermodynamic calculations to predict the theoretical gas output, combustion temperature and gas composition on basis of selected composition's components and stoichiometry. Based on a wide range of experiences on the work field in scope, it was possible to preselect some promising raw materials. Those raw materials are described below. The gas generator formulations, which are taken into consideration, are:

- Fuel: 3-Nitro-1,2,4-triazol (Nitrotriazol)
  Oxidizer: Potassium perchlorate (KClO4); **I**
  or Potassium perchlorate (KClO4) and basic Copper nitrate (BCN) (1:1); **II**
- Fuel: Guanidine nitrate (GUNI)
  Oxidizer: with Potassium perchlorate (KClO4); **III**
  or Potassium perchlorate (KClO4) and basic Copper nitrate (BCN) (1:1); **IV**
- Fuel: Nitro guanidine (NIGU)
  Oxidizer: Potassium perchlorate (KClO4); **V**
  or Potassium perchlorate (KClO4) and basic Copper nitrate (BCN) (1:1); **VI**

Summarized, the thermodynamical calculations showed the below listed results:
The gas generator formulation containing 3-Nitro-1,2,4-triazol (Nitrotriazol) as fuel and Potassium perchlorate (PP) as oxidizer has the highest dry gas yield:

- sub-stoichiometrical combustion (λ <1): ca. 22.5 Mol/kg GG formulation
- stoichiometric combustion (λ =1): ca. 18.5 Mol/kg GG formulation

However, this formulation with the highest gas yield shows a temperature maximum compared to the remaining formulations: T~3800 K. This is against the requirements, where a low temperature is the goal.
By adding basic copper nitrate (BCN) to the oxidizer the gas yield of this formulation is reduced, but so is the temperature; which is desirable. Besides this, copper slag is formed.
Nitroguanidin (NIGU) as fuel with and without BCN as part of the oxidizing agents is suitable as well:

- sub-stoichiometrical combustion (λ <1): ca. 21.5 Mol/kg GG formulation
- stoichiometric combustion (λ =1): ca. 17.5 Mol/kg GG formulation

NIGU shows a significantly lower CO content and a lower temperature: T~3200 K
Due to these ambiguous results every considered gas generator formulations was manufactured and tested in a small scale to gain a clearer result.

Still, the propellant geometry was varied between three different types: tablets, tubes and single perforated tubes (SP tubes). The reason behind this is the dependence between the linear burning rate and the specific shape of the propellant (e.g. flakes, spheres, tubes, multi-perforated tubes etc.) The burning rate describes the velocity with which the volume of the burning propellant changes. This is important, because the application for RAPTOR requires a fast burning behaviour. However, pellets were found to show best properties.

Propellant production involves the shaping of propellant compositions into final gas generator propellant pellets. But first the mixtures have to be obtained. Five basic operations are necessary to receive a reproducible, stable and high-quality RAPTOR propellant (see Figure 21).

Summarizing the pilot plant production uses pressed pellets, final decision for the formulation was drawn.

The technology for propellant manufacturing to be used is:

- grinding and mixing of raw materials
- wetting of powder propellant
- granulation and drying of propellant
- separation of fractions
- pressing of pellets

The steps of the process are shown in Fig. 21

Figure 21: Process steps in gas generator processing

The temperature of gases emitted from the combustion chamber of a gas generator might still to be to high not to affect the inflating textiles, in this case the stabilizing structure of the demonstrator. However, if these hot gases pass a cooling agent like a carbonate, they cool down by the energy consumed by the decomposition of the cooling agent and in addition add further gas to the inflating stream. Such an approach is called a cold gas generator (CGG).
After the basic characterization of the propellant, three campaigns in the specially designed RAPTOR cold gas generator chamber were realized. The performance in dependence of the geometry of the RAPTOR propellant mixtures have been evaluated in a first test series. Unfortunately, in the first test series, not all needed data could be collected, due to a missing pressure sensor. Moreover, the different propellant geometries proved to be difficult in handling and over performed in several attempts. In accordance with the ballistic bomb results, the propellant tubes and SP tubes showed an unpredictable and far too strong pressure increase which lead also to the decision to use pellets (see above). So, the first CGG was damaged and the coppered ignition squib for example indicated a undesired leakage. The need for a second test series became very evident and several enhancements in the set-up of the cold gas generator (CGG) as well as in the design had to be taken into account.

The analysis of the various experiments ended up with the final design. The design for the RAPTOR Gas Generator combustion chamber is not circular like in the most standard applications, but tube shaped to obtain a directed flow of hot exhaust gases. Nevertheless, the device features a high robustness. The material used is mainly stainless steel for a high safety. Since the RAPTOR Gas Generator module is still a prototype and high pressure levels may occur, it is not advised to use new lightweight materials yet. In a later optimization step, the wall thickness of all components may be reduced significantly to receive a light weight device. This can be realized only after the possible occurring pressure levels produced by the RAPTOR propellant are known exactly and have been proven in several test runs. For the cooling principle the favourite is the use of a cooling chemical. The reason for this is obvious: the cooling chemical reacts fast and efficiently. It creates even more gaseous reaction products, which are used to inflate the security kit tube structure and it reduces the heat of the exhaust gases drastically. The only disadvantage is the add-on weight, which is created by the design of a cooling chamber. However, the benefits clearly outweigh the disadvantage described. A CAD model of the final version which fulfilled all the criteria is plotted in Fig. 22

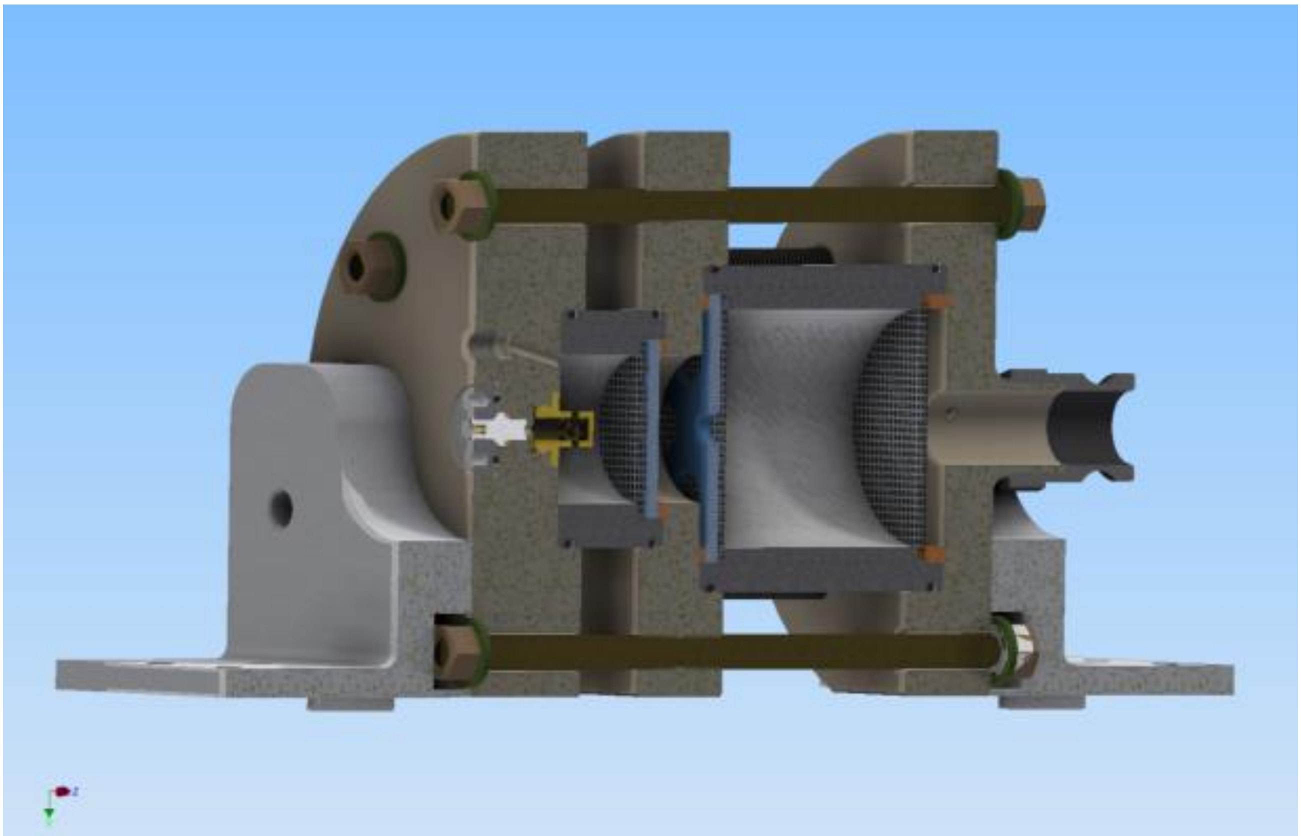


Figure 22: Coloured 3D CAD-model of the final RAPTOR CGG module (left) and a CAD model in a fictional laboratory environment to illustrate the real-life dimensions of the RAPTOR CGG module. Since it is still a prototype, the ready-for-market module will be a magnitude smaller.

The gas generator tests used the tablets provided by Explosia, the characteristics were described above and used in all CCG experimental versions described here. The masses of the booster (to initiate the GG propellant), the propellant and cooling agent are listed below and are illustrated by Figure 23:

- M_{AZM}=1g B/KNO3 (Booster for initiation)
- M_{TS}=70g Raptor propellant provided by Explosia
- M_{KM}=320g bas $MgCO_3$
- 258g = residue

Figure 23: Fresh RAPTOR propellant in tablet geometry and fresh cooling agent (left: green: propellant, white: cooling agent); used cooling agent with slag residue on surface (right)

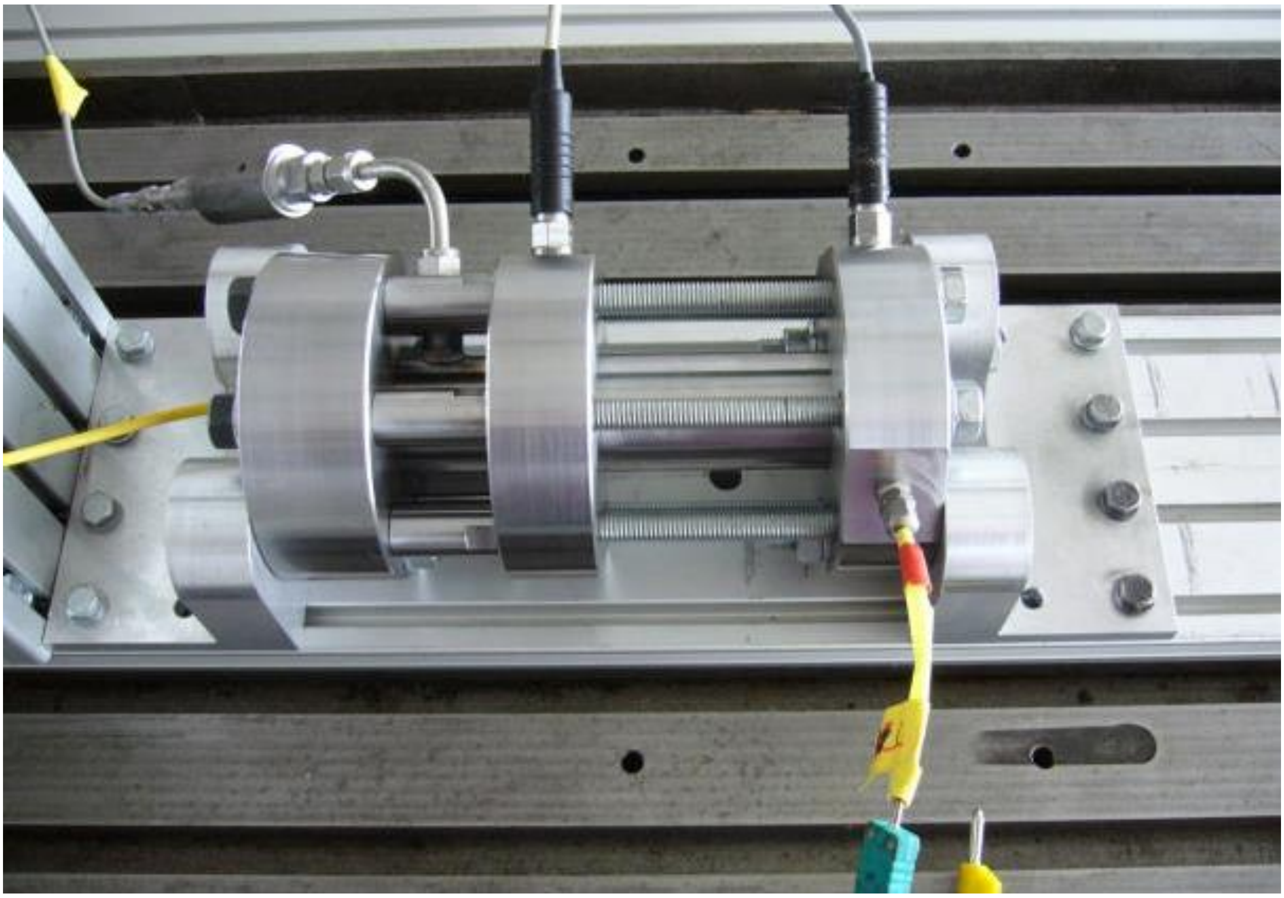


Figure 24: Real life impressions from the final CGG test series: CGG module with three pressure measuring point and one temperature measuring point

Figure 25: Photographs from the third CGG test series: transfer nozzle quadruple-hole-Design before experiment (left); transfer nozzle triple-hole-Design after experiment (right)

The results are shown in Figure 26. The profiles of pressures at measuring spot P1 and measuring spot P3 are quite similar. Pressure maxima vary between 165 and 240 bar in a range of 7 to 25 ms. The temperature varies between 400 and 480 ^{o}C. The shapes of the profiles are also similar. These profiles are full within the range to be suited for a favourable inflation of the demonstrator structure and time scales lie well below 1 s.

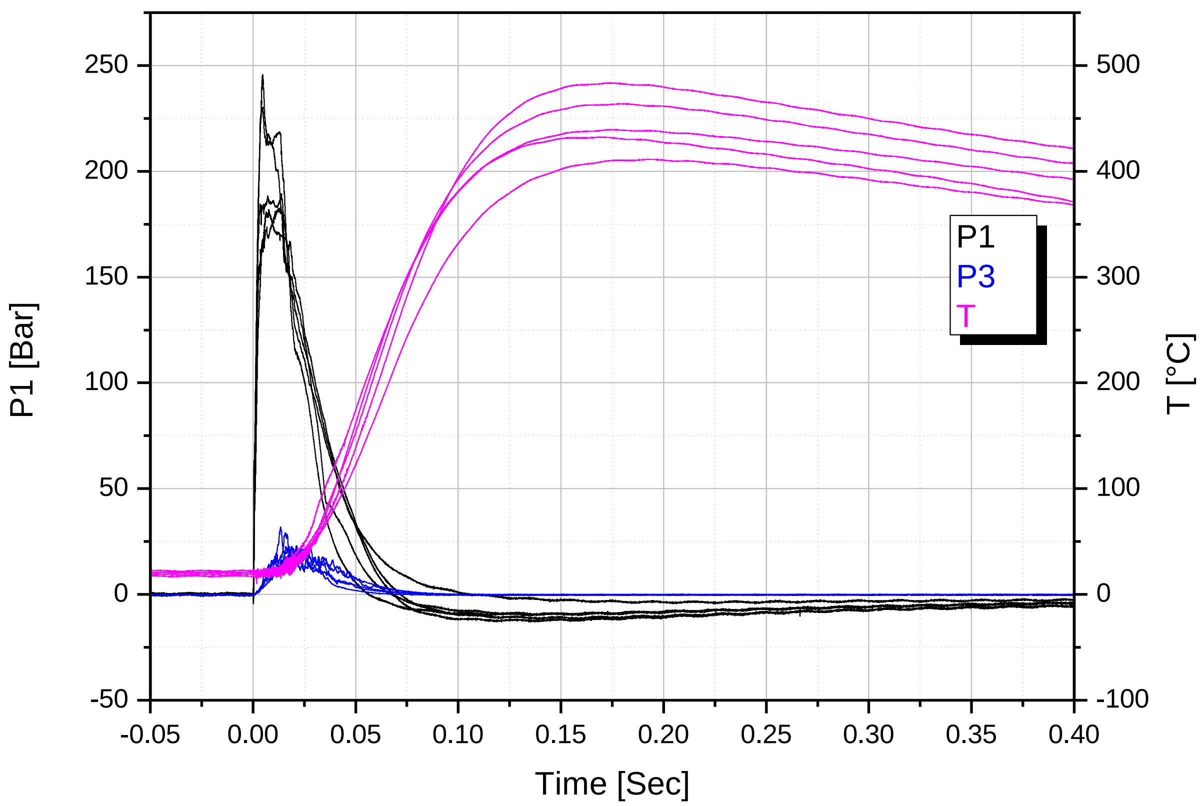


Figure 26: Results pressure and temperature time curves of the test runs of the final version CCG

Finally, the CGG has to be adapted to the inflatable structure of the ballistic shield. It was done by quick connecting device (see Figure 27).

Figure 27: Quick connect device with safety interlock and matching plugs for the Gas Generator Module – tube – interface

4.1.3.4 Security kit demonstrator

An overall scheme of the security demonstrator is given in Figure 28. It considers the operational components to be fulfilled in the final product. The demonstrator includes the key elements which consist of the gas generator, the connection to the inflatable structure which leads to a stable standing of the ballistic shield (antiballistic pack).

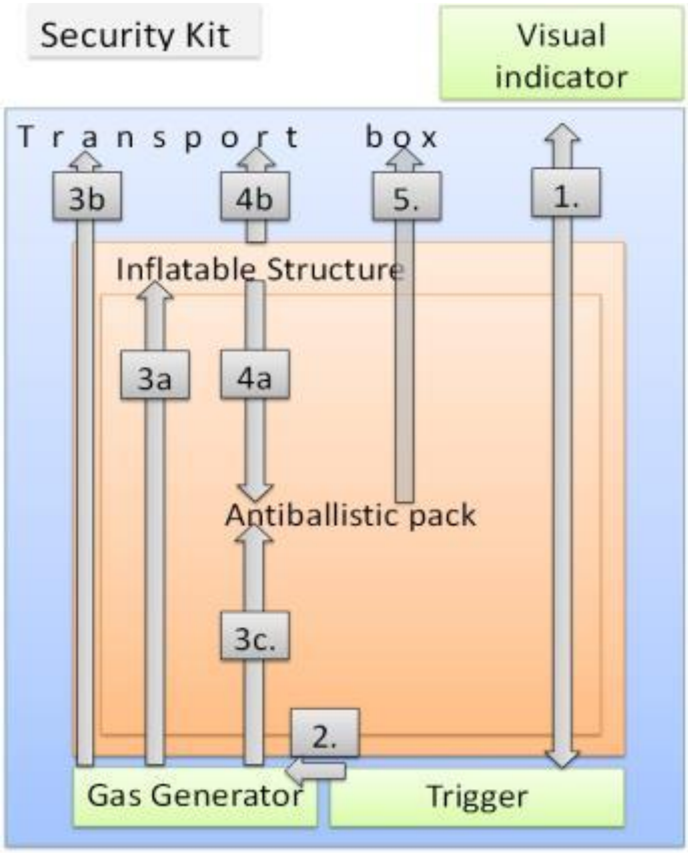


Figure 28: Scheme of the security kit

Interactions

1. Visual Indicator shows the readiness for operation of the trigger mechanism

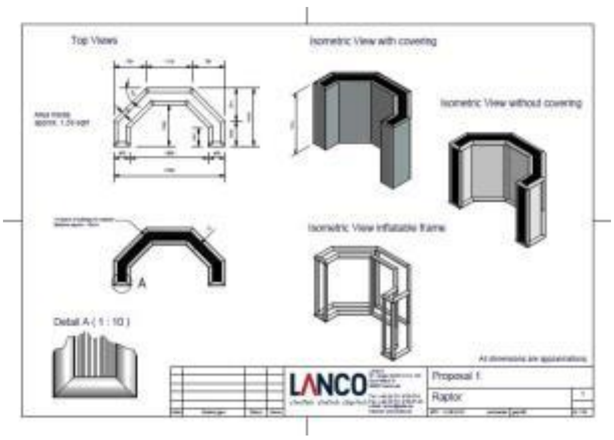
2. Triggering of the gas generator

3a. Gas generator inflates the inflatable structure
3b. Opening of the transport box initiated by the gas generator
3c. Gas generator unfolds the antiballistic pack

4a. Unfolding , setting upright and holding up of the antiballistic pack by the inflatable structure
4b. Opening of the transport box initiated by the inflatable structure

5.Opening of the transport box initiated by unfolding the antiballistic pack

The design of the of the ballistic shield with its layers of bullet resisting textile layers had on the one hand to take care of the protection area and on the other hand solve the problem of folding and unfolding in a short time scale (<1 s). The approach started with design studies of inflatable structures, partially including frames, shown in Figures 28-31:



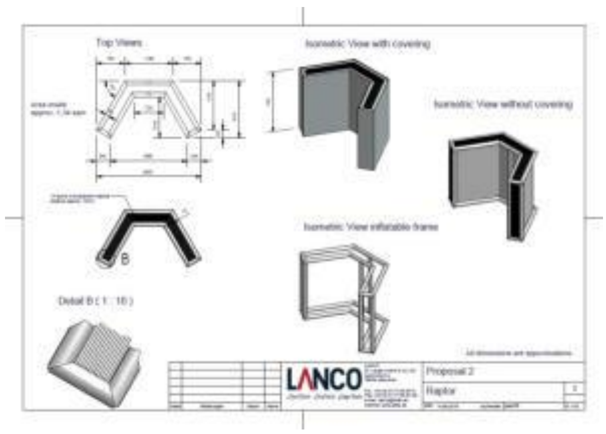


Figure 28: Approach 1 – Frame Structure with a semi-honeycomb and the various layers of the ballistic pack integrated

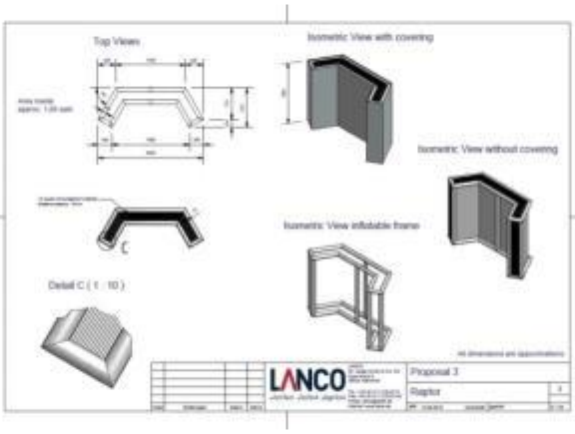


Figure 29: Approach 1 – Frame Structure with 3 bended shield areas with extended sides which contain the ballistic pack and the various layers of the ballistic pack integrated

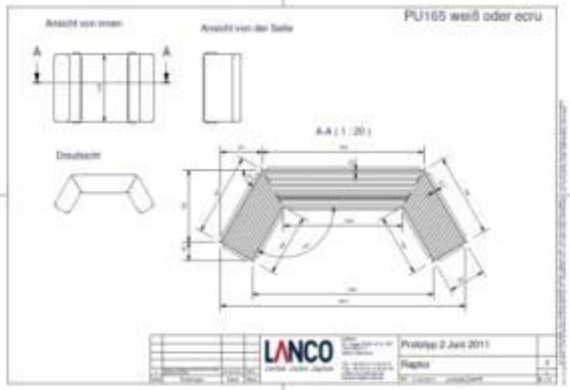


Figure 30: Approach 1 – Frame Structure with 3 bended shield areas with extended front end which contain the ballistic packs and the various layers of the ballistic pack integrated

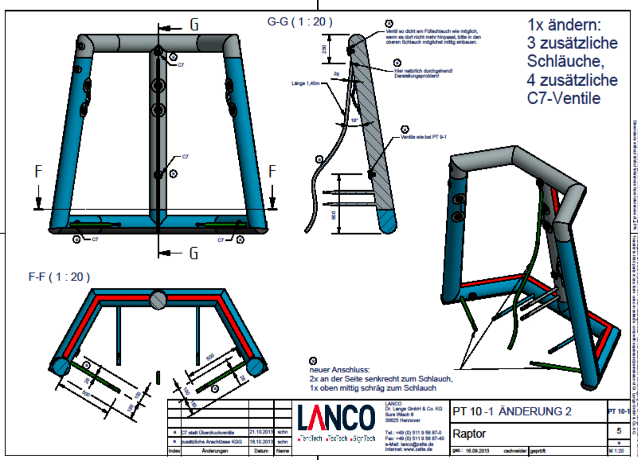


Figure 31: Approach 1 – Frame Structure with 3 bended shield areas with extended front end, describing the integration of the ballistic pack

Figure 32: Inflatable frame of the demonstrator and the folded antiballistic pack integrated in a cover (transport box)

The design of the final design of the inflatable structure ended with the decision to inflate a frame which bears the ballistic shield as shown in Fig.32. The antiballistic pack is rather stiff and is difficult to fold and the unfolding depends on the inflation from the gas generators. The technique was investigated by many experimental trials, one example is shown in Figure 33

Figure 33: Unfolding of a ballistic pack by inflation by compressed air

Figure 34: Three cold gas generators adapted to inflate the frame structure for unfolding of a ballistic pack

Three cold gas generator modules were used to inflate the frame safely. Their adaptation to the inflatable frame is shown in Figure 34, in a configuration which could safely unfold the stiff antiballistic pack for shielding. The inflation time with this configuration could deploys the antiballistic package within 500 ms. The pressure stability in the chamber with 3 CGGs and ballistic package (after inflation) was found to be in accordance with the specifications above.

- After 600 ms: 2.35 bar
- After 650 ms: 1.7 bar
- After 750 ms: 1.7 bar
- After 1 s: 1.35 bar
- After 1.5 sec: 1 bar
- 5 minutes after the structure is still inflated

Finally, all components were combined in a demonstrator which was tested at a shooting range. The RAPTOR demonstrator shows an excellent protective behaviour against bullet impact, blast and fragments from a hand grenade, even at short distances. The structure remains in its position, and the ballistic package is able to stop the entirety of the fragments received from the hand grenade. The current weight of the ballistic package has still to be reduced for which effective proposals were made. The folding might also be improved in future developments to achieve substantially reduced deploying times.

Figure 35: Sequence of a ballistic package when inflated by three cold gas generators as seen in Fig. 34, important steps of the deployment observed from head and back side

4.1.4 The potential impact

Starting the dissemination and exploitation broadly and early was essential for RAPTOR and for the economic success of the participants, especially the industrial ones. The plans were outlined within the project duration and target the security related research communities and industries throughout Europe and beyond. Awareness of the addressed community and involved key persons is the very first issue to be organized after the project. The main impact is seen for peace keeping and law enforcement staff acting in Europe or deployed in crisis areas of the world where they are needed. Scenarios of European security forces contain threats from hand held guns or improvised explosive devices (IED), which have much lower ballistic performance than military equipment e.g. machine gun or mortar grenade. However, a fast response should enable a rapid deployment which should by the inflation of the gases from gas generator as used in airbags for cars.

This awareness, the dissemination and exploitation is based on the results, essentially to the innovations of the RAPTOR project.

However, it should be taken into account that the details of the expected product are only described in fewer details and have to be handled with care. Components of the protective product or downgraded versions might be also of interest to be put on the market later or included in other products for improvements.

The project summary above describes the main results achieved at the end of the project and will be continued in a final development in a technical implementation plan of the RAPTOR project. The innovative results are related to the competences of the participants of the project and the type of later continued developments, dissemination activities and exploitations to bring the system to market In general, the innovations concern security technologies of especial ballistic protection.

It summarizes and addresses the innovations in time to enable the participant to include the treatment of these innovations throughout the remaining project duration. The innovations concern the various components, where new results were obtained as well as the complete system, where a demonstrator was developed. They consist of:

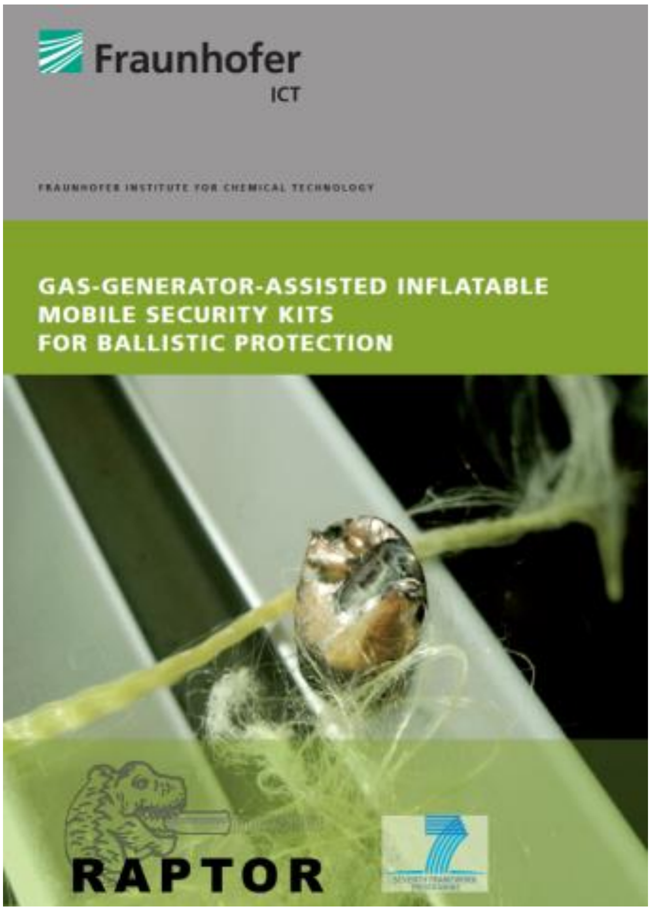
1. Various ballistic packs consisting of textiles and coated textiles and their classification by test results
   The **scientific use** of the results is mainly related to Fraunhofer ICT and will be published if there are no problems with confidentiality
   The **technical use**, especially the textiles and coatings, are innovations of Valmiera Glass
   The **economic use** of the textile and coating results is also for the use of Valmiera

2. The gas generator components per se including formulations, burning chamber design, shapes of pellets, gas production rates and manufacturing techniques
   Fraunhofer ICT will use the **scientific results** and they are independently useful beyond the actual application as driver gas for the demonstrator kit and could be outside the project used for publication or used for other projects and objectives
   The **technical use**, especially the formulations and manufacturing techniques of the gas generator propellant are innovations related to Explosia which also will organise its commercial use in case similar requirements are found

3. The security kit consisting of the ballistic pack, the design of the deployable ballistic shield, the cover, the opening, the folding and the protecting capability
   The **use of the results** is a joint responsibility for all partners, the lead be related to LANCO and a special version with **technical/commercial** use of BKA

Dissemination and exploitation however, have to be sensitively handled, because of the limitation of information especially when concerning the detailed performance of the demonstrator kit for the personnel protection of VIPs. In addition, further applications with different specifications are possible, especially downgraded versions of the demonstrator.

4.1.5 Project Flyer, logos of project partners and project logo



RAPTOR

PARTNERS

Bundeskriminalamt

EXPLOSIA

LANCO
TentTech TexTech SignTech

interglas

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