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The Concept of a Poly-Functional Ballistic Shield

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Abstract. Police and military units are employing the use of additional, portable protection in the form of various types of ballistic shields ever more often. They are not only used for protecting a single operator, but rather entire assault groups or bystanders. The work analyses the ballistic shields used presently and the requirements of the law enforcement forces; on this basis, the assumptions used for designing a poly-functional ballistic shield have been formulated. The design employed so-called "origami engineering", i.e. a field tasked with designing geometrically-shifting materials by changing the location of the components. The prototype's design is presented, and the path to its development is indicated.
Keywords: shield, ballistic protection, origami engineering

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1. INTRODUCTION

For centuries, shields have been an indispensable component of the equipment of warriors and soldiers on battlefields. Unlike armour, they served as cheap and mobile protection against numerous kinds of injuries. Along with the development of firearms, their defensive significance dropped, almost leading to the complete elimination of shields in combat units. However, presently, with the development of new engineering materials, shields and mobile protection are regaining significance. This is happening, in particular, among the forces of order which, contrary to the military, tend to have equipment offering less protection. This is why many police storm units often employ additional means of defence: ballistic shields. Presently, no other assault group action scenario ensures a level of team protection greater than that granted by the use of a portable shield [1].

The work presents a new solution in shield making. In order to determine the purposes the project would serve, the author used sources from the field of activities of public order forces, manuals and training materials for fighting inside rooms, as well as informative materials of companies producing such shields. Using the new field of material structure and analysing the situations the shield's operation may partake in, an attempt at creating a concept project has been made.

2. BALLISTIC SHIELDS – AN ANALYSIS

Ballistic shields are portable protection, usually meant for a single person, whose components grant at least IIIA-class protection, in accordance with standard NIJ.0101.04 (example in Fig.1). This condition excludes any deflective shields used, for example, by the police during riots. There are no other conditions for including shields in this group [2].

Fig. 1. An example ballistic shield (Intruder™ G2 – Type IIIA Shield) [3]

In the last 20 years, the guidelines pertaining to making all types of shields have changed. Designers no longer merely focus on providing protection against puncturing and the projectile's impact energy, now also attempting to treat mobility issues (low mass, optimal dimensions) on par with the defensive ones, as well as versatility (mounting on various surfaces, extra equipment clips), and even additional functionalities against the opponents (blinding and incapacitating systems). The reason for this are the ever-more frequent attacks with the use of firearms in the centres of crowded cities, where the law enforcement forces must be equipped with shield mechanisms of even greater functionality [3, 4].

The ballistic shields manufactured hitherto were made of various engineering materials, often identical to the fillings of bulletproof vests. However, contrary to them, shields of this type are to be used ever more often as the main defensive tool, which translates to the specifications of their structures. However, in the context of armament technology, no uniform ballistic shield classification exists – various divisions exist, determined by users and manufacturers. Based on their analysis, the following categories can be adopted [3, 5, 6]:

1. Intended use:
   - Hidden personal shields – low mass and small size, usually featuring a folding system making it to resemble a suitcase, a backpack, or even an umbrella;
   - For active use – for first response units, granting the operator the ability to fire shots;
   - For protection against constant fire – heavier and bigger than before, characterised by better ballistic protection, sometimes allowing the operator to fire shots as long as, for example, support suspenders are used.
   - Shields for protection against large-calibre weapons – due to their mass and size, they are not suitable for use in rooms. They offer the highest class of ballistic protection and are usually transported by two people, or by their driving systems.
2. Mass:
   - Light (up to 6 kg);
   - Medium (6 to 15 kg);
   - Heavy (15 kg and above).
3. Size:
   - Small (0.06 to 0.2 m^2);
   - Medium (0.2 to 0.4 m^2);
   - Large (0.4 m^2 and above).

4. Shape:
    - "Bunker" type (flat cuboid with an arching curve);
    - "Batshield" type (flat or convex deltoid, wedge or diamond shapes);
    - Oval (flat or convex);
    - Flat polygons.
5. Structure:
    - Stiff and monolithic;
    - Stiff and folded;
    - Soft and monolithic;
    - Soft and folded.
6. Ballistic protection class (depending on the standard used).
7. System of use:
    - Freely transportable by the user;
    - Transported by the user with the aid of clips (e.g. with the use of suspenders with hooks);
    - Stationary, with driving systems.
8. Materials used for manufacturing:
    - Ceramic-polymer composites;
    - Metal alloys;
    - Polymer composites;
    - Ceramic-metal composites.

3. THE CONCEPT OF THE NEW BALLISTIC SHIELD

Nowadays, organised firearm attacks in municipal metropolises are becoming ever more commonplace. Standard police units are the first to appear at the site of the event; however, due to the fact that they only use standard equipment, they usually do not possess any means of protection capable of withstanding the attacks of the most oft-used weapons, such as AK47 rifles. For this reason, ballistic shields should be part of the standard police car equipment, not just that of the special units as shown in Fig.2. Their functionality should be adapted to the possible scenarios the officers might find themselves in. The currently-produced shields are able to raise safety and the law enforcement forces' tactical capabilities to a great degree; however, their functions are limited.

A ballistic shield that may surpass the hitherto-manufactured shields when it comes to the range of possible applications has been developed. During the course of the project, various usage situations for special and law enforcement forces were considered. It is, however, necessary to emphasise that the presented project, with no field research to back it up, is merely a concept. Therefore, the shield's description and its properties are presented as assumptions.

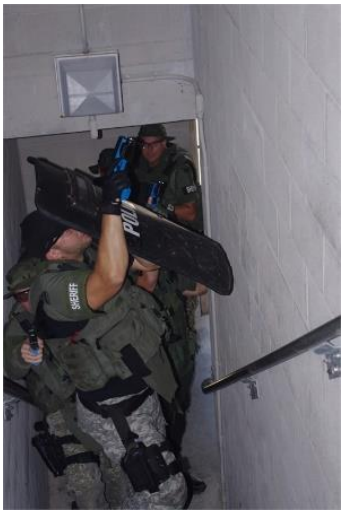

Fig. 2. American police's assault exercises [2].

3.1. Determining the tasks of the poly-functional ballistic shield

The reason at the root of the very existence of military and law enforcement units is the need to provide safety to civilians. Therefore, the first task for the forces arriving at the site of an attack should be that of ensuring the safety of the victims and the threatened people, as well as evacuating them from the area. Ballistic protection capable of protecting the police officer or the soldier when approaching the victim, then protecting both afterwards, may prove to be the best tool for this end. In the case of injuries rendering movement impossible, the capability of providing static protection to the victim until the threat is neutralised or medical aid arrives should be available. The structure of the shield should also allow for creating static, segmented protective barriers that would make it possible to evacuate bystanders and isolate the site of armed action. Presently, this is almost not taken into consideration at all when designing such items.

An important functional aspect is the use of a surface-size changing system in order to adapt the shield to the surrounding conditions (making the protective surface larger or smaller). This would grant the ability to act quickly in urban zones.

Moreover, should no intelligence as to the number and locations of the opponents be available, the ability to provide a greater protection radius may prove key. The ability to change the shield's size is another property that will allow for equipping the shield on any police or military vehicle, without taking up too much space in the load compartment.

Due to the reaction speed requirement and the frequent drops of manual capabilities in stressed people, the shield must be ready to use even when folded. Considering, among others, the average height of an adult male (177.4 cm) and the dimensions of the space where using the shield would be required (1 x 1 m – the minimum surface of staircase platforms), the most optimal dimensions of the shield when folded are approx. 0.8 m tall and 0.59 m wide. This size also meets the assumptions of the small-room movement and combat strategy [7].

In the present reality, mobility is vital when it comes to efficient action on the battlefield. In order to achieve this, one of the basic factors – the mass – should be taken into account. Analysing the weight and distribution of the standard special unit equipment, as well as the basic physical standards usually imposed upon law enforcement functionaries, it has been assumed that the mass of the shield may not exceed 16 kg [8].

The shield's new applications should not hinder its basic function – it should enable the operator to conduct active combat activities, while still retaining a good class of protection. While moving with the shield, the operator should be able to safely observe the area (through a visor) and fire shots freely (through a weapon cut-out). Moreover, taking into consideration extended fights in open areas, maintaining the shield in a defensive position should not be entirely dependent on the user. Placing the shield in a stationary position that would lift its weight off the user should be made possible. Adaptation for the needs of the given forces deserves attention as well; the shields may be adapted by, for example, installing a system for mounting accessories such as lighting.

3.2. The shield's design

Developing a shield folding system is the pivotal element of meeting the above-stated requirements. The most common solution to this requisite is the use of so-called ballistic blankets, i.e. soft covers that can be folded freely [3]. However, such a structure does not meet all of the author's requirements, even with stiffening systems. The material's thinness and the time taken to shift between various surface arrangements in order to enable it to play a given role reduce the comfort of use and speed of action.

So-called "origami engineering" may prove to be a possible solution; it is a new type of design, based on special ways of folding stiff materials in order to create other utility structures.

These systems allow for turning compressed materials into structures with a surface area as many as 20 times greater than their initial size. The technology traces back to the ancient art of folding paper, which inspired many folding systems and basic rules, e.g. that the creation of new structures must take place only through folding, without tearing, cutting, or gluing.

For several years now, this new field has been finding applications in architecture, medical device design, and micro- and macro-structure modelling [9]. Many techniques of creating so-called origami systems are being applied, dictated mostly by their intended function and the materials used. In some cases, when the design dictates the use of stiff plates, a system of thin membranes (with plates of appropriate shapes mounted in the proper intervals), hinge connections (connecting stiff plates) or both systems may be used [10].

The author's design is not the first work employing "origami engineering" to create a ballistic shield. A similar project is being implemented by the Birmingham Young University – in June 2017, a fully functional prototype was presented (Fig.3). This product, however, does not meet a great number of the requirements for the shield [11].

Fig. 3. Brigham Young University's Ballistic Barrier [11]

The author's concept project (presented in Fig.4) assumes the possibility of unfolding the shield into the following forms:

- Small assault shield – the fully folded form for very dynamic action, with the smallest protective surface (for a single person)
- Large assault shield – the folded form for dynamic action with a large protective surface (for a single person)
- Small stationary shield – the form assuming the shape of a short, stationary protective barrier (for 2 people)
- Big stationary shield – the form assuming the shape of a relatively tall, stationary shield (for 2 people)
- Full barrier – the form with the largest surface, but with the weakest protective parameters (works as a barrier)

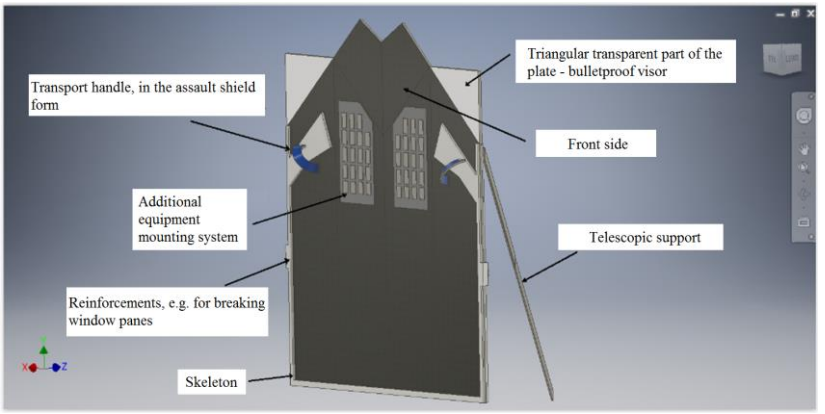

Fig. 4. Full-barrier ballistic shield concept

It is assumed that the shield should consist of 3 basic elements:

- Ballistic plates
- Surrounding materials such as the base membrane and the front material;
- Skeleton.

3.2.1. Ballistic plates

Figures 5-9 show the initial project in various protective material folding "stances". The shield is made of a total of ten replaceable plates, among which four kinds may be distinguished:

- 4 lower, rectangular plates
- 2 main, rectangular plates with triangle visors;
- 2 smallest, trapezoid-shaped plates that constitute a stiffening component when the shield is completely unfolded;
- 2 main, trapezoid-shaped plates.

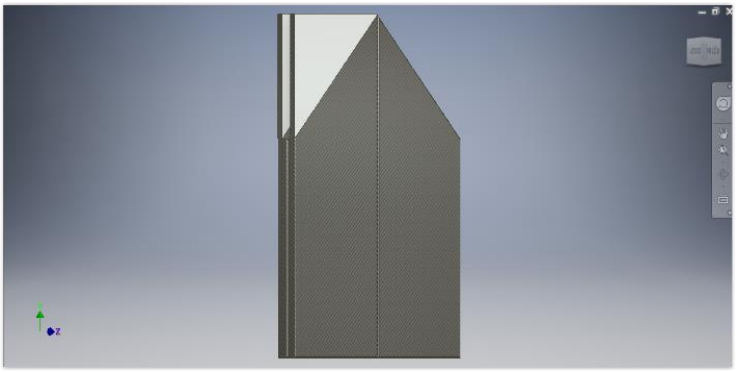

Fig. 5. Ballistic shield concept: small assault shield

Fig. 6. Ballistic shield concept: large assault shield

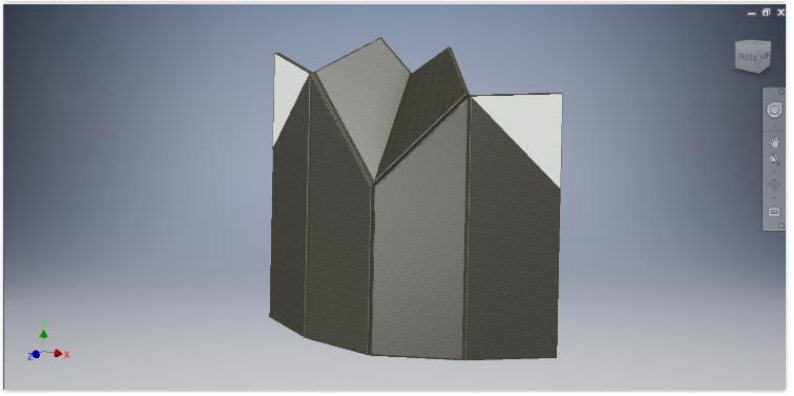

Fig. 7. Ballistic shield concept: small stationary barrier

Fig. 8. Ballistic shield concept: large stationary barrier

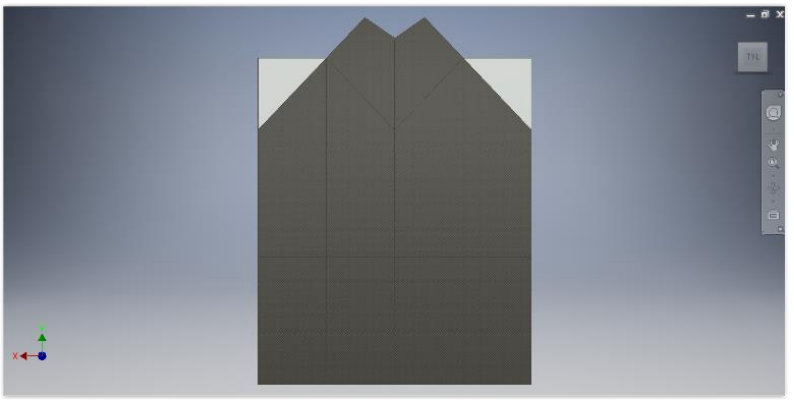

Fig. 9. Full-barrier ballistic shield concept

The project assumes appropriate profiling of the edges of every plate in order to increase the durability of the joining places, as shown in conceptual Fig. 10. All of the plates would be mounted using a temporary fastening system in the form of industrial velcro. They would be mounted on the partially-stiffened membrane constituting the base of the entire structure.

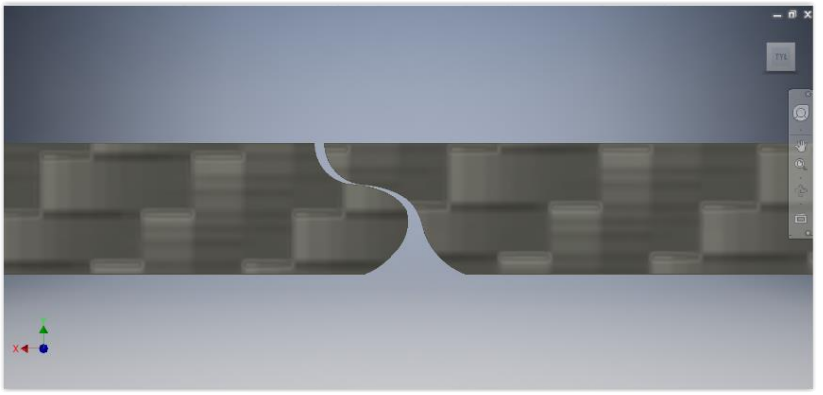

Fig. 10. The shape of the edges of the adjacent plates

In accordance with the folding system applied in the project, the plates must be stiff, and their thickness should not exceed 0.014 m (no other limitations pertaining to the protective part have been planned). They may be made of materials of a frontal structure (similarly to composite ceramic-polymer ballistic shields) thanks to folding while maintaining the same working space. Moreover, every folded form grants a different level of ballistic protection.

This is proven by the preliminary tests conducted within the scope of creating the prototype – a single panel (20 layers of 220 g/m^2 Kevlar plus a cast polycarbonate plate with a thickness of 0.002 m) is capable of stopping a 9 x 19 mm projectile travelling at a velocity of approx. 398 m/s, and four joined panels are able to stop a projectile as large as 5.56 x 45 mm.

3.2.2. The base membrane and the frontal material

The membrane's material would consist of aramid fabric stiffened with polycarbonate where the plates are mounted, in order to determine the places of folding. In order to give it special properties, such as heat emission screening (in order to counteract thermography), it would be possible to mount, for example, metallised mylar foil. Mounting support slam hinges with a 105° opening lock (range: 0° – 180°) for stabilising the position of the upper stiffening plates (playing an important role in the stationary barrier forms) on the membrane has been accounted for as well (visualization in Fig.11).

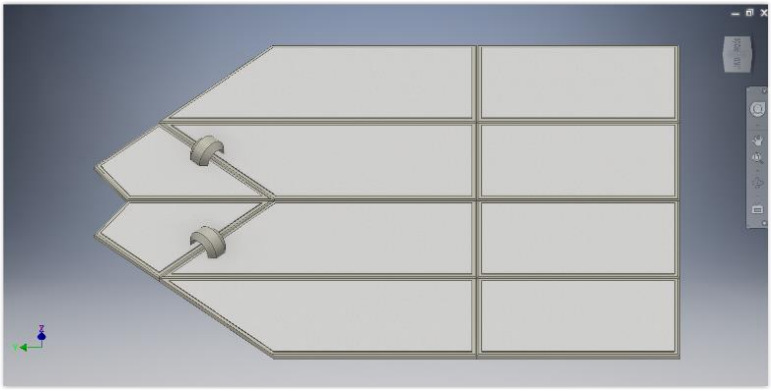

Fig. 11. The membrane's design, along with the stiffening parts and hinges

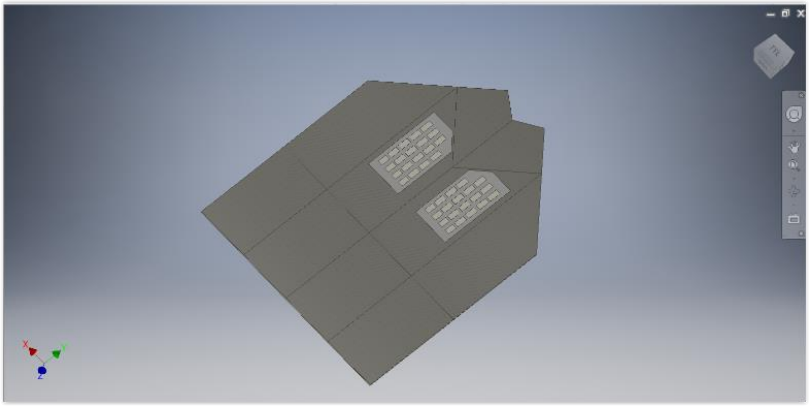

Fig. 12. Frontal cover with the molle system

At the front, the protective plates would be a material connected to the membrane on the circuit using a ziplock in order to facilitate replacing ballistic fillings or itself. This modularity would, for example, enable changing the camouflage. Moreover, fitting the shields with a molle-type mounting system for extra equipment, such as lighting, is planned (shown in Fig. 12).

3.2.3. Skeleton

The third basic element is the skeleton. Fastened to the edges of the membrane and supporting the ballistic plates, it would allow for strengthening the edges of the shield with functional elements (used for, e.g. breaking glass panes), shield stabilisation (the use of telescopic supports) and its shape, as well as quickly forming the shape by the operator. The skeleton itself would be made of carbon or aluminium profiles, connected with slam hinges, allowing for cooperation with:

- The hinge's lock at the narrowest and widest opening angles (0° – 180°) – marked in red in Fig. 13;
- The hinge's lock at an angle of 160° – marked in yellow in Fig. 13.

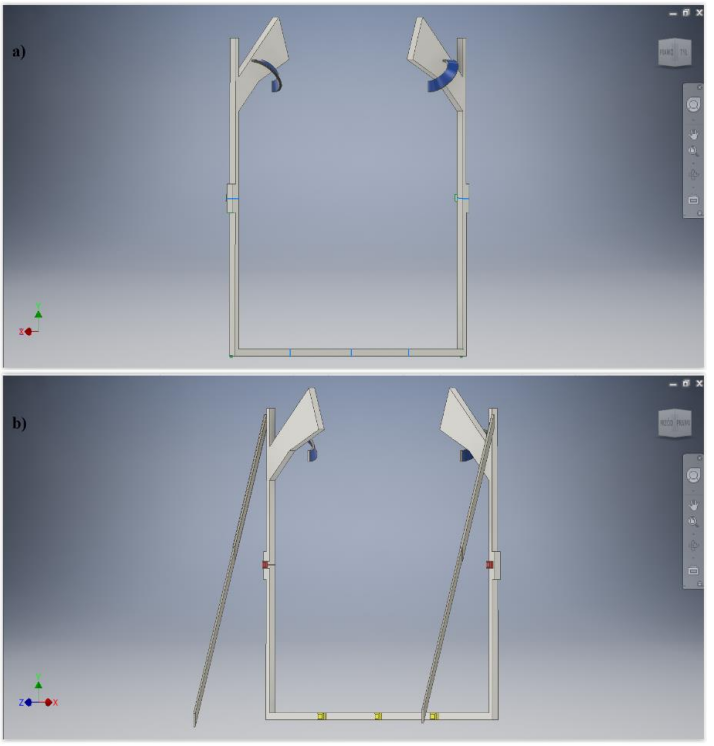

Fig. 13. The skeleton of the ballistic shield: a) from the front side, with the supports dismounted, b) from the inner side of the shield, with the supports mounted and expanded

The skeleton would also constitute the base for the poly-functional handles (marked blue in Fig. 13). In assault form, they would be used by the user to hold the shield (right- or left-handed), and in the expanded form, they would play the role of connectors for other shields, thus enabling the creation of a larger barricade.

3.3. Analysis of the project from a functional viewpoint

The conceptual project of the ballistic shield may fulfil many tasks depending on the shape assumed, as shown in Table 1.

Table 1. List of tasks for a given folding form

Folding form	Tasks
Small assault shield	• In the folded form, it provides very good ballistic protection, even when using low-grade plates; • Dimensions allowing for action in small rooms while simultaneously providing optimal body space protection (approx. 0.59 x 0.8 m) • The visor and the weapon cut-out allow the operator to fire short and long firearms; • Ability to break car windows or glazed passages; • Additional equipment may be mounted on both sides.
Large assault shield	• Shields a very large body surface (approx. 0.59 x 1.4 m); • The visor and the weapon cut-out allow the operator to fire short and long firearms; • Additional equipment may be mounted on both sides.
Small stationary barrier	• Ability to fire shots without the need to control the shield while kneeling; • Stationary barrier ensuring frontal protection (approx. 0.8 x 1 m) at an angle of 100°; • Multiple units may be joined together to form a low barricade; • Providing a low barrier for two kneeling shooters
Large stationary barrier	• Ability to fire shots without having to control the shield while standing • Stationary barrier ensuring frontal protection (approx. 1.4 x 1 m) at an angle of 100°; • Multiple units may be joined together to form a low barricade; • Providing a low barrier for two standing shooters.
Full barrier	• Flat barrier, largest surface area (1.4 x 1.2 m); • Protection for two people not participating in combat • A barrier blocking windows and door openings.

Preliminarily, it has been determined that the shield may meet the requirements pertaining to mass (i.e. up to 16 kg), owing to the type of panels used. Based on the weight of the ballistic composites that meet the protection requirements and are currently in use [3], it has been demonstrated (based on the calculations of the engineering program) that it would be possible to obtain a mass between 13.12 and 22.1 kg.

4. CONCLUSION

The use of direct defence tools such as shields is becoming (or should become) ever more commonplace. This translates to creating various products according to the situations they are intended to be used in, the operation strategy, and the costs. Creating a universal, fully-modular structure would allow various services to uniformise their training systems when it comes to the equipment used while maintaining customisability.

The presented project of the poly-functional shield may prove itself to be a protective structure, preferred by numerous services. In its current state, the idea, if a novel one, meets the majority of the assumptions only in theoretical analysis. However, without field testing, it is impossible to determine the real degree of mobility and the time taken to change between the folding forms. Detailed prototype testing, currently being carried out, is necessary.

The aspects of "origami engineering" merit greater interest on the part of institutions dealing with armament technology. The structures, shifting shapes in a simple manner, may prove useful while designing, for example, antennas, large-sized shields, or military building structures.

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Koncepcja wielofunkcyjnej tarczy balistycznej

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Streszczenie. Oddziały policyjne i wojskowe coraz częściej sięgają po dodatkowe, przenośne osłony w postaci różnych typów tarcz balistycznych. Służą one nie tylko do ochrony pojedynczego operatora, ale często też całej grupy ofensywnej lub osób postronnych. W pracy przeanalizowano obecnie wykorzystywane tarcze balistyczne, wymogi służb porządkowych i na tej podstawie określono założenia, które wykorzystano do zaprojektowania wielofunkcyjnej tarczy balistycznej. Projekt wykorzystał tzw. „inżynierię orgiami" – dziedzinę dotyczącą projektowania materiałów geometrycznie zmiennych poprzez zmianę położenia części składowych. Zaprezentowano projekt prototypu i wskazano dalszą drogę jego rozwoju.
Słowa kluczowe: tarcza, ochrona balistyczna, inżynieria origami