

DEVICE SUPPORTING MILITARY VEHICLES BUOYANCY AND BALLISTIC RESISTANCE

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Abstract

A deep modernization of equipment due to its assembling to the modern requirements of a battlefield and getting full compatibility to NATO structures caused that some military vehicles equipment with additional staff lose their buoyancy or are at the edge of losing it. The solution to this problem can be setting an additional device which helps to increase mass that allows to keep buoyancy of a military vehicle. The panels are fixed as the outer elements of the container which is simultaneously used for storing the elastic air cushions. Before the water crossing, the air cushions are filled with gas and additional buoyancy force is generated. The paper presents a structure and usage of a multi-purpose ballistic protection which, in the passive state, is an additional armour and in the unfolded state increases buoyancy lost in the case of setting additional devices or armament. In the paper, initial simulations developed with the use of Ls-Dyna software are described. The influence of modules number of the air cushion on the buoyancy of the multi-purpose ballistic protection is considered. The advantage of the solution is possibility of the chamber volume change which causes the increase of device volume of the whole module of the chambers is dependent on the vehicle buoyancy which results from its current weight.

Keywords: FEM, ballistic protection, buoyancy, military vehicles, panels, elasto-plastic

1. Introduction

A multi-purpose ballistic protection (Fig. 1) is a construction for both military and civil application [1]. Its basic purpose – ballistic protection – is obtained through application of protective panels suitable for a required class of ballistic resistance. The panels are fixed as the outer elements of the container which is simultaneously used for storing the elastic air cushions. Before the water crossing, the air cushions are filled with gas (for example, the air from the container or air compressor) and additional buoyant force is generated. In such a position, the protection performs a function of air cushion displacement. The application of a greater number of air cushions (at least three in one cassette) made of high-strength material resistant to atmospheric factors, including UV, maintain the protection ability of the construction even in the case of damage of one of them.

a)



b)



Fig. 1. Multi-purpose ballistic protection: a) unfolded state, b) passive state (ballistic protection)

A multi-purpose ballistic protection is an independent construction assembled additionally on the selected vehicle. A fastening bar included in a module and universal overall dimensions of the construction enable its assembly on the vehicles of any class. Placing a pair of modules of a multi-purpose ballistic protection on the buoyancy vehicle results in increasing of its displacement during water crossing. In the case of objects of small self weight it can also assure its buoyancy. A cuboids shape of the multi-purpose ballistic protection facilitates transportation and storage of the construction.

The assembly of the multi-purpose ballistic protection does not require any changes in the existing construction due to the fact that it is fixed on the fastening bar which is attached to the vehicle with the use of the existing technological openings. The protection displacement function allows to provide the buoyancy vehicle with the equipment without the loss of its buoyancy.

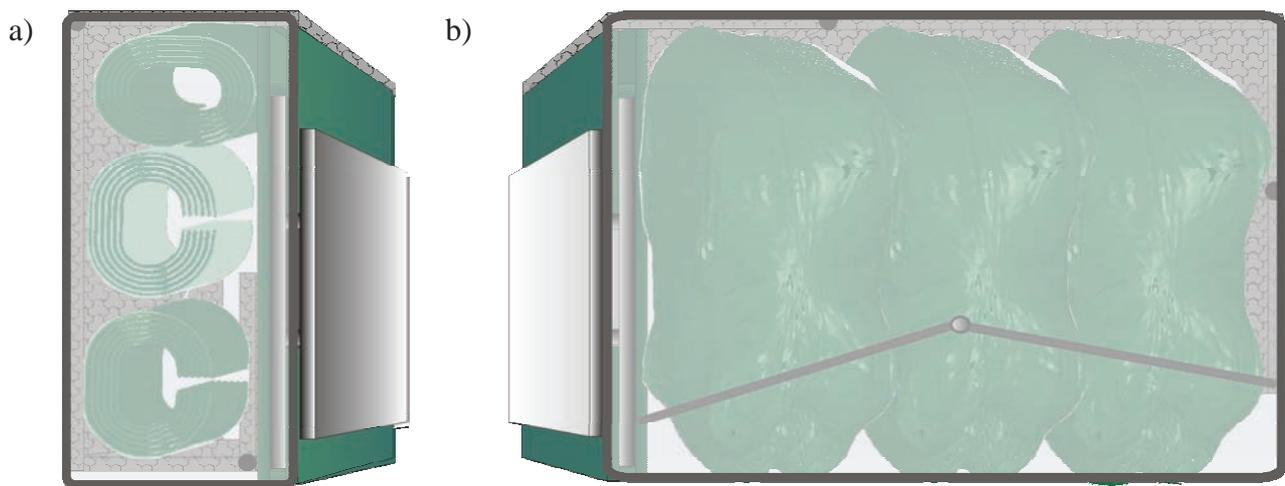


Fig. 2. Two stages of construction operation: a) passive state (ballistic protection), b) unfolded state – an idea

The constructions which is presented in the article has two states of work. The first one is a passive state (Fig. 2a) during which it works as a ballistic protection and a container for an elastic air cushion. Ballistic resistance of the device depends on the type of protective panels which are used to build it. The second one is an unfolded state (Fig. 2b) during which an elastic air cushion filled with air assures additional buoyancy.

The presented solution has the following advantages:

- ballistic resistance according to User's requirements (depends on the type of protective panels),
- assurance of additional buoyancy,
- high – strength non-flammable resistant elastic air cushion,
- an independent construction which can be assembled on any vehicle,
- regular shape – convenient transportation and storage,
- alternative sources of filling the air cushion,
- replaceable cushions.

2. Module dimensions

Dimensions of the multi-purpose ballistic protection are calculated mathematically. Initial overall dimensions of the module are presented in fig. 3. For the assumed dimensions, the displacement of the module with a filled elastic cushion equals 0.076 t. Additional displacement depends on the length of a vehicle and the number of modules sets placed on it. A modules set consists of two modules placed symmetrically on the both sides of the vehicle. Total additional displacement depending on the number of modules are shown in Table 1.

Tab. 1. Total additional displacement depending on the number of modules of multi-purpose ballistic protection

Number of modules	1	2	4	8	12	24	28
Width of module [m]	0.71	1.41	1.41	1.41	1.41	1.41	1.41
length of module [m]	0.50	0.50	1.00	2.00	3.00	6.00	7.00
height of module [m]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
volume of module [m ³]	0.18	0.35	0.71	1.41	2.12	4.24	4.94
bering area [m ²]	0.35	0.71	1.41	2.82	4.24	8.47	9.88

3. The scheme of working

The multi-purpose ballistic protection is a self construction which can be set on any vehicles. Inflatable buoyancy devices are kept in storage housings on the outside of vehicle. During a normal use, buoyancy bodies are folded up and stored under covers. Only when the vehicle is on the water the covers open and buoyancy bodies fill with air. An on-board compressed air system supplies air for filling buoyancy bodies. The additional use of outside air enables more air to be supplied to the buoyancy bodies at lower pressure than the sole use of the on-board compressed air system. After unlocking, due to compressed air, the elastic cushion increases its volume causing rotation of the cover to the horizontal position. A two-segment bottom of container unfolds making the straight line which lies vertically in the passive state.

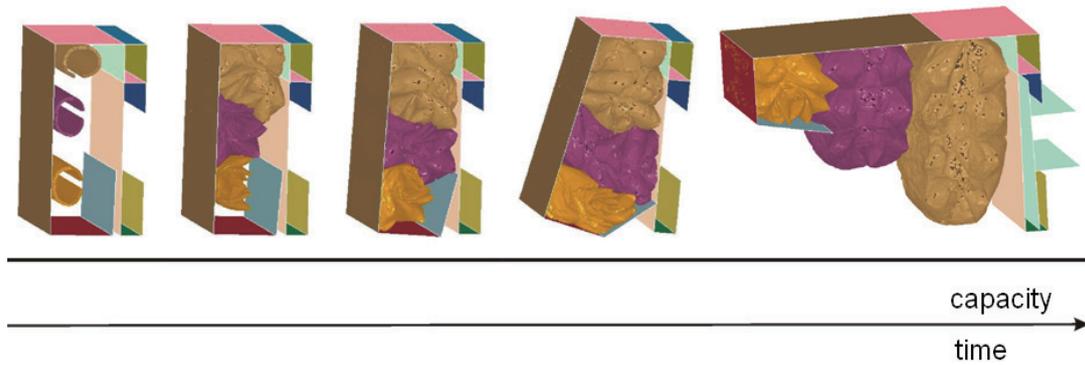


Fig. 3. Scheme of working of multi-purpose ballistic protection

4. Numerical Models

Such composed construction of the multi-purpose ballistic protection requires consideration of many problems such as gas dynamics (airbag filling), contact problem and rigid body dynamics. For example, angular accelerations of the metal parts are described by the second order differential equations in the terms of an angle. Boundaries velocities of the cushion wall can be calculated mathematically, assuming simplification, for example, that a shape of the cushion is a regular cylinder and has infinite length. The equation to solve this problem has the following form [2]:

$$\int_{V_{c.v.}} \frac{d\rho}{dt} dV + \int_{S_{c.v.}} \rho U_b dV = \int_{S_{c.v.}} \rho U_m dA, \quad (1)$$

where: the first term in the above equation describes increase pressure, the second one the boundary velocity and the right hand side is in a flow rate.

The boundary velocity is then [2]:

$$U_b = \frac{3m_i RT}{7f\pi^2 R_c^3}, \quad (2)$$

where: the gas mass is supplied in uniform way of m_i [kg/m/sec], R is the universal gas constant and T means temperature, R_c is the instantaneous cylinder radius, f is a coefficient with the right dimension.

To get the exact solutions of the above problem the numerical methods should be used, therefore LS-Dyna code based on an explicit time integration is employed. The LS-PrePost program is a pre-processor for defining all necessary parameters such as boundary conditions, element properties, material properties, solution type, and many others.

To define thermodynamic behaviour of the gas flow into the airbag as well as a reference configuration for the fully inflated bag, the airbag option is used [3, 4]. The gamma law equation of state is used to determine the pressure in the airbag:

$$p = (\gamma - 1)\rho e, \quad (3)$$

where: p is the pressure, ρ is the density, e is the specific internal energy of the gas, and γ is the ratio of the specific heats at constant volume and pressure, respectively:

$$\gamma = \frac{c_p}{c_v}, \quad (4)$$

where: c_v is the heat capacity at constant volume and c_p is the heat capacity at constant pressure.

The curves of the inflow mass rate are given in Fig. 4.

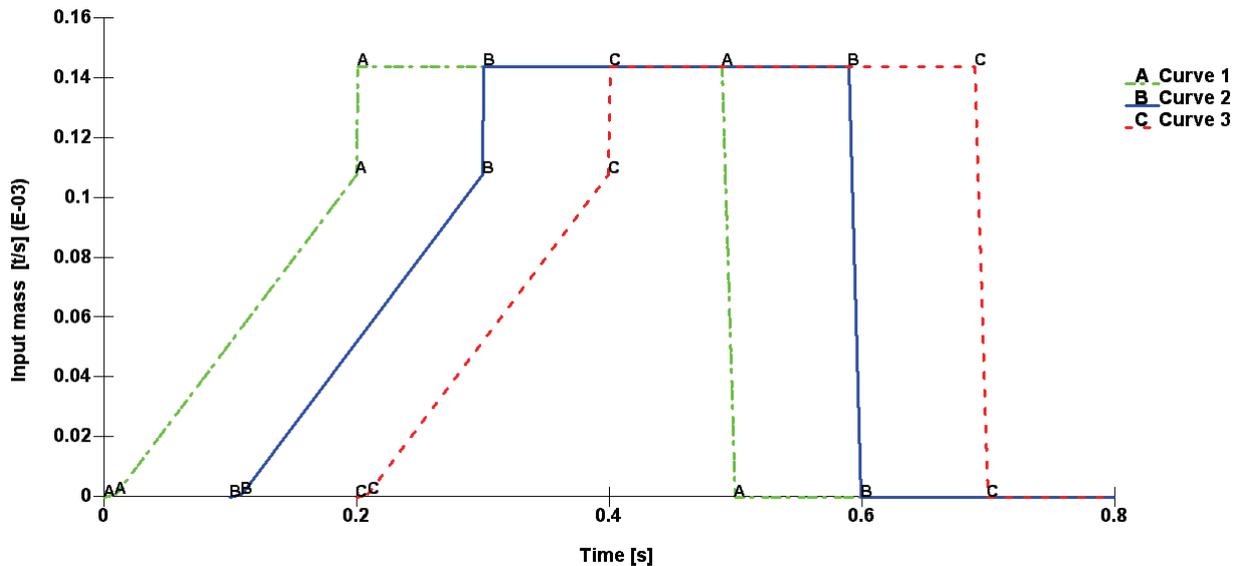


Fig. 4. Load curves specifying input mass flow rate for three air bags

The FEM simulation of the simple structure model consisted of three deformable walls and an inflatable air bag (Fig. 5) is performed. Two fixed perpendicular walls are made of steel. One air cushion is attached to the horizontal wall. The two other are attached to the the vertical wall. This vertical wall is a moving part made of light metal or of composite material corresponding to the metal with strength and stiffness, for example composite sandwich (Fig. 5). One revolute joint is placed between the horizontal wall and the other vertical wall. Its rotation is assured by the filled air bag. Extending volume of the air bag presses on a moving metal part causing its rotation. This moving part is connected to another horizontal wall by weld.

The presented FE model consists of about 150 000 shell elements used for the multi-purpose ballistic protection modelling (Fig. 5).

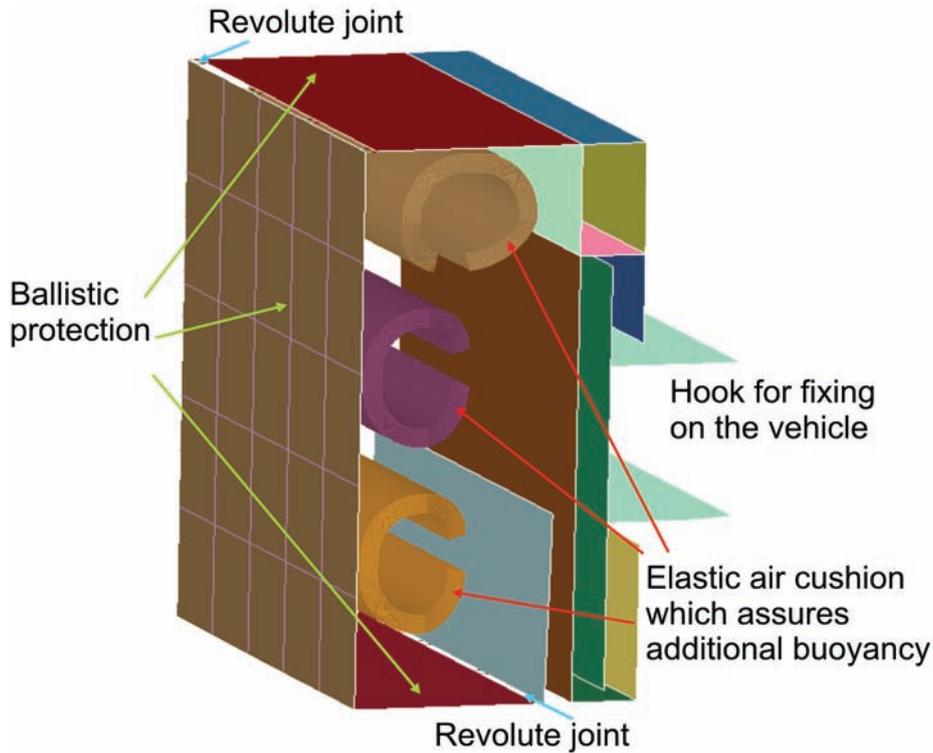


Fig. 5. Numerical model of multi-purpose ballistic protection

Elasto-plastic material models are considered to describe parts of the container. Tensile and compressive testing is required to determine mechanical property data like: Young’s modulus of elasticity, yield strength and nonlinear behaviour of a stress - strain curve above the yield stress level. Material property data are presented in Table 2.

Tab. 2. Properties of the elasto-plastic material model

Materials	Young’s modulus [MPa]	Poisson’s ratio ν	Yield stress [MPa]	Strenght [MPa]	Elongation [-]
Steel	210 000	0.3	220	630	0.19

A fabric elastic - perfectly plastic material model is applied for the purpose of air cushion modelling. In addition to being a constitutive model, this model also invokes a special Belytschko-Tsay membrane element formulation with 1 integration point through the element thickness which is more suited to the deformation experienced by fabric under large deformation [5]. These elements are based on a combined co-rotational and velocity-strain formulation. Properties of the fabric are presented in Table 3.

Tab. 3. Properties of the fabric material model [5]

Young’s modulus’s [GPa]	E_1	24.1
	E_2	24.1
Poisson’s ratios [-]	ν_{12}	0.12
Shear modulus’s [GPa]	G_{12}	5.90

6. Conclusions

Numerical three-dimensional simulation of such a big device requires an access to a powerful computer or a cluster due to huge numbers of equilibrium equations to be solved. Describing deformable parts of the containers as rigid is a good modelling technique in early design studies. It becomes aware of the behaviour of a whole device and determines the main problems which may

occur. For example, it is easy to notice that the influence of the chamber mass is negligible due to the air cushion rubber-like material in presented models.

The advantage of the proposal solution is possibility of the change of the chamber volume which causes the increase of device . Thus, this device can be built in the way that volume of the whole module of the chambers is dependent on the vehicle buoyancy which results from its current weight.

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