FINITE ELEMENT ANALYSIS OF BALLISTIC RESPONSE OF LAMINATED TEXTILE FABRIC MULTILAYERS IN LS-DYNA

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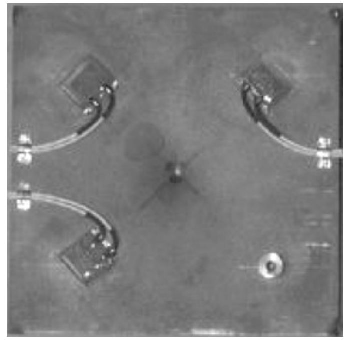
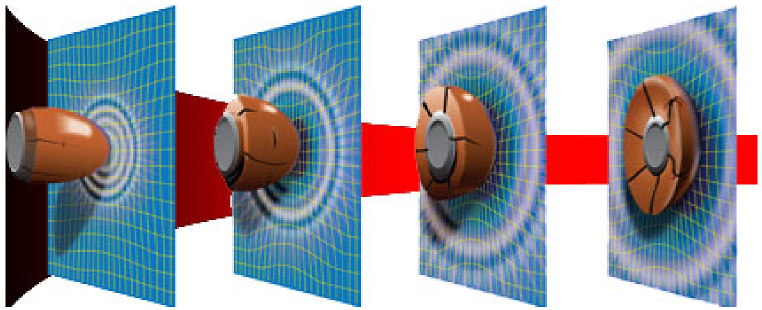
PROBLEM FORMULATION – development of multifunctional ballistic protective package applying:

- **Hybrid constructions**

- **Mechatronic structures**

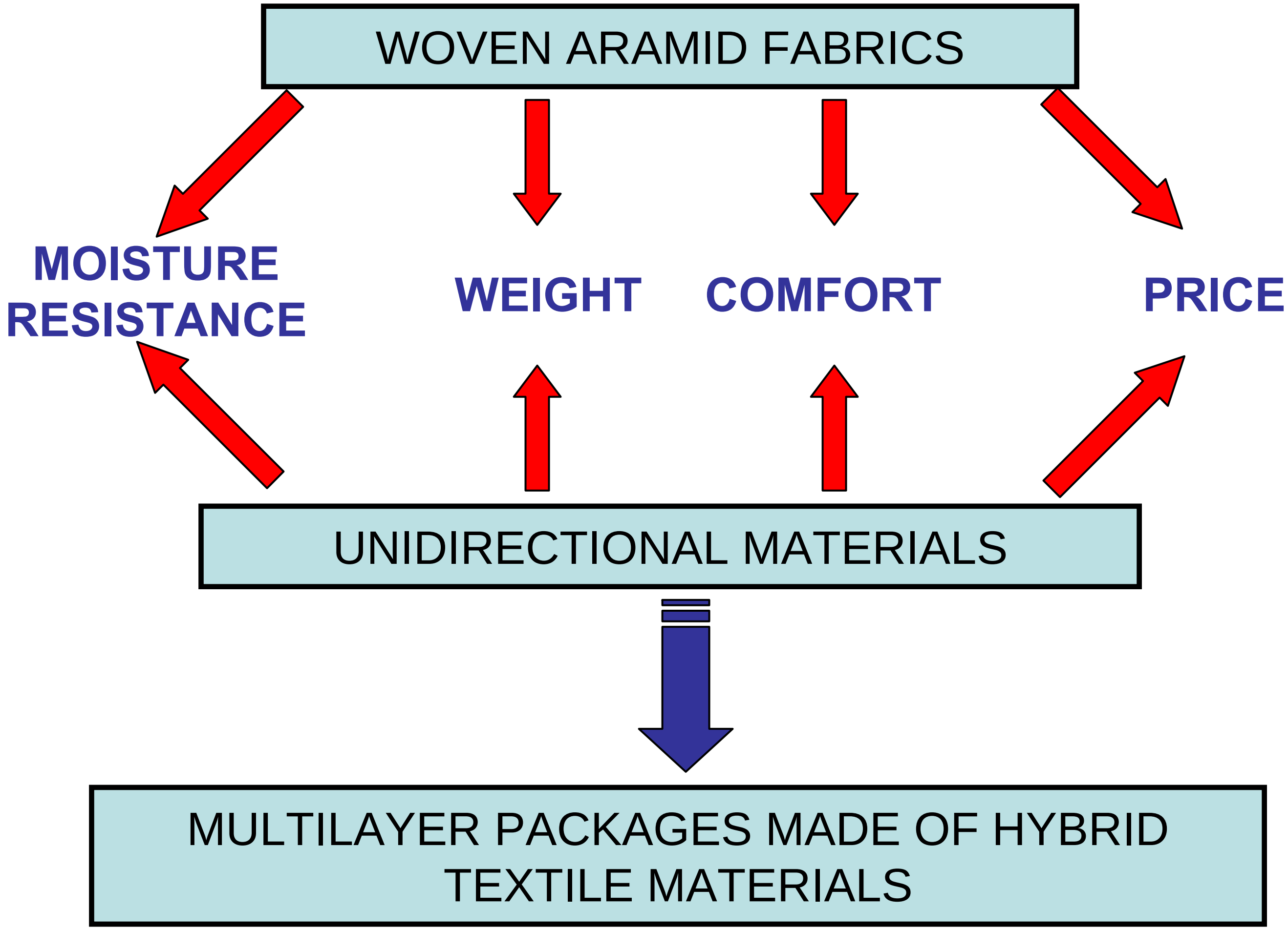


- **Computational models**

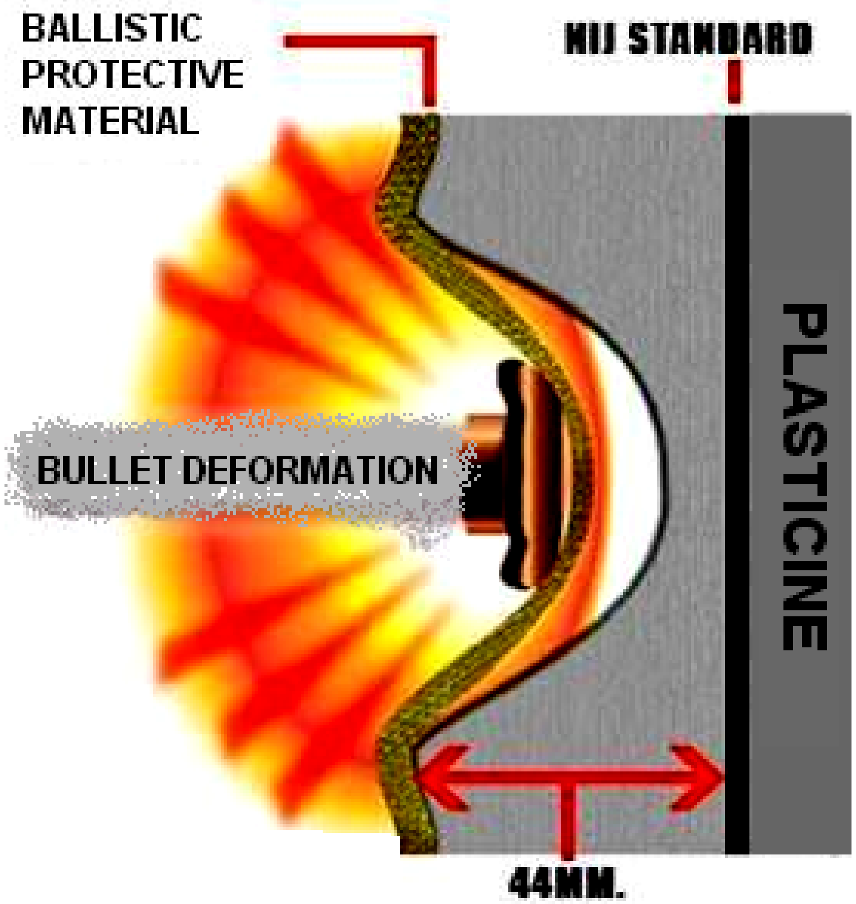


INVESTIGATION AND COMPARATIVE ANALYSIS OF CHEMICAL FIBERS AND FABRIC STRUCTURES USED FOR BALLISTIC PROTECTION

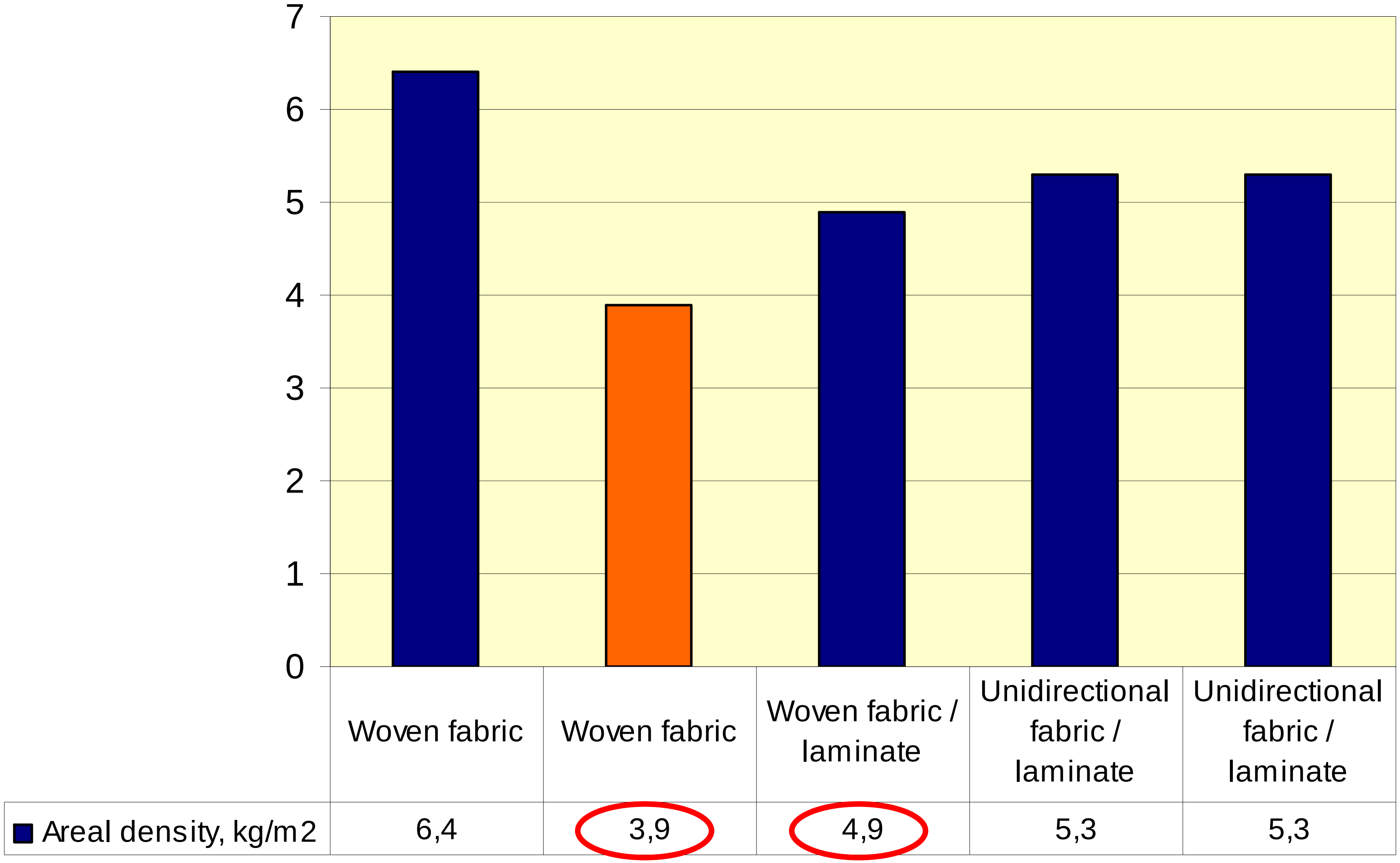
Textile materials for ballistic protection:



BALLISTIC TESTING AND EVALUATION

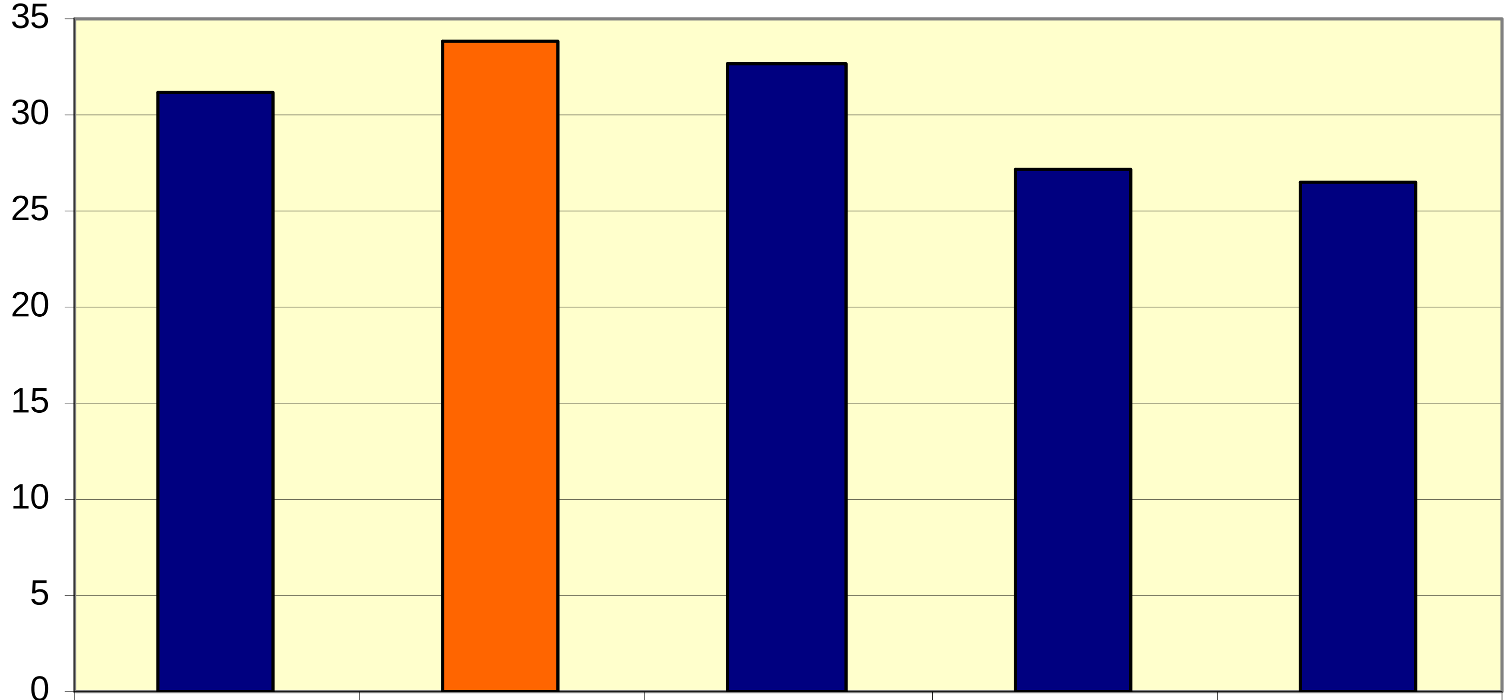


Comparative investigation of ballistic properties of homogeneous ballistic packages from various materials



Packages protecting from 9 mm FMJ RN bullet; standard velocity – 436±9 m/s.

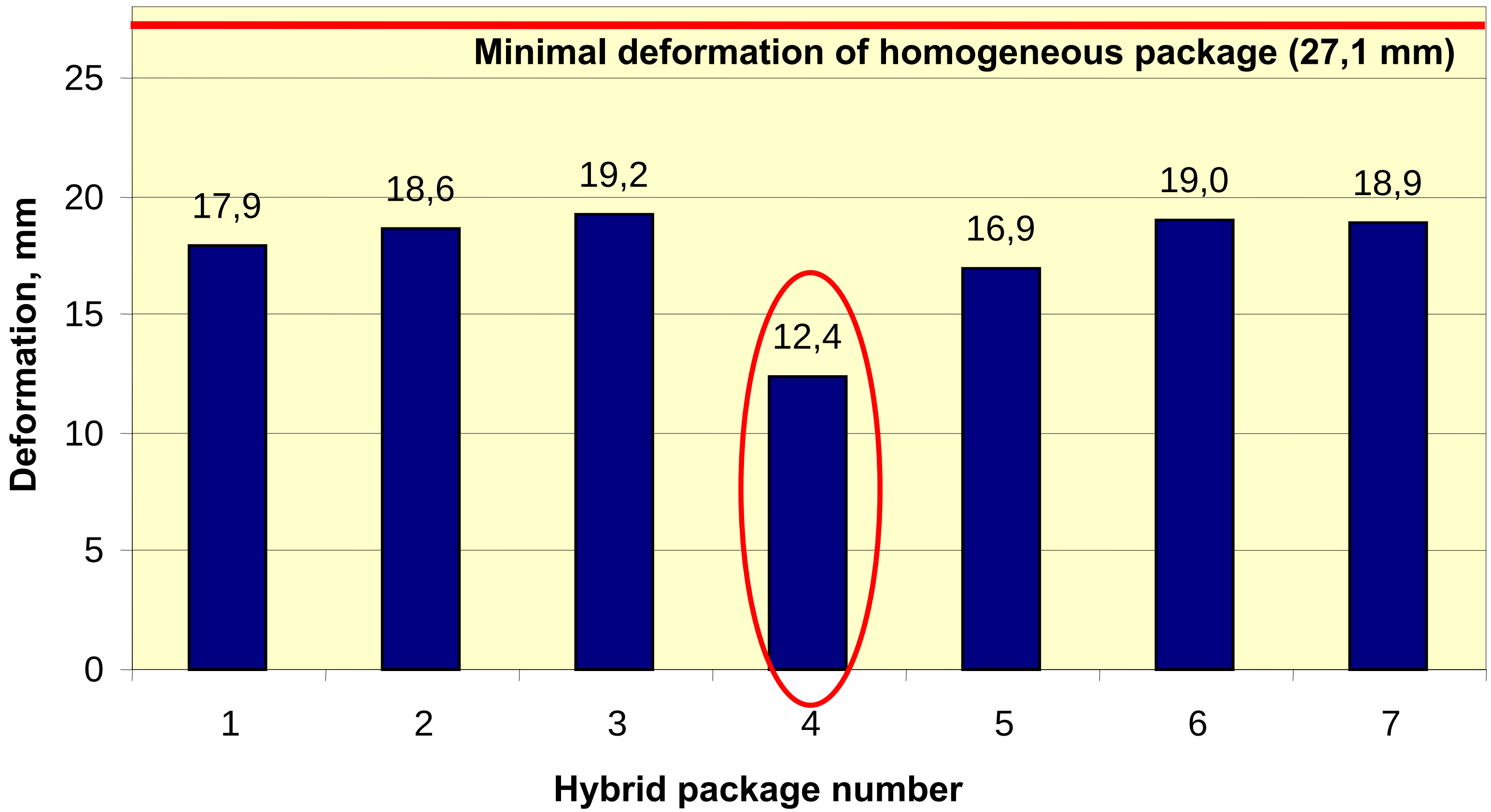
Comparative investigation of ballistic properties of homogeneous ballistic packages from various materials



	Woven fabric	Woven fabric	Woven fabric / laminate	Unidirectional fabric / laminate	Unidirectional fabric / laminate
Deformation, mm	31,24	33,9	32,73	27,11	26,56

Packages protecting from 9 mm FMJ RN bullet; standard velocity – 436±9 m/s.

Ballistic testing of packages from hybrid textile materials



Packages protecting from 9 mm FMJ RN bullet; standard velocity – 436±9 m/s.

Ballistic properties of textile packages can be predicted by using the *finite element models*

- FEM is a technique, which enables to represent realistically the physical behavior of complex systems;
- By means of FEM a complex structure is represented as an assembly of small fragments of simple geometrical forms (finite elements);
- The behavior of each FE is described by equations based on physical laws.

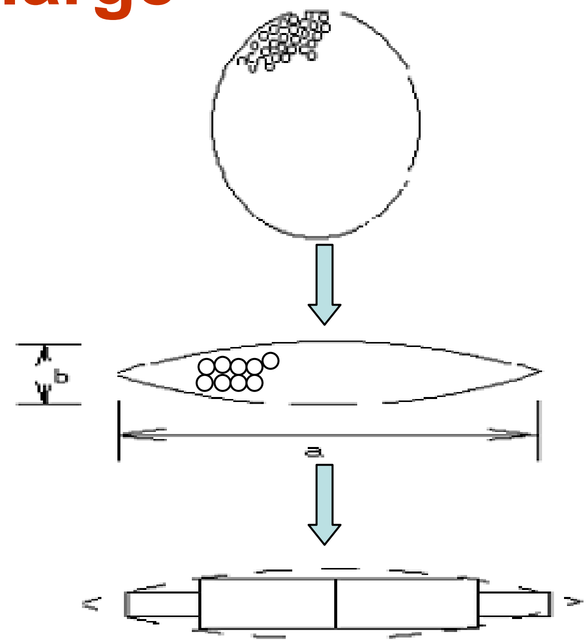
Models of Textile Fabric Layers

•"Micro-mechanical": <u>filament</u> as primary component

Not used: model dimensionality too large

- "Mezo-mechanical": <u>yarn</u> as primary component

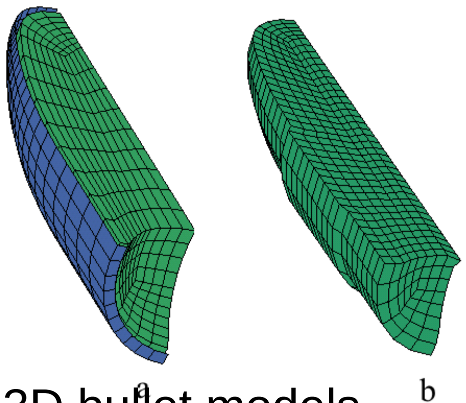
Yarns presented as thin shells



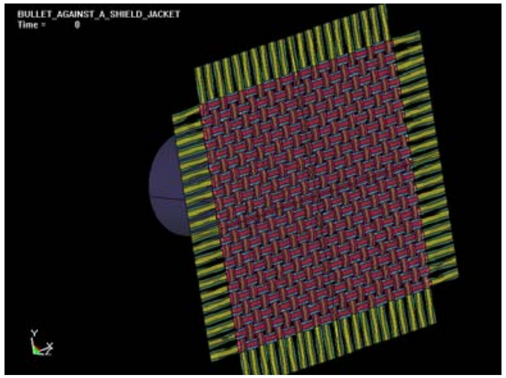
- "Macro-mechanical": <u>fabric</u> as primary component

Fabric presented as a continuous membrane

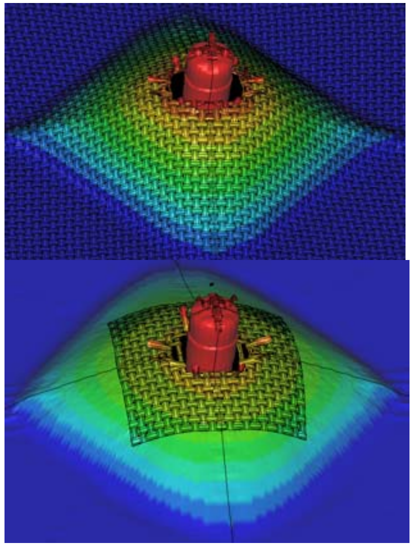
- **FE models of terminal ballistics are complex and multi-component;**
- **Model components are experimentally validated in order to adjust their parameters for ensuring the adequacy of the results to the reality;**
- **Model validation is performed according to the rationally planned sequence of physical and computational experiments.**



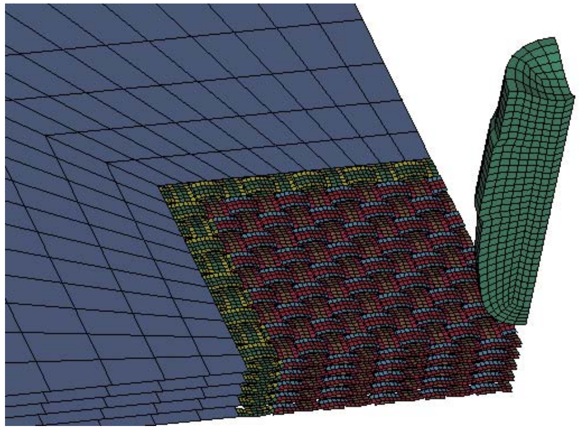
3D bullet models



Mezzo-mechanical model of the woven structure



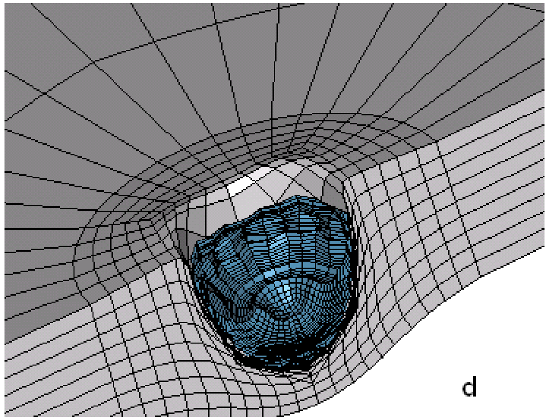
Combination of mezzo- and macro- mechanical models

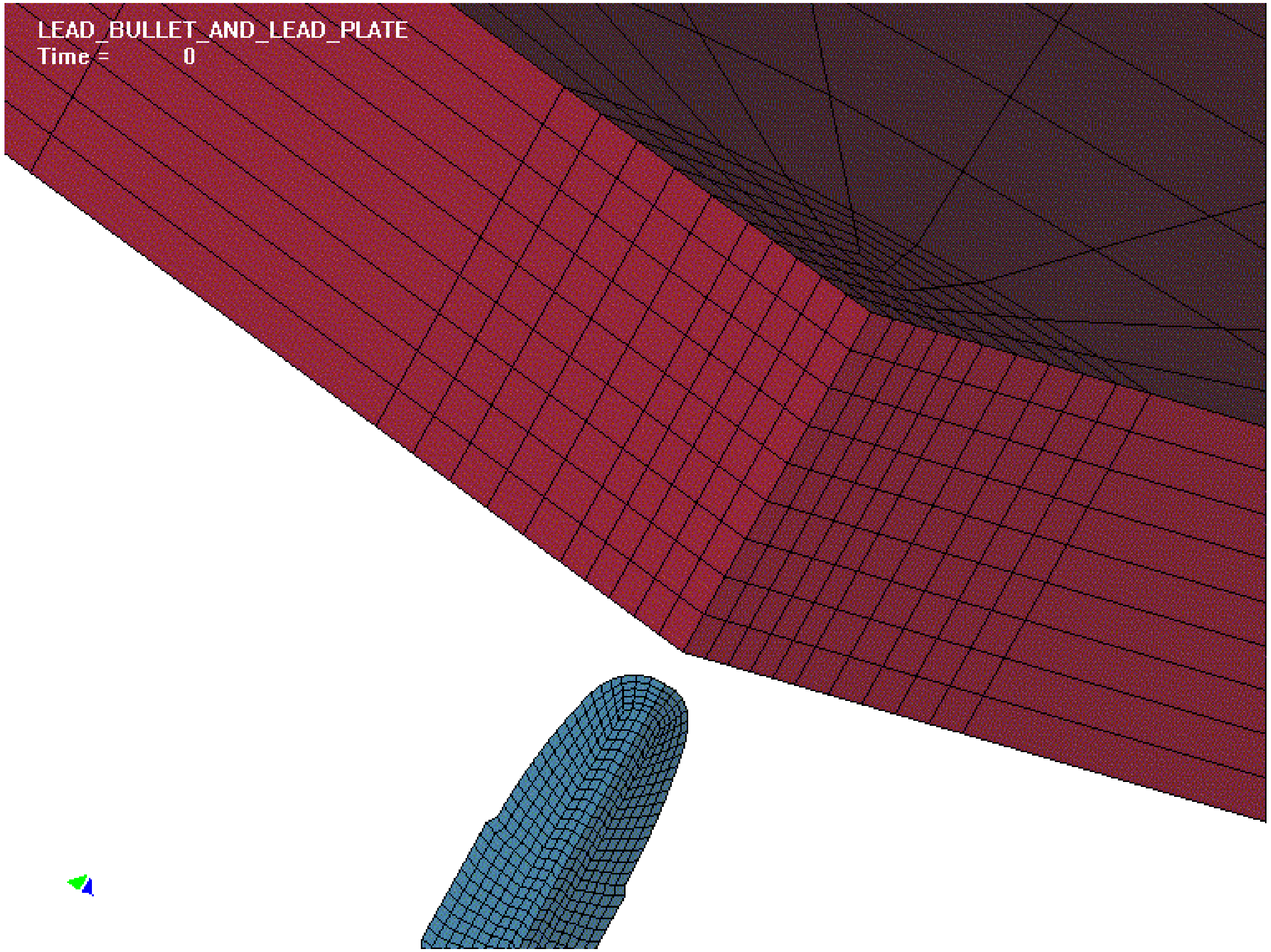


Joined model of ballistic interaction

Validation of model components:

Ballistic interaction of a lead bullet against a lead plate (determination of dynamic parameters of the material)





Sources of possible inadequacy of the model:

adjusting the material constants values in the process of the model validation

- Very approximate model of a yarn;
- Lack of a full set of material constants (mostly dynamic ones);
- Limited size of a multilayer package presented by a woven structure model

*adjusting the *MAT_FABRIC constants values in the process of the model verification*

Material models

- brass and lead are elastic-plastic materials (*MAT_PLASTIC_KINEMATIC)
- TwaronCT assumed to be perfectly elastic up to failure limit
- in high velocity impact interaction the yield stress is dependent upon the strain rate (Symonds-Couper model):

$$\sigma_Y = \sigma_{Y0}\left[1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{p}}\right]$$

Bullet model validation:

Determining the lead material dynamic parameters

- numerical and physical experiments of shooting the lead bullet into 10mm thickness lead plate;
- The data obtained from the physical experiment:

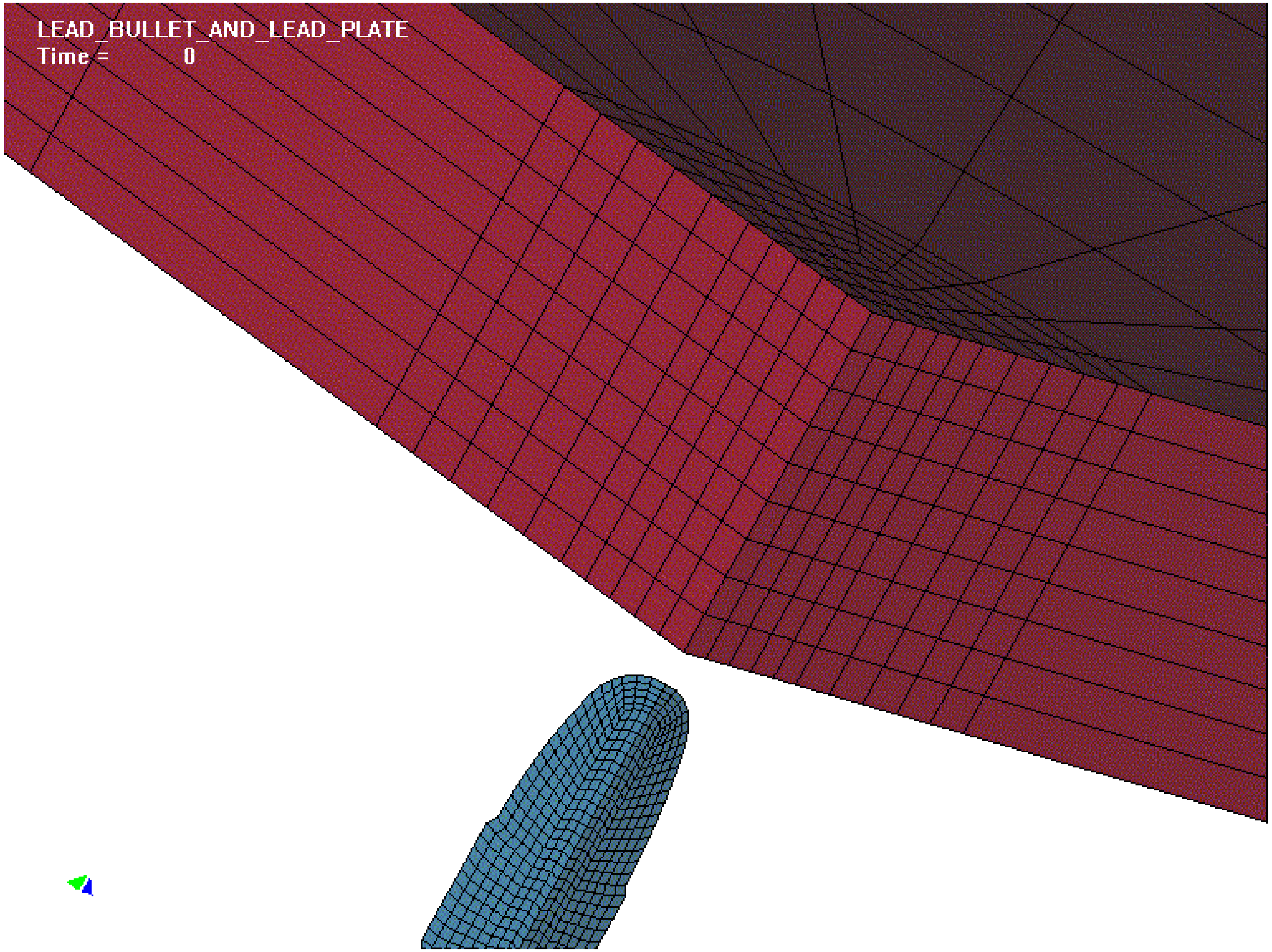
  -the measured linear momentum supplied to the plate;

  -the deformed shape of the bullet imbedded into the target

$MID	RO	E	PR	SIGY	ETAN	BETA
1	**11270**	**1.7E+10**	**0.4**	**8.00E+06**	**1.5E+07**	**0.1-0.2**

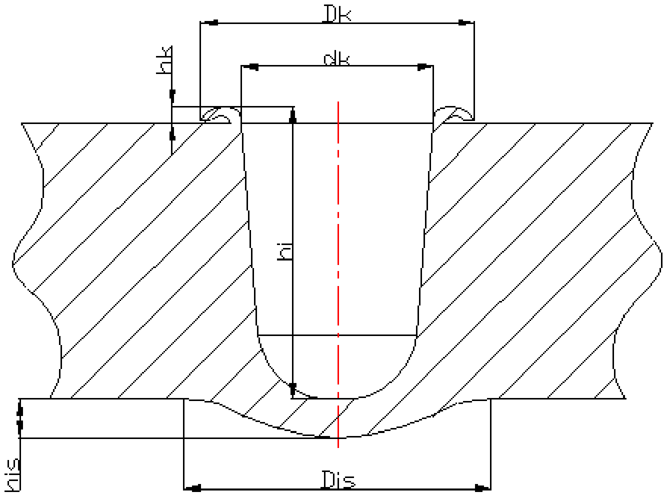
$SRC	SRP
600	**3**

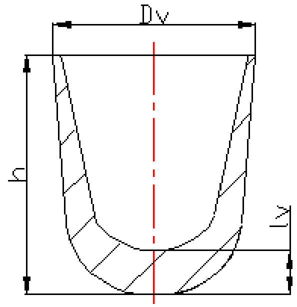
Simulation of Impact of the Lead Bullet Against the Lead Plate

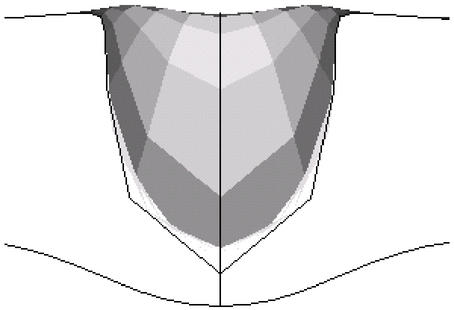


Scheme of experimentally measured dimensions

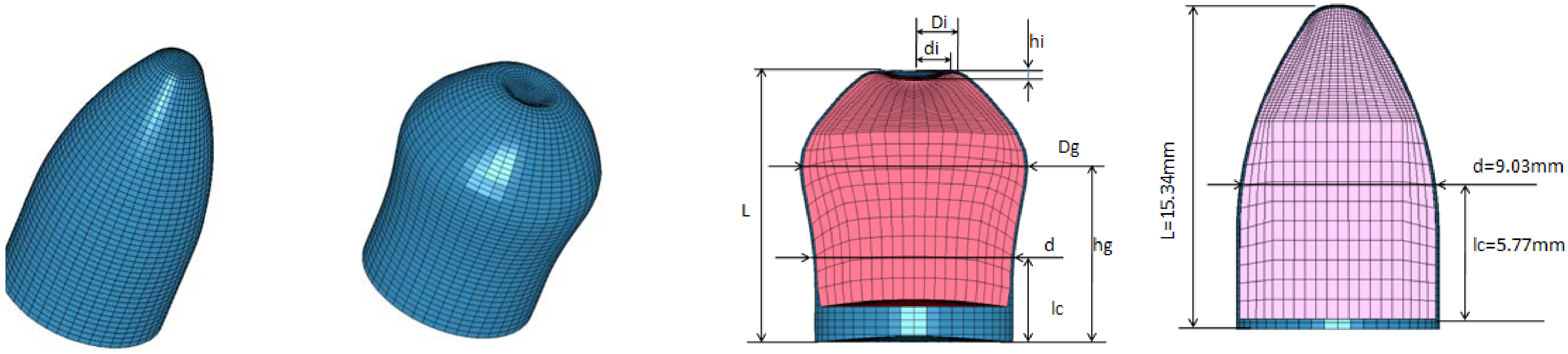
- the pit punched in the plate (a)
- the remains of the bullet (b)





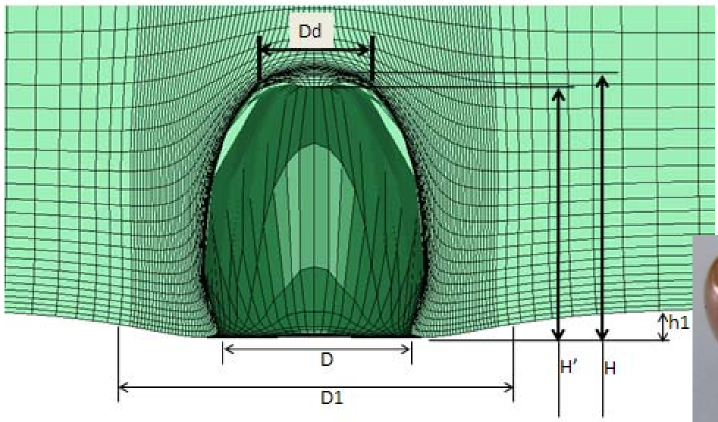


measured value	D_k	d_k	h_k	h_i	D_{is}	h_{is}		m_l	D_v	h	l_v
experimental	13,27	9,34	1,82	13,34	14,89	4,77		2,36	8,93	9,75	3,03
simulated		11,00		11,30	19,00	3,20		2,23	10,20	9,40	3,80



1 - 129m/s;
2- 162m/s;
3- 193m/s
f

2.9 pav. Į švino plokštę įsmigusios kulkos ir išmuštos duobutės geometriniai parametrai:
a,c – kulkos išeities matmenys ir erdvinis vaizdas; b,d – deformuotos kulkos išeities matmenys ir erdvinis vaizdas; e – duobutės geometriniai parametrai; f – de
kulkos nuotraukos esant skirtingiems sąveikos greičiams

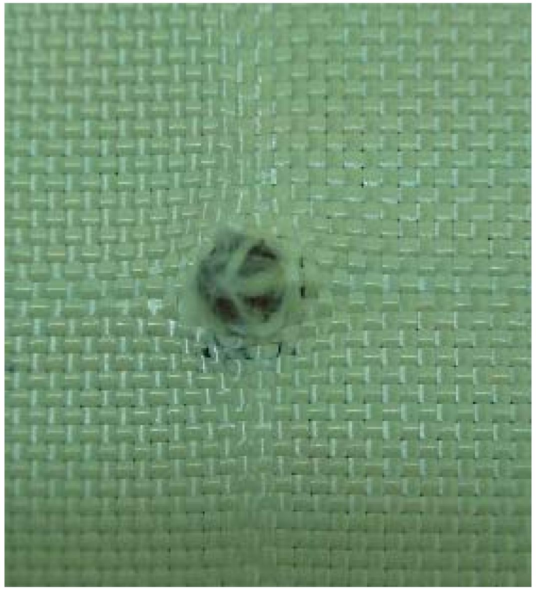


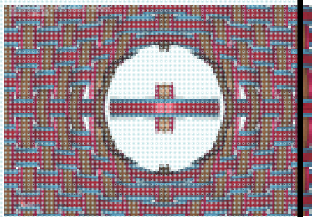
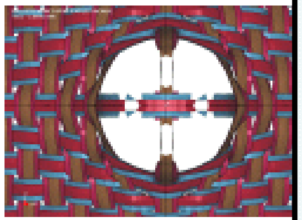
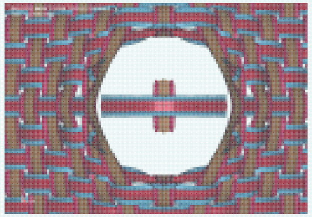
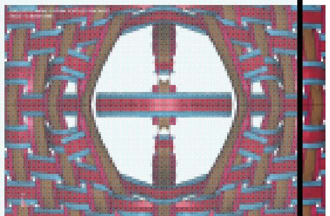
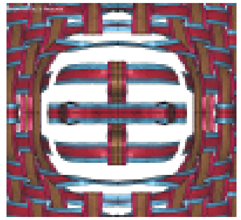
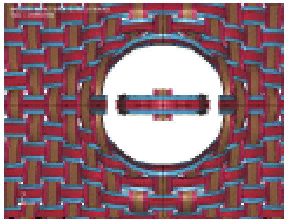
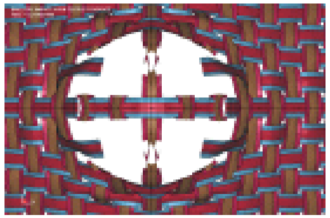
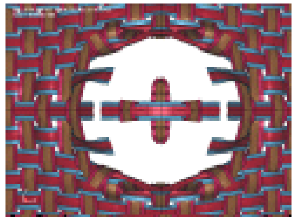
Model validation of a single textile layer : number and patterns of broken yarns (dynamic friction coefficients determined)

$$0.1 < FSk < 0.2;$$

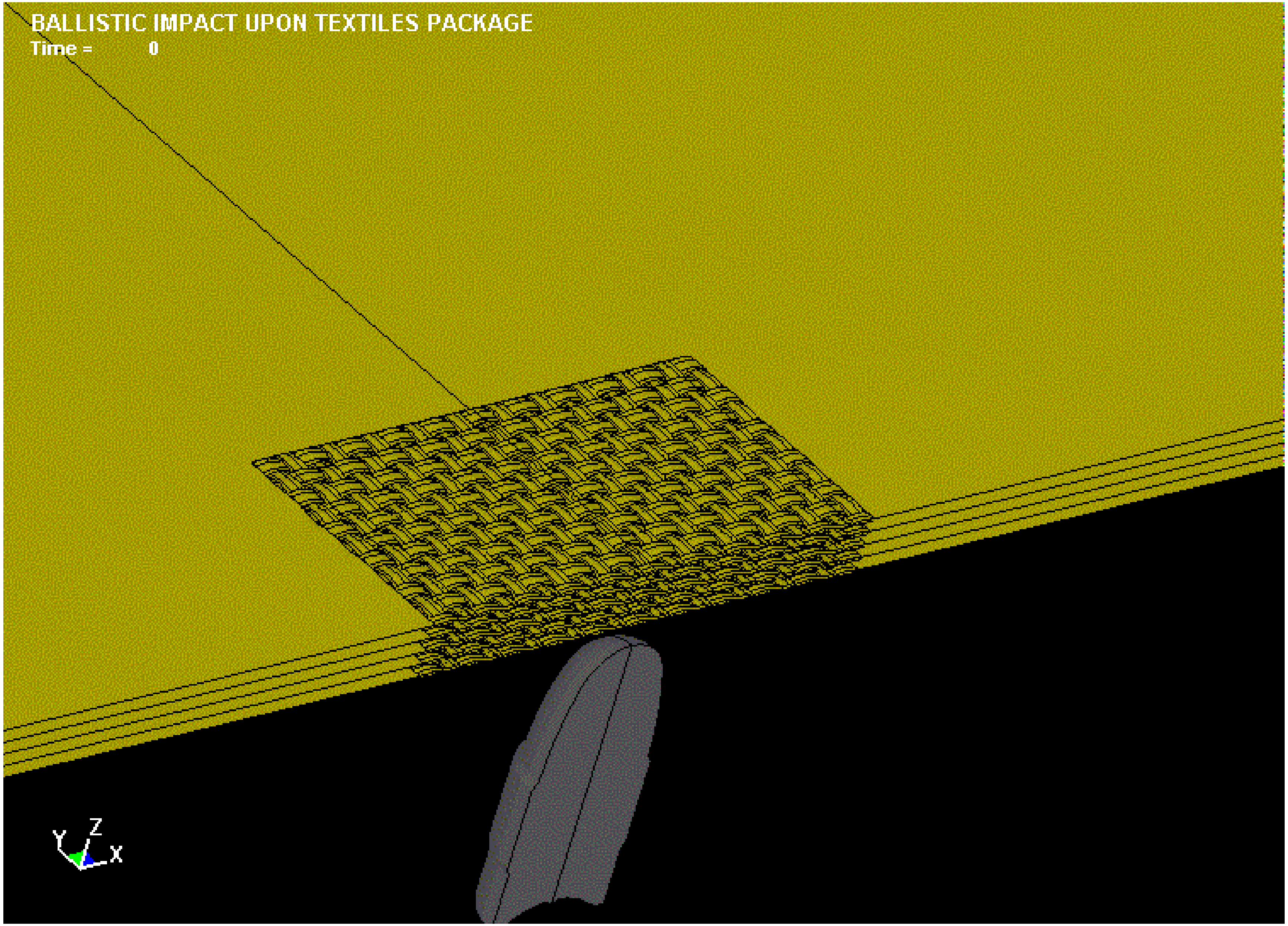
$$0.1 < FSs < 0.2;$$

$$FSs + FSs < 0.3$$

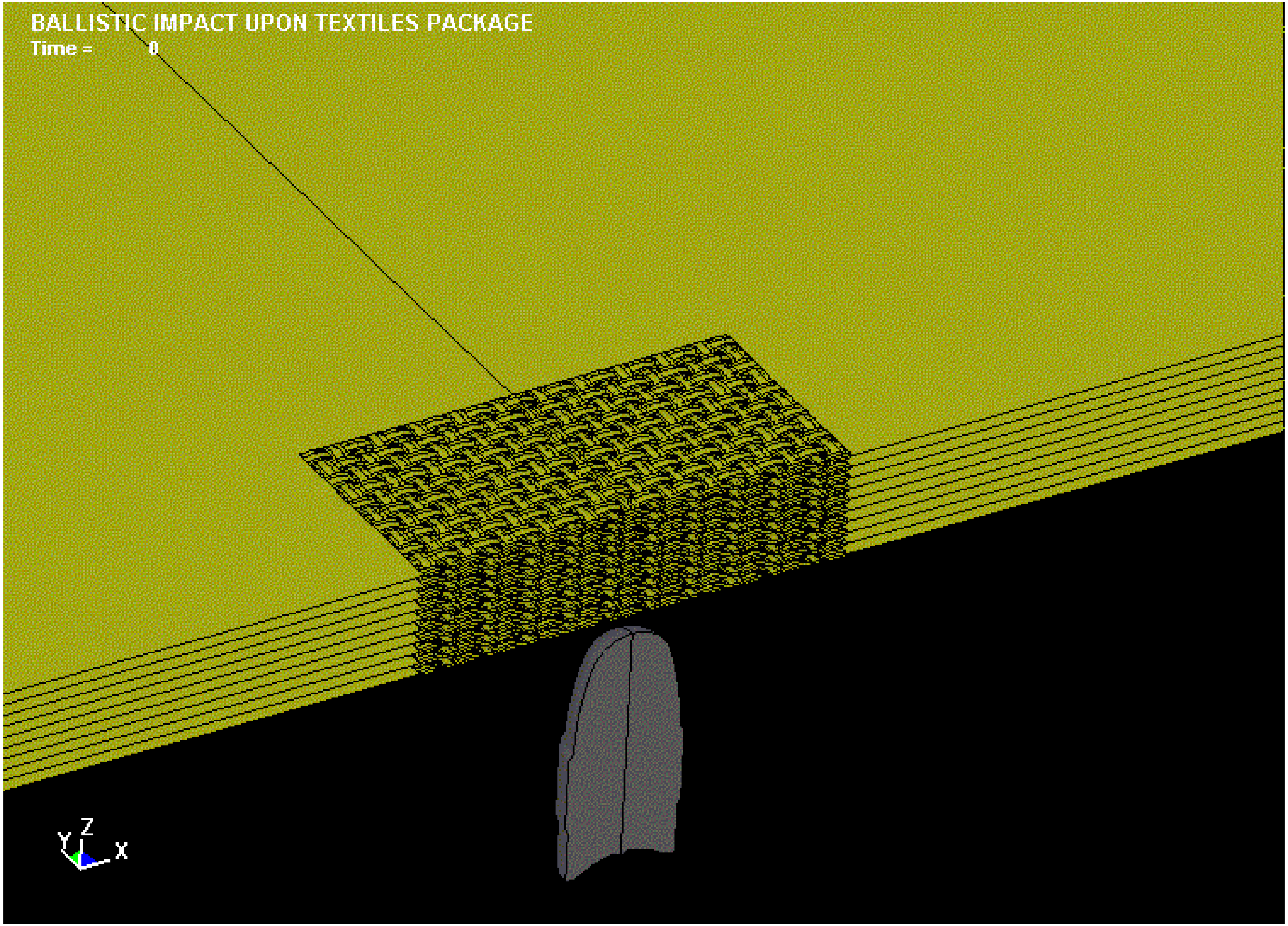


FSs	FSk=0	FSk=0.1	FSk=0.15	FSk=0.2
0.15			t=2.58e-5;3.06e-5s; z=0.0063;0.0075 epmax=0.55 **Wf0, 2Wp1 -> Wp0 (4)** 	
0.2	t=2.4e-5;2.7e-5s; z=0.0058;0.00665 epmax=0.45 **Wf0 -> Wp0 (2)** 	t=2.58e-5;3.36e-5s; z=0.0063;0.0082 epmax=0.5 **2Wp1 -> Wf0 -> Wp0 (4)** 	t=1.86e-5;3.06e-5s; z=0.0044;0.00715 epmax=0.55 **2Wp1 -> Wf0-> Wp0 (4)** 	t=3.18e-5;4.68e-5s; z=0.0077;0.01166 epmax=0.6 **2Wf1 -> Wf0 -> Wp0 -> 2Wp1 (6)** 
0.3	t=2.28e-5;3.6e-5s; z=0.0055;0.00873 epmax=0.5 **2Wf1 -> Wf0->Wp0 (4)** 	t=3.54e-5;5.22e-5s; z=0.0085;0.0124 epmax=0.65 **2Wf2 -> 2Wf1 -> 2Wp1-> ->Wf0 >Wp0 (8)** 		t=3.18e-5;4.98-5s; z=0.0077;0.0118 epmax=0.65 **2Wf2 ->2Wf1,2Wp1-> ->Wf0 >Wp0 (8)** 

300 m/s ballistic interaction against 5 layer package



300 m/s ballistic interaction against 10 layer package

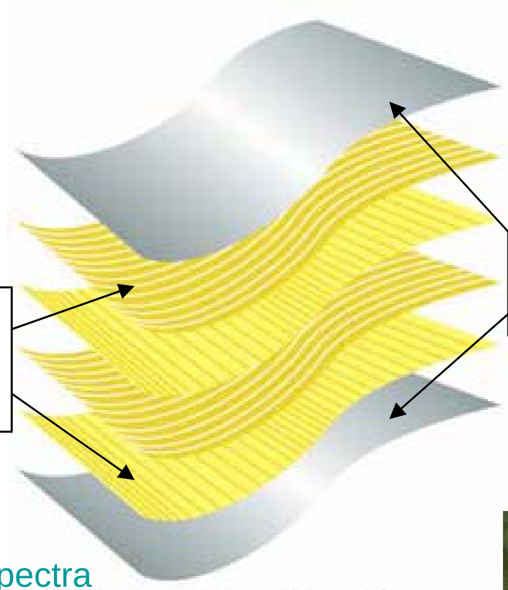


Models of Layers and Packages

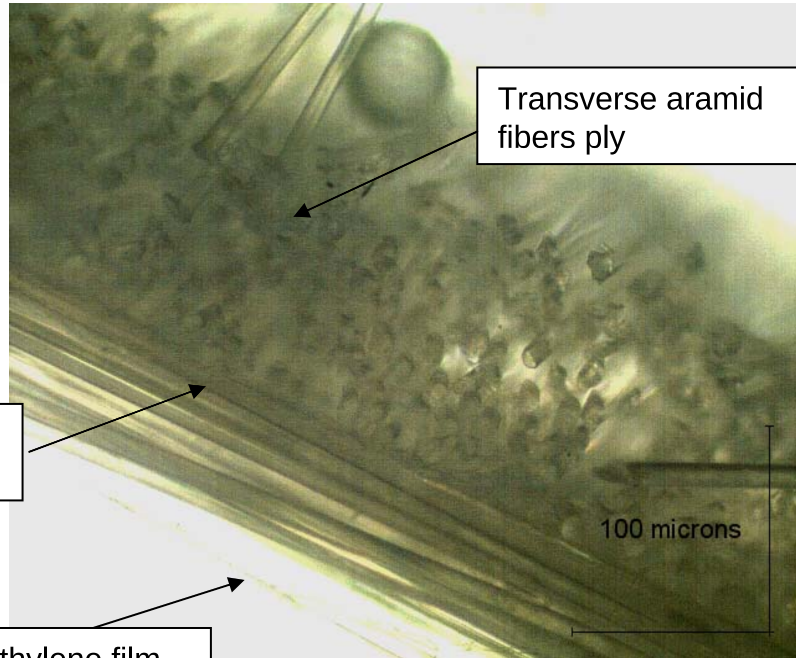
- Creation and validation of *single layer models* allows to explain the regularities of their physical behavior and thus prepares the main components for creation of structural models of packages.

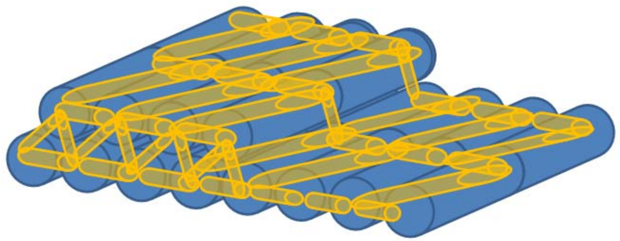
- On the base of models of separate layers the *structural models of ballistic packages* are created, the calculation of which enables to improve the structural designs of textile packages and to improve their ballistic performance.

New research problems : Textile laminates

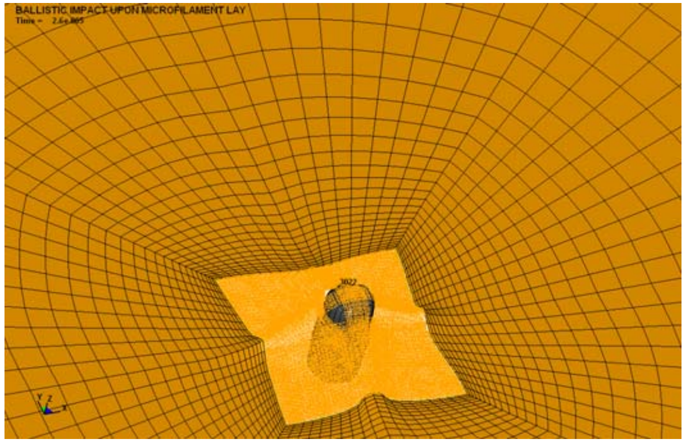


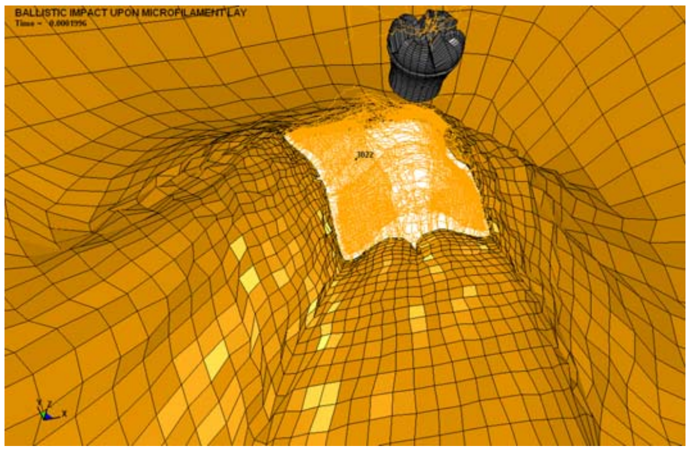
http://www.honeywell.com/spectra

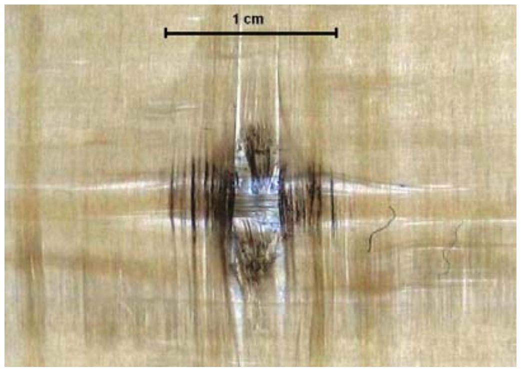


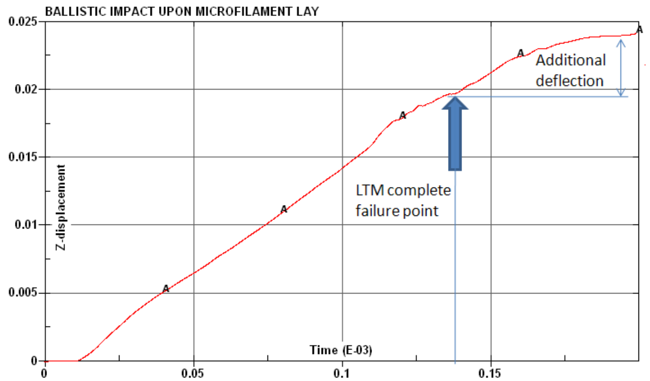


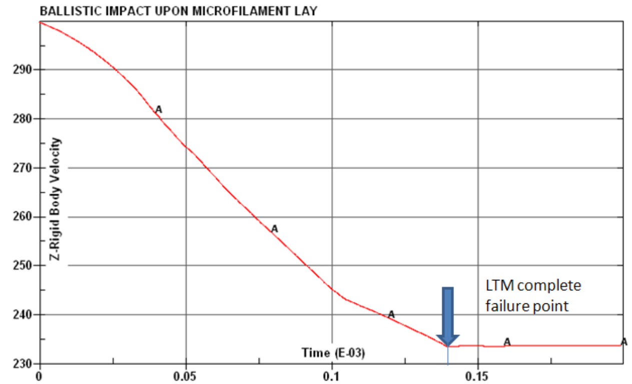
2.11 pav. Paraaramido filamentų BE ir jų suklijavimą elastomeru pavaizduojančių strypelių (šviesesnė spalva) apytikris išdėstymas meco-mechaniniame LTM modelyje (žr. taip pat 28 pav.)

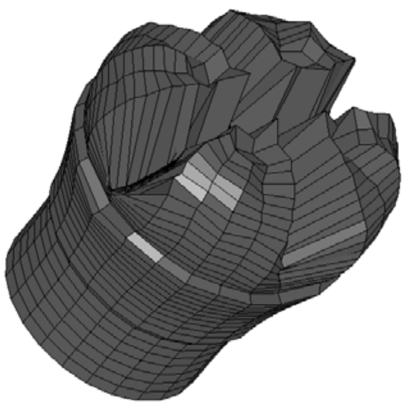







BALLISTIC IMPACT UPON MICROFILAMENT LAY
Z-displacement
Time (E-03)
Additional deflection
LTM complete failure point
0.025
0.02
0.015
0.01
0.005
0
0
0.05
0.1
0.15


BALLISTIC IMPACT UPON MICROFILAMENT LAY
Z-Rigid Body Velocity
Time (E-03)
LTM complete failure point
290
280
270
260
250
240
230
0
0.05
0.1
0.15

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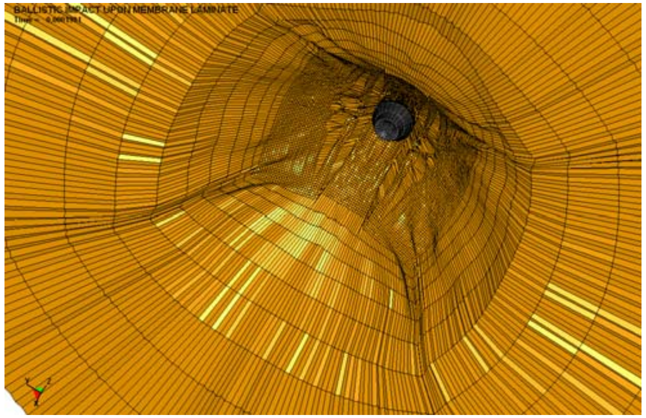
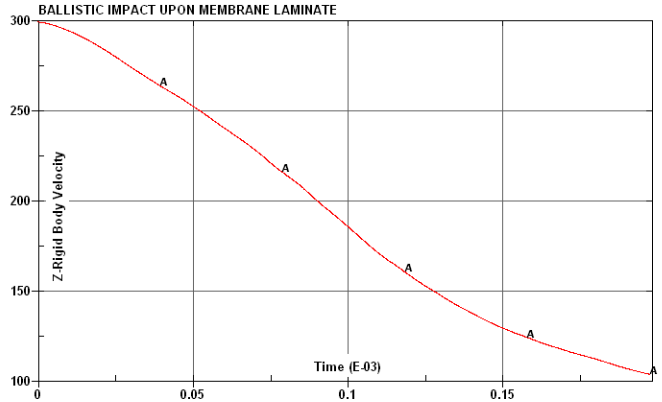
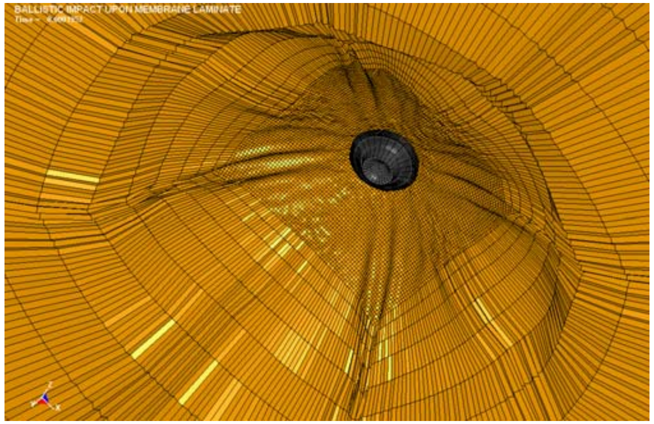
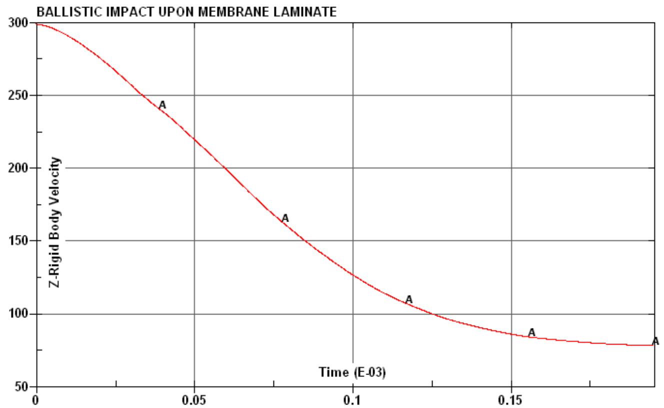

BALLISTIC IMPACT UPON MEMBRANE LAMINATE


BALLISTIC IMPACT UPON MEMBRANE LAMINATE
Z-Rigid Body Velocity
Time (E-03)
300
250
200
150
100
0
0.05
0.1
0.15
A


BALLISTIC IMPACT UPON MEMBRANE LAMINATE


BALLISTIC IMPACT UPON MEMBRANE LAMINATE
Z-Rigid Body Velocity
Time (E-03)
300
250
200
150
100
50
0
0.05
0.1
0.15
A

CONCLUSION - 1

- Strength of the packages of unidirectional materials against the ballistic impacts is higher and their weight and thickness are less compared to conventional woven textiles packages;
- Computational models of textile laminates have been developed in LS-DYNA finite element software. They integrally describe the properties of the laminate layers fastened by elastomer pitch and their failure characteristics by using failure strain and stress criteria;

CONCLUSION - 2

- Preliminary computations have been performed for model verification and model dynamic parameter validation experiments projected;
- Schemes of ballistic experiments have been planned and initial shooting-through experiments performed demonstrated the advantages of hybrid packages. The equipment has been arranged for more complex experiments foreseen in the nearest future.

End of Presentation