Journal scientific and applied research, vol. 25, 2023
International Journal

ISSN 1314-6289 (Print)
ISSN 2815-4622 (Online)

Original Contribution

STUDYING THE APPLICATION OF CAD/CAM/CAE SYSTEMS IN THE DESIGN OF COMPONENTS FOR PERSONAL BALLISTIC PROTECTION EQUIPMENT

Stamen I. Antonov[1], Mariela L. Ivanova[2]

[1]NATIONAL MILITARY UNIVERSITY "VASIL LEVSKI", VELIKO TARNOVO, FACULTY "ARTILLERYQ AD AND CIS", SHUMEN, BULGARIA, E-MAIL: STAMANTONOV@ABV.BG

[2]KONSTANTIN PRESLAVSKY UNIVERSITY OF SHUMEN, SHUMEN, BULGARIA, E-MAIL: M.L.IVANOVA@SHUV.BG

ABSTRACT: *The article presents a study of the possibilities for applying the virtual set of tools for 3D modeling, manipulation, and testing of components that are part of individual ballistic protection equipment.*

KEY WORDS: *Design, Model, Engineering analysis, Individual ballistic protection equipment.*

1. INTRODUCTION

1.1 Purpose of the Article

The purpose of this scientific research is to explore modern technologies for computer-aided design of components within the composition of individual ballistic protection equipment. The possibilities and specific areas of application of CAD/CAM/CAE systems are described in the conceptual design stage of individual ballistic protection equipment, primarily through virtual modeling of components and engineering analysis of their models.

1.2 Structure

An assessment of the potential of the latest information technologies is presented for further automation of the process of designing, simulating, and prototyping components of individual ballistic protection equipment. The possibilities of reducing the timeframes from concept to product realization, flexibility in response to market changes and user requirements are analyzed.

2. ACTIVITIES CONDUCTED

2.1. Analysis of Information Systems in Manufacturing Related to Maintenance of Engineering Solutions Regarding Individual Ballistic Protection Equipment

The advancement of science and manufacturing technologies requires, at every stage of human evolution, the presence of well-prepared, highly skilled specialists who bear the responsibility for introducing innovations. This trend is particularly relevant today, when to a large extent, the entire production cycle of creating a given product is concentrated in one role – that of the design-technologist [2]. They must be intimately familiar with all stages of product development – from the conceptual design phase, through economic analysis for product feasibility, prototyping and engineering analysis, creation of three-dimensional conceptual models, development of control software, technological organization of production, and quality control. In order to accomplish these assigned tasks, the modern engineer must possess comprehensive knowledge in areas including industrial management, computer-aided design systems, technological characteristics of equipment, control software, tooling, and last but not least, be acquainted with the physical essence and phenomena accompanying the various technological processes [5].

The automation of design as an independent scientific field emerged in the last two decades. The process of establishing this field, developing theory, and summarizing the practical results obtained continues even now.

The goal of automating the design and engineering activity is to enhance engineering labor productivity and product quality, reduce material costs, and shorten design timeframes without increasing the number of engineering personnel.

Automation of design refers to the systematic utilization of computer technology at all stages of the design process, with a scientifically justified distribution of functions between the designer and the computer. This entails that the designer should handle tasks that are currently resistant to formalization (tasks requiring creativity and those with extremely diverse solution possibilities), while the computer manages routine tasks related to design and validation calculations, visualization of results, documentation creation and management, and others that can be formalized.

Currently, the most effective organization of automated design is achieved through the use of computer-aided design systems (CAD/CAM/CAE systems). In these systems, mathematical methods and computer technology serve as the foundation for systematizing the design process on a shared methodological, informational, and technical basis.

The design process unfolds as a complex process of abstract thinking (a creative process), which demands a comprehensive understanding of information regarding the object being designed and its associated domains [2].

According to existing standards, design is a process in which a description of a not yet existing object is composed. This process occurs when there is a design assignment, which represents the initial description of the object and the legal document for initiating the design. The process itself consists of multiple transformations and additions to the initial description, rectifying its errors, and optimizing (rationalizing) the object's characteristics through a sequential presentation of object descriptions in various forms (textual, tabular, graphical, etc.).

The result of the design represents a final description of the object in the form of a complete set of documentation for the material reproduction of the object under specific production conditions.

In the process of design, intermediate descriptions of the object are created, which either define the end of the design process or the pathways for its continuation. These descriptions are referred to as design solutions, and design can be viewed as a purposeful sequence of actions related to making design decisions.

From an informatics perspective, design can be seen as an information process in which the initial information about the object being designed, knowledge in the relevant field, past and similar experiences are transformed into output information - the documentation of the new object with a specified level of detail [4].

Undoubtedly, the best form of organizing automated design, creating 3D models, and visualizing the behavior of key elements of individual protection equipment are computer-aided design and manufacturing systems, known as CAD/CAM/CAE (Computer-Aided Design/Computer-Aided Manufacturing/Computer-Aided Engineering) systems - Fig. 1.

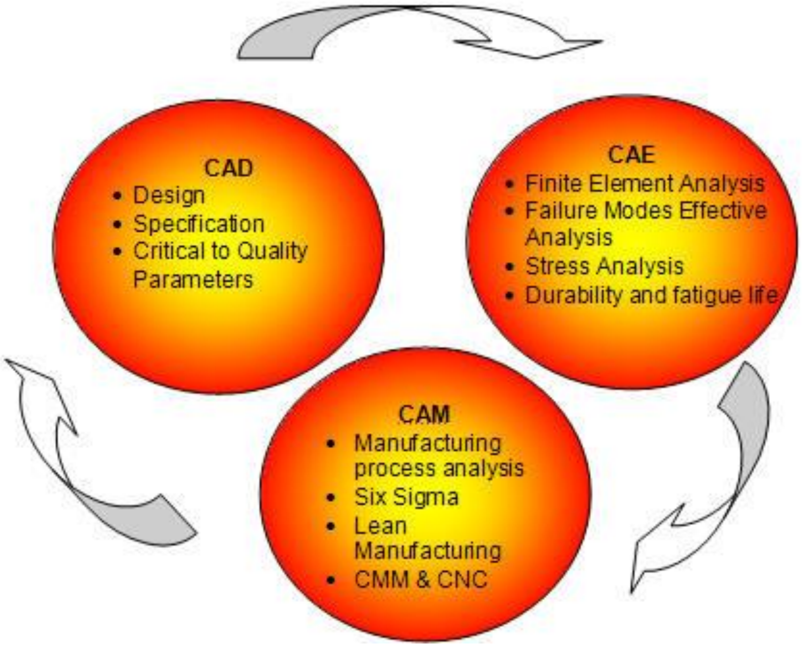


Fig. 1. Connections between modules of automated design and engineering systems

CNC - computer (or computerized) numerical control

CMM - Coordinate Measuring Machines

2.2. Classification of models, the final product of CAD applications for mechanical engineering.

Since the object doesn't physically exist at the time of design, it's necessary to work with its model (one or several). Models are the primary means for synthesizing and evaluating the designed object based on various criteria. They are used for communication among participants in the process as well as for connection with those involved in production, realization, and product usage [1]. For the purposes of automated design, mathematical models are utilized, and the type of model depends on the characteristics of the designed object that need to be modeled and the design tasks that need to be solved.

According to the nature of the modeled properties, mathematical models are classified into structural and functional models. Structural models are used to describe the structure and form of the designed objects, and they are further divided into topological and geometric models (Fig. 2).

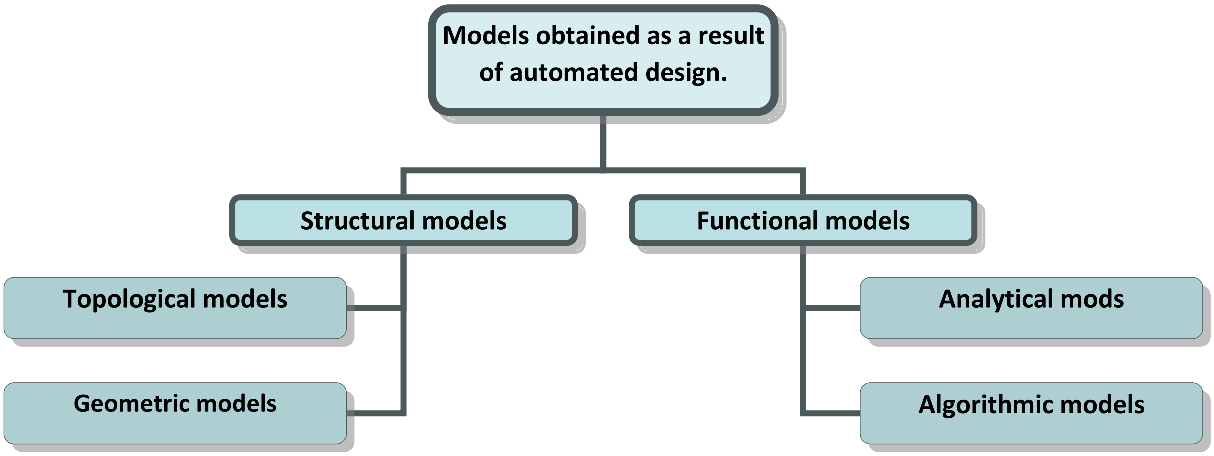


Fig. 2. Types of models, based on the nature of the modeled properties

Topological models describe the structure of objects, meaning the collection of elements composing the object and the relationships between them. Graphs, matrices, tables, lists, and other mathematical tools are used for their formulation.

Geometric models contain information about the geometric shape and dimensions of the designed objects (details and their arrangement within the assembled unit). The mathematical tools for constructing geometric models include equations of lines and surfaces, graphs, matrices, lists, and more.

Functional models are used to model the physical and informational processes occurring in objects during their fabrication and operation. Depending on how the object's properties are represented, functional models are divided into analytical and algorithmic types.

Analytical models contain explicit mathematical dependencies expressing the quality indicators of the object as functions of the parameters of the elements within the object and the environment in which it operates (equations, inequalities, or systems thereof). In algorithmic models, these dependencies are provided in the form of algorithms.

In automated design engineering, geometric models (Fig. 3) serve as the foundation. The structure of the designed objects (components) is synthesized based on these models. Depending on the object's specifics, various functional models are created, which can include kinematic, dynamic, strength, deformation, thermal, and other types. These models are used to assess the functionality and quality indicators of the designed object. Based on the geometric models, engineering documentation is generated, including information for production and testing of the product.

Digital prototyping using CAD systems for specific elements of individual ballistic protection equipment allows for the creation and investigation of an entire product before it's even manufactured (Figure 4). Through computer-aided design (CAD) systems, users can easily grasp the advantages of digital prototyping by integrating 2D drawings and 3D data into a unified digital model [1]. This model represents a virtual representation of the final product and assists engineers in better and more efficient design processes. As a result,

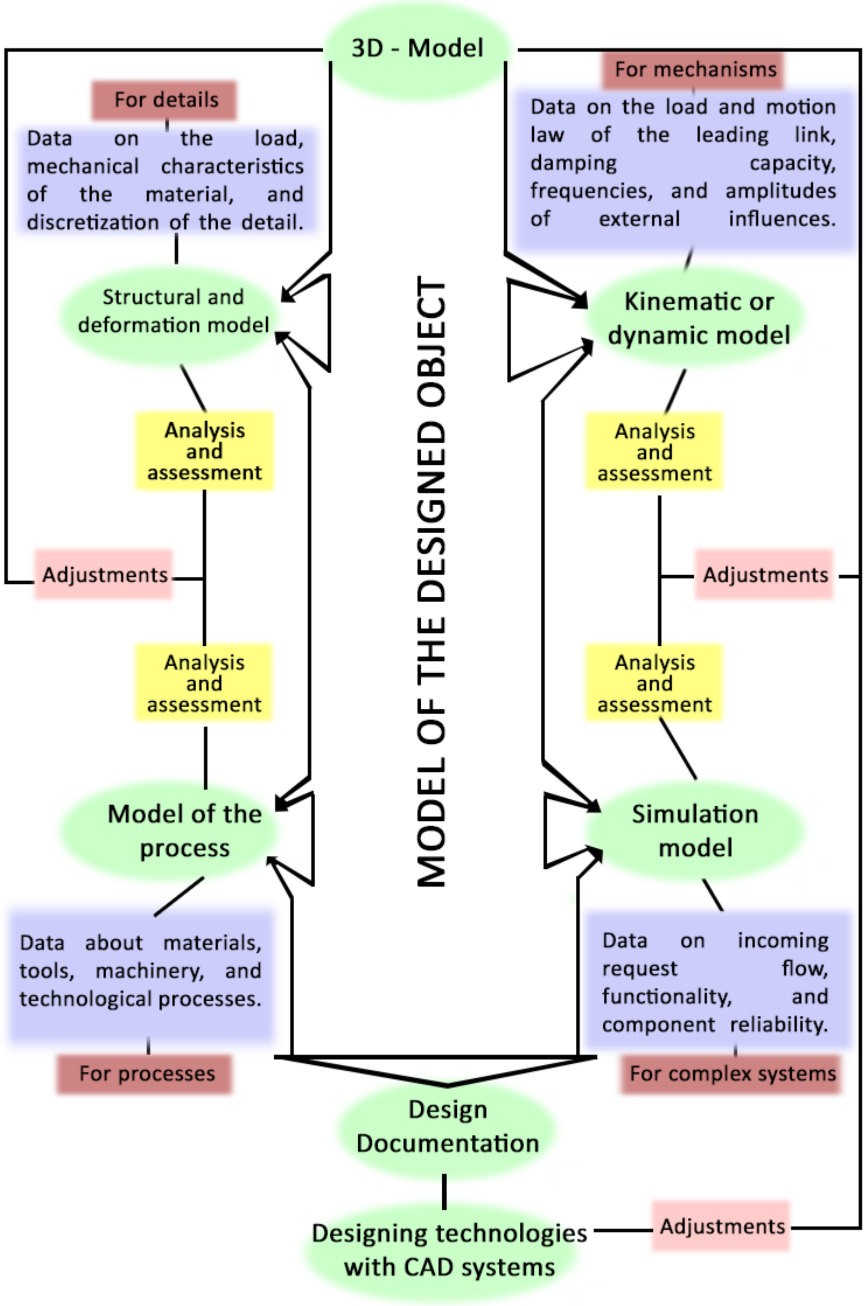


Fig. 3. Modeling in Automated Design

development costs and the time required for realizing new products are significantly reduced.

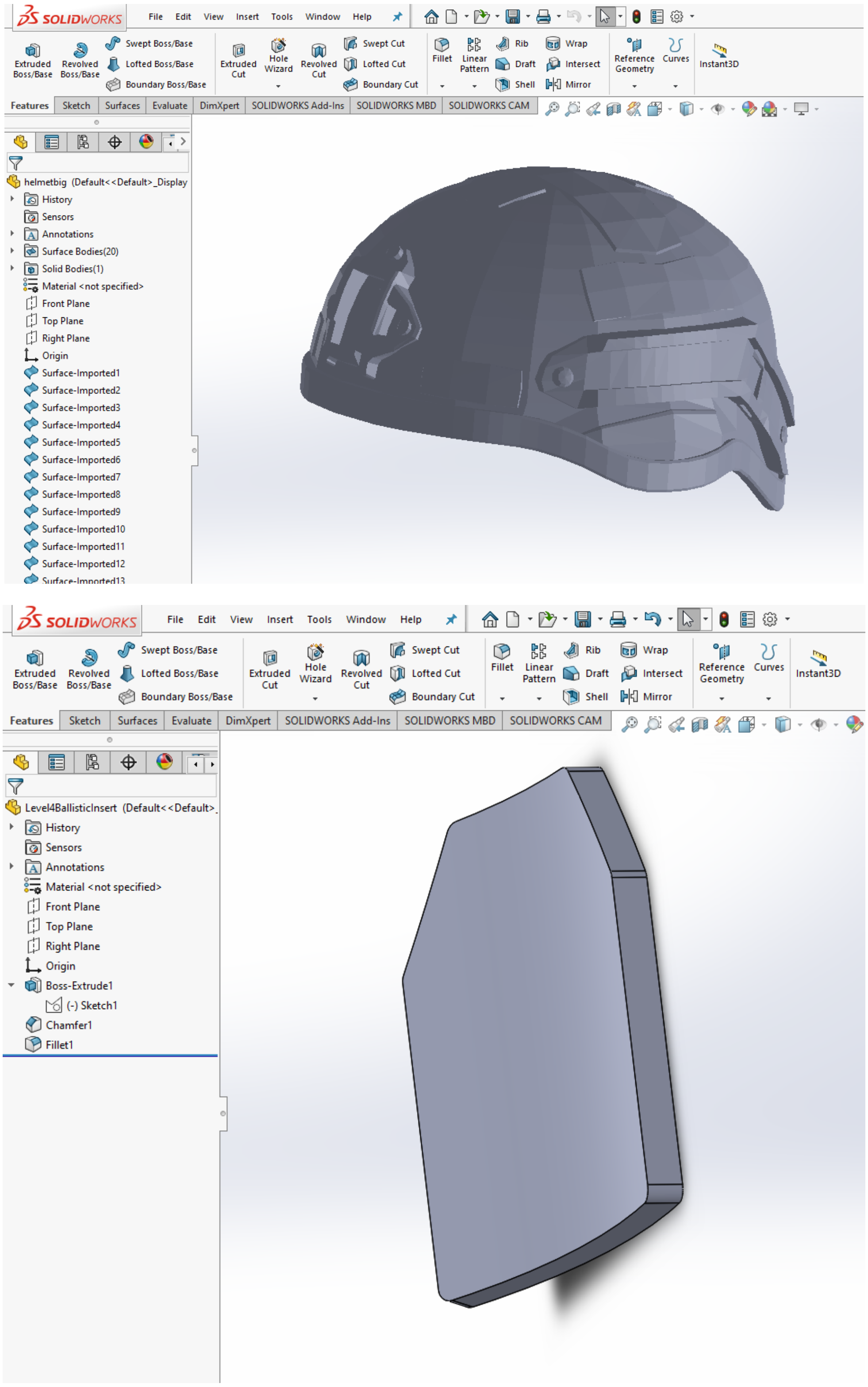


Fig. 4. 3D Models of Combat Helmet and Armor Plate (SolidWorks)

2.3. Object-parametric solid modeling of components for individual ballistic protection.

In parametric design of components for individual ballistic protection equipment, the drawings for all variants share the same topology. Only the parameters that determine the dimensions vary. The solution, i.e., the construction algorithm, is pre-defined and can be encoded into a computer program.

Parametric modeling of solid bodies (volumetric or 3D modeling) in CAD/CAM/CAE systems provides opportunities for designing rotational and enclosure components related to the manufacturing process. Some of the more essential functionalities include [4]:

- Creating basic shapes (blocks, cylinders, bounding boxes, bounding cylinders, cones, spheres).
- Extruded forms with or without taper, based on a contour or surface.
- Revolved forms based on a contour or surface.
- Tubes with arbitrary cross-sections.
- Geometric shapes constructed from equations.

The construction and manipulation of models in object-parametric modeling within CAD/CAM systems are procedural, carried out through the use of a specific toolkit for creating structural designs from ready-made parametric components for repeated use. Object-parametric modeling systems provide a unified electronic environment for modeling, analysis, optimization, documentation, production, and testing. This way, product development becomes an integrated part of its entire lifecycle, as integrated CAD/CAM/CAE systems offer tools for: 3D modeling, working with complex surfaces, creating and investigating assemblies, 2D drafting and technical documentation preparation, a wide range of engineering analyses, and generating CNC programs. They allow parallel work by CAD/CAM specialists on structural design projects, whether conventionally or through pre-defined parametric components, both in local networks and over the Internet.The concept embedded in object-parametric modeling (Figure 4) within CAD/CAM systems involves cataloging the created 3D CAD model into a Geometric Database (GDB). Through the capabilities of parametric modeling in the CAD environment, this database can be customized for specific manufacturing conditions. Using the embedded programming toolkit (PT - Program tools), a range of components is configured, following the principles of standardized and grouped manufacturing processes.

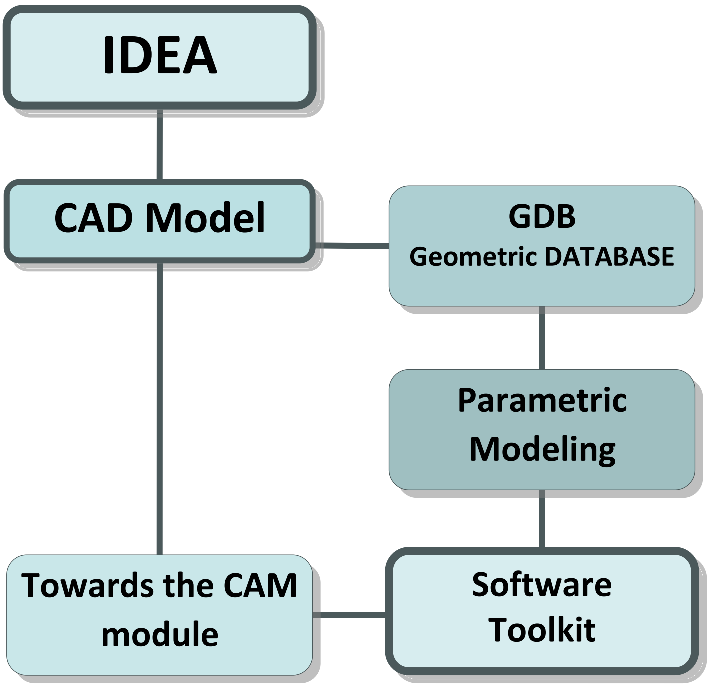


Fig. 4. Creating a CAD Model, Accumulating Geometric Database: Application of Parametric Modeling through the Software Toolkit

2.4. Computer Aided Engineering

The constant drive for development in armies around the world prompts specialists in specific fields to conduct daily experiments and explore variables of interest to them for the purpose of optimization. To perform such procedures, two possibilities for conducting research are well-known – physical and virtual.

For physical investigations, it's necessary to use n functional models of the existing or future product due to the need to gather sufficient data for drawing valid conclusions. Additionally, the "black box" effect is observed, characterized by a high number of variables during experiments that can influence results and significantly complicate understanding of the final outcome (requiring technical equipment, technological systems for altering geometry and mass characteristics, research facilities, etc.) [6].

On the other hand, in virtual analyses conducted through CAE (Computer Aided Engineering) products, almost limitless possibilities are provided for investigating a given object and simulating it in desired environments [8]. These extensive examination capabilities lead to the "white box" effect, which is particularly encountered in virtual analyses. Another advantage in these analyses is the elimination of the need for physical prototypes of the researched object, as well as the potential for immediate optimization in the models based on the analysis of previous results. Building such types of analyses requires substantial computational power and expertise in creating the mathematical model and properly interpreting the derived outcomes [5].

One of the areas with numerous studies and the potential for creating models for virtual research is the production of components for individual ballistic protection equipment (ballistic panels and inserts for bulletproof vests, ballistic shields, combat helmets, etc.).

Various software tools are used for modeling and virtual testing of combat helmets and body armor, especially in industries such as military and police equipment, and also in the development of personal protective equipment. These are some of the popular tools and software that can be helpful:

- Autodesk Fusion 360: Fusion 360 is a powerful CAD/CAM/CAE software that allows the creation of 3D models and their testing in a virtual environment. This software is used to design various types of gear, including combat helmets and body armor.
- LS-DYNA is a powerful and widely used software for numerical simulation of dynamic and nonlinear engineering problems. This software product is used in industries such as automotive, aviation, construction, and others to perform simulations that evaluate the behavior of materials and structures under various loads and operating conditions. LS-DYNA is also used for explosion simulations, structural analyses, collisions, and other complex engineering problems where dynamic aspects and nonlinear behavior of materials are important. This software provides accurate and reliable results and is the tool of choice for engineers involved in the analysis of dynamic systems and events. These features put it at the forefront of design and virtual testing of ballistic protection equipment such as helmets, shields, etc.
- SolidWorks: SolidWorks is a popular CAD and engineering design software used to create 3D models of products, including combat helmets and body armor. It offers multiple tools for simulation and endurance analysis.
- ANSYS: ANSYS is specialized engineering simulation software that enables durability and safety testing of various designs, including protective equipment.
- COMSOL Multiphysics: This software is used for modeling and simulation of physical processes and can be applied to study various aspects of protective equipment.
- Blender: Blender is free and open source 3D modeling and animation software. Although not specialized for engineering calculations, it can be used to create visually appealing 3D models of gear.

Limiting the software tools to the relatively powerful LS-DYNA, the article presents an example of virtual testing of an element of the means of individual ballistic protection (figure 5.).

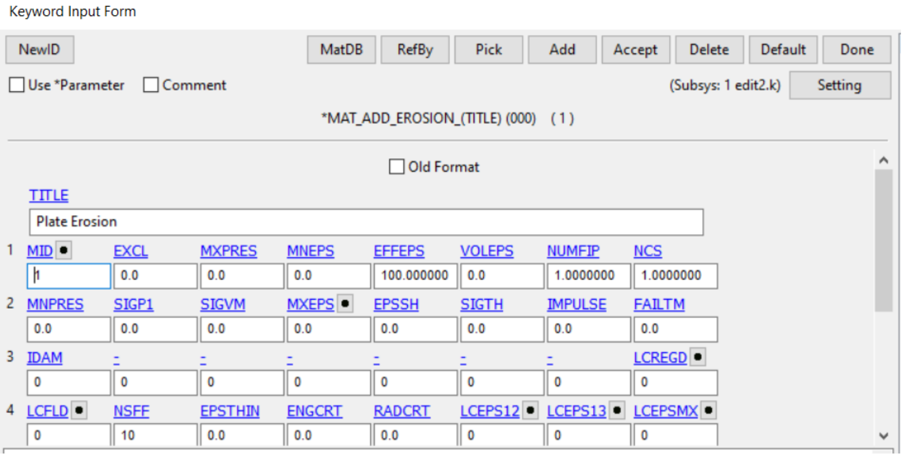
Testing a body armor or body armor with LS-DYNA can be a complex process that involves simulating different types of loads and scenarios to evaluate the effectiveness of the protective gear. Here's an example of a basic bulletproof vest testing scenario with LS-DYNA:

Purpose of testing: Evaluation of the bulletproof vest's ability to protect its wearer from high-velocity bullets and shrapnel.

Simulation Steps:

1. Create a 3D model: A 3D model of the bulletproof vest is created, including all details and materials used for its construction. The model must be accurate and realistic.
2. Define Materials: Set the properties of the materials used for the body armor, such as density, mechanical properties and load behavior.
3. Define Boundary Conditions: Set the initial conditions for the simulation, including initial velocities, body armor position, and other parameters that define the initial state of the system.
4. Define loads: Set the loads on the bulletproof vest. This may involve simulating the impact of a bullet of known velocity and energy.
5. Start the simulation: Run the LS-DYNA simulation and observe how the body armor reacts to the impact. The software will provide data on strains, stresses and other parameters.
6. Analysis of the results: The results of the simulation are analyzed to determine the effectiveness of the bulletproof vest under the specified conditions (figure 5.). It be can assessed whether the bulletproof vest protects its wearer or needs improvements.

This example represents a basic scenario, but testing body armor and other protective items can include many other factors and parameters, such as different types of projectiles, different angles of impact, and more. Specialized software packages for the mechanical engineer, and LS-DYNA in particular, provide powerful simulation and analysis tools that can be used for more complex and realistic protective equipment testing scenarios.



☐ Use *Parameter ☐ Comment (Subsys: 1 edit2.k)

*MAT_ADD_EROSION_(TITLE) (000) (1)

☐ Old Format

TITLE: Plate Erosion

1	MID ●	EXCL	MXPRES	MNEPS	EFFEPS	VOLEPS	NUMFIP	NCS
	1	0.0	0.0	0.0	100.000000	0.0	1.0000000	1.0000000
2	MNPRES	SIGP1	SIGVM	MXEPS ●	EPSSH	SIGTH	IMPULSE	FAILTM
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	IDAM	-	-	-	-	-	-	LCREGD ●
	0	0	0	0	0	0	0	0
4	LCFLD ●	NSFF	EPSTHIN	ENGCRT	RADCRT	LCEPS12 ●	LCEPS13 ●	LCEPSMX ●
	0	10	0.0	0.0	0.0	0	0	0

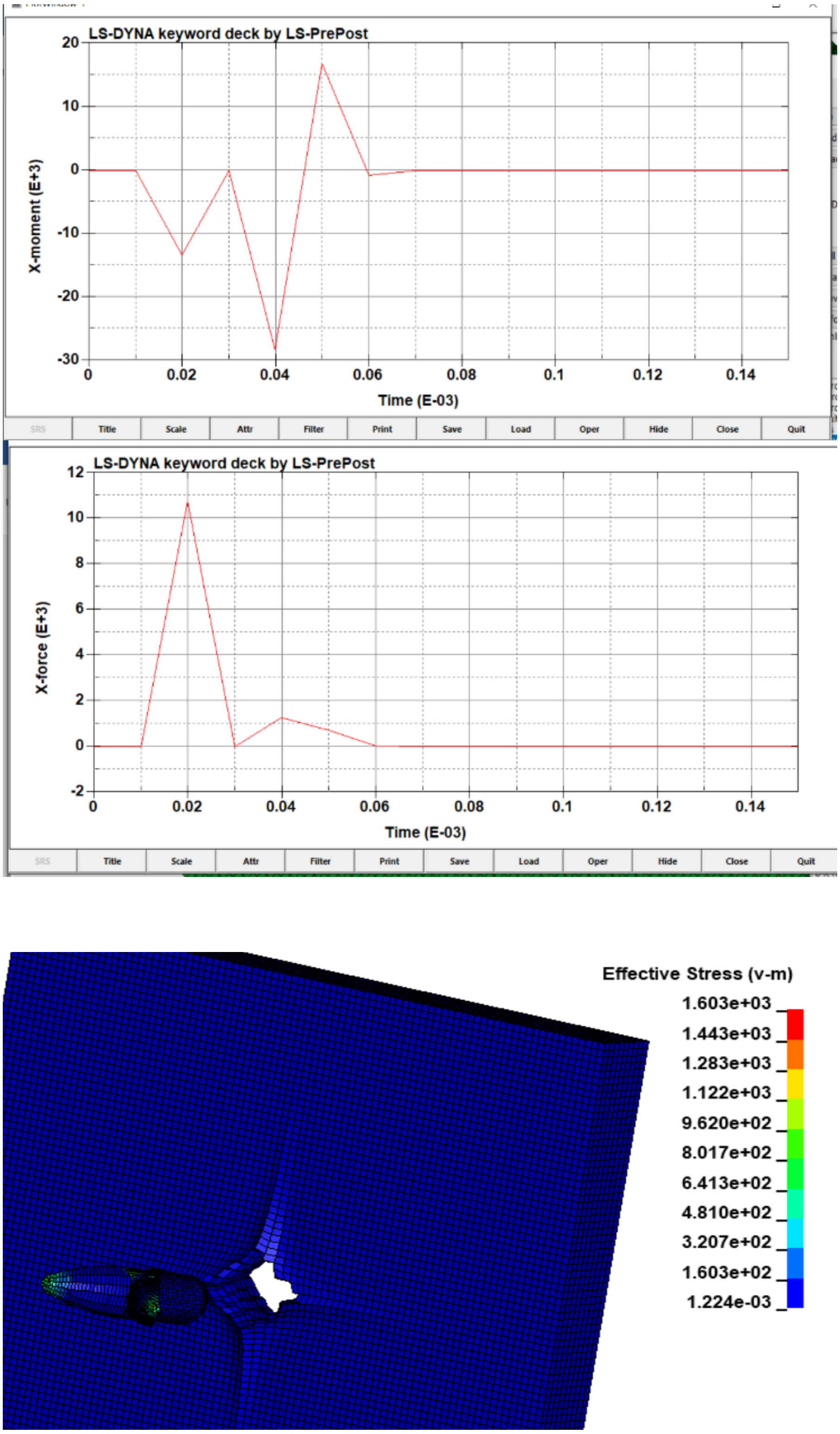


Fig. 5. Input Data Entry and Results Generation in Virtual Engineering (CAE), General-Purpose Multiphysics Simulation Software (LS-DYNA)

As evident, modern automated design systems offer the capability, in the early stages of design, to anticipate the behavior of the final product, in this case, individual ballistic protection equipment. Additionally, based on the expected outcomes, material types can be chosen with the goal of ultimately meeting the requirements. All of this is accomplished in a virtual environment with minimal resource and labor costs, extensively utilizing the collaborative capabilities of automated engineering applications. Through this approach, complete optimization of the final product's parameters is achieved, along with significant reduction in its cost.

3. CONCLUSION

Automated design systems hold a significant place among computer applications because they are industrial technologies that directly impact material production through a comprehensive solution for mechanical engineering. They provide every engineering team with a complete set of tools for 3D design, analysis, data management, and communication. In this context, modern CAD/CAM/CAE systems can be successfully used for three-dimensional modeling of individual components of individual ballistic protection equipment. These systems assist in creating the graphical part of the engineering documentation, including drawings, engineering calculations, and analyses. They also facilitate rapid prototyping, technological preparation for production, the generation of control programs for CNC machines for producing various complex products, as well as comprehensive management of project and engineering data.

4. REFERENCES:

[1] Antonov S.I., Izsledvane na prilozhenieto na CAD/CAM/CAE sistemite i tehnologiite za barzo prototipirane pri proektiraneto na komponenti na tehnicheskite sistemi, Shumen, 2021g., ISBN 978-619-7531-31-2;

[2] Dimitrov V., Kompyutarni sistemi za proektirane v mashinostroeneto, Top Solid'design 2012, Sliven, 2013;

[3] Marinov R., Myastoto na 3D tehnologiite v oblastta na voennata sigurnost, Nauchna konferentsia „Aktualni problemi na sigurnostta” 2018, 25-26 oktomvri 2018g., Izdatelski kompleks na NVU „Vasil Levski”, VT, str. 237-244, ISSN 2367-7473;

[4] Mat Lombard, SolidWorks: Ovladyavane Tom.1, Alekssoft, Sofia, ISBN: 789546564047;

[5] Teodora Petrova, Zhivo Petrov, „Osobenosti pri razpredelyane na temperaturata pri vazdeystvie na lazernia lach v mnogokomponentna sreda“, Sbornik dokladi „Tenth Anniversary Scientific Conference with

International Participation SPACE, ECOLOGY, SAFETY“, Sofia 2014 g., str. 201;

[6] Zdravkov, Z., Proektirane na zashtiteni avtomatizirani informatsionni sistemi, monografia, Sofia, izdatelstvo "Dio Mira", 2019 g., stranitsi 210, ISBN 978-954-2977-55-1;

[7] https://www.marsarmor.com/bg/;

[8] https://lsdyna.ansys.com/.