UDC 004.94

EXAMPLES OF USAGE AND FACILITIES OF SYSTEM *MATHEMATICA* AT TEACHING OF DISCIPLINES AND LEARNING OF SECTIONS ON BASES OF COMPUTER MODELLING IN THE MECHANIC

V.B. Taranchuk, M.A. Zhuravkov

The article discusses the possibilities of using the Wolfram Research technologies, the methodological and technical solutions, which considerably implement a set of tools for creation, maintenance and distribution of the live dynamic content which is recommended for use in the educational process in teaching disciplines and learning sections on the basics of computer modelling in mechanics. The authors explain the typical elements, providing the interactivity of electronic resources, the key constructions, functions and options of the Mathematica computer algebra system.
Examples from practice of preparation of teaching materials of disciplines «Computer Modelling» several specializations are reduced.

Introduction

Enhancing the efficiency of the use of information technologies is one of the major trends in the development of the modern educational process [1 - 3]. Nowadays hardware and software of computers and the various peripheral devices provide a wide range of possibilities for creating specialized electronic "documents" with intelligence components and dynamic interactivity components. Such materials ("documents") have certain advantages over printed materials. An important goal (especially in organizing distance learning [1, 3]) is finding the software which would able to solve the problem of creation and support of the interactive educational resources by a wide community of teachers, including those who don't have any experience in programming.

In this paper we extensively dwell upon the technical solutions described at [4], comprising the use of the technologies developed by Wolfram Research company. In particular, the paper emphasizes the additional features of technical computing program *Mathematica* [5], the Computable Document Format (CDF) [6], the Wolfram Demonstrations Project [7] which allow the users to create, support and freely distribute interactive graphic applications, program units that visually represent the solutions of classic and modern problems of continuum mechanics. The paper provides examples from the practice of preparing the educational materials for the academic subjects in "Computer service of computational experiment" [8], "Computer modelling" fields [9]. The specificity of teaching the above-mentioned academic subjects is that many topics of these academic subjects feature theoretical fundamentals of advanced mathematics, the understanding of which requires the use of supporting graphic material, with illustrations of the dynamics of the processes. In particular it's worth mentioning that the visual representation of the material, the possibility of building imaginary models based on their mathematical descriptions is one of the essential requirements for correctly understanding the meaning of the models and their description. In certain topics of the mentioned subjects not only

mathematical component is immensely complicated, but the visual representation is labor intensive as well, that's why it's vital to have the opportunity of their simplification and transformation on a personal computer, in mathematical notation. The general issues of preparing and adapting the relevant interactive freely distributed program units for specific user groups are considered at [10], particularly, the practicality of adopting the *Mathematica* system as the basic platform is proved.

Examples and Illustrations of Interactive Study Materials

It is worth noting that the mathematical apparatus of continuum mechanics is represented in *Mathematica* system in a volume exceeding any university textbook. The system includes all known analytic methods for solution of ordinary differential equations and partial differential equations, the solutions are illustrated by examples which the users can change, include in their own applications; mathematical notation grad (gradient), div (divergence), curl, Laplacian is available; all functions of vector analysis are implemented, moreover, in different systems of coordinates.

The substantive aspects of computer models studied by undergraduates in specialization subjects taught by the authors of the work are described, in particular, in [7, 9]. A number of representative examples of interactive applications from collections [7] that are used in the studying process, granted to students, and adapted to the topics under study are given below. Methods of setting and adaptation of interactive program organization units are described in [4, 10].

The first series is represented by designs used during the study of the topic "Calculation of the of Stress-Strain State of Structures and Their Elements". The basic bridge structures are also exemplified in the selected program organization units. Fragments of module screen copies of this series are given in figures 1 - 5.
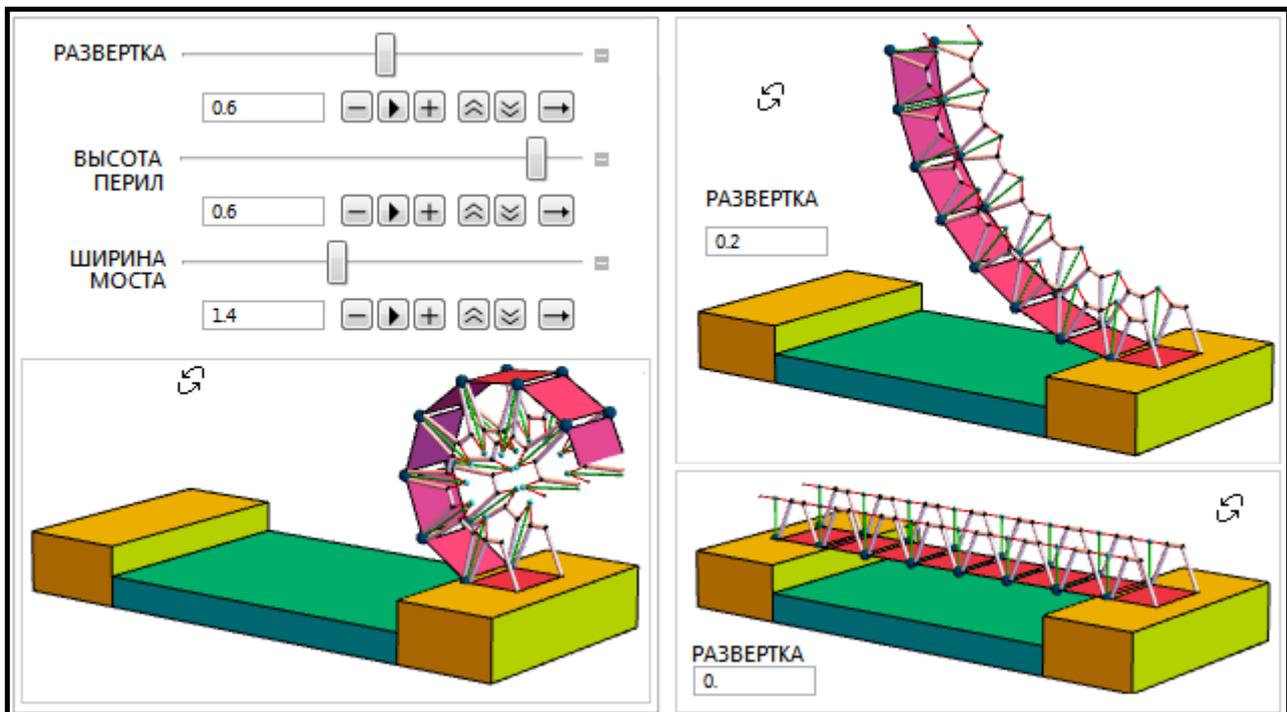

Fig. 1. The types of software applications and the simulated design interface
for different values of the parameter sweep

Figures 1 - 4 show screenshots of the same control panel, shots with outputs of several program modules. Change of the parameter values on the panels leads to change in the structure appearance; each control action can be carried out, which is illustrated by figure 1, by entering the parameter value in the input field or by moving the slider; it is also possible to play video with automatic parameter changing, to regulate the speed and direction of playing. In all visualization modules in NB format notebooks and in CDF documents, the user can not only move sliders on the panels to change geometric parameters, colors, and transparency, but also change the scale of the output 3D graphics objects and rotate them in different directions.
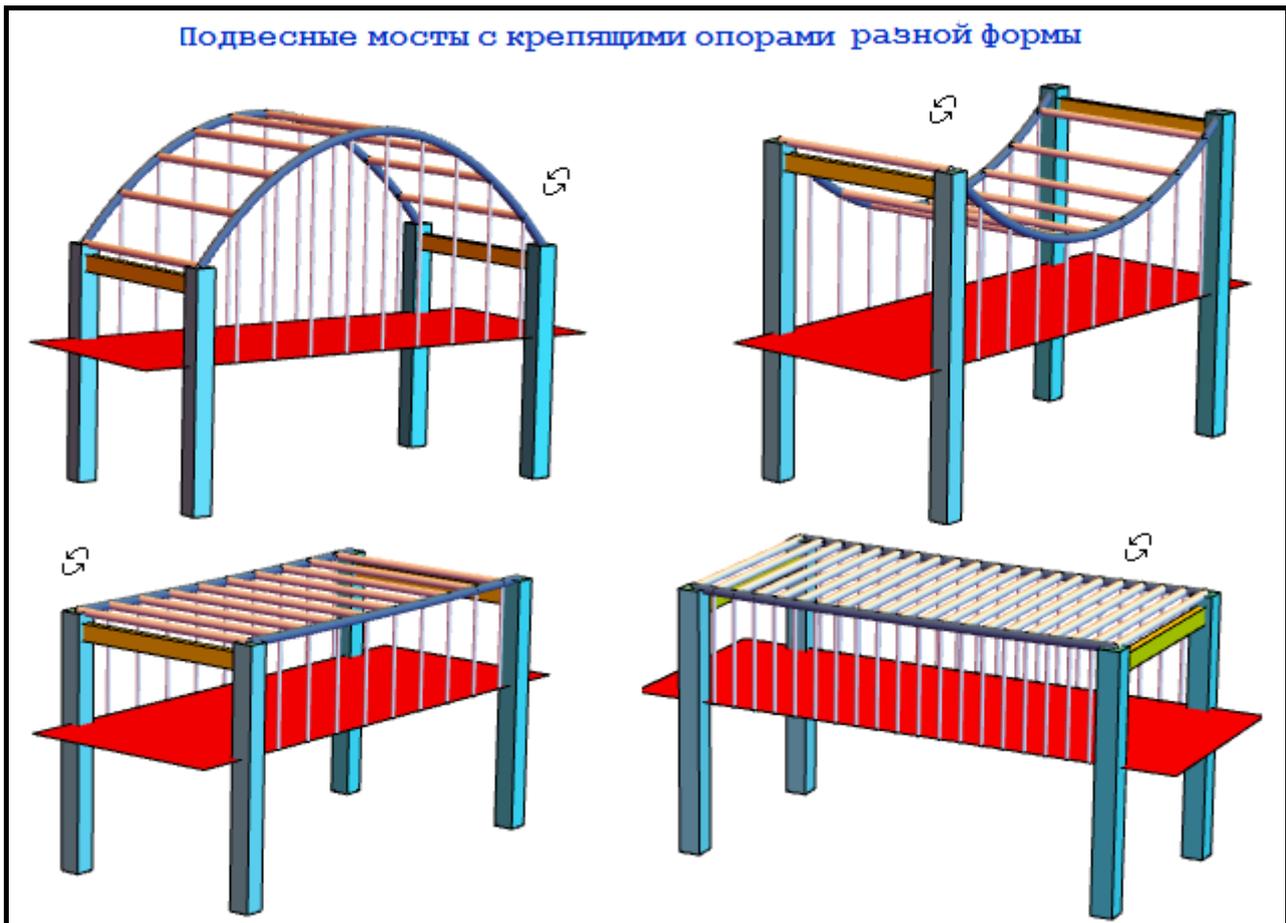

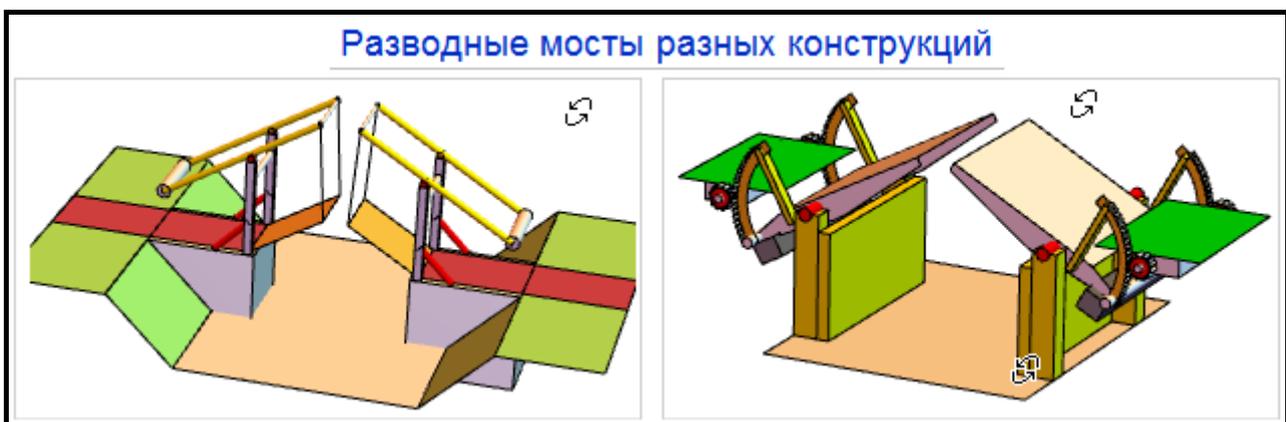Fig. 2. Models of bridges with catenary shaped supports

Fig. 3. Models of Dutch Drawbridge and Bascule (Seesaw) Bridge

Fig. 4. Models of Gateshead Millennium Bridge and Cantilever Bridge

Since the collections [7] contain the source codes, students are provided with program modules, which are included in study materials, not in their original version, but revised. In particular: alternative geometric primitives are suggested for the bearing elements of structures; textual explanations are given with the use of Russian terms; the graphics design is the same as in the basic manuals and textbooks; comments in the modules are translated into Russian, and their volume is significantly increased.

Note that the quest in the search field of the website [7] by the key word 'bridge' gives a list of 36 different designs ([11]). It includes references to presentations with presentations and descriptions of:

• specific bridge structures and models; namely, the following designs: Cantilever Bridge, Bridges with Catenary Shaped Supports, Rolling Bridge, Dutch Drawbridge, Bascule (Seesaw) Bridge, Gateshead Millennium Bridge;

• generic issues of calculation methods, in particular, the following designs: Girder Bridge Model, Analysis of Forces on a Truss, Bridge Varieties, Stress Propagation in a Truss Bridge, Stress-Strain Analysis by the Finite Element Method.

Figure 2 shows fragments of the application windows which exemplify some of the above bridge models.
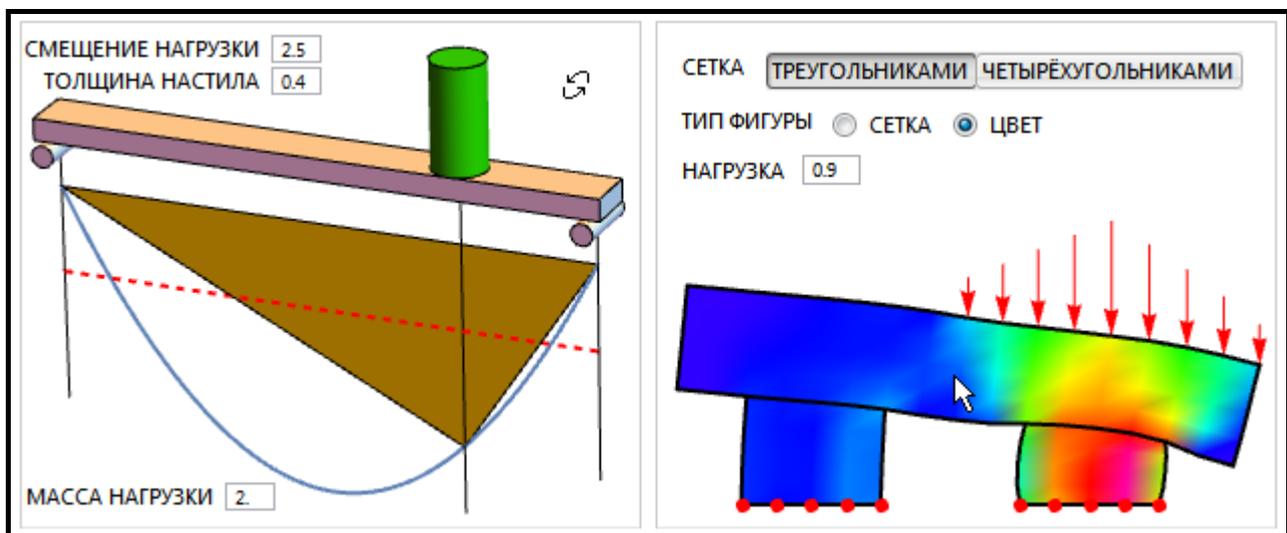

Fig. 5. Examples of load-visualization modules

Figure 5 shows fragments of the windows of the adapted applications Girder Bridge Model and Stress-Strain Analysis by the Finite Element Method, which illustrate visualization models and variants for the results of stress-strain analysis of structures and their elements.

The second series is represented by the designs used for studying the topic "Fluid Mechanics". It is worth mentioning that there are over 217 models of this type in the collection [7, 12]). Students are encouraged to master the models below and program them with certain modifications during practical classes (figures 6, 7).

The basic models of this series used for controlled independent work of students: Flow through an Open Channel, Flow of Liquid through a Hole, Fluid Flow around a Corner, Couette Flow and Double-Sided Couette Flow, Laminar Flow between Two Eccentric Tubes, Streamlines for Laminar Flow Past a Rotating Solid Cylinder, Velocity Profile for Immiscible Viscous Fluids, Potential Flow over an Airfoil Specified by Numerical Data File, Launching a Rocket, De Laval Nozzle.
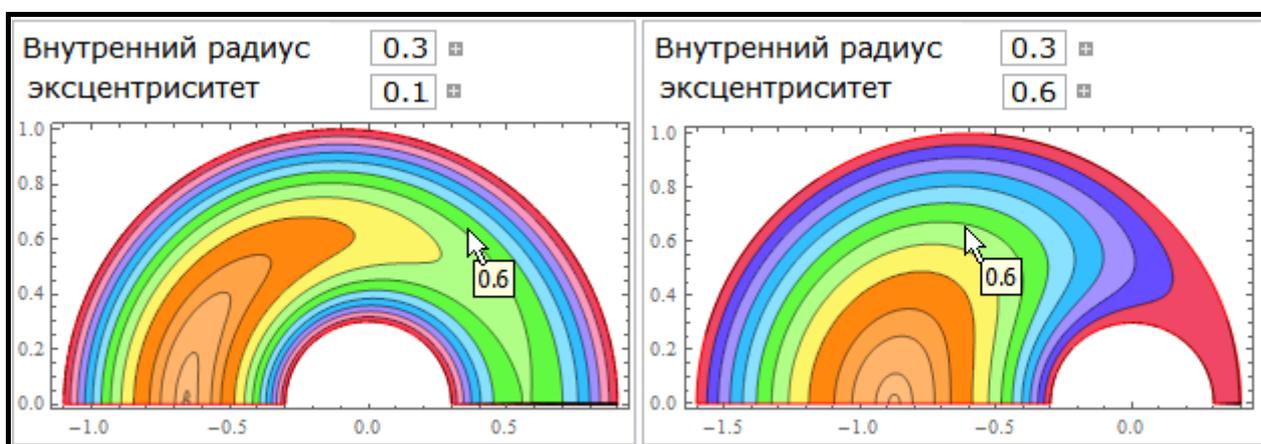

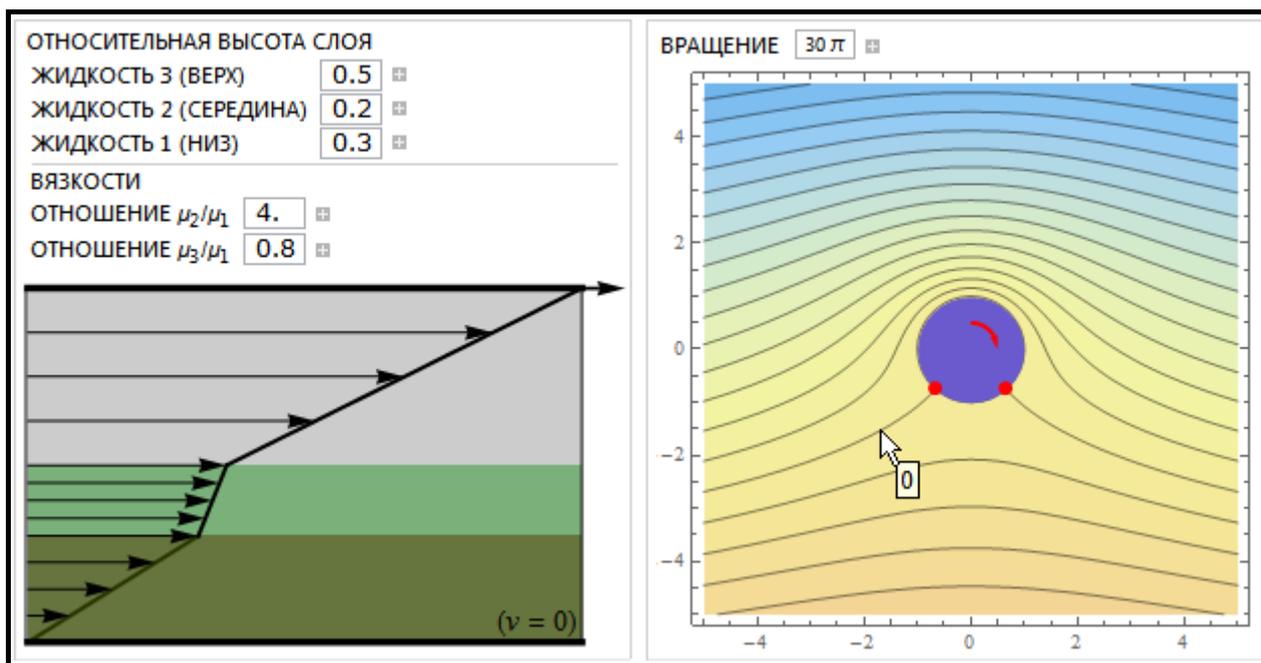Fig. 6. Examples of modules with visualization, the effect of changing the value of eccentricity

Fig. 7. Examples of modules with visualization of velocity and streamlines

Illustrations of typical applications of this series are given in figures 6, 7. Here we can see the results of work with adapted program organization modules "Laminar Flow between Two Eccentric Tubes" (isolines of the dimensionless velocity module are shown), in figure 7 – the velocity profile for immiscible viscous fluids (to the left) and streamlines for laminar flow past a rotating solid cylinder (to the right):

Basic Software Tools

On Dynamic Interactivity Configuration Tools

In most cases, dynamic interactivity, dialog boxes, input data parameter management for calculations, construction and viewing of charts are realized in *Mathematica* notebooks with the use of the functions Manipulate, Animate, Dynamic. In particular, Manipulate module helps create various interactive tools according to the set expression 'expr' with arguments (parameters), while the expression 'expr' is treated in its most general form and can be represented by a list with names, mathematical expressions, function graphs, etc. As for explanations in the applications presented to the students, special attention is paid to the issues of dynamic output programming, interactive tool use – examples are given for the functions and options of dynamic calculations, activation and deactivation of indicators, organization of checkboxes, buttons, hierarchical and pop-up menu, locators. Explanations are provided for the following elements: PopupMenu (pop-up menu), ActionMenu (action menu), ButtonBar (button bar), Delimiter, CheckboxBar (checkbox bar), RadioButtonBar (radio button bar), SetterBar (setter bar), TogglerBar (toggler bar), ControlType (control type), Locator, Slider, Slider2D (two-dimensional slider), ColorSlider (color slider), ListPicker (list picker), AutorunSequencing (autorun sequencing).

Dynamic Interactivity Options in CDF Documents

When preparing notebooks in *Mathematica* and planning to save or view them in CDF Player, one should perform initialization (Initialization:->) or save animation parameters (SaveDefinitions). This is obligatory since CDF Player cannot load user data while in operation. It is allowed to work only with those lists, bundles, and sets that are included in the data base that is all information used by Manipulate function should be embedded in the interactive elements of a CDF file.

Design

As for the design and scene object view customizing, the exercises include explanations of the rules for setting the line thickness and type (Thickness, Thick, Thin, AbsoluteThickness, Dashed, Dotted, DotDashed), colors, and opacity (Colors, Opacity). There are also detailed examples of using the functions and output frame control options: PlotRegion (option for graphics functions that specifies what region of the final display area a plot should fill), PlotRange (option for graphics functions that specifies what range of coordinates to include in a plot), PlotRangeClipping (criteria for clipping the graphics objects at the edge of the region), AspectRatio (the ratio of height to width for a plot), BoxRatios (ratios of side lengths for the bounding box of the three-dimensional picture), Translate (translation), Rotate (rotation), GeometricTransformation (geometric transformation), ViewPoint (view point), ViewAngle (view angle).

On the Main Service Functions of Computer Models

The following functions of *Mathematica* system can be used for model visualization in the presence of analytic description:

- Plot – a plot of an analytic function (or several functions), both scales are linear;
- ParametricPlot – a plot of a parametric curve (as well as surface);
- PolarPlot – a plot of a function expressed in polar coordinates, with the radius-vector as a function of the angle in the prescribed range (polar plot).
- Graphics – generation of 2D graphics primitives (rays, polygons, various triangles, rectangles, parallelograms, rhombs, circles, arcs, segments, B-spline curves, Bézier curves);
- ContourPlot – a contour plot; a plot which shows lines of different levels (isolines); contour plots (or horizontal plots) are used to depict isolines of a scalar data set which are distributed over the surface;
- DensityPlot – density plot (area map), makes a density plot of f as a function of arguments x and y;
- RegionPlot – visualization of a restricted area on the plane; makes a plot showing the region, the region plotted by RegionPlot can contain disconnected parts;
- ParametricPlot – a plot of a parametric region on the plane;
- Plot3D – a three-dimensional visualization of an analytic function of two variables prescribed in Cartesian coordinates; the user can work with the plot interactively; scale conversion, rotations, and translations are available;
- ContourPlot3D - a contour plot of a function prescribed in Cartesian coordinates in space; a three-dimensional contour plot also includes isolines showing the edges of 3D shape layers in the cutting planes located in parallel to the supporting plane of the figure;
- RegionPlot3D – geometric figure visualization in space;
- DensityPlot3D – a space plot illustrating spatial distribution of the prescribed function of two variables on the basis of a continuous color scheme or specially set color scheme;
- ParametricPlot3D – a plot of a parametric curve or surface in space;
- SphericalPlot3D – a plot in spherical coordinates.

In cases when mathematical description of models is created on the basis of approximation in accordance with the results of observations and measurements on regular or irregular grids (on a scattered point set), the following functions can be used:

- ListPlot – a scatter plot; shows a plot of the list of values the coordinates of which are set by the list values;
- ListLinePlot – a line plot by data list points (list of values or list of coordinate-value pairs);
- ListStepPlot – a step plot according to the value list; plots the data so that each point, including the first and last, is part of a horizontal step;
- ListPolarPlot – a scatter plot in polar coordinates; draws a line through the list of points;
- TimeSeries –represents a time series specified by time-value pairs;
- DateListPlot – a calendar time plot; draws a line through the list of points;

- ListContourPlot – a contour plot according to the value array; generates a contour plot from values defined at specified points;
- ListDensityPlot – a density plot according to the value array;
- ListPlot3D – a three-dimensional scatter plot, spatial representation of a surface according to an array of height values in points;
- ListContourPlot3D – a 3D contour plot according to the value array;
- ListSurfacePlot3D – a 3D plot of a surface reproduced according to the point list;
- ListPointPlot3D – a 3D scatter plot, spatial generation of images of points with three set coordinates;
- ListDensityPlot3D – a space density plot according to data.

Tools and functions for work with vector fields:

- StreamPlot – a stream plot (flow diagram); plots streamlines that show the local direction of the vector field at each point;
- StreamDensityPlot – a stream plot superimposed on a background density plot (density flow diagram);
- VectorPlot – a vector plot (vector diagram); shows vectors from the vector field at a regular grid of positions;
- VectorDensityPlot – a vector density diagram; generates a vector plot of the vector field as a function of arguments, superimposed on a density plot of the scalar field (to be the norm of the vector field);
- ListVectorPlot – a vector diagram formed based on data;
- ListVectorDensityPlot – a density vector diagram based on data;
- ListStreamPlot – a flow rate diagram formed according to data charts, that is approximation is followed by flow line plotting;
- ListStreamDensityPlot – a density diagram of flow rate according to data;
- ArrayPlot – an array image; generation of an image where array values correspond to colored squares;
- VectorPlot3D – a spatial vector diagram (vector fields); generates a 3D vector plot of the vector field;
- ListVectorPlot3D – a 3D vector diagram according to data; by default interpolates the data given and plots vectors for the vector field at a regular 3D grid of positions.

Conclusion

The work gives typical examples of use in the process of teaching subjects on the computer modelling fundamentals in the mechanics of live dynamic content created and supported on the basis of the proposed method of *Mathematica* tool integration, CDF format, modules of freeware interactive application collection. The work also defines and specifies basic software tools recommended for the method implementation.

The literature list

1. Ablameiko S.V. Modern Information Technologies in education / S.V. Ablameiko, V.V. Kazachenok, P.A. Mandrik // Informatization of Education – 2014:

Pedagogical Aspects of the Development and Functioning of Virtual Educational Environment : materials of International Scientific Conference, Minsk, Oct. 22-25, 2014. - Minsk, 2014. - P. 7-13.

2. Listopad N.I. Informatization of education: tendencies and new approaches / N.I. Listopad, S.Y. Mikhnevich // Informatization of education, 2014, N 2. - P. 3-14.

3. Knox J. Digital Culture Clash: 'massive' education in the E-learning and Digital Cultures MOOC / Jeremy Knox // Distance Education, v. 35, N 2, 2014. – P. 164-177.

4. Taranchuk V.B. Capabilities and Tools of the Wolfram *Mathematica* for Development of Intelligent Tutoring Systems / V.B. Taranchuk // Nauchnye vedomosti BelGU. Ser. Istoriya. Politologiya. Ekonomika. Informatika (Belgorod). № 1 (198) issue 33/1. - P. 102-110.

5. WOLFRAM *MATHEMATICA* [Electronic resource]. – Mode of access: http://www.wolfram.com/mathematica. – Date of access: 18.03.2016.

6. CDF. Documents Come Alive with the Power of Computation [Electronic resource]. – Mode of access: http://www.wolfram.com/cdf. – Date of access: 18.03.2016.

7. Wolfram Demonstrations Project [Electronic resource]. – Mode of access: http://demonstrations.wolfram.com. – Date of access: 18.03.2016.

8. Taranchuk V.B. The Graphics Services of the Computational Experiment: a study-guide / V.B. Taranchuk. - Minsk: BSU, 2009. - 124 p.

9. Bosyakov S.M. The Solution of Problems of Mechanics in the Package of Structural Mechanics Mathematica Computer System: a guide for students of the Faculty of Mechanics and Mathematics / S.M. Bosyakov, M.A. Zhuravkov/ - Minsk: BSU, 2011. - 295 p.

10. Taranchuk V.B. Features of Functional Programming of Interactive Graphical Applications / V.B. Taranchuk // Vestnik Samarskogo Gosudarstvennogo Universiteta. Estestvennonauchnaja serija, razdel Matematika № 6 (128), 201. -P. 178-189.

11. Wolfram Demonstrations Project. Search results for "bridge" [Electronic resource]. – Mode of access: http://demonstrations.wolfram.com/search.html?query=bridge. – Date of access: 18.03.2016.

12. Wolfram Demonstrations Project. Fluid Mechanics [Electronic resource]. – Mode of access: http://demonstrations.wolfram.com/topic.html?topic=Fluid+Mechanics. – Date of access: 18.03.2016.

Taranchuk Valery Borisovich, head of department of computer applications and systems of Belarusian state university, doctor of physical and mathematical sciences, professor, taranchuk@bsu.by

Zhuravkov Mikhail Anatolievich, minister, head of department of theoretical and applied mechanics of Belarusian state university, doctor of physical and mathematical sciences, professor, zhuravkov@bsu.by