Development of a visualization module for aerogasdynamic computations

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Abstract. In this paper we present a concept and implementation details of a new visualization subsystem for presentation of the results of scientific computations. The subsystem is built into the interactive information and simulation system for gas dynamics and multiphysics problems as a comprehensive visualization module. This module is based on the open-source cross-platform application frameworks Qt and VTK. The paper describes basic functions of the visualization subsystem and presents examples of its graphical capabilities for drawing spatial images and two-dimensional plots, as well as examples of dialogue boxes for controlling the process of visualization. The subsystem supports main geometric and grid formats. The new subsystem has the unified implementation for Windows and Linux operation systems.

1. Introduction

In developing new flying vehicles (aircrafts, spacecrafts, landers) it is necessary to perform numerical simulations of their aerothermodynamic characteristics [1-5]. These simulations allow significantly decrease the number of ground and flight tests, and, consequently, greatly reduce the cost of developing the future models. In the previous work [6] an interactive information and simulation system (IISS) was presented. This system combines computational modules for performing aerogasdynamic simulations (both outside a vehicle and within its engine), interactive environment for controlling and monitoring computations, databases of physical and chemical properties, and different information facilities.

When working with the information and simulation system, it is necessary to have capabilities for visual presentation and interactive analysis of obtained results. At the moment, most computational modules in the IISS produce results in the formats suitable for visual processing by the commercial software Tecplot [7]. This software has become widespread in computational fluid dynamics and aerodynamics. In fact, it is now one of de facto standards in the field of scientific visualization.

In order to achieve independency on commercial software and to avoid problems of a licensing nature, we’ve set a goal to create a domestic visualization subsystem for aerogasdynamic computations. By this goal, such subsystem should possess some functionality of Tecplot and be partially compatible with it.

This paper presents the first version of the visualization module implemented within the framework of the interactive information and simulation system. The module can be deployed on a computer running a Windows or Linux operating system.
2. Functional structure of the visualization module

Interface of the visualization module was implemented similar to the interface of the commercial visualizer Tecplot. This similarity allows users familiar with the Tecplot to easily switch to the new module.

The new visualizer can be used at all stages of the computational session. The main function of the visualizer is the graphical presentation of the following sorts of objects:

- electronic geometry of the surface of a vehicle;
- computational grid of the domain surrounding a vehicle (for controlling grid quality), in particular spatial grid and surface grid;
- spatial distributions of physical quantities around a vehicle, on its surface and in selected cross-sections by different ways for intermediate and final results of computations;
- combination of the above spatial objects;
- two-dimensional plots (linear diagrams) and distributions of quantities.

Figure 1 presents an example of the interface of the visualizer, along with the distribution of some physical quantities in the vicinity of a space vehicle. It can be seen that the visualization screen consists of several fields – interface field, control field and window for graphical presentation.

![Figure 1](image_url)

**Figure 1.** Example of the interface and graphical window showing the spatial distribution of flow density and temperature around a vehicle.
The visualization module supports the following input data formats:

- standard formats for geometric presentation of objects (*\ .stl in binary and text forms);
- standard formats for presentations of computational grids (*\ .neu);
- graphical formats of common visualization systems used for scientific computations – Tecplot (*\ .plt, *\ .dat) and ParaView (*\ .vtk, *\ .vtu).

The module supports some formats of control files used by the Tecplot (*\ .lay). Up to the moment, a number of configuration and tuning option are supported.

The visualizer supports two main regimes of graphical presentation and analysis of data – spatial mode and two-dimensional mode.

2.1. Spatial visualization mode

The spatial visualization mode is intended for representing images of three-dimensional objects and their fragments, including pictures of two-dimensional cross-sections, with spatial distributions of physical quantities on them. The visualizer supports several ways of graphical presentation of computational results (physical quantities), as well as the combination of thereof. Below is a list of main types of spatial images, with examples of visualization for all image types:

- contours (isolines) and color distributions of physical quantities on the surfaces of an object and in cross-sections around it (figure 1);
- images of surface and spatial (volume) computational grids with the ability to hide invisible lines (figure 2, a);
- halftone images of the surfaces of objects and their structural elements (figure 2, b);
- smooth and discrete color distributions of physical quantities in cross-sections of a computational domain with the ability of combining with other spatial images (figure 3);
- isosurfaces (surfaces of equal value) of physical quantities with the ability to depict color distributions of another quantities on these surfaces (figure 4);
- spatial trajectories and streamlines.

![Figure 2](image)  
**Figure 2.** Example of the presentation of a computational grid; zone that corresponds to a surface of a vehicle is highlighted (a). Halftone visualization of the surface of an aircraft (b).
Figure 3. Examples of smooth color distribution of physical quantities in the cross-section of a computational domain. Distribution of flow density around a vehicle and on its surface (a). Distribution of flow temperature around a vehicle and streamlines behind it (b).

Figure 4. Example of the surface of equal flow density (isosurface) around a vehicle, with the color distribution of flow temperature depicted on this surface.

For all sorts of spatial images, the visualizer support different graphical manipulations – moving around the screen, scaling and rotation. These manipulations can be performed through the control fields of the screen and by the computer mouse.

The overall control on the graphical presentation, its configuration and tuning are performed in dialog boxes. To control pictures in the above example, several types of dialog boxes are used, describing correspondingly contours, zones, slices (cross-sections), isosurfaces and streamlines.
Contour description dialog box describes the way and parameters of representation of physical quantities at a plane in form of isolines or color distributions (figure 5, a). There are two main sets of parameters in this dialog box:

- ranges and contour levels for presenting quantities as isolines, color grades for presenting them as a color distribution;
- legends of contour or color presentations of quantities.

![Figure 5. Examples of dialog boxes describing contours (a) and zones (b).](image)

Zone description dialog box describes a picture that presents several zones, with separate configuration of each zone (figure 5, b). This box specifies the following parameters:

- list of zones to be presented on the picture;
- specification of a type of graphical presentation for each zone – grid, surface, contour or color distribution, slice (cross-section), isosurface, streamline;
- particular way of the presentation in each zone, parameters of presenting the distribution of physical quantities (contours, discrete or smooth color distributions);
- colors for grids, surfaces and other line in each zone;
- indication of the symmetry of a zone with respect to the chosen plane.

Slices (cross-sections) dialog box describes configurations of several parallel slices and their mutual placement (figure 6) and the way of presentation of data on them. This box specifies the following parameters:

- number of slices;
- parameter of a plane to which the slices will be parallel;
- points on the axis perpendicular to this plane on which the slices will be places;
- indication whether a slice will be colored (for each slice), slice color;
- indication whether the surface will be colored, surface color;
- indication whether the grid will be projected on a slice (for each slice), grid color;
- parameters of presenting the distribution of physical quantities for each slice (contours, discrete or smooth color distributions).
Figure 6. Example of dialog boxes describing a group of several slices.

Isosurface dialog box describes surfaces of equal value and distributions of a physical quantity on them (Figure 7). This box specifies the following parameters:

- physical quantity represented as isosurfaces;
- values for which isosurfaces will be presented;
- indication whether the isosurfaces will be colored, isosurface color;
- indication whether the grid will be projected on isosurfaces, grid color;
- parameters of presenting the distribution of physical quantities on isosurfaces (contours, color distributions).

Figure 7. Example of dialog boxes describing the isosurface (a) and the color distribution of a physical quantity on it (b).

Streamline description dialog box describes the characteristics of trajectories (streamlines) for a given velocity field. It is possible to manipulate with trajectories – add new trajectories by indication of their starting points, delete existing trajectories. This facility is convenient for analyzing flow fields interactively.
2.2. Two-dimensional visualization mode
The two-dimensional visualization mode is intended for representing distributions of physical quantities as functions of variables on an argument in the form of plots or linear diagrams (figure 8). Different ways of the presentation can be used – lines, points and their combinations.

![Figure 8](image8.png)

Figure 8. Two-dimensional mode. Example of a comparison of calculated and experimental data.

![Figure 9](image9.png)

Figure 9. Example of the dialog describing two-dimensional visualization.
Two-dimensional visualization if controlled by the corresponding dialog box (figure 9). This box specifies the following parameters:

- dependent variables and their argument;
- zones from which this variables will be extracted;
- way of the representation of values (lines, points), the appearance and color of lines and points;
- way of the representation of legends, texts of legends.

Thus, the developed visualization module contains all necessary elements and methods of graphical representation of data, as well as tools for interactive control of the viewing process.

3. Implementation of the visualization module

The visualization module is implemented as a constituent part of the interactive information and simulation system (IISS). It is written on C++ language, using the open-source cross-platform software package Qt [8, 9] version 5.5 for implementing the interactive window interface. The graphical output and manipulation functions are built upon the open-source visualization toolkit VTK [10, 11] version 7.1.

The new module was tested and validated by several authors when performing aerogasdynamic computations. It was successfully used for spatial visualization and analysis of external flows [12-15], two-dimensional visualization [16] and simulation of an engine [17-19].

4. Conclusion

The developed visualization module provides a wide range of possibilities for graphical representation of the results of numerical simulations, as well as for viewing the geometries of modelled object and the computational grids. The visualizer supports different manipulations with the resulting images – moving around the screen, scaling and rotation. The overall control on the graphical presentation, its configuration and tuning are performed in dialog boxes.

The visualization module supports the geometric and grid formats and provides partial compatibility on data formats and control methods with the widespread commercial visualizer Tecplot. Throughout the development of the module, the amount of functional capabilities and the number of supported data formats will be increased.

The new visualizer is integrated into the interactive information and simulation system (IISS) and is a constituent part of it. The developed platform will become an effective and convenient tool both for performing aerogasdynamic calculations and for visual analysis of obtained results.

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