ENGINEERING MODEL OF SPACE DEBRIS ENVIRONMENT

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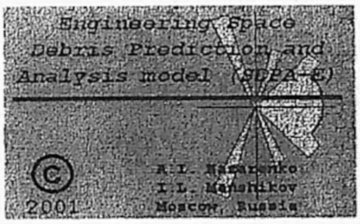
ABSTRACT



The model considered in our paper is named the "Engineering Space Debris Prediction and Analysis model" ("SDPA-E").

This model is implemented as the special software. The model is intended for fast, convenient and visual estimation of basic characteristics of space debris environment. These characteristics relate to particles sizing larger than 1 mm and to two regions of space: LEO and GEO. The model allows to calculate the following five characteristics of space debris:

- spatial density;
- cross-sectional area flux with respect to typical orbits of spacecraft;
- angular distribution of aforementioned cross-sectional area flux;
- angular dependence of the mean velocity of collisions;
- predicted values of cross-sectional area flux.

The paper contains the brief description of the model, examples of solution of different tasks and basic technical characteristics of the software.

1. MODEL DEVELOPMENT PRINCIPLES

- The basic files of the space debris initial data are prepared on the basis of a more complicated SDPA-model (the Space Debris Prediction and Analysis model). These data are recorded in the database and are accessible to the user for surveying.
- The current initial data for solution of the chosen task are specified in the dialogue mode.
- For calculating the characteristics to be determined for arbitrary input data values the interpolation is applied.
- The task solution results are displayed on the «Results» panel.
- The software provides the possibility of putting calculation results into the database of the user.
- The software also provides the possibility of saving the graphs.

2. MAIN MENU. SELECTION OF THE TASK AND ITS SOLUTION.

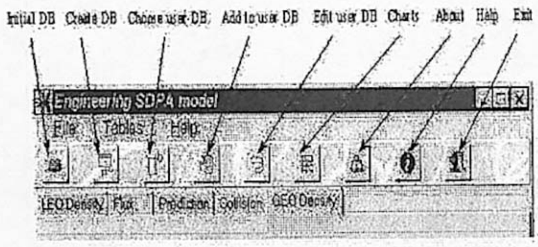


Fig. 1. General menu of SDPA-E model

The SDPA_E model allow to solve four basic tasks:

1. "Spatial density" ("LEO Density" and "GEO Density") - the determination of spatial distribution of technogenous (man-made) space debris spatial density (the number of objects in 1 cub. km);
2. "Flux" - the determination of averaged values of a space debris (SD) current flux with respect to typical spacecraft (SC) orbits;
3. "Prediction" - the forecasting of the SD flux with respect to typical spacecraft (SC) orbits.
4. «Collision» - the calculation of the distribution of impact directions, as well as the dependence of collision velocity on its direction.

The main window of the software contains five pages. Each page contains its proper task. The name of the active page corresponds to the active task. The active task can be changed by choosing the appropriate page or by means of commands in the «Task» menu.

The initial data for solution of the chosen task are incorporated in the group «Initial data» panel and are specified by the user in the dialogue mode. To solve the task with specified initial data the «Run» button should be pressed.

The results of solution of the task are displayed on the "Results" panel. For the "Prediction" task the results are presented for two technical policy factors (K=0.4 and K=0.8).

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The software provides the possibility of plotting the graphs as well. For this purpose it is necessary to choose one of commands in the «Graphs» menu or to choose the appropriate command in the menu appeared after pressing the «Graphs» button. One of calculation results is plotted on the graph as a function of the chosen initial parameter for specified remaining initial parameters.

3. INITIAL DATABASES AND USER'S INPUT DATA

The databases, prepared by the developer, are used in solution of tasks (in the Paradox 6.0 format). The initial database can be overlooked by choosing the database of interest in the «Tables - initial» menu or in the menu appeared after pressing the «Initial database» button at the control desk. To view the initial tables of the database it is possible, having selected the data set of interest in the "Tables - initial" menu. The example of the input data table is shown in Figure 2.

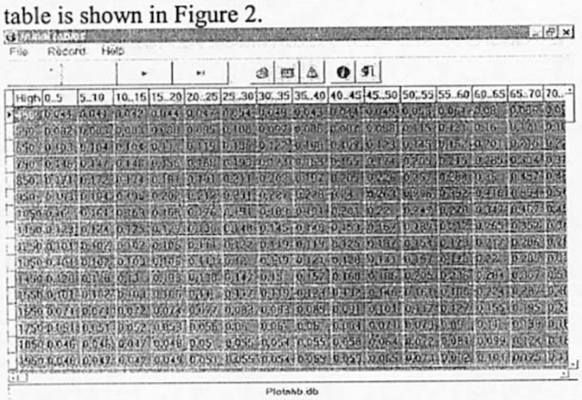

Fig.2. An example of the input density data («Plotnhb.db» file)

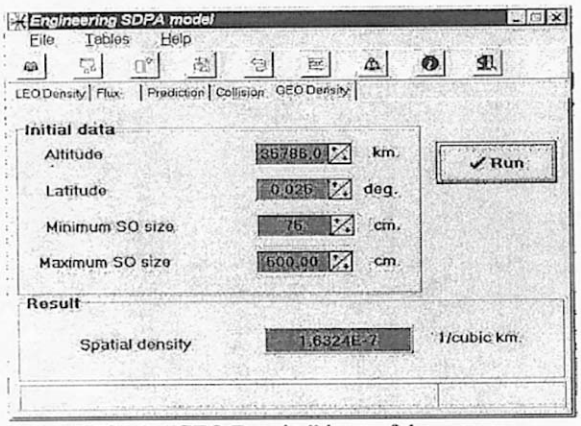

Fig. 3. "GEO Density" item of the menu

Among the data, which are specified by the user, the common input data (for solution of each of the tasks) are as follows:

1) the minimum and the maximum size of particles (cm);
2) the altitude of point/orbit (km);
3) the latitude of a point or the orbit inclination (degrees).

In addition, the following data are used:

4) the mean size of a spacecraft (SC), with respect to which the space debris flux is evaluated - for the «Flux», «Prediction» and «Collision» items of menu;
5) the initial and final time (years) of the collision probability prediction - for the "Prediction" item of the menu.

These input data are combined in the group panel.

4. APPLICATION OF VARIOUS ITEMS

4.1. Calculation of the spatial density of SD of different sizes (the "LEO Density" and "GEO Density" items of the menu)

Two altitude ranges are considered: from 400 to 2000 km (LEO) and from 35300 to 36200 km (GEO). The selection of the range is performed with the help of some special ("LEO Density" or "GEO Density") submenu. In the first case the possible range of latitudes equal up to 90 degrees, and in second case - up to 15 degrees. The example of density calculation is presented in Figure 3. The solution results are mapped on the "Result" panel. In this case the average number of SD particles in 1 cubic kilometer in the given space point vicinity in the year 2000 is calculated for the given particle size. There exists a possibility of constructing the dependence of density on one of input data parameters.

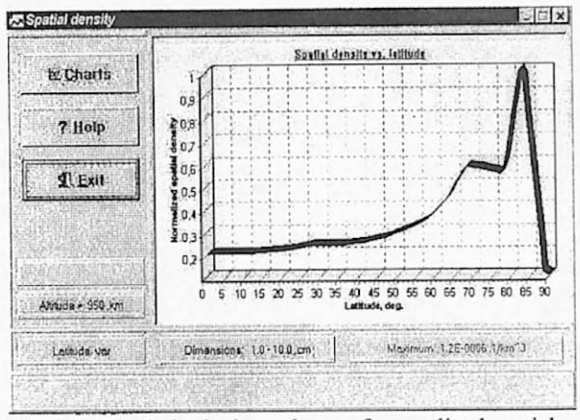

Fig. 4. The latitude dependence of normalized spatial density for the LEO region. The altitude is 950 km, the SD size is in range from 1.0 to 10 cm.

The example of such latitude dependence for LEO is presented in Figure 4. Other example is given in Figure 5. It relates to the GEO region (latitude of 0 degrees) and presents the latitude dependence of the normalized spatial density values for particles sizing larger than 1.0 cm.

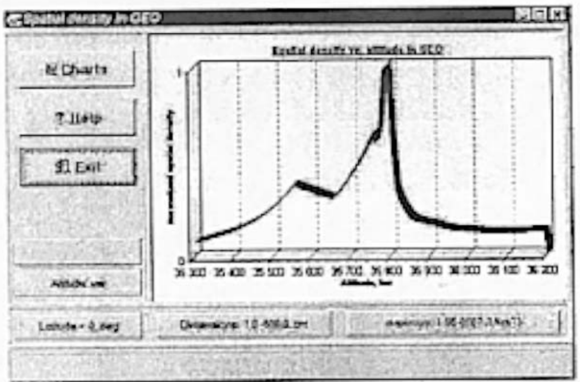

Fig. 5. The altitude dependence of normalized spatial density for the GEO region. Latitude is 0 degree. The SD size > 1 cm.

4.2. Estimation of the SD flux with respect to the given SC in 2000 (the "Flux" item of the menu)

The average number of SD particles passing per time unit through the surface of spherical-shaped SC of the given size ("Average SC size") is calculated. Along with the total flux values, the flux components related both to catalogued objects (sizing larger than 20 cm) and to non-catalogued ones (sizing less than 20 cm) are calculated in this case. The example of such a calculation is presented in Figure 6.

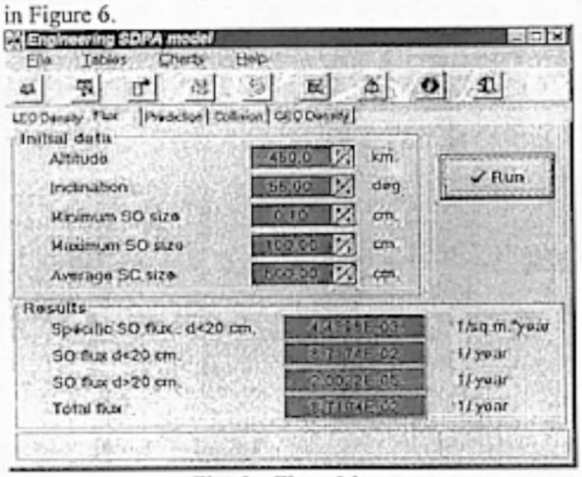

Fig. 6. «Flux» Menu

Addressing to the «Charts» item allows to obtain the graphical representation of the SD flux dependence on different arguments. The example of construction of such a dependence on the SC inclination is shown in Figure 7. The normalization with respect to the maximum flux value is made here.

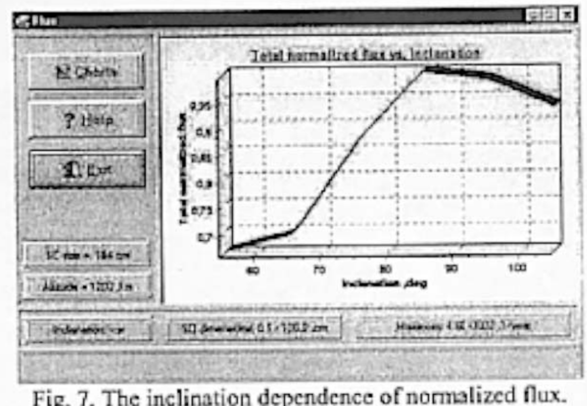

Fig. 7. The inclination dependence of normalized flux. Altitude is 450 km. SD size >0.1 cm. SC size is 184 cm.

4.3. Prediction of flux estimates over the time interval from 2000 to 2022 ("Prediction" item of menu).

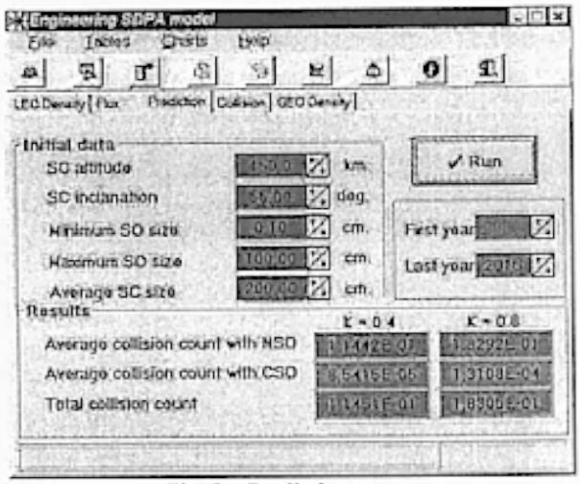

Fig. 8. «Prediction» menu

The total number of SC collisions with non-catalogued (NSO) and catalogued (CSO) space objects on a preceding time interval up to the given time ("Last year") is calculated. The results are determined for two levels of space contamination intensity in the future: pessimistic (K=0.8) and optimistic (K=0.4). Addressing to the «Charts» item allow to obtain the graphical representation of the time dependence of number of collisions per year. The example of such dependence is presented in Figure 9.

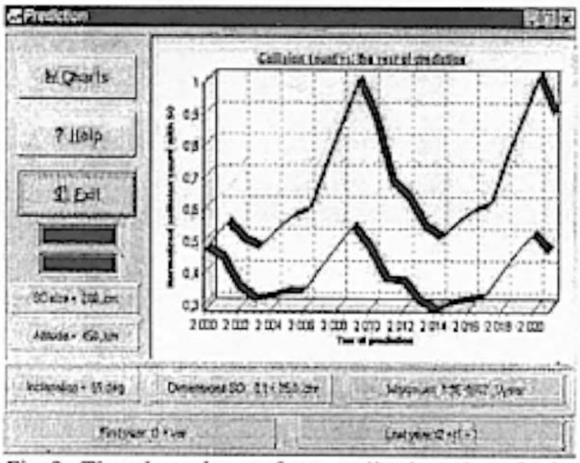

Fig. 9. Time dependence of a normalized number of collisions per year.

4.4. Calculation of characteristics of the velocity possible SD collisions with the given spacecraft ("Collision" item of menu)

The distribution of directions of possible collisions, as well as the dependence of relative velocity on its direction are calculated in this menu item. The direction of a relative velocity is characterized by its deviation from the SC motion direction. The plots of aforementioned functions are displayed directly in the window of the menu item under consideration. One of examples of calculation of these characteristics is presented in Figure 10.

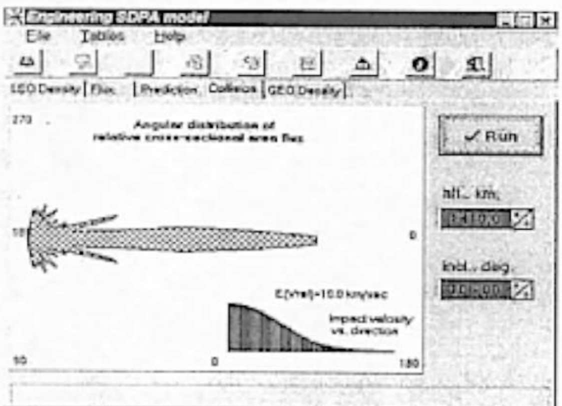

Figure 10. Angular dependence of the relative velocity characteristics

5. SAVING OF CALCULATION RESULTS

During the program operation the user can apply the obtained results according to the following scenarios:

1. *Operation in the visual familiarization mode*. This is the simplest version of interaction with the program, which includes the following steps: a) specifying of the initial parameters, b) starting of the calculation process, and c) obtaining of the data required. This result can either be read from the monitor screen or simply taken into consideration. For example, at opening of the «GEO Density» item (Fig. 3) the corresponding input data panel (altitude, latitude, minimum and maximum SD size) displayed. When all parameters are settled, the pressing of the «Run» button actuates the calculation process, and the numerical value of density will appear in the «Result» window.

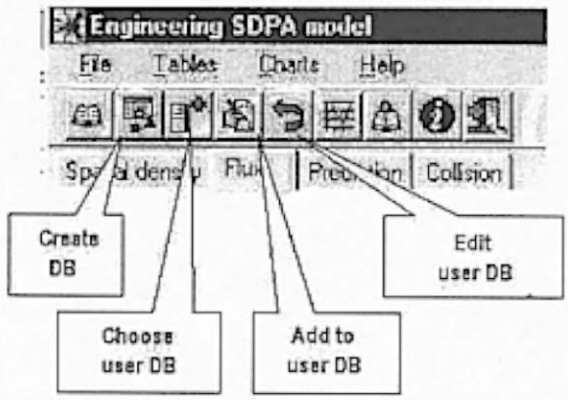

Fig. 11. Operations with user's database

2. *Operation with user's database* is logical continuation of the previous scenario. Let us assume that some version of any task (menu items) must be calculated in order to have a possibility of processing the results in the future. In this case it is convenient to take advantage of the database, in which the input data and calculation results can be saved. For this purpose the following operations are applied (see Figure 11):

- Generation of the database template. The template represents an empty bar of the table in Paradox 6.0 format. The input data and the results can be recorded in this table. Several tables can be used in this case, but it should be remembered that only one table is accessible for data recording at the current time.
- Activation of the required table of the database. There is possibility of selection this table from the possible versions available. As a rule, we already have a ready template of the table after the program installation, but it is

always possible to generate and activate a new base. In this case, however, the templates for each task are not interchangeable; i.e. the template of the table from one task can not be used in another one. This condition allows to avoid confusions and annoying errors.

- Saving results in the database. The command «Add to user DB» is applied for this purpose. All necessary data are automatically recorded in the last line of the table. In some cases this option may be inaccessible because of the absence of the active base. This happens before making calculations.
- Editing the table of user's database. It is possible to take advantage of the built-in editor, which allows to make such operations as survey and navigation over the table, editing the lines or their deleting.

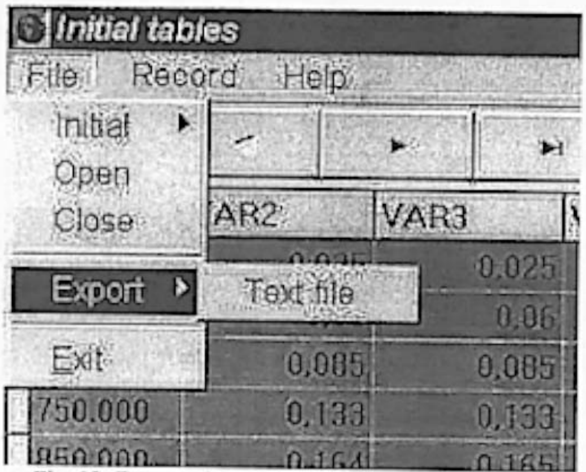

Fig. 12. Export of the table of results to the text file

In addition, for data processing in the table it is possible to take advantage of any accessible program, such as «Paradox for Windows», «Statistica» or to export the tables to the ASCII format from the «File» menu of the built-in editor (see Figure 12).

Note: The operation with user's databases is not supported in the «Collision» item of the menu. In this item the data can be saved in the ASCII format only, or reproduced as the graphs.

3. *And, finally, the last possibility of using the Engineering model results is the construction of graphs.* For the "Collision" item the graph of the angular distribution of a relative flux is constructed directly in the application window. For other tasks some dependencies can be constructed, which are of greatest interest (see Figures 4, 6, 7 and 9). In this case the general rule is follows: for constructing the dependence only one selected parameter varies, and all rest parameters containing in the "Initial data" group panel are remained fixed. For example, if we construct the altitude dependence of spatial density in LEO, then the latter one will lie in the limits from 200 km to 2000 km.

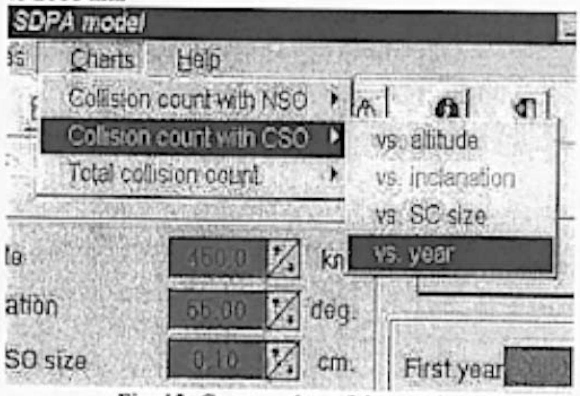

Fig. 13. Construction of the graphs

6. GENERAL CHARACTERISTICS OF THE SDPA-E SOFTWARE

The program executes the calculation of current and forecasted SD characteristics in two regions: LEO (Altitude up to 2000 km) and GEO (the altitude range from 35300 km to 36200 km). The objects larger than 1 mm in size are considered. The list tasks to be solved is presented above in Section "Abstract". The computing time expenses for solution of any item of the menu do not exceeds 1 second.

The requirements to the PC configuration and to operating system are as follows:

1. The computer on the processor 486 DX 33 processor basis (the Pentium - 233 or better is recommended).
2. The RAM is 8 MB (the RAM not lower than 32 MB is recommended).
3. The free memory size of hard disk should be about 1.5 MB at installation.
4. The video adapter is arbitrary, supporting the 640x480 mode and 256 colors. The recommended mode is 800x600 True Color.
5. The CD-ROM drive (for installation or starting from a laser disk) or the floppy drive (for installation from a diskette).
6. The operating system on the win32 platform (Microsoft Windows 95, 98).

The accuracy of the results, obtained by means of considered Engineering model, corresponds to the accuracy of calculation with using of our more complicated SDPA model. This is confirmed by the data of Figure 14, which represents the comparison of SD cross-sectional area flux values with respect to SC (with altitude of 450 km, inclination of 51.6 degrees) for two aforementioned models.

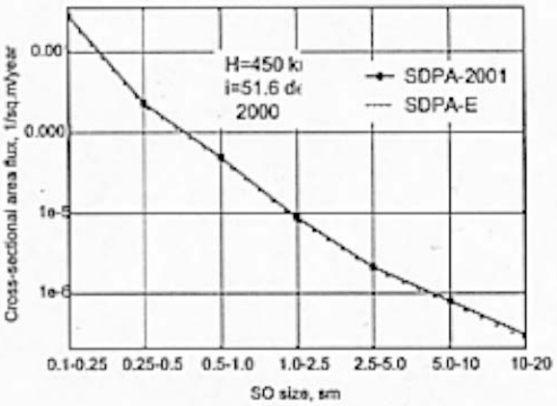

Figure 14. Comparison or results for the SDPA and SDPA-E models

The comparison of density estimates was also made for the GEO region (altitude of 35786 km, latitude of 0 degrees, the year 2000). Corresponding data for objects of different sizes are presented in Figure 15. The results of MASTER' 99 density calculations are adduced also. It is seen from these data, that the difference between our model estimates is much less, than the distinction from the data of the MASTER'99 model. The additional analysis for clarifying the reason of these differences is required. First of all, this guideline concerns the catalogued objects larger than 75 cm in size.

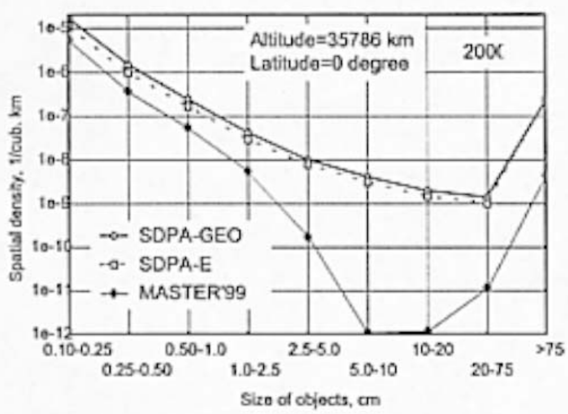

Fig. 15. Comparison of density estimates for GEO region

The demo version of our SDPA-E software is also available. More detail information about this software and its demo version (in a slightly reduced volume) can be found on the Internet page of the Space Observation Center: http // monitor.cpi.space.ru /, and to receive by the E-mail address "nazarenko@iki.rssi.ru" also.

7. CONCLUSION

1. The Engineering model of space debris environment (SDPA-E) is developed on the basis of approximation of the SD characteristics calculated on the basis of more complicated Space Debris Prediction and Analysis model (SDPA-model).
2. The Engineering model is intended for fast, convenient and visual estimation of basic characteristics of space debris environment in the LEO and GEO regions for SD particles larger than 1 mm in size.
3. The Engineering model is produced as software compatible with the usual PC.
4. The Engineering model is intended for a wide circle of the experts and students, who are interested in the characteristics of technogeneous space debris environment contamination.

8. REFERENCES

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