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PREDICTION AND ANALYSIS OF ORBITAL DEBRIS ENVIRONMENT EVOLUTION

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1. INTRODUCTION

For the analysis of the orbital debris environment two variants of technique are used, that is numerical and analytical ones.

The first approach, which is mentioned in works by D.Rex, A.Rossi and P.Farinella, Z.Khutorovsky and S.Kamensky (Refs. 1-3) has a specific feature, namelly, it is based on a large set of initial data (the full catalog of space objects) and on modelling of the real motion for all of them.

The second approach (D.Kessler, A.Nazarenko, Refs.4-6) is based on a limited amount of simplified initial data in the form of statistical distribution. Each of techniques has both positive and negative features. Using the second approach we have worked out original methods, algorithms and programs of statistical detailed analysis to solve the following tasks.

1. Forecasts of altitudes distribution for catalogized and non-catalogized space objects (SO).
2. Estimates of the asymptotic altitude distribution.
3. Creation of the altitude-latitude distribution of objects density.
4. Creation of the altitude-latitude distribution of the velocity vector of SO.
5. Estimates for probability of collision between spacecraft and SO, taking into account the intensity of space objects flux in various points of orbit.

Software modules were integrated in a complete set of programs that enable the any PC-AT user to accomplish all the above tasks. Certain results of respective modelling experiments are presented below, and a comparison with the data published in other references is also given.

2. THE DEBRIS ENVIRONMENT EVOLUTION

At the first stage the efficiency of the model and the possibility of obtaining acceptable results using this technique were verified. This can be done in a most rational way by modelling the situation in the near-Earth space throughout the time interval of its extensive exploratoin (since 1960 approximately) and by comparing modelling results with the known data on catalogized objects. It was assumed that $\Sigma = 480$ new SO's have been formed annually throughout the prediction interval up to the altitude of 2000 km as a result of new launches, explosions and other causes.

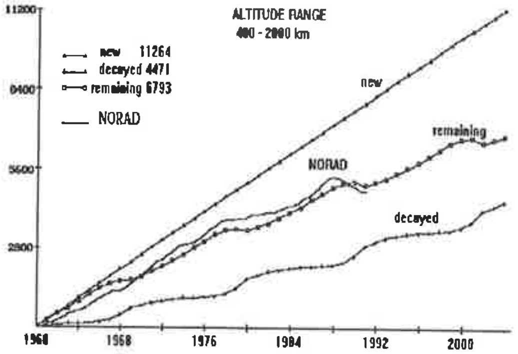

Fig.1 The number new. decayed and remaining objects

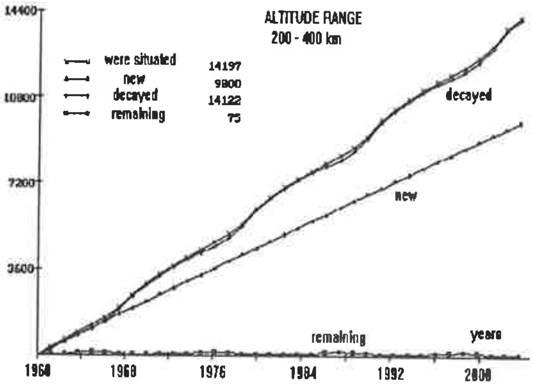

Fig. 2. The number of new, decayed and remaining objects

Figure **1** and **2** show the obtained data on number of formed, decayed and catalogized SO's for the period from 1960 to 2004. The NORAD catalogue volume data are also given. The ratio of decayed-to-formed number SO's for each of 4 successive 11-year solar activity cycles amount to 61, 67, 69 and 71 percent, respectively. It grows with the time. The predicted number of objects for 1990 was 5100. The difference from the NORAD catalogue volume data does not exceed 5%. The expected catalogue volume for 2004 is 7000 objects.

Figure **3** shows the altitude distribution prediction results (for 29 and 44 years) and compares them with the real distribution of 1990. The results are seen to have rather good quantitative and qualitative coincidence. It is also seen that the SO number grows

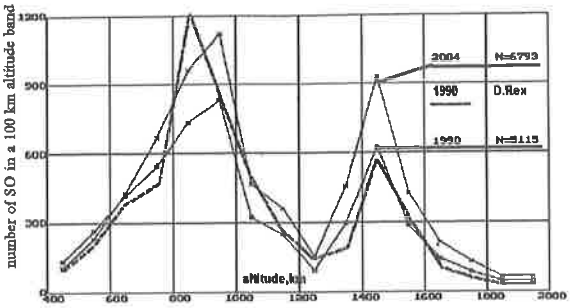

Fig3 The prediction altitude distribution of space objects in 1990 and 2004 years

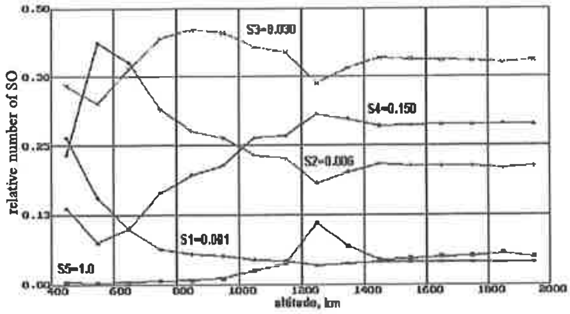

Fig.4 The relative number of objects with various ballistic coefficients

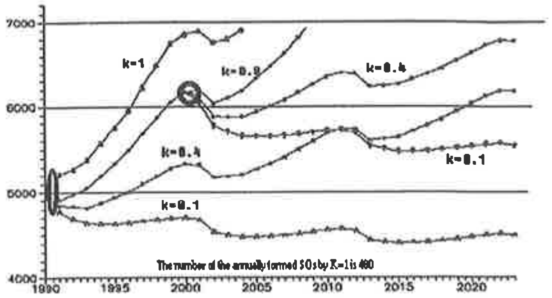

Fig5 The catalogized SO number under different option of technical polices

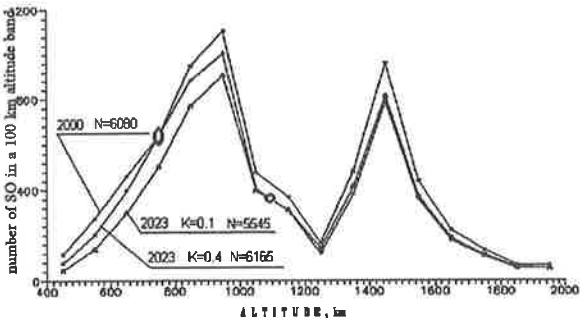

Fig6 The comparison of the prediction altitude distribution by the different rate of SO density increment

faster at higher altitudes than at lower ones. The SO number stabilization tendency becomes noticeable only at altitudes up to 600 km.

Figure **4** gives the relatuve SO number variation for different ballistic factors **(S)** as a function of altitude within the 33 year prediction time interval. The initial distribution **p(S)** is seen to be strongly reshaped. At altitude up to 800-1000 km the relative SO number rises for small **S** and drops for greater ones. The fraction of SO with higt **S** reaches the maximum within the 1100-1200 km altitude interval. This information is important for proper intrpretation of experimental data and for correct forecasting the fragmentary situation.

The second stage was the prediction up to 2023. The technical policy was characterized by the ratio **(K)** of annually formed SO number to the foregoing nominal estimate **Σ.** Three options of technical policy were considered.

1. **K**=0.8. This option corresponds to recent years trend, when the number of launches had been cut by any reason.
2. **K**=0.4. This estimate may be realized on the basis of decreasing number of separated technological fragments, recovering of rockets and reduction of SO explosions.
3. **K**=0.1. This estimate corresponds to the entire exclusion of SO explosions as well as reduction of launch number.

Figure **5** shows the data on cataloguized SO number under different options of future space exploration policies. It shows that the curbing of further SO number growth, which threats the mankind by great troubles, demands cuting down the SO formation intensity by an order of magnitude. Fidure **6** compares altitude distribution of SO number: the initial one for 2000 and predicted one for 2023, to **K**=0.4 and **K**=0.1, respectively. The reduction of new SO`s formation intensity is seen to cause the reduction of SO number at low altitudes only, up to 750 km for **K**=0.4 and up to 1050 km for **K**=0.1. At higher altitudes the number of SO`s will grow. This result has a principal significance. It points to the fact that the reduction of new SO's formation intensity by an order of magnitude would not "purge" the near-Earth space at altitudes higher than 1000km. These altitudes need additional measures: the full exclusion of fragment formation and returning of exhausted spacecraft back to the Earth.

The noted trend of irreversible growth of SO number at high altitudes is illustrated in Figures **7** and **8**, which give an asymptotic altitude distribution of SO number as well as the ratio of the SO layer top number to their surplus. The SO top number under considered condition was to be 2 000 000, and the ratio of annual surplus in layer changes by 3 orders with the altitude. Such flood of SO's is evidently inadmissible. Taking of measures to avert the SO number growth should be started just now.

Figure **9** gives the data on predicted number of non-cataloguized SO's for the 1960-1993 year interval as an altitude function of the volume density of this type of fragments more then 1 cm in size. Since the initial data on the number and features of small fragments are inaccurate and contradictory, the latter results should be considered as an illustration of our technique possibilities only.

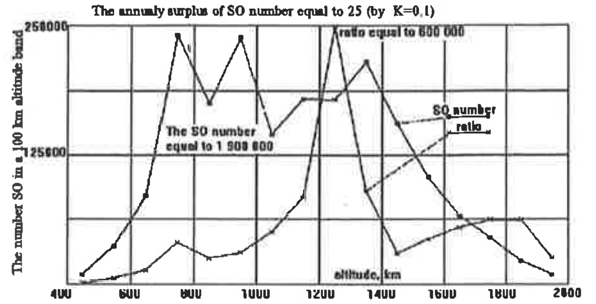

Fig.7. The asymptotic altitude distribution of SO number and ratio of the SO layer top number to their annual surplus

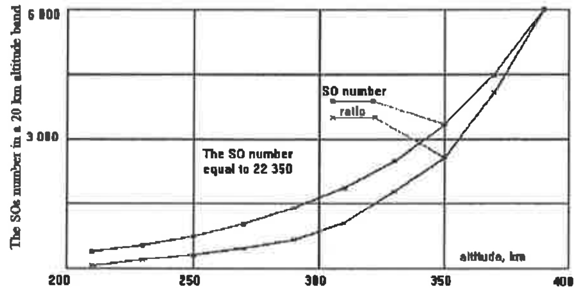

Fig.8. The asymptotic altitude distribution of SO number and ratio of the SO layer top number to their annual surplus

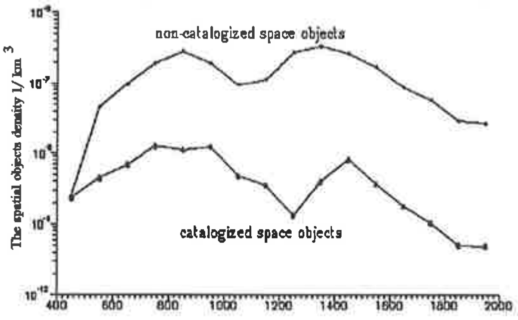

Fig.9. The prediction of non-catalogized SO number for the 1960 - 1993 years interval

3. THE FRAGMENTARY SITUATION ANALYSIS

The results given below were obtained from the distribution data on cataloguized SO's for the end of 1992. The total SO number is assumed to be 5900. Figure **10** give a normalized latitudinal depedence of number of SO situated in the latitude range (φ, φ+10degr) for a certain time moment. The similar function plotted from numerical data of a real catalogue is given for comparison. The data obtained by analytical means is seen to pretty well coinside with the numerical solution results. Some interesting feature of the plotted function is a practically constant relative number of SO's in the latitudinal range of 0 - 70 degr. latitude (90% of all SO's are situated in this layer), that is steeply drops theh.

Fig. **11.** shows two-demensional altitude and latitude dependenses of SO volume density. The well-known local density maxima in the 800-1000 and 1400-1600 altitude ranges are distinctly seen. Some characteristic feature of the latitudinal function is its 2 fold increment with the latitude growth succeeded by a sharp downfall of the latter. The maximum is achieved in the region of 75 degr and 950 km and equals 17 E-9 1/km km km.

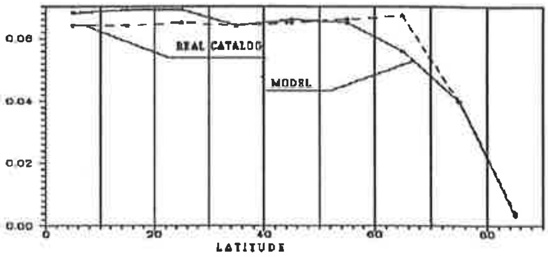

Fig.10. The normalized SO number in the latitude range 10 degr

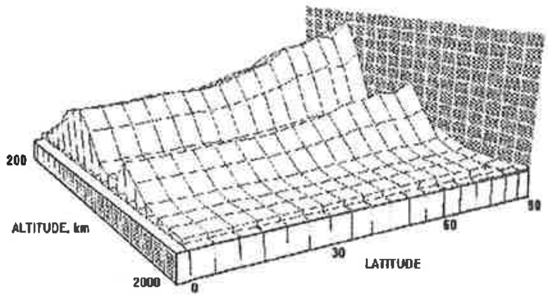

Fig. 11. The spatial objects density as function of the altitude and latitude

Figures **12 - 16** show polar coordinate distribution of the velocity vector azimuth for five different latitude points: 5, 35, 65, 75 and 85 degr. Low latitudes have the azimutal distribution rather close to the initial distribution of inclinations. As the latitude grows, the "lobes" merge and align. The distribution tends to be homogenous.

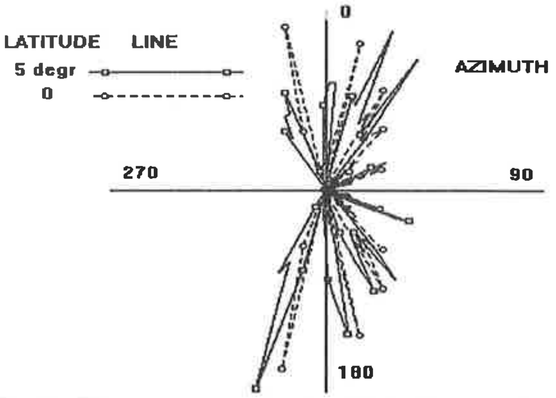

Fig.12. The polar coordinate distribution of the velocity vector azimuth

The analysis results allow to calculate the probability of spacecraft collision with the space debris for any of its orbital parameteres (at the altitudes up to 2000 km). The averaged-over-revolution SO flux distribution at the relative azimuth (the course angle) and the distribution of collision number at the relative collision velocity are colculated along with it. The results are given in figures **17 - 20.** One of spacecraft is chosen in such a way, that the calculation results could be compared with the published data on the station designed at the West (**h**=500 km, i=28 degr, **A**=1000m m).(Ref.1) Under the above mentioned conditions the probability of collision with catalogized SO during the 10-year period equals 1.2%. This probability turned out to be essentially higher than the published estimates.

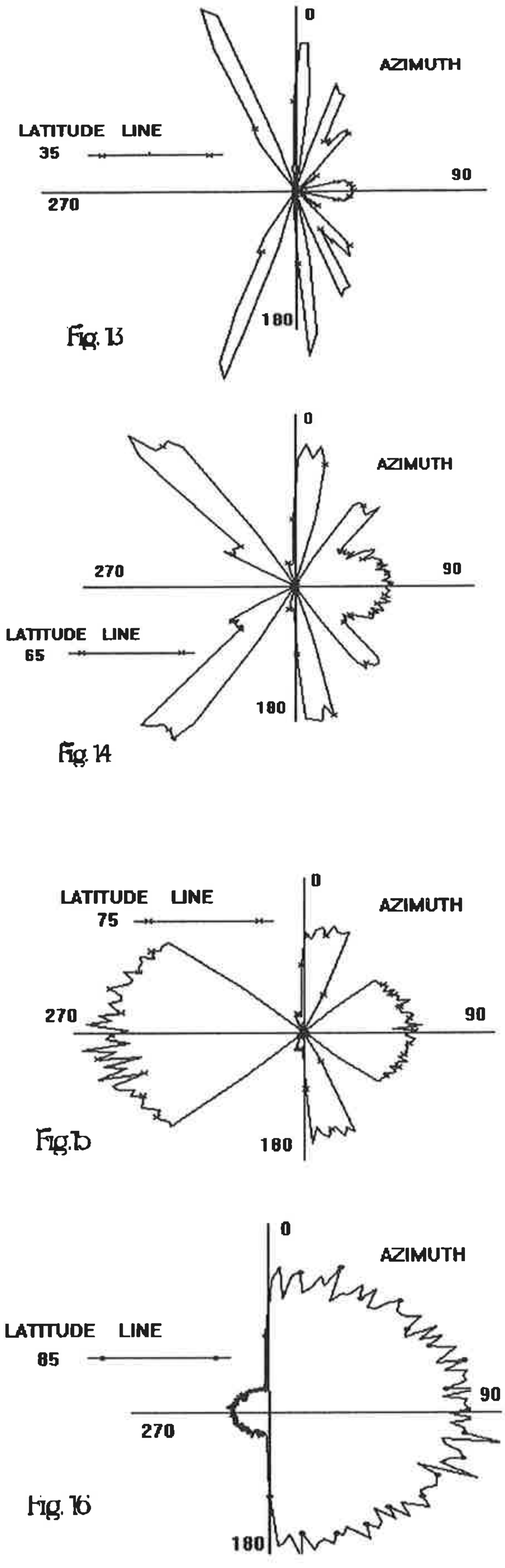

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 13-16. The polar coordinate distribution of the velocity vector azimuth

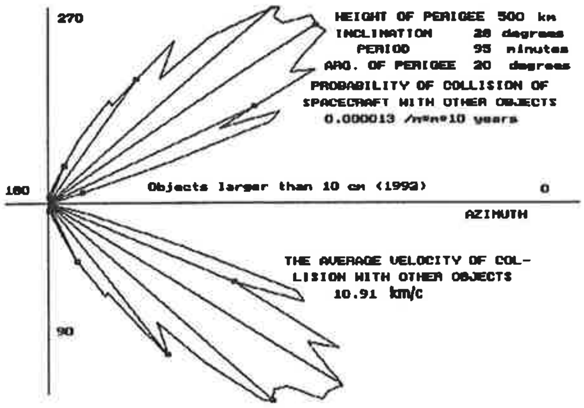

Fig. 17. Angular distribution of relative impact velocity for space station

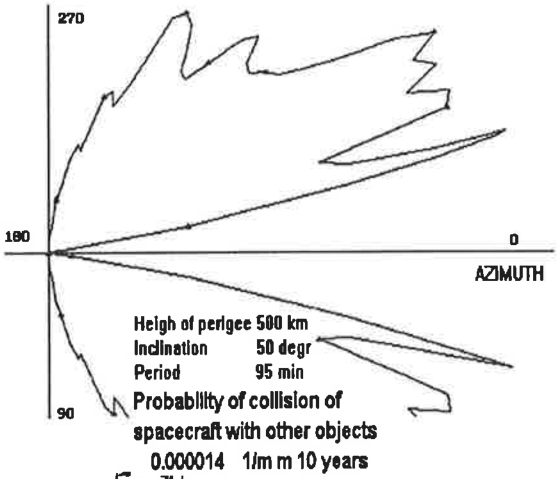

Fig. 18.

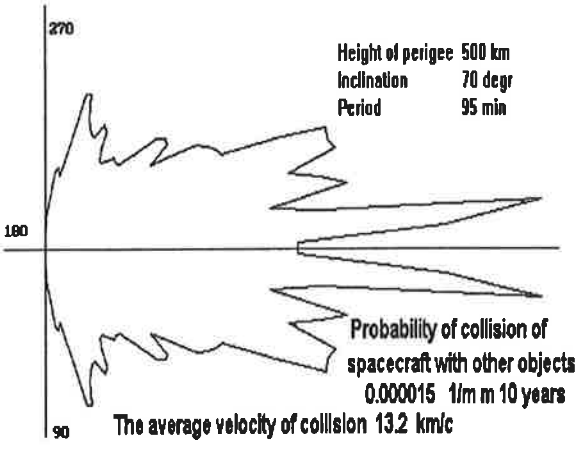

Fig.19.

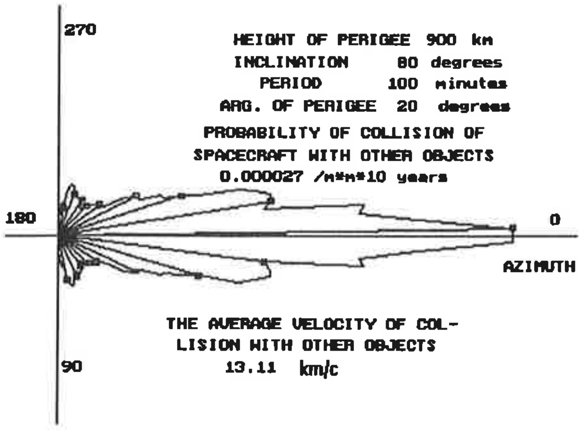

Fig. 20. Angular distribution of relative impact velocity

4. CONCLUSION

1. Comparison of results obtained by use of the proposed modelling technique for each of the above tasks with the existing data has revealed their good overlap. This fact shows that the model proposed describes quite adequately the process of ongoing pollution of the Earth orbit environment with space debris.

2. The proposed technique enables one to get quite interesting and useful results. In the first place, they include those supporting long-term technical policies and plans for further space exploration activities, which provide the minimization of damage to the orbital environment.

3. The technique and results of estimation of a collision danger can be employed in the spacecraft design process to enhance the reliability characteristics as well as to assess the insurance risks for a complete or partial loss of working efficiency of spacecraft during their sustained operations.

4. The model is implemented as a PC AT application software program and enables one to solve each of the above tasks in the interactive mode within 5-10 minutes. The results are presented as color pictures on the display and then stored as data files. The model has unique capabilities and characteristics. It is recommended for employment by a variety of users involved in space debris and flight safety activities both in Russia and abroad.

All the requestes concerning additional information and purchasing of the software are welcome to address our point of contact: Center for Program Studies, Russian Academy of Sciences, Moscow 117810 Russia,
FAX:7(095) 420 22 75.

REFERENCES

1. Rex D., European Investigations on Orbital Debris, *Adv.Space Res.* Vol. 10, No. 3-4, pp(3)347-(3)358, 1990.
2. Rossi A., Farinella P., Collision Rates and Impact Velocities for Bodies in Low Earth Orbit, *esa Journal 92/3.*
3. Khutorovsky Z., Kamensky S., Direct method for the analysis of collision probability of artifical space objects in LEO: techniques, results and applications, *First Eurppean Conference on Space Debris,* Darmstadt, Germany, April 1993.
4. Kessler D., Derivation of the Collision Probability between Orbiting Objects: The Lifetimes of Jupiter's Outer Moons, *ICARUS* 48, pp 39-48, 1981.
5. Назаренко А.И. Моделирование процесса самоочищения околоземного космического пространства, *Доклад на канференции "Техногенное засорение космоса: проблемы и направления исследований, Центр программных исследований РАН, 1992.*
6. Назаренко А.И. Построение высотноширотного распределения объектов в околоземном пространстве, *Сб. Проблемы загрязнения космоса (космический мусор), Москва, Косминформ, 1993.*