# THE ESTIMATES OF JOINT CONTRIBUTION OF THE RSSS AND THE US SSN TO INFORMATIONAL SUPPORT OF THE ISS FLIGHT SAFETY

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ABSTRACT

The problem of informational-ballistical support for the future ISS "Alpha" flight safety under conditions of high probability of its collision with space debris and limited resource of making collision avoidance maneuvers is discussed. Solution of this problem requires very high accuracy of orbit determination both for the ISS and for all potentially dangerous space objects alongside of the ISS trajectory. The capabilities of each of the two Space Surveillance Systems (Russian and American) as well as of the joint one for the ISS flight safety informational support are estimated. For the case of getting measurement information from the united system (RSSS + US SSN) the estimates of the required annual number of collision avoidance maneuvers of the ISS for different values of time advance of calculation of the maneuver parameters and different methods of space debris motion parameter propagation were obtained.

In view of comparatively large surface area of the International Space Station (ISS) "Alpha" which is potentially subject to space debris impacts, durable manned flight program, and significant space debris density in its operational altitude range the maintenance of its flight safety needs special care on the part of the project designers and related experts.

The peculiarity of the problem of the ISS flight safety informational-ballistical support is the necessity of predicting position parameters several hours in advance both for the ISS and potentially dangerous space objects round about the track.

Such forestalling is needed for computing well-timed estimates of the jeopardy extent on the part of space debris passing close by the ISS and for calculation and implementation of the collision avoidance maneuver. For today this forestalling is received to be equal to 6 h.

Whereas the ISS position parameters can be determined with required accuracy with the help of its own on-board and ground-based measuring system, the spatial coordinates and motion parameters of potentially dangerous passive space debris can be measured only with the help of sensors usually being used by the US SSN and the RSSS with possible enlisting some additional facilities of different affiliation.

Taking into account the limitation of the total maneuver resource for the ISS, the accuracy of passive space debris orbit determination should be rather high for the guarantee against unnecessary maneuvers. And as the ISS surface vulnerable to space debris attack is very large (as a sum - about 1800 sq. m ), the collision probability grows rather high and elimination of unnecessary maneuvers appears to be a notably live issue.

Table 1 contains estimates of the probability of at least one collision a year for the ISS and the cataloged space objects (more than 10-20 cm size) at altitudes 350, 400 and 450 km. The calculation was made with the help of the model described in Ref.1, which is based on the space debris flux density determination through the unit square at the proper altitudes using the real RSSS catalog.

| H, km | 350 | 400 | 450 |
|---|---|---|---|
| P | 0.00008 | 0.0001 | 0.00017 |

Table 1. Probability of one collision a year.

Now let's proceed to estimate the separate and joint capabilities of the both Space surveillance systems on informational support of solving the problem of collision avoidance maneuver implementation.

For each of the system consider 2 possible sensor compositions really used in different situations:

1. The measurement data sources comprise only organic regular sensors (dedicated ones). For the US SSN these are 9 phased array radars and 1 continuous wave radar fence (NAVSPASUR), and for the RSSS - 9 phased array radars.

2. Besides the dedicated sensors some additional high accuracy facilities are enlisted, which is usually done when working on the risk space objects and in special experiments. For the US SSN mechanically steered

dish radars were added. and for the RSSS - 3 multipurpose precision radars.

The composition of sensors corresponds to Ref.2 (as to the US SSN) and to Refs. 3, 4 (as to the RSSS).

For the first sensor composition for each of the systems separately and for their hypothetical informationally united configuration the 6-hour propagation r.m.s. errors (km) for 3 different inclinations (30, 50 and 70 deg.) are given in Tables 2-4. A conditional time origin at the 24-hour interval was used for calculations.

| h / deg | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 0.79 | 1.02 | 1.00 | 1.12 | 1.35 | 1.40 | 1.56 | 1.71 | 1.89 | 2.04 | 2.10 | 2.29 | 2.45 | 2.72 | 2.92 | 3.09 | 3.28 | 0.84 | 0.94 | 0.86 | 0.82 | 0.74 | 0.78 | 0.90 |
| 50 | 0.69 | 0.77 | 0.66 | 0.77 | 0.95 | 1.02 | 1.16 | 1.35 | 1.48 | 1.66 | 1.82 | 2.03 | 2.22 | 2.39 | 0.74 | 0.61 | 0.70 | 0.71 | 0.63 | 0.71 | 0.68 | 0.72 | 0.72 | 0.61 |
| 70 | 0.70 | 0.78 | 0.70 | 0.72 | 0.79 | 0.96 | 1.09 | 1.19 | 1.39 | 1.55 | 1.67 | 1.88 | 0.66 | 0.77 | 0.67 | 0.61 | 0.68 | 0.66 | 0.59 | 0.74 | 0.76 | 0.87 | 0.76 | 0.67 |

Table 2. 6-hour propagation errors for the RSSS.

| h / deg | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 2.77 | 0.62 | 0.82 | 0.67 | 0.73 | 0.71 | 0.66 | 0.72 | 0.70 | 0.81 | 0.69 | 0.80 | 0.94 | 1.06 | 1.20 | 1.32 | 1.49 | 1.64 | 1.79 | 1.97 | 2.14 | 2.35 | 2.53 | 2.75 |
| 50 | 0.81 | 0.68 | 0.80 | 0.70 | 0.78 | 0.71 | 0.68 | 0.74 | 0.64 | 0.57 | 0.68 | 0.72 | 0.84 | 0.95 | 1.08 | 1.25 | 1.38 | 1.55 | 1.74 | 1.91 | 0.72 | 0.84 | 0.90 | 0.75 |
| 70 | 0.85 | 0.65 | 0.82 | 0.76 | 0.57 | 0.76 | 0.84 | 0.95 | 0.74 | 0.66 | 0.80 | 0.72 | 0.69 | 0.86 | 0.74 | 0.86 | 0.97 | 0.76 | 0.71 | 0.82 | 0.97 | 1.13 | 0.95 | 0.81 |

Table 3. 6-hour propagation errors for the US SSN.

| h / deg | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 0.79 | 0.52 | 0.71 | 0.67 | 0.73 | 0.71 | 0.65 | 0.71 | 0.71 | 0.80 | 0.68 | 0.80 | 0.94 | 1.06 | 1.20 | 1.31 | 1.49 | 0.69 | 0.81 | 0.76 | 0.68 | 0.72 | 0.72 | 0.84 |
| 50 | 0.68 | 0.68 | 0.64 | 0.67 | 0.75 | 0.70 | 0.64 | 0.70 | 0.60 | 0.53 | 0.64 | 0.70 | 0.80 | 0.90 | 0.69 | 0.60 | 0.67 | 0.70 | 0.60 | 0.67 | 0.65 | 0.70 | 0.70 | 0.60 |
| 70 | 0.70 | 0.64 | 0.69 | 0.70 | 0.54 | 0.72 | 0.82 | 0.92 | 0.74 | 0.66 | 0.80 | 0.70 | 0.65 | 0.75 | 0.62 | 0.60 | 0.63 | 0.58 | 0.55 | 0.72 | 0.73 | 0.82 | 0.73 | 0.61 |

Table 4. 6-hour propagation errors for the joint system.

For this case the needed mean numbers of the avoidance maneuvers per year are as follows: 18 - when only the RSSS is used, 16 - when only the US SSN is used, and 9 for the joint system. All that is under the assumption that the decision on maneuver implementation is taken if and only if the predicted ISS trajectory comes through the cataloged object position uncertainty domain of 6 r.m.s. error diameter.

Here and henceforth the real measurement accuracy of the RSSS facilities is used and transferred to the similar US SSN ones of the same frequency bands. All the calculations were made using the real RSSS space object catalog with the help of the model mentioned above.

Tables 5-7 and Figs. 1-3 illustrate the comparison of the cataloged object position prediction accuracy on the base of data from the US SSN and the RSSS (being used separately and jointly) during 24 hours for inclinations 30, 50 and 70 deg. There can be seen that at the 24-hour time interval the "bottle necks" exist in each system. So their unification can give an essential effect.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RSSS | 0.79 | 1.02 | 1.00 | 1.12 | 1.35 | 1.40 | 1.56 | 1.71 | 1.89 | 2.04 | 2.10 | 2.29 | 2.45 | 2.72 | 2.92 | 3.09 | 3.28 | 0.84 | 0.94 | 0.86 | 0.82 | 0.74 | 0.78 | 0.90 |
| US SSN | 2.77 | 0.62 | 0.82 | 0.67 | 0.73 | 0.71 | 0.66 | 0.72 | 0.70 | 0.81 | 0.69 | 0.80 | 0.94 | 1.06 | 1.20 | 1.32 | 1.49 | 1.64 | 1.79 | 1.97 | 2.14 | 2.35 | 2.53 | 2.75 |
| joint | 0.79 | 0.52 | 0.71 | 0.67 | 0.73 | 0.71 | 0.65 | 0.71 | 0.71 | 0.80 | 0.68 | 0.80 | 0.94 | 1.06 | 1.20 | 1.31 | 1.49 | 0.69 | 0.81 | 0.76 | 0.68 | 0.72 | 0.72 | 0.84 |

Table 5. Propagation accuracy comparison (i=30°).

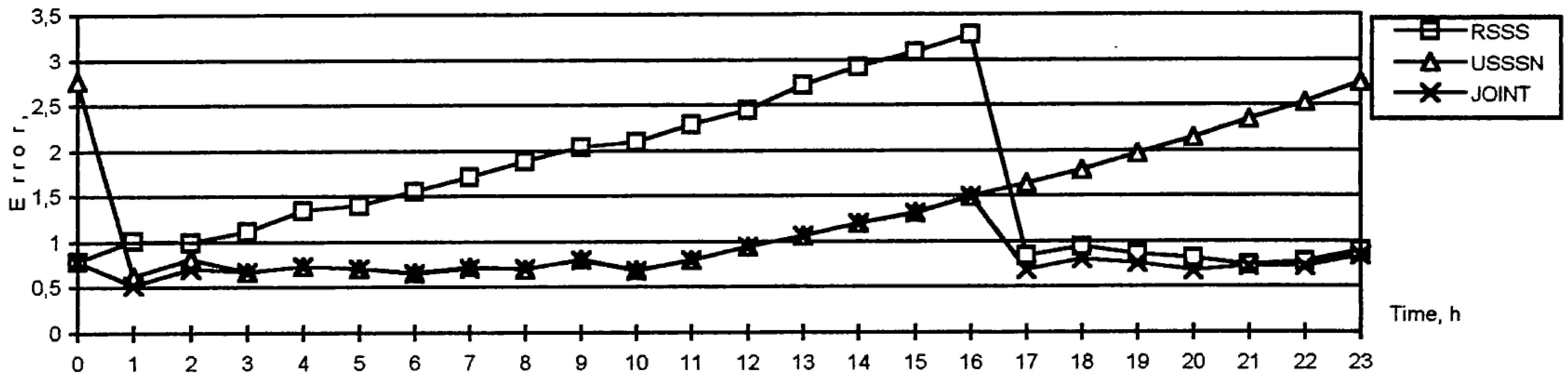


Figure 1. Propagation accuracy comparison (i=30°).

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RSSS | 0.69 | 0.77 | 0.66 | 0.77 | 0.95 | 1.02 | 1.16 | 1.35 | 1.48 | 1.66 | 1.82 | 2.03 | 2.22 | 2.39 | 0.74 | 0.61 | 0.70 | 0.71 | 0.63 | 0.71 | 0.68 | 0.72 | 0.72 | 0.61 |
| US SSN | 0.81 | 0.68 | 0.80 | 0.70 | 0.78 | 0.71 | 0.68 | 0.74 | 0.64 | 0.57 | 0.68 | 0.72 | 0.84 | 0.95 | 1.08 | 1.25 | 1.38 | 1.55 | 1.74 | 1.91 | 0.72 | 0.84 | 0.90 | 0.75 |
| joint | 0.68 | 0.68 | 0.64 | 0.67 | 0.75 | 0.70 | 0.64 | 0.70 | 0.60 | 0.53 | 0.64 | 0.70 | 0.80 | 0.90 | 0.69 | 0.60 | 0.67 | 0.70 | 0.60 | 0.67 | 0.65 | 0.70 | 0.70 | 0.60 |

Table 6. Propagation accuracy comparison (i=50°).

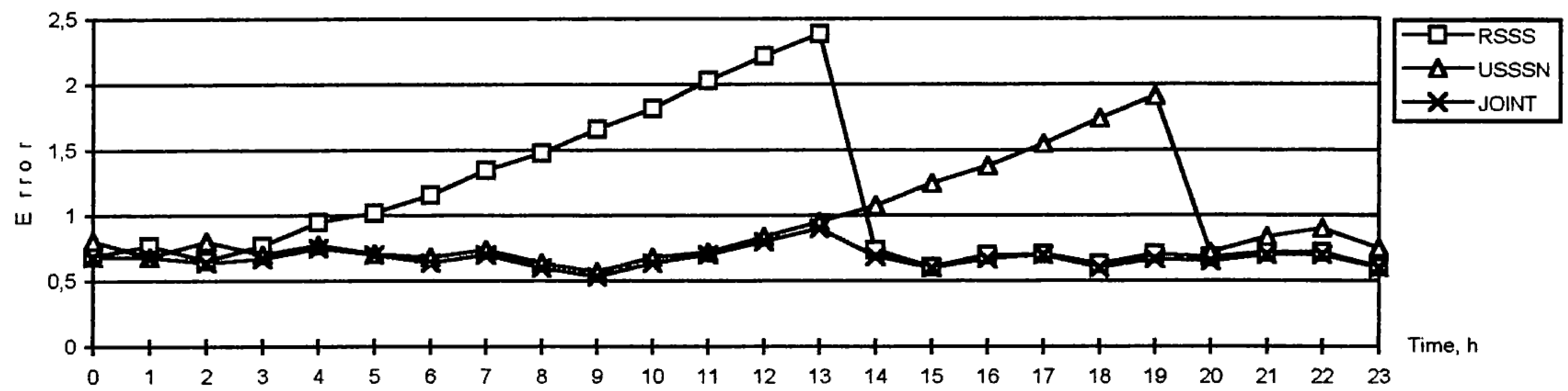


Figure 2. Propagation accuracy comparison (i=50°).

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RSSS | 0.70 | 0.78 | 0.70 | 0.72 | 0.79 | 0.96 | 1.09 | 1.19 | 1.39 | 1.55 | 1.67 | 1.88 | 0.66 | 0.77 | 0.67 | 0.61 | 0.68 | 0.66 | 0.59 | 0.74 | 0.76 | 0.87 | 0.76 | 0.67 |
| US SSN | 0.85 | 0.65 | 0.82 | 0.76 | 0.57 | 0.76 | 0.84 | 0.95 | 0.74 | 0.66 | 0.80 | 0.72 | 0.69 | 0.86 | 0.74 | 0.86 | 0.97 | 0.76 | 0.71 | 0.82 | 0.97 | 1.13 | 0.95 | 0.81 |
| joint | 0.70 | 0.64 | 0.69 | 0.70 | 0.54 | 0.72 | 0.82 | 0.92 | 0.74 | 0.66 | 0.80 | 0.70 | 0.65 | 0.75 | 0.62 | 0.60 | 0.63 | 0.58 | 0.55 | 0.72 | 0.73 | 0.82 | 0.73 | 0.61 |

Table 7. Propagation accuracy comparison (i=70°).

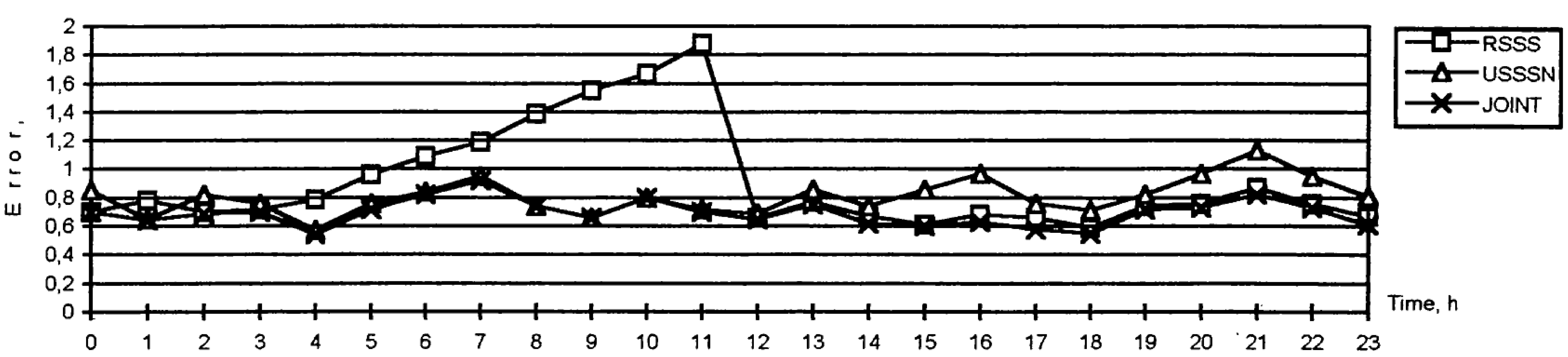


Figure 3. Propagation accuracy comparison (i=70°).

Table 8 and Fig. 4 show the result of comparison of the joint system operation given the first and the second sensor compositions (dedicated and enlarged) for orbit inclination 30 deg as an example. There can be seen a time interval within 24 hours where nearly twofold accuracy increase can be reached by means of unification of the systems.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| dedic. | 0.79 | 0.52 | 0.71 | 0.67 | 0.73 | 0.71 | 0.65 | 0.71 | 0.71 | 0.80 | 0.68 | 0.80 | 0.94 | 1.06 | 1.20 | 1.31 | 1.49 | 0.69 | 0.81 | 0.76 | 0.68 | 0.72 | 0.72 | 0.84 |
| enlarged | 0.71 | 0.50 | 0.70 | 0.66 | 0.50 | 0.70 | 0.60 | 0.69 | 0.70 | 0.75 | 0.60 | 0.70 | 0.80 | 0.72 | 0.93 | 0.68 | 0.75 | 0.65 | 0.80 | 0.74 | 0.67 | 0.62 | 0.70 | 0.66 |

Table 8. Joint system accuracy comparison for sensor compositions 1 and 2.

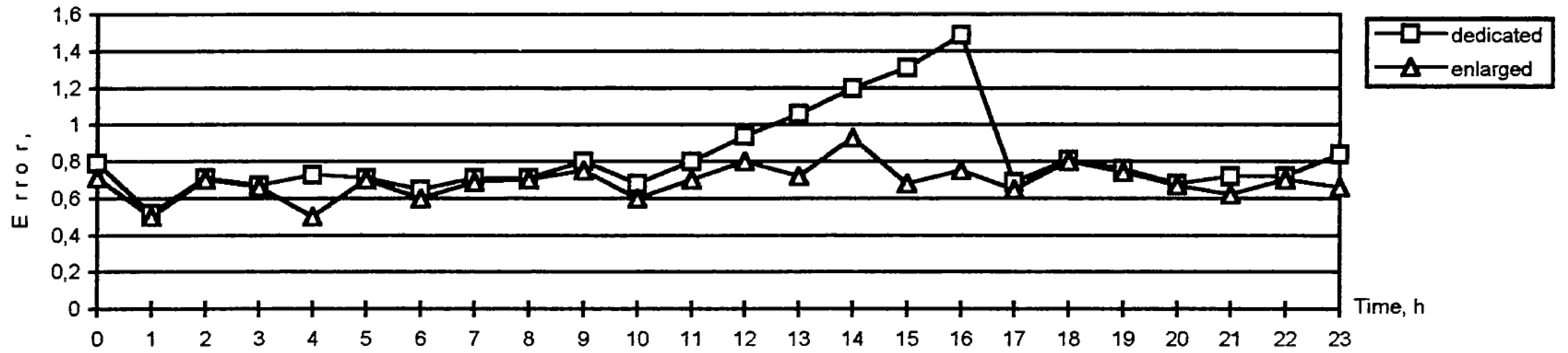


Figure 4. Joint system accuracy comparison (after Table 8).

The second (enlarged) sensor composition lowers the required annual mean number of maneuvers to 8.

All the above data were obtained given the assumption of using analytical orbit propagators both at the RSSS and the US SSN (relative r.m.s. error of presentation of geopotential is 0.000003 and of atmospheric perturbations - 0.1). Transition to the handling of semi-analytical propagators (geopotential error - 0.0000001 and of atmosphere - 0.1) in case of the second sensor composition increases position determination accuracy by 3 times more, as it can be seen from Table 9 and Fig. 5, the needed mean number of avoidance maneuvers being reduced to 4 a year.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| analit. | 0.71 | 0.50 | 0.70 | 0.66 | 0.50 | 0.70 | 0.60 | 0.69 | 0.70 | 0.75 | 0.60 | 0.70 | 0.80 | 0.72 | 0.93 | 0.68 | 0.75 | 0.65 | 0.80 | 0.74 | 0.67 | 0.62 | 0.70 | 0.66 |
| semi- | 0.21 | 0.18 | 0.20 | 0.17 | 0.15 | 0.18 | 0.17 | 0.21 | 0.18 | 0.18 | 0.22 | 0.19 | 0.24 | 0.27 | 0.32 | 0.23 | 0.21 | 0.22 | 0.27 | 0.29 | 0.20 | 0.18 | 0.22 | 0.19 |

Table 9. Accuracy comparison of using analytical and semi-analytical propagators.

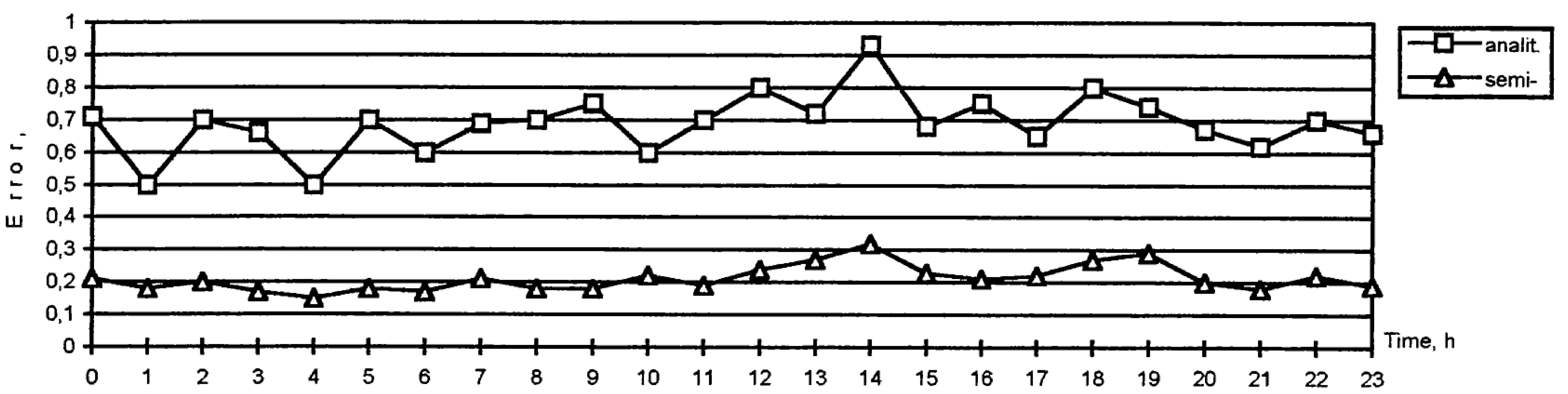


Figure 5. Comparison of propagators (after Table 9).

Further improvement of accuracy seems to be problematical since for the above prediction interval and orbit altitudes it is determined in the main by atmospheric perturbations.

Taking into account all this, the following strategy of enlisting the precision sensors for informational support of solving the avoidance maneuver problem can be suggested. It is advisable to use as a rule only dedicated sensors for tracking the cataloged space debris, whereas enlisting the additional high accuracy sensors for tracking the given space object only after its predicted close approach to the ISS has been classified as dangerous.

All the above results are based on using measurement information from the total large net of sensors possessed now by the RSSS and the US SSN and the most modern methods for processing measurements and predicting space debris motion parameters (Ref.5). Addressing the sensors of other states of course can contribute to the space object catalog accuracy, however, its further essential improvement and as a consequence further reduction of the number of avoidance maneuvers really can be reached only by shortening the prediction interval (if it is admissible).

Table 10 and Fig. 6 feature the estimates of the cataloged object position prediction accuracy for 6 and 3 hours (for the joint enlarged system and semi-analytical propagators), the orbit with inclination 50 deg. being used as an example. As can be seen the r.m.s. position error became less than 100 m. The needed number of avoidance maneuvers is now 2 a year (given the same maneuver energy consumption).

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 0.16 | 0.20 | 0.18 | 0.18 | 0.17 | 0.19 | 0.15 | 0.16 | 0.18 | 0.17 | 0.18 | 0.22 | 0.22 | 0.30 | 0.19 | 0.16 | 0.20 | 0.16 | 0.17 | 0.17 | 0.17 | 0.17 | 0.19 | 0.16 |
| 3 | 0.06 | 0.08 | 0.07 | 0.07 | 0.07 | 0.08 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.09 | 0.11 | 0.15 | 0.08 | 0.06 | 0.08 | 0.06 | 0.07 | 0.06 | 0.07 | 0.06 | 0.08 | 0.06 |

Table 10. 6- and 3-hour propagation errors for the joint enlarged system.

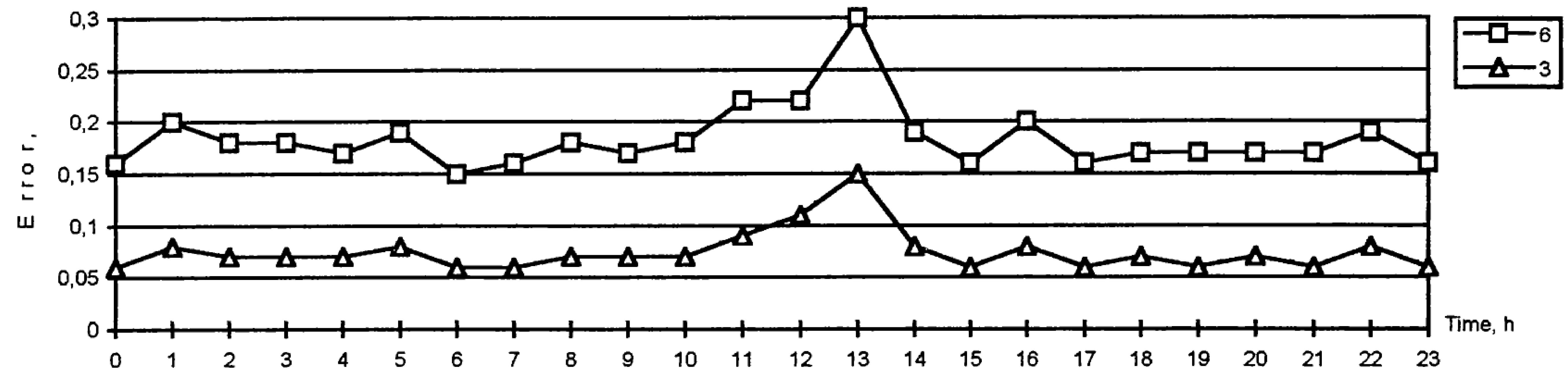


Figure 6. 6- and 3-hour propagation errors (after Table 10).

Even if for regular (organic) calculation and implementation of avoidance maneuvers the 6-hour prediction interval is needed, it is expedient to continue specifying the collision position and time parameters so that to have a possibility to stop the maneuver program at any moment or, at any rate, to reduce fuel consumption.

## REFERENCES

1. Andrewshenko, V., Batyr, G., Dicky, V. and Veniaminov, S., On Some Estimates of Large Size Space Debris Density and Related Characteristics, *International Workshop on Space Debris*, Moscow, Russia, Oct.8-11, 1995.

2. Chamberlain, S. and Slauenwhite, T., US Space Command Space Surveillance Network Overview, *First European Conference on Space Debris*, Darmstadt, Germany, 1993.

3. Batyr, G., Veniaminov, S., Dicky, V., Yurasov, V., et al., The Current State of Russian Space Surveillance System and its Capability in Surveying Space Debris, *First European Conference on Space Debris*, Darmstadt, Germany, 1993.

4. Batyr, G., Veniaminov, S., Dicky, V., et al., Some Preliminary Results of ODERACS experiment, *Proceedings of the US/Russia Orbit Determination and Prediction Workshop*, SNO, Washington, D.C., USA, 1994.

5. *U.S.-Russian Second Space Surveillance Workshop*, Poznan, Poland, July 1996.