The HIPPARCOS satellite in simulated micrometeoroid environment

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1. INTRODUCTION

Although the effects of micrometeoroid impacts on the Hipparcos satellite are expected to be very small, it may be interesting to make simulation studies based on published micrometeoroid data. In our study, the meteoroids hit the satellite randomly under a period of 10000 s with a cumulative flux as given by Landolt-Boernstein (1981) and with different velocities. The resulting motion was calculated and a cubic spline fitted to the angle versus time. The residuals of this fit were taken as a measure of the micrometeoroid effect.

2. METHOD

At times uniformly distributed within the interval 0 to 10000 s the satellite was hit by a random sized meteoroid, with a velocity (v) uniformly distributed in the interval -47 to +47 km/s. The process was simplified so that every hit reached a target point r = 1.8 m from the center of the satellite on one of the solar panels. This is halfway to the edge from the center of mass. Hits on the satellite body were omitted. The number of hits in the interval was calculated from the flux data as the product of the cumulative flux (for particles heavier than 1E-15 kg), the total area of solar panels (6.8 m**2) and the integration time, times two (both forward and backward hits allowed). This gives a delta angular momentum per hit dL = m*v*r and a delta angular velocity domega = dL/I. A mean value of the satellite's moment of inertia was used (I = 400 kgm**2). In this way successive impacts gave positive or negative increments of the angular velocity. In every time interval between hits, the velocity increment was integrated up to a delta angle and finally a new angle value. For simplicity, the nominal rotation of the satellite and the (smooth) perturbations due to solar radiation pressure etc. were not included. The results therefore only represent the additional effects caused by micrometeoroids.

When generating the masses of the impacting meteoroids the cumulative flux data were once again used. These data can be represented by the relation:

\[( m / m_0 ) ^n = \frac{\text{flux}}{\text{flux}_0} = R \]

where \( m_0 \) is the smallest mass considered, \( \text{flux}_0 \) is the flux of particles with \( m > m_0 \), and \( n \) is a (negative) constant. With \( R \) uniformly distributed between 0 and 1, masses consistent with these flux data can then be generated according to the formula:

\[ m = m_0 \times (R \times (1/a)) \]

Because of the nature of the data, two different \( n \)-values had to be used,
namely $a = -0.4$ for $m < 1.4E-10$ kg and $a = -1.1$ for higher masses (see discussion). In practice this was done by correcting the masses generated with $a = -0.4$ whenever they exceeded $1.4E-10$ kg.

In order to get more data points, angle values were linearly interpolated between impact times so that one data point was obtained for every 10 s of the 10000 s interval. A cubic spline function was then fitted, with a knot every 100 s, and the difference between the data and the spline function was calculated.

3. RESULTS

1000 simulations of 10000 seconds were made. The distributions of the rms and maximum residuals of each simulation are shown as histograms in Figures 1 and 2 and as cumulative frequency diagrams in Figures 3 and 4. In the latter, n is the ordinal number of the rms or max residual when sorted on magnitude. Also individual plots of angle and (angle - spline) versus time were made for a few sample cases (Figures 5 - 6).

4. DISCUSSION

In the mid 1960's doubts were raised whether the then present flux data in the near Earth space were too high or not. (Nilsson, 1966) These data were based on measurements made with acoustical microphone techniques, which turned out to be strongly dependent of e.g. temperature gradients in the vehicle when passing through the Earth's shadow. The data published since then show a much smaller flux. As previously discussed we used the data from Landolt-Boernstein (1981), also consistent with NASA (1966). These can be represented by the relation:

\[
\text{flux} = 5E-5 \left( \frac{\text{mass}}{1E-15} \right)^{**(-0.4)} \quad \text{for mass} < 1.4E-10 \\
\text{flux} = 2E-1 \left( \frac{\text{mass}}{1E-15} \right)^{**(-1.1)} \quad \text{for mass} > 1.4E-10
\]

The flux is given in impacts per m**2 and second and half-space; m is in kg.

As seen in the histograms, the most frequent residual lies around 1E-5 arcsec which is by a factor of 0.001 smaller than expected accuracy of the individual measurements by the Hipparcos instrument. Only a few of the 1000 simulations have rms residuals in the vicinity of above 0.01" and the median rms effect was 2.6E-6 arcsec. The effects of micrometeoroid impacts on Hipparcos are thus, according to the simulation and as expected, very small. When discussing the results in histogram form, it is interesting to look at some specific simulations from different parts of the histogram. Figures 5a and b show a "giant" hit with residuals around 0.5". In 5b it is shown that this is the result of principally two major hits. At 20 km/s impact velocity, these correspond to masses around 4E-10 and 3E-9 kg. Figure 6a shows residuals around 0.01". As seen in 6b this residual is the effect of one meteoroid with an approximate mass of 6E-11 kg, if the same mean velocity is assumed. Figures 7a and 7b, finally, show a more probable picture, according to the histograms. Here the effects are even smaller and correspond to masses around 7E-13 kg, at 20 km/s.

In the cumulative frequency diagrams, it is seen that the distribution of spline residuals reflects the flux distribution of different masses. The break at rms = 1E-2.5 or max = 1E-1.5 corresponds to particles of 1.4E-10 kg, and
the slopes on both sides of the break are close to those of the flux distribution.

5. CONCLUSIONS

From a simulation based on published micrometeoroid fluxes, we conclude that it is not likely that impacts will have any major effects on the accuracy of Hipparcos observations. The residuals after a spline fit lie mostly in the vicinity of 1E-5 arcsec and only seldom do they reach 0.01". In 2.5 years (the nominal life time of Hipparcos) our simulation predict about 500 impacts resulting in residuals > 0.01". The single largest impact during that time will probably produce residuals of the order of 10 arcsec based on an extrapolation of the curve in Figure 3.

6. REFERENCES

Landolt-Boernstein VI / 2a (1981)
Nilson Carl, Science 153, 3741 (1966)
HISTOGRAM (max) 1000 sim. of 10000s

Figure 1

HISTOGRAM (rms) 1000 sim. of 10000s

Figure 2
CUMULATIVE FREQUENCY

Figure 3

CUMULATIVE FREQUENCY

Figure 4
SIMULATION  mass limit: .10E-14  time:  10000.

Figures 5a and 5b
SIMULATION  mass limit: .10E-14  time:  10000.

Figures 6a and 6b

SIMULATION  mass limit: .10E-14  time:  10000.
SIMULATION  mass limit: .10E-14  time:  10000.

Figures 7a and 7b

SIMULATION  mass limit: .10E-14  time:  10000.