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Study of Vehicle Attitude Effect on Shuttle Radiation Measurements

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Abstract

This paper reports on the evaluation of the effect of shuttle attitude on data collected by a miniature radiation spectrometer that flew on the STS-95 in October 1998.

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1. Introduction

The High-LET Radiation Spectrometer (HiLRS) is a low power, small size, and lightweight radiation monitor composed of a sensor in the form of a large-scale array of p-n junctions and its supporting electronics [1]. The spectrometer, which operates on pulse-height analysis (PHA) principles, is able to measure the energy deposited by ionizing particles such as heavy ions or their daughter products. It was placed on the HST/HOST platform located in the payload bay on the STS-95 Discovery shuttle mission. Figures 1 and 2 present a view of the HOST platform and its position inside the shuttle. Measurements included energy deposited by Galactic Cosmic Rays (GCR) and by trapped protons of the Van Allen belts in the South Atlantic Anomaly (SAA) region. These data, once collected, were analyzed and, on the basis of heavy ion and proton calibration results, compared to the existing models of the space environment [2]. Disagreements between predicted and measured proton-induced events in the SAA indicated that a significant proton attenuation was affecting the measurements [2]. Three possible causes were identified: material shielding, east-west proton asymmetry, and shuttle attitude [2]. This study addresses specifically the effect of the attitude, which intrinsically also involves the other two causes.

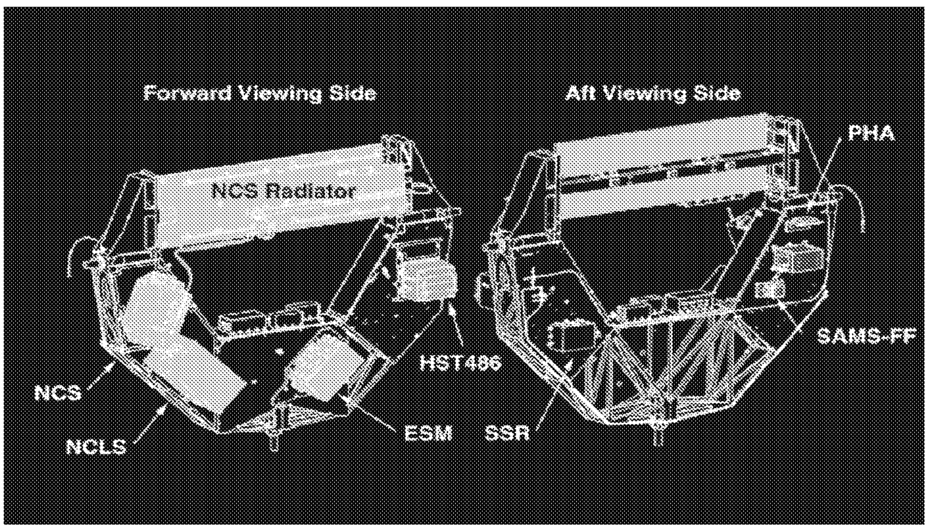

Figure 1. View of the HOST platform and the position of the HiLRS (or PHA).

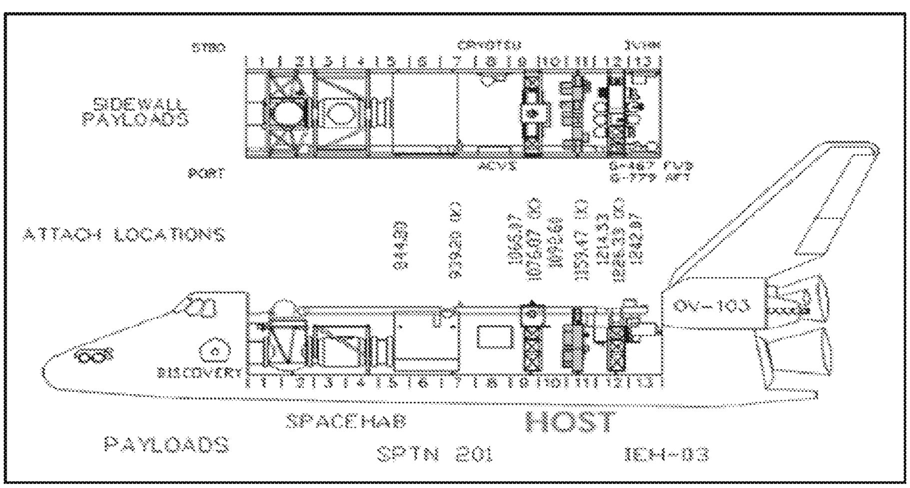

Figure 2. Position of the HOST platform inside the shuttle cargo bay.

2. The mission

The orbit of the shuttle was circular at an altitude of 550 km with an inclination of 28.5 degrees. It provided to the detector passes through the South Atlantic Anomaly (SAA), which, at this altitude, is the only area where non-transient fluxes (protons of the Van Allen belt) can be found. A typical orbit on a 2-D map is shown in Figure 3.

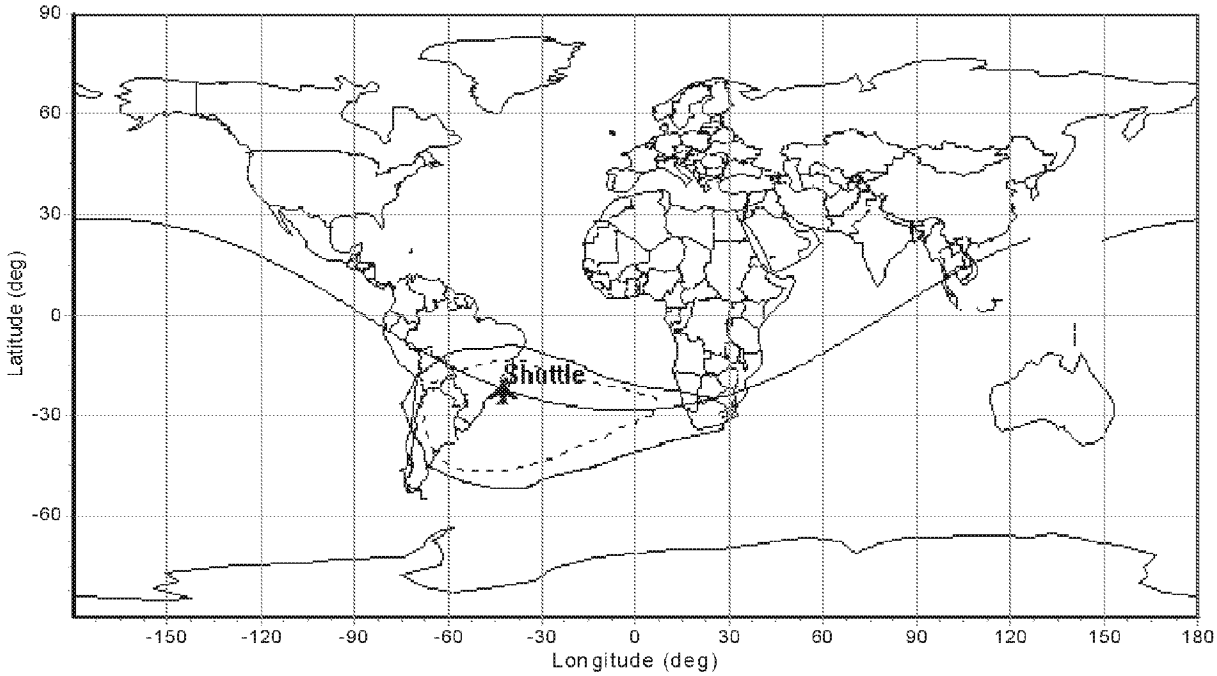

Figure 3. Typical orbit of STS95 mission. The solid line represents the isoflux line of 10 protons/cm^2/s; the dashed line is the isoflux of 100 protons/ cm^2/s of the SAA for a proton energy greater than 50MeV. No events were detected during this particular shuttle pass through the SAA.

3. The shuttle attitude and its visualisation

To study the effect of the shuttle attitude we needed to visualize it in three dimensions. For this purpose we used the software Satellite Tool Kit (STK) by Analytical Graphic [3]. STK permits us to have 3-D or 2-D representations of the shuttle during its orbit. The orbit can be either created by the user or imported as an input file and then be viewed on a computer screen. Figures from 5 to 9 are all made with STK.

We used the exact ephemeris and attitude files provided by the NASA Johnson Space Center, Houston, Texas, as input files to recreate the shuttle orbit. In the following 3-D pictures the shuttle center of mass is always in the middle of the screen and as the orbit has an inclination of 28.5 degrees the position of the Earth under it is never the same. It was the only option offered by STK for seeing the shuttle for the duration of the orbit

The shuttle attitude can be described in many ways depending on the referenced system (geocentric, shuttle center of mass), the rotation angles (Euler angles, quaternion) or the sequence of the rotation chosen. In this paper we use three angles called Euler angles (referenced throughout this paper as Pitch-Yaw-Roll) representing the shuttle rotation sequence around its three body axes, Y, Z and X, respectively. The origin of these three axes is the shuttle center of mass. The X body axis is going from the tail to the shuttle nose and roll is its associated angle. The Y body axis is going from the left to the right shuttle wing and pitch is its associated angle. The Z-axis forms a right-handed orthogonal system with other axes and yaw is its associated angle. Figure 4 represents a view of these axes and angles. The basic attitude configuration 0,0,0 (Pitch=Yaw=Roll=0) is when the X body axis is parallel to the shuttle velocity vector and its Z body axis points to the center of the Earth. The attitude is expressed in the sequence pitch, yaw, roll. Figure 5 and 6 show a 0,0,0 and a 45,45,45 configuration.

In order to understand the attitude effects on the proton events we started to look at the shuttle attitude evolution over the entire mission duration. For this purpose, with STK, we created movies for each day of the mission representing the shuttle with different views. These movies allowed us to see and understand the different position of the shuttle in terms of Pitch-Yaw-Roll.

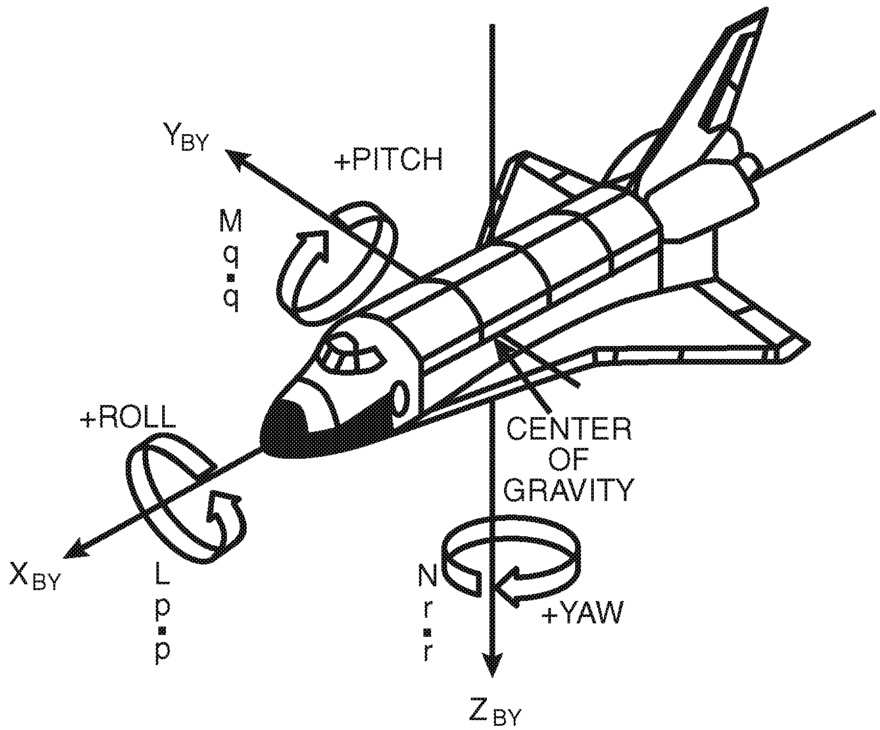

Figure 4. View of the body axis and the shuttle rotation angles.

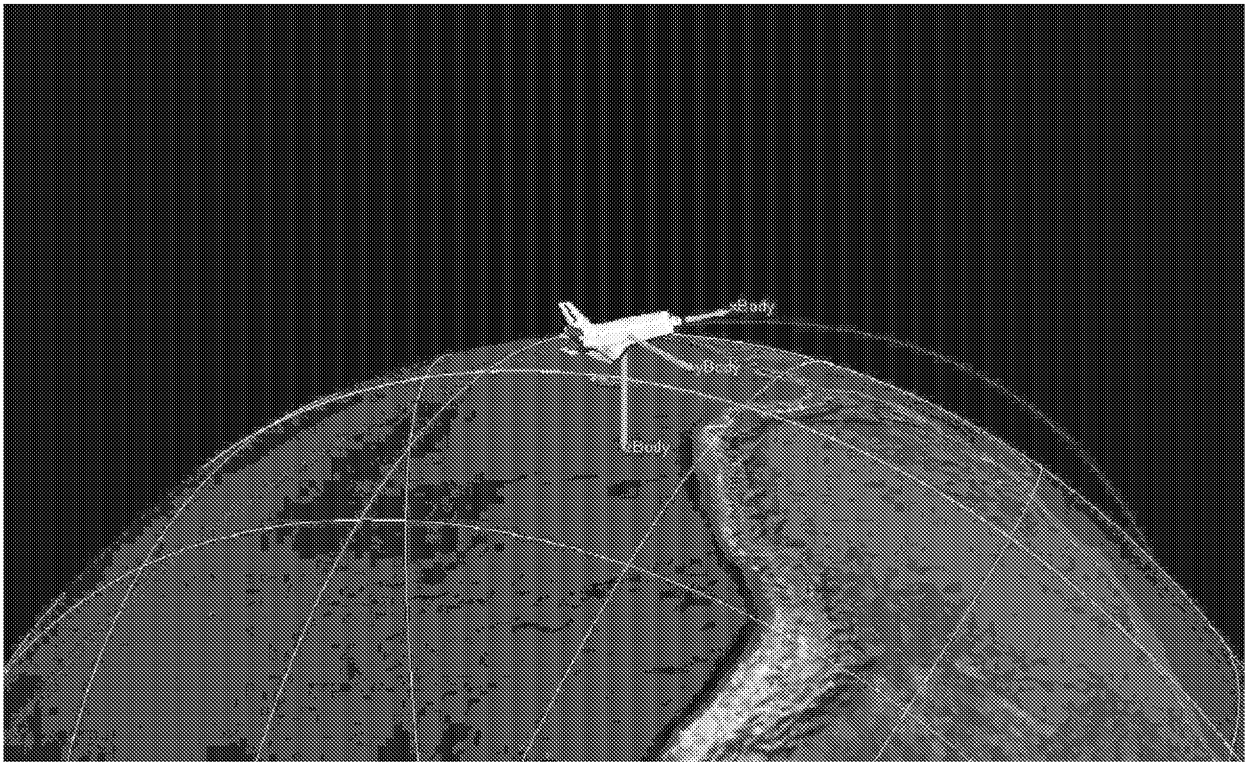

Figure 5. View of the shuttle body axis. Here the attitude configuration is 0,0,0 and the X-axis is parallel to the shuttle velocity vector while the z-axis points to the center of the Earth.

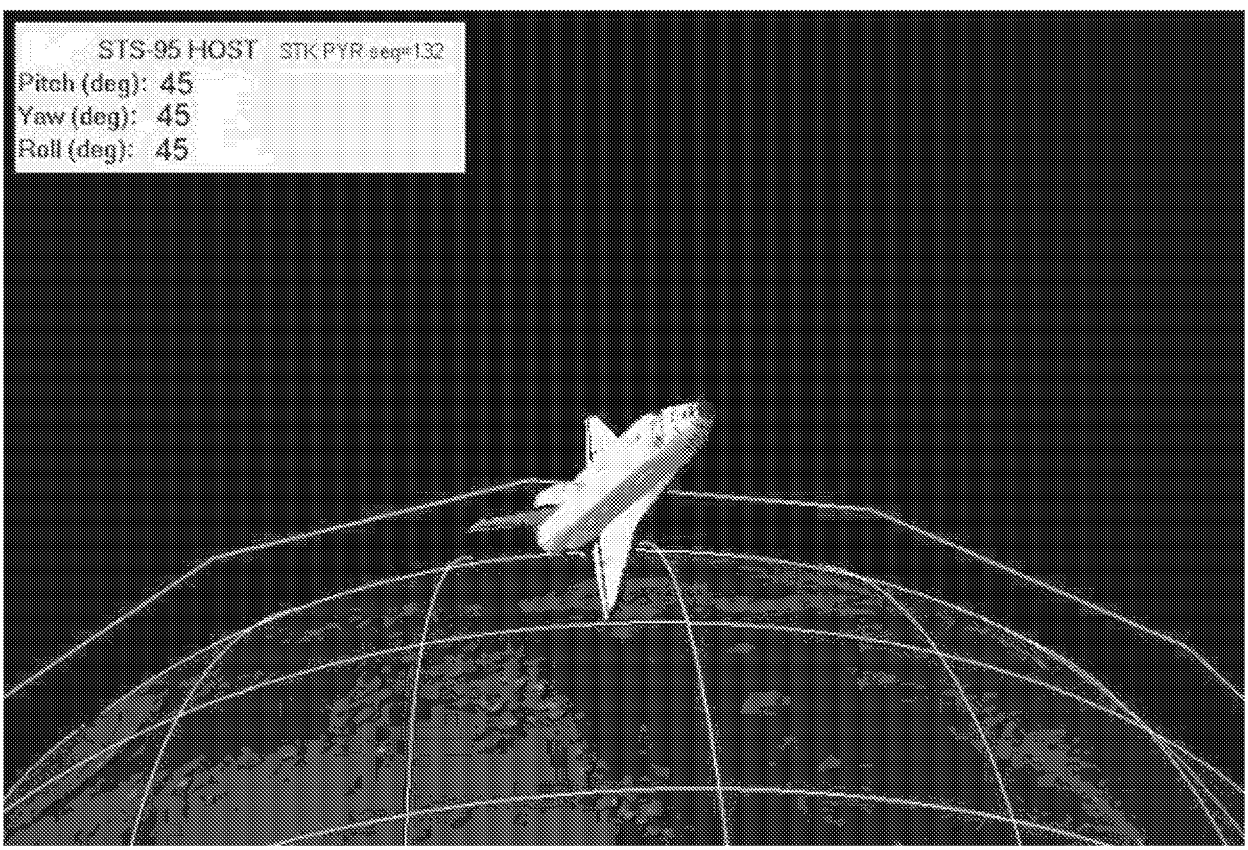

Figure 6. Position of the shuttle with an attitude of 45,45,45; the line crossing the shuttle represents the shuttle trajectory going from the left to the right.

Then we looked more specifically at the shuttle attitude evolution for SAA passes with and without events. STK does not allow creating a movie for two different times simultaneously. Therefore we have created movies for each pass through the SAA and then combined two or three different movies into one for side-by-side comparison purposes. With these movies we can see at the same time the shuttle attitude for passes with events and without events. To have an accurate view of the shuttle attitude during events we also created pictures for both proton- and cosmic-ray events. These pictures represent the shuttle position (latitude, longitude, altitude) and its attitude (Pitch-Yaw-Roll) at the event time. The study of all these movies and pictures indicated that the shuttle attitude does not seem to have any influence on the GCR events (GCR are so energetic that they are not attenuated by spacecraft materials), but it appears to have one on proton events.

4. Attitude effect on proton events

The orbit shown in Figure 3 represents a shuttle orbit with a pass through the SAA and its intense proton flux regions where, according to the calibration curve, events should be detected [2]. This pass lasted 24 minutes and generated no event. Figure 7 shows a very similar orbit but this time the pass through the SAA generated 3 events for a pass duration of 23 minutes.

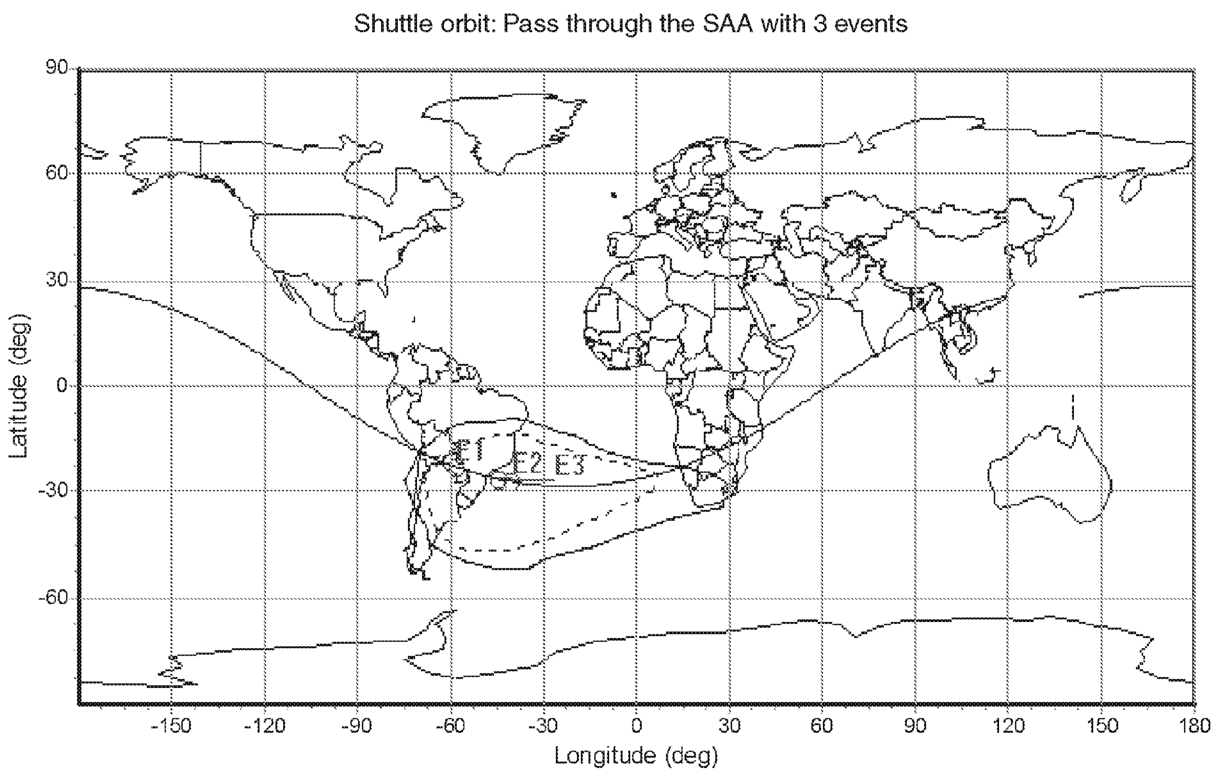

Figure 7. Pass through the SAA with 3 events. Circles represent the location of the events E1, E2, and E3. The SAA contours are the same as on Figure 3.

These two passes show that the pass duration and the flux intensity of the crossed regions are not the only factors in the event occurrence. In some cases the shuttle attitude could have a primary influence. Different shuttle attitudes will offer several degrees of shielding to the east-west constituent of proton fluxes. It will have to penetrate more spacecraft material to reach the detector when the nose of the shuttle faces west rather than its bay. A more attenuated flux will, then, generate fewer events than a less attenuated flux. The combination between the shuttle attitude, the spacecraft material thickness, and the east-west asymmetry could explain the difference between predicted and detected proton events.

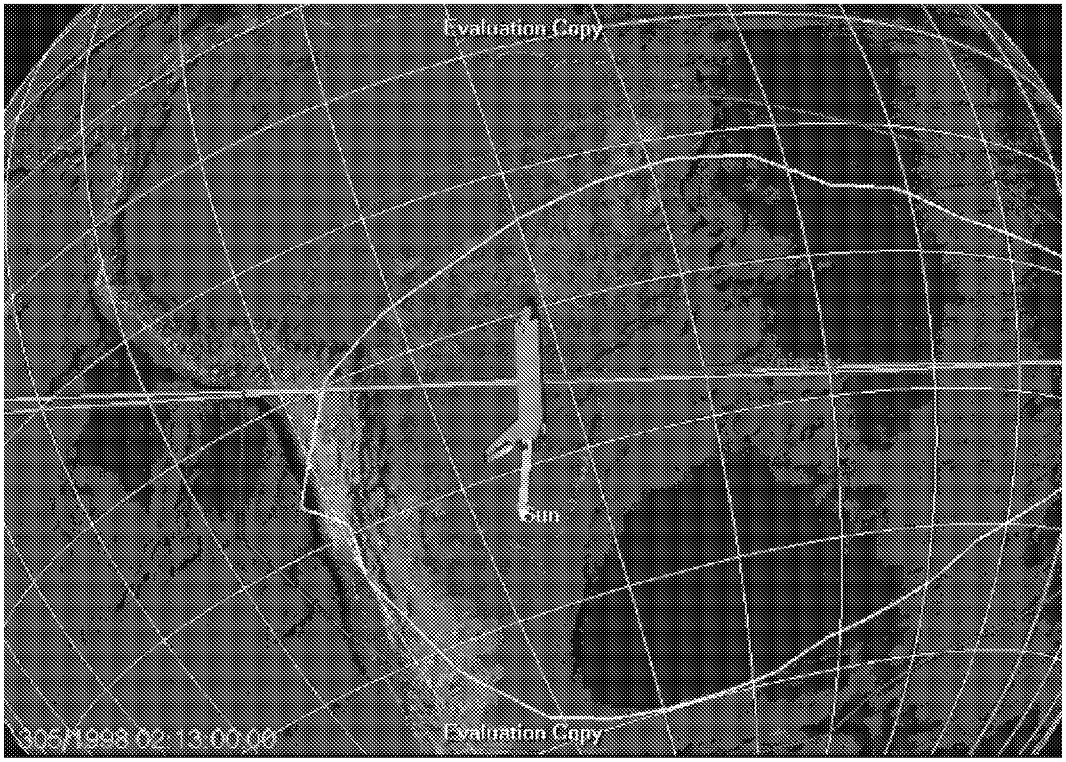

Figure 8. Position of the shuttle inside the SAA when an event occurred. We can see that the bay of the shuttle is oriented to west-north-west. The main constituent of the flux has to cross just this bay to reach the detector. The SAA contours are the same as in Figure 3.

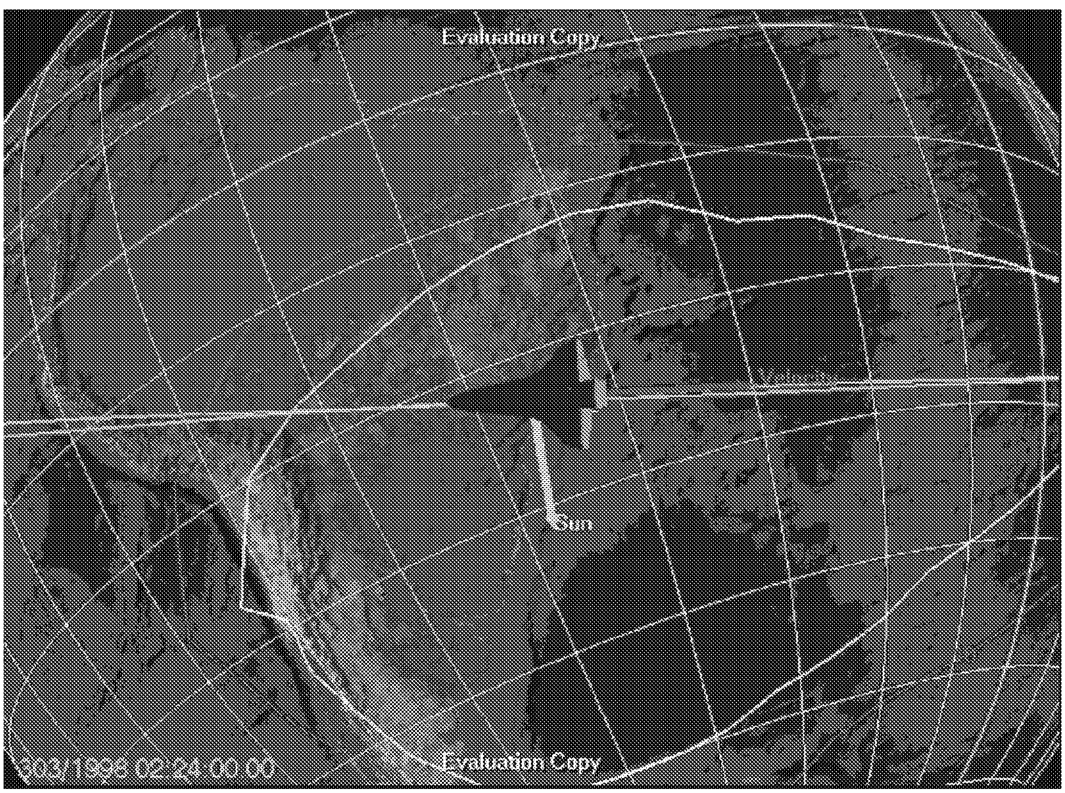

Figure 9. Position of the shuttle inside the SAA without event. This time the trapped protons have to cross a significantly bigger shielding before reaching the detector. The SAA contours are the same as in Figure 3.

Events E1, E2, and E3 of Figure 7 occurred with the same attitude configuration. Figure 8 shows the shuttle position when the event E1 of Figure 7 occurred. The shuttle attitude is 90,-90,0 and the shuttle bay faces a west-north-west direction. Figure 9 shows the shuttle position of the pass without event shown on Figure 3. Its attitude is 180,0,0 showing the bay facing the Earth and the nose facing west.

If we are comparing these two figures we can see that in Figure 8 the east-west constituent of the flux has less spacecraft material to traverse than on Figure 9. This configuration could then explain why 3 events were detected on the pass described in Figure 8 and why no events were detected for the pass described in Figure 3. 80% of the SAA passes with event occurred with a shuttle attitude of 90,-90,0 where the main constituent of the proton flux has less spacecraft material to penetrate. In almost all the deep passes through the SAA without events, proton fluxes had to cross a bigger thickness of spacecraft material due to the attitude of the shuttle (180,0,0 or 0,0,0 configurations) than on passes with events. This reason could explain why no events were detected.

5. Conclusion

The flux intensity of crossed regions and the pass duration through the SAA are not the only elements that have to be taken into account for measurements of proton events in a shuttle mission.

Due to the asymmetry of proton fluxes in the SAA a different shuttle position will allow different flux levels to reach the detector for the same orbit. The shuttle attitude then plays a primary role in the number of detected events.

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[3] Satellite Tool Kit, distributed by Analytical Graphics, Inc., 325 Technology Drive, Malvern, PA 19355 USA.

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