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DATA ANALYSIS FOR SKYLAB PROTON SPECTROMETER BIMONTHLY PROGRESS REPORT

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Prepared by:

C. W. Hill

Prepared for:

George C. Marshall Space Flight Center

Marshall Space Flight Center, Alabama 35812

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SCIENCE APPLICATIONS, INC.

2109 W. Clinton Avenue, Suite 800, Huntsville, Alabama 35805
205-533-5900

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I. CURRENT PROGRESS

During the first two months of the contract, the effort has proceeded at a low level while programs were being integrated and debugged. John Watts, SSL-MSFC has contributed greatly to program preparation.

The transformations to appropriate coordinate systems have been checked. The Proton Spectrometer (PS) is rigidly mounted to the MDA structure with the cone opening in the -Y direction of the MDA coordinate system. The column vector representing this direction is (0, -1, 0). The SKYBET tape furnishes Euler angles to transform to the OWS coordinate system. This transformation accounts for bending at the flexible Airlock-OWS coupling. The OWS direction cosines of the PS axis are as follows:

$$\text{PSOWS1} = -\cos E1 \sin E3 \cos E2 - \sin E1 \sin E2$$
$$\text{PSOWS2} = -\cos E1 \cos E3$$
$$\text{PSOWS3} = -\cos E1 \sin E3 \sin E2 + \sin E1 \sin E2$$

where

(E1, E2, E3) are the Euler angles to transform between the MDA and OWS systems.

The PS axis must be related to earth-oriented coordinates of date for the pitch-angle distribution analysis and the east-west asymmetry analysis. A series of transformations are required.

$$\begin{pmatrix} \text{PS1} \\ \text{PS2} \\ \text{PS3} \end{pmatrix} = E \cdot D \cdot B \cdot A \cdot C \cdot \begin{pmatrix} \text{PSOWS1} \\ \text{PSOWS2} \\ \text{PSOWS3} \end{pmatrix}$$

Here (PS1, PS2, PS3) are the desired direction cosines of the PS axis in the rotating earth coordinate system at the time of the measurement.

Matrix C transforms from the OWS system to the ECI (Earth Centered Inertial, of date 1950.0) system. The Z-axis of the ECI system points along the north pole of the spin vector. The X-axis is toward the vernal equinox. In terms of the SKYBET-furnished Euler angles, (U1, U2, U3), The C matrix is as follows. Note that CU1 = cos U1 and SU1 = sin U1, etc.

$$C = \begin{pmatrix} CU1 \cdot CU2 & CU1 \cdot SU3 \cdot CU2 + SU1 \cdot SU2 & -SU1 \cdot SU3 \cdot CU2 + CU1 \cdot SU2 \\ -SU3 & CU1 \cdot CU3 & SU1 \cdot CU3 \\ -CU3 \cdot SU2 & CU1 \cdot SU3 \cdot SU2 - SU1 \cdot CU2 & SU1 \cdot SU3 \cdot SU2 + CU1 \cdot CU2 \end{pmatrix}$$

Matrix A transforms a column vector in ECI (epoch 1950) to ECI (epoch 1973) coordinates. It is a precession correction. Matrix A is furnished by the Dudley Observatory, Albany, New York. It was checked against Transformation 33, pp. 418-419, of Methods of Orbit Determination, Escobal, John Wiley & Sons, Inc., New York, 1965, and found identical to within two units in the seventh place after the decimal.

$$A = \begin{pmatrix} .99998\ 42912 & -.00514\ 04016 & -.00223\ 46372 \\ .00514\ 04016 & .99998\ 67880 & -.00000\ 57437 \\ .00223\ 46372 & -.00000\ 57433 & .99999\ 75032 \end{pmatrix}$$

Matrix B corrects for nutation (Wobble) from ECI (epoch 1973) to ECT (Earth Centered True, epoch 1973). This small correction is based on observational data and may be computed only after the fact. Matrix B is furnished by the Dudley Observatory.

$$B = \begin{pmatrix} .99999\ .99968 & -.00007\ 37907 & -.00003\ 19975 \\ .00007\ .37903 & .99999\ .99972 & -.00001\ 09138 \\ .00003\ .19983 & .00001\ .09114 & .99999\ 99994 \end{pmatrix}$$

Matrix D rotates the ECT coordinate system around the Z-axis so that the X-axis is moved from the vernal equinox to the Greenwich meridian.

$$D = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\theta = 99.6909833 + 36000.7689 \cdot TU + .00038708 \cdot TU^2$$

TU = elapsed time in Julian centuries, or

TU = (2441682.5 - 2415020.)/36525

A half day has been subtracted to change from Greenwich noon, Jan 0, 1950, to 0 hr, 0 min, Jan 0, 1973.

Matrix E corrects from ECT (1973.0) to the time of measurement.

$$E = \begin{pmatrix} \cos wt & \sin wt & 0 \\ -\sin wt & \cos wt & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

t = time since 0 hr., 0 min., Jan 0, 1973

w= .26251 61453 radians/hr

The six rotations shown above convert the PS axis from the local MDA system to the rotating earth system.

The counts in proton channels P1-P8 are screened for validity. Total counts fewer than 10 distributed among the 8 channels during a 1.2 second period are discarded. Counts greater than 50 in a single channel indicate a probable error and that period is discarded. The counts are normalized to counts per second and dead time corrections are applied.

In this analysis, the measured values will be compared to values derived from the Vette AP7 proton environment model. An attempt will be made to compare spectral data. However, preliminary results point to a gain change on the instrument. If corrections are not possible, then the integral flux above 50 MeV will be compared.

In keeping with these objectives, the analysis finds the AP7 omnidirectional fluxes, ties a range of assumed pitch angle distributions to it, folds in instrument response, and computes the values which would be seen by an idealized PS immersed in the AP7 model environment. These calculations are made at each measurement point, i.e., every 1.2 seconds along the trajectory where sensible flux is encountered. The measured values and calculated values are summed over time, then ratiod to provide spectral correction factors.

At the same time, the data are tabulated according to location (B, L), pitch angle (α), energy, assumed pitch angle distribution (σ), and orientation in the earth-fixed coordinate system (θ_{LV}, ψ_{LV}). With the aid of this data, detailed corrections to the AP7 model environment are derived. "Best fit" energy-dependent pitch angle distributions are also obtained. Finally, some information is derived concerning the east-west asymmetry, though this effect is blurred at higher energies due to acceptance in the backward cone of the PS above 100 - 150 MeV.

In order to accomplish the above objectives, the analysis continues from the point at which corrections were applied to the measured data.

The Vette AP7 flux parameters, a and b, are found by table look-up using values of B and L from the SKYBET tape.

$$\text{AP7 FLUX } (> E) = a\, e^{-b\, E}$$

This form is differentiated, and the resultant is integrated over energy ranges corresponding to those of the eight proton channels. The angle α between the local magnetic field line, B, and the axis of the PS primary cone is found using the scalar product. The angle α is used in a table look-up to determine that fraction of the AP7 omnidirectional flux which would be observed by an ideal PS. The measured angular response of the instrument is triangular, peaked on the axis and going to zero at $\pm$ 22.5°. The assumed pitch angle distribution is Gaussian:

$$\frac{e^{\frac{-(90-\alpha)^2}{2\sigma 2}}}{\sigma\sqrt{2\pi}}$$

The idealized instrument reading is obtained by numerical integration and condensed into tables for this program. Note that σ determines the angular distribution of the flux. A set of 10 values are chosen for σ so that parallel calculations may be made. The best value will later be determined for each energy group, or the total flux.

The flux values computed above will be denoted by Φ. The measured fluxes will be denoted by Φ^*. Each quantity will be further identified by two sets of subscripts.

The first set of subscripts is described as follows.

$$\Phi^*_{ijkl}\, ,\ \Phi_{ijklm}$$

where

$i = B'$ (note prime)

$j = L'$ (note prime)

$k = \alpha$

$l = E$

$m = \sigma$

Figure 1 shows that rectangular boxes in B - L coordinates would be wasteful of computer space, or would have large variations in flux level within a box. Therefore a transformation is applied to obtain B' - L' coordinates which are better suited here.

$$\begin{pmatrix} B' \\ L' \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} B \\ L \end{pmatrix} + \begin{pmatrix} -.12942\ 2374 \\ -1.19972\ 9073 \end{pmatrix}$$

$$\theta = -3^{\circ}\ 23'$$

The B' box limits are 0-.004, .004-.01, .01-.02, and >.02. The L' box limits go from 0 to .7 in steps of .1, then >.7.

The box limits in the α dimension are 0 - 40, 40 - 60, 60 - 70, 70 - 75, 75 - 80, 80 - 85, and 85 - 90 . Angles greater than 90° are reflected back to the first quadrant.

The box limits in the energy dimension are identical with those of the PS.

Thus, the measured fluxes, Φ^*, are tabulated in a 4-dimensional table with 4 x 8 x 7 x 8 = 1792 subdivisions. The calculated fluxes, Φ, have an extra dimension, pitch angle distribution σ, and 10 parallel calculations are made for this quantity.

Flux units are $\frac{p(E > 50\ MeV)}{cm^2 - sec}$

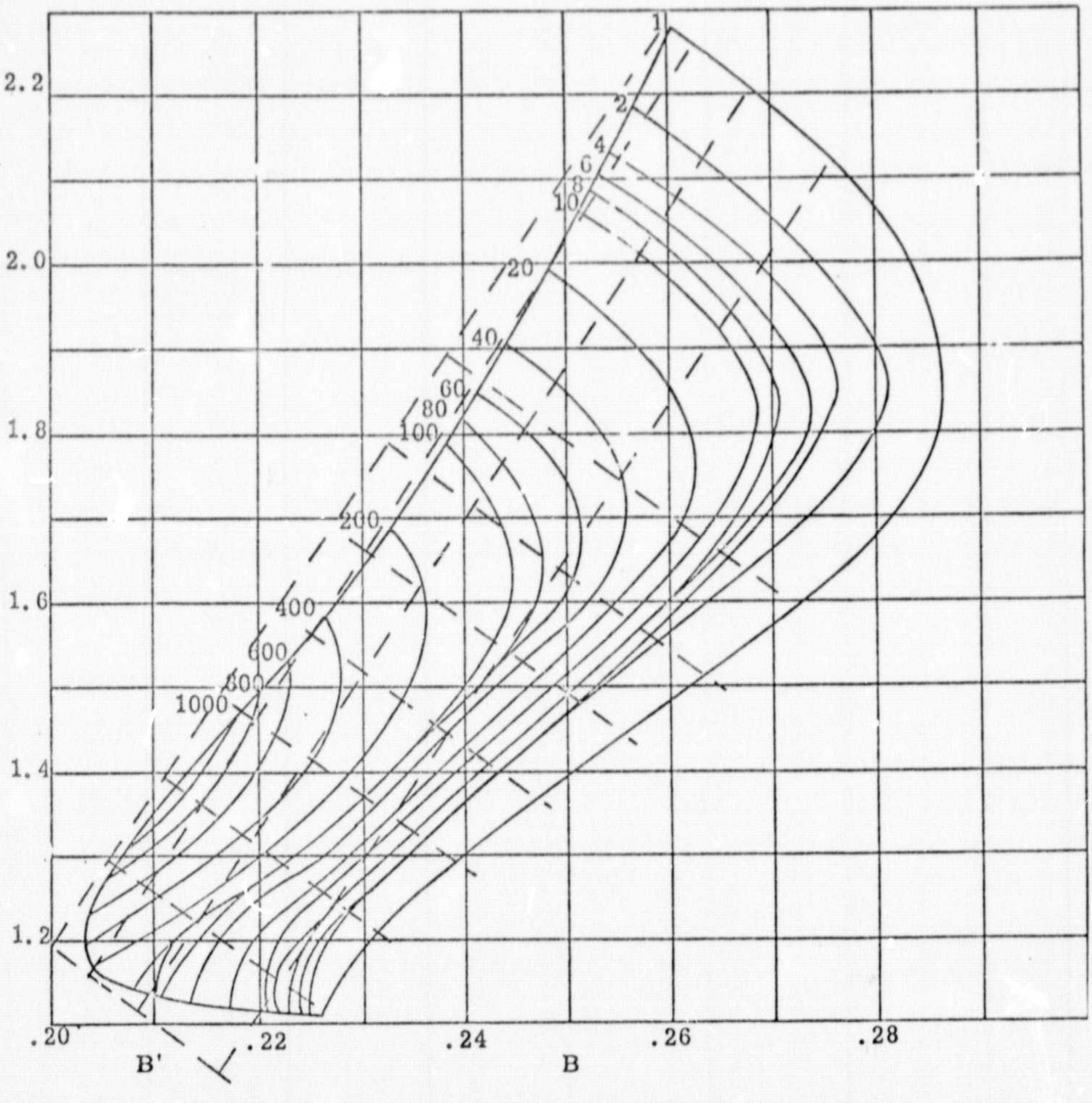

Figure 1. Flux Contour Map of the Skylab Orbit in B - L Space
235 n. m. - 50^0

A second set of subscripts and tables is necessary for the east-west asymmetry study. These subscripts are:

$$\Phi^*_{ijl}{}^{n1\,n2} \quad ; \qquad \Phi^*_{ijlm}{}^{n1\,n2}$$

where

$i = B'$ $\qquad m = \sigma$

$j = L'$ $\qquad n1 = \theta_{LV}$

$l = E$ $\qquad n2 = \psi_{LV}$

The α subscript, k, is replaced by two subscripts, n1 and n2, identifying equal solid angle boxes in the Local Vertical system. Here n1 labels the polar angle with boundaries at 0, 60, 90, 120 and 180°, while n2 labels the azimuthal angle with limits at 330, 30, 90, 150, 210, and 270°. The solid angle is subdivided into 4 x 6 = 24 equal size boxes. Here, the measured fluxes, Φ^*, are tabulated in a 5-dimensional table with 4 x 8 x 8 x 4 x 6 = 6144 subdivisions.

Values of Φ^*, Φ^{*2}, and Φ are determined for each measurement (1.2 seconds) and are accumulated in separate tables according to the two sets of subscripts described above. Auxiliary tables are compiled to show the number of entries in each box of each table.

The tables described above are too lengthy to keep in fast storage. Therefore Φ^*, the 10 Φ's, and the two sets of subscripts will be placed in a buffer. When the buffer is full it is dumped into mass storage. After the input tape is processed, the values are brought back into fast core and processed. The subscripts, maximum value, and quantity represented are listed below:

l	8	E	m	10	σ
j	8	L'	n2	6	ψ_{LV}
i	4	B'	n1	4	θ_{LV}
k	7				

The measured and calculated data are sorted into tables as described above. The cumulative tables are stored on tape in the following order.

Number of Entries Tables

1. Number of entries per bin for the pitch-angle tables (8 E's, 8 L's, 4 B's, 7α's = 1792 words)
2. Number of entries per bin for the east-west tables (8 E's, 8 L's, 4 B's, 6 azimuthal angles, 4 polar angles = 6144 words)

Pitch-Angle Tables

3. Measured pitch-angle, Φ^*, 1792 x 2 words (Φ^*, Φ^{*2})

4-13. Calculated pitch-angle for 10 assumed distributions, Φ_m, 10 x 1792 x 2 words

East-West Tables

14. Measured east-west table, Φ^*, 6144 x 2 words

15-24. Calculated east-west tables for 10 assumed distributions, Φ_m, 10 x 6144 x 2 words

The total table storage is 182528 words.

Values are accumulated over each 12 hour period, then added to previous accumulations. Within each box, the mean values are:

$$\overline{\Phi^*} = \frac{1}{n}\sum\Phi^* \quad , \quad \overline{\Phi} = \frac{1}{n}\sum\Phi \; , \quad \overline{\Phi^{*2}} = \frac{1}{n}\sum\Phi^{*2}$$

where n is the number of entries in that box. The standard deviation of Φ^* is estimated from:

$$(S.D.)^2 = \frac{1}{n} \sum (\Phi^* - \overline{\Phi}^*)^2 = \frac{1}{n} \sum (\Phi^{*2} - \overline{\Phi}^{*2})$$

Here the subscripts have been omitted for brevity. Note that summation over some of the subscripts is feasible before determining means and standard deviations.

It is planned that the following results will be computed following the processing of each 12 hour tape.

A pitch angle distribution analysis will be made. The flux values will be summed over B' and L'. These sums are called S* and S for the sums of Φ^* and Φ, respectively. Then

$$R(E,\alpha\ \sigma) = \frac{S^*\ (E,\ \alpha\ )}{S(E,\alpha\ ,\sigma)} = \frac{F^*(E) \int g(\beta)\ t(\beta)\ d\beta}{F(E) \int f(\beta\ ,\sigma\ )\ t(\beta)\ d\beta}$$

Here, $R(E,\ \alpha\ ,\ \sigma\ )$ is the ratio of observed to computed flux. The parameter σ labels the 10 assumed pitch angle distributions. $F^*(E)$ is the true omnidirectional flux in the energy band E. F(E) is the AP7 model omnidirectional flux in the same band. The top (bottom) integral specifies the fraction of omnidirectional flux counted by the real (idealized) PS. The limits on the integrals involve α_k and α_{k+1} but are complex because of the wide acceptance cone of the PS. The quantity $t(\beta)$ concerns the angular response of the instrument. The quantity of $g(\beta)$ is the true (but unknown) pitch angle distribution, while $f(\beta,\ \sigma\ )$ is one of the assumed distributions,

$$f(\beta, \ ) = \frac{e^{-\frac{(90^{o} - \beta)^{2}}{2\sigma 2}}}{\sigma\sqrt{2\pi}} \qquad .$$

The values to be extracted from the second equation above are $F^*(E)/F(E)$ and σ; $R(E, \alpha, \sigma)$ is known. Consider the following: the limits on the integrals are identical, as is the PS angular response, $t(\beta)$. Therefore, if a choice of $f(\beta)$ can be found that matches the true pitch angle distribution, $g(\beta)$, then the integrals will be identical and will cancel. In effect, the α dependence would vanish. A plot of $R(E, \alpha, \sigma)$ versus α would be a horizontal line with ordinate $F^*(E)/F(E)$. For this reason, the best value of σ, for a given energy, will be determined by doing at least squares fit to a horizontal line in $R(E, \alpha, \sigma)$ versus α. The first one or two α values (0 to 40^{o} or 60^{o}) may have to be omitted due to sparse statistics. Alternatively, flux weighting may be employed.

In the above manner, the best pitch angle distribution and ratio of true to AP7 omnidirectional fluxes will be obtained for each energy channel. The latter is simply the desired spectral correction factor to the AP7 model averaged over the Skylab orbit.

The alternate tables using the second set of subscripts mentioned previously will be used to study the east-west effect. Ratios of the measured to calculated flux will be used here also because the orientation of the spectrometer may not sample different directions equally in a [illegible] time. Thus, the measured flux entering with polar angle between [illegible]0 - 90^{o} ($n1 = 2$) and from the east 330 -30^{o} ($n2 = 1$, divided by the corresponding calculated flux is:

$$A(n1 = 2.\ n2 = 1) = \frac{S^*(2,\ 1)}{S(2,\ 1)}$$

Here the subscripts on B', L', E and σ are omitted. Particular values of these subscripts may be examined, or summation over desired ranges may be made prior to this calculation. A similar quantity may be made for flux in the opposite direction:

$$A(n1 - 3,\ n2 = 4) = \frac{S*(3,\ 4)}{S(3,\ 4)} \quad .$$

The east-west ratio for this choice is

$$R_{E-W} = \frac{A(2,\ 1)}{A(3,\ 4)}$$

Fractional standard deviations may be computed for these values in the manner illustrated previously.

The spectral correction factors, pitch angle distributions, and east-west factors will be computed over an increasing data base as the mission progresses. Increased accuracy should be reflected in decreased fractional standard deviations.

II. PROBLEM AREAS

Spectral data may not be available due to gain changes in the PS. An attempt will be made to correct for gain changes. If this correction is not possible, the integral flux above 18 MeV will be analyzed.

III. FUTURE WORK

Over the next period, production runs will be made for the proton data. The codes will be modified to treat the electron and D3 channel data.