ORBITAL RADIATION EXPOSURE
OF THE ASTRONOMICAL NETHERLANDS
SATELLITE (ANS)

E. G. STASSINOPoulos

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND
ORBITAL RADIATION EXPOSURE
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A special report on expected radiation levels of the ANS Satellite.

by

E.G. Stassinopoulos

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FOREWORD

Orbital flux calculations were performed for the ANS Satellite at the request of the project office. This data is needed to determine the applicability of COS/MOS circuits for the ANS mission, for use in the flight system (in the on-board computer and the X-ray experiment logic).
Introduction

High inclination circular and elliptical trajectories ($i > 55^\circ$) or low inclination elliptical orbits of large eccentricity traverse the terrestrial radiation belts twice during each revolution. The vehicle thus executes a transverse motion in L-space, passing successively through a region of low L-values ($1.0 \leq L \leq 2.0$) and of high L-values ($2.0 \leq L \leq 6.6$), commonly referred to as the inner zone and the outer zone. The specified ANS trajectory performs in a very similar way.

Although the inclination of the proposed ANS orbit was fixed at 97 degrees prograde, which is identical to 83 degrees retrograde, the trajectories were nevertheless generated for a 83 degree prograde inclination. This was done in order to bypass difficulties usually encountered in the conversion of retrograde positions from geodetic polar to magnetic B-L coordinates and only after previous test runs had established that the results would be about equal if long enough intervals of flight-times were considered, provided the orbit-periods were comparatively small ($t \leq 2.5 \text{ hrs.}$) and were not an exact divisor of 24 (hours in a day).

Obviously, this happens because the same limited area of space is being sampled by either prograde or retrograde trajectory and when the sampling density is sufficiently increased by extending the time in orbit (the
flight duration considered in the calculations), the statistical
treatment of the data, the averaging process, produces the almost iden-
tical results.

Launch epoch for the ANS mission is given as sometime in 1972, which
falls halfway between the last solar maximum and the next solar minimum.
This means that conditions prevailing then in the radiation belts would
be similar to those of 1966-1967, except for the remnants of the artificial
"Starfish" electrons that populated the inner zone from July 1962 to about
1968. Since the electron fluxes are calculated with Vette's AE2 model
(Vette et. al, 1966) which describes the environment as it actually existed
back in 1964, at which time the artificials were still vastly predominant
in the inner zone, it is necessary (a) to entirely remove the artificial
component from the inner zone fluxes and (b) to account for solar cycle
variations in the outer zone. The first objective was achieved by
decaying the fluxes exponentially with experimentally determined decay
lifetimes, defined as functions of B, L, and E (energy), up to an epoch,
when it is felt, that natural background levels had been reached
(Stassinopoulos and Verzariu, 1971). The second by increasing the
uncertainty factor attached to the results. The increase is in pro-
portion to the time spent in the outer zone, and the expected variations
of the intensities, both taken as a function of the parameter L.

Orbital flux integrations for high energy protons were performed with
the current models AP1 (Vette, 1966), AP6 (Lavine and Vette, 1969), AP7
(Lavine and Vette, 1970), while low energy protons were obtained
with the AP5 (King, 1967). All are static models, including the
AE2, which do not consider temporal variations. For the protons this
is a valid representation because experimental measurements have shown
that no significant changes with time have occurred. With the excep-
tion of the fringe areas of the proton belt, that is, at very low alti-
tudes and at the outer edges of the trapping region, the possible error
introduced by the static approximation lies well within the uncertainty
factor of 2, attached to the models. Consequently, the proton models
may be applied to any epoch without the need for an updating process.

Occasionally discontinuities appear in the proton spectra. These
"breaks" occur because the complete proton environment is being described
by three (formerly four) independent maps or grids, each valid only
over a limited energy range; for certain critical orbital configurations
the discontinuities are than produced when moving from one energy range
to another. They are caused, in part, by the exponential energy para-
meter of the model which in many instances had to be extrapolated to
make up for lacking data and, in part, to insufficient experimental
measurements over some areas of B/L-space; furthermore, the discontinui-
ties reflect the fact that the available data cannot be completely
matched at their overlap. In order to overcome such spectral breaks,
a continuous weighted mean curve is usually drawn, connecting the ad-
jaent segments; it should be regarded as an approximate spectral dis-
tribution. In doing this, the AP1 results (30< E(Mev)< 50) have to
be totally ignored sometimes. The ANS orbit belongs to the affected group.
Classification of orbit integrated spectra as hard or soft is relative; it is based on an overall evaluation of near earth space in terms of circular trajectories between equatorial and polar orbits.

Attachment A contains other pertinent background information with regard to units, field models, trajectory generation and conversion, etc.

At this point, we wish to emphasize again that our calculations are only approximations; we strongly recommend that all persons to receive parts of this report be advised about the uncertainty in our data.
Results: Analysis and Discussion

Our calculations for the proposed ANS orbit are summarized in Table 1 for electrons and Table 2 for protons. The superimposed spectral distribution for both types of particles is given graphically in Figure 1.

The spectrum for electrons with energies $E > 1$ Mev may be classified as "hard" for near earth space missions, while the protons rate a "hard" to "very hard" classification for energies $E > 5$ Mev. Figures 2 and 3 are computer plots depicting the characteristic electron and proton spectra of the flightpath, separately.

Table 3 indicates what percent of its total lifetime the satellite spends in "flux-free" regions of space, what percent of its total lifetime in "high intensity" regions, and while in the latter, what percent of its total daily flux it accumulates.

In the context of this study, the term "flux-free" applies to all regions of space where trapped-particle fluxes are less than one electron or proton per square centimeter per second, having energies $E > .5$ Mev and $E > 5$ Mev respectively; this includes regions outside the radiation belts. Similarly, we define as "high intensity" those regions of space, where the instantaneous, integral, omnidirectional, trapped-particle flux is greater than $10^5$ electrons with energies $E > .5$ Mev, and greater than $10^3$ protons with energies $E > 5$. Mev. The values given in Table 3 are statistical averages, obtained over extended
intervals of mission time. However, they may vary significantly from one orbit to the next, when individual orbits are considered.

Predictably, the high energy proton population, which occupies a smaller volume of the radiation belt, affords a larger flux-free time than the electrons, especially for orbits with inclination \( i > 30^\circ \). It should be noted that at the indicated height, a change in altitude does not alter significantly the flux-free time afforded the satellite, in either the electron or the proton medium.

If the flux-free time is important in mission planning, it is advisable, before decisions are made, to evaluate and compare the radiation hazards or effects due to the predicted electron and proton fluxes, either in regard to the entire mission or in regard to specific mission functions or requirements. For, while the proton intensities are on the average about two orders of magnitude smaller than the electrons, and while they apparently do afford more flux-free time, their greater mass and harder spectra may prove more damaging to the mission than the more numerous electrons with their lesser flux-free time.

In Table 4 the percentage of total lifetime \( T \) spent by the vehicle in the inner zone \( (T^i) \) and in the outer zone \( (T^o) \) is given, with the percent duration spent outside the trapped particle radiation belt \( (L > 6.6) \), denoted by \( T^e \) (T-external).
For any mission then:

\[ T = T_i + T_o + T_e = 100\% \]

Evidently, at the selected altitude, the high inclination ANS spends almost equal amounts of its entire lifetime in the inner and the outer zone trapping regions (see footnote on Table 4). It extendedly visits regions of space outside the Van Allen belts (about 27% of T). The satellite thus performs a complete sweep through magnetic L-space, which constitutes the transverse motion mentioned in the first paragraphy, executed twice during each revolution (orbit). Part of this information is used to evaluate the possible contribution of the outer zone solar cycle dependence to the uncertainty factor attached to the results.

The following related points are submitted for consideration in connection with the lifetime distribution over distinct regions of space;

a. Lasting solar cycle effects are more severely experienced in the outer zone (significant changes in the trapped electron population from solar minimum to solar maximum).

b. Energetic artificial electrons from high altitude nuclear explosions (Starfish) have displayed a remarkable longevity, but only in the inner zone; there they contaminated the environment for over 5 years, while they rapidly decayed to background levels in the outer
zone (within weeks to months). A planned or accidental explosion of another atomic device with the appropriate yield and at the right latitude and altitude may, very likely, produce conditions similar to those experienced with "Starfish", transforming the inner zone again into a radiation hotbed.

c. Transient solar flare effects (high energy solar proton fluxes) may be especially hazardous and damaging in regions external to the trapped particle belts.

Figures 4 and 5 are additional computer plots for the ANS trajectory showing the vehicle encountered instantaneous peak electron ($E > .5\text{ Mev}$) and proton ($E > 5\text{ Mev}$) intensities per orbit for a sequence of about 30 revolutions. On these graphs a periodic pattern emerges that indicates a daily cycle of about 15 orbits which may shift slightly in the plotting. This is due to the relative orbit period, which determines the precession of the trajectory.

It is known that altitude affects the peaks for both types of particles. The tendency at the ANS level is towards greater fluxes for higher altitudes. There is a relatively small variation in the peak-levels of the electrons over a daily cycle (maximum about a factor of 5), contrary to the protons, which experience totally flux-less intervals of time, lasting for several revolutions of the interphase between successive cycles.
Finally, two more computer plots are included, Figures 6 and 7, for protons and electrons respectively, depicting the characteristic averaged instantaneous intensities of the trajectory in terms of constant L-bands of .1 earth radius width; the percent of total lifetime spent in each L-interval is shown on the same graph by the contour marked with x's.
ATTACHMENT A

General Background Information

For the specified ANS trajectory, orbit tapes were generated with an integration stepsize of one minute for a sufficiently long flighttime, so as to insure an adequate sampling of the ambient environment; on account of its period, which determines the rate of orbit-precession, the following circular light path of 48-hour duration was produced:

<table>
<thead>
<tr>
<th>Inclination</th>
<th>Altitude</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>83° prograde (97° retrograde)</td>
<td>500 km</td>
<td>1.577 hrs.</td>
</tr>
</tbody>
</table>

The orbit was subsequently coverted from geocentric polar into magnetic B/L coordinates with McIlwain's INVAR program of 1965 (Hassit and McIlwain, 1967), and with the field routine ALLMAG (Stassinopoulos and Mead, 1971), utilizing the POGO (8/69) geomagnetic field model (Cain and Sweeney, 1970) calculated for the epoch 1972.0 (B is the field strength at a given point and L is the geocentric distance to the intersect of the field line, passing through that point, with the geomagnetic equator).

Orbital flux integrations were performed with Vette's current models of the environment, the AE2 for electrons, the AP1, AP6, AP7 for high energy protons, and King's AP5 for low energy protons. All are static models which do not consider temporal variations. See text for further details on this matter.
The results, relating to omnidirectional, vehicle encountered, integral, trapped particle fluxes, are presented in graphical and tabular form with the following unit convention:

1. Daily averages: total trajectory integrated flux averaged into particles/cm$^2$ day,

2. Totals per orbit: non-averaged, single-orbit integrated flux in particles/cm$^2$ orbit,

3. Peaks per orbit: highest orbit-encountered instantaneous flux in particles/cm$^2$ sec,

where 1 orbit = 1 revolution.

Please note: We wish to emphasize the fact that the data presented in this report are only approximations. We do not believe the results to be any better than a factor of two (2) for the protons and a factor of five (5) for the electrons. It is advisable to inform all potential users about this uncertainty in the data.
References


ORBITAL FLUX STUDY WITH COMPOSITE ELECTRON ENVIRONMENT*  

DATE OF RUN = YEAR 1971, DAY 0291 
FLUXES EXponentially DECAYED WITH DECAY-FACTOR D1 = VETTE TBBLE * 
DECAY DATE = YEAR 1967, MONTH 6, DAY 30 

AVERAGED FLUXES ON THIS TABLE ARE IN UNITS OF PARTICLES/CM**2/DAY *** 
NON-AVERAGED FLUXES ARE IN UNITS OF PARTICLES/CM**2/SEC. 
ALL FLUXES ON THIS TABLE ARE FOR ENERGIES E>5 MeV (EXCEPT WHERE ENERGY IS SPECIFIED AS IN SPECTRUM) 

INCLINATION = 83°  
PERIGEE = 500  
APOGEE = 500 KM  
BELL ORBIT TAPE TD 7410  
PERIOD = 1.577 
VEHICLE = ANS 

<table>
<thead>
<tr>
<th>ENERGY (MEV)</th>
<th>AVERAGED RANGES (PER CENT)</th>
<th>TOTAL FLUX (PER DAY)</th>
<th>SPECTRUM ENERGY AVERAGED</th>
<th>INTENSITY (EL/CM**2/SEC)</th>
<th>EXPOSURE INDEX (HRS)</th>
<th>TOTAL NO. OF PARTICLES (E&gt;5)</th>
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<th>SPECTRUM ENERGY AVERAGED</th>
<th>INTENSITY (EL/CM**2/SEC)</th>
<th>EXPOSURE INDEX (HRS)</th>
<th>TOTAL NO. OF PARTICLES (E&gt;5)</th>
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</table>
**Table 2**

AVERAGE FLUXES IN THIS TABLE ARE IN UNITS OF PARTICLES/CM²/DAY. TAI- AVERAGED FLUXES ARE IN UNITS OF PARTICLES/CM²/SEC. ALL FLUXES IN THIS TABLE ARE FOR ENERGIES E>5 MEV (EXCEPT WHERE ENERGY IS SPECIFIED, AS IN SPECTRUM).

<table>
<thead>
<tr>
<th>ENERGY (MEV)</th>
<th>TOTAL FLUX (PER CENT)</th>
<th>SPECTRUM IN % E</th>
<th>EXPOSURE INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGES</td>
<td>AVERAGED</td>
<td>ENERGY (MEV)</td>
<td>RANGE (FT/CM²/SEC)</td>
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<td>6.657</td>
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<td>50-100</td>
<td>4.646E+05</td>
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<td>&gt;100</td>
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<td>TOTAL</td>
<td>2.460E+07</td>
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<td>1.0E-1.0E6</td>
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</tbody>
</table>

ORBITAL FLUX STUDY FOR COMPOSITE PROTON ENVIRONMENT. GRIDS A1, A7, A8, A9, ARE TAE CF TAN = YEAR 1571, DAY 026. INCLINATION = 03, PERCE = 600, APOL = 360 KM, BIL ORBIT TAP TO 7410. PERIOD = 1.577, VEHICLE = ANS.

HIGH-ENERGY SPECTRUM IN % E.

INTENSITY (FT/CM²/SEC) | CURTAIN CF | TOTAL NO. OF ACCUMULATED PARTICLES (E>5)
Table 3

ANS

Circular
Inclination 83°
Altitude 500 km
Approx. Decay Epoch: 1967.6

<table>
<thead>
<tr>
<th>Electron (E &gt; 0.5 Mev)</th>
<th>Proton (E &gt; 5. Mev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fraction of total lifetime spent in flux-free regions*</td>
<td>73.54%</td>
</tr>
<tr>
<td>2. Fraction of total lifetime spent in high-intensity regions* of Van Allen Belts:</td>
<td>3.06%</td>
</tr>
<tr>
<td>3. Fraction of total daily flux accumulated during (2):</td>
<td>54.95%</td>
</tr>
</tbody>
</table>

*See text for definition
Table 4

ANS

Circular
Inclination $83^\circ$
Altitude 500 km

Percent of total lifetime spent inside and outside the Trapped Particle Radiation Belt

<table>
<thead>
<tr>
<th>Zone</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Zone ($T^i$)*</td>
<td>47.5%</td>
</tr>
<tr>
<td>Outer Zone ($T^o$)</td>
<td>35.9%</td>
</tr>
<tr>
<td>External ($T^e$)</td>
<td>16.6%</td>
</tr>
</tbody>
</table>

100.0%

*This time may be subdivided into two parts:

37.5% in the $L$-interval $1.1 \leq L < 2.0$

10.0% in the $L$-interval $1.0 \leq L < 1.1$

where the $T^i$ ($1.0 \leq L < 1.1$) lies outside the actual trapping region.
PERK FLUX ENCOUNTERED IN EACH PERIOD

\[ E > 5 \text{ MeV} \quad \text{PERK FLUX (ELECTRONS/CM}^2\text{-SEC)} \]

PEAK FLUX ENCOUNTERED IN EACH PERIOD  83DEGR  50OKM ANS  DATA SET 1

ORBIT NUMBER

0,000  5,000  10,000  15,000  20,000  25,000  30,000  35,000
PEAK FLUX ENCOUNTRED IN EACH PERIOD 83DEGR 500KM ANS DATA SET 1
Figure 6

AMBIENT TRAJECTORY, ENVIRONMENT  83 DEG  500KM ANS  DATA SET 1

J (E-SHEV) (ELECTRONS/CM^2-SEC) MARKED GRAPH IS PERCENT TIME-RANGE 1E-3 TO 1E-2