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SAMPEX Science Pointing Modes with Velocity Avoidance

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Abstract

The Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) science pointing modes are presented with the additional constraint of velocity avoidance. This constraint has been added in light of the orbital debris and micrometeoroid fluxes that have been revealed by the Long Duration Exposure Facility (LDEF) recovered in January 1990. These fluxes are 50-100 times higher than the flux tables that were used in the September 1988 proposal to NASA for the SAMPEX mission. The SAMPEX Heavy Ion Large Telescope (HILT) sensor includes a flow-through isobutane proportional counter that is susceptible to penetration by orbital debris and micrometeoroids. Thus, keeping the HILT sensor pointed away from the velocity vector, the direction of maximum flux, will compensate for the higher than expected fluxes. (The angle between the HILT boresight and the velocity vector is defined as the RAM angle.)

Using an orbital debris model and a micrometeoroid model developed at the Johnson Space Center (JSC), and a SAMPEX dynamic simulator developed by the Guidance and Control Branch at the Goddard Space Flight Center (GSFC), an "optimal" RAM angle of 90 degrees has been determined. It is optimal in the sense of minimizing the science pointing performance degradation while providing approximately an 89 percent chance of survival for the HILT sensor over a 3 year period. The velocity avoidance algorithm is independent of the normal science pointing modes.

1.0 Introduction

The first in the Small Explorer (SMEX) series, the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) spacecraft will be launched by a Scout launch vehicle from the Western Test Range in June 1992. The mission is designed to obtain scientific data on several different natural phenomena. This includes obtaining a statistically large sample of anomalous cosmic ray oxygen nuclei to estimate their ionization state and obtaining a continuous record of the intensity, latitude, and local time dependence of the precipitating magnetospheric particle fluxes, particularly relativistic electrons. In addition, the SAMPEX mission hopes to detect solar flare events during a low altitude, near-polar orbit during the declining phase of solar activity. The scientific instruments on board are the Low Energy Ion Composition Analyzer (LEICA), the Heavy Ion Large Telescope (HILT), the Mass Spectrometer Telescope (MAST), and the Proton/Electron Telescope (PET).

The scientific objectives translate into several orbit and attitude requirements. The spacecraft must have a three year lifetime in order to obtain sufficient data. Also, the 450 km X 850 km orbit will be in an 82 degree inclination. The instruments should be zenith pointing over the poles while minimizing exposure to micrometeoroids and orbital debris. Pointing the instruments away from the velocity vector will help to achieve this goal. A minimum RAM angle of 90 degrees will minimize exposure of the HILT sensor to hazardous debris without seriously degrading the science pointing performance.

The spacecraft power requirements demand that the solar arrays be pointed within 5 degrees of the Sun line during normal science modes. In addition, there is an independent safehold mode in case of anomalous behavior of the attitude control system. These are the only spacecraft imposed requirements on the attitude.

The spacecraft mechanical configuration is shown in Figure 1. The yaw axis is oriented along the instrument boresights, the pitch axis perpendicular to the solar panels, and the roll axis completes the orthonormal triad.

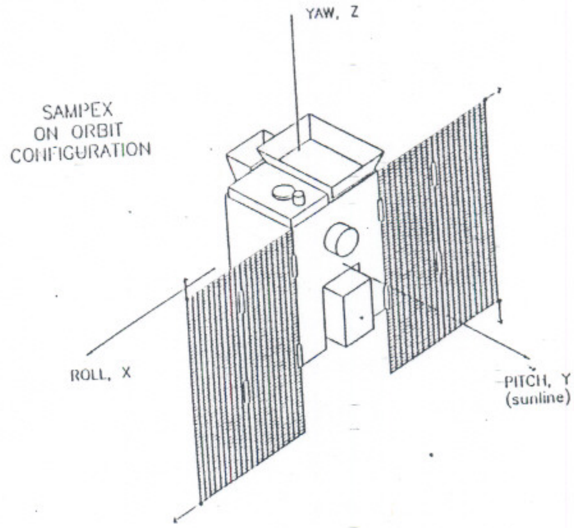
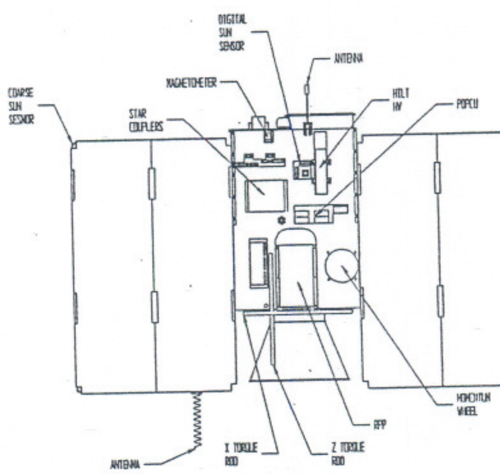


Figure 2 shows the location of some of the Attitude Control System (ACS) hardware and science instruments. The ACS hardware consists of one momentum wheel, three torquer bars, one two-axis fine Sun sensor, five coarse Sun sensors, and one three-axis magnetometer. A PID controller is used for the reaction wheel and an $\vec{H} \times \vec{B}$ control law is used for the magnetics. For a complete discussion of the ACS control laws, see Forden, et. al. [1]. The ACS control laws will not be presented in this paper.



There are two science pointing modes. The orbit rate rotation mode satisfies the Sun constraint but does not maximize zenith pointing over the poles. It does, however, provide a smoother scan of the celestial sphere than the vertical pointing mode. The orbit rate rotation mode is discussed in Section 2.1. The vertical pointing mode tends to maximize zenith pointing over the poles while maintaining the Sun angle constraint. However, this mode produces undesirable behavior when the Sun is near the orbit plane. The vertical pointing mode will be discussed in more detail in Section 2.2.

The SAMPEX scientists have determined that the LDEF results imply the orbital debris and micrometeoroid fluxes are 50-100 times higher than the fluxes used in a 1988 proposal to NASA for the SAMPEX mission. In this proposal, a mean time between penetrating impacts of 25 years for the HILT sensor was determined, almost an order of magnitude larger than the mission lifetime. Using the LDEF flux values, the HILT sensor is expected to have a lifetime of less than one year. Since the direction of maximum flux coincides with the velocity vector, a velocity avoidance scheme may be necessary to achieve a 90 percent chance of survival for the HILT sensor over a 3 year period. The velocity avoidance scheme is discussed in Section 3.0 and results for each science pointing mode are given in Section 4.0.

Fluxes were determined by using an orbital debris model and a micrometeoroid model developed at the Johnson Space Center (JSC). The mean time between impacts was computed and then Poisson statistics were used to determine the probability of survival. This analysis is discussed in Section 5.0. Conclusions are presented in Section 6.0.

2.0 Science Pointing Modes

2.1 Orbit Rate Rotation Mode

2.1.1 Introduction

The orbit rate rotation mode provides a smooth scan of the celestial sphere over the lifetime of the SAMPEX mission. The pitch axis points directly at the Sun to satisfy the power constraints, and the yaw axis rotates about the pitch axis at one revolution per orbit. The boresights of the instruments are located along the yaw axis. The yaw axis points as close to north as possible at the northernmost point of the orbit, as close to south as possible at the southernmost point of the orbit, and parallel to the equator at the equatorial crossings.

2.1.2 Mathematical Formulation

The formulation given below for the orbit rate rotation mode is taken from the SAMPEX ACS Flight Software Algorithm Document.

First, define the north pole vector NP in GCI coordinates:

$$NP = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}.$$

Now compute the orbit normal vector N,

$$N = \frac{R \times \dot{R}}{\left| R \times \dot{R} \right|},$$

where R, $\dot{R}$ are the inertial position and inertial velocity of the spacecraft, respectively. The next step is to compute the orbit angle as measured from the northernmost point in the orbit. First form the following two vectors:

$$AN = \frac{NP \times N}{\left| NP \times N \right|}, \quad NMP = N \times AN .$$

AN is a unit vector in the direction of the ascending node. Taking the cross product of N and AN yields a unit vector NMP in the direction of the northernmost point of the orbit. The sine and cosine of the orbit angle can now be computed,

$$\sin(\alpha) = \frac{-R \cdot AN}{|R|}, \quad \cos(\alpha) = \frac{R \cdot NMP}{|R|}.$$

The target vector U must lie in the plane perpendicular to the Sun. The following two vectors provide an orthornormal basis for the target vector U:

$$W = \frac{NMP \times S}{\left| NMP \times S \right|}, \quad S \times W .$$

W is a unit vector perpendicular to the Sun and lies in the equatorial plane. Thus when the spacecraft is near the equator, we would like U to point along W. This corresponds to orbit angles of $\alpha = \pi / 2$ and $\alpha = 3\pi / 2$. The unit vector $S \times W$ is also perpendicular to the Sun and points as close to the northernmost point as possible, given the Sun constraint. Thus when the spacecraft is near the poles, we would like U to point along $S \times W$. This corresponds to orbit angles of $\alpha = 0, \pi$. Since it is desired to rotate the yaw axis about the positive Sun line, the orientation of the orbit normal relative to the Sun line must be taken into consideration. A candidate for the target vector U is

$$U = \cos(\alpha)\,(S \times W) - \text{SIGN}(S \cdot N)\,\sin(\alpha)\,W .$$

This satisfies all the desirable features described above. However, there is one problem with this target vector. If the Sun passes through the orbit plane when the spacecraft is near the equator, this will cause a 180 degree flip. To prevent this from happening, a variable TargetSign is defined.

If the Sun passes through the orbit plane, the next time the spacecraft comes within 0.5 degrees of the northernmost or southernmost point of the orbit (which ever comes first), the variable TargetSign will change sign. (The initial value of TargetSign is - SIGN (S · N)). This will keep the spacecraft rotating about the Sun line without causing a flip. The target vector for the orbit rate rotation mode is

$$U_{orr} = \cos(\alpha)\; S \times W + \text{TargetSign}\,\sin(\alpha)\,W .$$

The orbit rate rotation mode can be summarized as:

$$\text{yaw axis} = U_{orr}$$
$$\text{pitch axis} = S$$
$$\text{roll axis} = \text{pitch} \times \text{yaw}.$$

2.1.3 Limiting Cases

2.1.3.1 Sun Perpendicular to the Orbit Plane

For the case where the Sun is perpendicular to the orbit plane , the orbit rate rotation mode reduces to a zenith pointing mode. Figure 3a shows that

$$S = N,$$
$$W = NMP \times S,$$
$$S \times W = NMP,$$

and since

$$U_{orr} = \cos(\alpha)\,(S \times W) + \text{TargetSign}\,\sin(\alpha)\,W,$$

the orientation of the yaw axis along the orbital path is zenith pointing. (See Figure 3b.)

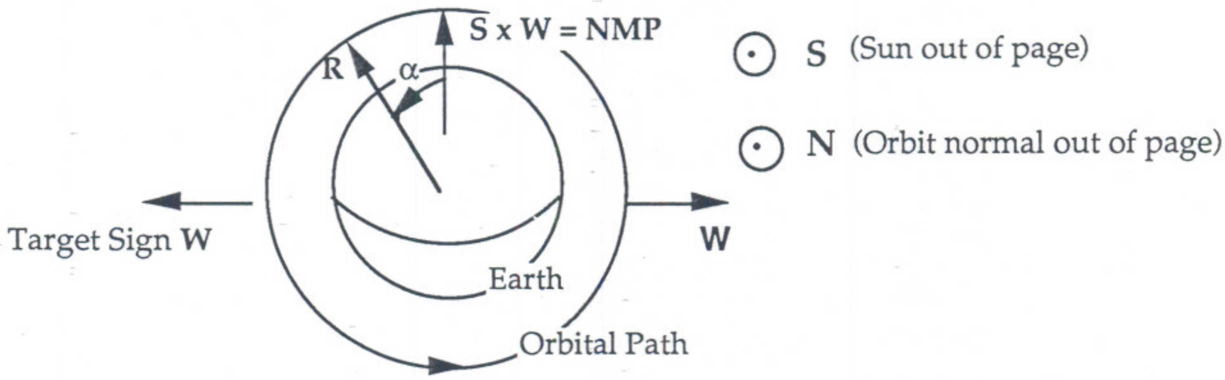


Figure 3a - Orbit Rate Rotation Mode geometry when the sun is perpendicular to the orbit plane.

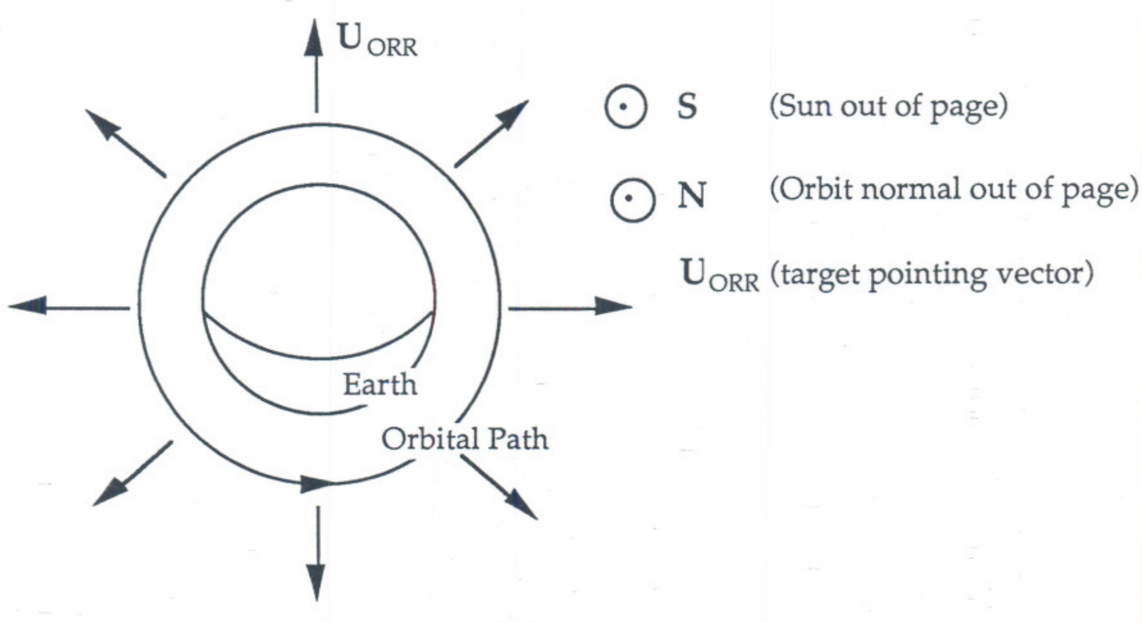


Figure 3b - Orbit Rate Rotation Mode target pointing vector along the orbital path (sun perpendicular to orbit plane).

2.1.3.2 Sun Parallel to the Orbit Plane

For the case where the Sun is parallel to the orbit plane , the orbit rate rotation mode becomes a zenith pointing mode over the poles and points in the $R \times NP$ direction at the equator. Figure 4a shows that

$$W = NMP \times S,$$

and since

$$U_{orr} = \cos(\alpha)\ S \times W + \text{TargetSign} \sin(\alpha)\ W,$$

the orientation of the yaw axis can be determined throughout the orbital path and is shown is Figure 4b.

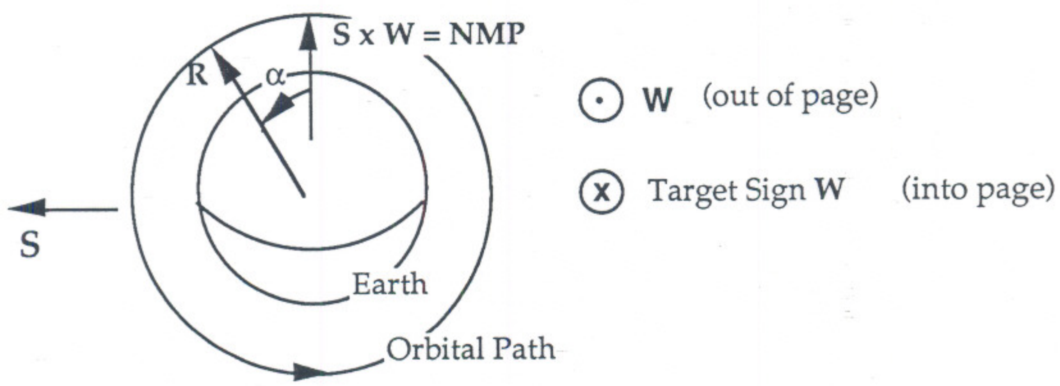


Figure 4a - Orbit Rate Rotation Mode geometry when the sun is in the orbit plane.

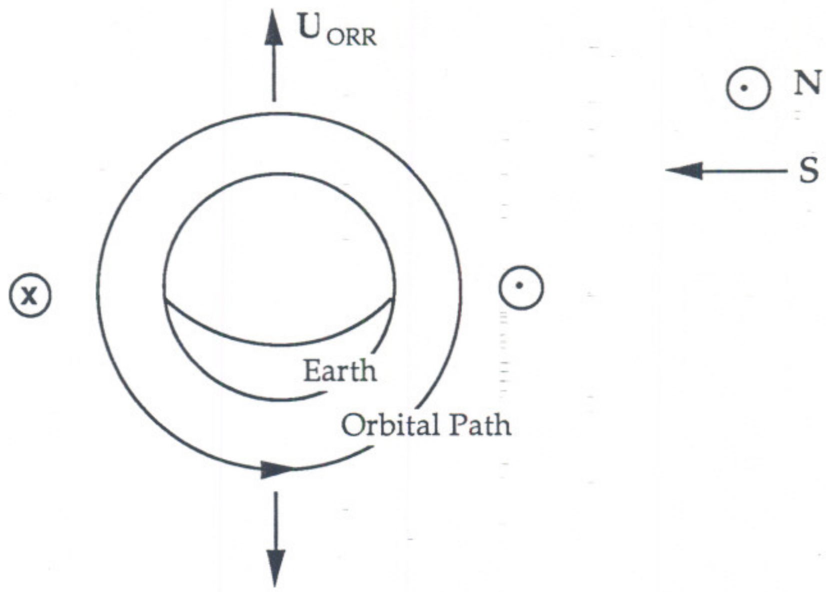


Figure 4b - Orbit Rate Rotation Mode target pointing vector along the orbital path (sun parallel to orbit plane).

2.2 Vertical Pointing Mode

2.2.1 Introduction

The vertical pointing mode maximizes zenith pointing over the poles. Again, the pitch axis points directly at the Sun, while the yaw axis points as close to zenith as possible while satisfying the Sun constraint. However, it has the undesirable property of pointing directly into the velocity vector twice per orbit when the Sun is in the orbit plane. (This can be prevented with the addition of the velocity avoidance algorithm which will be discussed in Section 3.0.)

2.2.2 Mathematical Formulation

The target vector for the vertical pointing mode is given by

$$U_{vp} = \frac{S \times (R \times S)}{\left| S \times (R \times S) \right|}.$$

By inspection, the yaw axis is as close to zenith as possible while remaining perpendicular to the Sun. The vertical pointing mode can be summarized as

$$\text{yaw axis} = U_{vp}$$
$$\text{pitch axis} = S$$
$$\text{roll} = \text{pitch} \times \text{yaw}.$$

2.2.3. Limiting Cases

2.2.3.1. Sun Perpendicular to the Orbit Plane

When the Sun is perpendicular to the orbit plane, the vertical pointing mode reduces to a zenith pointing mode which is equivalent to the orbit rate rotation mode for this particular geometry. Figure 3b illustrates the nominal pointing along the orbital path.

2.2.3.2 Sun Parallel to the Orbit Plane

When the Sun is in the orbit plane, the yaw axis points towards the north when above the Sun line and points towards the south below the Sun line. When the spacecraft crosses the Sun line, it flips 180 degrees directly into the velocity vector. Figure 5 illustrates this behavior.

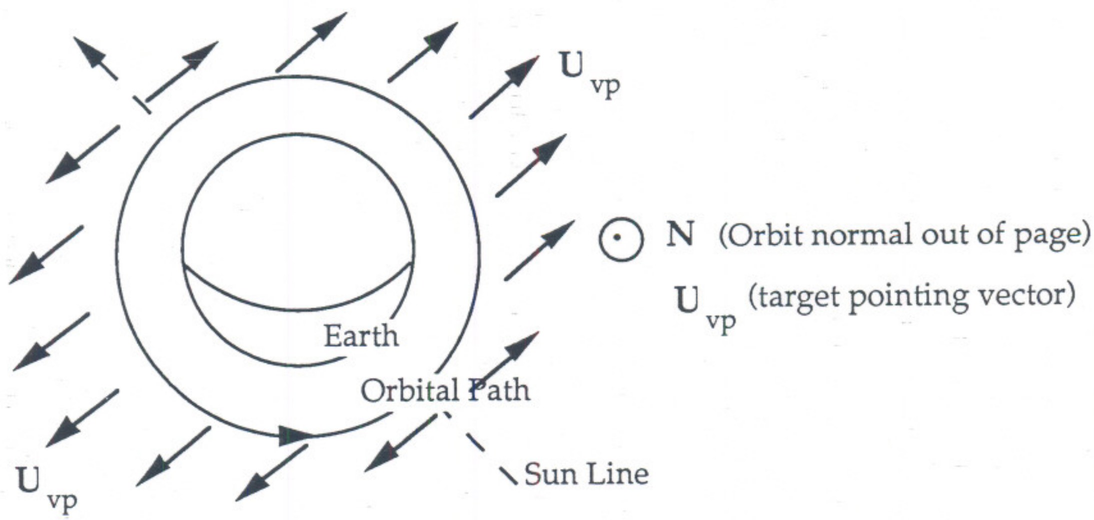


Figure 5 - Vertical Pointing Mode target pointing vector along the orbital path when the sun is in the orbit plane

3.0 Velocity Avoidance Algorithm
3.1 Introduction

The velocity avoidance algorithm has been added to the normal science pointing modes to help protect the HILT sensor from hazardous debris. The spacecraft can operate, however, without the velocity avoidance feature if desired. It can be turned on and off by a ground command. Currently, the maximum allowable RAM angle is 80 degrees, but it can also be modified by a ground command if desired. The algorithm is independent of the normal science mode and only requires that the target vector (from any mode) be perpendicular to the Sun.

3.2 Mathematical Formulation

Let

V - unit velocity vector (body coordinates)
U - target vector (as determined by the science pointing mode)
φ_{min} - minimum RAM angle (currently 90 degrees)

If $V \cdot U \leq \cos \varphi_{min}$, then the velocity avoidance algorithm is unnecessary. The spacecraft target vector is determined solely by the normal science pointing mode. However, if $V \cdot U > \cos \varphi_{min}$, then the algorithm is implemented.

The algorithm is defined in the Flatley coordinate system. Let the Sun unit vector S be the 1 axis, the normal science mode target vector U be the 3 axis (which by construction is already perpendicular to the Sun vector), and $U \times S$ be the 2 axis. (See Figure 6.)

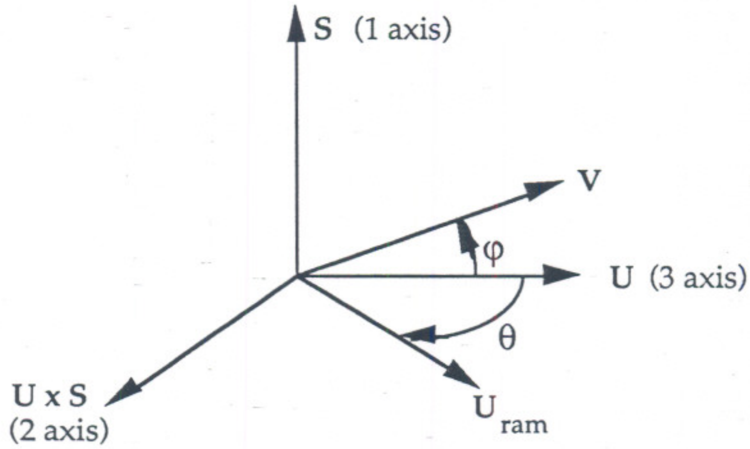


Figure 6 - Flatley Coordinate System

The unit velocity vector V and the target vector with velocity avoidance U_{ram} can be expressed in the Flatley coordinate system as

$$V_F = \begin{bmatrix} V_{F1} \\ V_{F2} \\ V_{F3} \end{bmatrix}, \quad U_{ram} = \begin{bmatrix} 0 \\ \sin(\theta) \\ \cos(\theta) \end{bmatrix}.$$

The desired constraint

$$U_{ram} \cdot V_F = \cos \varphi_{min}$$

is used to determine U_{ram}. This implies

$$V_{F2} \sin(\theta) + V_{F3} \cos(\theta) = \cos \varphi_{min} .$$

Squaring both sides produces

$$V_{F2}^2 \sin^2(\theta) + 2V_{F2}V_{F3} \sin(\theta)\cos(\theta) + V_{F3}^2 \cos^2(\theta) = \cos^2\varphi_{min} .$$

Using the relations

$$\cos^2(\theta) = 1 - \sin^2(\theta)$$
$$V_{F3}\cos(\theta) = \cos \varphi_{min} - V_{F2}\sin(\theta) ,$$

results in the following quadratic equation for $\sin(\theta)$:

$$(V_{F2}^2 + V_{F3}^2)\sin^2(\theta) - 2V_{F2}\cos \varphi_{min} \sin(\theta) + \cos^2\varphi_{min} - V_{F3}^2 = 0 .$$

The solution is

$$\sin(\theta) = \frac{V_{F2} \cos(\varphi_{min}) \pm |V_{F3}| \sqrt{V_{F2}^2 + V_{F3}^2 - \cos^2(\varphi_{min})}}{(V_{F2}^2 + V_{F3}^2)} .$$

If $V_{F2} \geq 0$, then $\sin(\theta) < 0$ and the negative sign is chosen for the radical. If $V_{F2} < 0$, then $\sin(\theta) > 0$ and the positive sign is chosen for the radical. Thus U_{ram} is given by

$$U_{ram} = \sin(\theta)\,(U \times S) + \cos(\theta)\,U ,$$

and the normal science pointing mode with velocity avoidance can be summarized as

$$\text{yaw axis} = U_{ram}$$
$$\text{pitch axis} = S$$
$$\text{roll axis} = \text{pitch} \times \text{yaw}.$$

Section 4.0 Results

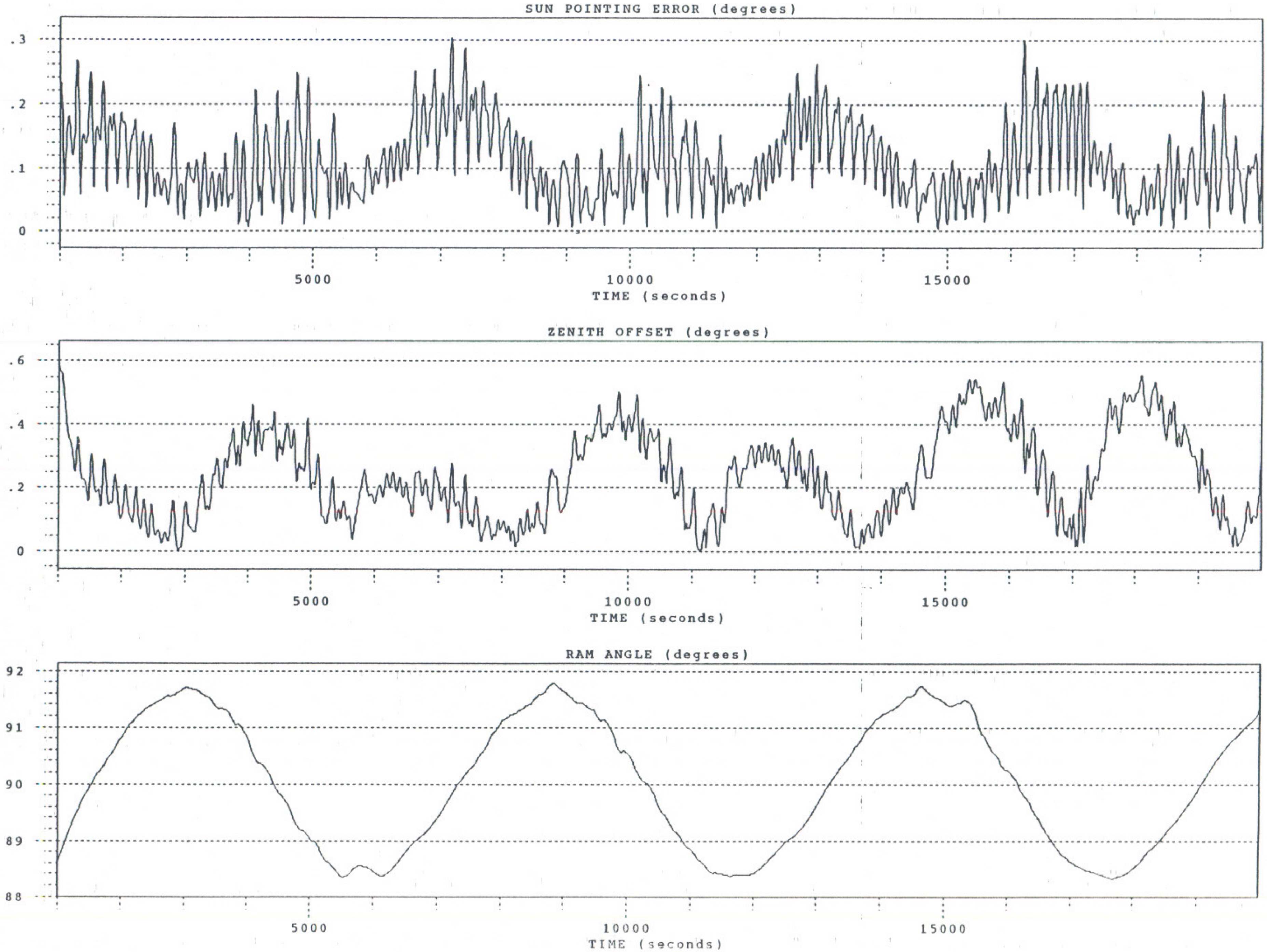
Results from the SAMPEX ACS dynamic simulator are shown for both modes and for three orbit geometries while varying the minimum RAM angle. The "best case" orbit geometry is a 6 PM ascending node on 9/1/93, the "intermediate case" is a 9 PM ascending node on 9/21/93, and the "worst case" is a 12 PM ascending node on 12/21/93. Both modes are analyzed without the velocity avoidance algorithm and with minimum RAM angles of 80, 90, and 100 degrees.

For the best case orbit geometry, both modes have a small Sun pointing error (< .3°) for all minimum RAM angles. Only for the 100° minimum RAM angle does the zenith offset (≈ 10°) become significant. The RAM angle plots show that the velocity avoidance scheme keeps the yaw axis pointed at least the desired minimum RAM angle away from the velocity vector. Also, science pointing performance is not affected by including the velocity avoidance algorithm.

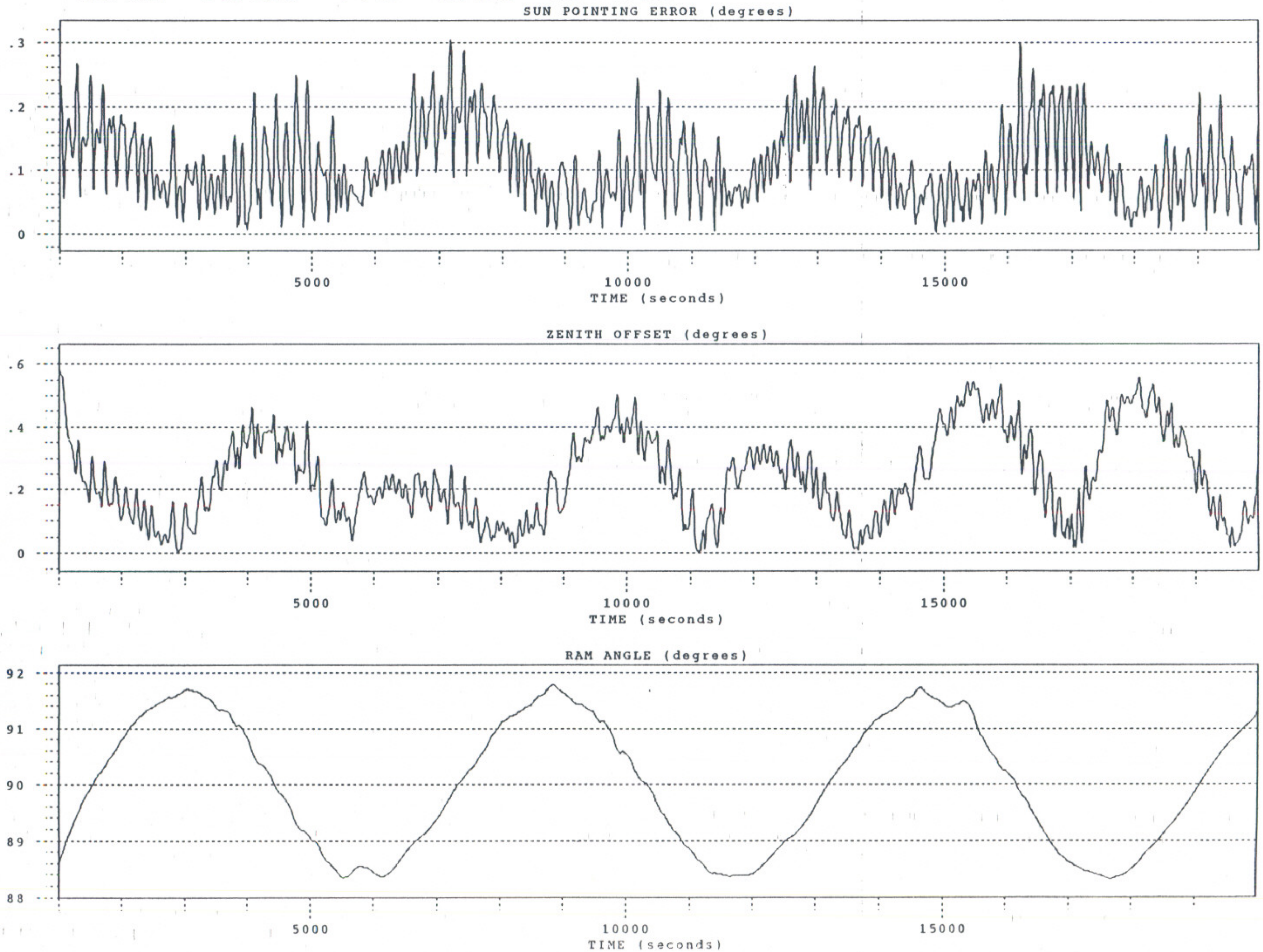
Similar results are obtained for the intermediate case. The Sun pointing error is approximately 2° for all minimum RAM angles, which is well below the design goal of 5°. The zenith offset varies between 0° and 45° and the RAM angle behaves as expected. The decrease in science pointing performance is insignificant.

The worst case orbit geometry dramatically illustrates the effect of increasing the minimum RAM angle. For the orbit rate rotation mode, the Sun pointing error increases from 1° to 2°. The zenith offset and the RAM angle show that the spacecraft flips when the minimum RAM angle reaches 100°. Also, science pointing performance begins to decrease significantly for increasing minimum RAM angles. The vertical pointing mode causes the spacecraft to flip for this particular orbit geometry and the velocity avoidance algorithm is unable to prevent the spacecraft from flipping when it enters eclipse. Again, the pointing performance decreases with increasing minimum RAM angles.

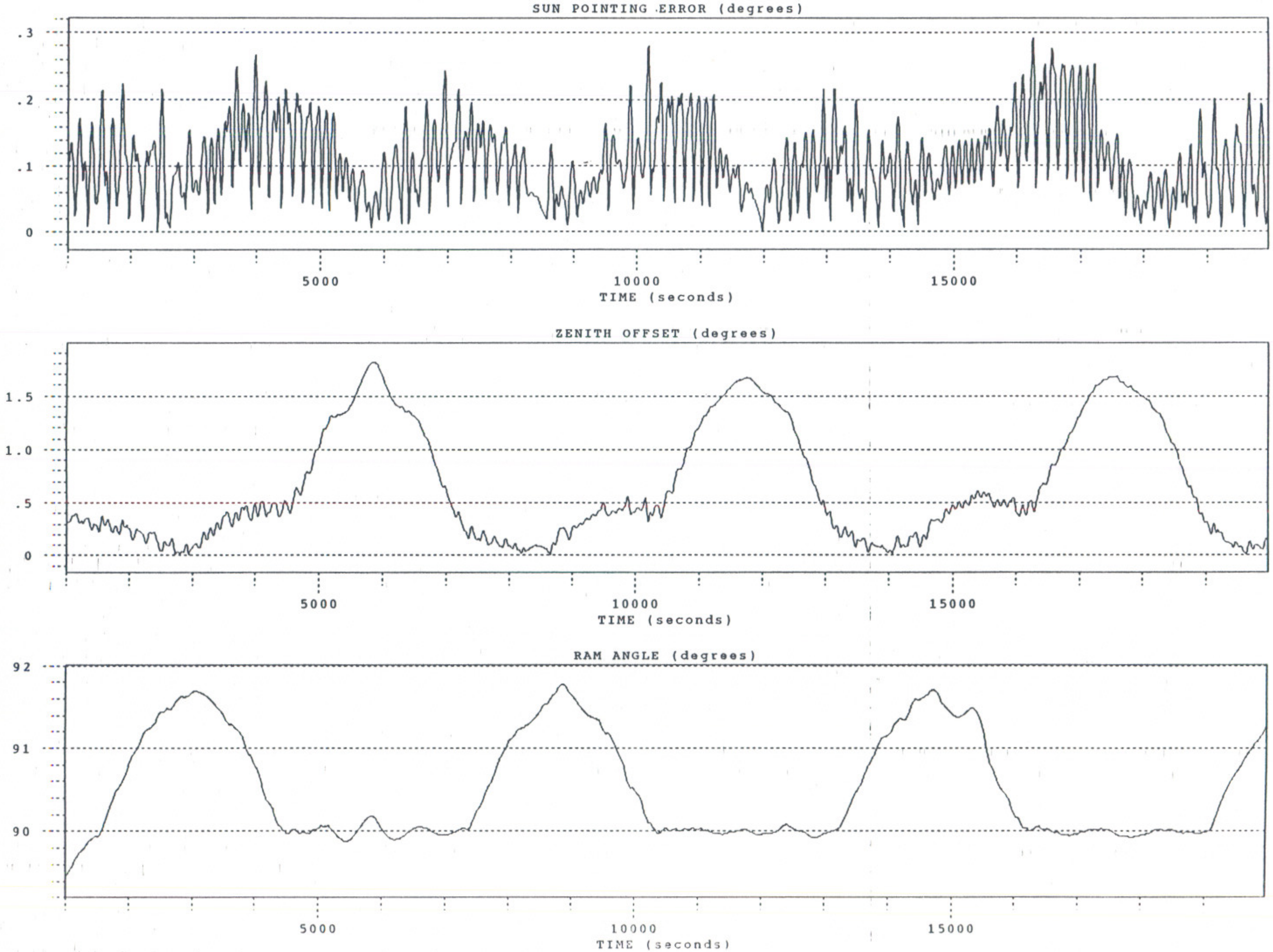
BEST CASE -- 6 PM ORBIT -- 9-1-93 -- ORR MODE -- NO VELOCITY AVOIDANCE



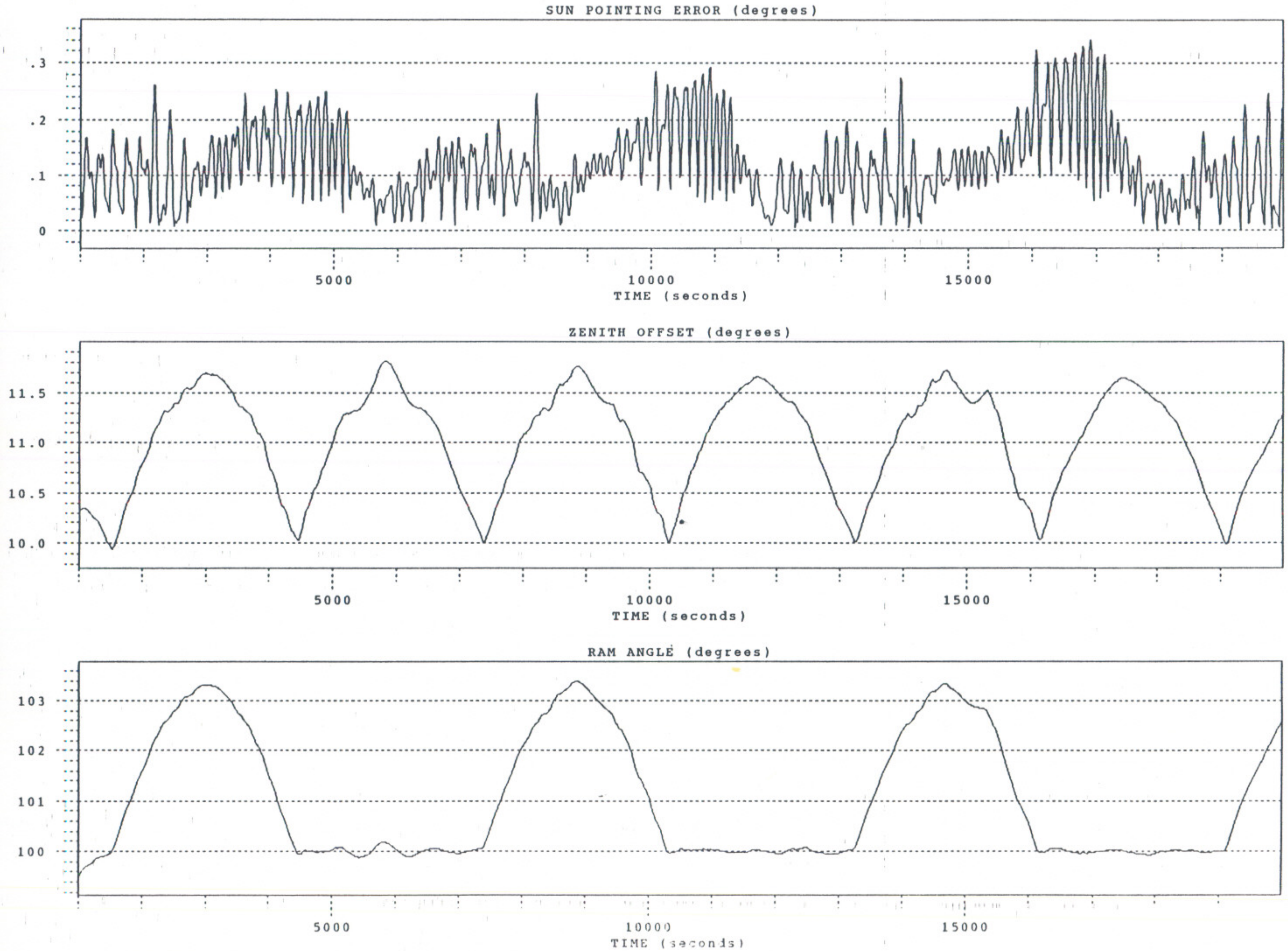
BEST CASE -- 6 PM ORBIT -- 9-1-93 -- ORR MODE -- RAM = 80 DEG



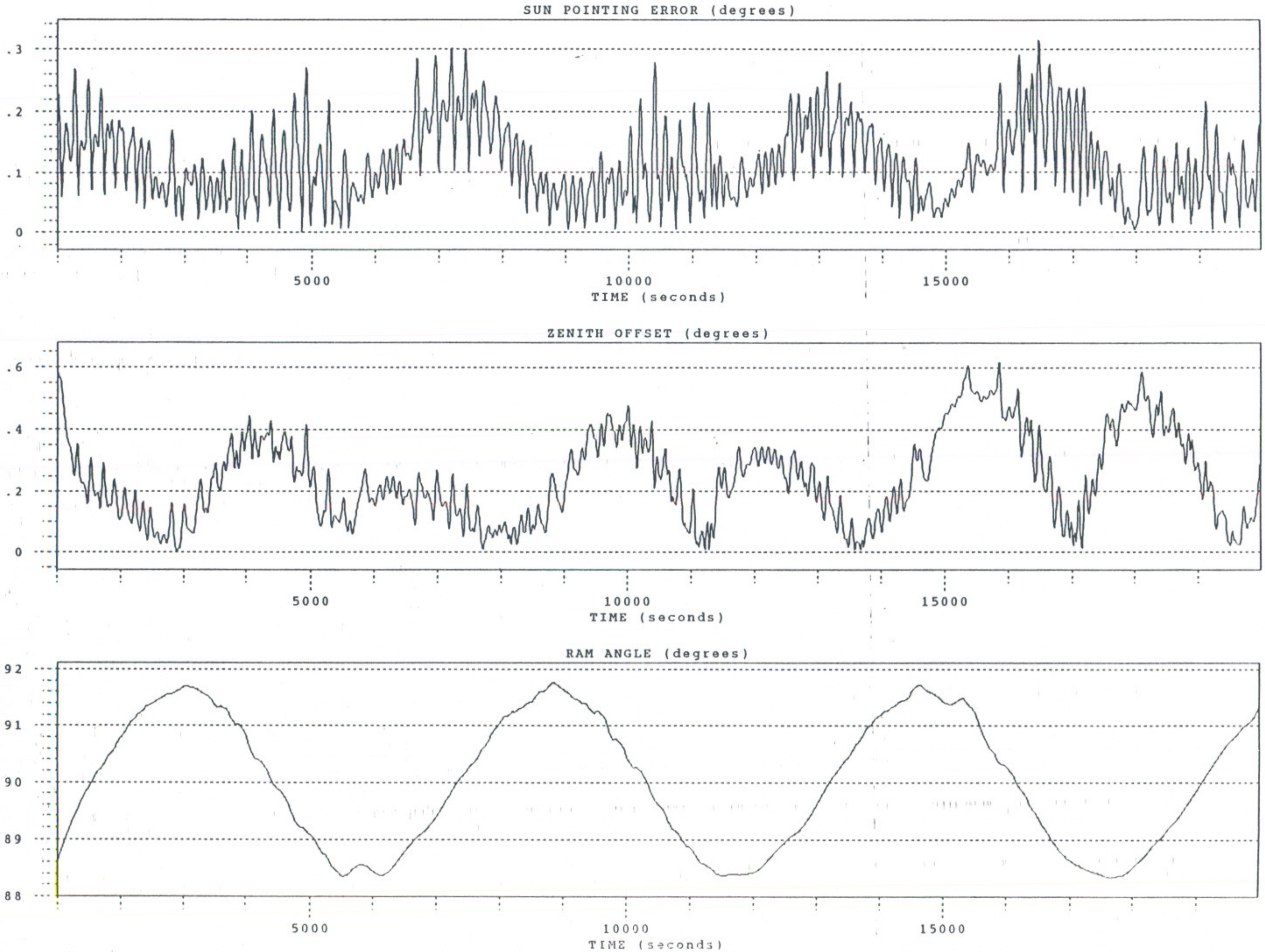
BEST CASE -- 6 PM ORBIT -- 9-1-93 -- ORR MODE -- RAM = 90 DEG



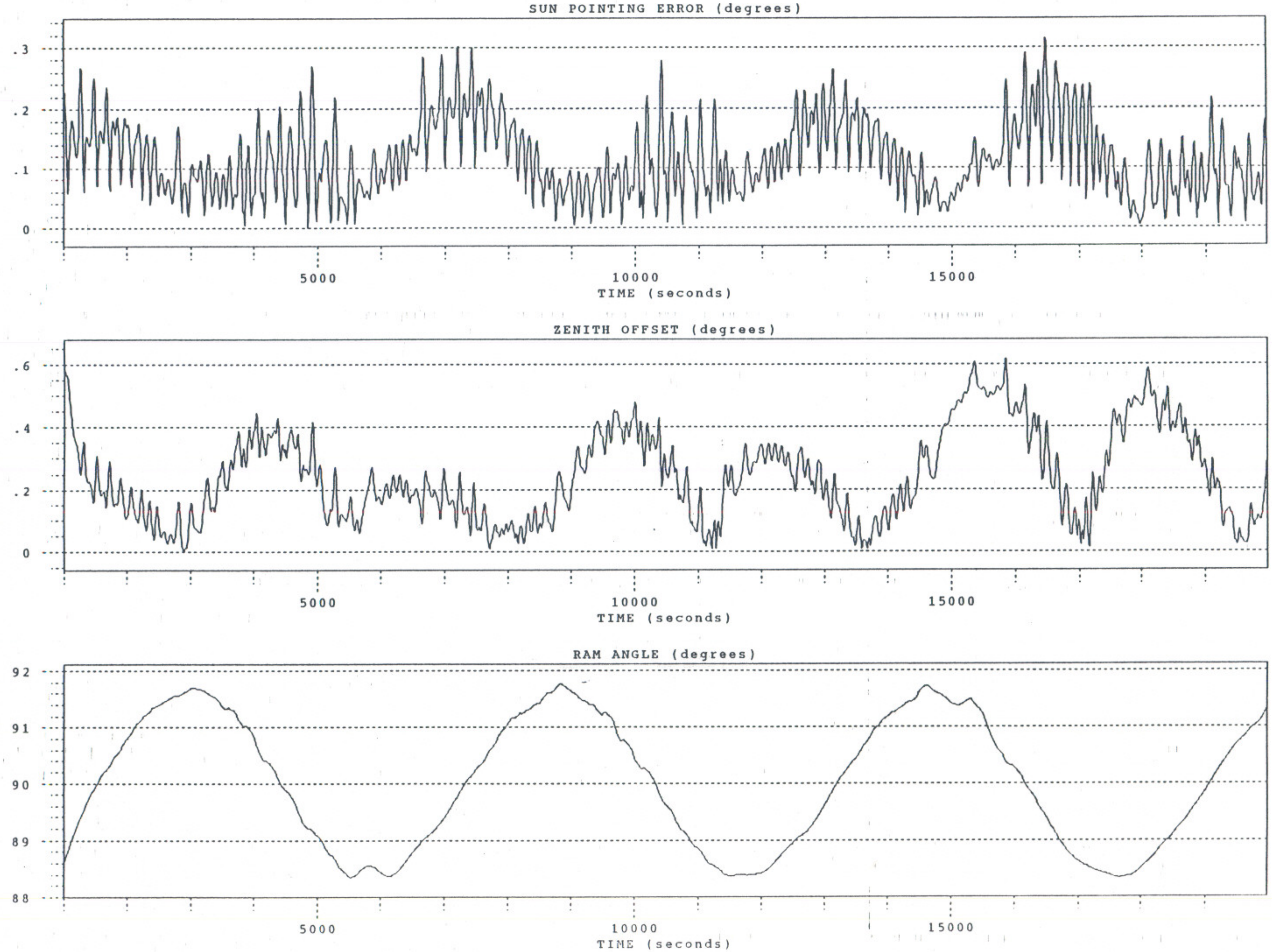
BEST CASE -- 6 PM ORBIT -- 9-1-93 -- ORR MODE -- RAM = 100 DEG



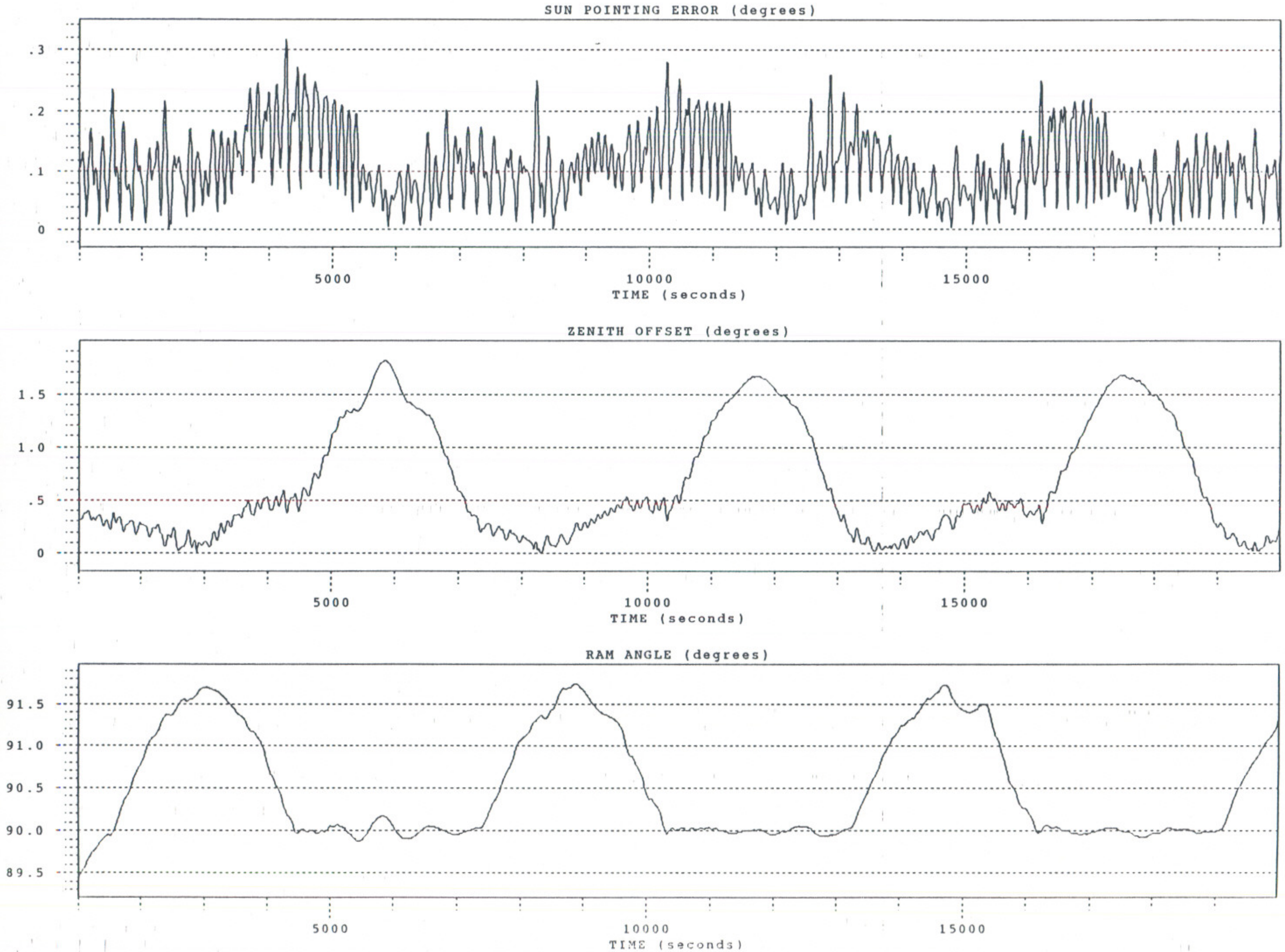
BEST CASE -- 6 PM ORBIT -- 9-1-93 -- VP MODE -- NO VELOCITY AVOIDANCE



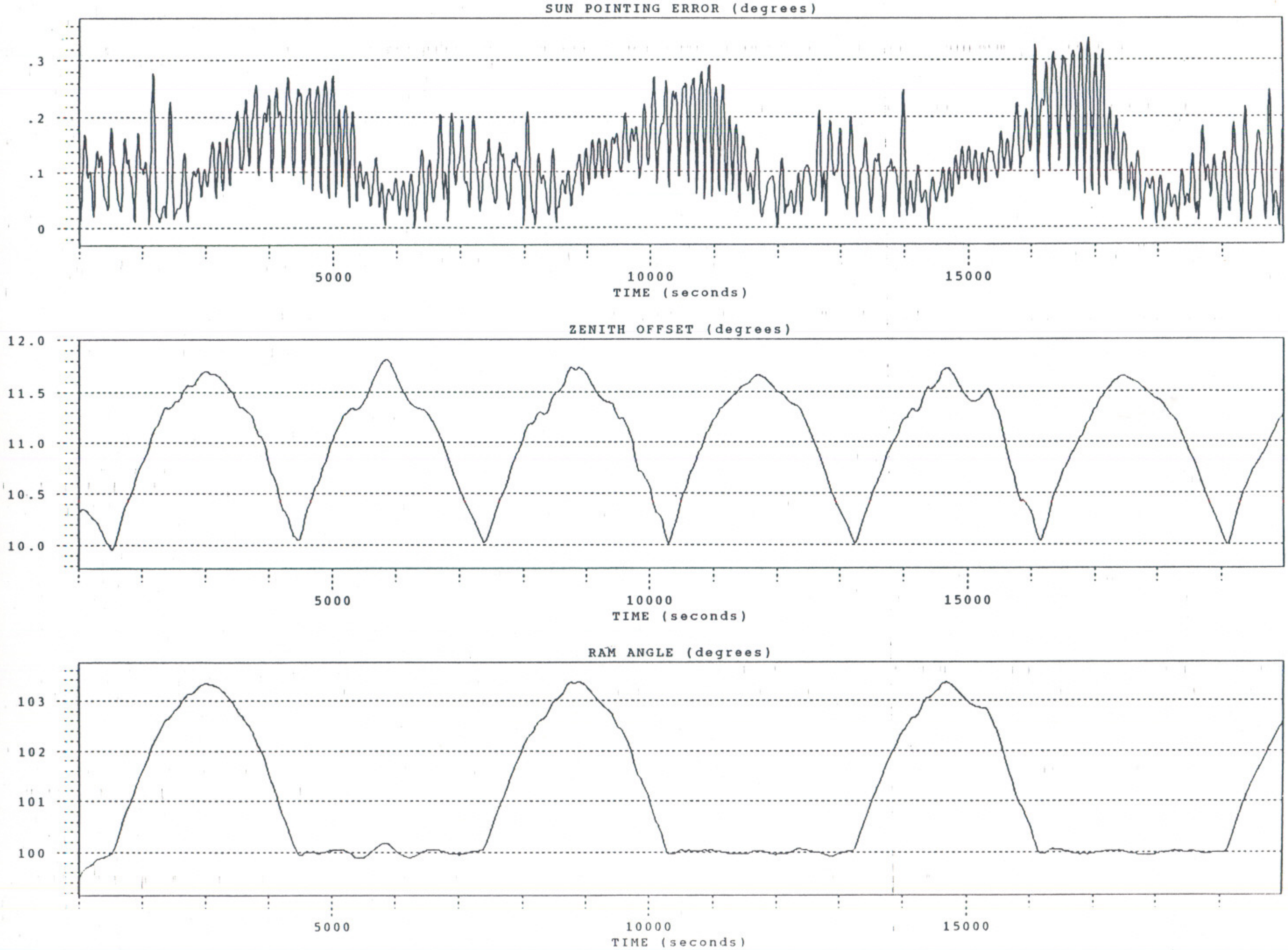
BEST CASE -- 6 PM ORBIT -- 9-1-93 -- VP MODE -- RAM = 80 DEG



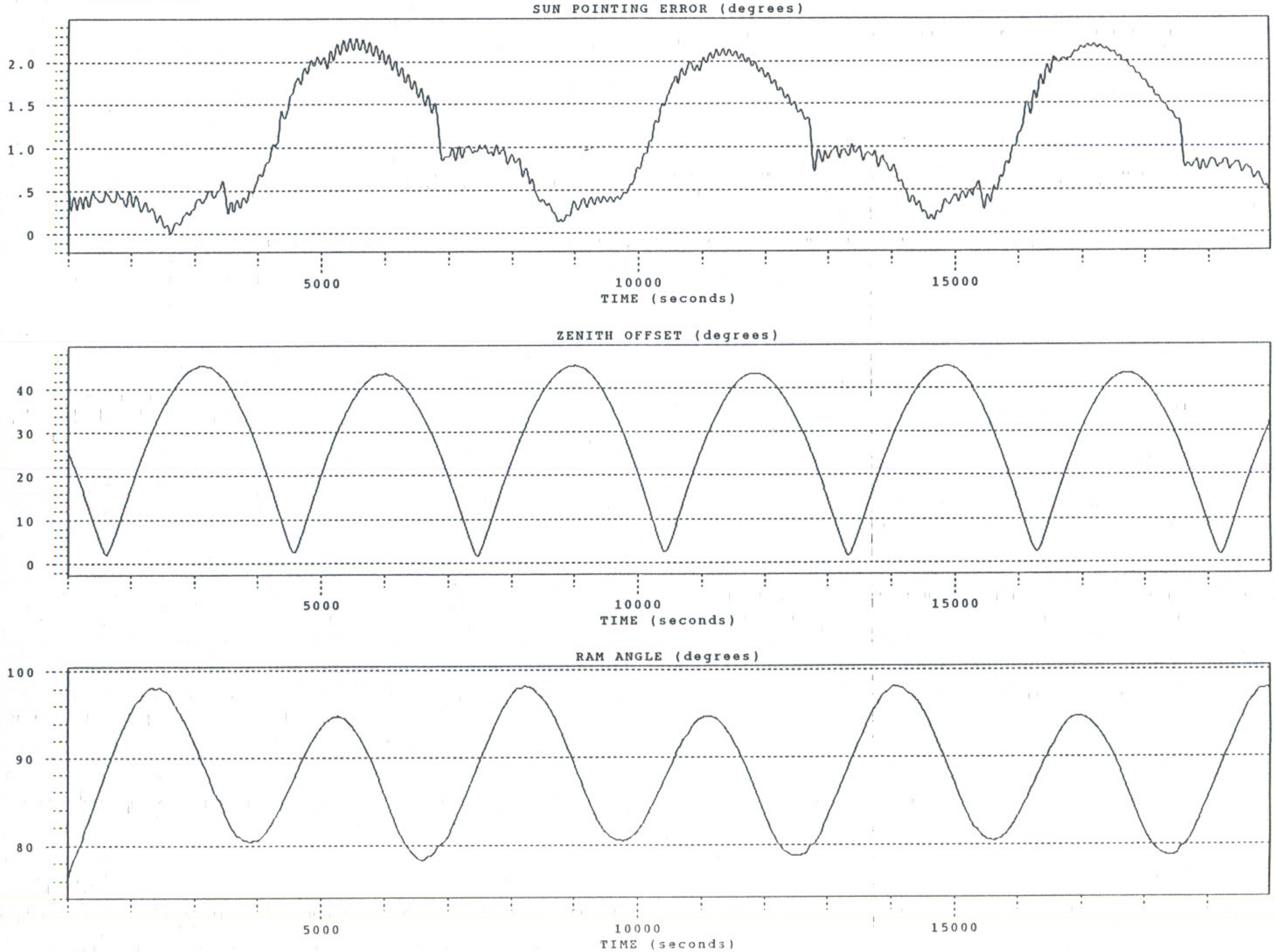
BEST CASE -- 6 PM ORBIT -- 9-1-93 -- VP MODE -- RAM = 90 DEG



BEST CASE -- 6 PM ORBIT -- 9-1-93 -- VP MODE -- RAM = 100 DEG

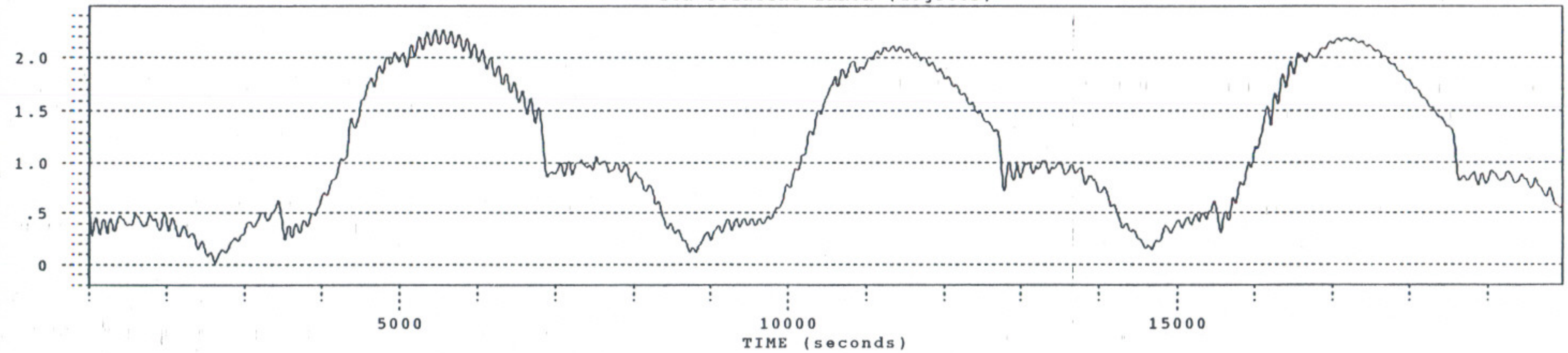


INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- ORR MODE -- NO VELOCITY AVOIDANCE

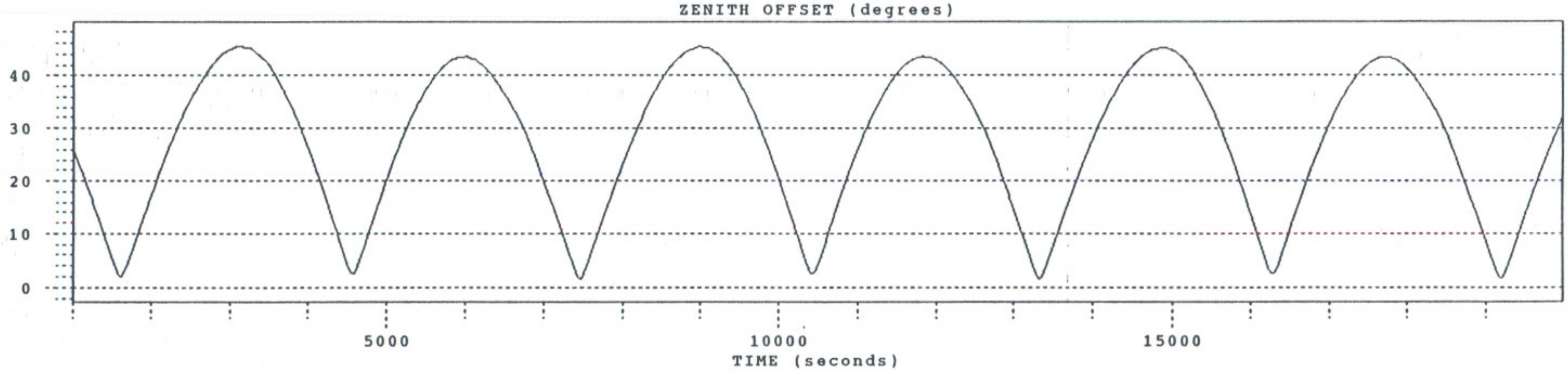


INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- ORR MODE -- RAM = 80 DEG

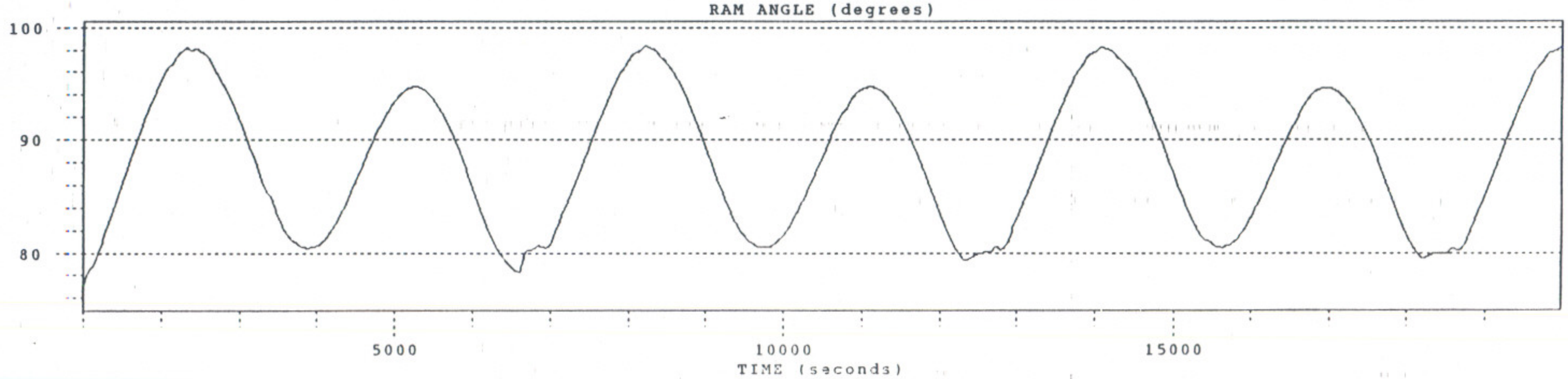
SUN POINTING ERROR (degrees)



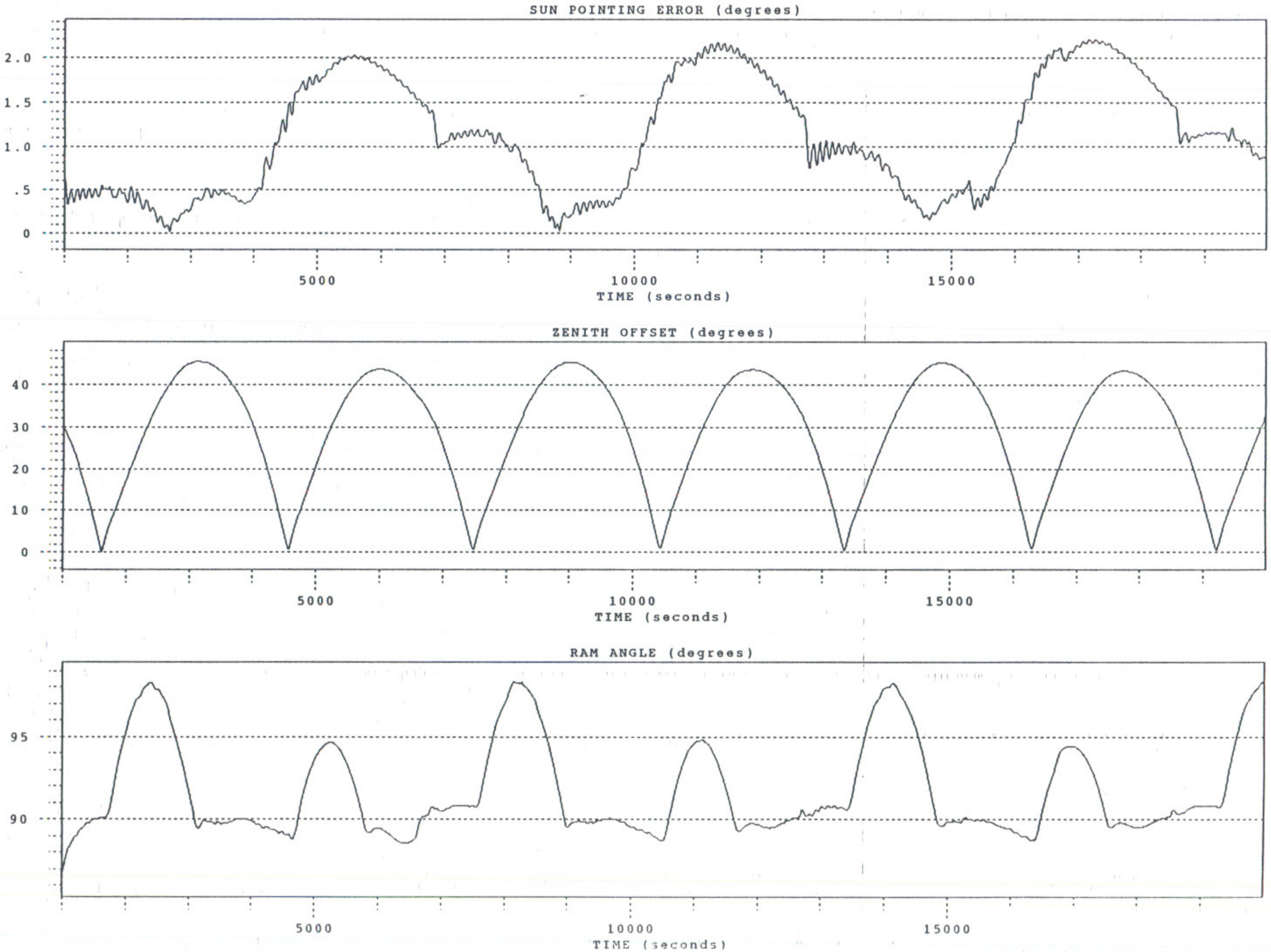
ZENITH OFFSET (degrees)



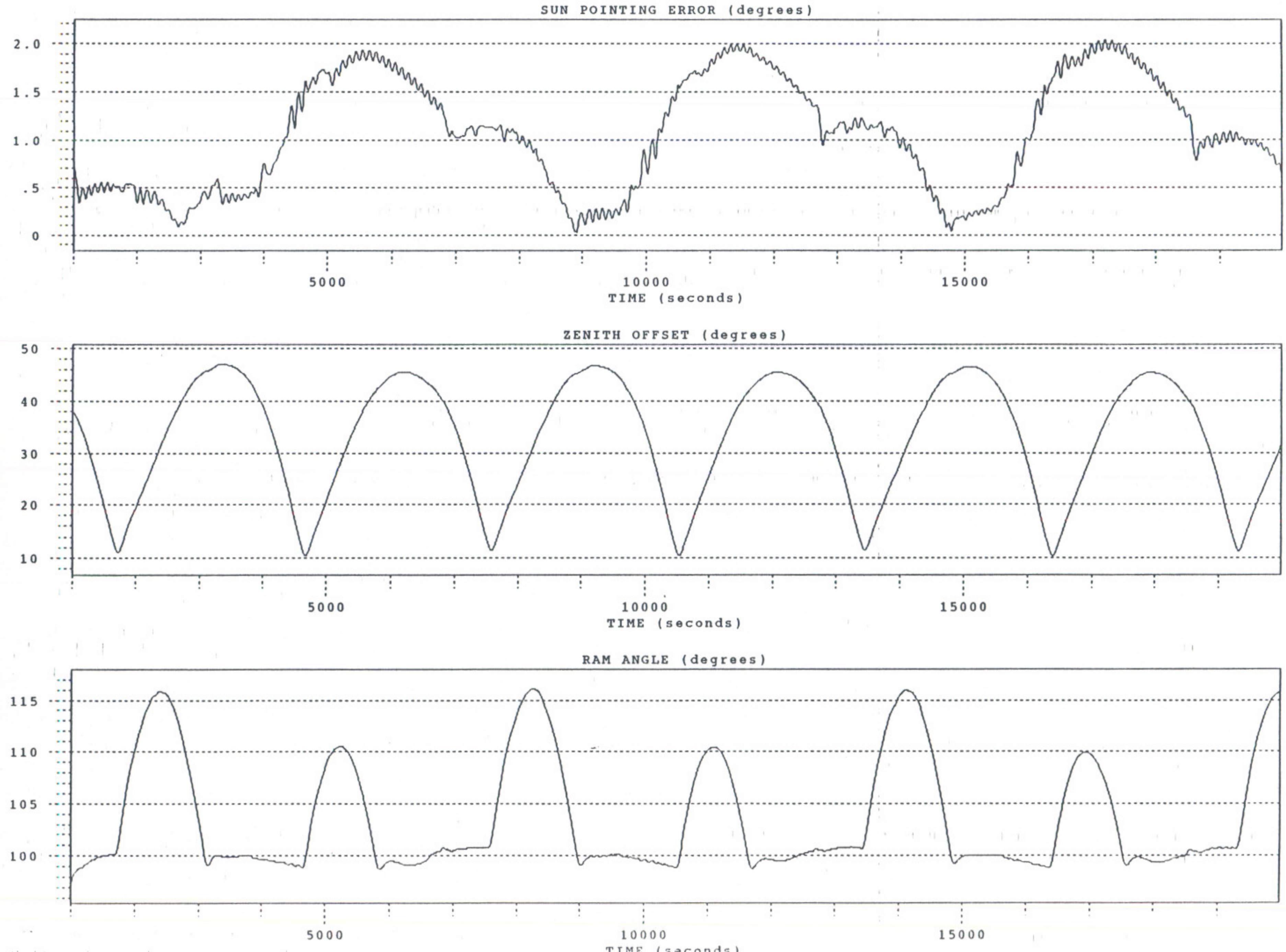
RAM ANGLE (degrees)



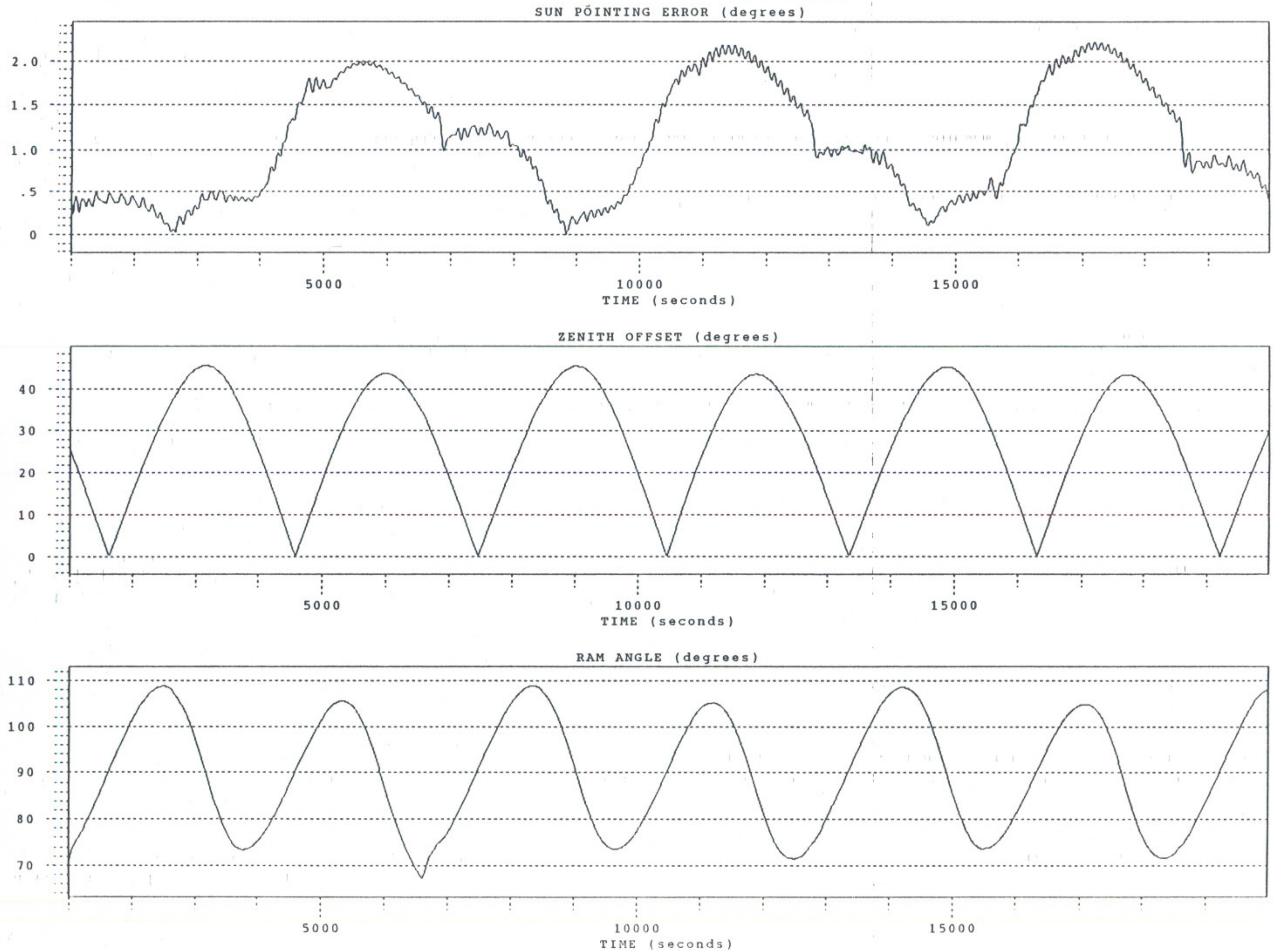
INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- ORR MODE -- RAM = 90 DEG



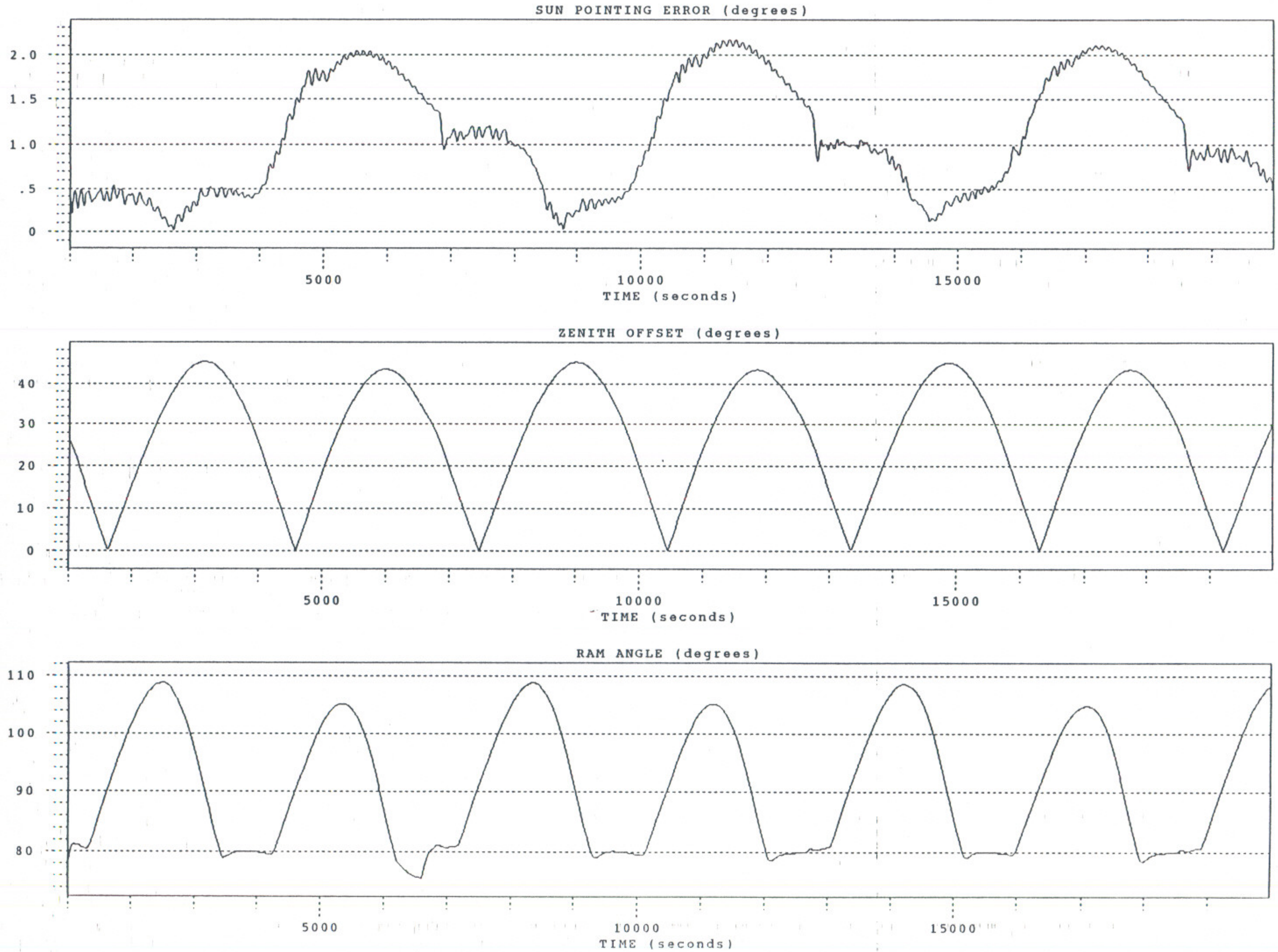
INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- ORR MODE -- RAM = 100 DEG



INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- VP MODE -- NO VELOCITY AVOIDANCE

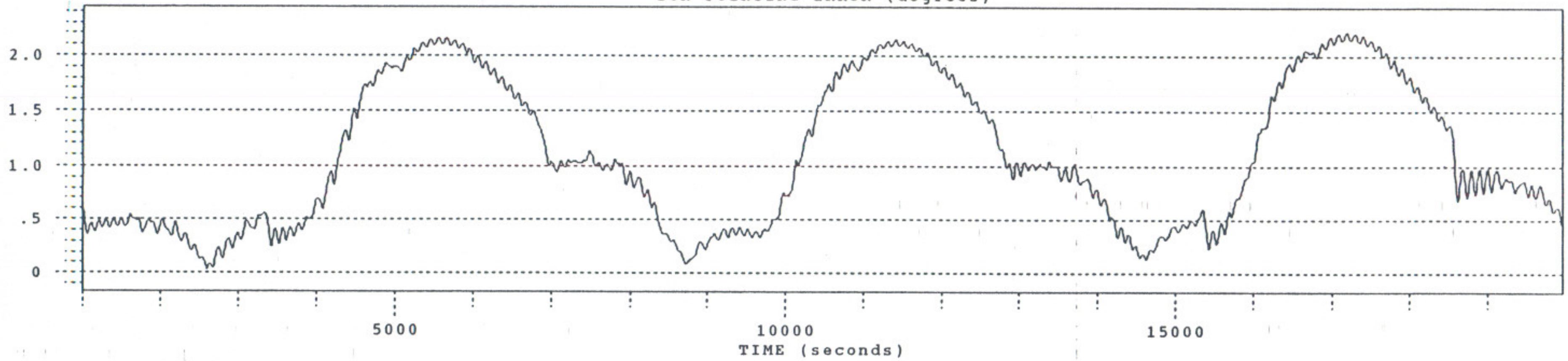


INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- VP MODE -- RAM = 80 DEG

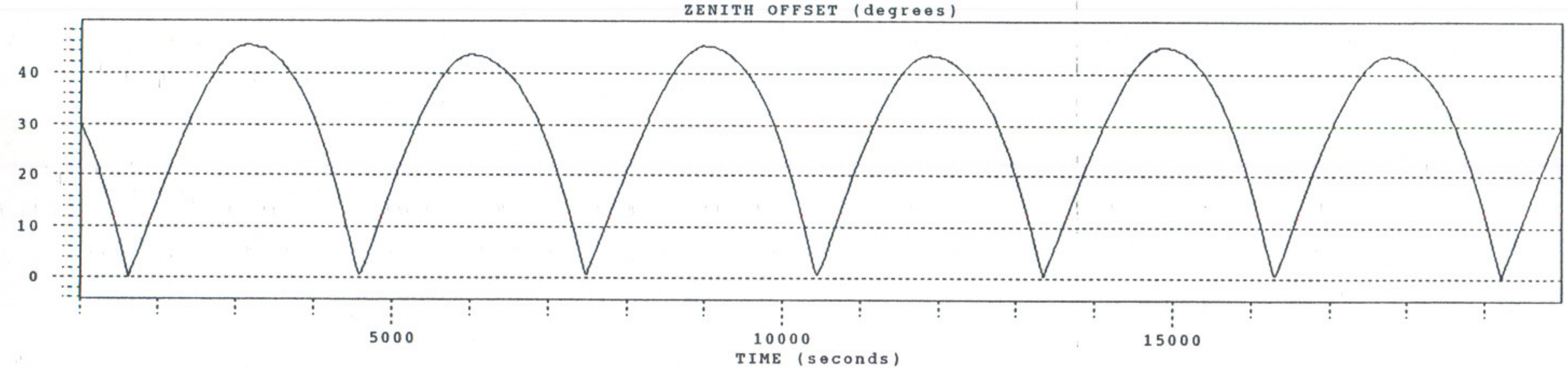


INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- VP MODE -- RAM = 90 DEG

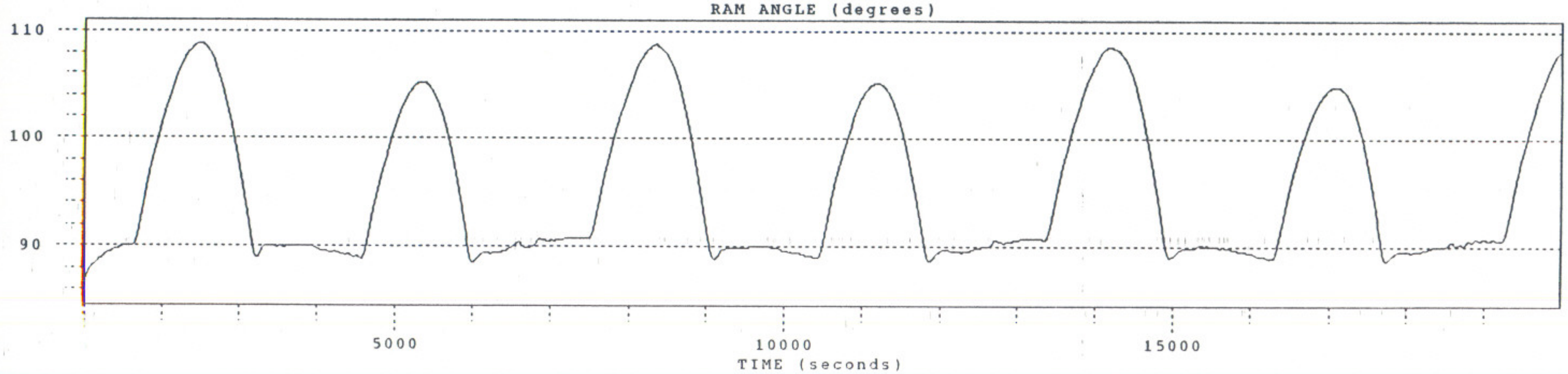
SUN POINTING ERROR (degrees)



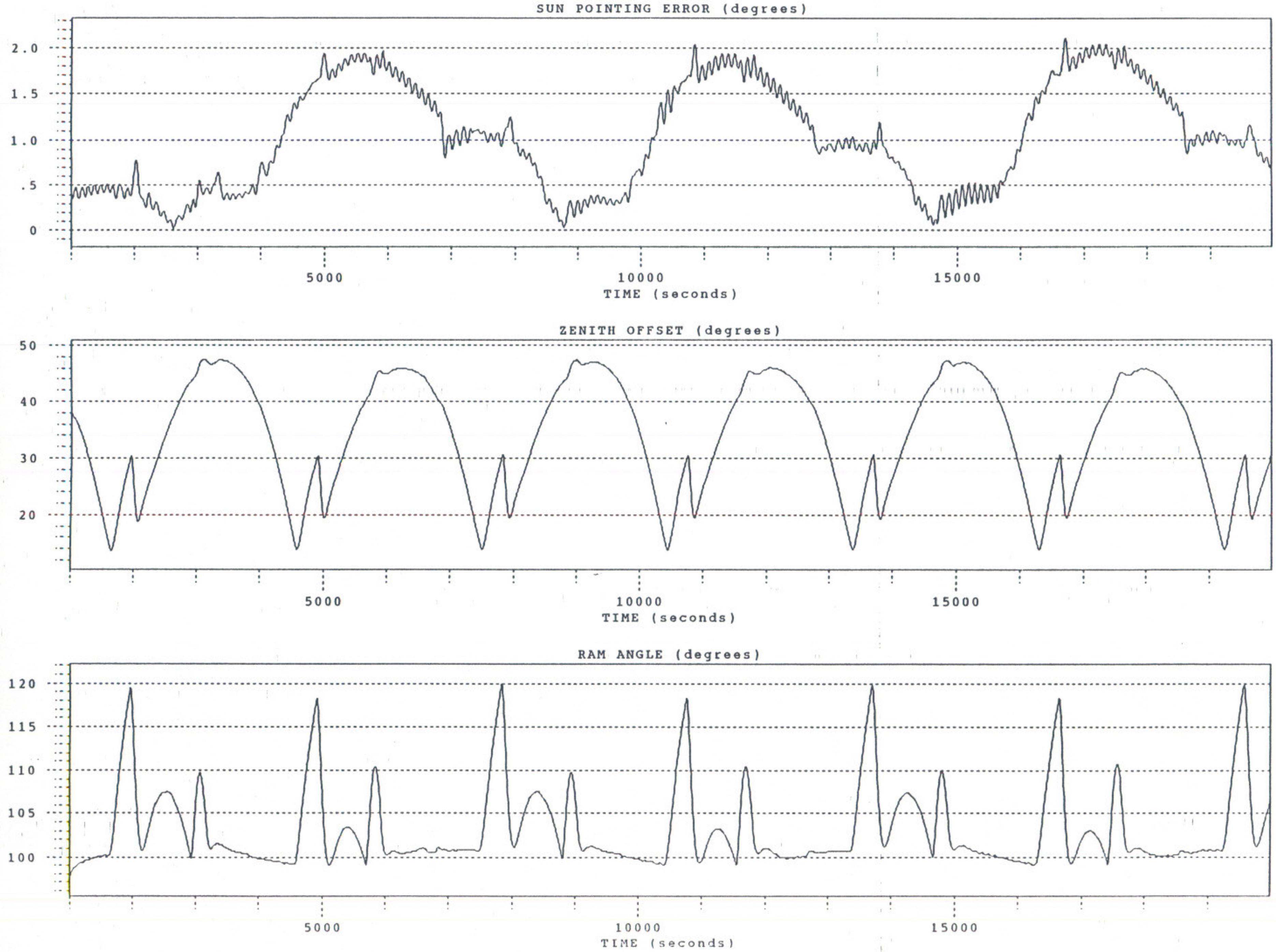
ZENITH OFFSET (degrees)



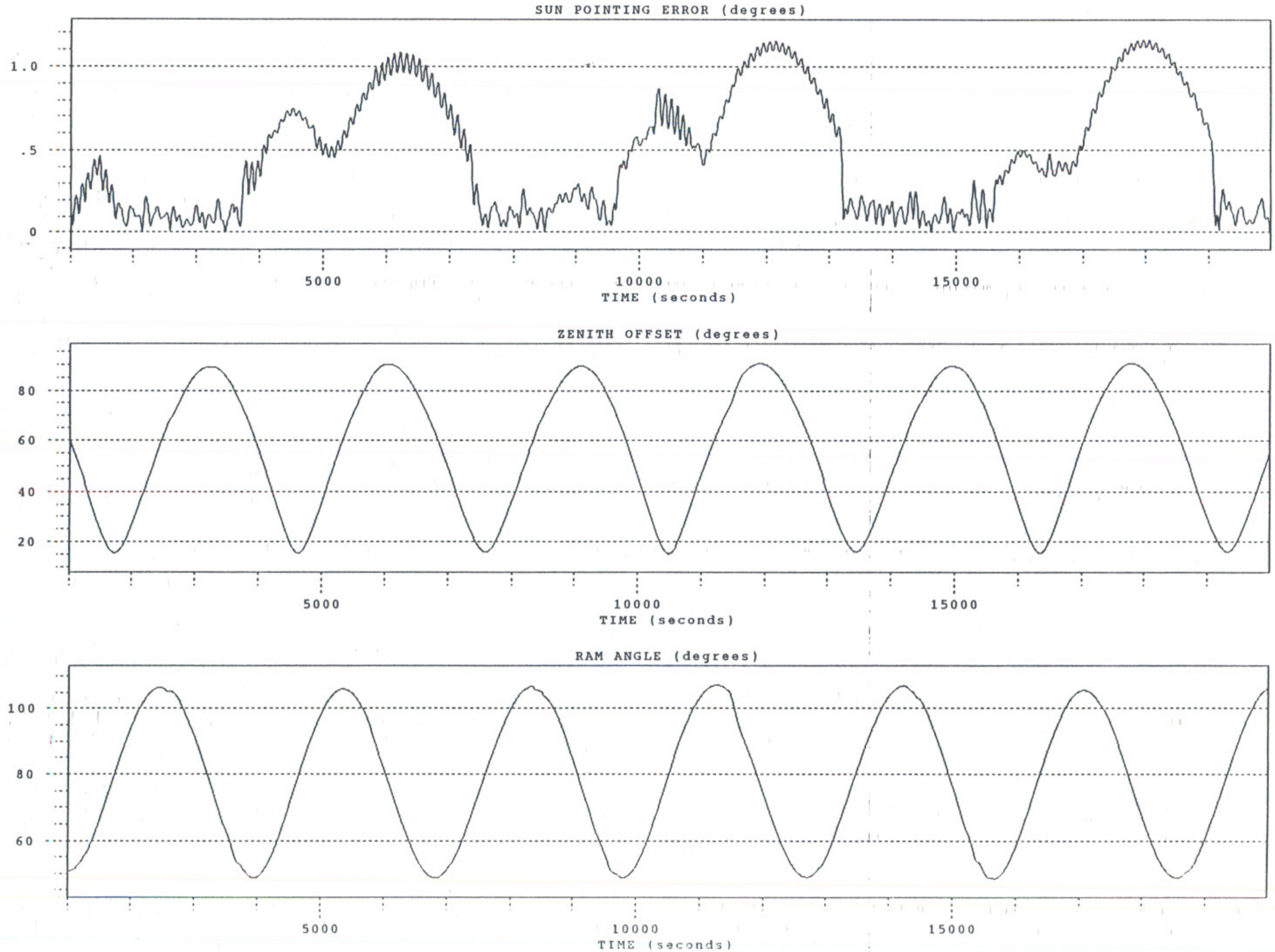
RAM ANGLE (degrees)



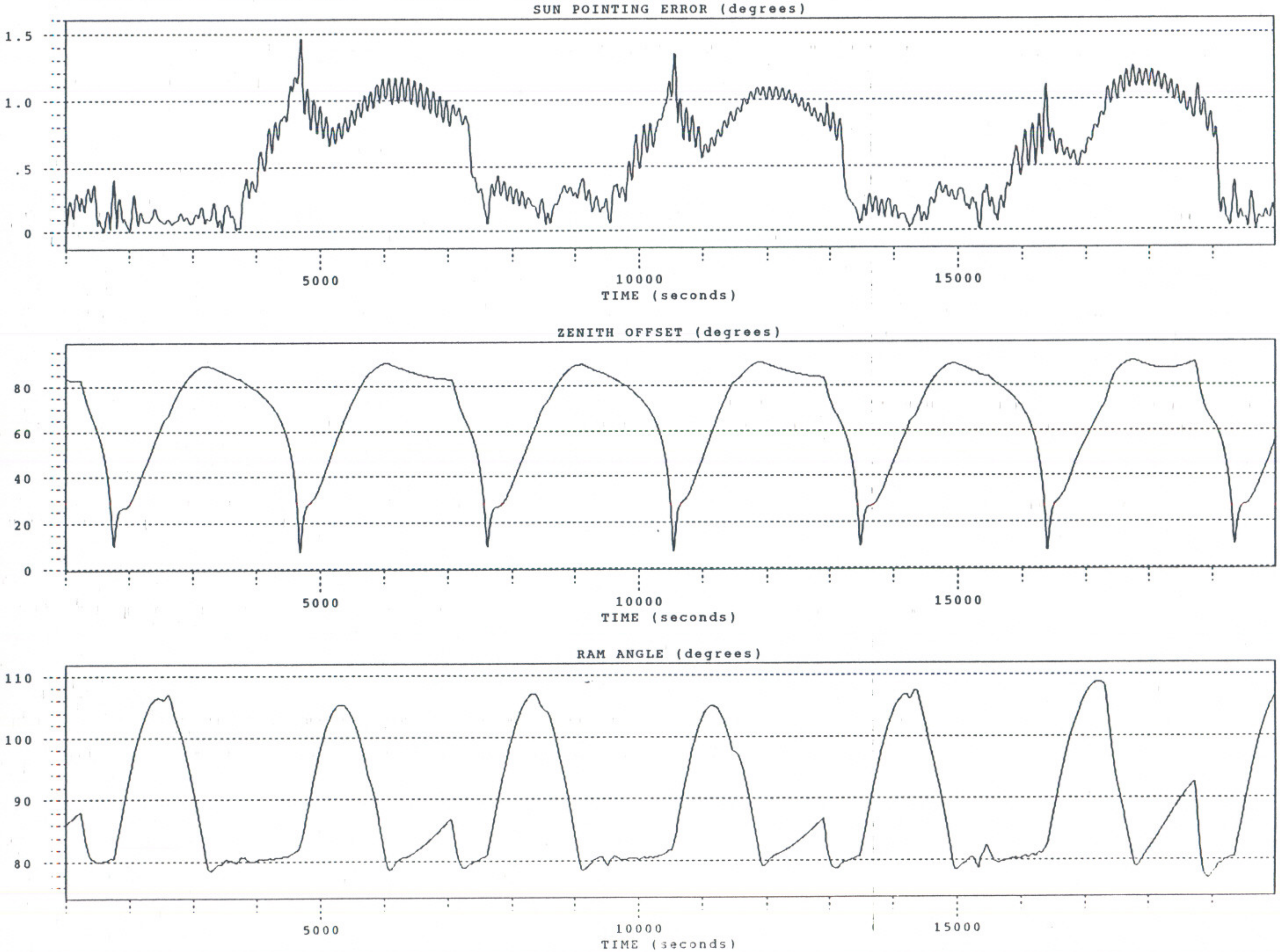
INTERMEDIATE CASE -- 9 PM ORBIT -- 9-21-93 -- VP MODE -- RAM = 100 DEG



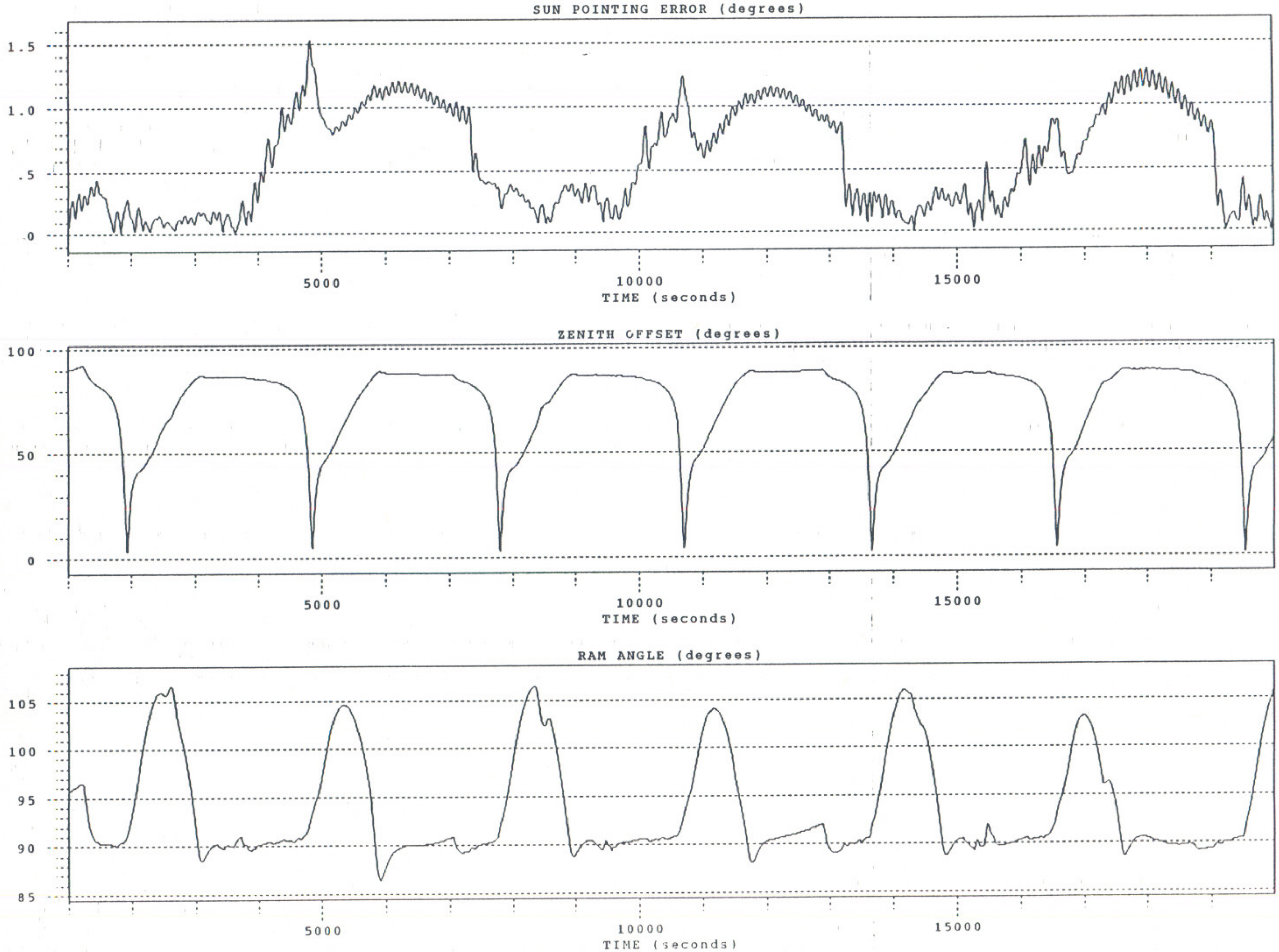
WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- ORR MODE -- NO VELOCITY AVOIDANCE



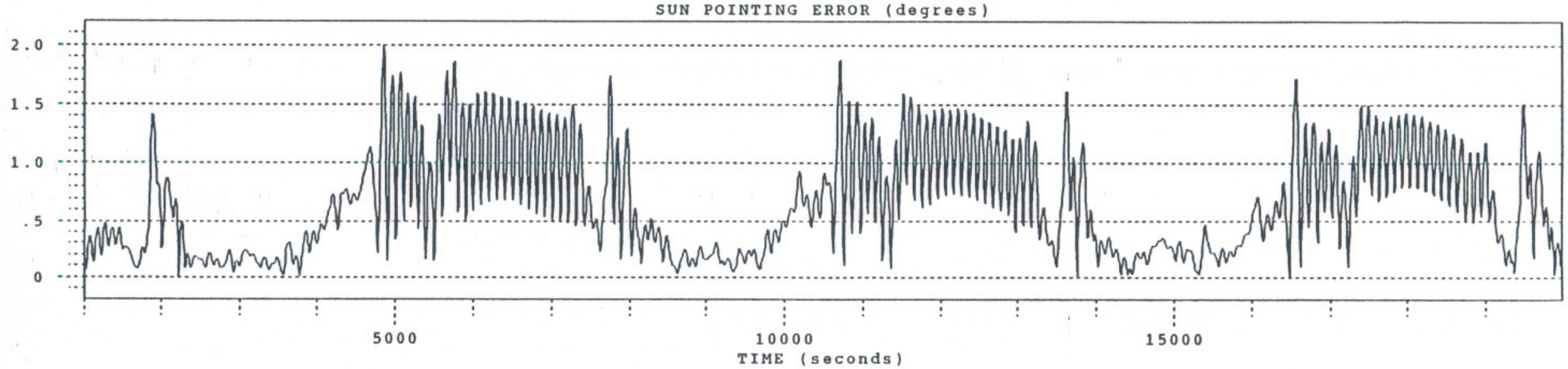
WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- ORR MODE -- RAM = 80 DEG

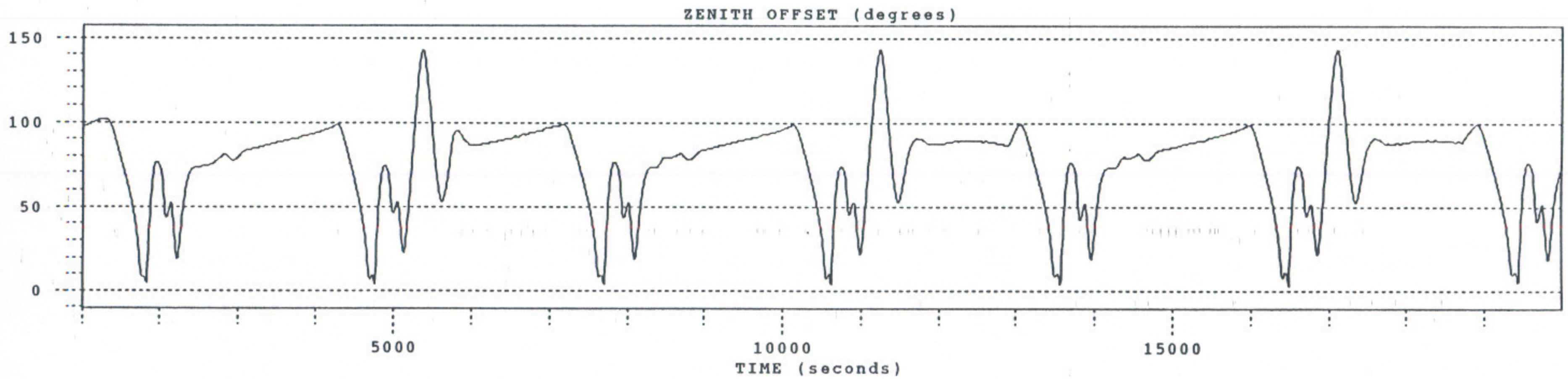


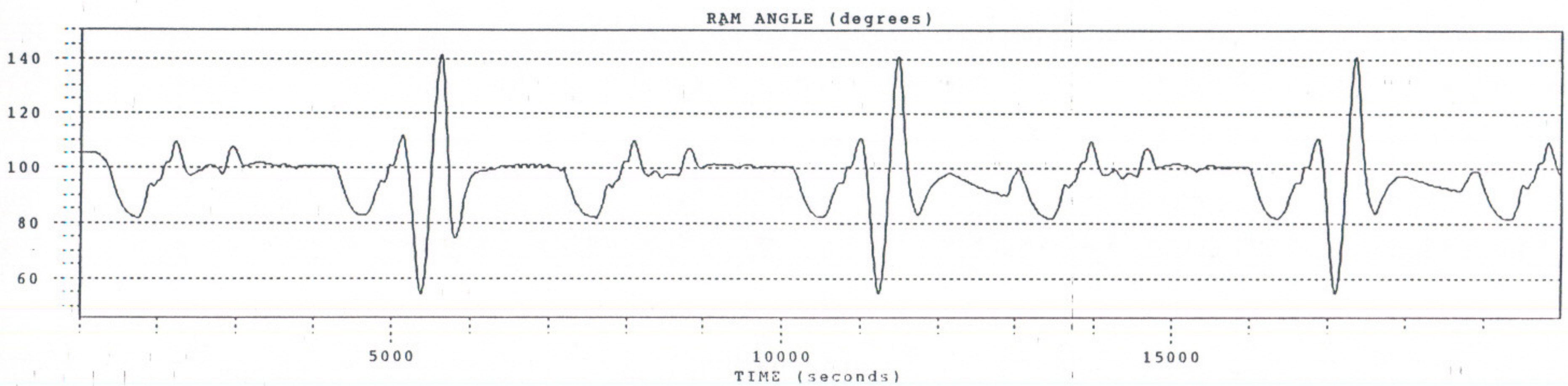
WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- ORR MODE -- RAM = 90 DEG



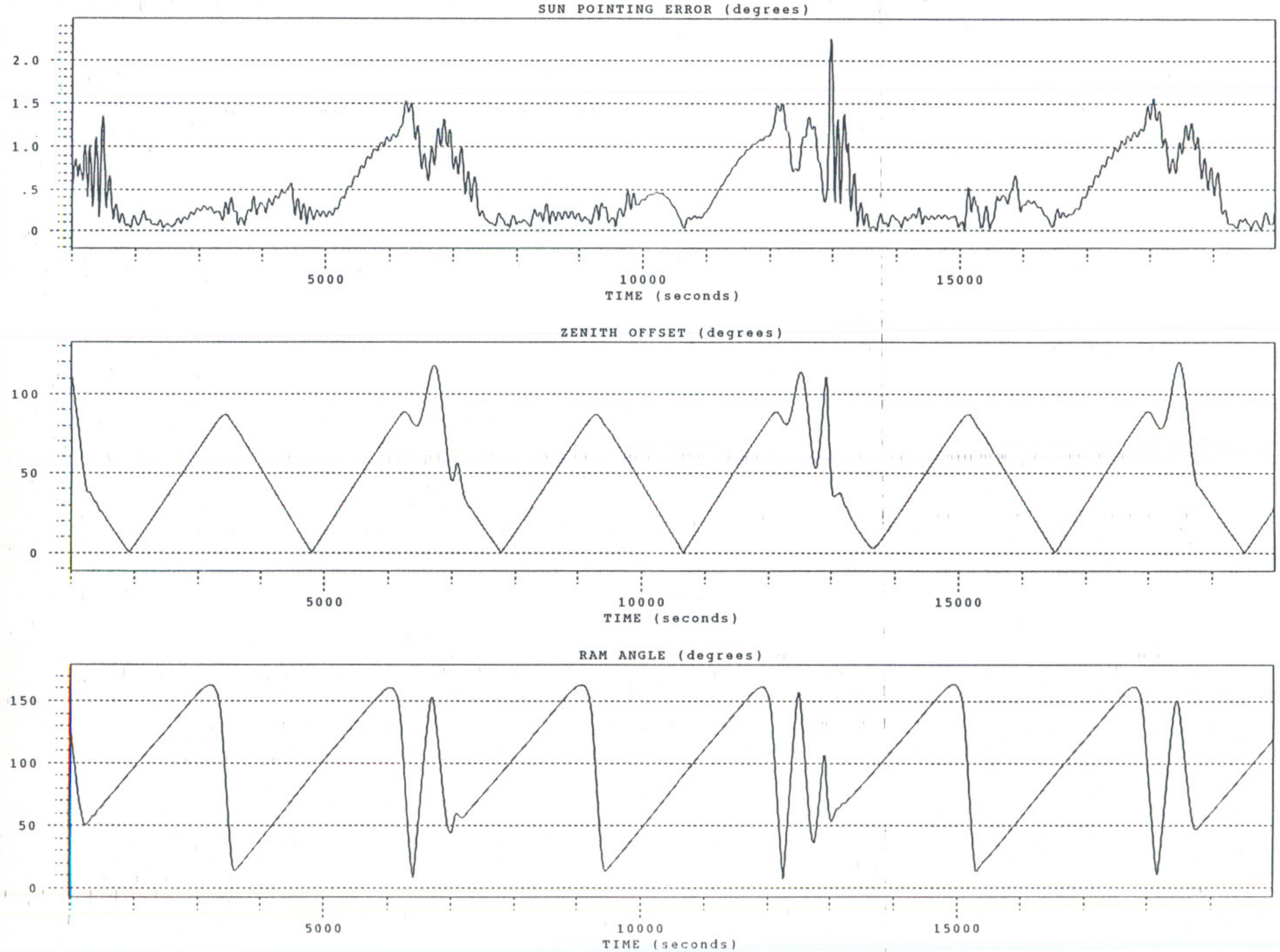
WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- ORR MODE -- RAM = 100 DEG



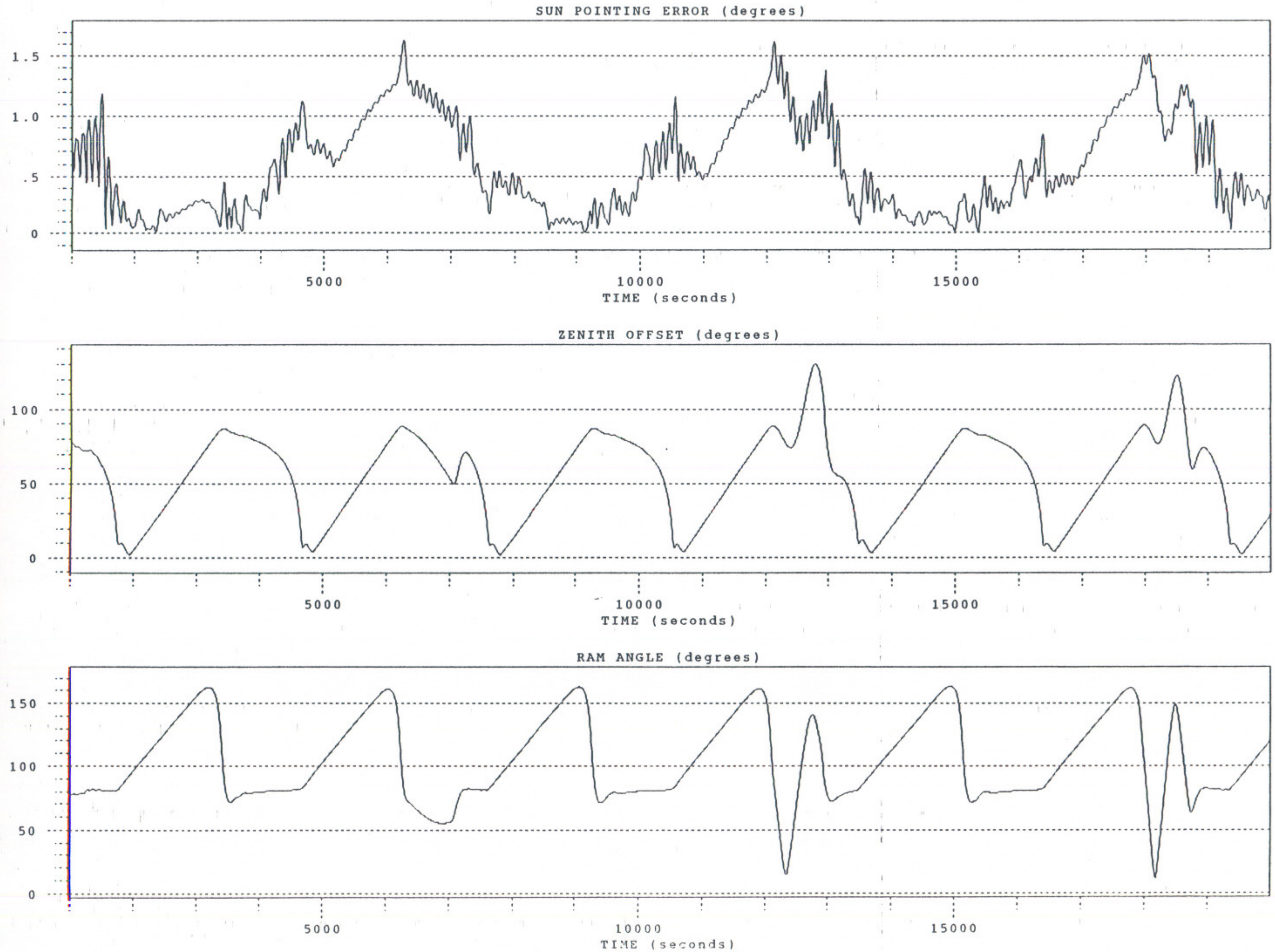




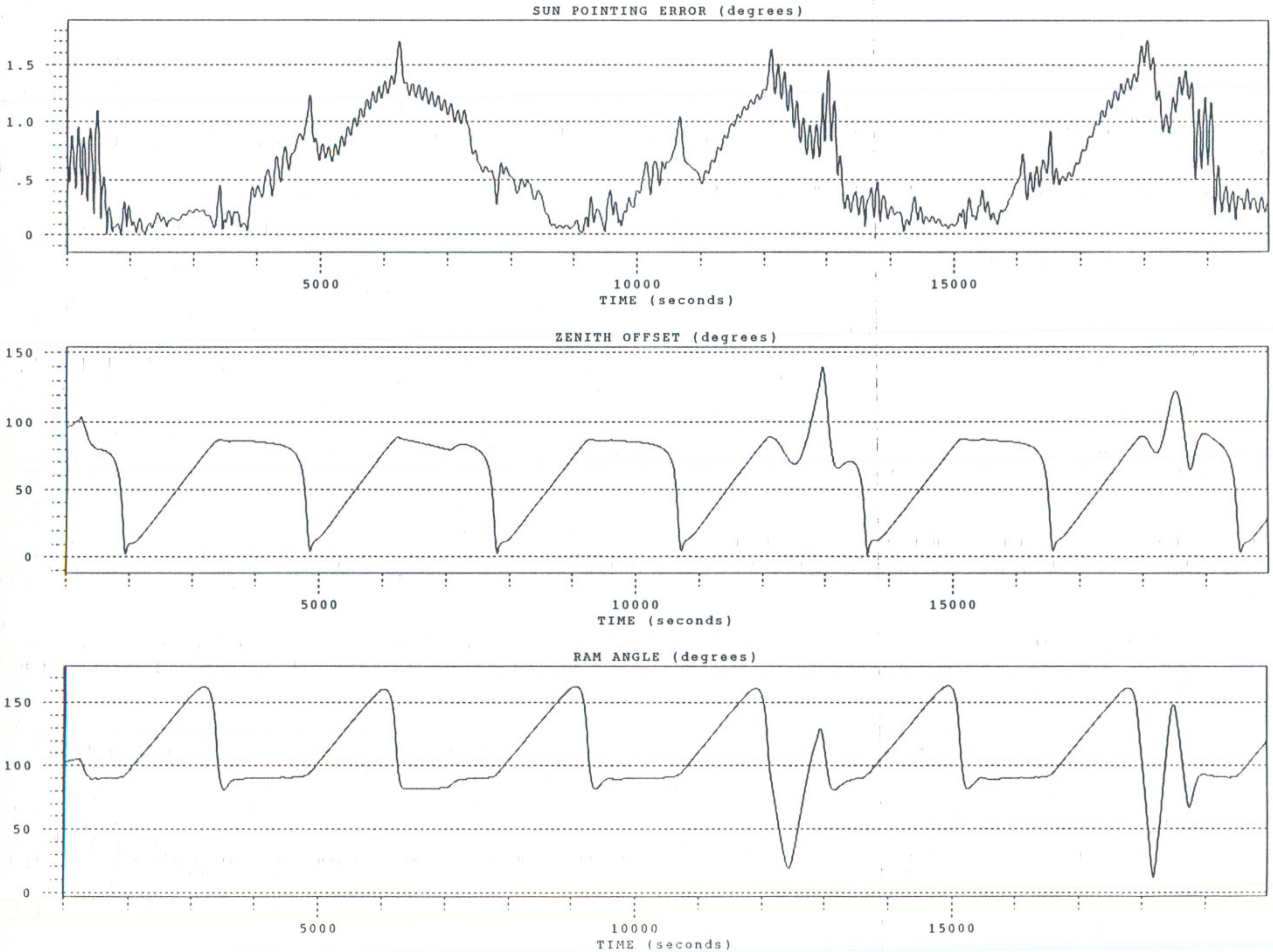
WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- VP MODE -- NO VELOCITY AVOIDANCE



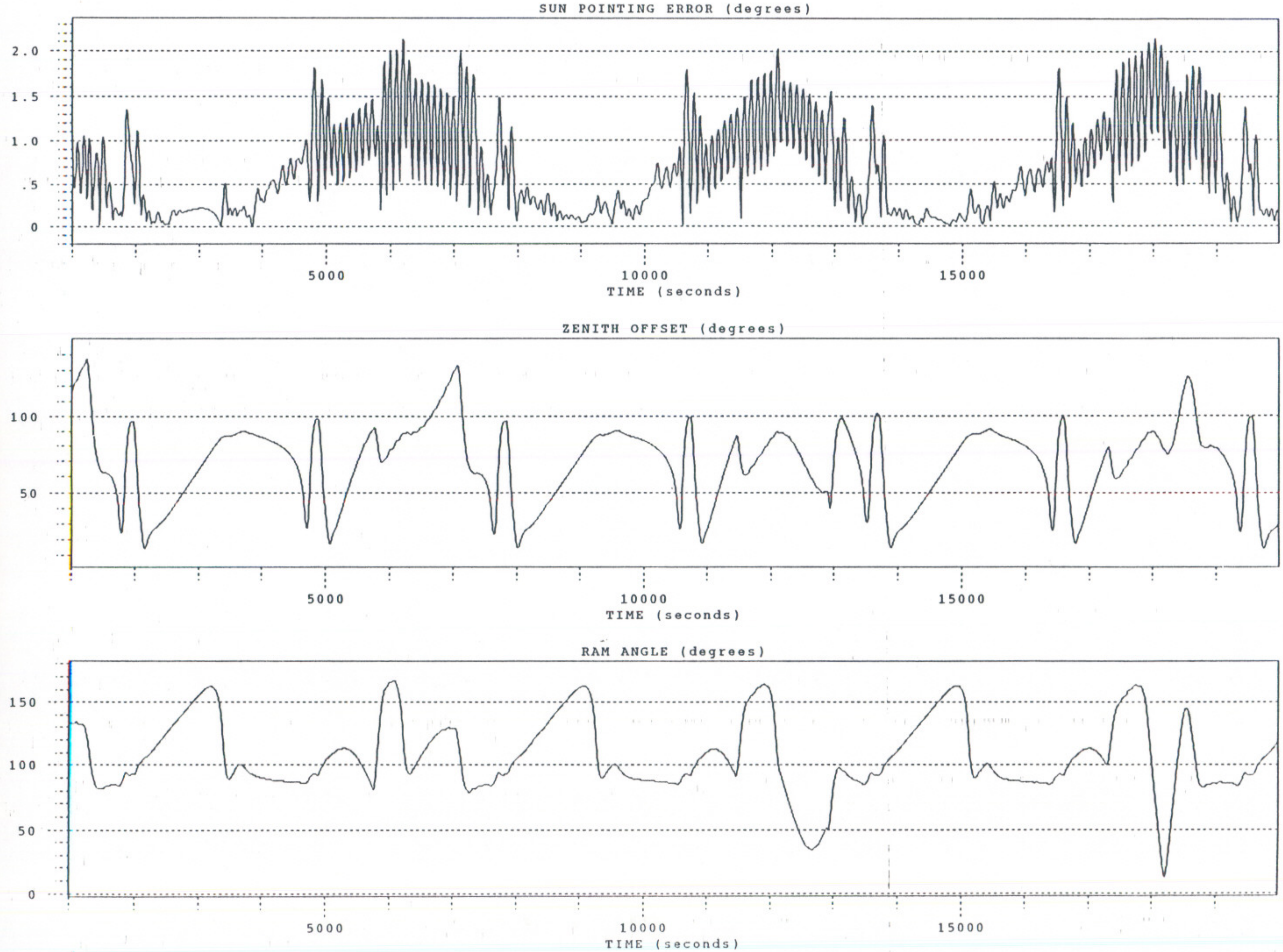
WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- VP MODE -- RAM = 80 DEG



WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- VP MODE -- RAM = 90 DEG



WORST CASE -- MIDNIGHT ORBIT -- 12-21-93 -- VP MODE -- RAM = 100 DEG



Orbit Rate Rotation Mode

	6 PM			9 PM			Midnight		
	9/1/93			9/21/93			12/21/93		
	5°	15°	30°	5°	15°	30°	5°	15°	30°
No Avoidance	100.0	100.0	100.0	20.8	68.9	100.0	0.0	0.0	61.2
80 deg RAM	100.0	100.0	100.0	20.8	68.9	100.0	0.0	4.9	30.2
90 deg RAM	100.0	100.0	100.0	17.0	59.3	98.9	1.3	4.7	10.2
100 deg RAM	0.0	100.0	100.0	0.0	27.0	73.4	1.2	11.2	15.7

performance when S/C within 30° of either pole.

Vertical Pointing Mode

	6 PM			9 PM			Midnight		
	9/1/93			9/21/93			12/21/93		
	5°	15°	30°	5°	15°	30°	5°	15°	30°
No Avoidance	100.0	100.0	100.0	24.7	73.4	100.0	16.7	35.5	60.3
80 deg RAM	100.0	100.0	100.0	24.6	73.2	100.0	9.2	27.3	31.1
90 deg RAM	100.0	100.0	100.0	21.0	62.6	98.9	2.3	8.9	11.2
100 deg RAM	0.0	100.0	100.0	0.0	7.8	71.4	0.0	0.0	4.3

Section 5.0 Orbital Debris/Micrometeoroid Hazard
Section 5.1 JSC (GSFC/EnviroNET) Orbital Debris Model

Man-made orbiting objects are now more hazardous to most spacecraft in LEO than the meteoroid environment. Within 2000 kilometers of the Earth's surface, there are 3,000,000 kilograms of orbital debris [2]. Orbital debris consists of fragments from explosions, solid rocket effluent, paint flecks, waste, refuse, etc. There are 6,645 orbiting objects currently being tracked which comprise 99.9% of the total mass of all orbiting objects. However, untrackable orbiting pieces (diameter less than 10 cm) number in the millions and are potentially catastrophic or at the least mission degrading [3]. These pieces are almost all in high inclination circular orbits with velocities on the order of 10 km/sec.

The EnviroNET [4] orbital debris model was used to calculate fluxes for the SAMPEX mission. EnviroNET is a computer database containing information on the near Earth space environment. The assumptions and equations used in computing the fluxes can be found in Kessler, et. al., [2]. The models have been developed from returned surfaces such as LDEF and Solar Max, optical observations, and radar.

The EnviroNET orbital debris model requires seven input parameters. The first, debris diameter, is the smallest particle of concern to the user. This will be discussed later. The others are orbital altitude, inclination, growth rate, year, solar flux, and attitude. Since this model assumes circular orbits and SAMPEX is in a 450 X 850 km elliptical orbit, an 800 km circular orbit was chosen since the flux values are at a maximum at this altitude. The inclination is 82 degrees and the year chosen is 1992. The growth rate is chosen to be 5 percent per year and the default value was used for the solar flux. The "attitude" is the RAM angle.

The smallest particle of concern for the HILT sensor is 0.01 cm. This has been determined by Klecker [5]. The HILT proportional counter has a triple entrance foil system with 80μm combined thickness. However, it has the effectiveness of a 380μm single foil for a particle velocity and density of 15 km/sec and 1 gm/cm^3, respectively. Using these results and triple foil penetration limit equations, Klecker determined the smallest particle of concern to be 0.01 cm.

The orbital debris fluxes as a function of RAM angle as calculated by the EnviroNET model are given below:

RAM Angle (degrees)	Flux ϕ_D (collisions / m^2 yr)
0	10.73331
10	10.57478
20	10.11987
30	9.40035
40	8.44768
50	7.29271
60	5.98068
70	4.69073
80	3.68148
90	2.78009
100	1.81769
110	1.01969
120	0.69139
130	0.39341
140	0.22545
150	0.10501
160	0.03385
170	0.00453
180	0

As expected, maximum flux is found in the direction of the velocity vector. Note that the flux is reduced by a factor of 3 for an 80 degree RAM angle.

Section 5.2 JSC (GSFC/EnviroNET) Meteoroid Model

Meteoroids are part of the interplanetary environment and have average velocities of 20 km/sec with respect to the Earth's orbital space. There are 200 kg of meteoroid mass within 2000 km of the Earth's surface and most of the mass is concentrated in particles of diameter .01 cm [2]. This coincides with the smallest particle of concern for the HILT sensor.

The EnviroNET meteoroid model was used to calculate fluxes for the SAMPEX mission. The assumptions and equations used can be found in Grun, et. al. , [6].

Since meteoroids are equally likely to come from any direction, the model requires only two inputs. These are smallest particle of concern to the user (0.01 cm) and altitude of a circular orbit (800 km). The meteoroid flux is

$$\Phi_M = 0.26872 \text{ collisions} / \text{m}^2 \text{ yr}.$$

Thus, orbital debris is significantly more hazardous than micrometeoroids for the SAMPEX mission.

Section 5.3 Survival Analysis

The total hazardous flux is

$$\Phi_T = \Phi_D + \Phi_M .$$

The mean time between impacts τ is given by

$$\tau = \frac{2\pi}{\Phi_T A_\Omega},$$

where $A_\Omega = 0.093 \text{ m}^2 \text{ sr}$ is the geometry factor of the HILT window. The probability of a damaging hit P_H in one year is

$$P_H \approx \frac{1}{\tau} e^{(-1/\tau)},$$

and the probability of survival P_s for the HILT sensor over a 3 year period is

$$P_S \approx e^{(-3/\tau)} .$$

The probability of survival for the HILT sensor is computed for vertical pointing and orbit rate rotation with and without the velocity avoidance scheme. The orbital debris fluxes were time averaged over 16 different orbits. These orbits represented a sample of the different types of geometry (e.g., Sun perpendicular to the orbit plane, Sun parallel to the orbit plane, Sun 45 degrees to the orbit plane) and different dates throughout the year (e.g., Summer/Winter Solstice, Autumnal/Vernal Equinox, etc.). The orbits are

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Ascending Node	Date
3 PM	3/22/92
6 PM	6/22/92
9 PM	9/22/92
12 PM	12/22/92

The mean flux for each mode is computed as the average of the 16 time averaged fluxes. The results are tabulated below.

Mode	Mean Flux (coll/m^2 yr)	τ (yrs/coll)	P_S (%)
ORR	3.11485	21.690	87.1
ORR w/ 80° RAM	2.92332	23.111	87.8
ORR w/ 90° RAM	2.68487	25.164	88.8
ORR w/100° RAM	1.90232	35.515	91.9 ← causes flipping
VP	3.28653	20.557	86.4
VP w/ 80° RAM	2.83250	23.852	88.2
VP w/ 90° RAM	2.49490	27.080	89.5
VP w/ 100° RAM	1.91654	35.252	91.8

6.0 Conclusions

A velocity avoidance algorithm with a minimum RAM angle of 90 degrees added to the orbit rate rotation mode provides the HILT sensor with an 89 percent chance of survival over a three year period without seriously degrading science pointing performance. Larger RAM angles cause the spacecraft to flip and seriously decrease science pointing performance. The orbit rate rotation mode is the preferred mode since the vertical pointing mode causes the spacecraft to flip when the Sun is near the orbit plane. A viable option would be to turn off the velocity avoidance algorithm since the orbit rate rotation mode provides an 87 percent chance of survival without it. During safehold mode or when the HILT is swithched off for an extended period of time, a retractable cover will be closed to protect the HILT sensor.

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